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Psychophysiological Factors Analysis in Unpressurized Aircraft Cabins

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Dedicatory

I dedicate this work to my family, particularly to my parents who always gave me strength, to my friends and all the people that help me along these years.

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Abstract

In the versatile aviation environment, the pilot's well-being is a crucial and demanding factor which is directly related to his good performance. Adding the fact that most of the aircraft that belong to the light aviation do not have pressurized cabins, this type of aviation can become a dangerous activity for the safety of pilots and passengers.
The change in pilot's performance during the changing of psychological and physiological parameters has proved to be a very significant factor in terms of flight safety. Also the increasing of altitude in different phases of flight corresponds to a reduction in oxygen partial pressure. This occurrence may lead to early symptoms of hypoxia which may become an even greater danger if the pilots do not have time to feel, or recognize their symptoms.

A review of international legislation indicates a high tolerance to establish safety limits in this matter, taking into account the unpredictability of reactions of the human body of each pilot for the same flight conditions.
This work is generally focused in acquired data during different flight situations, with different pilots and respective processing of data obtained during different tasks of flight.

To achieve the proposed objectives the acquired data contain parameters such as altitude, absolute pressure and temperature inside the cabin; as well as registration oximetry, peripheral and cerebral, to study the phenomenon hypoxia. Also comprises electrocardiogram (ECG) and electroencephalogram (EEG) in order to establish a correlation between the influence of mental workload and other physiological parameters during different phases of flight.

The specific objective of this research is the acquisition and processing of data collected directly from the aircraft and the pilot, performing flight simulation tests in different scenarios, contributing to trying to define the physiological limits of each individual with the purpose of creating an alert system on board to avoid possible incidents or accidents.
This study also aims to suggest a restriction in the legislation on licensing of light aviation, within physiological limits of each individual, thus contributing to a safer flight environment.

Keywords:

Pilots performance, Light aviation, Non-pressurized cabins, Psychological and physiological parameters, Flight safety, Acquisition and data processing.

Resumo

No ambiente versátil da aviação, o bem-estar do piloto é um factor crucial e exigente que está directamente relacionado com o seu desempenho. Adicionando o facto da maioria das aeronaves que pertencem á aviação ligeira não possuírem cabines pressurizadas, este tipo de aviação pode tornar-se numa actividade perigosa para a segurança de pilotos e passageiros.
A mudança de desempenho dos pilotos aquando da alteração de parâmetros psicológicos e fisiológicos tem-se revelado um fator bastante significativo em termos de segurança de voo. Também o aumento da altitude nas diferentes fases de voo corresponde a uma diminuição da pressão parcial de oxigénio. Esta ocorrência pode levar a sintomas iniciais de hipoxia o que se pode tornar um perigo ainda maior se os pilotos não possuírem tempo para sentir, ou reconhecer, os seus sintomas.

Uma revisão da legislação internacional indica uma grande tolerância a estabelecer limites de segurança neste tema, tendo em conta a imprevisibilidade de reacções do corpo humano de cada piloto para as mesmas condições de voo.

O objectivo geral deste trabalho consiste na aquisição de dados durante distintas situações de voo, com diferentes pilotos, e o respectivo processamento dos dados obtidos durante as diferentes tarefas de voo.

Para realizar os objectivos propostos os dados adquiridos contêm parâmetros como altitude, pressão absoluta e temperatura no interior da cabina, bem como o registo de oximetrias, periférica e cerebral, para estudar o fenómeno hipoxia. Também compreende electrocardiogramas (ECG) e electroencefalogramas (EEG) de modo a estabelecer uma correlação entre a influência da carga de trabalho mental e outros parâmetros fisiológicos durante as diferentes fases de voo.

O objectivo específico desta investigação é a aquisição e processamento de dados recolhidos directamente da aeronave e do piloto, realizando testes de simulação de voo em diferentes cenários, contribuindo para tentar definir os limites fisiológicos de cada individuo com a finalidade de criar um sistema de alerta a bordo para evitar possíveis incidentes ou acidentes.
Com este estudo pretende-se também sugerir uma restrição na legislação no licenciamento da aviação ligeira, dentro dos limites fisiológicos de cada individuo, contribuindo assim para um ambiente de voo mais seguro.

Palavras – Chave:

Desempenho de pilotos, Aviação ligeira, Cabines não pressurizadas, Parâmetros psicológicos e fisiológicos, Segurança de voo, Aquisição e processamento de dados.

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List of Acronyms

ACT	Altitude Chamber Training
ATA	Atmospheres Absolute
bpm	Beats Per Minute
ECG	Electrocardiography
EEG	Electroencephalography
FAR	Federal Aviation Regulations
ft	Feet
FL	Flight Level
hPa	Hectopascal
Pa	Pascal
HR	Heart Rate
ICAO	International Civil Aviation Organization
JAR-OPS	Joint Aviation Requirement – Operation Performance Standard
MHR	Maximum Heart Rate
MSL	Mean Sea Level
O_2	Oxygen
rSO2	Regional Oxygen Saturation
SpO2	Haemoglobin Saturation
TUC	Timo Useful of Consciousness
USA	United States of America

1. Introduction

1.1 Motivation

Flying is an activity that is increasing in recent times and is still growing. The majority of light aviation pilots fly their aircrafts with unpressurized cabins thus are subject to the same pressure as in the outside of the aircraft in other words the atmospheric pressure.

With altitude increasing, pressure decreases and therefore also decreases the partial pressure of oxygen. This falling of partial pressure of oxygen is responsible for the appearance of hypoxia phenomenon. Hypoxia becomes a serious danger when flying in these conditions and several accidents have occurred with fatalities involved.

In low altitude flights, generally, hypoxia will not be a large problem to well-trained pilots but is dangerous for amateur pilots who are not as well trained in the same conditions.

The light aviation and glider pilots are exposed to various decisions during the flight that involve interactions between four risk elements: the pilot, the aircraft, the environment, and operation. The process of decision making during each flight involves a correct evaluation of each situation of flight, which often does not happen due to various factors.

Recent works have been developed at the University of Beira Interior regarding Flight Safety.

Ana Fonseca [1], in 2010, started an experimental part involved measuring heart rate and peripheral oximetry, during a glider flight, to prove that the increase in altitude (and the consequent pressure falling) decreases the oxygen in the blood.

Leandro Rocha [2], in 2011, made the measurement of pilot's physiological parameters, as brain oximetry, in the study of hypoxia phenomenon, during ultralight flights.

This work comes in sequence of other two related studies. André Marques [3], in 2012, developed a data acquisition system that helps to improve the overall flight safety. Working in parallel with Sara Zorro [4], that extended the work trying to relate parameters, like heart rate and brain oximetry, to pilot's everyday habits and the flight environmental conditions. The interpretation and comparison of collected data helps to decide what parameters may be relevant in the pilots' flight performance.

Selected the parameters the next step in this study is extending the acquisition of flight and physiological data from the aircraft and the pilot, monitoring parameters as both oximetry, peripheral and cerebral, ECG and EEG.

A review of international legislation indicates a high tolerance to establish safety limits, once only establishes limit altitudes to which supplemental oxygen is required and there are no requirements for ground training in flight physiology for light aviation and glider pilots.

This dissertation was made in order to contribute with one more step to Flight Safety.

1.2 Object and Objectives

The object of this work is the acquisition of flight and physiological data from the aircraft and the pilot, monitoring parameters defined previously as potential to establish the physiological boundaries of each pilot.

The first step of this work is to establish a sample of light aviation pilots differentiated by their own characteristics like age, daily habits and experience in flight and submit them to the same type of situations.

The equipment allow obtaining synchronized data between physiological parameters: peripheral oximetry, brain oximetry, ECG and EEG and flight parameters: altitude, absolute pressure and temperature inside the cabin.

The second step is to submit all the pilots to different scenarios.

Firstly a flight on a hypobaric chamber, where the pilots have no extra work, only feel the decrease of pressure caused by the increasing of altitude.

The second scenario is a simulated flight in a flight simulator creating some stressful situations for the pilot.

The third and final scenario is then a real flight where, the pilot and the aircraft are also submitted to environmental conditions.

The main objective of this study is show that there are many factors that can compromise the flight safety of the pilot and passengers that not just pass by establish limit altitudes to which supplemental oxygen is required.

The final purpose is contributing to the ultimate goal of this entire set of works developed so far, to build a device possible to carry on board that can alert each individual to his physiological limits.

Have a device to alert the pilot to the danger will be an asset for this (and all) type of non-pressurized aircraft. With this device making an alert, the pilot have enough time to take the necessary decisions, for example, descend to an altitude considered safe or to resort to any supplemental oxygen system that is installed on board.

These decisions, taken in time, are crucial to prevent incidents and accidents that may endanger the life of the pilot and the integrity of the aircraft.

Consequently of its predecessors, the last objective implies making a set of recommendations, based conveniently, to revise the legislation in force in Portugal related to this subject.

1.3 Dissertation Structure

This work is divided in five main chapters.

Chapter one is the Introduction, which is divided into three sub-chapters, the motivation, the object and objective, and the structure of the dissertation, respectively.

Chapter two is the State of Art review that reports the studied physiological factors, which are the basis of this work, and its effects on pilots' physiology. This chapter also includes a review on aviation legislation about the theme of this work.

Chapter three addresses the Case of Study and it contains the pilots' characteristics and the experimental results obtained from the hypobaric chamber, flight simulator and real flight tests.

Chapter four reports the experimental work analysis.

Finally, chapter five reports the final conclusion of this work where are indicated a dissertation synthesis, final considerations and perspectives for future work in this matter.

2. State of Art

2.1 Introduction

This chapter discusses the State of the Art in general which is defined, in the first place, by the flight physiology, the different psycho-physiological parameters, their influence on pilots and consequent dangers to flight safety.

In this chapter is also mentioned the different methods and techniques applied to monitoring psycho-physiological parameters under study.

Since the laws for a safe operation are already legislated, this chapter also includes a part of it relating to this dissertation.

2.2 Flight Physiology

If we make a search on aviation accident investigation reports we will find that one of the common causes is the human factor or more specifically the pilot performance during the flight.

Thus, it is important that aviation and medicine are connected, working side by side with the main goal of making the flight a safer activity.

From very early, man's curiosity leads him to make progress in knowledge. Paul Bert, acclaimed as the father of altitude physiology and aviation medicine, built in 1870 a decompression chamber to simulate the effects of altitude. Therefore he was able to validate his idea about the deleterious effects of high altitude due to the lack of oxygen [5] [6].

Nowadays, in Portugal, essentially, only the military aviation gives a lot of importance to the physiological factors by doing specific crew training. In civil aviation the approach to these matters resumes to a theoretical classes few hours during the pilot course despite the fact that these factors can compromise safety, i.e. without specific practical training.

The knowledge of their physiological parameters by each pilot has a great importance for an activity of high responsibility, as is the flight.

2.2.1 Hypoxia Phenomenon

Hypoxia has been recognized as a physiological threat at altitude since the earliest days of flight when humans took to the skies in balloons. [7]

It is also known that those who live and work in mountain terrain experience a limited range of altitudes and have time to adapt to the hypoxia experienced at high terrestrial elevations. In contrast, flyers may be exposed to abrupt changes in barometric pressure and to acute, life-threatening hypoxia. [8]

Earth's atmosphere is vital to our existence; it provides a moderate temperature environment at the surface, a protective barrier against the effects of radiation, and the oxygen needed for the release of biological energy. Flyers depart from the safety of this surface putting your account in risk.

The oxygen concentration in the atmosphere is constant (about 20.95%) up to altitudes of about 100,000 feet (ft). This means that, according to Dalton's Law, the partial pressure of oxygen at sea level is 212 mbar (20.95% of 1,013 mbar, 1013 mbar which is the standard atmospheric pressure at sea level). As altitude increases, the partial pressure of each gas in the atmosphere decreases, but the oxygen concentration remains unchanged; for example, at 40,000 feet altitude atmospheric pressure is 187.54 mbar and the oxygen partial pressure of 39.29 mbar, which continue to be about 20.95% of atmospheric pressure. The problem for pilots is that at high altitudes there is not enough pressure for the alveolus absorb the necessary oxygen. [2]

Hypoxia is defined as a deficiency of blood reaching tissues and organs of the body which is generally associated with a drop in the blood oxygen level. An extreme loss of oxygen over a sufficient period of time will cause the individual to become unconscious. [9]

Flying at high altitudes in non-pressurized aircraft and without supplemental oxygen can put pilots vulnerable to hypoxia.

The symptoms of hypoxia vary from individual to individual and anyone is subject to the effects of oxygen deprivation. However, the most common symptoms include [8] [10] [11]:

- Cyanosis (blue fingernails and lips);
- Numbness (inaction in the face a certain task/problem);

- Tingling in fingers and toes;
- Lightheaded or dizzy sensation;
- Drowsiness;
- Euphoria;
- Impair judgment;
- Decrease in reaction time;
- Decrease visual capacity;
- Decrease ability of perception color;
- Headache;
- Lack of concentration;
- Increased self-confidence;
- Speech uncoordinated;
- Tunnel vision;
- Amnesia.

Therefore to what may seem by the symptoms listed above, the effects of hypoxia can induce the pilot to a false sense of security and normality. The insidious nature of hypoxia is its true danger. This is another worrying factor that leads us to the realization of this work.

The appearance and intensity of the symptoms of hypoxia depend on factors like the speed of ascent, the absolute altitude flight, the duration of exposure to low atmospheric pressure, temperature and individual characteristics such as a disease, everyday habits, physical fitness, acclimatization and emotion. [4]

The tests performed to further identify this phenomenon consist in measuring the quantity of oxygen in tissues. This measurement may be done by oximeters, which in turn may be cerebral oximetry or peripheral oximetry.

The cerebral oximetry (and somatic) is the only non-invasive method that allows the simultaneous monitoring of oxygen in the brain tissue and the body surface.

The regional oxygen saturation or peripheral reflects the leftover oxygen after tissues withdraw the oxygen they need. [12]

Time of useful consciousness (TUC) is a definition very important also to this matter, defined as the amount of time an individual is able to perform flying duties efficiently in an environment of inadequate oxygen supply. [13] It is the period of time from the interruption of the oxygen supply or exposure to an oxygen-poor environment to the

time when useful function is lost, and the individual is no longer capable of taking proper corrective and protective action. It is not the time to total unconsciousness.
TCU is a very limited period of time, and is therefore very important to take into account because a crew member after passing the limit of TCU becomes unable to make any appropriate corrective action and assume an attitude of defense, by simple it is.
In table 2 is shown the TUC variation for various altitudes.

Altitude (FL)	Altitude (ft)	Altitude (m)	Time Useful of Consciousness
150	15,000	4,572	30 minutes, or more
180	18,000	5,486	20 to 30 minutes
220	22,000	6,705	5 to 10 minutes
250	25,000	7,620	3 to 5 minutes
280	28,000	8,534	2,5 to 3 minutes
300	30,000	9,144	1 to 3 minutes
350	35,000	10,668	30 to 60 seconds
400	40,000	12,192	15 to 20 seconds
450	45,000	13,106	9 to 15 seconds
500, or above	50,000	15,240	6 to 9 seconds

Table 1: Time of Useful Consciousness. [4]

As can be seen in Table 2, TUC decreases with the altitude increasing. For example, in case of rapid depressurization, the TCU is reduced to half. [14]
The times shown in Table 2 are not permanent, i.e., may vary depending upon the individual (physical condition, quotidian habits, smoking habit, etc.), time… [4] Any kind of activity that increases cellular metabolism implies a decrease TCU. [2]
The aviation does involve a cocktail of stressors which is unique when combined with a critical need for a high level of performance.
Perhaps the earliest stressors recognized were those created by the immediate environment such as noise, vibration, temperature, humidity extremes and acceleration forces. Many of these now have less significance than formerly and have been replaced by more complex factors. [15]
For example, stress that is the body's response to physical and psychological demands placed upon it, causes metabolism increasing to provide more energy to the muscles. [10]

The pilot are always under some tension but despite a certain amount is beneficial because it keeps a person alert, an excessive amount of stress can impair the ability to make effective decisions during the flight. [4] Factors such as stress and prolonged performance of cognitive work result in mental fatigue. Fatigue is frequently associated with pilot error. Some of the effects of fatigue include degradation of attention and concentration, impaired coordination, and decreased ability to communicate. These factors seriously influence the ability to make effective decisions. [10] Therefore, it is very difficult to establish safety boundaries.

2.2.2 Cardiac and Respiratory Rates

To perform its main function, to pump blood, the heart must perform mechanical contraction and its activity depends on its electrical activity. For the heart pump blood efficiently and continuously its electrical activation should occur repeatedly in the proper sequence.

The heart rate is an indicator of cardiac work; usually expressed as the number of beats per minute (bpm).The heartbeat occurs with the formation and propagation of action potentials sequentially along the cardiac anatomical structures.

There are many factors that have an important role in heart rate values, as the stress level of the individual, eating habits, drinks with caffeine, smoking habits and intake of medicines. [16]

The heart rate can be measured by heart monitors watches, or can be calculated without any special equipment, by placing the fingers on certain body points. [16] However another method can be used, the electroencephalography. Nowadays, it is possible to record an ECG with small and light devices that are extremely portable.

Heart rate in aviation has been studied for several decades. A large number of papers have been published in which heart rate either alone or, more commonly, with other variables has been recorded as part of a study into physiological responses to different stimuli. Of particular interest are those studies where heart rate has been monitored to assess the influence of various so-called "stressful" activities, in particular, those associated with flying in real airplanes and flight simulators. Regarding heart rate and

ECG, a review with more than 20 years is still up to date in what concerns the relation between heart rate and mental work load. [17]

HR increase has been referred to as a good marker of high workload demand in several articles. All those studies lead to the conclusion that increased HR is a marker of stress and mental workload. However, in some stressful situations such as landing approach, than in a subjective self-reported way pilots did not consider to be highly demanding, HR increased. On the contrary, in some situations where pilots reported high workload, such as simulated emergencies, there were not accompanied by an HR change. These results draw attention to the fact that there appears to be a cognitive workload that pilots are not aware of.

Respiration is the physiological process primarily concerned with the interchange of oxygen and carbon dioxide between body tissues and the atmosphere. Cellular activity utilizes oxygen obtained from air during inspiration and produces carbon dioxide which is removed during expiration. The quantity of oxygen required by the body is determined by the level of activity or metabolism in various tissues, increased demands being met by increasing the rate and depth of respiration.

A healthy person at rest has a respiratory rate of about 12 breaths per minute.

Physical activity causes an increase in heart rate and depth but emotional influences and increased arousal levels normally cause an increase in rate with a decrease in depth. During periods of stress and intense mental effort, a phenomenon known as hyperventilation or over-breathing sometimes occurs. [17]

During a flight, a pilot may be subject to a high burden of mental activity. This activity can be linked to several mechanisms / psycho physiological factors such as attention, concentration, decision making, level of responsibility, tasks and physical capacity during the entire flight, highlighting phases of takeoff and landing.

In short, the respiratory system of the human body works very efficiently. It gives the human body the capability to adjust and function in a variety of environments. But, the body has its limitations. If the change is too abrupt, then these systems can't adjust quickly enough and the body will suffer the effects. It is important know the body's limitation at altitude and take appropriate measures to compensate for those limitations.

Thus, the measurement of respiratory rate is probably the most relevant and useful index, because it is easier to obtain and serves as an indicator of emotional state, level of stress, arousal and mental effort. [4]

2.3 Physiological Parameters Data Acquisition

The acquisition of human physiological parameters becomes very important especially in non-pressurized aircraft where changes in cabin environment can be significant.
Information about the flight dynamics of the aircraft are important to understand some correlation that may exist when occur changes in behavior and performance of the pilot.

2.3.1 Peripheral and Cerebral Oximetry

Pulse oximetry measures the saturation of arterial blood (SpO_2), peripheral oximetry that reflects the leftover oxygen after tissues withdraw the oxygen they need. [12]
Several sensors can be used for peripheral oximetry measurement. In a systematic way they can be divided in 2 major types: reflectance and transparency sensors.
Transparency sensors determine oxygen saturation by using light absorptive characteristics of hemoglobin. Once the arterial hemoglobin saturated with oxygen is bright red, and venous hemoglobin without oxygen is darker, the probe, which consists in a light source, a light detector, and a microprocessor, will calculate the difference between the red bright and darker hemoglobin. The probe light source has two different types of light, infrared and red, which are transmitted through the finger or earlobe tissue and received by the light detector on the other side of the probe. Therefore, and as the oxygen-rich the hemoglobin absorbs more infrared light and oxygen-poor hemoglobin absorbs more red light, the microprocessor may distinguish both and calculate the oxygen level in the blood. The majority of the sensors of this type are for finger or earlobe probing, being the first much more interfering with piloting because it has to be attached to the pilot’s finger.
Reflectance sensors were developed more recently than transparency probes and have great potential for research even though they also depend on light for oximetry. Their greatest advantage lies on the fact that these probes do not limit pilots’ movements

since they can be placed in other areas than the fingers or other body extremities. [18] [19]

Regional hemoglobin oxygen saturation (rSO2), cerebral oximetry, estimates regional tissue oxygenation by transcutaneous measurement of the cerebral cortex, on area of the brain that is most susceptible to changes in oxygen supply and demand and has limited oxygen reserve. Measurement is based on the ability of light to penetrate the skull and determine hemoglobin oxygenation according to the amount of light absorbed by hemoglobin. [20]

Unlike pulse oximetry, cerebral oximetry uses two photo-detectors with each light source, which allows selective sampling of tissue beyond a specified depth beneath the skin. Adhesive pads (sensors) are applied over the frontal lobes that both emit and capture reflected near-infrared light passing though the cranial bone to and from the underlying cerebral tissue. [21]

As will be noted forward, there are differences between the values obtained in both oximetries. And there are two main reasons for that: firstly, cerebral oximetry indicates the oxygen saturation of both venous and arterial blood in the brain while peripheral oximetry measures the oxygenation of arterial blood. Secondly, cerebral oximetry measurements are not affected by peripheral vasoconstriction, while this affects peripheral oximetry. [22]

2.3.2 Electrocardiography

Electrocardiography is the recording of the electrical activity of the heart. Traditionally this is in the form of a transthoracic (across the thorax or chest) interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the surface of the skin and recorded or displayed by a device external to the body. [23] The recording produced by this procedure is named an electrocardiogram (ECG).

An ECG picks up electrical impulses generated by the polarization and depolarization of cardiac tissue and translates into a waveform. The waveform is then used to measure the rate and regularity of heartbeats, but the obtained information is not limited to hearth rate (HR). Other parameters such as intervals between ECG waves, wave amplitude or heart rate variability can also be retrieved from an ECG. [17] [24]

The ECG recorder has electrical cables attaching the electrodes. The electrodes usually consist of a conducting gel, embedded in the middle of a self-adhesive pad.
The following figure shows the placement of electrodes for a four channels ECG.

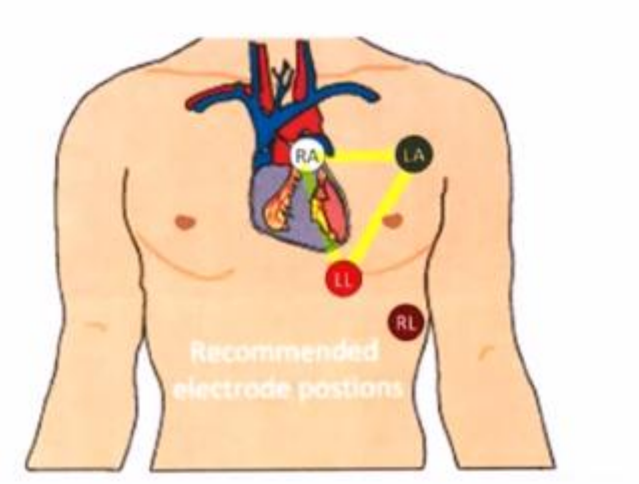


Figure 1: ECG electrodes placement.

2.3.3 Electroencephalography

Electroencephalography consists in the recording of electrical activity of the brain over a certain time. An electroencephalogram (EEG) is a test that detects electrical activity in the brain using electrodes attached to your scalp. The brain cells communicate via electrical impulses and are active all the time, even when individuals are asleep.
To record an EEG it is necessary several wires connected to a person's head, never less than 4 or 5 need to be glued to the scalp. Those wires and electrodes to detect brain waves also work as antennas for every electromagnetic interference, because, as stressed, brain waves have very low amplitude.

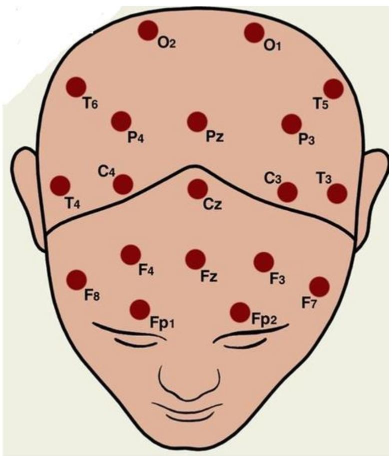


Figure 2: EEG sensors placement

Performing an EEG recording on an airplane during flight, although not impossible, needs a good preparation and a high quality portable device.

2.4 Legislation

A review of the legislation that affects unpressurized aircrafts was performed with the objective to understand the requirements regarding supplementary oxygen systems.
In order to have an idea of how this issue is approaching at the global level was made a search within the international law, after the EU, followed by American and Portuguese.
The next four subchapters are devoted to each of these legislative approaches. International law on the subject is given by ICAO Annex 6, the American by FAR 91.211, the European is given by JAR-OPS 1.775, and finally the legislation in place in our country is given by Decreto-lei nº289, November 14, 2003.

2.5 Conclusion

In Portugal it has seen an increase in leisure flights, particularly in non-pressurized aircraft like glider and ultra-light aircrafts. Fly in a non- pressurized aircraft can become a danger activity when the altitude increases. In pilot courses seems not to be given much importance to several symptoms related to this flight condition which can compromise the pilot’s performance. However, the dangers associated with high altitude flying can be avoided by flying in a pressurized cabin, providing supervised ground training and education, as ACT. [25]
In short, the International law, American, European, Portuguese and Portuguese current to enter into vigor, do not differ much for this topic, merely to make altitude and time restrictions, with or without supplemental oxygen support, not taking into account that the responses to different stimuli vary from person to person and pilots of unpressurized aircrafts have a significant vulnerability to environmental and flight conditions.

3. Case of Study

3.1 Introduction

This study's main purpose is to analyze the influence of flight environmental conditions and pilots psycho physiological parameters on task performance, during different flight situations, considering some of his everyday habits. This may be a concerning situation once different pilot's react differently to the same flight conditions. For that reason, it is very difficult to establish general safety boundaries regarding the psycho physiological factors.

Therefore experimental work was done to observe the human body physiological reactions to the psychological factors combined with the environmental conditions in different flight scenarios.

3.2 Pilots Characteristics

In the current work, the experimental tests were performed by four male individuals with different characteristics which are shown in the following table.

Individual	Gender	Age	Physical Exercise	Smoker
1	Male	62	Assiduously	No
2	Male	50	Rare	No
3	Male	27	Rare	No
4	Male	26	Assiduously	No

Table 2: Characteristics of the tested pilots.

3.3 Experimental Work

The current work comes in succession of a previous study [4] that consisted in the collection of physiological data, cerebral oximetry and HR, synchronized with the flight parameters as altitude, temperature and humidity, in hypobaric chamber, and in real flight scenarios.

In this work, referent to equipment was added peripheral oximetry, ECG and EEG, and referent to flight scenarios was added the flight simulator.

In this work, the adopted equipment, for brain oximetry, was the same used in the previous work [4], i.e., the Nonin Medical Inc. Model 7600 Regional Oximetry System (Figure 1).

Figure 3: Nonin Medical Inc. Model 7600 Regional Oximeter System, 2 Channel Configuration. [26]

The Nonin Model 7600 Regional Oximetry is a simple, versatile and intuitive to the user device. It offers the latest Bluetooth wireless technology connectivity and two sensors with great precision regardless of skin type, features or blemishes. This equipment has a battery life of approximately 3 hours that can be storage in temperatures from -30 to 70º C (-22 to +158º F) and it can be operated in temperatures between -5 to 40º C (+23 to +104º F) with humidity varying from 10 to 90% non-condensing and up to 3,657 meters (12,000 feet). [27] Each sensor of the equipment was placed on the frontal region of each cerebral lobe (Figure 2).


Figure 4: Nonin Medical Inc. Model 700 equipment configuration.

For this work, in the placement of the sensors was adopted to put only one lobe collecting data, so as to be able to synchronize all the remaining equipment. This does not reveal a problem for data analysis, once the obtained values for each one was, approximately, equal.

Such as in previous work [4] was also used a flight data recorder, to record the flight parameters, as geographical coordinates, altitude, ground speed, gravitational force (G-force), temperature, humidity and pressure inside the aircraft cabin. This device can be powered by a direct connection to a computer for power supply and data storage or using a battery.


Figure 5: Flight data recorder.

In the previous study [4], several experimental tests were performed with both devices and it is possible synchronize them in the same time scale to allow the comparison between physiological and flight data.

For the peripheral oximetry measurement, the equipment used was the Nonin LifeSense LS1-9R (Figure 4). It is portable, accurate and simple to use. Among others, this equipment provides information about peripheral oximetry and heart rate. This equipment has a battery life of approximately 8 hours that can be storage in temperatures from -30º to 70º C (-22º to 158º F) and it can be operated in temperatures between 0 to 45º C (32º to 113º F) with humidity varying from 0 to 90% non-condensing and up to 1060 hPa. [28] The sensor of the equipment is placed on the finger. (Figure 5)

Figure 6: Nonin Medical Inc. Model LS1-9R Pulse Oximeter System.

Figure 7: Nonin Medical Inc. Model LS1-9R equipment configuration.

The equipment used to obtain ECG information was the Avatar EEG. The Avatar EEG is one of the most cost effective EEG recorders currently available. It is a recorder extremely portable weighing only 60 grams and small enough to fit in a pocket. It provides over 24 hour's continuous recording. [29]

This equipment has eight channels and it can be used for EEG, EOG, EMG or ECG and support monopolar and bipolar reference electrode configurations possible.

The Avatar Android App allows users to view the signal from an Avatar EEG device without linking to a laptop or desktop device. The EEG signal from any Avatar EEG recorder can be viewed directly through Bluetooth. [30]

Figure 8: Avatar EEG equipment.

To record an EEG and an ECG seven wires were used, five electrodes in a pilot's head to record an EEG and two electrodes in pilot's chest for ECG (figure 7). This process takes some time and several tests were required to find a correct configuration.


Figure 9: Avatar EEG equipment configuration.

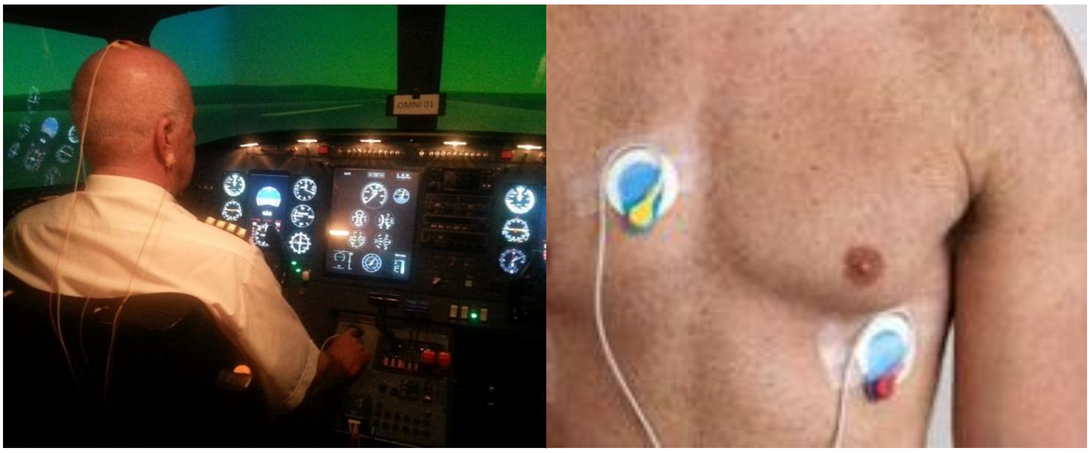


Figure 10: Electrodes placement.

3.3.1 Hypobaric Chamber Tests

The hypobaric chamber tests were conducted with the support of the Portuguese Air Force. The tests were performed in the Centro de Medicina Aeronáutica of Portuguese Air Force (Figure 1), in the Lumiar military base, in Lisbon, Portugal.

Figure 11: Hypobaric Chamber of Centro de Medicina Aeronáutica of the Portuguese Air Force.

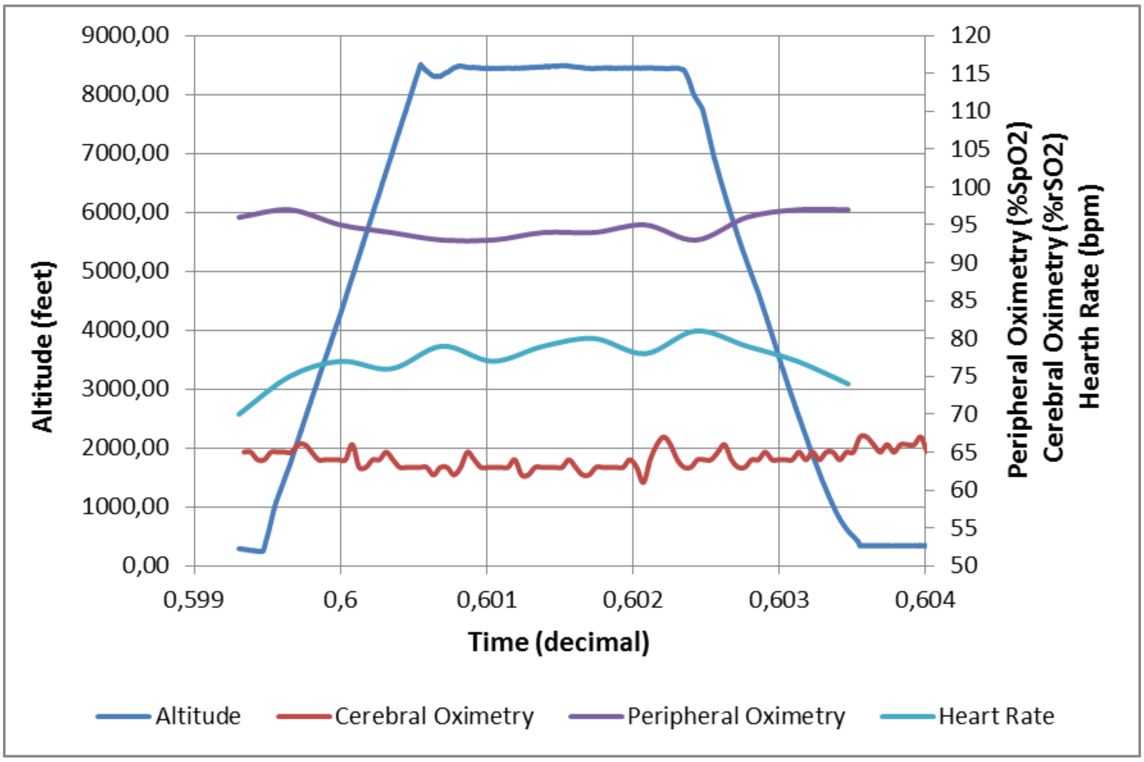
The full training done in hypobaric chamber for military crews simulates a flight up to 35,000 ft. In the initial part of the simulated flight there was an initial climb to 8,000 ft followed by a descent back to sea level pressure. The tests had an average duration of 6 minutes, 2 minutes to reach the maximum altitude, 2 minutes stabilized in the maximum altitude and 2 minutes to achieve the ground level. This initial test has the objective to ensure that all individuals that are going to perform the test are capable to equalize pressure in their ears and are safe to continue.

The tests conducted in hypobaric chamber were done with authorization from Portuguese Air Force up to 8,000 ft, and the maximum simulated altitude was 8,617.83 ft above the sea level.

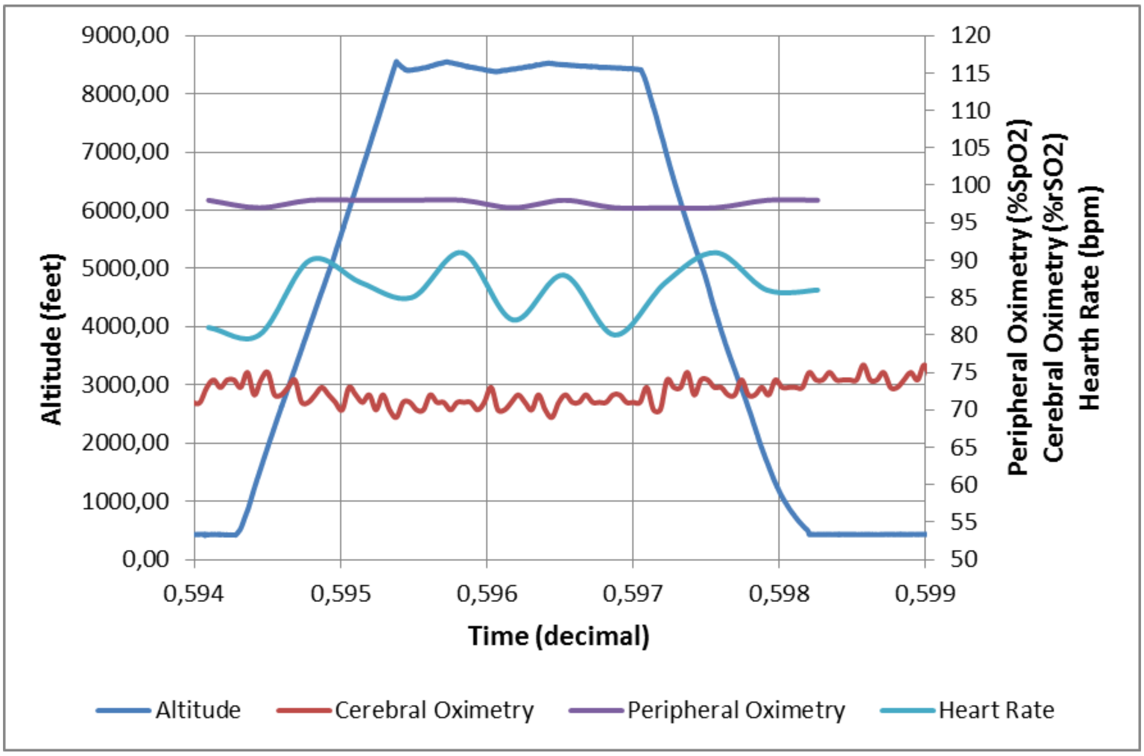
In this scenario all the equipment mentioned above was used and all the group of pilots experienced this scenario.

Several tests were performed in this scenario, many of them to test equipment and place them working properly.

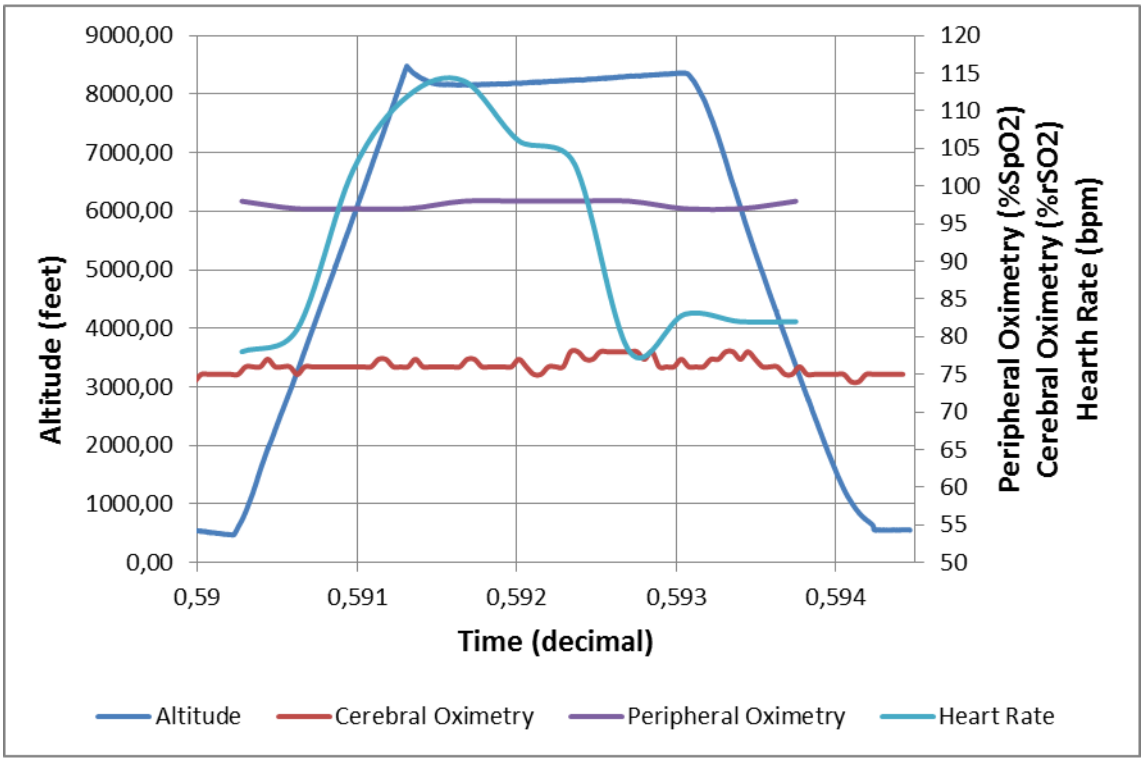
From all tests realized, four of them, one per pilot, are exposed in Graphics 1 to 4 below.



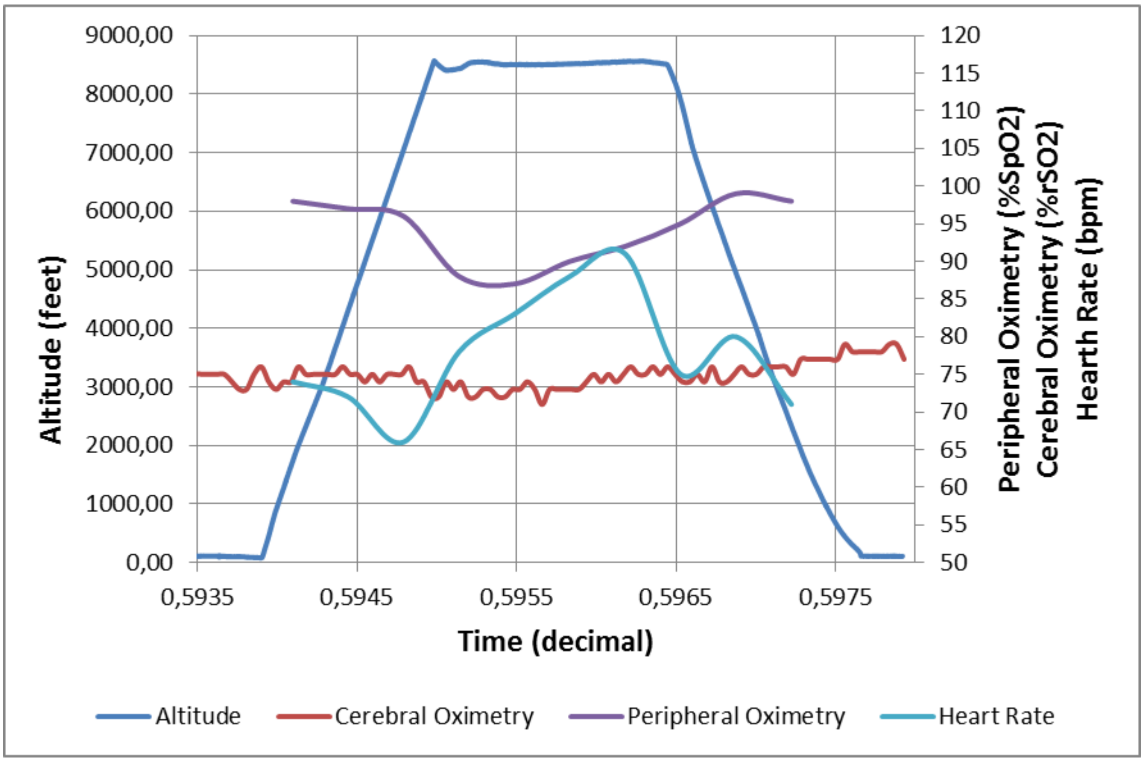
Graphic 1: SpO2, rSO2, heart rate and altitude variation during hypobaric chamber test for individual 1.



Graphic 2: SpO2, rSO2, heart rate and altitude variation during hypobaric chamber test for individual 2.



Graphic 3: SpO2, rSO2, heart rate and altitude variation during hypobaric chamber test for individual 3.



Graphic 4: SpO2, rSO2, heart rate and altitude variation during hypobaric chamber test for individual 4.

During this presented tests all the equipment worked properly and all information collected was recorded and processed.

3.3.2 Flight Simulator Tests

The flight simulator tests took place in OMNI Aviation Training Center, in Tires, Portugal.

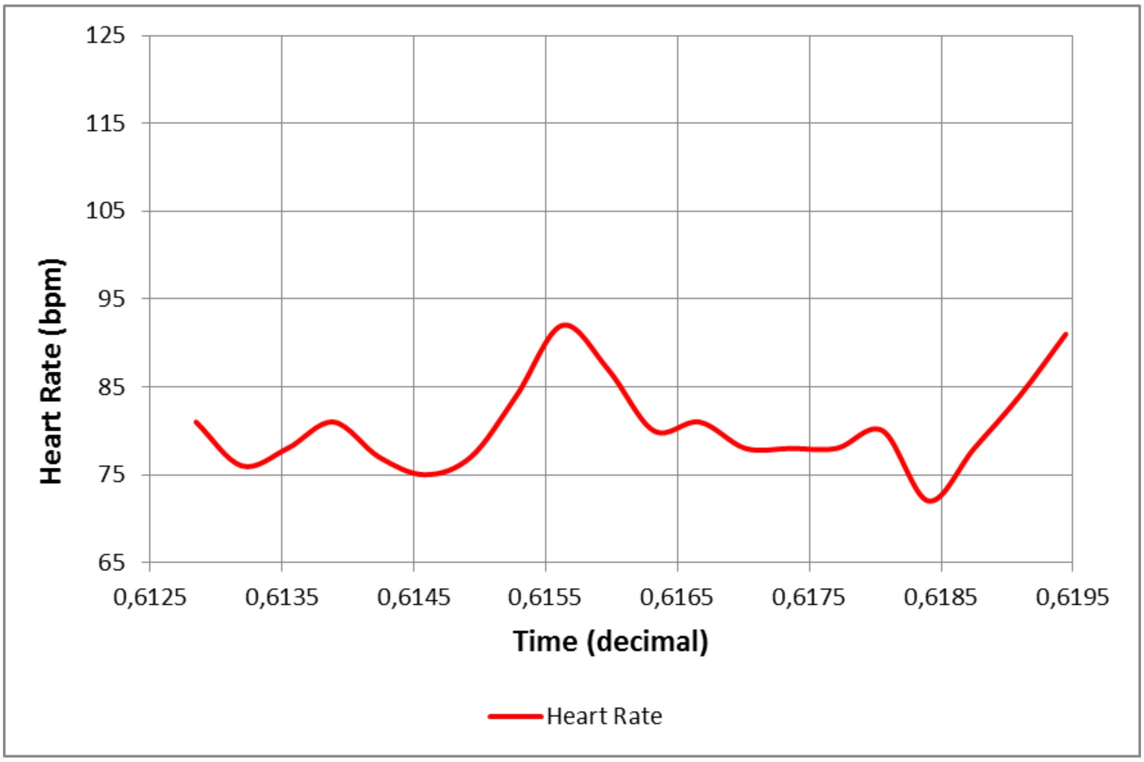
Figure 12: Flight simulator of OMNI Aviation Training Center.

This is an important scenario since it is possible simulate factors like, the weather conditions and some stressful situations that highly influences the psychophysiological behavior during conditions of high mental workload, attention and concentration.

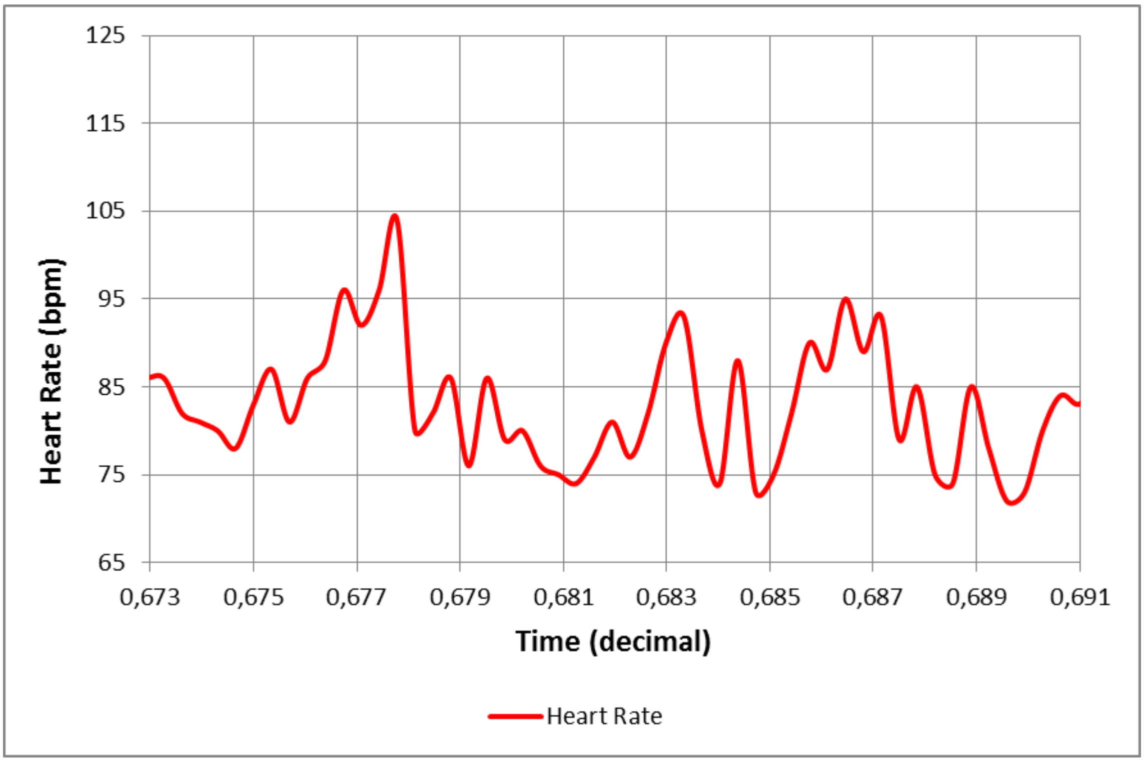
The parameter measured in these tests was only the HR. How it is a simulated scenario, is performed on the ground, so the altitude is not an important factor.

Only three of the sample of pilots had done this test. The first and second individual were equipped only with peripheral oximeter, for the fourth individual, the information about the HR was given by the ECG.

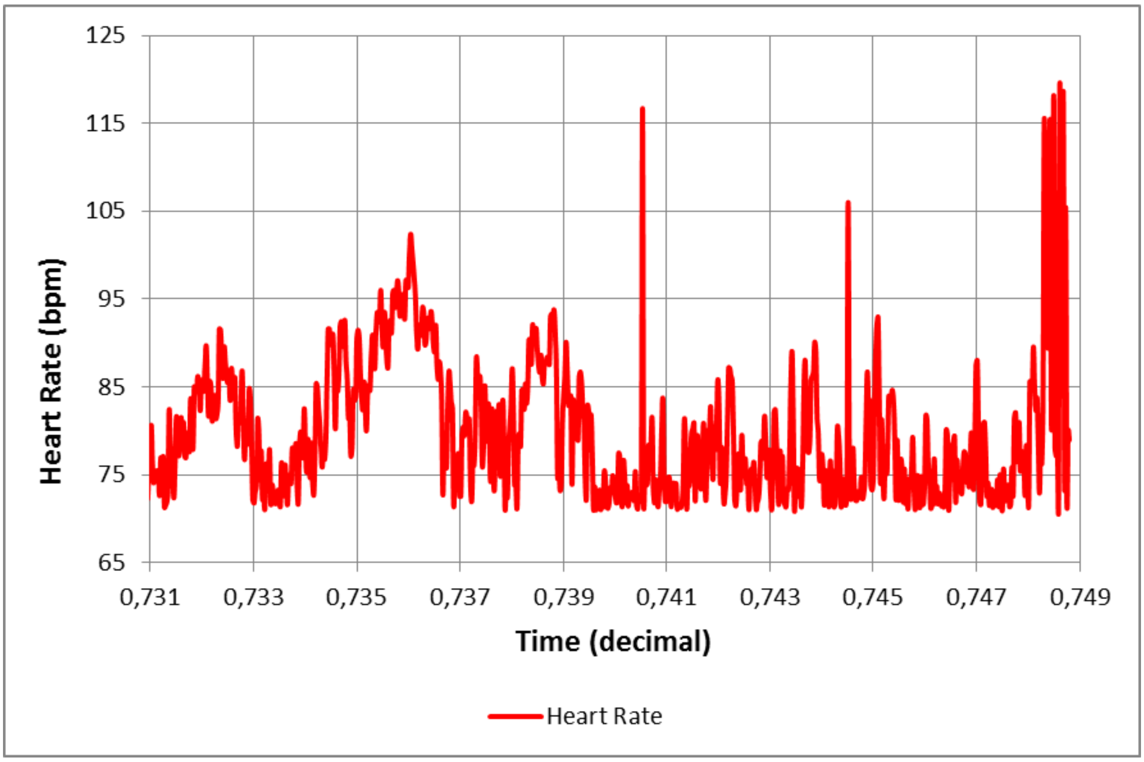
The graphics obtained are presented below.



Graphic 5: HR variation during flight simulator test for individual 1.



Graphic 6: HR variation during flight simulator test for individual 2.



Graphic 7: HR variation during flight simulator test for individual 4.

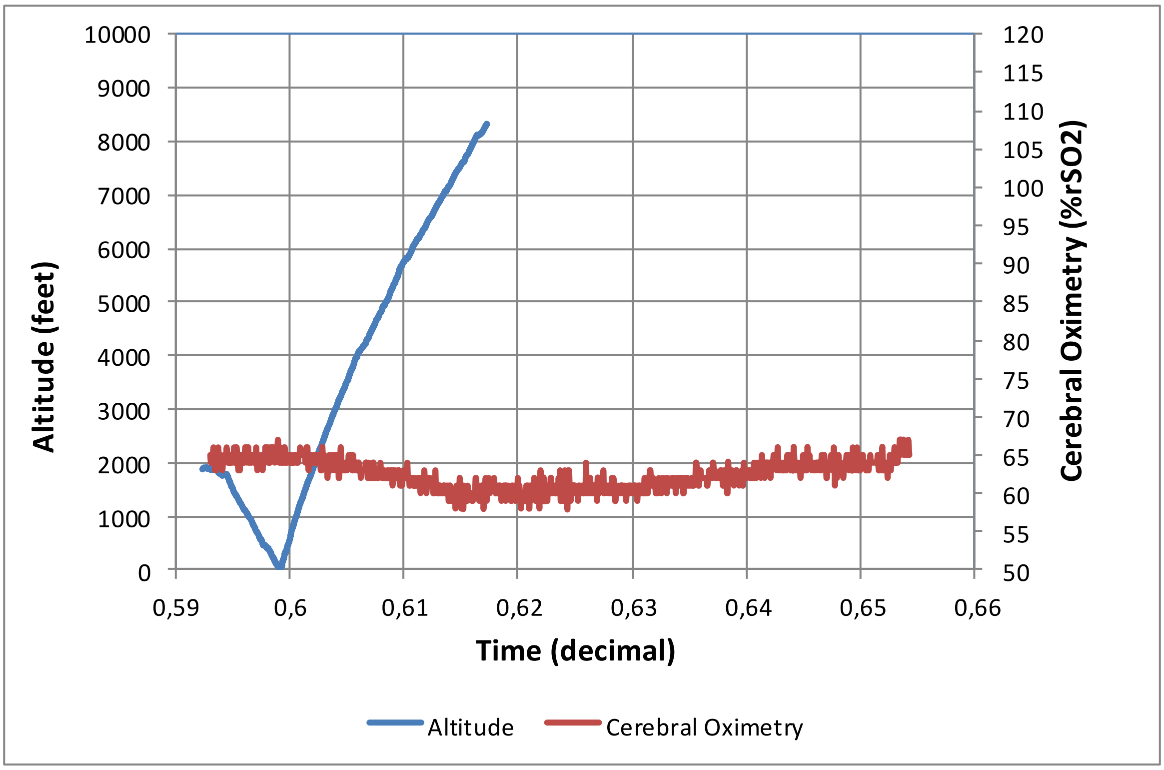
3.3.3 Real Flight Tests

Three real flight tests were realized. Two flights were performed in Viseu airfield, Portugal, by individuals 2 and 3. The other flight with individual 1 was realized between Tires airfield, in Cascais, Portugal, and Faro, in Algarve, also in Portugal.

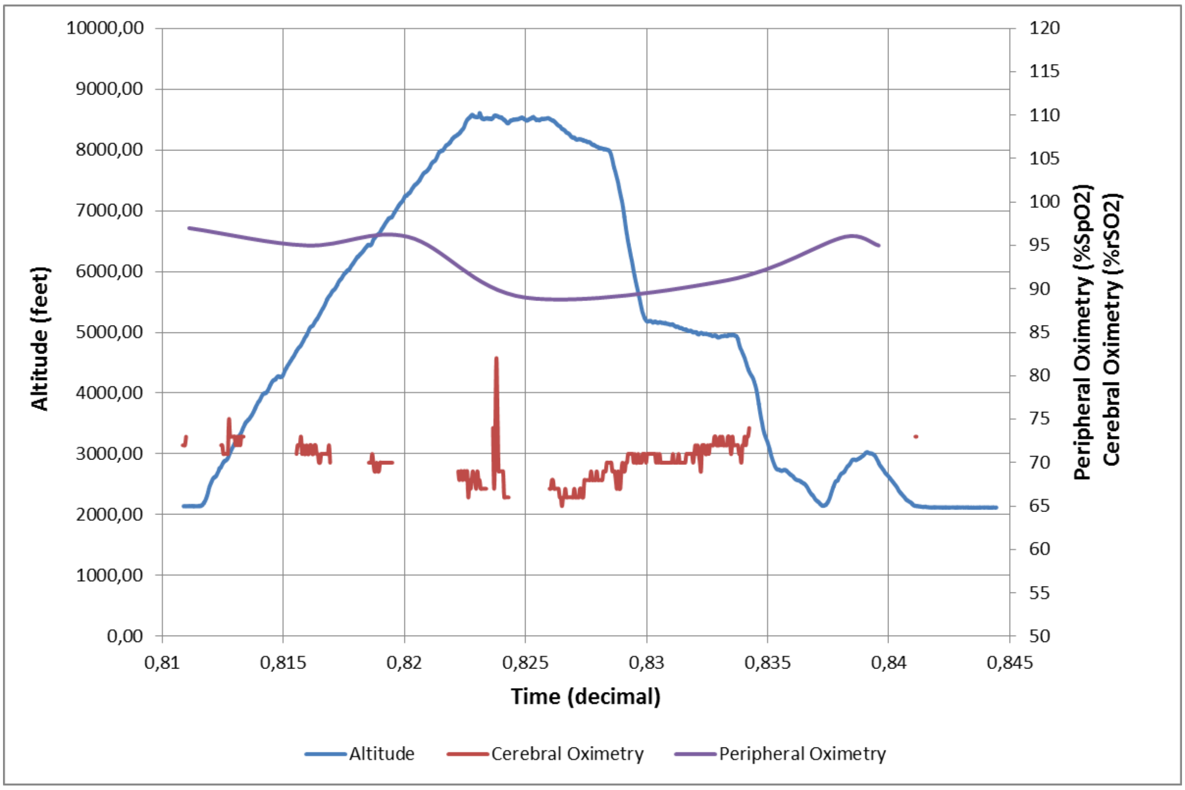
The table next is a summary of some important characteristics of each flight conducted.

Figure 13: Cessna FR172F Remis Rocket, aircraft used by individual 1.

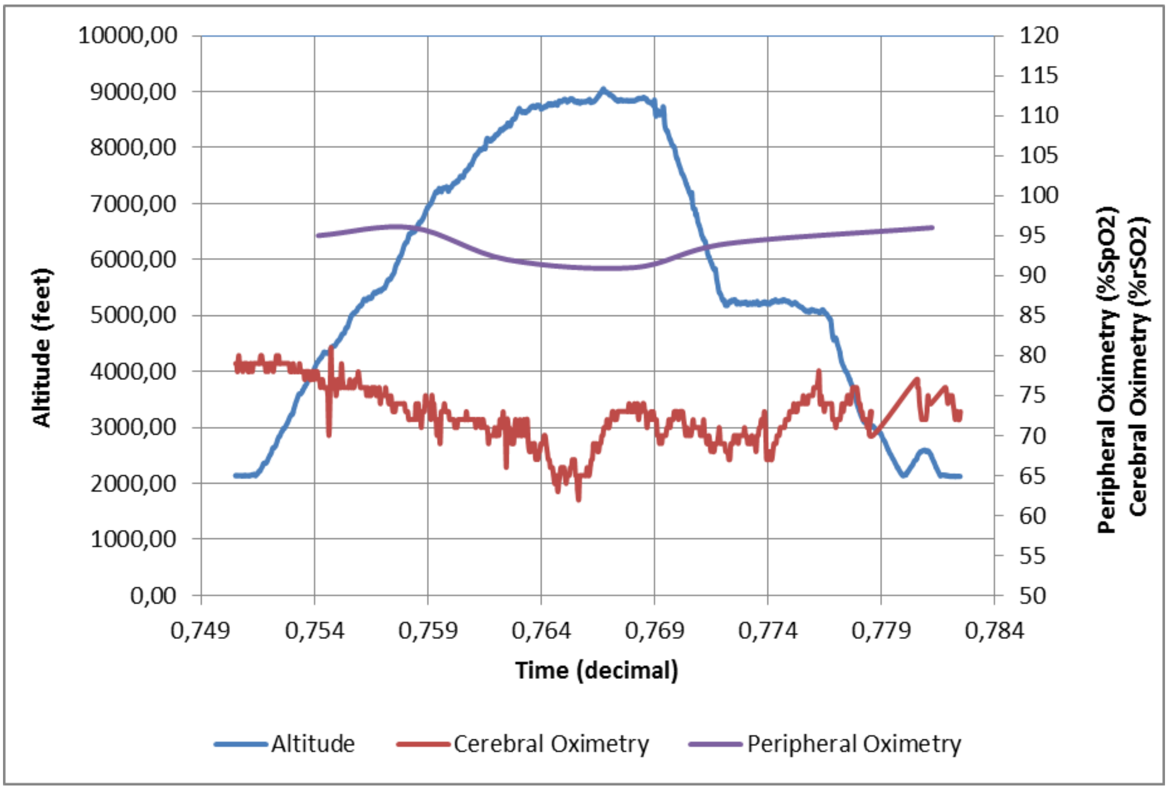
All equipment was placed aboard the aircraft (figure 1), which implied a cautious logistics. After synchronize all data, the following graphics were obtained.



Graphic 8: Altitude and rSO2 variation during real flight test for individual 1.



Graphic 9: Altitude, rSO2 and SpO2 variation during real flight test for individual 2.



Graphic 10: Altitude, rSO2 and SpO2 variation during real flight test for individual 3.

3.4 Conclusion

The experimental work consisted in combine all the equipment referred before on this chapter, to obtain several data from the flight and the pilot. Although the tests were done with various scenarios and different pilots all the data from the different equipment can be downloaded to a computer and processed to match the same timeline. Thus it is easier to visualize the physiological differences between when the pilot is at rest and when he is performing tasks.

Performing the tests in different scenarios and in a group of individuals with different characteristics we can realized by the data collected how relevant these differences are in flight safety.

4. Discussion

4.1 Introduction

The current chapter contains the analysis and discussion of the results presented in the previous chapter.

Following the same structure before the results in analysis are referred to the hypobaric chamber, flight simulator and real flight tests.

4.2 Experimental Work

"In the hypobaric chamber tests, was possible to observe that despite of the difference of age between both individuals, the eldest individual showed inferior levels of HR and a minor variation of the rSO2, when compared with a much younger individual. However, the eldest individual, individual 2, was a flight instructor with many hours of experience and many hypoxia trainings in hypobaric chamber. For the individual 1, the experimental test was his first time in the hypobaric chamber. These differences, in levels of experience and life habits, may be the main cause for the disparity of values between the subjects. Upon comparison of cerebral oximetry and HR with the altitude variation in both tests, was observed that, in the hypobaric chamber test, where the maximum reached altitude was 9,577.9 ft, the rSO2 and HR variation, between the minimum and maximum altitude, was 3% and 4%, and 14 bpm and 5 bpm, for individual 1 and individual 2, respectively. In the real flight tests, for the test 1, the rSO2 and HR variation, between the minimum and maximum altitude, was 2% and 3 bpm, for the test 2, was 2% and 2 bpm, for the test 3, was 1% and 5 bpm, and for the test 4, was 3% and 7 bpm, respectively. However, was also found that the minimum value of rSO2 and the maximum HR did not occur when the maximum altitude was reached, as expected. Such inconsistency does not have an apparent justification due to the scarce information available for this type of study, so, and only as a superfluous suggestion, these may be due to psychophysiological characteristics, such as concentration, attention, adrenaline, emotional condition or even the reaction time that the human body takes torespond to the external environment.

For individual 1, was possible to observe that the variation of the rSO2, between the maximum and the minimum altitude, was smaller during the real flight test (real flight test 4) than during the hypobaric chamber test. Although, besides the fact that the real flight was performed at a lower altitude, and so this smaller variation may be justified, according to what is generally known, the pilot wasn't at rest and his initial rSO2 mean value was, approximately, 3.5% higher when compared with the obtained values from the hypobaric chamber test. However, the HR variation was significantly higher for the real flight test.

For individual 2, it was possible to observe that the variation of the rSO2 and the HR values was smaller when he was at rest (hypobaric chamber) and at a higher altitude, than when he was performing tasks (real flight tests) but flying at a lower altitude. Although, in the real flight test 2, where the atmospheric conditions weren't the best, with strong wind, the pilot rSO2 and HR values oscillated expressively, not in the higher altitude moments, but when the aircraft wasn't stabilized due to the wind. In the real flight test 3, was found that in comparison with the hypobaric chamber test, where the simulated altitude was, approximately, 3,000 ft higher, the rSO2 and HR variation was more pronounced. Also, from the cerebral oximetry analysis for both individuals, regarding both tests, can be seen that they had different basis values of rSO2, which may happen due to the disparity of quotidian habits and physical characteristics; and that sporadic peak values occur, because, in both cases, the studied pilots weren't completely immobile and therefore, there was the susceptibility of poor contact with the cerebral oximetry sensors. Although, still, and in the near future, these data have to be carefully analysed by clinical experts in the determination of the existence or not of significant changes, that may constrain the psychophysiological capacity and, consequently, compromise the flight safety. In conclusion, the discussed results may show that the human body can be trained to adapt to different situations and that when under an unknown environment, the stress, arousal and adrenaline levels may compromise the initial rSO2 and HR values and the normal response to an external stimulus, increasing, psychologically, its intensity." [4]

4.3 Conclusion

"Generally, most of the respondent pilots considered that hypoxia education and training for unpressurized aircraft pilots isn't significant. Although, almost all the respondents affirmed to be willing to use a flight physiology monitoring system, in order to improve flight safety.

Could be found that factors as arousal, stress, fear and adrenaline, processed by our brain due to an uncontrolled and unpredictable environment, may be even more dangerous than a physical and logical factor like altitude, especially if the individual isn't aware of his physiological limits.

In short, it is general belief that this is an interesting and justified research that deserves the best attention, as also as an exhaustive research in the psychophysiological field, in order to understand the human behavior when an unpredictable and stressing situation is combined with oxygen deprivation." [4]

5. Conclusion

5.1 Dissertation Synthesis

“The practice of gliding and ultralight aviation in Portugal has been growing in the past few years and with it the responsibility to make this an activity even safer for those who fly and those who are in the ground. Simultaneously, it has been found that accidents and incidents, with no apparent mechanical causes, have also suffered an increment, and that some pilots after returning from their flights, reported having noticed in themselves, while performing the flights, euphoria, decreased reaction time, and inability to perform simple tasks. Therefore, these symptoms report a variation in the psychophysiological response compatible with the phenomenon of hypoxia that, in terms of flight safety, may represent a worrying situation.”

5.2 Final Considerations

“The Flight Physiology concept is taken into high consideration in the commercial and military aviation, but the competent authorities, in general aviation, have neglected it’s applicability to pilots who fly in unpressurized and unacclimatized aircraft cabins, namely, the glider, ultralight and light aircraft pilots. This is an even more serious problem once, today, the general sport aviation is a booming business throughout the world, and the regulatory frameworks of the different countries aren’t following this growth and are currently outdated of reality and its needs.”

5.3 Prospects for Future Work

Due to the current work and acquired knowledge and experience it’s believed that the next steps in this work should cross the following investigation lines:

- Validate the implementation, in the current system, of the EEG and EP;
- Combine the used monitoring systems with a live alert software, in order to warn the pilot when his limits are crossed, and so he can recall the safety procedures;
- Apply for a potential restriction to pilots licensing legislation of light aviation, within definitions of physiological limits.

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