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INNOVATIVE MAN MACHINE INTERFACES IN AERONAUTICS

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Innovative Man-Machine Interfaces in Aeronautics

A dissertation submitted in partial satisfaction of the requirements for the degree of Doctor of Philosophy by

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Abstract

The interaction with complex systems is an important issue especially in safety critical sectors as aeronautics. The quality and efficiency of the interaction between operators and complex systems strongly depends on the design of the man –machine interface that allows the operator to monitor and control the system itself. In aeronautical literature man-machine interaction has been widely studied and special attention has been paid to the adoption of innovative man machine interfaces in cockpit design, air traffic control and maintenance operations.
The research activity was focused on the study, design and evaluation of innovative human-machine interfaces based on virtual three-dimensional environments and multimodal interaction.
Multimodal interaction is one of the most challenging topics. Next generation interfaces will allow users to interact with the controlled system more and more naturally achieving the challenge of a Brain-Machine Interaction in which the user can directly interact with the system through his/her brain. Such interfaces have already been studied in the biomedical sector for controlling artificial limbs providing promising results.
In order to be able to achieve the objective settled for this research, during the first year the activity was focused on identifying the enabling technologies and their level of maturity (TRL Technology Readiness Level). Throughout the second year, the design of a prototype based on the integration of the brain machine, motion and eye-tracking devices was accomplished. In the third year, the research progressed based on the evaluation of the prototype designed combining the innovative man-machine interfaces in a virtual three-dimensional environment. Here are the milestones corresponding to the activities achieved throughout the three years process.

Year I:

- Classification of the existing tools and understanding the way they work;
- Aeronautical applications to which the new interface might be implemented;
- Identification of other research groups focused on similar works. Review of existing literature.

Year II:

- The design of the prototype to be implemented integrating the brain machine and head tracking devices;
- The implementation of the hardware on the (CAVE) Cave Automatic Virtual Environment in the Virtual Lab;
- The evaluation of a part of the prototype using a simple version of the brain-machine device.

Year III:

- The evaluation of the prototype designed combining the innovative man-machine interfaces in a virtual environment;
- Collection and analysis of data coming from the evaluation phase.

This research focused on the brain electrical activities by recording in real time the electrical impulses emitted by the brain waves of the user. Brain waves were detected with the aid of a non-invasive sensor namely electroencephalography (EEG). The achieved target is to identify and sort in real time the different brain states generally classified based on their waves frequencies. The emotional intensities were detected through online measurements and depending on the amplitude, the classification of the “state of mind” of the user was achieved. The emotions detected are the excitement, frustration, and engagement.
The experimental methodology based on the setup of an experimental facility for “man in the loop" simulation; allowed to involve both pilot and flight examiner for comparing subjective evaluations to objective measurements of the brain activity. This was done recording all the relevant information versus a time-line. The new concept worked on, aimed at improving the efficiency between a user and the interface, and gaining capacity by reducing the user’s (mainly the pilot or the pilot trainee) workload and hence improving the system overall safety.

This research resulted in the study, design and evaluation of an interface that adapts the control of the machine to the situation awareness of the user (pilot), based on the use of innovative components of the interface itself. Different combinations of emotional intensities obtained during specific flight tasks virtually simulated on a large immersive display (CAVE - Cave Automatic Virtual Environment), led to an evaluation of the current situational awareness of the user. These results could have a great implication in the current training methodology of the pilots, and its use could even be extended as a tool that can improve the evaluation of a pilot/crew performance in interacting with the aircraft when performing tasks and procedures, especially in critical situations.

Advancement in technology has stimulated an interest in trying to apply it and improving already existing interfaces in aeronautics. Being able to monitor and detect in a non-invasive way and in real-time, the general unconscious state of the user, will result in a stronger and more efficient human machine interaction by mitigating the different human factors considerations.
This innovative research combining emotions measured through electroencephalography resulted in a human-machine interface that would have three aeronautical related applications:

- An evaluation tool during the pilot training,
- An input for cockpit environment, and
- An adaptation tool of the cockpit automation.

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Chapter 1 Introduction

Advancement in technology has stimulated an interest in trying to apply it and improving already existing interfaces in aeronautics. The new concept described in this research aimed at **improving efficiency between a user and the interface, hence gaining capacity by adapting the pilot's situation awareness to the workload and as a consequence, improving safety**. An effective and objective measurement procedure for the mental state of the user had hence to be established without influencing (whether positively or negatively) the mental state of the pilot, or even without increasing his/her workload.

In this part of the report, the main motivations that led to the implementation of the Human Machine Interface in the different aeronautical fields (as it will be discussed in Chapter 5) are stated. Special focus will be dedicated to the workload and situation awareness focusing on the human element (in chapter 4) and how to identify and be able to mitigate the potential damages that might be happening due to the lack of proper assessment and focus.

1.1 Accidents in Aeronautics and Human Performance

A study by NASA revealed that more than 60% of incidents have their origin in the pre-flight phase of operations. Moreover, high workload is a factor in 80% of incidents and accidents resulting from crew error (Hayhurst & Holloway, 2003).

As per the Airbus classification of the Human Factors Markers used to qualify the contribution of each operational and human factor to a given event, one can notice the human-machine interface aspect that plays a role in the situation recognition and crew diagnosis during a certain event (Airbus, 2004).

- **Situation recognition and crew diagnosis**: Cockpit alerts, other cockpit / cabin effects, crew diagnosis, and human-machine-interface aspects;
- Procedure(s): Type of procedure, access to procedure, procedure contents;
- **Human performance**: Procedure execution by flight crew, other crew actions, threat management, crew-error management, aircraft attitude / flight path control, crew coordination;
- Operating environment and circumstances: Operational environment, weather conditions, runway conditions, aircraft systems condition / configuration, crew factors, organizational factors.

Moreover pilots in some events, inadvertently (very rarely intentionally) deviate from the Standard Operating Procedures (SOPs) along with the normal checklists and standard calls. Based on a study made by Airbus (Airbus, 2004), here are some of the factors and conditions cited in discussing the deviations from SOPs that are related to this research:

- **Task saturation** (i.e., task overload);
- Inadequate knowledge of and/or failure to understand the rule, procedure or action; this includes:
    - **Training**;
    - Quality of wording or phrasing; and/or,
    - **Perception** of rule or procedure or action as inappropriate;
- Insufficient emphasis on strict adherence to SOPs during transition training and recurrent training;
- Lack of vigilance (e.g., **fatigue**);
- **Distractions** (e.g., due to cockpit activities);
- Interruptions (e.g., due to pilot/controller communications);
- Incorrect management of priorities (i.e., absence of decision-making model for time-critical situations);
- Reduced attention (tunnel vision) in abnormal or **high-workload conditions**;
- **Overconfidence**; and/or,
- High time on aircraft type (i.e., condition possibly conducive to complacency and overconfidence).

Furthermore, in aviation, there has been a **great increase in the level of automation** as for example during flight and air traffic control operations. It has also given rise to issues and concerns pertaining to human intervention, accidents and incidents and issues on human factors.
In reference to some dictionary definition of automation described below, one can see the link between the computers and the implication on humans in the performance of a certain task:
"The use of computers to control a particular process in order to increase reliability and efficiency, often through the replacement of employees." (InvestorWords)
A basic search on the word automation leads to a definition of this kind: Automation is the use of control systems and information technologies reducing the need of human intervention. (NUST-SEECS, 2010)
Automation has widely developed the aviation field. It has relieved the pilots of their workloads by assuring the availability of essential flight information at all times. Therefore, the flight crewmembers are able to allocate their concentration towards maintaining awareness with their environment as well as on communication between them. Furthermore, the introduction of automation had also an effect on reducing the operating cost for airlines, by a reduced number of flight crewmembers, efficient flight performance, reduced fuel usage.
On the other hand, automation can be also considered as a disadvantage if one looks at the **overdependence on automation**, the adverse impact on airmanship.
In 1974 Eastern Air Lines Flight 212 crashed short of the runway while executing a precise instrumental approach in poor visibility conditions into Charlotte/Douglas International Airport. Out of the 82 people aboard the flight, only ten survived. The accident investigation concluded that the

mishap occurred due to the pilot distraction. Many other accidents were due to pilot distraction during crucial flight phases.

As a consequence, the Federal Aviation Administration in 1981 introduced the Sterile Cockpit Rule: this regulation prohibits the flight crew from engaging in unnecessary activities during important flight phases (more often, below the flight altitude of 10,000feet). Additionally, the introduction of the Crew Resource Management (CRM) training in 1979 also strives to enhance pilot decision-making skills by highlighting the importance of situational awareness, leadership capabilities and interpersonal communication skills even during the presence of automation and convenience.
Both the CRM training and the Sterile Cockpit Rule aim to emphasize the role of the automation only as an additional supporting assistance tool. Even with the introduction of the automation, flight crewmembers are still educated to direct as much attention to piloting the flight as before the debut of the technology.

An interesting definition of airmanship illustrated in Figure 1 (Ebbage & Spencer, 2003): “A personal state that enables aircrew to exercise sound judgment, display uncompromising flight discipline and demonstrate skillful control of an aircraft and a situation. It is maintained by continuous self-improvement and a desire to perform optimally at all times.”

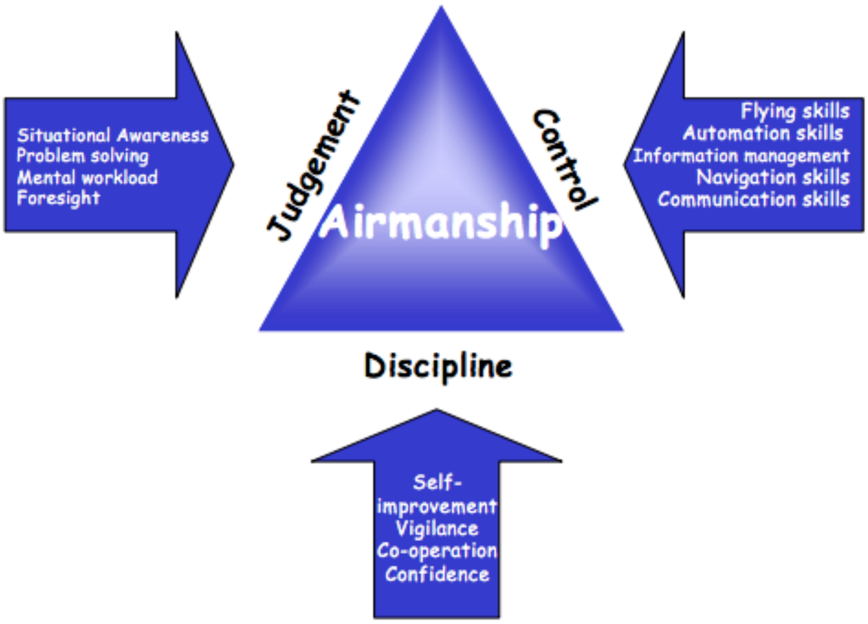

Figure 1 The Elements of Airmanship

But, if pilots rely totally on the autopilot function to maintain a particular altitude and airspeed of the aircraft, this excessive dependence may adversely affect their skill development. This causes pilots to reduce their application of airmanship. The ability to fly an aircraft manually despite regular exposure to automation and convenient information access is important, especially during emergencies. Here is an incident describing the effect of airmanship: in 2008, United Airlines Flight 731 lost half of its display panels, radios, transponders and Traffic Collision Avoidance System (TCAS). Fortunately, the pilots were able to maintain manual flight control to land back at their departure aerodrome. The necessity to maintain airmanship is thus highlighted even during this age of automation.
Only with the emphasis of cognitive skills to eliminate human errors, such technological advances can then enhance flight safety. The benefits of automation may be highly regarded but this should not prevent the "operator" to exercise his "human touch" or intervention in the fulfillment of a task (More details in Chapter 5).

1.1.1 Operational Events Related to Fatigue and High Workload

The research then converged onto the operational aeronautical events that are related to fatigue and high workload on the user. The following results were obtained.

1.1.1.1 The Pilot/Controller Communication

According to Crew Resource Management, an effective communication is achieved when the mental process for interpreting the information contained in a message accommodates the message being received. Some factors may affect the correct understanding of communications:

• **High workload**; • **Fatigue**; • Non-adherence to “sterile cockpit” rule; • **Distractions**; • Interruptions; and/or,	This may result in:	• Incomplete communications; • Omission of call sign or use of an incorrect call sign; • Use of nonstandard phraseology; and/or, • Failure to listen or respond.

1.1.1.2 Altimeter Setting and Altitude Deviation Issues

The incorrect setting of the altimeter reference often is the result of one or more factors. The list below represents the factors related to man machine interface.

- **High workload**;
- **Inadequate pilot/system interface**;
- Interruptions and **distractions**.

1.1.1.3 Rushed and Unstabilized Approaches

The circumstances, factors and errors often cited when discussing rushed and unstabilized approaches are plenty. The cited ones below are related to the aim of the research:

- **Fatigue**, regardless of short/medium-haul or long-haul operation;
- **Pressure** of flight schedule (e.g., making up for takeoff delay);
- **Lack of awareness** of tail wind component;
- **Failure to recognize** excessive parameter-deviations or to remember the excessive-parameter-deviation criteria;
- PNF (Pilot Not Flying) **excessive confidence** in the PF (Pilot Flying) in achieving a timely stabilization;
- PF/PNF **excessive reliance** on each other in calling excessive deviations or in calling go-around.

1.1.2 European Aviation Safety Agency Cockpit Automation Survey

Published on the European Aviation Safety Agency (EASA) website from 30 April to 23 July 2012, this survey was aimed at consolidating the Automation Policy by evaluating the degree of agreement with the identified automation issues and suggested paths for improvement (EASA Internal Group on Personnel Training, 2013).

The respondent assessed the flight crew automation interaction issues, and the improvement paths. Here are **the most agreed and consensual flight crew-automation issues related to the applications to which the designed interface will be applied**:

- Basic manual and **cognitive flying skills** tend to decline because of **lack of practice** and feel for the aircraft can deteriorate;
- **Pilots interacting with automation** can be distracted from flying the aircraft. **Selection of modes, annunciation of modes, flight director commands may be given more importance** than value of pitch, power, roll and yaw and so distract the flight/crew pilots from flying the aircraft;
- Unanticipated situations requiring to manually overriding automation are **difficult to understand and manage**, create a surprise or startle effect, and can induce **peaks of workload and of stress**;
- For highly automated aircraft, **problems may occur when transitioning to degraded modes** (e.g. multiple failures requiring manual or less automated flight).

Regarding the most agreed and consensual improvement paths that could be done:

- **Improve basic airmanship and manual flying skills of pilots**;
- **Improve recurrent training and testing practices with regard to automation management.**

Many more improvement paths were listed; only the two stated above are linked to the scope of the research.

1.1.3 Use of Automation in Accidents

Also by reference to the study made by Airbus (Airbus, 2004), the errors in using and managing automatic flight systems and/or lack of awareness of operating modes, are observed as causal factors in more than 20% of approach and landing accidents and near-accidents.

The following common errors in handling auto-flight systems can increase the risk of accident during any flight phase, but particularly during approach-and-landing:

- Inadvertent selection of an incorrect mode;
- Failure to verify the selected mode by reference to the Flight Mode Annunciator (FMA);
- Failure to arm a mode when required;
- Failure to select a required guidance target;
- Inadvertent change of a guidance target;
- Selection of an incorrect altitude and failure to confirm the selection on the Primary Flight Display (PFD);
- Selection of the altitude target to any altitude below the final approach intercept altitude during approach;
- Preoccupation with Flight Management System (FMS) programming during a critical flight phase, with consequent loss of situational awareness; and/or,
- Failure to monitor the automation, using raw data.

The issues stated (in 1.1.2 and 1.1.3) related to the aircraft/cockpit automation, represent the **need for developing countermeasures to restore the level of vigilance and alertness for the descent, approach and landing. This research, based on the integration of innovative technology, will focus on a new type of interface that will aim in monitoring the level of vigilance and alertness of the user, and adapt the corresponding outputs**. Future details will be discussed further in the report.
Based on the results found earlier, a further application is designed: the monitoring of the workload and the corresponding reaction of the user.

1.2 Mental Workload and Human Factor

Workload was an active research area during 1930's. The interest in the mental workload topic in aviation started around 1976 due to the increasing air traffic in addition to the more stringent fuel constraints and the stricter noise regulations that simply led to the increase of pilot workload (Sheridan & Simpson, 1979). On the other hand, during this period, the automation increased, the aircrafts became larger and more sophisticated due to the evolution of the technology during that period. These latter definitely reduced the workload connected to direct manual control. The pilot became a "flight manager". The aim of setting up a scientific basis for the definition of measurement of the mental workload is thought of to be able to define the number of aircrew needed for safety, to decide on work/rest schedules, on relative roles for pilot (and ground controllers), to work on cockpit design and procedures.

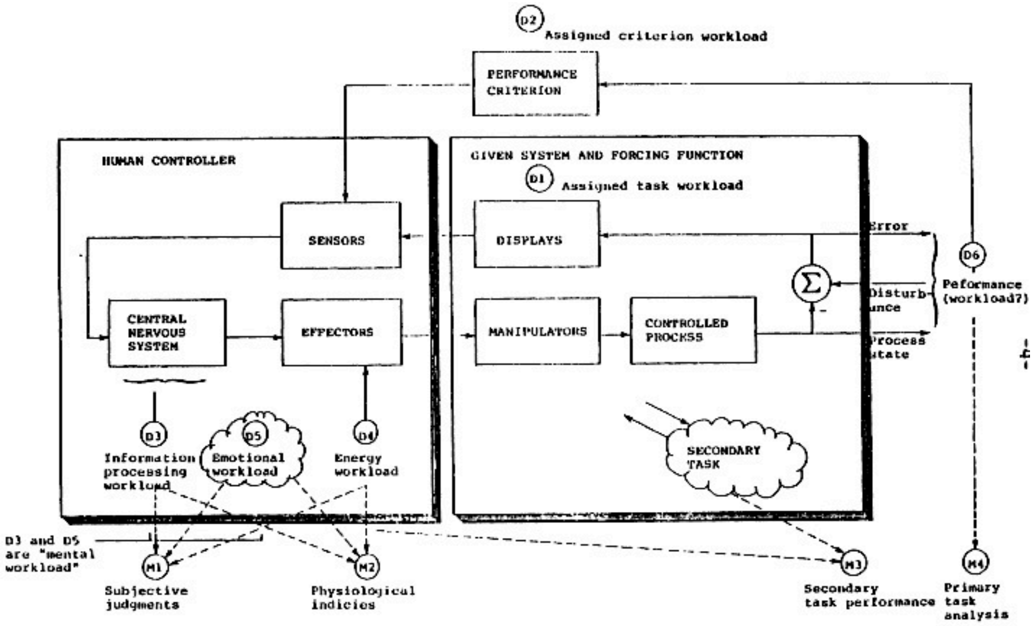

Figure 2 Definition of Workload and Performance

In Figure 2, an alternative definition of workload and performance is represented: consider a certain task demand (D1) to a human controller, i.e. a user. This latter is described as a normative straightforward detailed description of what has to be done. For each task assigned, the task criteria (D2) are described as the conditions for performance in achieving the dedicated task. The information processing (D3) of the task in the central nervous system of the user might be affected by emotions (D5) and the amount of energy of the user (D4). Since the task demand, the task performance and the task criteria can be measured, one can always say that it is a relative performance, and will vary depending on the user accomplishing the corresponding task. Hence, mental workload has nothing to do with neither performance nor task demand; mental workload has to do with mental effort along with the information processing and the emotions in response to a task demand (Sheridan & Simpson, 1979).
Existing measures of workload in the field of aviation attempt to quantify performance or verbal constructs of performance in order to assess new equipment and procedures. These measures provide subjective estimates of workload. Mental workload can be deduced, not directly measured.
The thesis objective is to measure the mental workload by monitoring the emotions of the user felt in response to a task. With the help of a new wearable technology that will be elaborated in more details in the next chapters of this report, it is now possible to objectively estimate relative cognitive responses to complex aviation tasks.

1.2.1 Assessment Techniques

Mental workload can be defined as the ratio of the resources required to the resources available. Time is considered as one of the resources available but not the only one as compared to in the concept of workload in general, which is a ratio of the time required to do the task to the time available to do the task in (Wise, Hopkin, & Garland, 2009). **The assessment of workload in**

this research is to make inference about an operator's capability to perform with respect to a certain task, and compare this assessment to the physiological measures obtained in parallel. Following the traditional and reliable techniques of measuring the workload, it has been assessed using at least three of the four techniques (Meshkati, Hancock, & Rahimi, 1992):

- Primary task measure;
- Secondary task method;
- The physiological measure;
- The subjective measure.

The primary task measure is not really a workload measure by itself, but it is mainly influenced by the mental workload and therefore assumed to reflect workload. A simple example (that is not always applicable) is when the workload is high, the performance will be worse. In some cases a very good primary task performance is attained but only at a cost of high workload.
The secondary task method is focusing on the performance of the secondary or concurrent task and it provides a method of measuring the "reserve capacity" the user is capable of having. Assuming that a certain amount of cognitive resources are dedicated to the performance of the primary task, the secondary (or concurrent) task will use whatever residual resources are left.
The **physiological measures** are the one the researches usually favor. In particular the heart rate variation measures have proven to be relatively consistent and reliable measures for the mental workload. Measures of visual scanning are also a good example of the reliable physiological parameters with respect to the mental load corresponding to a certain task (Rubio, Diaz, Martin, & Puente, 2004). In the following chapter, researches currently being done in this field will be listed. Based on a previous research, **findings indicate that the EEG can provide a valid and objective index for mental effort but, in addition, may reveal task-related cognitive resource allocation, task mastery and task overload** (Sterman & Mann, 1995).
Last but not least, **the most intuitive measure of mental workload is the subjective measures technique: it is in the majority of the assessed tasks, being used to extensively assess the operator workload**. The multidimensional subjective workload assessment instruments usually used in this technique are: the Cooper-Harper Scale (Cooper & Harper, 1969), the Bedford Scale (Roscoe & Ellis, 1990), the SWAT (Subjective Assessment Technique) (Reid & Nygren, 1988) and the NASA-TLX (Task Load Index) (Hart & Staveland, 1988), and the Workload Profile (WP) (Tsang & Velazquez, 1996).

The suitability of the procedures for the evaluation of mental workload depends on the extent to which they meet the different requirements varying from sensitivity to diagnosticity to intrusiveness, reliability and subject acceptability (Eggmeier, Wilson, Kramer, & Damos, 1991).

In this research, the assessment techniques of the mental workload chosen are:

- The physiological measure – electroencephalography (EEG): In this research the physiological measure that we will focus on are the brainwaves emitted in real time by the user while performing the task asked for. Further details will be found in the next chapters regarding the innovative and non-invasive technology being used and the secrets behind the brainwaves emitted, recorded and interpreted.

- The subjective measure: The operator will be asked at the end of the task, to rate the workload on a subjective scale. In this research we will be using the NASA Task Load Index (Hart & Staveland, 1988) that imposes six different subscales with seven levels (Wickens, Hollands, Parasuraman, & Banbury, 2012). A deeper insight on this procedure will be elaborated in the paragraph below.

A comparison of results will be made in order to find a correlation between a pattern of the physiological parameter measured and the subjective feedback from the operator.

The Human Performance Group at NASA Ames Research Center developed the NASA Task Load Index (TLX) during a three-year research effort that involved more than forty laboratory, simulation and inflight experiments. It is a multi-dimensional rating procedure that provides an overall workload score based on a weighted average of ratings on six subscales. Three dimensions are related to the demands imposed on the operator: mental demands, physical demands and temporal demands; and three to the interaction of the subject with the task: own performance, effort and frustration. In this research in order to get this subjective measure of the mental workload, the ratings were obtained just after the task was over.

The NASA TLX is a two part evaluation procedure consisting of two steps: the weight i.e. the source loads, and the ratings (or the magnitude of the loads). Each subject will evaluate the contribution of each of the six factors defined above, to the workload of a specific task. The second evaluation is for the operator to attribute a numerical rating for each scale that reflects the magnitude of that factor in a given task. These ratings may be obtained during the task, after task segments or following an entire task. In Appendix A, a description of each NASA-TLX rating scale is elaborated.

This innovative research is technology based, and will grow along with the growth of the product in the market. For many humans nowadays, their days are spent in front of screens and smartphones, immersed in the use of software. This latter have more advantages than a hardware with its faster rate of evolution (Bennett, Munro, Gold, Layzell, Budgen, & Brereton, 2001), easy modifiability by a larger proportion of the population (Resnick, et al., 2009). On the other hand, hardware can help the human user to overcome physical limitations, strength and endurance.

The target of this research, based on the earlier results, converged into implementing already existing hardware in the aeronautical field to the possibility of using software to address mental states and adapt to extreme situations by monitoring the mental workload and fatigue of the user. More details will be found in chapter 5 of this document.

In order to implement the already existing interfaces in the cockpit or flight simulator or any other aeronautical or non-aeronautical related interface, an emphasis on the design of the interface will be explained later on in this dissertation. Designing an efficient human-machine interface dwells around the consideration of the human capabilities and limitations. Human are an essential (and critical!) part of the loop in the interaction process. The user should be engaged in every step of the interaction. Involving the human machine interaction since the early stages of the training, will allow every user to know his/her capabilities along with his limitations. It will help the operators save costs and improve efficiency of both trainees and trainers. The interface will allow determining whether the user is overloaded or maybe unable to process the information. When a technology enables the user to perform a certain task more easily, the user will be more likely to perform that task in a better way than he/she used to accomplish it. Constantly monitoring the mental workload of the user will help avoid cases in which the user is overwhelmed by the current situation, hence preventing major hazards leading to breaching the system's defenses.

Chapter 2 State of the Art Description

In this chapter emphasis is made on the current worldwide researches in similar domains related more or less to the ideas lying behind this innovative project. An overview of the current major projects focused on the interaction through brains will be listed. The motivation of these projects is based on the methods to understand how the brain works and maps it to represent the synapses and the neural pathways. These projects are mainly centered on the medical field applications; but they could nonetheless be implemented to any application related to enhancing the connection between a human and the machine. Furthermore, projects related to mental workload measurements will be described whether related to electroencephalography or other physiological measures described earlier.

2.1 The Brain

Already existing projects worldwide with the aim of mapping and simulating the entire brain are taking place. When successfully accomplished these projects will result in disseminating results and be able to **use and target specific regions of the brain depending on the task required**. Below some main projects involving partners all over the globe are described:

The Human Connectome Project (Human Connectome Project | Mapping the human brain connectivity) aims at mapping the neural pathways that underlie the human brain function. It will advance the capabilities for imaging and analyzing brain connections. Altogether, the Human Connectome Project will lead to major advances in our understanding of what makes us uniquely human and will set the stage for future studies of abnormal brain circuits in many neurological and psychiatric disorders. The Human Connectome Project, with support from the National Institute of Mental Health (NIMH) and other leading National Institutes of Health (NIH) in the United States, involved the participation of the following partnered primary institutions: Washington University, University of Minnesota, the laboratory of neuro imaging and the Massachusetts General Hospital.

The National Institutes of Health (NIH), the Defense Advanced Research Projects Agency (DARPA), the National Science Foundation (NSF), and the Food and Drug Administration (FDA) are leading the Brain Research through Advancing Innovative Technologies (BRAIN) Initiative. Its seven scientific goals in the long-term vision range from identifying and access the different brain cell types to determine their roles in health and disease, to mapping of the circuit diagrams to the whole brain, generating a dynamic picture of the functioning of the brain and linking brain activity to behavior, leading to developing innovative technologies in order to understand the human brain and treat its disorders (U.S. Department of Health and Human Services). Here is a quote by President Barack Obama in April 02, 2013 “There is this enormous mystery waiting to be unlocked, and the brain initiative will change that by giving scientists the tools they need to get a dynamic picture of the brain in action and better understand how we think and how we learn and how we remember. And that knowledge could be — will be — transformative.”

The Max Planck Institute for Brain Research in Germany is elaborating on a project called Brain Flight using a combination of machine learning and human data analysis to enable the large-scale reconstruction of neural circuits (Max Planck Institute for Brain Research).

German researchers at the Munich Technical University have created a simulated plane controlled by the brain of the pilot. Under a EU-funded project called Brainflight, the aim of this research was to prove that brain-controlled flight is possible (TechCrunch, 2014). Pilots are fitted with a cap fitted with electroencephalography electrodes that measure electrical impulses along the scalp. These signals are then fed back to a computer, which uses an algorithm, developed by scientists from the Berlin Institute of Technology, to translate these impulses into commands.

Methods of monitoring the brain and the different applications in which these could be implemented will result in improving the performance of the user.

2.2 Workload Measurement and Similar Monitoring Methods

Focusing on electroencephalography (EEG) and interpreting the minor voltage fluctuations, Honeywell is aiming on developing algorithms and software that can take data from these systems and make interferences about the subject’s cognitive state (Deener, 2013). They are working in parallel with the evolution of the hardware, since ten to eleven years ago the subject in the laboratories were wearing a cap with many electrodes and wires making it difficult for the subject to move. Their goal is to build a model of the brain activity that outputs a single-value estimate for workload, attention or other state if interest.

The Defense Advanced Research Projects Agency’s (DARPA) augmented cognition program focused on developing sensing technologies in order to determine when soldiers or pilots were so occupied that adding tasks would overwhelm them (St. John, Kobus, Morrison, & Schmorrow, 2004).

Boeing’s Crew Fatigue Monitoring study: the research is a cooperative project with Delta Air Lines to collect and interpret a massive data set examining the biometrics of tired pilots (Paur, 2013). The goal is to better understand the signals that indicate fatigue and perhaps implement a warning system based on the warning signs. The program could see a future where sensors that monitor signs of fatigue like eye movement could warn pilots they are becoming tired even before they realize it.

Here is a research related to attention: a study at Oxford University showed an inverse relationship between the brain’s idle signal (‘alpha’ EEG signature as it will be explained in further details in section 4.3) and the subjective rating of how attentive the subjects were. The results could be useful in the detection of states when people are vulnerable to lapses of attention and potentially avoiding situations where operators fall asleep or pilots loose attention.

The U.S. Air Force Research Laboratory has also completed a proof-of-concept testing of non-invasive brain stimulation to help imagery analysts, cyber security specialists and UAV operators flight fatigue. The research showed that a specific stimulation could extend alertness and accelerate learning.

Here is a study on electroencephalography (EEG) and electrocardiography (ECG) changes during simulator operation that reflects mental workload and vigilance. The results showed that the different simulated flights had different effects on the brain waves frequencies. The different flight sequences performed on the simulator resulted in electrophysiological changes that expressed variations in mental workload. (Dussault, Jouanin, Philippe, & Guezennec, 2005)

The Air force Research Laboratory and the Human Effectiveness Directorate at Wright-Patterson has already conducted many studies on mental workload and analysis and laboratory, simulator, and flight settings. Their results indicated that the most influential psychophysiological features in classifying mental workload levels are brain electrical activity; heart rate, breath rate, and eye blink measures (Wilson G. F., Applied use of cardiac and respiration measures: practical considerations and precautions, 1992) (Wilson G. F., Air-to-ground training mission: a psychological workload analysis, 1993) (Wilson & Fisher, 1995). Already made studies to measure driver's mental workload using EEG were accomplished with interesting results (Kincses, Hahn, Schrauf, & Schmidt, 2008). Many studies were also made focusing on the combat aircrafts and the demands on the pilots. Their study was triggered due to the importance of predicting high pilot mental workload in the United States Air Force because lives and aircrafts have been lost due to errors made during periods of flight associated with mental overload and task saturation (Noel, Bauer, & Lanning, 2005).

Researchers at Tufts University are measuring mental workload with a headband that senses blood flow and oxygenation in the brain by bouncing light off the scalp. The aim is to detect whether the user is overstressed or relaxed and ready to take on more tasks. It has been used in air-traffic simulations to detect if a controller is overworked and scale back workload (BBC News, 2014).

Here is a study made in Tokyo on physiological measurements on pilots in a flight simulator through electrocardiogram (ECG) and eye data using a camera in order to measure the pupil diameter of the user. It was shown how pupil diameter, heart rate, heart rate variability and control style van reveal a pilots mental effort and task load. It was also investigated how mental effort can be measured during simulated flight (Entzinger, Uemura, & Suzuki, 2014).

In an article in the Aerospace Journal published by the Royal Aeronautical Society, it is stated that Rockwell Collins is focusing its research and development efforts to provide greater safety, security and efficiency through enhanced situational awareness, improving human-automation interaction and efficiency in operations (Mattai, 2014).

The university spin-off company "Brain Signs" applies neuroscience for different industrial applications. They record and analyze high quality signals for biofeedback in different areas in which monitoring instant attention and emotional states of the human are needed. Interesting researches are made on the estimation of mental workload, fatigue and stress in driver cases or in air traffic controllers (Borghini, Aric, Graziani, Salinari, Babiloni, & al., 2014).

There are also EU and SESAR co-funded projects that are working on similar methods for evaluation and measurement of workload related to aeronautics.

- All Condition Operations and Innovative Cockpit Infrastructure (ALICIA): ALICIA's aim in developing a new cockpit technology and new cockpit architectures by the introduction of enabling technologies and applications in order to increase the Situation Awareness and decrease the workload on the crew member was presented in the early morning presentations. During the project, ALICIA technologies and applications have been evaluated and validated by operational, safety and human factors experts.
- Advanced Cockpit for Reduction of StreSs (ACROSS) and workload aims at developing new applications and Human-Machine Interface in a cockpit concept that will help the crew in managing peak workload situations, ensuring the opportunity to address relevant issues in a timely effective manner. 60% of the total accidents in aviation are due to crew aspects from 1999 to 2010. Predictable crew performance is one of the major remaining limitations in the safety field. Moreover an interesting fact presented was regarding the peak load situations during the different flight phases along with the level of pilot capabilities [Figure 1].
- Manual Operation for 4th Generation Airliners (MAN4GEN): The project aims at identifying current deficiencies of situational awareness and manual control of modern flight decks, and impact the design of procedures, training and cockpit design in the aerospace industry.
- Applying Pilot Models for safer aircraft (A-PiMod): This project addresses improved flight safety by proposing a new approach to human centered cockpit design, which expands the understanding of the human factor in joint human-machine system, taking into account increasing levels of operational complexity and new operational concepts.

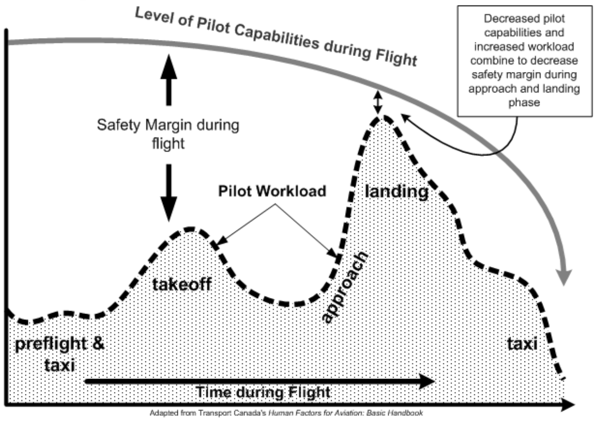

Figure 1 Workload and Pilot Capabilities During Flight

Chapter 3 Technology

The aim of the research is to create a stronger and more intimate connection between the user and the machine. Hence, the study started with a **screening of the existing technologies** and the **identification** of the devices that will take part in the intended design of the interface. A **classification** of the current tools and understanding the way they work was completed in order to have a vision of the future. The search was based on the different **technology readiness levels** of the available interfaces in the market, their patents, the existing individual applications and whether or not these are open systems. This part of the report will initially start by going through some history of human-machine interfaces along with some relevant applications that marked the history of technology.

3.1 Introduction

The first part of the research work was focused on identifying and understanding how a Brain Computer Interface (BCI) works, its level of development and the way it could be applied in the aeronautical field.
Before going through the history of the Brain Computer Interfaces, the focus on the Human Machine Interface (HMI) is an elementary stage. This three words title opens the door to a whole new branch that encloses many different fields like the computer science area, the behavioral science, design, etc. Taking a deeper look at the three words:

- The **Human** in general are the people involved (generally more than one) or a community of users, they are the end users of the program;
- The **computer** (or more than one) is a machine program running on specific or multiple task scenarios;
- The **interaction** links both earlier terms: interaction is the dialog where the user tells the computer what they wish to accomplish and the computer(s) processes that and communicates the result back. That interaction is mainly done through the User Interfaces (UIs), which includes both software and hardware.

HMI in the large sense is the design, prototyping, implementation and evaluation of UIs whether they are hardware or software [Figure 1].

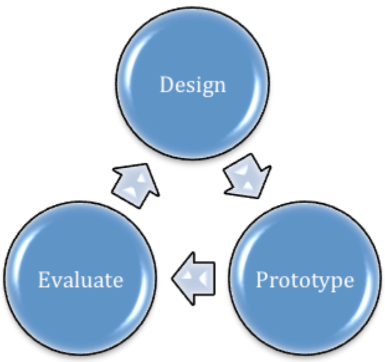

Figure 1 Iterative Design Cycle

3.2 History of Human Machine Interfaces

Wide-ranging chronological reviews have been made regarding this domain; only the crucial parts will be reviewed in this document. Extensive progress has been achieved in this field in the past years, hence, this historical review of HMI, will be divided the in two parts: 74 years from now and 15 years ago.

3.2.1 Human Machine Interfaces: 1941 - 1999

The past HMI are considered between 1941 and 1999. They were not using graphics and were more function centered (Tan & Nijholt, 2010). The most famous examples of this early stage in the HMI are the early Personal Computers (PC) and the mouse; in other words, the ancestors of Robots, Computers and Operating Systems in general!

Without going into the full examples that were invented during this period, only famous HMI's will be listed below. The Zuse's Z3 is the first automatic, program-controlled, fully functional and general-purpose digital computer built from the 1938 till 1941. Doug Engelbart invented in 1963 the computer mouse we all use in our every digitalized day, in his research lab at Stanford Research Institute (now SRI International), for which the patent was issued in 1970. Although many impressive innovations for interacting with computers have followed in the last 50 years since its invention, the mouse remains to this day the most efficient hands on pointing device available.

The picture below [Figure 2] describes how the early HMIs used to see the Human: the use of application started with (O'Sullivan & Igoe, 2004):

- One finger for clicking and typing;
- Two ears because of the stereo sound;
- One eye for one screen.

3.2.2 The Present Human Machine Interfaces: 1999 – Nowadays

The present HMI are considered to be between 2000 and nowadays; they are user centered, with many developments of Operating Systems (OS). New technologies are emerging and targeting a natural feel, motion capture, touch screen multi-touch interactions. The Xbox 360 Video Game Console, the Nintendo Wii, the Apple Smartphone IPhones and the Windows 8 Latest OS 2012 are some examples that one could refer to.

The next generation of HMI, will be faster, more precise as compared to current HMI technology. It will be a multi technology on one gadget with motion and sound capture along with touch screen, and having high mobility. The holographic technology or some kitchen technologies (glass stove and refrigerator) could be good examples for this future promising area (Morris, 2014).

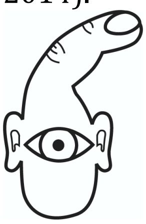

Figure 2 Traditional Interfaces

3.3 Brain Computer Interfaces

Brain Computer Interfaces have gained greater attention in the past several years (Lee, Shin, Woo, Kim, & Lee, 2013); they provide the possibility to directly create a communication channel between the human brain and the computer by translating human thoughts into control signals for the computer. Since the mid 1990s, several groups were able to capture complex brain signals recorded from neural ensembles and using these records in order to control external devices. There has been a rapid development in BCIs since then. In 2008, the first commercial Electroencephalography (EEG) neuroheadset was launched in the market for gaming and PC users (Tan & Nijholt, 2010).

3.3.1 A Closer Technological Glance

According to Gartner, Inc. - the world's leading information technology research and advisory company – (Gartner Inc) and in order to be able to differentiate the publicity from what's commercially viable amongst new technologies, Gartner Hype Cycles provide a graphic representation of the maturity and adoption of technologies and applications. Moreover, Gartner Hype Cycle methodology gives a view of how a technology or application will evolve over time.

Each Hype Cycle splits down into the five key phases of a technology's life cycle [Figure 3]:

- Technology Trigger: A potential technology breakthrough kicks things off. Early proof-of-concept stories and media interest trigger significant publicity.
- Peak of Inflated Expectations: Early publicity produces a number of success stories—often accompanied by scores of failures.
- Trough of Disillusionment: Interest vanishes as the usability of the product fail to deliver. Producers of the technology shake out or fail, unless investments continue if the providers improve their products to the satisfaction of early users.
- Slope of Enlightenment: More instances of how the technology can benefit the enterprise start to crystallize and become more widely understood. Second- and third-generation products appear from technology providers.
- Plateau of Productivity: Mainstream adoption starts to take off. Criteria for assessing provider viability are more clearly defined. The technology's broad market applicability and relevance are clearly paying off.

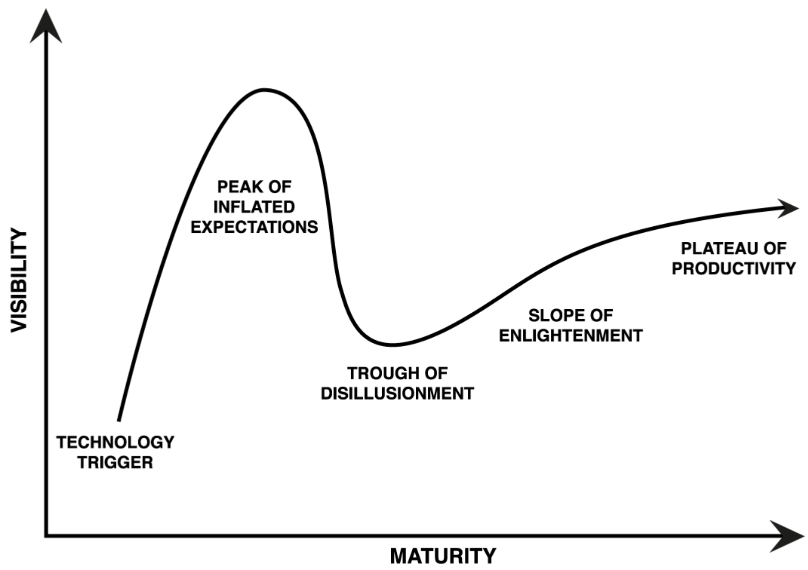

Figure 3 Gartner Hype Cycle

Applied to technology, as 2014, the corresponding Hype Cycle is presented in the figure below [Figure 4] (Gartner, Inc. and/or its Affiliates). The Brain Computer Interface needs more than 10 years to be commercialized, but this fact doesn't mean that the research domains are not working on it and with it. According to Scopus search engine, the "Brain Computer interface" search as a keyword returned only two scientific papers in 1991; while in 2011 the same search returned 897 journals and conference papers for 2011 (Lee, Shin, Woo, Kim, & Lee, 2013). The Brain Computer Interface is in an innovation trigger phase that can lead it to exponential growth depending on the application it can proves itself in. The BCIs have been widely exploited in many research fields and have been proving their reliability and innovative concepts in every day life. One of the most successful concepts of BCI is the use of the brain wave emitted by the user: Electroencephalography.

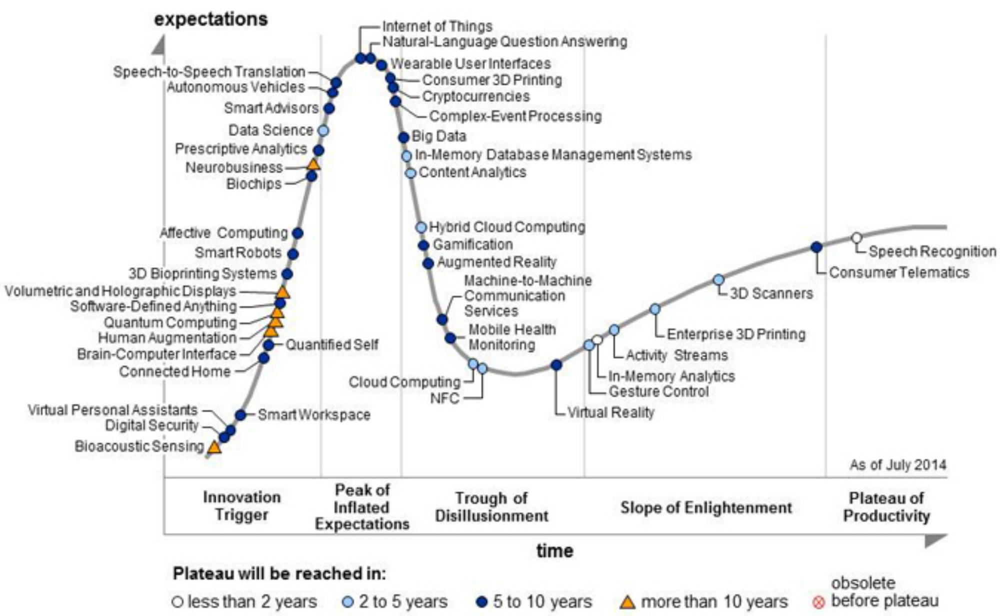

Figure 4 Hype Cycle for Emerging Technologies 2014

3.3.2 Electroencephalography

Electroencephalography waves are created by the connections between the neurons in the brain and were first measured by Vladimir Pravdich-Neminsky on the electrical brain activity on dogs in 1912 (Niedermeyer & Lopes Da Silva, 2005). Hans Berger did the first measurement of EEG waves on human ten years later; since then, intense research in exploiting these electrical measurements in the fields of neuroscience and psychology were done. EEG waves are measured using electrodes that are placed on the scalp (non-invasive neural sensors types), and are sensitive to changes in postsynaptic potentials of neurons in the cerebral cortex. Electrodes are usually placed along the scalp following the "10-20 International System of Electrode Placement" developed by Dr. Herbert Jasper that allows for standard measurements of various parts of the brain (Collura, 1993); The 10-20 electrode setting for 21 electrodes is shown in the figures below [Figure 5 and Figure 6], the odd numbers are on the left, the even on the right, the electrodes on the center are appended with the letter z, and the letters correspond to cortical lobes above which the electrode lies – "Fp" frontal pole, "F" frontal, "Fp" frontal polar, "C" central, "T" temporal, "P" parietal, "A" ear lobe, and "O" occipital (Tyner & Knott, 1983). The International Federation of Societies has recommended this setting for Electroencephalography and Clinical Neurophysiology (International Federation of Clinical Neurphysiology, 1999).

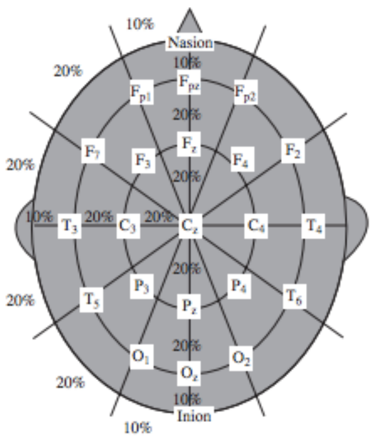

Figure 5 10-20 International System of Electrode Placement for 21 electrodes

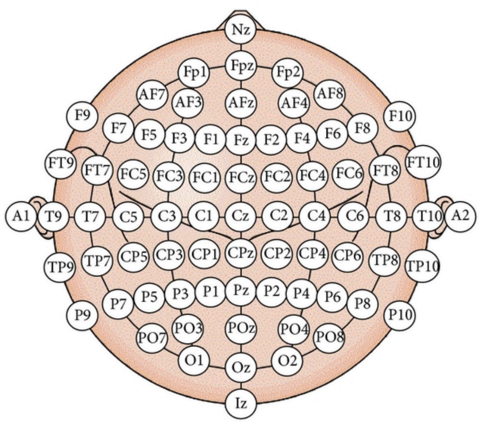

Figure 6 10-20 International System of Electrode Placement for 75 electrodes

Recently, there has been a growing interest in using EEGs for Human-Computer Interfaces (HCIs) as the prices for low cost EEGs have been fallen to a level that makes them affordable for consumers (Hwang, Kim, Choi, & Im, 2013). Moreover the idea of BCIs, which allow the control of devices using brain signals, evolved from the core of science fiction to simple devices that currently exist in the market.

3.3.3 Neuroheadset

A Human Computer Interface or brain–computer interface, that are sometimes called a direct neural interface, are based on a direct communication pathway between the brain and an external device. Measuring the signals from the brain is the basis of the communication; in order to measure and interpret the signals naturally produced by our brain, there are three types of neural sensors: the invasive, the partially invasive and the **non-invasive**. The research described here was based on this latter type of neural sensors.

Initially the search started with a review of the already existing Brain Machine Interfaces available in the market. This technology has been widely used in the medical field. **The objective here is to use a portable non-invasive and reliable headset**. The emerging headsets, this research is focused on, are being applied by users all over the world in different applications that are non-medical related: the intended users can range from researchers to gamers to artists and even athletes. Based on the same principle of electroencephalography and on a technological review of mainly two companies in this field, the choice went through headsets with a different number of electrodes (ranging from 1 to 14), with different inputs measured (whether mental states, facial expressions and/or conscious thoughts), belonging to different price ranges.

Both these BMIs are non-invasive types of neural sensors to measure neural activity. The two companies have developed a non-invasive, biosensor family of products that capture the electrical waves generated by neurological activity and eye movements. These products translate mental state information into digital signals for simple BCI and are both being used for research purposes. The data is fed to the computer via wireless Bluetooth; hence the headsets are easily wearable. The main difference between the two products is the detection (or not) of the facial expression (Emotiv) (Neurosky). In order to be able to create a stronger and more intimate connection between the user and the machine, the choice in the devices stated above, went on the Neuroheadset that is able to interpret conscious thoughts along with facial expressions and head movements. Different versions of this Neuroheadset are also available in the market, based on the end use of the application.

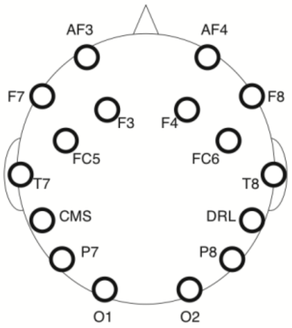

Figure 7 Emotiv EPOC Neuroheadset - Sensors Location

The brainwaves (or impulse) are measured in real time, with the aid of the non-invasive method sensor (EEG). The device used is the Emotiv EPOC Neuroheadset [Figure 7]. The headset is made up of 14 saline sensors in which the electrodes continuously measure voltage levels from different areas of the user's scalp and send them to the PC. The sampling rate is 128 Hz. Below are the channel names based on the International 10-20 locations are: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4, and two additional reference channels CMS/DRL.

The tool is based on the Neuroheadset for recording the EEG measurements and software that processes and analyzes the data. Emotiv offers many types of headset along with software development kits, some can support product development through additional programming, and others could allow access to raw data. This research used the consumer headset along with the Emotiv Software that converts the raw data (mainly the electrical impulses) into a more digestible form. That processed output falls into main categories type retrieved from built-in suits: the Expressiv™ Suite (based on facial expression), the Affectiv™ Suite (based on the emotions), the Cognitiv™ Suite (based on the thoughts) (Emo). The main category of interest to our research is the "Affectiv" which reflects the passive measurements of a user's mental state / Emotions.

3.3.4 Technology Evaluation - Technology Readiness Level

The objective of this stage of the research was to evaluate the usability of the neuroheadset described in section 3.3. Different definitions for the Technology Readiness Level (TRL) are being used by different agencies; the most common ones are those used by the Department of Defense and the National Aeronautics and Space Administration (Mankins, 1995). On a scale from 1 to 9, below is a summary for each Technology Readiness Level;

- TRL 1: Lowest level of technology readiness. At this stage, scientific research begins to be translated into applied research and development;
- TRL 2: Invention begins - Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions;
- TRL 3: Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology;

- TRL 4: Basic technological components are integrated to establish that the pieces will work together;
- TRL 5: Fidelity of breadboard technology improves significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment;
- TRL 6: Model/prototype is tested in relevant environment. This level represents a major step up in a technology's demonstrated readiness;
- TRL 7: Prototype near or at planned operational system – it represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment;
- TRL 8: Technology is proven to work. The actual technology has been completed and qualified through test and demonstration;
- TRL 9: Actual application of technology is in its final form. Facilities, structures, systems and components successfully operated for one full cycle.

In terms of this classification, the Emotiv Neuroheadset as a Brain Computer Interface is considered as a **TRL 8 or 9**, depending on the application considered (Hugo, Gertman, & Tawjik, 2013).

Chapter 4 The Human Element

In this chapter the focus will be on the Human: The User. The events related to the human on the major aeronautical accidents will be presented. The human parameters, which in case monitored and interpreted (even in non-aeronautical fields), could result in an enhancement of the efficiency of the over-all human machine interface. The brainwaves emitted unconsciously by the brains which are the basis lying behind the electroencephalography and the neuroheadset described in the earliest chapter will be explained in more details.

4.1 Human and Accidents

Most of the hazards related to aviation safety leading to accidents and/or incidents worldwide are directly related to the human. For instance, the poor flight crew, poor flight crew procedures, and incorrect flight crew operation or equipment. In the figure below [Figure 1] a list of the worldwide aviation safety hazards for commuter/regional aircraft between 1979 and 1996 is shown.

Moreover, Table 1 represents the different causes related to human errors of fatal accidents by decade (in percentage), in which the **total pilot errors are the most contributing factor in a fatal accident**. It was compiled from an accident database (Kebabjian).

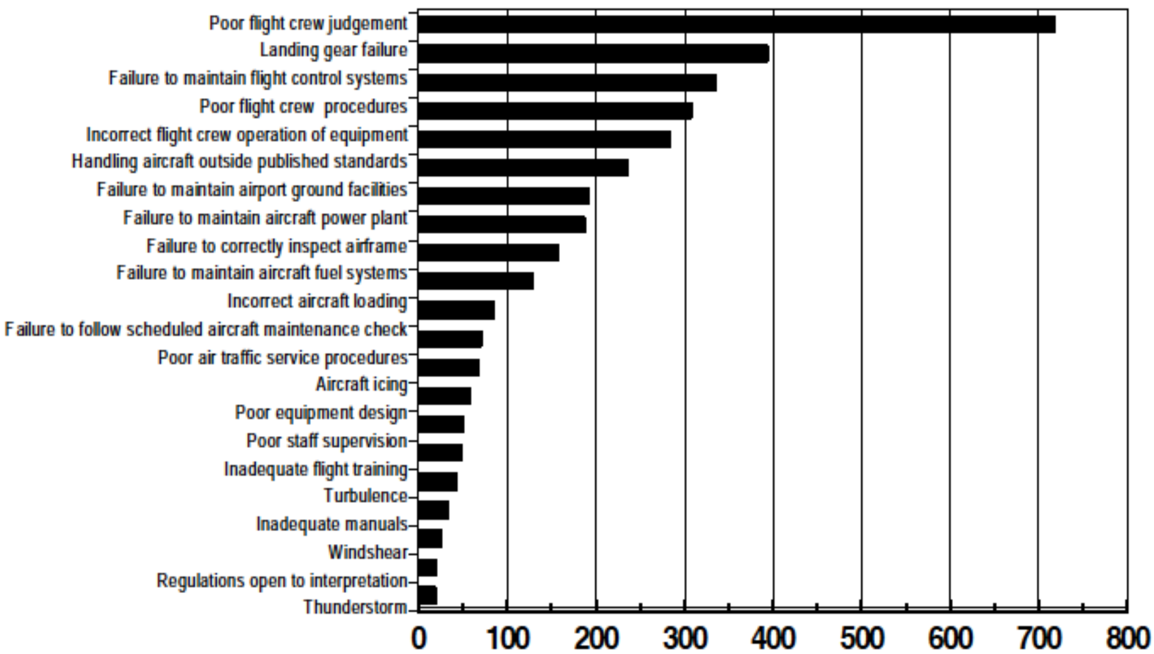

Figure 1 Worldwide Aviation Safety Hazards

Cause	1950s	1960s	1970s	1980s	1990s	2000s
Pilot Error	41	34	24	26	27	30
Pilot Error (weather related)	10	17	14	18	19	19
Pilot Error (mechanical related)	6	5	5	2	5	5
Total Pilot Error	**57**	**56**	**43**	**46**	**51**	**54**
Other Human Error	2	9	9	6	9	5
Weather	16	9	14	14	10	8
Mechanical Failure	21	19	20	20	18	24
Sabotage	5	5	13	13	11	9
Other Cause	0	2	1	1	1	0

Table 1 Human Error Different Causes Related to Fatal Accidents

The table is based on 1,085 fatal accidents involving commercial aircraft, world-wide, from 1950 to 2010 for which a specific cause is known. This does not include aircraft with 18 or less people aboard, military aircraft, private aircraft or helicopters. "Other human error" includes air traffic controller errors, improper loading of aircraft, fuel contamination and improper maintenance procedures.

Humans, by nature, make mistakes; therefore, human error has been implicated in occupational accidents, up to 70% to 80% in civil aviation (Shappell & Wiegmann, 1999). While the number of aviation accidents that can be attributed to mechanical failure decreasing over the past 40 years, those attributed to human error have declined at a much slower rate (Shappell & Wiegmann, 1996). Below are some figures representing the different causes of fatal and non-fatal accidents in percentage of accidents [Figure 2].

Here are some examples of errors illustrated in the figure above:

- Skill-based Error: Directional control, Airspeed, Stall/spin, Aircraft control, Compensation for winds.
- Decision Error: Inflight Planning, Planning/Decision Making on the Ground, Fuel Management, Unsuitable Terrain Selection, Go Around.
- Perceptual Error: Distance, Flare, Altitude, Clearance, Visual/Aural Perception.
- Violation: Procedures/Directives Not Followed, Operating Aircraft With Known Deficiencies, Hazardous Maneuver.

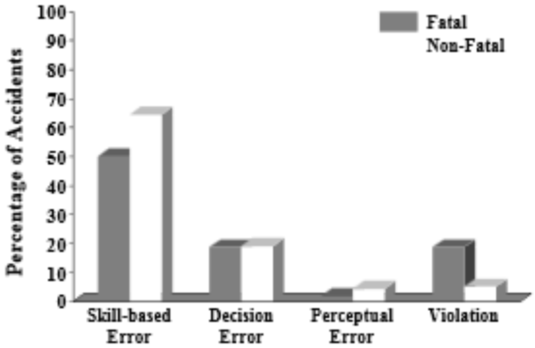

Figure 2 Percentage of fatal accidents associated with each error categories across years

Aviation is a complex field that requires interaction between many fields such as communication between people or interaction between a technician and a machine. As seen in the past figures and table of this chapter, the Human element is highly involved now in the drastic numbers of aeronautical hazards and airplane accidents.

4.2 Cognition and Human Factors

Human factors constitute the greatest percentage weight when it comes to aviation problems where they contribute to 70% of the misfortunes; human mistakes are not only related to pilots in the cockpit but also to other crewmembers, maintenance, Air Traffic Controller (ATC), design and organization.

Accidents often occur when flying task requirements exceed flight crew capabilities. There is a margin of safety between these two: the task requirements and the pilot capabilities. Below is an illustrated example [Figure 3] in which the margin of safety is minimal during the approach and landing. At this point of the phase of flight, an emergency or distraction could overtax pilot capabilities, causing an accident.

Being able to determine and monitor the task requirements along with the pilot capabilities, the margin of safety during all phases of flight could be optimized, hence mitigating the hazards affecting the level of safety and reducing the number of accidents.

Furthermore, **the absence of a pilot's Situation Awareness (SA) plays a major role in aircraft accidents.** When it comes to pilot related accidents, 85% of the human errors are associated to lack of SA, according to Airbus; this is because the loss leads to inappropriate decision making, tension in the cockpit and misleading actions [Figure 4] (Smith, 2012). Whereas as NASA ASRS stated, high workload (as defined in Chapter 1) make up 80% of those accidents.

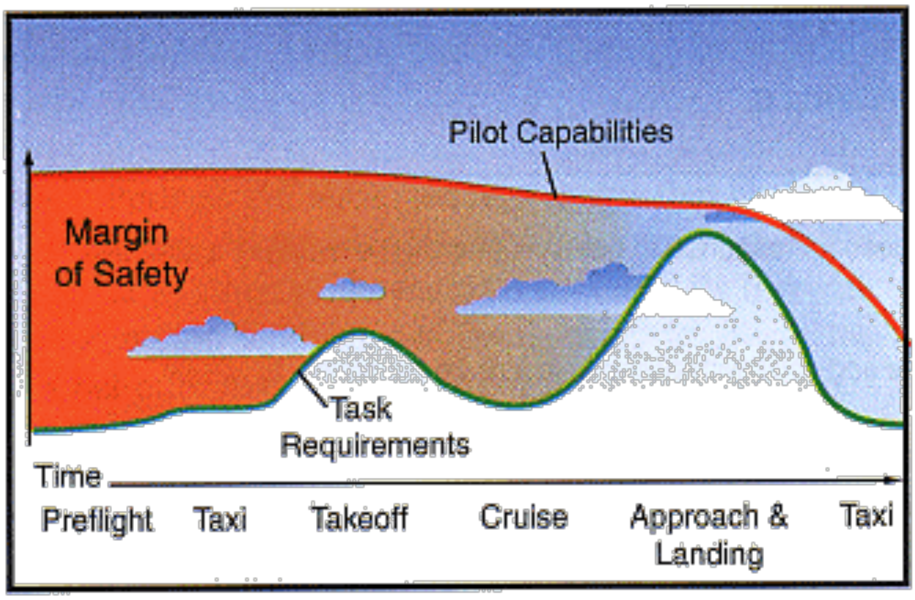

Figure 3 Safety Margin Depending on the Phase of Flight

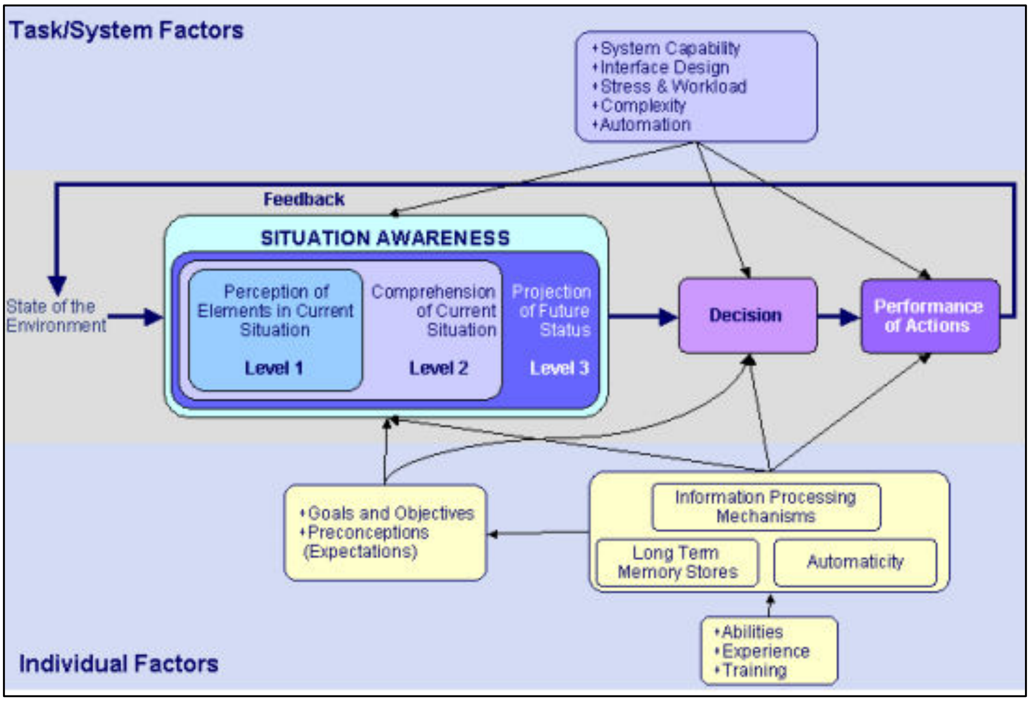

Figure 4 Situation Awareness and its Reflection on an Interaction

Figure 4 represents a model of decision-making factors (Endsley, 1995) in which situation awareness is comprised of three levels of perception, comprehension and projection of current situations.
Situation awareness is a term that is usually referred to when discussing the cockpit environment. The several levels of SA are:

- **Perception**: it is when sensory information is received, organized, recognized and interpreted. It is lost when the data is not detected or when visual illusions take place.
- **Comprehension**: it is the understanding of the perceived information. It is lost due to poor knowledge, inexperience and improper training or because of confirmation bias. Comprehension may be built further by enhancing knowledge of the equipment used and the situations the pilot may face in the training phase.
- **Projection** (or thinking ahead): it is when assumptions that some things may happen. It is lost when pilots over rely on equipment or on other pilots or when they expect a series of events that don't actually happen. Instructors who can give a view of what to expect can overemphasize projection while training and what to do if something unexpected occurs.

The idea in this research is to relate the online physiological brainwaves measurements of the pilot (whether an expert or a novice pilot), to his/her cognitive capacities depending on the phase of flight he/she was flying. **Monitoring the situation awareness and the personal capabilities of the user would enhance the interaction between the human and the machine** [Figure 4].

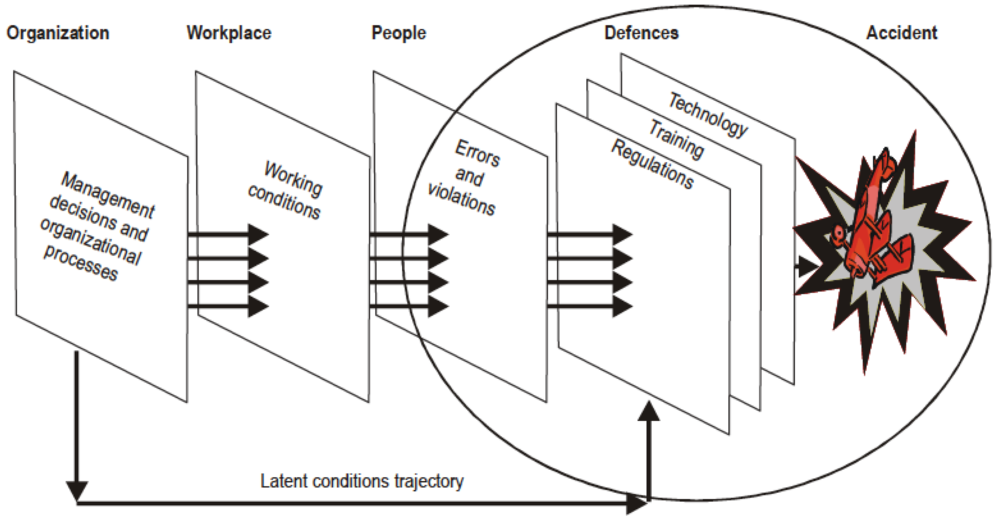

Figure 5 Organizational Accident - Building Block Approach

Accidents are not born instantaneously; it is the accumulation of errors that leads to an accident. According to the Reason model, in the aviation system, there are various defenses that are built to protect against fluctuations in human performance or decisions with a downside at all levels of the system (Reason, 1997). The aim behind an organizational accident is to identify and mitigate latent conditions on a system-wide basis rather than by localized efforts to minimize active failures by individuals. A concept of accident causation can be described by the building block approach characterizing five blocks that could prevent the breaching of the latent conditions. As seen in the figure above [Figure 5], **the last safety net to contain latent conditions is the defenses including the training and technology nets**.

In this innovative technological research, one of the application in which the designed interface is applied on the training phase of the pilots (section 5.1), other two applications described in the next chapter (section 5.2 and 5.3) can be categorized in the technology field.

4.3 Brainwaves

The focus of this research is on the types of brain waves emitted from the user depending on his **level of engagement, frustration, and boredom**. This could be done based on a classification done by neuroscientists according to the different ranges of frequencies that characterize the emitted brain wave: The brain is constantly emitting nearly every type of brainwave. The brain waves are the superposition of the multitude of electrical states being formed by the nervous system. However, based on the strength of certain bands of brainwaves a person can be said to be "in" a certain brainwave or band [Table 2]. The brain doesn't operate in only one brainwave state at a time but instead pulses in all these states simultaneously, with one of the states being dominant at any given time. The dominant state indicates the “state of mind” or level of consciousness.

Wave	Frequency (Hz)	Experienced during
Delta	1 – 4	Deep dreamless sleep
Theta	4 – 7	Light sleep, sleeping wave
Alpha	7 – 13	Deep relaxation
Beta	13 – 30	Full awake, generally alert

Table 2 Brain Waves Frequency

- The Delta state is associated to deep sleep, essential to the healing process.
- The Theta state is also known as the twilight state, which is experienced as one goes out of the depths of delta upon waking or drifting off to sleep.
- The Alpha state is when deep relaxation takes place, but not quite meditation. It is the entry point that leads into deeper states of consciousness.
- The Beta state is associated with a heightened alertness and visual acuity.

4.3.1 Brainwaves and the Neuroheadset

Focusing on the Affectiv™ Suite described in section 3.3.3, according to the Emotiv User Manual (Emotiv, 2011), the Affectiv™ Suite **reports real time changes in the subjective emotions experienced by the user**.
The Affectiv™ Suite is used to measure and identify the emotional state; for example nervousness, alertness, concentration, etc. Specially designed filters filter muscle signals and ocular signals; thus, **the identification algorithm uses clear brain signal**. Emotiv Corporation patents the type and structure of the applied neural network, and the specific information about the algorithm is protected.
Emotiv currently offers three distinct Affectiv™ detections:

- Engagement,
- Instantaneous Excitement, and
- Long-Term Excitement.

An alternative way to have access to the different wave frequencies is by using the Emotiv Test Bench in the Software Development Kit (SDK) Edition that represents the delta, beta and theta waves and can be displayed using a fast Fourier transform (FFT). Using the Emotiv Test Bench [Figure 6], The FFT data monitors directly the user's brain waves. It can measure the different waves, delta, theta, alpha and beta described above.

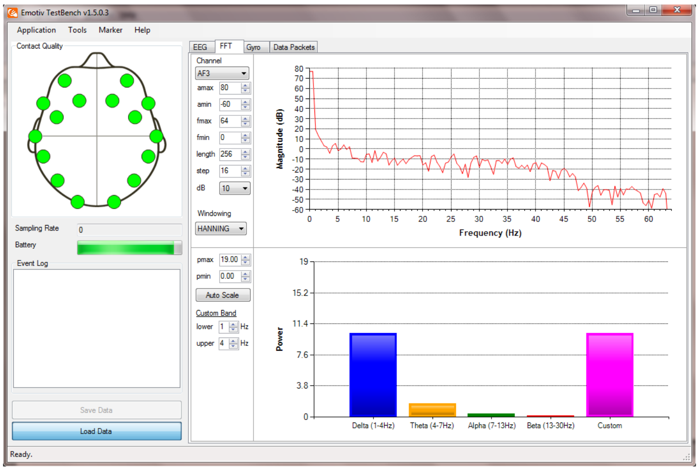

Figure 6 Emotiv Test Bench

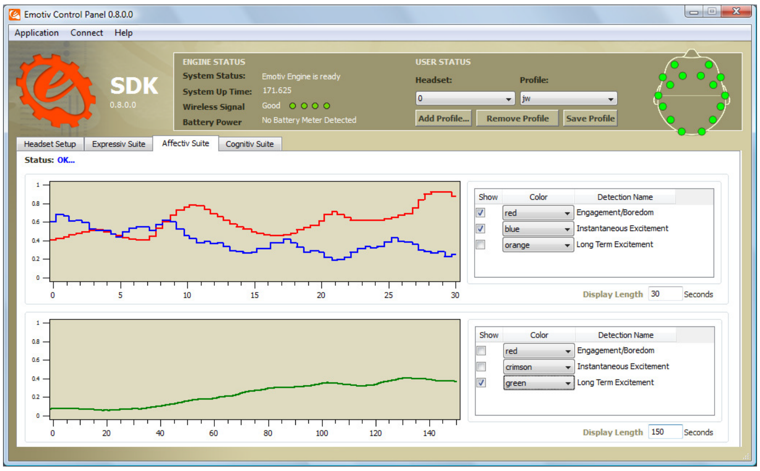

Figure 7 Affectiv™ Panel

The architecture of the interfaces created for this research in the three applications described in Chapter 5 is based on the Affectiv™ Suite output.
The Affectiv™ detections look for **brainwave characteristics that are universal in nature and don't require an explicit training or signature-building step on the part of the user**. As shown in the Figure 7, on the top chart of the Affectiv™ Panel Display, the engagement and instantaneous excitement detections are displayed over 30 seconds (by default, it can be changed using the "display length"). On the lower chart, over 5 minutes (time scale can also be customized), the long-term excitement detection is plotted.
Here are some definitions behind the emotions according to the Emotiv User Manual (Emotiv, 2011).

4.3.1.1 Engagement

Engagement is experienced as alertness and the conscious direction of attention towards task-relevant stimuli. It is characterized by increased physiological arousal and beta waves (a well-known type of EEG waveform) along with attenuated alpha waves (another type of EEG waveform).
The related emotions can be described as alertness, vigilance, concentration, stimulation and interest. The greater the attention, focus and cognitive workload, the greater the output score reported by this detection type.
According to the Emotiv forum, here are some examples in which the engagement pattern is involved:

- Engaging video game events that result in a peak in the detection are difficult tasks requiring concentration, discovering something new, and entering a new area.
- Deaths in a game often result in bell-shaped transient responses.
- Shooting or sniping targets also produce similar transient responses.
- Writing something on paper or typing typically increases the engagement score.
- Closing the eyes almost always rapidly decreases the score.

Going deeper into the Beta wave:
It has a frequency of 14 Hz and greater [Table 3]. It is usually seen on both sides of the brain in symmetrical distribution and is most evident frontally. It is the dominant rhythm in those who are alert or anxious or who have their eyes open. It is the state that most of brain is in when we have our eyes open and are listening and thinking during analytical problem solving, judgment, decision making, processing information about the world around us. The Beta band has a relatively large range and is divided into low, midrange and high distributions.
The Emotiv Epoc Neuroheadset Affectiv™ Panel doesn't differentiate between the different distributions of the Beta wave but it relates the Beta wave state of the user to alertness, thinking, and focus.

Associated	**Low Beta (12-15 Hz)**	**Mid Beta (15-18 Hz)**	**High Beta (above 18Hz)**
Feelings	Relaxed yet focused Integrated	Thinking Aware of self and surroundings	Alertness Agitation
Tasks and Behaviors	Lack of focused attention	Mental activity	Mental activity

Table 3 Beta Waves

4.3.1.2 Instantaneous Excitement

It is experienced as an awareness or feeling of physiological arousal with a positive value. Excitement is characterized by activation in the sympathetic nervous system that results in a range of physiological responses including pupil dilation, eye widening, sweat gland stimulation, heart rate and muscle tension increases, blood diversion, and digestive inhibition. The related emotions are the titillation, nervousness, and agitation.

In general, the greater the increase in physiological arousal the greater the output scores for the detection. The Instantaneous Excitement detection is tuned to provide output scores that more accurately reflect short-term changes in excitement over time periods as short as several seconds.

4.3.1.3 Long-Term Excitement

It is experienced and defined in the same way as Instantaneous Excitement, but the detection is designed and tuned to be more accurate when measuring changes in excitement over longer time periods, typically measured in minutes.

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Chapter 5 Aeronautical Applications

As discussed in the previous chapters, this research is based on the brain electrical activities by recording the electrical impulses emitted by the brain waves of the user. In order to record these different brain states of the user, electroencephalography portable Neuroheadset were used. This latter was used to **measure in real time the user's mental state of mind without interfering with the task since the headset is completely wireless, allowing the user free, natural movement**.

In this section of the report, the design of the Human Machine system will be described, along with the three applications related to aeronautics.

5.1 Evaluation Tool during Training

The target of this research is to focus on the human element as shown in all the previous figures playing a major role in aviation accidents (Chapter 1). The system built based on virtual reality technologies described earlier, will be in this section applied to the training of the future pilot, or even to re-current pilot training. The BCI system is used here **to evaluate the emotional sensitivity of specific flight phases of flight**, that will be virtually simulated on a large immersive display (CAVE - Cave Automatic Virtual Environment) using the Microsoft Flight Simulator X (Gold Edition). While virtually flying, **the pilot is being assessed by a real-time evaluation based on the EEG classification and by flight examiner's usual assessment**.

5.1.1 Experimental Setup

Centered on the human element, and innovative technologies, the experimental setup designed and built in the virtual reality and simulation laboratory is described below. The resultant could be applied in different aeronautical (and non-aeronautical) related applications. In this research the **user is in the center of the loop between the interface and the task**. The process of brainwaves classification consists of steps as shown in the Figure 1. The user is the focal point, without him/her, the process vanishes. The user is first exposed to the usual environment (whether a cockpit, a simple office or a simulator), the user will be wearing the neuroheadset that is capturing in real time the brainwaves emitted. These EEG data will be analyzed and the relevant features and/or emotions classified. The major step after the classification is the **interface** (to which the user was exposed at the beginning of the process) that will **adapt** to the corresponding "brain state" of the user. Depending on the application (or task) chosen, the user will be exposed to a consequent stimulus that will **enhance the situation awareness, and increase the efficiency between the user and the interface itself.**

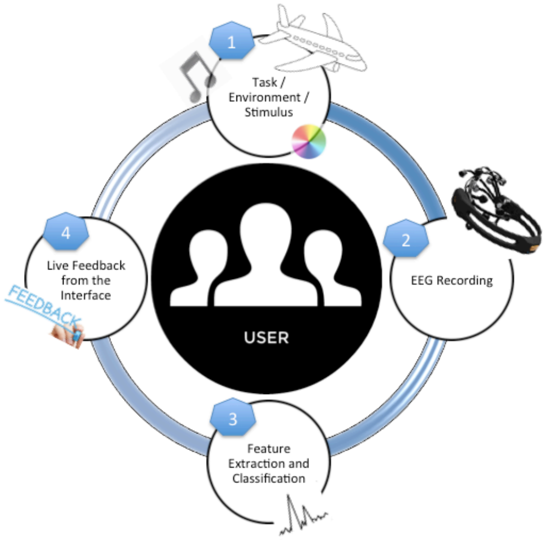


Figure 1 Process of User in the Loop

In order to enhance the immersive feeling of the user (mainly the pilot in the following applications described later on), a **cockpit replica was settled in the virtual reality and simulation laboratory**. The following are the hardware implemented in the laboratory for future simulation and different applications:

- The BMI produced by Emotiv already described earlier (sections 3.3.3 and 4.3.1) [Figure 2].
- Flight Controls "Logitech Flight System G940", consists of flight rudder pedals, throttle and a force feedback joystick [Figure 3].
- Cockpit Chair "Playseat Flight Simulator" including a frame linking the flight controls to the cockpit chair. It is shown in the Figure 4 with the Logitech Flight System installed.

Figure 2 Neuroheadset

Figure 3 Logitech Flight System G940

Figure 4 Playseat Flight Simulator

Figure 5 Logitech HD Webcam

- Logitech HD Webcam C615, Video Camera recording in parallel what happens while the experiment is running [Figure 5].
- Desk used for any assessor as a flight instructor present during the flight settled in a non-intrusive position.

Below is the list of the corresponding Software used in combination of the above-mentioned hardware:

- Microsoft Flight Simulator X Gold Edition, that is used to simulate any type of flight by choosing meticulously-modeled aircrafts. The experimenter can select any starting location among the 24 000 airports listed, set the time, the season and the weather. Below is a picture representing a flight scenario projected on the CAVE (Cave Automatic Virtual Environment screen [Figure 6]. The back of the Playseat chair is seen in the middle of the picture.

Figure 6 Microsoft Flight Simulator X - Gold Edition

Figure 7 Emotiv SDK Research Edition

- Emotiv Software Development Kit Research edition (already described in section 4.3.1).

Below is a top view of the CAVE - Cave Automatic Virtual Environment representing the architecture of the experimental setup [Figure 8].

5.1.2 Evaluation of a First Version of the Prototype

Prior to implementing all the hardware and software described in the earlier section in the virtual immersive environment, **a part of the research was focused on testing the accuracy of the neuroheadse**t described in the earliest chapters in predicting the emotional state of the user. This part of the study was conducted on novice pilots (without any prior experience in flying) to **investigate the potential value of EEG data related to engagement and workload during their first training flight on a basic flight simulator**. The electroencephalographically data were obtain using the consumer headset type from the same brand described earlier. By using this latter, no software development kit was used; hence no access to raw data was available.

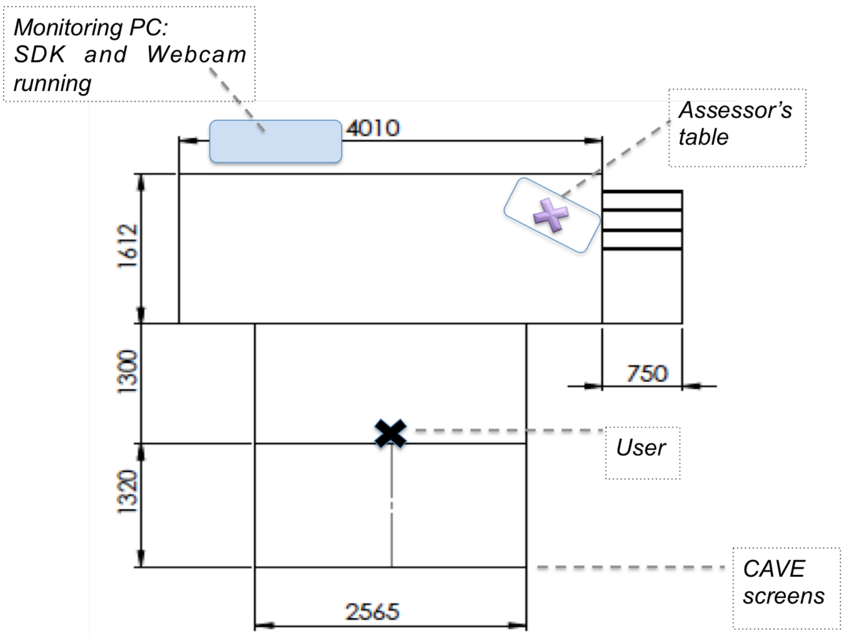


Figure 8 CAVE Architecture

The aim was to capture and classify the emotions of a pilot during a simulated flight. Based on the tasks to accomplish whether landing or taking off, the level of engagement, frustration, and boredom were correlated to the workload level, assessed in a questionnaire based on the NASA-TLX methodology that is filled by the pilot after completion of the tasks. After gathering and correlating the experimental data, this method proved to be a driving tool for pilots training.

The duration of the simulated flight was approximately twelve minutes on a Cessna 208 and the brainwaves of nine users were measured during the complete flight duration. The departure and arrivals airports were chosen based on their approachability and easy to handle runways. The Microsoft Flight Simulator was used on a single basic monitor. The experiment was arranged in a non-immersive environment, sitting on a desk with a monitor in front of the user. The novice pilots got briefed on the basic steps to follow during the flight, focusing on the flight parameters in terms of the take-off speeds, the flaps configuration and how to land the plane. They got introduced to the neuroheadset used to capture their brainwaves, and on the debriefing that will happen right after the landing phase. They aged between twenty and twenty eight years old. Worthwhile noting here that the flight was taking place on a single basic monitor with a joystick and a keyboard. Moreover, questions were asked during the take-off phase of the flight (about the rotation speed and the current heading) in order to determine the level of attention of the user to his/her instrument, and the level of confidence he/she was feeling, brainwaves were captured while being asked the questions and the estimated answer will be correlated below.
The emotions observed from the control panel of the consumer neuroheadset version used in this testing phase and the corresponding physiological symptoms are described in the table below [Table 1].

Emotions	**Physiological Aspect**
Engagement	• The user is in an alert state; • The user has a conscious attention directed towards a relevant stimulus; • The user feels concentrated and interested.
Excitement	• The user feels agitated and nervous; • A low level of excitement is interpreted by the calm the user is feeling; • Demonstrated by some specific symptoms: pupil dilation, eye widening, sweat gland stimulation, heart rate and muscle tension increases, etc.

Table 1 Emotions Observed and Related Physiological Symptoms

The NASA-TLX provided feedback regarding both the subjective input from the pilot and his/her estimation regarding the overall workload of the task required (Hart & Staveland, 1988). A correlation between the values (high or low) of three out of the six proposed rating scales and key factors were envisaged; below various factors that may affect the different rating scales during a flight are listed in the table below [Table 2].

The subjective feedback of all the subjects during the take off phase showed that the temporal demand had the highest weight; the mental demand comes at the third place while the frustration is at the sixth place. For the landing phase and based on the total subjects' feedback, the mental demand has the highest score, the temporal demand comes second, and the frustration rating, at the fifth place.

Rating	**Description** (Hart & Staveland, 1988)	**Affecting Factors during Flight Phases**
Temporal Demand	The amount of time pressure felt due to the rate at which a task should be accomplished in. The main question describing the feeling: "Was the pace slow and leisurely or rapid and frantic?"	• High time constraint during taking off while reaching the rotation speed and the take off run; • High time constraint due to runway limitation (applied in both take off and landing phases); • High time constraint to achieve a good and safe performance.
Frustration	The level of insecurity, discouragement and irritation during the task. It refers to the level of stress and annoyance vs. the security that the user felt.	• High frustration when in a fully immersive training flight (or real flight); • Low frustration during a normal standard simulated flight.
Mental Demand	Related to the effort dedicated to thinking, deciding, looking and searching or even remembering.	• High mental demand remembering the rotation speed value; • High mental demand during the landing happening after about ten minutes of the debriefing; • High mental demand while searching for the runway in order to land.

Table 2 NASA-TLX Ratings and Corresponding Affective Factors during Flight Phases

Below is a tabulated representation [Table 3 and Table 4] of the observed emotions correlated with the following parameters:

- Corresponding flight phase,
- Novice Pilot experience in flight simulator, and
- Flight type (with or without failures).

The orange curve represents the instantaneous excitement while the grey curve represents the engagement emotional level. The graphs presented are taken from screen shots of the user interface of the neuroheadset, since this testing phase was based on the user consumer neuroheadset without any access to raw data (not the SDK version).

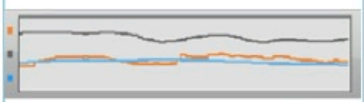
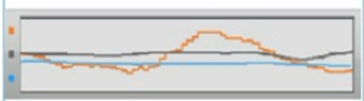
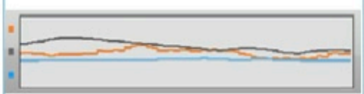
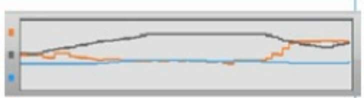
Flight Conditions	Affective Results	Interpretation
• Flying in standard conditions • No failures • No experience on a simulator		• Slight increase in Excitement - pilot's awareness • High Engagement – Alertness of pilot (new workload)
• Flying with crosswind • Speed indicator and altimeter malfunction • 10 hours flight experience		• Increase Excitement - situation awareness and physiological arousal • No increase in Engagement. Low alertness
• Standard conditions • No failures • 166 hours flight		• Slight increase in Excitement - awareness and physiological arousal • Slight decrease in Engagement – User is comfortable during Take-off phase
• Engine 2 off and flaps malfunction • 166 hours flight		• Increase in awareness and physiological arousal (Excitement level) • High engagement – new high workload

Table 3 Emotional Results and Interpretation

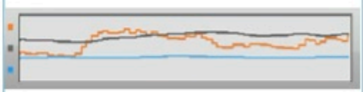
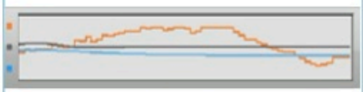
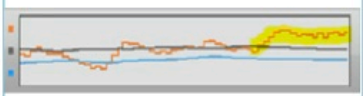
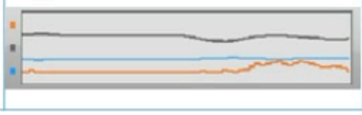
Flight Conditions	Affective Results	Interpretation
• Flying in standard conditions • No failures • No experience on a simulator		• High Excitement - Situational awareness is very high • High Engagement – Alertness of pilot (new workload)
• Flying with crosswind • Speed indicator and altimeter malfunction • 10 hours flight experience		• Variation of Excitement - situation awareness and physiological arousal • No increase in Engagement. Low alertness
• Standard conditions • No failures • 166 hours flight		• Increase in Excitement - awareness and physiological arousal (Touchdown) • No changes in Engagement – User is comfortable during Landing phase
• Engine 2 off and flaps malfunction • 166 hours flight		• Decrease in Excitement - awareness and physiological arousal (Touchdown) • No changes in Engagement

Table 4 Emotional Results and Interpretation

Flight Phases: Take off and Landing Flight Phases
The Weighted Workload Ratings (Hart & Staveland, 1988) **for both the landing and the take-off phases revealed a greater importance in terms of scale values for the landing phase** as seen in the figure below [Figure 9] (except for the third subject). Moreover, **the amplitude of the brainwaves measured in these two phases reflected similar subjective result.**

Figure 9 Weighted Workload Rating for Take off and Landing Phase

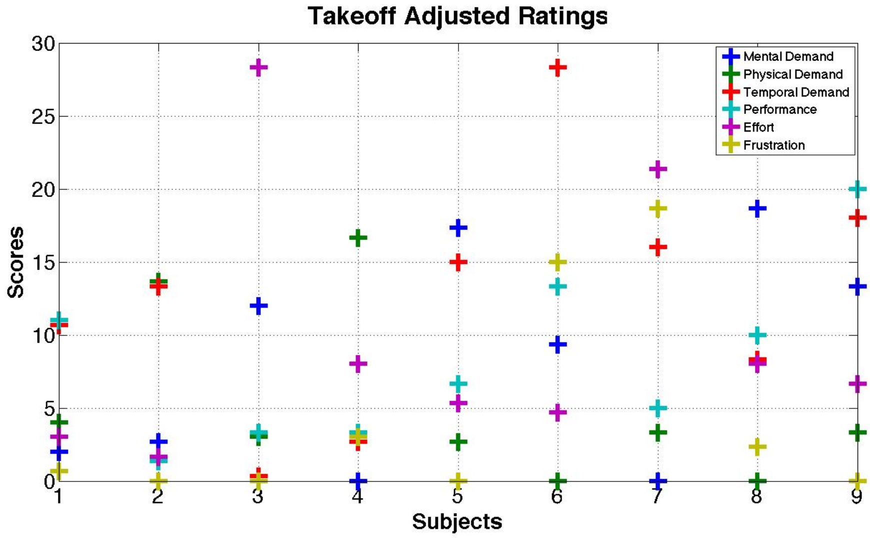


Figure 10 Take Off Adjusted Ratings

The subjective feedback of almost all the subjects during the take off phase showed that the temporal demand (represented by the red cross) had the highest weight; the mental demand (dark blue cross) comes at the third place while the frustration (yellow cross) is at the sixth place [Figure 10].

For the landing phase and based on the total subjects' feedback, the mental demand has the highest score, the temporal demand comes second, and the frustration rating, at the fifth place [Figure 11].
Centered on the methodology described earlier, and in order to check the correlation (as presented in Table 3 and Table 4) between the brainwaves measured and the feedback from the corresponding ratings (as shown in Figure 10 and Figure 11), the results are based on two basic triggering events during the take off and the landing phases: the break release and the rotation, the touch down and the breaking respectively.

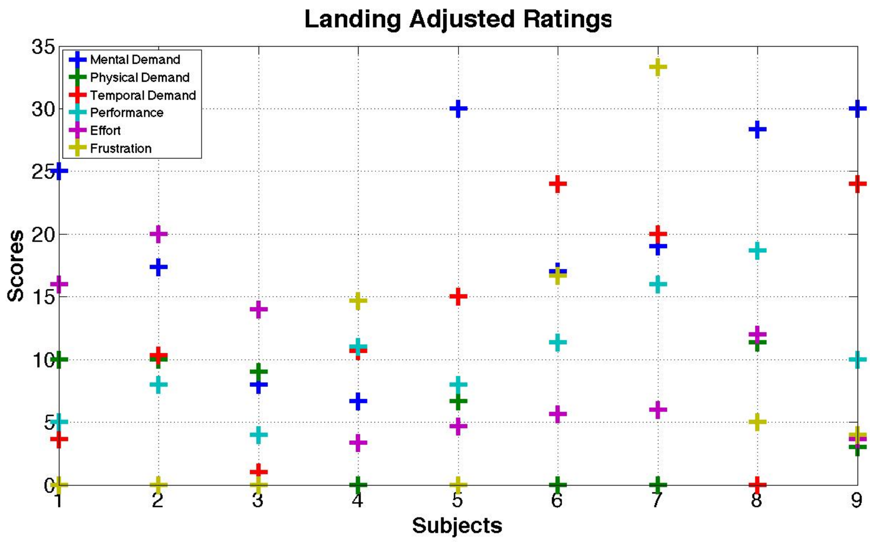


Figure 11 Landing Adjusted Rating

Comparing the subjective results felt by the subject and the corresponding emotional level measured by the neuroheadset, resulted in the **following correlations**:

- **The engagement level and the mental demand score,**
- **The excitement level and the temporal demand,**
- **The excitement level and frustration weight.**

This testing phase gave noteworthy results by simply using the basic type of neuroheadset, without any access to raw data, a single monitor on which the windows flight simulator was uploaded, basic flight controls comprising a joystick and a keyboard. The experimental set-up was not immersive in any way, and the users emotional levels correlated with the NASA-TLX scales.
Based on these results the software development kit with access to raw data was implemented in the virtual reality laboratory as described in the earliest section (5.1.1).

5.1.3 Methodology of the Designed Tool

In this part of the report, and based on the promising results described in the earliest section, all the hardware and software described in section 5.1.1 were implemented and tested.
Using the CAVE immersive simulation environment during a specific flight, the aim of this part of the research is to **collect the online brainwaves data reflecting the pilot's emotion during his/her evaluation of required task(s)**. The data obtained will be compared with:

- The examiner assessment,
- The subjective workload assessment using the pilot's NASA-TLX answers, and,
- The previous recorded data (during earlier similar flights), reflecting on a certain evolution or trend for each pilot throughout the flights.

Evaluation could be done on this new methodology of training and debriefing.

5.1.3.1 Using the pilot's emotions (objective) in correlation with the NASA-TLX subjective answers

Before going on, special care must be taken regarding the definition behind the emotions recorded (Emotiv, 2011). As already explained in section 4.3.1, the instantaneous excitement measured is experienced as an awareness feeling, and is characterized by a range of physiological responses that are usually related to nervousness, agitation and titillation. On the other side, the engagement is experienced as alertness to the conscious direction of attention towards task-relevant stimuli. It is characterized by an increase in the beta waves and an attenuation of the alpha waves. It is an emotion related to alertness, concentration and interest.
Table 5 summarizes the link that can be done based on the two assessments:

- The objective assessment: the online and unconscious brainwaves data measured from the pilot (namely, the excitement, engagement and frustration).
- The subjective assessment: the answers of the pilot based on the NASA-TLX that could be considered as subjective (namely, the mental physical and temporal demands, the performance, the effort and the frustration).

Emotions		NASA-TLX	Explanation	Notes
Excitement (Aasman, Mulder, & Mulder, 1987) (Vicente, Thornton, & Moray, 1987) AND Engagement	**Proportionally Related to ***	Mental Demand	<u>Relation with Excitement</u>: High excitement is related to high pupil diameter (Emotiv, 2011), and since this latter is related to high mental effort (Aasman, Mulder, & Mulder, 1987) & (Vicente, Thornton, & Moray, 1987), we can relate the excitement measured to the mental effort scaled according to the NASA-TLX. <u>Relation with Engagement</u>: Based on the results obtained using the user consumer neuroheadset described in section 5.1.2	Mental Demand is an essential component of workload during flight (Lee & Liu, 2003) High excitement will reflect high nervousness. High engagement will reflect high interest in the stimuli. Depending on the performance assed by the flight instructor, each pilot will have his/her "normal" threshold of emotion
Excitement		Temporal Demand	Based on the results obtained using the user consumer neuroheadset described in section 5.1.2.	Temporal Demand is an important component of workload during take-off (Lee & Liu, 2003)
		Performance		Frustration is experienced whenever the results (goals) expected do not seem to fit the effort and action one is applying. Therefore an overall good performance of the task will result in a low frustration curve, whilst the opposite works too.
Excitement (Aasman, Mulder, & Mulder, 1987) (Vicente, Thornton, & Moray, 1987)		Effort	High excitement is also related to a high heart rate (Emotiv, 2011) that is related to high stress and effort (Aasman, Mulder, & Mulder, 1987)& (Vicente, Thornton, & Moray, 1987), therefore we assume that the excitement measured will be related to the effort and frustration NASA-TLX scales.	
Excitement (Aasman, Mulder, & Mulder, 1987)& (Vicente, Thornton, & Moray, 1987) AND Frustration		Frustration	<u>Relation with Excitement:</u> Same as above. Moreover results obtained using the user consumer neuroheadset described in section 5.1.2 showed the same correlation. <u>Relation with Frustration</u>: Based on the definition of both the feeling named by Emotiv (Emotiv, 2011) and the scale name by NASA-TLX (Hart & Staveland, 1988)	

Table 5 Emotions and NASA-TLX

** Except for Frustration and Performance (un-proportionally related to)*

5.1.3.2 Using the pilot's emotions (objective) in correlation with the Flight Instructor's assessment

According to the practical test standards set by the Federal Aviation Administration, the examiner evaluation on each task is either satisfactory or unsatisfactory (Federal Aviation Administration, 2011). The examiner assessment is defined as follows: "The examiner conducting the practical test is responsible for determining that the applicant meets the acceptable standards of knowledge and skill of each TASK within the appropriate practical test standard." "If the examiner determines that a TASK is incomplete, or the outcome uncertain, the examiner may require the applicant to repeat that TASK, or portions of that TASK."

Satisfactory performance to meet the requirements for certification is based on the applicant's ability to safely:

- Perform the Tasks specified in the Areas of Operation for the certificate or rating sought within the approved standards;
- Demonstrate mastery of the aircraft by performing each Task successfully;
- Demonstrate satisfactory proficiency and competency within the approved standards;
- Demonstrate sound judgment and exercises aeronautical decision-making/risk management; and
- Demonstrate single-pilot competence if the aircraft is type certificated for single-pilot operations.

Unsatisfactory Performance:

The tolerances represent the performance expected in good flying conditions. If, in the judgment of the examiner, the applicant does not meet the standards of performance of any Task performed, the associated Area of Operation is failed and therefore, the practical test is failed.

In the table below, each emotion detected is interpreted with the possible examiner assessment and recommendations for each of them is proposed:

This **unsatisfactory assessment won't be altered by the emotional online assessment; but it could be implemented further with the use of the designed tool, to check the reason behind a failure in a particular task**: is it due to a high level of frustration that led the pilot to an uncontrollable situation? Or, is it due to a low level of engagement representing a low interest in the task? An unsatisfactory performance will always lead to more training, but special care must be put on the emotions felt during the corresponding performance.

In the tables below [Table 6, Table 7 and Table 8] each emotion detected is interpreted with the possible examiner assessment and recommendations for each is proposed.

- Frustration level vs. examiner assessment:

Frustration	Assessment	Interpretation	Recommendation
High	**Satisfactory**	Good outcome, but might need some training to decrease the level of frustration to an acceptable middle level. Frustration might alter the levels of situation awareness (perception, comprehension and projection).	Needs some training. The level of practice depends on engagement level. • High and deep level of training needed if combined with low-level engagement (i.e. bored and frustrated subject) and/or low level of excitement; *unless it is a special day and the subject is not in his/her good days*. • Moderate level of training if combined with high level of excitement. Subject is aware of his/her dynamic environment, but needs to practice in order to be capable to master his/her emotions
	Unsatisfactory	Need to master his/her emotion. Will need more training.	If combined with low level of excitement (low awareness): needs high and deep level of training.
Low	**Satisfactory**	A sign of confidence in the task, and/or a sign of self-containment.	*Note: Frustration should be relatively low, not too much.*
	Unsatisfactory	Signs of Recklessness and carelessness; Especially if combined with low level of engagement (i.e. bored subject).	Needs a high and deep level of training.

Table 6 Frustration Level and Examiner Assessment

Special care regarding the frustration feeling: it might be altered by the fact that the pilot during the experiment is using a new technology and will be frustrated at the beginning. The frustration level is expected to decrease while the pilot get used to the neuroheadset. Therefore some time is needed before the experiment could start in order to stabilize the signals.

- Engagement level vs. examiner assessment:

Engagement	Assessment	Interpretation	Recommendation
High	**Satisfactory**	Good outcome. Highly alert pilot.	If combined with a low excitement (i.e. low awareness), it is recommended to review the task to be able to control and preview what might happen.
	Unsatisfactory	Task should be repeated.	The pilot was highly alert but failed in achieving the task. The reason behind it might be due to a lack of comprehension and/or projection of the situation. Appropriate training needed.
Low	**Satisfactory**	Pilot was not alert, but was able to accomplish the task.	Aim fulfilled, but training is recommended. Was he/she bored?
	Unsatisfactory	Task should be repeated, and engagement should increase.	The pilot didn't even notice the first stage of the situation awareness: perception. This latter is when sensory information is received, organized, recognized and interpreted. Training should improve that emotional situation.

Table 7 Engagement Level and Examiner Assessment

- Excitement level vs. examiner assessment:

Excitement	Assessment	Interpretation	Recommendation
High	**Satisfactory**	Pilot aware of the task and the environment.	Check the stress level (by measuring the heart rate for example), check the muscle tension.
	Unsatisfactory	Pilot was aware of the task. Perception and comprehension were achieved successfully; the problem was in the projection part, pilot wasn't able to think ahead.	Training needed to enhance the projection part of the achievement of the task according to the given environmental situation. Moreover, in case the stress was behind this failure, the pilot was stressed (this can be checked in correlation with the NASA-TLX feedback regarding that specific task, he/she must be able to control his/her stress level.
Low	**Satisfactory**	Good outcome.	Special care must be made to the level of excitement. It shouldn't be too low.
	Unsatisfactory	Pilot unaware of the task to be achieved.	Training should be completed. Check with the pilot why he/she wasn't aware of the task to be achieved. In case engagement was high, the pilot was in the perception level of the Situation Awareness, but couldn't understand the perceived information. In case engagement was low, the pilot wasn't able to even perceive the task. Deeper training will be recommended.

Table 8 Excitement Level and Examiner Assessment

Emotion	Evolution expected
Engagement	Expected to decrease after a certain number of flights (number to be defined during tests, depends on the person), but shouldn't decrease below a certain level (amplitude to be defined) beyond which it will be reflected as boredom.
Excitement	Expected to decrease after a certain number of flights (number to be defined during tests, might depend on the person or not). Special care should be made due to the fact if we continually present the pilot with some extreme scenarios, he/she will anticipate it and may get used to it... Hence reducing the fidelity of the experiment.
Frustration	Expected to fluctuate depending on the performance of the required task. Frustration is experienced whenever the results (goals) expected do not seem to fit the effort and action one is applying.

Table 9 Emotion and Evolution with Time

5.1.3.3 The pilot's emotions (objective) throughout practice – An Emotional Logbook

At a later stage of this innovative system, student pilots can have a **digitalized emotional logbook** categorized for every type of flights, with the evolution of their emotional assessment plotted over time. The expected evolution for an average pilot training life is as presented in Table 9 above.

5.1.4 Structure of the Experiment

A call for participation was disseminated to a flight training organization targeting student pilots with different levels of experience willing to participate in the testing of the system at the virtual reality laboratory of the University of Bologna in Forlì. Two Flight Examiners positively responded to this call, and the details of the simulated flights along with the variety of the pilots' trainee were established.

The duration of the flight is around twelve minutes. The aircraft used is a single engine piston aircraft, a Cessna 172SP Skyhawk [Figure 12].
The outbound and inbound airports were chosen to be Forlì's airport since the flight training organization from which the student pilots were coming, is based at Forlì's airport. This latter airport has one runway (12/30) with an 8,399ft long runway [Figure 13]. The reason behind choosing a familiar airport for this testing phase of the system, is avoiding additional factors to the flight that might alter the already acquired knowledge of the pilots.

Figure 12 Cessna 172SP Skyhawk

Figure 13 Forlì's Airport - Runway

Every pilot, based on the following details, was asked to accomplish three flights:

- Flight condition 1: normal flight in a clear sky
- Flight condition 2: normal flight with low visibility (4.8 km)
- Flight condition 3: flying the traffic pattern in clear skies conditions with an engine failure simulation after the touch and go phase.

Based on the recommendations of the flight instructors, the tasks the pilots were assessed on are as follows:

- For flight conditions 1 and 2:
  - Task 1: Turning (left/right)
  - Task 2: Climb and Descent
  - Task 3: Slow Flight
- For flight condition 3:
  - Task 1: Touch and Go
  - Task 2: Controlling and Landing the aircraft with the engine failure

At the day of the test, the student pilot individually was briefed on the neuroheadset and the way it works. Special care was made on the fact that it won't be intrusive and that measurements will be made only on the excitement, engagement and frustration felt during the flights. They were also briefed on the three flight types (without specifying the engine failure case), and that they will be assessed by two Flight Examiners (whom they already know). Everything was settled in order to make sure they give out the best of their performance. They were briefed on the way the flight controls had to be used, and useful performance data regarding the Cessna 172SP Skyhawk were shown [Table 10].

Prior to officially start the recordings of the brainwaves and the Flight Examiners assessments, the pilot was allowed to have a ten minutes (on average) trial flight in order for the emotional signals to stabilize and to make him/her feel confident with the environment, and the feel of the flight controls.

TakeOff	FULL	ROTATION 65 kts
CLIMB	FULL	80 kts
CRUISE	2 300 rpm	110 kts
DESCENT	1 700 rpm	
V_{APP}	80 kts / 70 kts	
$V_{E\,MAX}$	75 kts	

Table 10 Performance Data Cessna 172SP Skyhawk

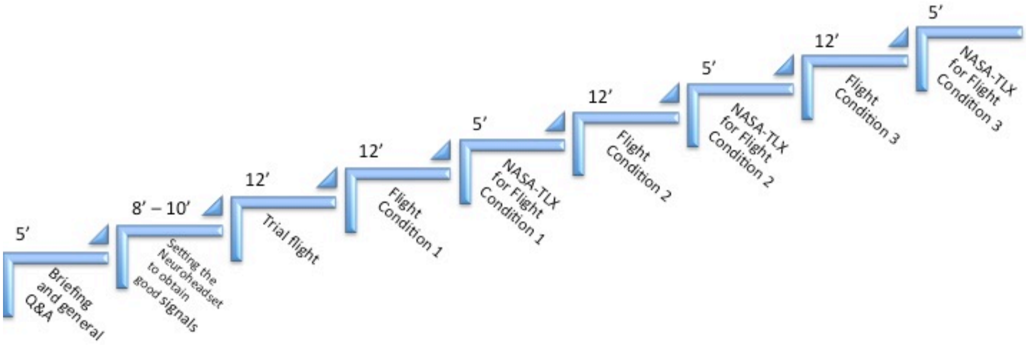


Figure 14 Experimental Procedure Showing the Average Duration of Each Individual Part of the Experiment

After every flight the pilot trainee was asked to fill inn the NASA-TLX assessment, and was briefed on how to do it and the exact meaning behind each question (Appendix A and Appendix B). The Flight Examiners were also given three sheets (corresponding to each flight) each with checklists in order to assess the student pilot on the individual tasks to be performed during the flight (Appendix C). In a chronological order, the procedure of the experimental phase for each pilot is explicitly stated in Figure 14. On average the time spent in the laboratory with one pilot was around one hour and twenty minutes; here are the details of each phase.

In Figure 15, taken during the experiment, one can see the projection on the CAVE screens of the inside view of the Cessna 172SP Skyhawk's cockpit along with the panorama above Forli's area around the airport as projected by the flight simulator described earlier. In the middle of the screen, the back of the cockpit chair with the student pilot flying the virtual Cessna. Notice the blue light at the back of the pilot's head: it shows the neuroheadset rear LED indicator ("When the power switch is set to the "on" position, the rear LED will illuminate and appear blue if there is sufficient charge for correct operation" (Emotiv, 2011)). On the left of the picture the silhouette of the Flight Examiner sitting on the table in a non-intrusive way to the pilot in order to assess the tasks described earlier. In this picture, the pilot was performing a left turn. Last but not least, on the foreground of the below picture the three screens computer are represented, in which all the online EEG recordings are being stored along with the recording of the movie of the overall scenery.

Figure 15 While the Experiment is Running

5.1.5 Results and Discussion

5.1.5.1 Debriefing Tool

Using the combination of software and hardware as described in section 5.1.1 a great tool for debriefing was obtained. A movie can be compiled for every pilot on particular flight. **A combination of the real flight and the online measured brainwaves could be projected in parallel resulting in a great and innovative way for the flight instructor to debrief with the student pilot**. As seen in the figure below a snapshot of a compiled movie screen is shown [Figure 16].
The Flight Examiner along with the pilot trainee could go back to specific flight phases, or tasks assessed on, and discuss the emotional results obtained. The other way around, they can choose to review a part of the flight in which a high frustration (curve in red in the below figure) was measured and rework on that specific moment of the flight in order to have a better understanding behind the reason of the high frustration level.

In total, twenty-four flights where successfully accomplished, recorded and corresponding brain waves were recorded. The **engagement amplitude was the highest among the emotions detected during 92% of the flights** [Figure 17, Figure 18, Figure 19]. The only two flights in which the engagement level was not the highest among the three detected emotions occurred in the third flight condition flight [Figure 19]. According to a study (Lee & Liu, 2003), the **mental demand is an essential component of workload during flight**. Furthermore, using the results obtained earlier concerning the pilot's (objectively measured) emotions in correlation with the NASA-TLX subjective answers, mental demand was correlated to the engagement measured. **The results obtained here highlight the fact that the pilots brain states reflected a high interest in the stimuli proposed for the majority of the flights.** Hence the data obtain are reliable and further interpretation could be done.

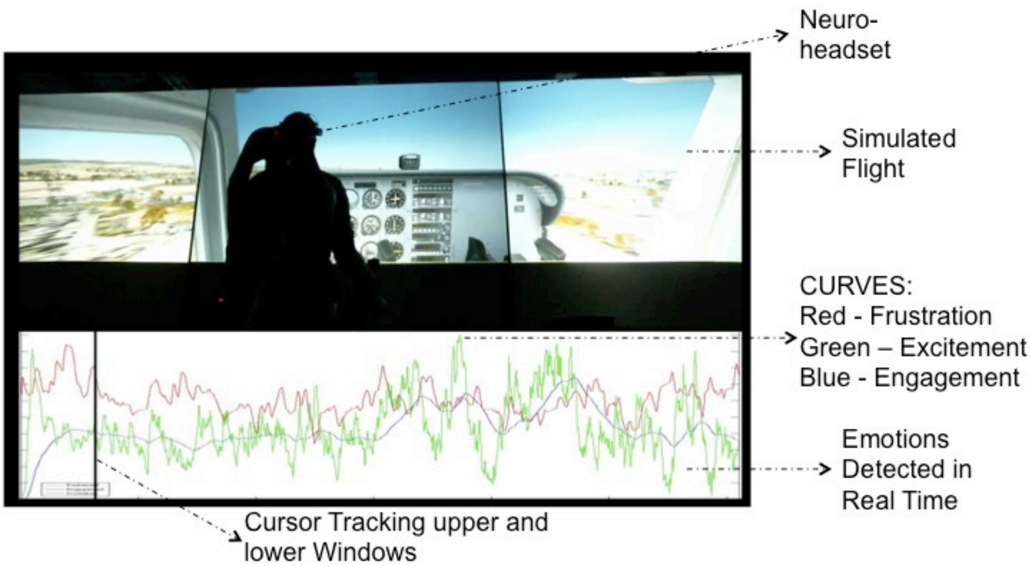


Figure 16 Debriefing Tool

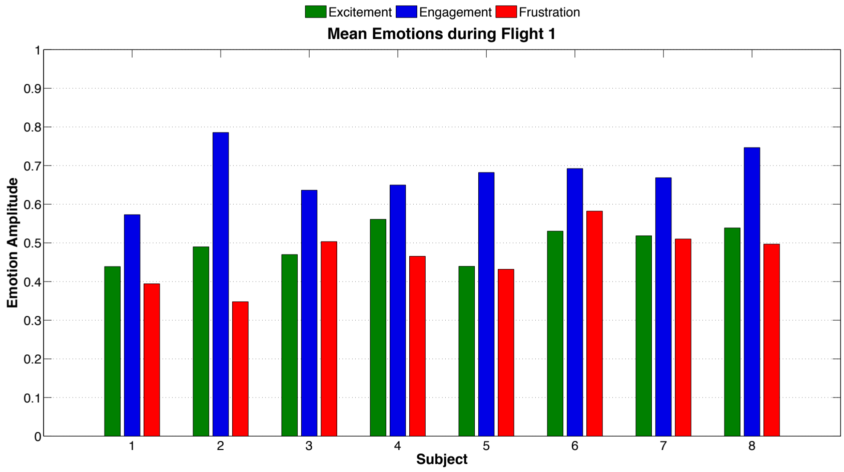


Figure 17 Mean Emotions Measured in Flight Condition 1

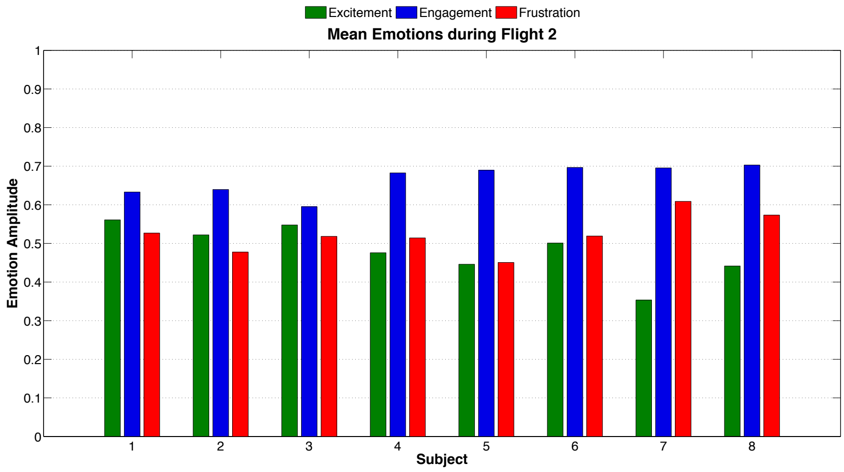


Figure 18 Mean Emotions Measured in Flight Condition 2

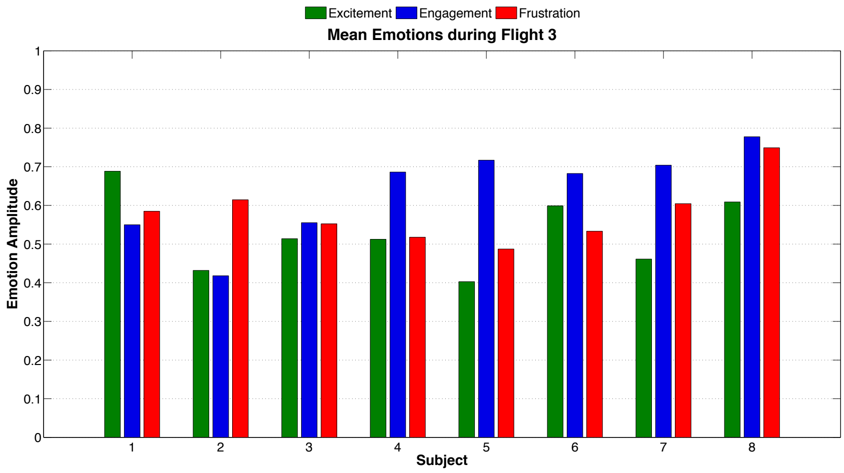


Figure 19 Mean Emotions Measured in Flight Condition 3

A trend was observed representing the levels of amplitude of the engagement, excitement and frustration. The best configuration of amplitudes reflecting a good behavior and situation awareness of the pilot trainee is as follows: **The level of engagement should be the highest** (around 0.65 for most of the subjects tested here) **and below it comes the excitement and frustration fluctuating**.
This state is clearly presented in Figure 21 during the climb descent and slow flight tasks. It could also be seen in Figure 20 more specifically during the third assessed task: the slow flight. Further details on these plots will be found in the coming paragraph.

Introducing dimensionless ratios namely:
$E_{exc} = \frac{Excitement\ Amplitude}{Engagement\ Amplitude}$ and $E_{fru} = \frac{Frustration\ Amplitude}{Engagement\ Amplitude}$;
Comparing the above values to 1, the Flight Examiner could assess the emotional level felt during a specific task, even if the pilot successfully achieved it. **This assessment will enhance and help the way the Flight Examiner assesses most of the time subjectively the pilots** (Federal Aviation Administration, 2011). **It will also reduce the training cost and help the training in a flight simulator to be more specific and pilot capabilities dependent**.

Average values of the three measured emotions during each assessed task could be plotted and presented to the assessed pilot. As seen below, relevant information was obtained: the average values of the emotions for each task were plotted and correlated to the Flight Examiner's assessment.

The tasks assessed (in a chronological order) are the turning, the climb, the descent and the slow flight. The emotions are plotted horizontally: the blue bar shows the engagement level, the red bar the frustration and the green bar the excitement. On the abscissa the amplitude of the measured waves are ranging from 0 to 1. On the right hand side of the plots, snapshots of the Flight Examiner's assessment for each task are represented in separate boxes. Four interesting cases will be described below based on their relevance to the training phases of the student pilot.

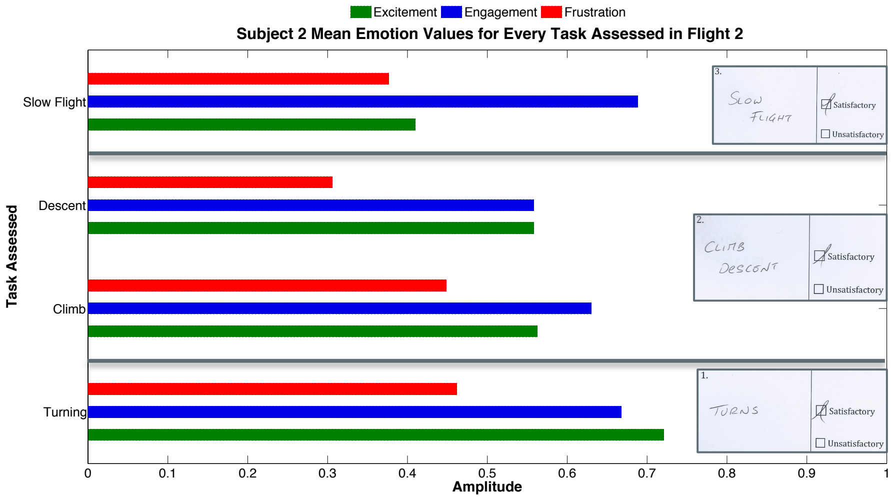


Figure 20 Mean Emotions Measured during Task Assessed - Student Pilot 2, Flight Condition 2

Case 1: All three tasks successfully accomplished in flight condition 2
All the **tasks were satisfactory, but, according to the measures of the emotional amplitudes, there is a need to review and analyze the turning and the descent tasks**:

- During the turning: the excitement amplitude (0.7206) is greater than the engagement (0.6674), hence $E_{exc(turn)} = 1.0797$.
  The **pilot was aware of the task and the surrounding environment. But he was not alert.** Correlating the brain state of the pilot to the levels of SA as described in section 4.2 (more specifically in Figure 14 of Chapter 4) and based on the interpretation in Table 7 and Table 8: the user with high amplitude of excitement reflects the awareness hence the perception with respect to the task to be achieved (namely here the turning). On the other side, the lower level of engagement relate to the alert state of the pilot, leads to the fact that **the pilot is not able to complete the comprehension phase of that specific task**.
  Recommendation: The pilot was able to accomplish the task, but further training in order to enhance his alert state during the turn would be recommended.
- During the descent: the excitement amplitude (0.5582) is higher than the engagement (0.5581), hence $E_{exc(descent)} = 1.0002$.
  In this case, the pilot is able to have a **fairly good perception and comprehension of that task**. But further training would also be recommended.

These two tasks could be repeated by the pilot, but on different intensities and priorities. The focus should be on the turning task (refer to the respective values of E_{exc}) during similar low visibility flight conditions.

TASK	$E_{exc(task\ i)}$	$E_{fru(task\ i)}$
Turn	0.9353	0.7849
Climb	0.7472	0.5241
Descent	0.7595	0.6650
Slow flight	0.8320	0.2371

Table 11 Emotional Ratio Values for Student Pilot 4 in the Tasks of Flight Condition 2

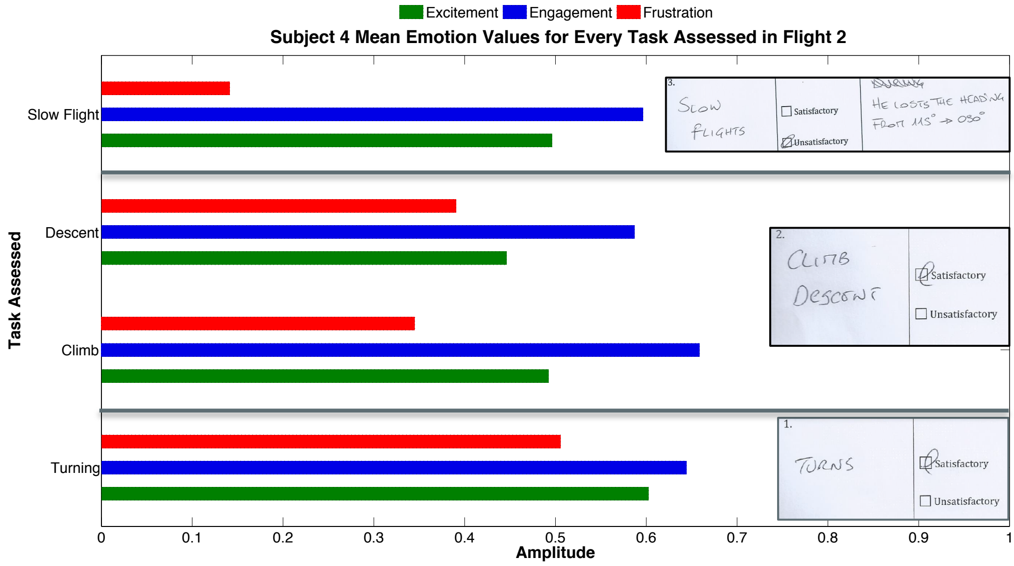


Figure 21 Mean Emotion Measured during Task Assessed - Student Pilot 4, Flight Condition 2

Case 2: Two out of the three tasks successfully accomplished in flight condition 2

The plot shown in Figure 21 represents the **optimal emotions classification case: engagement higher than excitement higher than frustration.** As seen in Table 11 the E ratios are all less then 1.

During the third task, namely the slow flight, the pilot got an unsatisfactory assessment from the Flight Examiner: note the frustration level is very low (0.1414) compared to the rest of emotions (0.5964 and 0.4962 for engagement and excitement amplitudes respectively). Comparing it to the Flight Examiner comment, the pilot was not able to hold a steady heading and he lost 100 feet of altitude while retrieving his speed and coming out of the task. A low frustration level combined with an unsatisfactory assessment of the task could be interpreted as already presented in Table 6, as a sign of recklessness and carelessness. In this case the **low frustration level is combined with a high level of engagement**, meaning that the subject was not bored, **he was alert regarding the task but wasn't giving it the needed effort to be successfully accomplished.**

It was also seen during the twenty-four flights achieved, while the pilot makes a mistake, in case he is aware of it and tries to correct it; the frustration level increases, at least achieving a higher amplitude compared to the excitement level. In this case, **in order to check whether the pilot was aware of his mistake the Flight Examiner can check more details of the instantaneous emotions**, by referring to the video of the flight correlated with the emotions throughout the whole flight (described earlier).

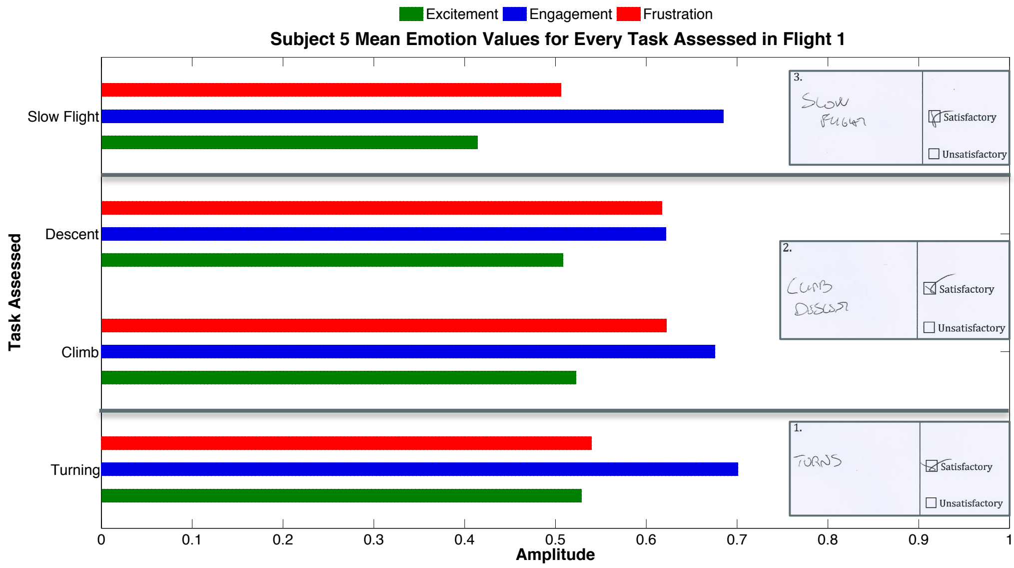


Figure 22 Mean Emotion Measured for each Task Assessed - Student Pilot 5, Flight Condition 1

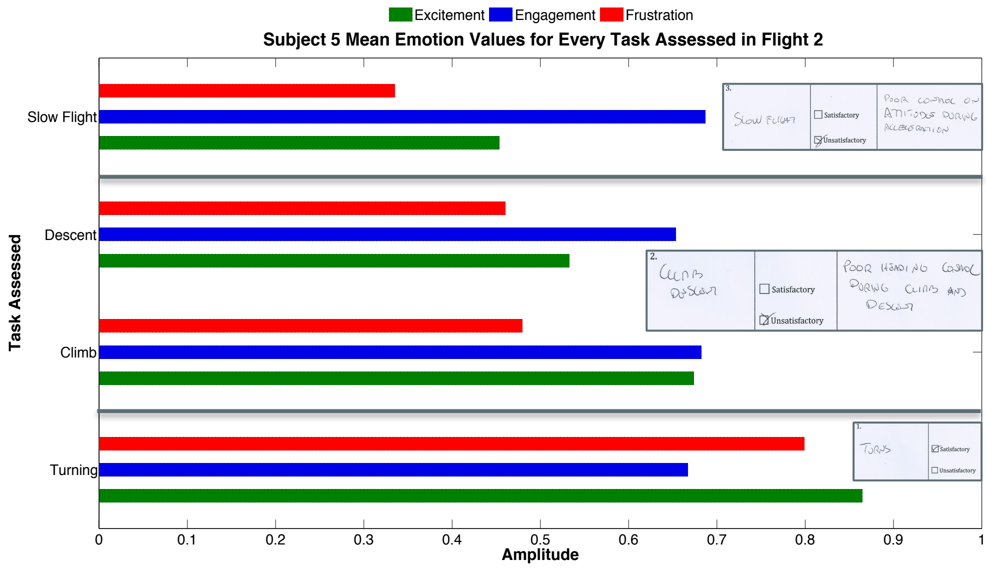


Figure 23 Mean Emotion Measured for each Task Assessed - Student Pilot 5, Flight Condition 2

Case 3: Student pilot flying for the first time in low visibility conditions
During the first flight condition, the pilot achieved successful assessments, and had a suitable emotional response as discussed earlier regarding the level of engagement being the higher compared to the rest [Figure 22].

Being exposed to the low visibility flight condition in the second simulated flight, the pilot encountered difficulties, since it was the **first time he was flying in such conditions**.
These **difficulties were reflected in the emotional measurements of the pilot during the assessed tasks** [Figure 23]: for the first task assessed (namely the turning), a higher amplitude for the frustration was recorded (0.7988 compared to 0.5399 for the first flight) along with a higher

excitement level (0.8649 compared to 0.5288 measured in the first flight). The engagement (0.7012 in the first flight condition and 0.6669 in the second flight condition) reflected in both flight conditions the interest and the alertness of the pilot to the stimuli proposed in both flights.

Furthermore, the frustration level in the second flight condition decreased during the assessment of the climb task (the second task to be assessed chronologically). The pilot during the first task, had a higher level of frustration compared to the measured frustration level in the first flight condition with a good visibility, due to the fact that it is a **different situation** to him, hence, he felt **nervous** towards that assessment. During the climb, descent and slow flight assessments, the frustration level decreased due to the fact that the pilot got more used to the low visibility condition hence decreasing his nervousness and anxiousness levels. There is an increase in both the engagement and the excitement levels as the flight was proceeding; reflecting on the good will of the student pilot to achieve good results in the tasks, while focusing and increasing his awareness and alertness levels. **This brain state behavior, correlates with a positive effect on the SA of the user, more specifically on the perception and comprehension of the task.**

Case 4: Student pilot not aware of his errors
In this case, the **level of excitement related to the awareness of the pilot, reflects the lack of perception, comprehension and hence projection of the user with respect to the tasks assessed** [Figure 24]. Moreover, the **low level of awareness resulted in an unsatisfactory assessment** of two tasks out of three in the low visibility condition flights.

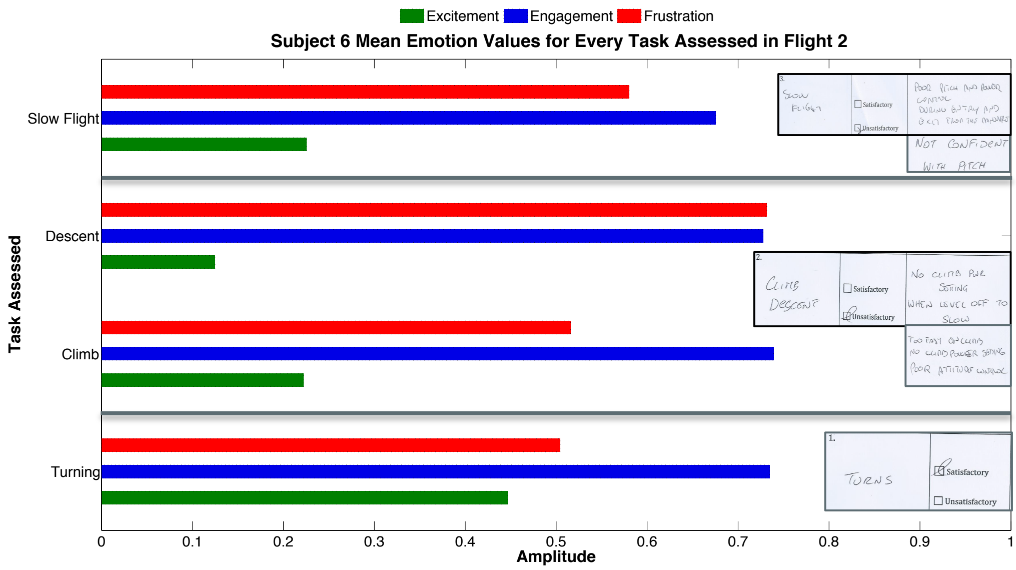


Figure 24 Mean Emotion Measured for each Task Assessed - Student Pilot 6, Flight Condition 2

5.2 Input for Cockpit Environment

This application dwells around the **efficiency of the overall human machine interface system by adapting the environment of the user and emitting stimuli that will alter the emotional state of the user**.

Success or failure of the human-machine system depend both on the reliability of the equipment and on the reliability of the human. On the machine side, equipment and technologies are becoming increasingly reliable and, in most safety critical cases, such as in aviation, failures are due to the human factors (Salvendy, 2012). **In order to improve the efficiency of the overall system it has been recognized that we need to account for the emotions that can impact on the human machine interaction**. Research done in the neurosciences and in social psychology (Rahman, 2006) demonstrated that **emotional states alter the cognitive processes non-consciously, well before the feelings of an emotion are perceived in the consciousness** (Damasio, 1994). Identifying emotions is usually done based on self-reporting of the person, or by monitoring one or more haptic channel going from the physiological changes (heart rate, skin temperature, etc.) to the physical stimulation (tickling) to the social touch (handshake, etc.). In this research, the innovation lies behind classifying the emotions based on the EEG non-intrusive measurements. The corresponding **stimulus** obtained from the waves classification (refer to Figure 1) is based on the concept of **chromotherapy.** The choice to implement the stimulus via a color code came from the fact that if this application should be implemented inside the cockpit (or a flight simulator), the sounds are an option to be rejected since there are a lot of noises inside the cockpit, and adding a new type of sound could be inefficient.

The brainwaves (or impulse) were measured in real time, with the aid of the non-invasive sensor (EEG) described previously. The focus of the interface is on color psychology in order to apply the relation between colors and emotions already demonstrated in previous studies (Nijdam, 2010). The emotions detected are the excitement, frustration, meditation and engagement. The emotional intensities are detected through online measurements and depending on the amplitude, the corresponding counter emotion is projected through its appropriate color. By retrieving the raw data from the neuroheadset and accordingly displaying through the adaptive interface the opposite emotional color, the end result was optimizing the user's alertness and situational awareness.

5.2.1 Methodology

5.2.1.1 Emotion Classification

Recognizing and categorizing emotions is not easy; the larger the number of emotions the harder the emotion recognition, and some emotions may overlap. Several models have been proposed. The most widely used basic emotions are the six basic emotions: anger, disgust, fear, joy, sadness and surprise. They have been widely used in facial expression recognition (Ekman & Friesen, 1982).

Focusing on the brainwaves classification on the built-in Affectiv™ Suite, the stimuli of the adaptive interface designed were based on the following four

emotions and their combinations: Short term excitement, frustration, meditation and engagement/boredom. As explained earlier in section 4.3.1, the short-term excitement is characterized by activation in the sympathetic nervous system that results in a range of physiological responses related to emotions such as the titillation, nervousness, and agitation. For instance, if the real time EEG measurements depicts a very high amplitude (the amplitudes measured range from 0 to 1) of excitement, the user should be stimulated by a color that would result in a decrease of that amplitude, hence a decrease of the negative trait of that emotion.
A choice [Table 12] had to made regarding the ranges of amplitude for every emotion measured that led to the assumption leading to "optimal amplitudes" for every emotion measured.
Optimal amplitudes of corresponding emotions, would lead to optimal situation awareness of the user, leading to an increase in the efficiency between the user and the interface.

Emotion	**Amplitude**	**Optimal Amplitude**
Short-term Excitement	Low: between 0 & 0.4 High: between 0.7& 1	Between 0.4 & 0.6
Frustration	High between 0.5 & 1	Less than 0.5
Meditation	High: between 0.4 & 1	Less than 0.4
Engagement/Boredom	Low: between 0 & 0.4 (bored) High: between 0.6 & 1 (engaged)	0.5

Table 12 High, Low and Optimal Amplitudes for Emotions

Figure 25 Shirley Willett Color Codifications of Emotions

Color	Positive Trait	Negative Trait
Red	Enthusiasm	Rage / anger
Orange	Pride	Disgrace / shame
Yellow	Awareness	Panic / fear
Green	Satisfaction	Hoarding / greed
Blue	Clarity	Racing / confusion
Purple	Leadership	Impotence / power

Table 13 Shirley Willett Color Table

5.2.1.2 Color Classification

It is known to be difficult to state facts about different colors and the way people interpret them, however, many researches has been done in this field; ranging from history with Goethe (Goethe, 1970), to a more global review from Claudia Cortes attributing positive and negative traits to colors (Cortes). Shirley Willett established a model presented in Figure 25 as a guideline for the basic colors and their corresponding emotions (Shirley Willet Color Codification), the same results are represented in Table 13.

The focus of this application is based on the basic colors to which most of the researches in this field converged to the same results in emotions felt.

5.2.2 Implementation of Emotion and Color Classification

Combining the above emotions and corresponding basic colors, the results in terms of RGB values are presented in the table below [Table 14]:

Color	Red-Green-Blue values	Related Emotion
Beige	**R**: 238 **G**: 236 **B**: 225	Calm, natural and relaxing
Blue	**R**: 63 **G**: 128 **B**: 205	Confidence, peaceful/sadness
Green	**R**: 118 **G**: 205 **B**: 56	Balance, stability/hopeful
Orange	**R**: 228 **G**: 108 **B**: 10	Joy, determination
Purple	**R**: 96 **G**: 74 **B**: 123	Introspective, melancholic
Red	**R**: 255 **G**: 0 **B**: 0	Anger, love
White	**R**: 255 **G**: 255 **B**: 255	Purity, innocence, empty/void
Yellow	**R**: 255 **G**: 255 **B**: 0	Fear, happiness/joy

Table 14 Colors and Emotions

```
if(frustration >0.500000 && engagement > 0.400000 &&
shortTerm>0.600000) {
        /*red=253/255;
        green=204/255;
        blue=233/255;*/
        red=0.992;
        green=0.8;
        blue=0.913;
        NSLog(@"5");
}
```

Figure 26 Emotions and Color Code

These latter were then inputted in a Mac Operating System based application written in Xcode. It involves a script based on the raw "Affectiv™" data from the Emotiv SDK (described earlier). The software checks for new emotional related data every 0.5-second and outputs colors according to the values gathered earlier. The choice behind the 0.5 seconds interval of time, as made upon trial and error steps: lower than 0.5 seconds resulted in a certain annoyance of the user with respect to the colors projected. A greater number would lead to loss of emotional states, since the neuroheadset internally samples at a frequency of 2048 Hz, which then gets down sampled to 128 Hz. The program also creates a ".csv" file that is automatically saved containing all emotional raw data that could be accessed for further research.

In Figure 26, is a section of the application's code that checks the amplitudes for a case of "panic" state described by a high frustration, engagement and excitement, and accordingly displays the convenient color with the specified RGB.

5.2.3 Results

Combining the emotions measured based on the classification of the brainwaves, and the stimulus projected in the user's environment, Table 15 summarizes the combination of inputs and outputs of the system.

Here are some cases where two combinations could be measured simultaneously, and the corresponding output of the designed interface:

- High Engagement with High Excitement: It is interpreted as high workload and high stress situation. The user needs to be calmed. The projected colored stimulus is a tonality of blue that reflects an emotion related to confidence and peacefulness.
- Boredom with High Meditation level: This case reflects on a serious problem (depending on the task the user is required to accomplished!); in case the user needs to be alert (ex: wake the user up) this could be accomplished with a combination of two stimuli: a flashing orange colored along with noise, and vibrations.

- High Frustration coupled with Boredom: The user actual state could be interpreted as stressed but in a giving up situation. There is a need to increase the motivation by projecting a type of blue color in the user's environment. That could also be combined with an external guidance from the interface in order to solve the encountered problem that led to this emotional combination.
- High Frustration combined with High Engagement level: this states reflects on a high workload situation, resulting in a high stress level, and a high awareness. The user might need to be calmed down and the appropriate stimulus could be projected.

In Figure 27 and Figure 28, snapshots of the application's stimulus are presented. The interface displays at the bottom right corner the live emotions amplitudes log being recorded continuously, and the top widow shows the color representing the targeted emotion to be achieved by the user. Two figures are represented below: Figure 27 shows the display on the interface in which the BCI is detecting a user in a high excitement emotional level, and would want hence to reduce the excitement amplitude detected by displaying the cyan color. Figure 28 represents the display of the interface in which the BCI is measuring low excitement emotional level of the user, and hence projects back a green color to increase the excitement level.

Brain Waves classified	**RGB of the Corresponding Stimulus**
Low Excitement	**R**: 136 **G**: 211 **B**: 60
High Excitement	**R**: 206 **G**: 235 **B**: 253
High Frustration	**R**: 178 **G**: 247 **B**: 223
High Meditation	**R**: 228 **G**: 108 **B**: 10
Boredom/Low Engagement	**R**: 205 **G**: 232 **B**: 115
Low Excitement & Low frustration	**R**: 156 **G**: 211 **B**: 31
High Engagement & High Excitement	**R**: 138 **G**: 223 **B**: 208
Low Engagement & High Meditation	**R**: 228 **G**: 108 **B**: 10
Low Engagement & High Frustration	**R**: 131 **G**: 255 **B**: 187
High Engagement & High Frustration	**R**: 136 **G**: 211 **B**: 60
High Engagement & High Frustration & High Excitement	**R**: 253 **G**: 204 **B**: 233

Table 15 Brain Waves and Stimulus

Figure 27 User in a High Excitement Emotional Level

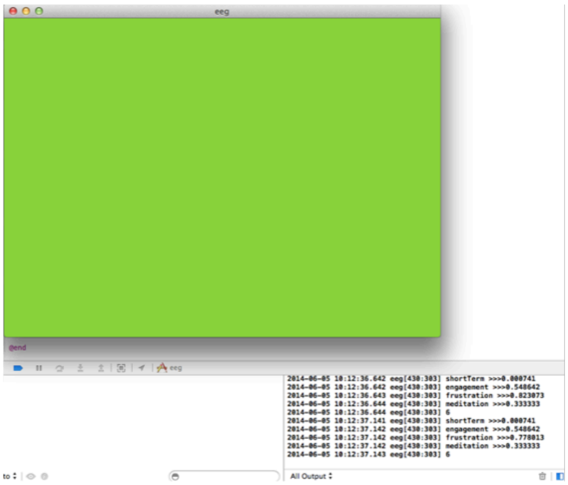


Figure 28 User in a Low Excitement Emotional Level

On the other side, here are some combinations that are unlikely to occur and will be disregarded and not taken into consideration in this system.

- High meditation combined with a high engagement level,
- High meditation combined with a high frustration,
- Low engagement combined with a high excitement, and
- High excitement combined with a high meditation.

5.3 Adaptation Tool for Cockpit Automation

The objective of this part of the research is to build a **man-machine interface able to readapt to the current situation of the user whether in terms of the workload and/or its situation awareness**.
Implications of automation related accidents were already described in Chapter 1. This tool could be used to enhance the entire hazard that automation is generating nowadays.
Targeting the adaptation of the interface to the current automation level in real-time based on the awareness of the user, deduced from the types of brainwaves measured; the objective of this part of the research led to design an interface that could be used to **control the automation level of the autopilot based on the brain state of the user**.

The setup of the hardware is represented in the figure below [Figure 29].
In the Brain Computer Interface hardware, the first step is to acquire in real time the EEG data of the user, process the signal, extract the corresponding brain wave and hence classify the user state of mind. The feedback generated based on the results of the BCI earlier steps, will be fed into the autopilot system that would adapt the corresponding level of automation (as it will be described in more details below) in the flight simulator scenery. The hardware described earlier is implemented on the CAVE environment, along with a head tracker following the movements of the head of the user immersed in the virtual environment (3D projection possibility). The CAVE screens projecting the flight simulator scenery will update the corresponding virtual environment (VE) to the position of the user's head.

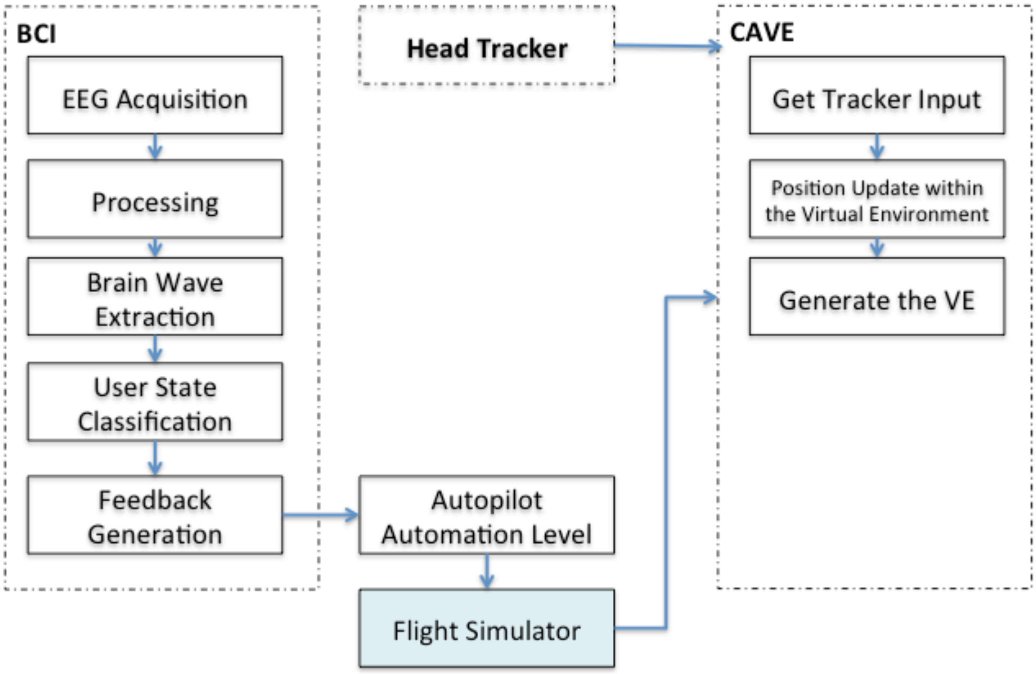


Figure 29 Hardware Setup

As described earlier, the feedback generated based on the results of the BCI steps, is then fed into the autopilot system that would adapt the corresponding level of automation to the actual brain state of the user.
Figure 30 is a diagram representing the general architecture of the system. The user being the essential part of the concurrent loops shown below, the BCI will capture the brain waves, analyze and classify the corresponding brain state (as described in Figure 29) in three different classifications: stressed and anxious user or focused user or sleepy and tired user. **The interface will monitor the brain state of the user providing back a live feedback called here the "Neurofeedback Process".**
Based on a study made by NASA on measuring the attention (which is a cerebral phenomenon) of a pilot and then use the neurofeedback to improve his/her performance; it is stated that the best way to monitor attention is directly through capturing and analyzing brain waves. In this study it was shown that biofeedback training could foreseeably help reduce the occurrence of what they call "hazardous state of awareness" which are both inattention and stress (NASA Spin Off).
In a parallel loop, when the user brain state has been classified in one of the three specifications described earlier, the autopilot automation level is then suggested (further details behind each combination is described below). The suggested automation level is then transmitted to the user before it is selected. **The input of the user is crucial in this phase, and the target of this architecture is to continuously have the user in the loop.**

Different phases describing the flow of the information in the interface are described in the subsections below.

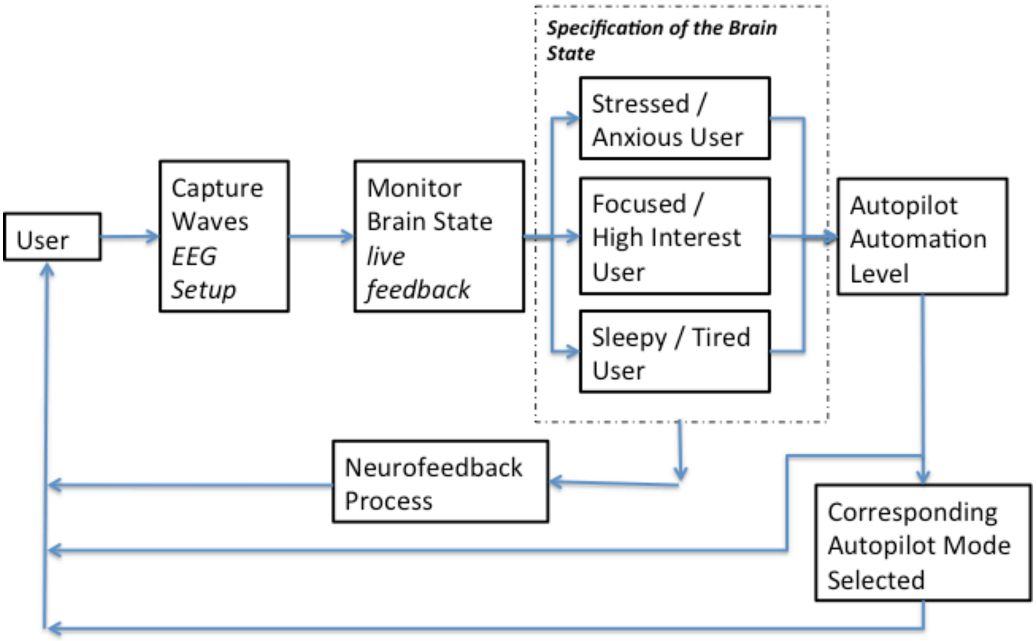


Figure 30 Adaptation Tool for Cockpit Automation - General Architecture

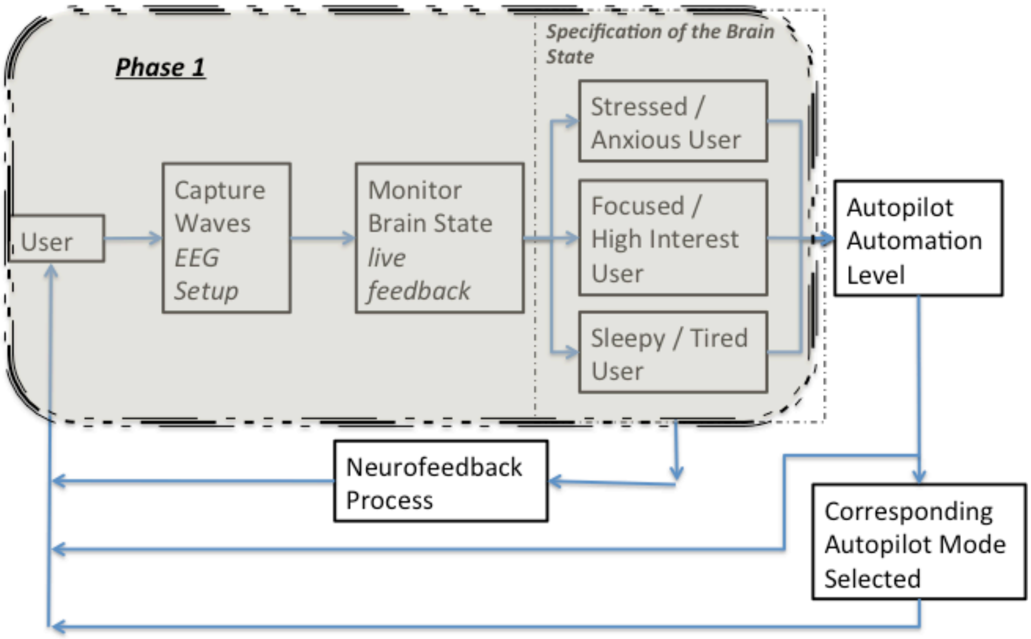


Figure 31 Phase 1

5.3.1 Phase 1 - Capturing, Monitoring, Classifying

Measure the level (degree) of engagement/excitement of the pilot during take off and landing phase or any other task to be achieved [Figure 31].

In real time some type of brain waves that the user emit will reflect his/her state. The purpose of this phase is to measure the brain waves of interest to our research: the level of engagement, excitement and frustration with respect to the task.

5.3.1.1 Capture Waves – EEG Setup

A human being's brain is made up of billions of active neurons. When these neurons interact, the chemical reaction emits an electrical impulse that can be measured.

The electrical activity of the brain changes depending on the current mental state of the individual. Simply, viewing/using/capturing the brainwave patterns will provide great insight into that individual's mental state. Using the Emotiv neuroheadset to capture the brain waves of the user, and hence his/her "emotion", the data used will be based on the ones obtained from the Affectiv™ Suite. More details on how this suite works can be found in section 4.3.1.

5.3.1.2 Monitor Brain State - Live Feedback

As discussed earlier, the electrical activity of the brain changes depending on the current mental state of the individual. When scientists first measured brainwaves they found that they were connected to different mind states, or states of consciousness. Since then they have divided the brainwaves into four predominant frequency ranges, or types that were elaborated in section 4.3. One can find in literature more bands (for example mu and gamma waves), taking into consideration that understanding the way the brain functions is a field that the researchers are still working on (chapter 2). In this research we will focus on the brainwaves needed to monitor the emotional state of the user (as described in 4.3.1), and Figure 1 illustrates again the process to be accomplished.

According to the Emotiv Epoc User Manual (Emotiv, 2011), the Affectiv Suite reports real time changes in the subjective emotions experienced by the user. Emotiv currently offers three distinct Affectiv™ Suite detections:

- Engagement,
- Instantaneous Excitement, and
- Long-Term Excitement.

Or by using the Emotiv Test Bench in the SDK Edition the displays of the delta, beta and theta waves can be displayed using a fast Fourier transform.

The Affectiv™ Suite detections look for brainwave characteristics that are universal in nature and don't require an explicit training or signature-building step on the part of the user.

5.3.1.3 Classification of the user's brain state

The end of the first phase is characterized by the specification of the pilot state depending on his/her brain wave monitored.

Referring to the two types of brain waves [Table 16] measured through the Emotiv EPOC neuroheadset, we will obtain two types of users:

- The Alert User
- The Aware User

Detection	**Experienced as**	**Related Emotions**	
Engagement	– Alertness, – Conscious direction of attention towards task-relevant stimuli.	– Alertness, – Vigilance, – Concentration, – Stimulation, – Interest.	Positive or Negative effect of workload
Instantaneous Excitement	– Awareness, – Physiological arousal with a positive value.	– Titillation, – Nervousness, – Agitation.	Situation Awareness

Table 16 Detections Classification

Alertness: Lively attentiveness, the process of paying close and continuous attention, a state of readiness to respond.
Awareness: Having knowledge of, state of elementary or undifferentiated consciousness.

5.3.2 Phase 2 - Neurofeedback Process

Neurofeedback (NFB), also called neurotherapy, neurobiofeedback or EEG biofeedback is a type of biofeedback that uses real-time displays of electroencephalography or functional magnetic resonance imaging (fMRI) to illustrate brain activity, often with a goal of controlling central nervous system activity. In the medical sector, the NFB method is typically used by placing sensors on the scalp of the "patient" in order to measure his/her brain activity. The measurements are then displayed back to the "patient" using video displays or sound. It is usually used to decrease migraines or to heal from depression. For example, those suffering from attention deficit disorder (ADD) or attention deficit hyperactivity disorder (ADHD) tend to produce an overabundance of slower Alpha/Theta brainwaves.
In this architecture, the results collected from the EEG in the first phase, will be used and displayed back to the user in order for this latter to see his/her level of engagement and/or excitement and/or frustration and attempts to improve it before the interface takes over.

As already discussed, simply, viewing the brainwave patterns will provide great insight into the individual's mental state.
Based on a study made by NASA on measuring the attention (which is a cerebral phenomenon) of a pilot and then use the neurofeedback to improve his/her performance; it is stated that the best way to monitor attention is directly through capturing and analyzing brain waves (NASA Spin Off) (Pope & Palsson). In this study it was shown that biofeedback training could foreseeably help reducing the occurrence of what they call "hazardous state of awareness" which are both inattention and stress.
The purpose is to teach pilots to maintain the necessary physiological conditions for good cognitive and psychomotor performance under the circumstances that are most likely to produce inattention or dysfunctional stress.

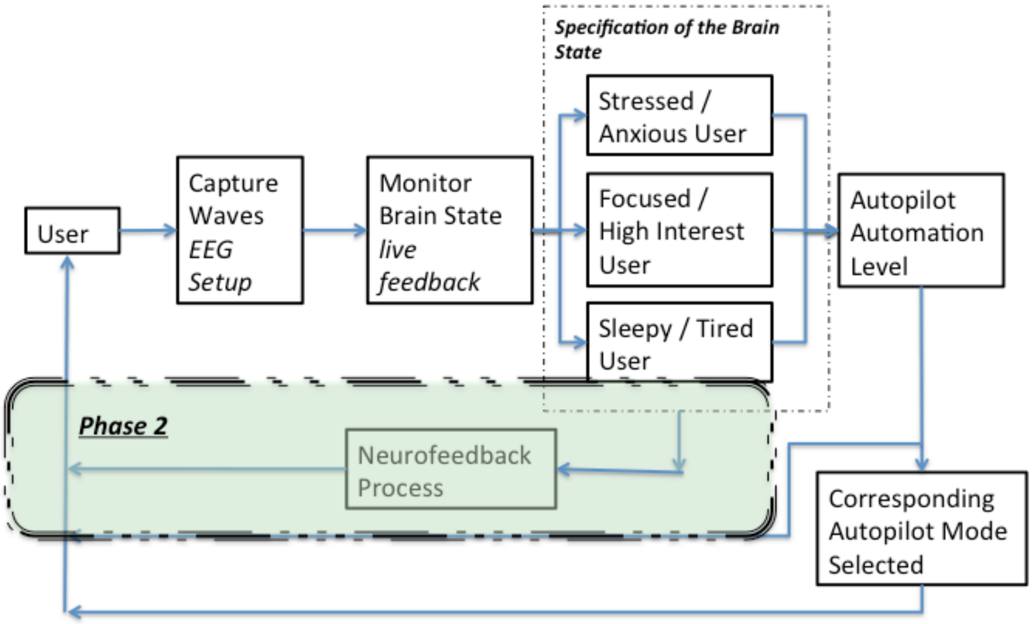


Figure 32 Phase 2

After the user's brain waves have been captured, monitored and the user's brain state classified, the result of the classification of the data measured in real time is transferred back to the user. A simple message displayed on a screen positioned on the left side of the cockpit seat could be beneficiary for the pilot to enhance his/her state or completely change it.

5.3.3 Phase 3 - Neurofeedback Process

An initial scale of levels of automation proposed by (Sheridan & Verplank, 1978) represents a continuum of levels between low automation, in which the human performs the task manually, and full automation in which the computer is fully autonomous [Table 17].

Levels of automation of Decision and Action Selection (Sheridan & Verplank, 1978):

Low	1	The computer offers no assistance, human must take all decisions and actions
	2	The computer offers a complete set of decision/action alternatives, or
	3	Narrows the selection down to a few, or
	4	Suggests one alternative, and
	5	Executes that suggestion if the human approves, or
	6	Allows the human a restricted veto time before automatic execution
	7	Executes automatically, then necessarily informs the human, and
	8	Informs the human only if asked, or
	9	Informs the human only if it, the computer, decides to
High	10	The computer decides everything, acts autonomously, ignores the human

Table 17 Level of Automation

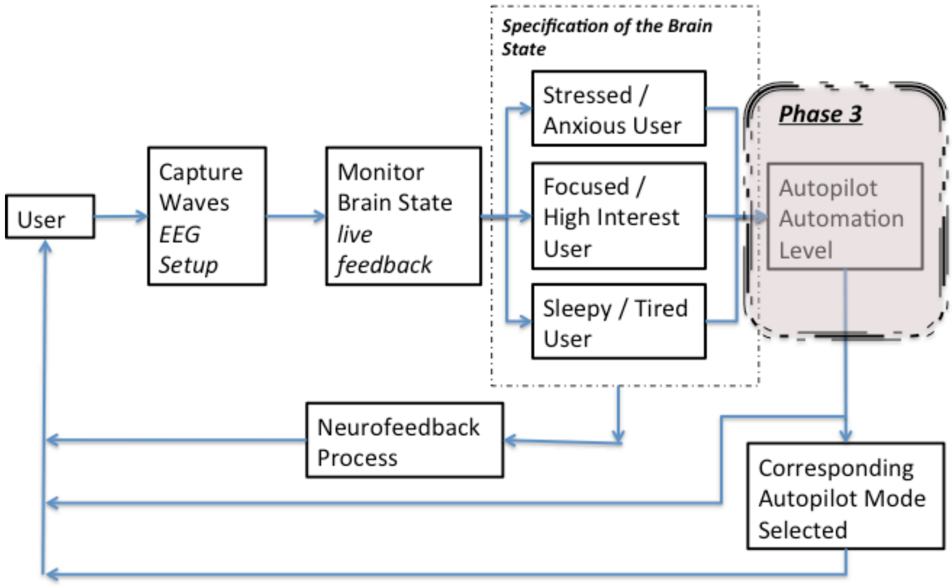


Figure 33 Phase 3

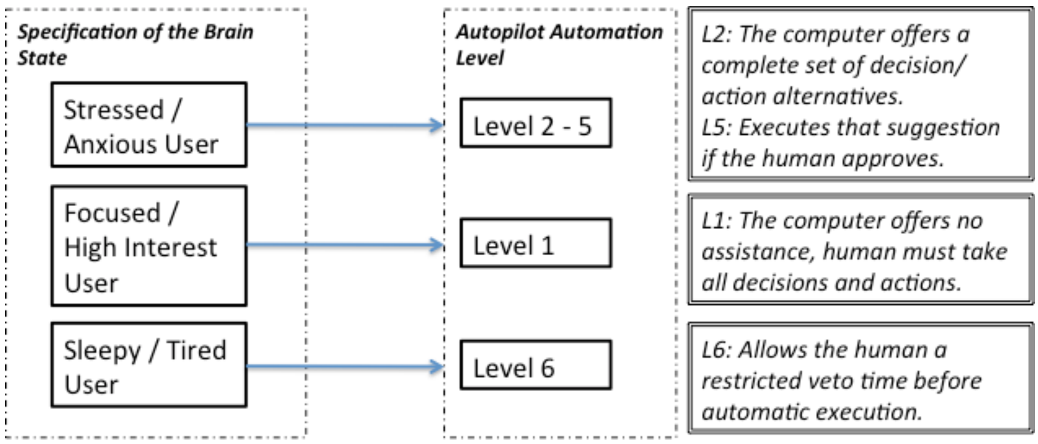


Figure 34 Brain State and Autopilot Automation

Based on the output of the second phase of the system (described in 5.3.2), there will be a correspondence to the autopilot automation level. This will be performed following this scheme [Figure 34]:

5.3.4 Phase 4 - Selection or Rejection of the Autopilot mode

Depending on the third phase's outcome [Figure 33] hence on the corresponding autopilot automation level suggested, the flow of the experiment would take either one of the cases described below.

- Case 1: Level 1 Identified (Sheridan & Verplank, 1978)
  The user is estimated to be focused and is showing a high interest with respect to the task [Figure 36]. In such a case, the computer offers no assistance; the user must and will take all decisions and actions. This fourth phase ends at this stage and the first phase starts again.

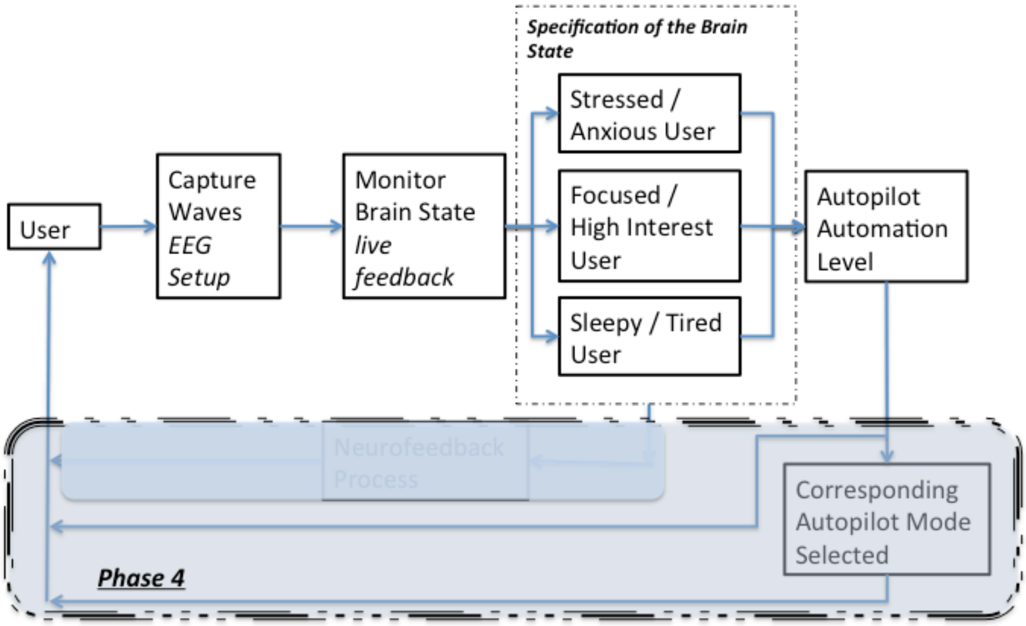


Figure 35 Phase 4

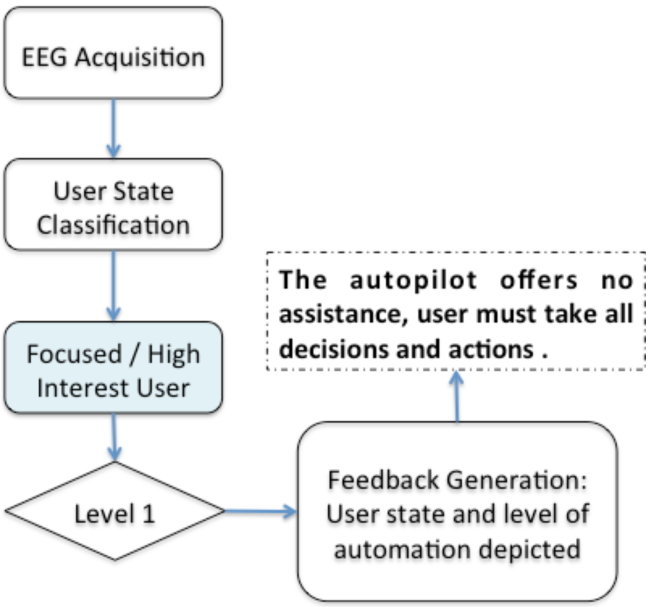


Figure 36 Workflow of Case 1 - Automation Level 1 Identified

In both following cases, the suggested autopilot automation level will first be transmitted to the user on the screen on his left hand side:

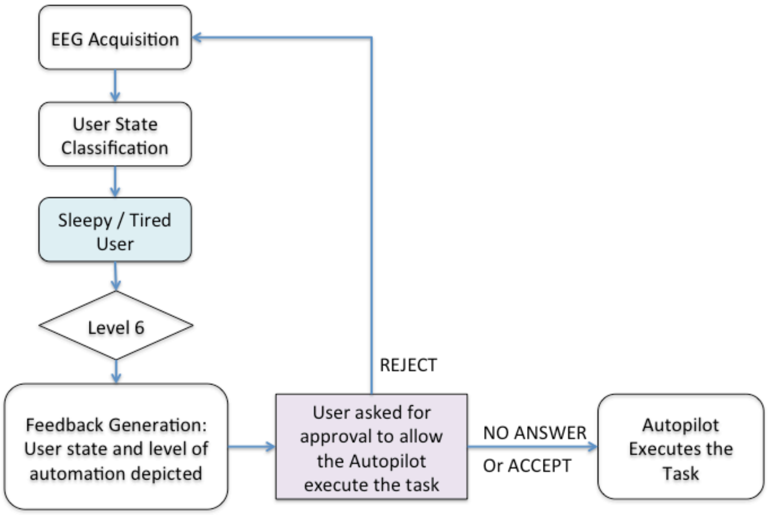


Figure 37 Workflow of Case 2 - Automation Level 6 Identified

- Case 2: Level 6 Identified
  By definition based on the initial scale of levels of automation proposed by (Sheridan & Verplank, 1978), the sixth level on automation, consists of the following action: the interface allows the users a restricted veto time before automatic execution.
  Adapting this situation to our interface: in case the user rejects the suggested automation level showing up on his left side, then the whole cycle of phases will start again till the user is in full control of the task (refer to case 1 above). If the interface receives no answer (or an approval) from the user, then the autopilot mode will be automatically selected [Figure 37].

- Case 3: Level 2 to 5 Identified
  The user is monitored to be stressed and or anxious. In this scenario, the computer either offers a complete set of decision/action alternatives, or it executes that suggestion if the user approves.
  Meanwhile, the neurofeedback process will still be undergoing and the user will be working on how to reduce his/her stress level and be more positively engaged in the task required [Figure 38].

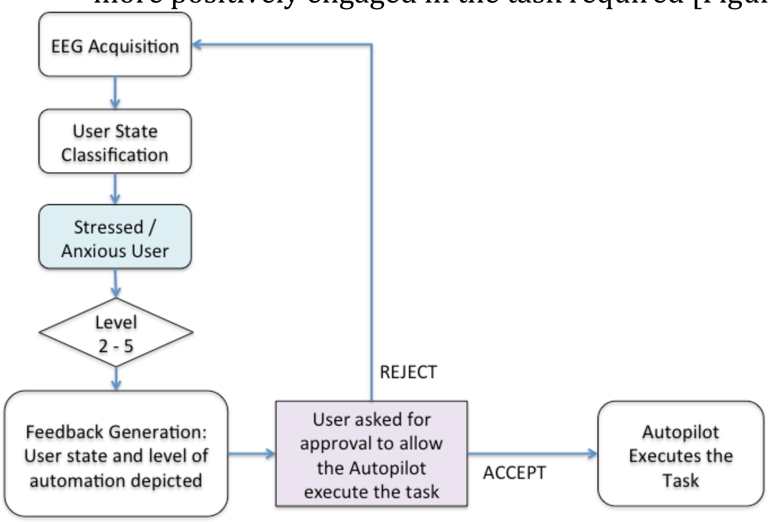


Figure 38 Workflow of Case 3 - Automation Level 2 to 5 Identified

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Chapter 6 Conclusion

This research is based on the brain electrical activities by recording the electrical impulses emitted by the brain waves of the user. Brain waves can be detected by electroencephalography (EEG). The target is to be able to **identify and classify in real time, the different brain states generally classified based on their frequencies** as follows: the Delta Waves (1 to 4 Hz) representing a deep sleep, the Theta Waves (4-7 Hz) representing light sleep, dreaming and meditation, the Alpha Waves (7-13 Hz) that predominantly originate during wakeful relaxation with closed eyes (Alpha waves are reduced with open eyes, drowsiness and sleep), and finally the Beta Waves (13-30 Hz) that represents an awake thinking “in a normal brain”. Numerous studies have demonstrated that with increased mental processing effort alpha waves (8-13 Hz) decrease and theta (4-7 Hz) activity is enhanced (Gundel & Wilson, 1992). In order to record these different brain states of the user, electroencephalography portable Neuroheadset were used. These psychophysiological measurement devices are becoming increasingly usable and affordable.

This kind of technology could provide the opportunity to record continuously and in real time the pilot’s mental state of mind without interfering with the task. The device on which this study is based is composed of electrodes continuously measuring voltage levels from different areas of the human scalp then sending them to a software application that converts raw data into a more digestible format. The headset processes the input brain waves into four main categories: the facial gestures and expressions; the passive measurements of a user’s mental state, emotions; the thoughts and intent; the gyroscopic data – this latter is generated from the head rotation and not from the brain waves measured through the electrodes. But rather than using the wires of traditional Electroencephalography tests, the headset is completely wireless, allowing the user free, natural movement.

6.1 Achieved Results

The use of neurophysiological measures of the cognitive activity of the pilot can provide an objective assessment and **new type of evaluation during training**. Based on the results obtained in Chapter 5, an innovative method was established in the training of pilot. Note that this method could be applied to any other field that is not aeronautically related. This innovative method would **reduce the time and cost it takes to train pilots**.

Operating on the experimental methodology based on the setup of an experimental facility for ‘man in the loop’ simulation, allowed to **involve both a pilot and a flight examiner for comparing subjective evaluations to objective measurements of the brain activity**. This was done recording all the relevant information versus a time-line.

Furthermore, the EEG amplitudes have been correlated with subjective feedback based on the experience of the user regarding definite tasks.

The HMI proved to be a promising and reliable tool. It could be used in researches related to:

- Personal behavior in flight regimes,
- Workload assessment,
- Personal abilities to evolve during the training phase,
- Interface designs assessments.

The use of the tool can also improve the evaluation of a pilot crew performance in interacting with the aircraft when performing tasks and procedures, especially in critical situations.

In an article published in the Aero Space Journal in October 2014, Tim Rolfe, Aviation Safety Director at Bristow Group examined the role of automation in the cockpit of the latest offshore helicopters. Mr. Rolfe specified that **there is a need to standardize behaviors associated with the use of automated systems and the need to update the training programs to reflect the new skills and competencies required**. Furthermore he added that their future success has three main building blocks. The one that could be related to this innovative research is **the provision of robust training programs that deliver consistent instructional standards**, a clear understanding of the automation design philosophy and an up to date human factors training related to research.

Researches and industry should work together without isolation. The gap that new technologies are sometimes forging should be overcome, and the emerging technologies have to be used in order to enhance the efficiency between the operator and the machine. Using all the results of the current worldwide projects (as described in Chapter 2) will **enhance the use of the cognitive and unconscious skills of the user, adapting the interface to currently changing scenarios**.

6.2 Future Developments

It is quite rare for an accident to be explained by one single cause; "an accident requires the coming together of a number of enabling factors, each one necessary but in itself not sufficient to breach system defenses" according to the Reason model. However, most mishaps are contributed to the flight crew. The main root cause is human error, next come aircraft failures, but these are less likely when it comes to modern aircraft.
Hence it is **important to center on the human element by focusing on the corresponding situational awareness, and trying to evaluate the related workload while monitoring the state of alertness and awareness of the operator.**

6.2.1 EEG measured and transmitted to a Ground Station

Based on a study done in 1979 (Sheridan & Simpson, 1979), the various tasks performed by a crew of an Air Traffic Control station, can be grouped into four main classes in decreasing order of significance:

1. Communication and Traffic Control
2. Navigation
3. Guidance (or Piloting or Steering)
4. Aircraft Systems Monitoring and Management

Based on the cognitive results obtained, a future project could implement the transfer of online EEG data measured in the cockpit, directly to the ground. The person responsible to monitor the transferred EEG data classified in the corresponding emotion, could guide, monitor, manage and communicate with the pilot in flight. Hence, monitoring the situation awareness and entering in the feedback process define in Chapter 5, Figure 1 'Process of User in the Loop'.

6.2.2 Pilot Training and Software Training

Once again the focus will be on the phase in which the most fatal accidents occur. Figure 1 represents a diagram showing the different phases of a typical standard flight in which one can clearly notice the importance of the takeoff and landing phase in terms of percentage of fatal accidents (PlaneCrashInfo).
Training could be done (depending on the pilot experience, history and flight hours), on specific flight phases. The continuous monitoring of the brainwaves during task achievement would be saved and categorized individually. Going a step ahead, with the help of technology and recurrent training, a training of the software could be implemented, in order to recognize a greater variety of emotional combinations and their consequences on the flight. In a real flight, the software will record and classify the online emotional data of the pilot being monitored, and compare it to already saved patterns. Why not warning him/her that an error in his/her decision-making might occur?

6.2.3 Implementing new Hardware

In order to be able to create a stronger and more intimate connection between the user and the machine, the following modes of interaction could be selected in addition to the Brain Machine Interface:

- The Motion Sensing Input Device;
- The Eye Tracking Device.

This compact choice in reducing the quantity of parts used is mainly due to the fact that the more devices used, the harder is their development. In addition to that the ways of communicating should be also abridged: one input can turn the other one obsolete, for example, the movement recognition cancels the need of a touch screen.

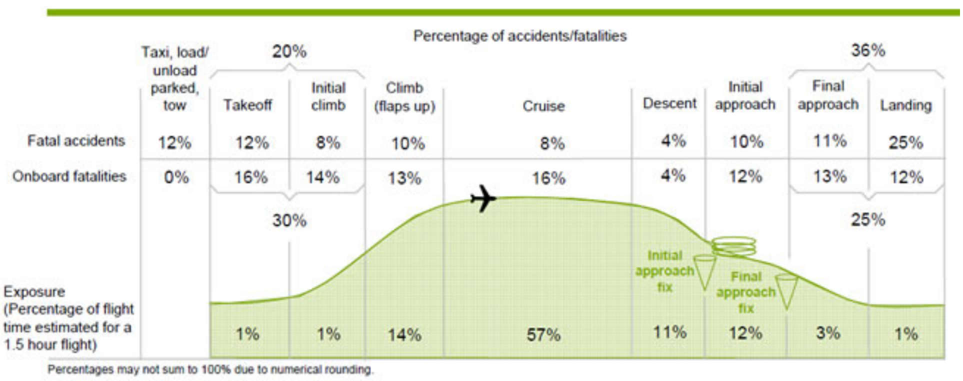

Figure 1 Statistical Summary of Commercial Jet Airplane Accidents 1959-2008

The aim is to make the system more stable, cost effective, faster and easier to develop. The challenges related to the integration of these three different devices are great and mainly related to technology and/or programming issues. The technologies in the Brain Machines Interfaces are growing so fast that the devices are still undergoing development and being tested by users worldwide. Hence updated versions will be emerging every year. The Eye Tracking Devices and the Brain Machines Interfaces are being integrated in one single device while the Motion Sensing Input Devices and the Voice Recognition System are undergoing the same merging. Therefore, the final interface might be the result of a combination of two devices rather than three.
The final product interface will have its own philosophy without any predecessor.

6.2.4 Industry Related Application

The BCI used in this research was used in parallel to evaluate emotional perception of passenger cabin design in virtual environments. Promising results were published (F. De Crescenzio, F. Lucchi, N. Mezannar, F. Persiani., 2014). The results presented and discussed in the paper are the first steps towards the adoption of new tools for the design of user centred products and systems in aeronautics or other fields.
Future developments could be achieved:

- Transport companies are willing to invest heavily on gaining information about the passenger comfort in the design stage of the product. Whether an aircraft interior cabin design or a car, the BCI could be used in order to assess and include the user in the loop in the design of a new interface of a new transport environment. The subject of travel comfort is crucial to the success of new airplanes. For example, larger windows and lighting comfort are new investments in order to achieve a better experience for the passengers.
- In addition to passenger comfort, the BCI design tool could also be applied on pilots during early development of cockpit layout even before the hardware is implemented in the cockpit. The pilot awareness and ability to react towards hazards during flight could be a key design driver. Currently, testing of such situation is only possible on Flight Simulators where most of the actual Cockpit Hardware is available. This is too late in the design process as changes are costly.

Appendix A – NASA Task Load Index Rating Scale Definition

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low /High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low /High*	How much physical activity was required (e.g.. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous. restful or laborious?
TEMPORAL DEMAND	*Low/ High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*good/poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL*i*	*Low /High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Appendix B – NASA Task Load Index Rating Sheet

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

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

Appendix C – Flight Examiners Assessment Sheet

Flight Examiner Checklist

Date (dd/mm/yyyy): _____ / _____ / _________

Pilot name: ______________________________________

☐ Student Pilot
☐ Professional Pilot

Flight condition:
☐ Condition 1
☐ Condition 2
☐ Condition 3

Tasks	Assessment	Suggestion(s)
1.	☐ Satisfactory ☐ Unsatisfactory	
2.	☐ Satisfactory ☐ Unsatisfactory	
3.	☐ Satisfactory ☐ Unsatisfactory	

Flight Examiner Name: ______________________________________

Flight Examiner Signature:

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Bibliography

Aasman, J., Mulder, G., & Mulder, L. (1987). Operator Aeffort and the Measurement of Heart-Rate Variability. *Human Factors , 29* (2), 161-170.

Airbus (2004). Human Performance, Human Factors Aspects in Incidents / Accidents. *Flight Operations Briefing Notes*.

BBC News (2014, May 27). *The headband that measures boredom*. Retrieved 2014, from http://www.bbc.com/news/world-us-canada-27578867

Bennett, K., Munro, M., Gold, N., Layzell, P., Budgen, D., & Brereton, P. (2001). An architectural model for service-based software with ultra rapid evolution. *Software Maintenance, 2001. Proceedings. IEE Internatonal Conference on* (pp. 292-300). IEEE.

Borghini, G., Aric, P., Graziani, I., Salinari, S., Babiloni, F., et al. (2014). Analysis of neurophysiological signals for the training and mental workload assessment of ATCos. *SESAR 2014 4th SESAR Innovation Days.*

Collura, T. F. (1993). History and Evolution of Electroencephalographic Instruments and Techniques. *Journal of Clinical Neurophysiology , 10* (4), 476-504.

Cooper, G. E., & Harper, R. P. (1969). The use of pilot ratings in the evaluation of aircraft handling qualities.

Cortes, C. (n.d.). *Claudia Cortes Meaning of Colors*. Retrieved from http://www.mariaclaudiacortes.com

Damasio, A. R. (1994). *Descartes' Error: Emotion, Reason and the Human Brain.* New York: G.P. Putnum's Sons.

De Crescenzio F., Lucchi F., Mezannar N., Persiani F. (2014). Using bcis (brain computer interfaces) to evaluate emotional perception of passenger cabin design in virtual environments. *ICAS 2014, 29th International Congress of the Aeronautical Sciences*. September 7th – 12nd, 2014, St. Petersburg, Russia.

Deener, S. (2013, December 12). *Research measures pilot workload, neurological sweet spot - AOPA.* Retrieved 2013, from http://www.aopa.org/News-and-Video/All-News/2013/December/12/EEGs-find-mental-sweet-spot-of-pilots

Dussault, C., Jouanin, J., Philippe, M., & Guezennec, C. (2005). EEG and ECG changes during simulator operation reflect mental workload and vigilance. *Aviation, Space and Environmental Medicine , 76* (4), 334-351.

EASA Internal Group on Personnel Training. (2013). *EASA AUtomation Policy: Bridging Design and Training Principles.*

Ebbage, L., & Spencer, P. D. (2003). *Airmanship Training For Modern Aircrew.* Retrieved 2012, from http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA428471&Location=U2&doc=GetTRDoc.pdf

Eggmeier, F. T., Wilson, G. F., Kramer, A. F., & Damos, D. L. (1991). General considerations concerning workload assessment in multi-task environments. (D. Damos, Ed.) *Multiple task performance* , 207 - 216.

Ekman, P., & Friesen, W. V. (1982). Measuring facial movement with the facial action coding system. *Emotion in the Human Face* .

Emotiv. (2011). Emotiv Software Development Kit- User Manual for Release 1.0.0.5.

Emotiv. (n.d.). *Emotiv | EEG System | Electroencephalography*. Retrieved 2012, from http://emotiv.com/

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors*, 37(1):32–64.

Entzinger, J., Uemura, T., & Suzuki, S. (2014). Mental Effort and Safety in Curved Approaches. *29th Congress of the International Council of the Aeronautical Sciences.*

Federal Aviation Administration. (2011). *Private Pilot Practical Test Standards for Airplane (SEL, MEL, SES, MES).* Retrieved 2014, from http://www.faa.gov/training_testing/testing/test_standards/media/FAA-S-8081-14B.pdf

Gartner Inc. (n.d.). *Technology Research | Gartner Inc.* Retrieved 2013, from http://www.gartner.com/technology/home.jsp

Gartner, Inc. and/or its Affiliates. (n.d.). Retrieved 2014, from Gartner's 2014 Hype Cycle for Emerging Technologies Maps the Journey to Digital Business: http://www.gartner.com/newsroom/id/2819918

Goethe, J. W. (1970). *Theory of Colours.* MIT Press.

Gundel, A., & Wilson, G. F. (1992). Topographical Changes in the Ongoing EEG Related to the Difficulty of Mental Tasks. *Brain Topography , 5* (1), 17-25.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empitical and theoretical research. *Human Mental Workload* , 139-183.

Hayhurst, K. J., & Holloway, M. C. (2003). *Second Workshop on the Investigation and Reporting of Incidents and Accidents, IRIA 2003.* Langley Research Center.

Hugo, J. V., Gertman, D. I., & Tawjik, M. S. (2013). *Development of Human Factors Guidance for Human-System Interface Technology Selection and Implementation for Advanced NPP Control Rooms and Fuel Cycle Installations.* Human factors, Controls and Statistics Department. Idaho National Laboratory.

***Human Connectome Project | Mapping the human brain connectivity*. (n.d.).** Retrieved 2014, from http://www.humanconnectomeproject.org/

Hwang, H.-J., Kim, S., Choi, S., & Im, C.-H. (2013). EEG-Based Brain-Computer Interfaces: A Thorough Literature Survey. *International Journal of Human-Computer Interaction , 29* (12), 814-826.

International Federation of Clinical Neurphysiology. (1999). *Recommendations for the Practice of Clinical Neurophysiology: Guidelines of the International Federation Clinical Neurophysiology.* (G. Deushcl, & A. Eisen, Eds.) Elsiever.

InvestorWords. (n.d.). *What is AUtomation? definition and meaning*. Retrieved 2012, from http://www.investorwords.com/6409/automation.html

Kebabjian, R. (n.d.). *Plane Crash INfo*. Retrieved 2014, from www.PlaneCrashInfo.com

Kincses, W. E., Hahn, S., Schrauf, M., & Schmidt, E. A. (2008). Measuring driver's mental workload using EEG. *ATZ worldwide , 110* (3), 12-17.

Lee, S., Shin, Y., Woo, S., Kim, K., & Lee, H.-N. (2013). Review of Wireless Brain-Computer Interface Systems. In R. Fazel-Rezai (Ed.), *Brain-Computer Interface Systems - Recent Progress and Future Prospects.* InTech.

Lee, Y., & Liu, B. (2003). Inflight workload assessment: comparison of subjective and physiological measurements. *Aviation Space Environ Med , 74* (10), 78-84.

Mankins, J. C. (1995, April 6). Retrieved 2014, from Technology Readiness Levels - EOSDIS - Earth Data Website: https://earthdata.nasa.gov/esdswg/technology-readiness-levels

Mattai, N. (2014, September). Technology Horizons. *Aero Space* , pp. 34-37.

Max Planck Institute for Brain Research. (n.d.). *Brainflight*. Retrieved 2014, from http://brainflight.org/

Meshkati, N., Hancock, P., & Rahimi, M. (1992). Techniques in mental workload assessment. (J. &. Corlett, Ed.) *Evaluation of human work. A practical ergonomics methodology* , 605 - 627.

Morris, G. (2014, September 9). *Holographic Chefs: Kitchen at the Cutting Edge.* Retrieved from http://news.sky.com/story/1331130/holographic-chefs-kitchens-at-the-cutting-edge

NASA Spin Off. (n.d.). *Technology Transfer Program - Bringing NASA Technology Down to Earth*. (J. Jones, Editor) Retrieved 2013, from A real attention getter: http://spinoff.nasa.gov/spinoff2003/hm_2.html

Neurosky. (n.d.). *Biosensor Technology | Neurosky*. Retrieved 2012, from http://neurosky.com/

Niedermeyer, E., & Lopes Da Silva, F. (2005). *Electroencephalography - Basic Principles, Clinical Applications, And Related Fields.* Philadelphia: Lippincott Williams & Wilkins.

Nijdam, N. A. (2010). Mapping Emotion to Color. Netherlands: University of Twente.

Noel, J. B., Bauer, K. W., & Lanning, J. W. (2005). Improving pilot mental workload classification through feature exploitation and combination: a feasibility study. *Computers & Operations Research , 32* (10), 2713-2730.

NUST-SEECS. (2010). *Center of Excellence for Industrial Automation*. Retrieved 2012, from http://ceia.seecs.nust.edu.pk/ioia.shtml

O'Sullivan, D., & Igoe, T. (2004). *Physical Computing: Sensing and Controlling the Physical World with Computers.* Thomson.

Paur, J. (2013, 08 22). *Flight Risks: How Scientists Are Combatting Sleep at 30,000 Feet.* Retrieved 09 2013, from http://www.wired.com/2013/08/ap_pilotfatigue/

PlaneCrashInfo. (n.d.). *Accidents Statistics*. Retrieved 2013, from http://www.planecrashinfo.com/cause.htm

Pope, A. T., & Palsson, O. S. (n.d.). Helping Video Games 'Rewire Our Mins'. NASA.

Rahman, M. (2006). Affective factors: A Model of Cognition Under Emotional States. *Human Factors and Ergonomics Society 50th Annual Meeting*, (pp. 472-476).

Reason, J. T. (1997). *Managing the Risks of Organizational Accidents.* Ashgate Publishing Company.

Reid, G. B., & Nygren, T. E. (1988). The subjective workload assessment technique: A scaling procedure for measuring mental workload. *Human mental workload* , 185-218.

Resnick, M., Maloney, J., Monroy-Hernandez, A., Rusk, N., Eastmond, E., Brennan, K., et al. (2009). Scratch: Programming for All. *Communications of the ACM* , *52* (11), 60-67.

Roscoe, A. H., & Ellis, G. A. (1990). *A subjective rating scale assessing pilot workload in flight. A decade of pracical use.* Technical, Royal Aerospace Establishment, UK.

Rubio, S., Diaz, E., Martin, J., & Puente, J. M. (2004). Evaluation of Subjective Mental Workload: A comparison of SWAT, NASA-TLX, and Wrkload Profile Methods. *Applied Psychology: An International Review* , *53* (1), 61-86.

Salvendy, G. (2012). *Handbook of Human Factors and ERgonomics* (Fourth ed.). New Jersey: John Wiliey & Sons, Inc.

Shappell, S. A., & Wiegmann, D. A. (1999). *Human Error and General Aviation Accidents: A Comprehensive, Fine-Grained Analysis Using HFACS.* Federal Aviation Administration Office of the Chief Scientific and Technical Advisor for Human Factors. Washington, D.C.: Federal AViation Administration.

Shappell, S., & Wiegmann, D. (1996). U.S. Naval Aviation mishaps 1977-92: Differences between single- and dual-piloted aircraft. *Aviation, Space, and Environmental Medicine* , *67*, 65-69.

Sheridan, T. B., & Simpson, R. W. (1979). Toward the definition and measurement of the mental workload of transport pilots. *DSpace* .

Sheridan, T. B., & Verplank, W. (1978). *Human and computer control of undersea teleporators.* Man-Machine Systems Laboratory, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachussets.

Shirley Willet Color Codification. **(n.d.).** Retrieved from http://home.earthlink.net/~smwillett/color of emotions.html

St. John, M., Kobus, D. A., Morrison, J. G., & Schmorrow, D. (2004). Overview of the DARPA AUgmented Cognition Technical Integration Experiment. *International Journal of Human-Computer Intercation , 17* (2), 131-149.

Sterman, M. B., & Mann, C. A. (1995). Concepts and applications of EEG analysis in aviation performance evaluation. *Biological Psychology* , 115-130.

Smith, D. (2012). Getting the Most from Your Flight Training. Retrieved 2014, from http://www.cfidarren.com/r-flightprofsafety.htm

Tan, D., & Nijholt, A. (2010). Brain-Computer Interfaces and Human-Computer Interaction. In *Brain-Computer Interfaces* (pp. 3-19). Springer.

TechCrunch. (2014, May 27). *German Researchers Build A Plane Controlled By Your Brain*. Retrieved 2014, from http://techcrunch.com/2014/05/27/german-researchers-build-a-plane-controlled-by-your-brain/

Tsang, P. S., & Velazquez, V. L. (1996). Diagnosticity and multidimensional subjective ratings. *Ergonomics , 39* (3), 358-381.

Tyner, F. S., & Knott, J. R. (1983). *Fundamentals of EEG Technology: Basic concepts and methods.* Lippincott Williams & Wilkins.

U.S. Department of Health and Human Services. (n.d.). *Brain Research through Advancing Innovative Neurotechnologies (BRAIN)*. Retrieved 2014, from http://braininitiative.nih.gov/

Vicente, K., Thornton, D., & Moray, N. (1987). Spectral Analysis of Sinus Arrythmia: A Measure of Mental Effort. *Human Factors , 29* (2), 171-182.

Wickens, C. D., Hollands, J. G., Parasuraman, R., & Banbury, S. (2012). *Engineering Psychology & Human Performance* (Fourth ed.).

Wilson, G. F. (1993). Air-to-ground training mission: a psychological workload analysis. *Ergonomics , 36* (9), 1071-1087.

Wilson, G. F. (1992). Applied use of cardiac and respiration measures: practical considerations and precautions. *Bological Psychology , 34* (2-3), 163-178.

Wilson, G. F., & Fisher, F. (1995). Cognitive task classification based upon topographic EEG data. *Biological Psychology , 40* (1-2), 239-250.

Wise, J. A., Hopkin, V. D., & Garland, D. J. (Eds.). (2009). *Handbook of Aviation Human Factors* (Second ed.). Taylor & Francis Group, LLC.