https://doi.org/10.26552/ pas.Z.2022.2.11

UNIVERSITY OF ŽILINA

IMPACT OF FATIGUE ON PILOT REACTION TIME

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Abstract

The main goal of the diploma thesis is to analyze the impact of fatigue on the reaction time of the pilot, its possib;ilities of elimination and ways of solving the problem, which greatly affects safety in air transport. The measurements took place at different times, in the morning and in the afternoon, on the basis of which we will compare the length of the reaction time to visual stimuli affected by fatigue. We performed measurements for safety reasons on the L-410 simulator. The simulator is equipped with two cameras based on which we will analyze the length of the reaction time.

Keywords

pilot, central nervous system, psychological aspects, reaction time, fatigue.

1. INTRODUCTION

Air transport is currently at a very high level in terms of safety. To transport passengers or cargo safely to their final destination depends on many factors that together make up a very safe mode of transport. These factors are, for example, the sufficient technical condition of the aircraft, security checks when checking passengers who would tend to deliberately endanger the aircraft by their actions. Another factor is the ground crew and staff who control safety when moving on the ground or in the air. However, these are factors that can be observed with sufficient controls. The problem arises, however, in the decision-making of the pilots themselves in a critical situation, who do not have the time to, for example, check the work as they have done it, or, alternatively, to correct mistakes again. In such a situation, the aircraft is very uncompromising and perhaps one wrong decision will trigger a sequence of events where there is no possibility of preventing a disaster. If we compare this with, for example, an aircraft maintenance engineer, after the work has been done, someone else will come to check how he has done it. If the work is not done according to the regulations, the work may be done again or the aircraft may be completely grounded and not allowed to take off until the fault is corrected. If the mechanic is unable to fix something, another qualified professional or team will be called in for advice and given enough time to make a decision. There are most often two pilots in the cockpit, sometimes three, and they have a very short time to choose the solution they think is best at that moment. And it is fatigue that is responsible for many of the bad decisions that pilots have made that have had fatal consequences later on. Therefore, we would like to focus the thesis on this very important topic from a safety point of view and to highlight the negatives caused by the lack of sleep or excessive workload of the pilot at work or before it. Many young people underestimate the fatigue factor and try to compensate for a lack of sleep or rest with various caffeinated drinks or snacks that maintain attention and suppress fatigue, but only for a very short while. However, such a solution is inadequate from a number of points of view, especially in the pilot profession.

2. ANALYSIS OF THE CURRENT SITUATION

In the early days of aviation development, aircraft were primarily used for military purposes and therefore the development emphasized the combat effectiveness of the aircraft, which included range, speed, maneuverability, and firepower. The quality of pilot training and pilot comfort was not greatly addressed. After a number of mistakes made by pilots, an essential component in aviation, namely the human factor, began to develop. It included the overall behaviour of the pilot in the cockpit from a psychological and health point of view. Statistics show that it is the human factor that bears the largest share in aircraft accidents. The material things in the construction of an aircraft are constantly improving with new technology and aircraft are becoming safer and safer. However, these are parts of the aviation industry that undergo a lot of testing and are only put into service after certification. Should any of the technical parts of the aircraft fail, for this reason aircraft are designed so that the systems are redundant, meaning that another system will replace it if it fails and the aircraft will land safely. The human factor is a part of aviation that can be well trained, the crew has flown many hours and accumulated a lot of experience and still make a mistake in a critical situation. Pilots are also just people and not machines, and are affected by the environment such as stress and fatigue. Therefore, new methods of pilot training are continually being improved to ensure that the number of accidents caused by human factors is eliminated. Overall aviation safety is at a high level and the number of accidents has decreased. According to statistics from PlaneCrashinfo.com, the amount of accidents has had a downward curve from 1950 to 2018.

Air transport is gaining more and more demand and is developing. It is particularly advantageous for passengers because of its speed, comfort and safety. The ever-increasing passenger demand for air travel is forcing air carriers to buy more aircraft and provide more flights. There is a very simple direct proportionality, which, however, is causing a shortage of pilots on the market. Boeing can build an aircraft from imported parts in a few days while it takes about 2 years to train a pilot.

With this imbalance, pilots experience a lack of free time and have to spend more time at work. This was especially the case in Asian countries where there was a shortage of pilots and pilots were very busy, which caused some accidents such as Korean Air's Boeing 747-3B5 flight 801 or TransAsia's ATR 72-500 flight 222 when they were extremely busy without enough rest.

In 1986, Braune and Wickens conducted research on reaction time in pilots flying different types of aircraft. After analysing the results, they concluded that the biggest factor affecting reaction time was age. They concluded that after the age of 40, reaction time speed increased and spatial ability decreased in pilots. In 2002, Werner B. and team decided to verify this statement and therefore created a research study focusing on pilots with different ages, flying different types of aircraft and different number of hours flown. According to their conclusion, the initial claim of Braune and Wickens was confirmed and the main factor that influenced the reaction time of the pilots was their age. What type of aircraft the pilot was flying had no effect on his reaction time rate. The experience the pilot had accumulated over his career had a positive effect and reduced reaction time.

Michael Russo and team focused their research on how reaction time can be affected by fatigue. This research concluded that fatigue primarily affects a pilot's visual perception, and during night flights, the ability to respond to visual stimuli is reduced.

Marcela Jančo, who is a forensic expert in road transport, claims that reaction times are deteriorating significantly after 60 years. With increasing age, a person succumbs to fatigue earlier and the ability to react changes.

3. PSYCHOLOGICAL ASPECTS

The main control system in the human body is the nervous system, which allows it to receive information about changes in the internal or external environment of our body. The nervous system sorts this information, processes it and sends a signal that is fed to the major organs such as muscles or glands. The basic cell in the nervous system is a neuron, and the connection between two neurons is called a synapse. Thanks to the nervous system, which has already reached its highest development, we can, for example, perceive emotions, think abstractly or speak.

The basic parts of the nervous system are the brain and the spinal cord. The nervous system provides several functions in the human body. Most of the information that we get from the external environment is through vision and hearing and hence the transmission of information from external stimuli to the brain is obtained from the sensory organs. In addition to the main sense organs mentioned above, we can acquire information by touch or smell. These sense organs use sensitive nerve cells called receptors to transmit information. The brain weighs approximately 1.4 kg and makes up 97% of the entire nervous system. The second part of the nervous system is the spinal cord. The function of the spinal cord is to nervously connect the brain to other parts of the body. Another function provided by the nervous system using muscles is motor control.

The peripheral nervous system consists of a group of special cells that move the information received from the muscles and organs of the body back to the central nervous system via sensory nerves. Another role of this system is to transmit information from the central nervous system to the muscles and organs via motor nerves. In this transmission, it is not necessary for the brain to be involved at all times. This is for example in the reflexive movement of the hand or foot if something hits, burns or stings us. The principle applies that the fewer nerves directly involved in the execution of the action, the faster the reflex.

The autonomic nervous system provides internal control of organs such as glands, autonomic muscles of internal organs and blood vessels. Autonomic nerves connect the ions to the central nervous system. The autonomic nervous system controls all processes automatically and without our knowledge. These are, for example, breathing, sweating, body temperature, pressure in the arteries or processes and movements in the digestive system.

4. SENSORY ORGANS

Not only in aviation, but also in everyday life, sight and hearing can be considered the two most important sensory organs. With these two organs we obtain most information from the external environment. The sense organs allow us to recognise the space around us, to maintain our balance, to smell different aromas, to recognise tastes, etc. Pilots have to undergo annual medical examinations by classified aviation doctors who check whether these sensory organs meet the minimum requirements for pilots. For some deficiencies, an exemption may be granted to the pilot, such as impaired vision due to increasing age, and the pilot is therefore required to wear goggles. However, there is also a condition attached to this whereby a pilot wearing goggles is required to carry a spare pair on board the aircraft.

We use the eye to visually project the space around us. Through this organ we perceive approximately 80% of information. It serves us to perceive and recognize light, colors, shapes of objects. The eye receives electromagnetic waves from the external environment in the visual spectrum and then sends these signals to the brain where we form an image.

When viewing an object that is in motion, it is important that both eyes are aligned together, so the brain controls the eye muscles to ensure that the signals received are the same. With fatigue, this coordination fails and double vision occurs, due to two different signals being received.

The ear performs several functions in the human body. One is the perception of sound, i.e. the reception of vibrations from the air, where we can detect tones, loudness, the direction from which the sound is coming, the pitch of the tone or the intensity of the sound. Sound waves are the impulse for hearing. A sound wave is made up of the longitudinal oscillation of air molecules. The human ear can hear tones from a frequency of 16 Hz to about 20 kHz. The second function it performs is providing balance and detecting acceleration. Pilots use this organ to perceive acoustic stimuli in normal flight, such as in a piston-powered aircraft to listen for the correctness of engine operation or then for safety systems to warn them. They use the function of the ear in terms of balance to orient themselves in space.

Humans have fairly well developed olfactory receptors. We can detect quite a lot of smells and odours, but compared to other mammals, rodents, for example, are better off than humans. But dogs have the best sense of smell. Compared to humans, their receptors are concentrated on one particular smell and its

intensity. The reason why some mammals have a better sense of smell is because of the difference in the size of the mucosal surface. Humans have a very small surface, dogs have the largest.

The input sensory organ is the skin, where the sensory cells are located, which are all over the body. Sensory cells can be divided into several types that perform different functions. With the help of sensory cells we perceive heat, cold, pressure touch or pain.

The human body was not adapted to move through the air in three-dimensional space, but only on the ground in two-dimensional space. After advances in technology and inventions in the field of aviation, man could move in the air. However, for this he needed a machine in which there was a need for a certain harmony between the crew and the aircraft. To make everything work properly, psychologist Elwyn Edwards devised a model in 1972 that described the relationship between man and machine. The name of this model was derived from the first letters of the words of which it is composed and therefore with which the human being forms some kind of relationship in the cockpit of the aircraft.

S = Software - software (computer systems, procedures, manuals)

H = Hardware - machine (cockpit instrument layout, aircraft design, controls)

E = Enviroment - environment (temperature, humidity in the cabin, weather on the flight path)

L = Liveware - human (pilot or other person with whom the pilot comes into contact, e.g. air traffic controller)

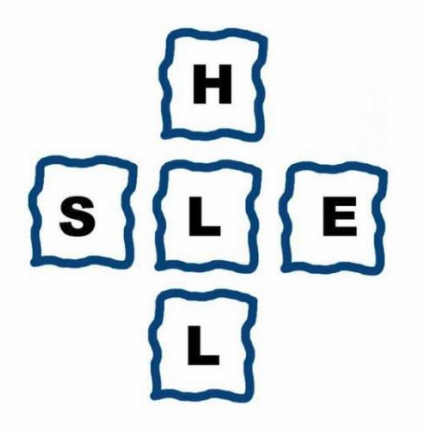


Figure 1 Model Shell

The edges of the individual parts of this model are deliberately irregular, but they must fit together so that if one part fails or fails, it will be able to interlock with other parts and thus not compromise the safety of flight. This is due to factors that affect this such as stress or other potential failure.

Before a person makes a decision, the body goes through a process that begins with a stimulus, i.e., information received that is influenced by attention and perception. Only then do we make either a right or wrong decision. Feedback then occurs, whether in the form of self-control or the reaction of, for example, an aircraft to the instructions we have given.

With aircrew, it is important to make the right decision over a long period of time rather than making a hasty decision without thinking about the consequences. For this reason, each pilot's reaction time is different. The correctness and speed of the decision is primarily influenced by the knowledge and experience of the pilot. The pilot acquires this information by memorising theoretical information about the aircraft and its behaviour in the atmosphere. Another factor that positively influences the amount of information acquired is the number of hours flown. Stress also has a major influence on pilots' decision making. If a crisis situation occurs during a flight, the aircraft should alert the pilot to the error. These indications are divided into visual and acoustic. The most dangerous situations or malfunctions inform the pilot by a combination of both indications.

Stress is a negative situation - a feeling of pressure, tension and negative emotions. From a psychological point of view, stress occurs when a person feels that his or her abilities are not sufficient to perform a desired activity. It has several components and therefore we need to distinguish between stressors and reactions to stress (Ayers, de Visser, 2011). Stress can be caused not only by the current critical situation in the cockpit but also in private life. Stress in combination with fatigue represents a potential risk and is closely related. For the more tired a person is, the more his potential stress and irritability increases.

Stress is beneficial to a person to a certain extent. As the stress load increases, so does our concentration and focus. Optimal performance is at the top of this curve. However, if stress continues to rise and exceeds the optimum, the body is unable to cope with the stress and we slip into anxiety, then into complete helplessness, where we are unable to cope and resolve the situation.

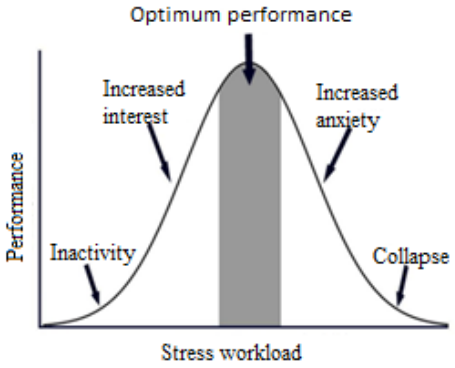


Figure 2 Stress curve

In order to improve safety, aircraft designers are also trying to apply modern technology directly into the cockpit. Air transport is modernising and advancing very rapidly. In the beginning, when airplanes were designed, they were primarily created for military purposes. Because of this, the quality of the aircraft was mainly focused on the combat effectiveness of the aircraft and the welfare of the pilot went by the wayside. Pilots therefore did not feel comfortable, the cockpit was cold or had hard seats and these factors consequently influenced the pilots' decisions. In the past, pilots in particular did not spend long hours in the cockpit as is currently the case for long-haul flights.

Analog instruments are slowly being replaced by modern LCD displays in aircraft cockpits. For new student pilots, this type of instrumentation and its operation is easier than it may be for old pilots who have been piloting airplanes with only analog instruments for three decades.

5. THE EFFECT OF FATIGUE ON THE PILOT

Pilot attention affected by fatigue can be fatal, especially in small one-man crews. With the amount of activities a pilot has to attend to during a flight, it is very difficult to concentrate one hundred percent on all tasks. His reactions are slower and there is therefore a risk of either being diverted from the correct course when his attention is diverted, for example, or focusing his attention purposefully on one particular activity, for example, steering the aircraft correctly on course, while the oil temperature instrument, for example, is soaring.

Piloting large transport aircraft over long distances is a monotonous activity after take-off and when the autopilot is engaged. Flying for five hours, for example, and only checking the instruments is exhausting for pilots. Fatigue can be divided into mental and physical fatigue. Mental is caused by the monotony of the flight and physical is caused by prolonged sitting when some parts of the body are not well blooded. In smaller general aviation aircraft, fatigue is caused by the exhaustion of a long flight when the pilot has to manually control the aircraft while still checking the heading, comparing the approximate location with the chart, communicating with air traffic control, recording the times when passing the turn point and then calculating the approximate time of arrival at the next turn point.

Short-term fatigue is a state of exhaustion caused by insufficient rest. It occurs when sleep is short, the body is taxed by strenuous exertion, a long work shift or when flying through several time zones. Short-term fatigue is quite easy to detect and easy to eliminate. All a pilot needs to do is rest and sleep well for a few days.

Long-term fatigue is a type of fatigue is harder to recognize. The pilot is also negatively affected by situations that do not only happen at work, i.e. during flight planning or the actual execution of the flight, but long-term fatigue can be caused by long-term exposure to stress, such as problems at home, in a marriage, health problems of a loved one or financial problems. With this type of fatigue, it depends on the personality of each individual individually, because someone can withstand such situations for much longer than a person who is very sensitive. If a pilot suffers from long-term fatigue, he should stop flying for some time.

The feeling of fatigue should be detected and evaluated by the pilot in the first place and it is best to cancel the flight completely if this condition is felt before the flight. Unfortunately, we are in a time when pilots are afraid of sanctions and subsequent termination of employment and therefore prefer to board the aircraft tired and hope that fatigue will not adversely affect the safety of the flight. In pilot training, in turn, students are afraid to tell instructors that they will not fly in the morning if they are not sufficiently rested and sleepy due to social activities the night before. The feeling of fatigue manifests itself in various ways, namely: lack of attention, impaired motor skills, narrowed eyes, head dropping, impaired focus, slower reactions, memory problems, sudden mood changes, an increase in errors while piloting, or tunnel concentration - paying attention to only one problem and not noticing others.

Sleep is a basic physiological need of humans. When there is insufficient rest and sleep, this deficiency begins to affect the human body through stress, nervousness, anxiety, poor memory, impaired concentration, slowed metabolism, or a weakening of the entire immune system. From this point of view, it is important to have a good quality sleep so that we can work, react or make decisions the next day without any feelings that could interfere with these activities.

In a profession such as being an airline pilot, it can be very challenging at first to get used to the variable working hours and especially the rest time between flights. If a pilot takes a night flight he comes to his room in the morning and goes to sleep. This changes his biological rhythm. The human body is a diurnal mammal and therefore our bodies are set up so that we should be asleep at night and awake during the day, which is why some pilots may have trouble falling asleep even when they are tired.

External factors that cause sleep problems are such as taking medications, noise from outside or surrounding rooms, phone calls, electromagnetic appliances near the body, or the negative feeling of a temporary apartment room.

Air transport is unique and the most widely used, mainly because of the fast transportation of passengers or cargo over long distances. The longest flights pass through several time zones which can cause sleep problems for the crew and consequently health problems with stomach disorders called jet lag or circadian dysrhythmia. Flying eastward makes acclimatisation and adjustment to the current local time worse. This effect is mainly related to the production of melatonin, which is produced in the brain during the night and then gives us information about when we should go to sleep.

Determining the cause of a civil aircraft accident is very important for the analysis of accidents from a safety point of view, on the basis of which new regulations, guidelines and recommendations are established to prevent similar accidents in the future.

Caffeine is a xanthine alkaloid that is found in commonly available plants such as coffee and cocoa beans, tea leaves, kola nuts or in guarana berries. Caffeine can be called a drug that is not only allowed in air travel but also in other modes of transport. It is mainly used in the form of liquid products for consumption, such as coffee or energy drinks, which are popular all over the world, but it also finds use in pharmaceuticals. Caffeine specifically stimulates adenosine receptors in nervous tissues and the brain. This achieves a state of alertness and activity. Adenosine is a substance found in the human body that regulates the brain activity of wakefulness and sleep.

Caffeine intake does not have a negative effect on a healthy human body, just the opposite is true and according to recent studies caffeine has a positive effect on the human body when consumed in smaller amounts. For more caffeine-sensitive individuals, there is a risk if the daily dose exceeds 300 mg. According to medical studies and research, caffeine causes a risk of minor heart attacks in these people. Younger people or people who are not used to ingesting larger amounts of caffeine

may experience short-term behavioural changes such as irritability, anger, nervousness, anxiety or excessive activity.

The right amount of caffeine ingested into the human body has a positive effect that improves the alertness, mind and coordination of the body. It is approximately 100-600 mg of caffeine. However, there is a risk where even a small amount of caffeine can affect even a healthy body's fine motor skills or concentration. When ingested in excess, caffeine causes insomnia, rapid breathing or induces shivering. With regular intake of this substance, the body builds up a tolerance to the negative effects. Caffeine also exacerbates the release of adrenaline and cortisol, causing blood pressure to rise and the heart to beat faster. It causes a feeling of need to urinate, relaxes the bronchial tubes, speeds up metabolism and increases the production of digestive juices.

Energy drinks are a recent trend, especially among young people, and form an almost daily part of their lives. We can already see these drinks in primary school children, where it can have the greatest negative impact on their attention and behaviour. They are also being used in motoring by drivers who are tired when driving for long periods of time. The two main substances that make up these drinks are sugar and caffeine. Sugar is supposed to provide energy and caffeine to suppress fatigue. A normal 250ml can of an energy drink such as Redbull contains 80mg of caffeine, that's the equivalent of almost two coffees, which suggests that there is not much risk in consuming one can. The problem can arise if more than one can is consumed in a short period of time or when combined with alcohol. Excessive consumption can cause insomnia, contribute to obesity caused by the high sugar content of unhealthy lifestyles and low levels of exercise, depression, cardiac arrhythmia or the increase in blood pressure caused by the substances taurine, guarana, various plant extracts or B vitamins that are added to energy drinks.

6. REACTION TIME

There is a period of time from when the pilot notices the stimulus, recognizes it, to when he performs an action. But reaction time can be affected in terms of not only how quickly the pilot executes his decision but whether he executes it correctly. The reaction time may therefore be longer before the pilot recognises the impulse and then makes a decision, which he must first think about and also consider the consequences it may cause.

Attention is the ability of a person to focus on one or more events or objects at the same time. The role of attention is to send only a certain amount of information to consciousness. It has a protective function, so that the brain is not overwhelmed by a lot of information, but concentrates only on the significant ones. We can divide it into active, which is purposely focused on an object, and passive, which draws our attention.

We divide the factors that influence attention either positively or negatively into external and internal. External factors include those that pull our unintentional attention such as: stimulus length, size, strength, non-anticipation of the stimulus, and so on. Internal factors include the overall mental and physical state, i.e., mood, interests, expectations, and so on.

Selective attention is a type of attention in which a person tries to focus on one particular action or object. With this type, there is an advantage that the pilot would be able to fully devote himself to one task. He does not perceive the other information that is happening in his surroundings so he loses track of the things and events that are happening in his surroundings. Selective attention is therefore not used in the aircraft, but on the contrary, it can cause a dangerous situation. Such attention occurs when the pilot concentrates on one activity, for example, steering the aircraft on the correct course according to the instruments, but does not perceive what is happening around the aircraft or on the instruments on the dashboard.

Pilots use this type of attention to pilot the aircraft correctly and safely. It is attention that is divided over several events or objects at the same time. During flight, the pilot receives a great deal of information from different quarters, which he must process and evaluate. Although full concentration on one particular action or object decreases with diffuse attention, it is essential for the pilot. An example of diffuse attention is flight, where the pilot manually controls the aircraft while having to communicate with air traffic control, adjust and check instruments, record time data, and much more. If he gets stuck at some point and goes into selective attention where all his attention is only on that problem, there is a problem with other events such as deviation from the correct course, altitude change, etc.

A type of remembering information and storing it in long-term memory is intended for later use of that information. Storing or encoding information is forever, but sometimes there may be a problem with recalling it due to prolonged unusability. Therefore, information should be continuously refreshed and recalled. If we refresh it regularly, we will remember it more quickly. Information is better and more quickly stored in our memory if it has some connection to information we have already acquired, or if we can make that connection, for example with foreign words that are harder to remember.

Civilian aircraft are predominantly piloted by a crew of two, i.e. a commander and a co-pilot. Before the flight, they determine which pilot will be the flying pilot and the other will be the monitoring pilot and will also communicate with the air traffic controller. Therefore, in order to improve the safety of air travel, NASA devised a concept in 1979 to help reduce the accident rate of transport aircraft. They called this concept CRM - Crew Resource Management. It is the precise division of cockpit activities between pilots, mutual cooperation and control. Currently, there is a lot of emphasis on this type of crew training. If a pilot shows signs of fatigue, with this model the co-crew member could be able to detect pilot fatigue, for example by long response reactions.

7. RESEARCH METHODOLOGY

The aim of the practical part of the thesis is to find out how much fatigue can affect the reaction time to visual cues from the instruments on the cockpit dashboard. From a safety and financial point of view, it is not possible to perform these experimental flights in a real aircraft, but only on the cockpit simulator of a Flight L-410 Turbojet.

The measurements were carried out on the L-410 UVP-E20 simulator operated by the Training and Education Centre of the University of Žilina in Žilina at the airport in Dolný Hričov. The

simulator has a fully controllable glass cockpit for a two-person crew and a control centre for simulating various situations, through which we will change the visual cues to the pilots. The simulator is an exact replica of the real cockpit of the Flight L-410 UVP Turbolet and therefore in 1:1 scale. The simulator has a simulation of two turboprop engines, their control with the possibility of reverse thrust. This simulator is certified and complies with all EASA regulations applicable in the Slovak Republic.

A total of 8 pilots with varying numbers of flight hours participated in the measurement. All of them are students in training. Most of them have already graduated by instrument flying. They have flown between 95 and 210 flight hours. The age range is from 21 to 26 years old. It is important to note, however, that none of the pilots have an official rating or professional training in that type of aircraft.

TABLE I. INFORMATION ABOUT TESTED PILOTS

Pilot	Age	Number of hours flown
1.	23	170
2.	23	175
3.	22	170
4.	21	210
5.	26	95
6.	25	215
7.	24	100
8.	25	200

After informing the test pilots prior to the flight, it was agreed that if they detected any visual warning or instrumentation change on the dashboard, they would point the finger at the fault. This agreement facilitates the subsequent analysis of the videos from the two cameras located in the simulator. These cameras are located at the top of the cockpit and facing each other. One records the general movement and behavior of the pilots and the other is pointed at the entire instrument panel. These cameras do not have an audio recorder. Therefore, a method of finger pointing to a given instrument or alert has been agreed with the pilots.

The video will be analysed in the Sony Vegas computer program, which will provide us with a timeline below the visual preview of the video, which can be used to accurately determine the length of the reaction time. The video will be easily comparable to the timeline as the program can accurately compare the video frames to the timeline. The second method was used directly during the conduct of the research in question by using stopwatch measurements, but after subsequent analysis of the data, this method was judged to be insufficient.

We selected indications for visual cues from different parts of the dashboard to gauge the test pilot's attention and insight. We first illuminated the pilot with the battery overheating indication. This indication is located on the left side of the instrument panel, is lit red, and consists of a pair of rectangular indicator lights. Second, we illuminated the pilots with the right engine low oil pressure indication, which glows amber and is located in the upper right portion of the instrument panel. Third, we deactivated the left engine torque needle indicator, which manifested itself by the needle in the instrument dropping to zero or showing no value. The detailed layout is shown in the following figure.

Figure 3 Cockpit

8. RESULTS

The first measurement was taken in the morning, at approximately 8:30. The pilots tried one short flight around the circuit to get familiar with the simulator controls. Then their reaction time measurements started. Pilots 6 and 7 had slept for 5 hours and the others stated that they had slept for approximately 8 hours. According to the measured values, we can see that the pilots had the biggest problem in the morning to detect the problem of the needle instrument indication, or they did not pay attention to the needle instruments at all.

TABLE II. MEASURED TIME IN THE MORNING

Pilot	Overheating of batteries [s]	Decrease in pressure [s]	Torque [s]	Length of sleep [h]
1.	0:19	0:02	0:04	8
2.	1:32	0:23	0:05	8
3.	0:03	0:06	0:04	8
4.	0:04	0:01	0:02	8
5.	0:05	0:06	0:04	8
6.	0:02	0:02	0:04	5
7.	0:03	0:45	1:14	5
8.	0:10	0:18	0:56	8

The second measurement was carried out in the afternoon when the pilots were fed after lunch.

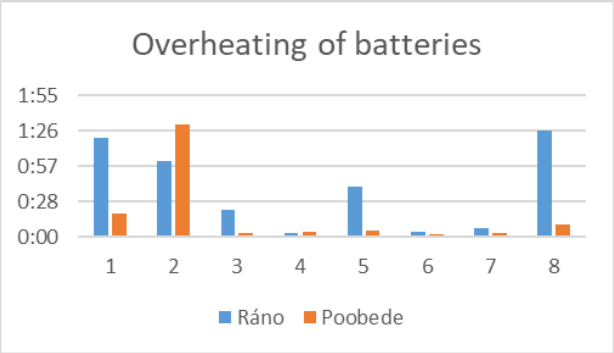
TABLE III. MEASURED TIME IN THE AFTERNOON

Pilot	Overheating of batteries [s]	Decrease in pressure [s]	Torque [s]	Length of sleep [h]
1.	1:21	0:02	1:11	8
2.	0:02	0:35	1:44	8
3.	0:22	1:34	2:19	8
4.	0:03	0:17	0:22	8
5.	0:41	0:02	0:04	8
6.	0:04	0:03	0:03	5
7.	0:07	0:10	2:42	5
8.	1:27	0:02	2:35	8

Comparison of the results shows that in the second measurement, although the pilots may have been more fatigued, their reaction time was more consistent and faster, especially when checking the needle instruments. Another possibility is that the pilots may even have been more tired in the morning than in the afternoon, which is due to the body not being sufficiently awake from sleep, and this is what prolonged their reaction time. Ignorance of the instruments and poor cockpit orientation had a big influence on the measurements. On the second measurement the pilots knew what to expect and this may have been what helped them to reduce their reaction time so much on some indications compared to the first measurement.

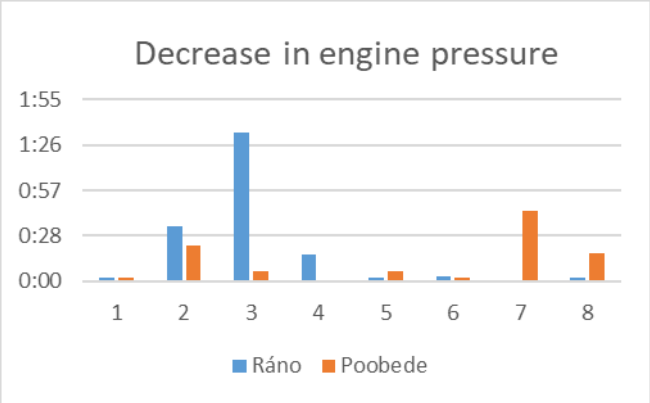
During the measurements we also noticed one shortcoming that the pilot made and that was that the pilot did not detect the wrong values of the given indicator even after visual checking.Perhaps this reaction of the pilot was also caused by fatigue, when the pilot checked the instruments by just looking at them, but did not think about them at all. Alternatively, other factors associated with fatigue, as mentioned in the theory (tunnel vision, distraction, etc.), may have contributed to his error rate.

Each of the simulated errors was specific. The first one was red and in the pilot's field of view, so it should have caught his attention earlier. However, according to the following graph, we can analyse that the simulated fault that had an orange indication attracted the pilots' attention faster, even though it was out of their field of view. The high values for the simulated battery overheating fault in the morning hours are due to the fact that pilots are not used to this kind of fault and therefore did not even notice the red-light indication.



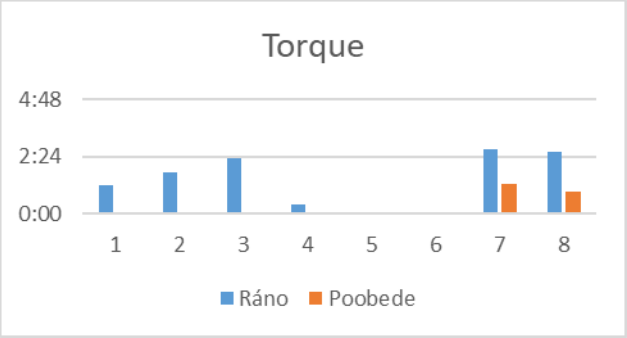
Graph 1. Overheating of batteries

The error that was associated with the amber warning light caught the attention of the pilots the fastest, which is why we can see such fast reaction times on the graph for almost all of the pilots tested. Pilots 7 and 8 may have started to experience tunnel vision in the afternoon, which is caused by fatigue.



Graph 2. Decrease in engine pressure

Thus, the attention reaction time graph for a malfunction where the pilot received no colour alert lasted considerably longer. Unlike the previous indications, no colour is used and therefore it is more difficult for pilots to get their attention. However, the pilot should continuously check all the instruments and the readings on their indications so that his attention is evenly distributed. In this case in particular, the pilots' reaction time was longer compared to previous errors, which may cause considerable problems in the future. Therefore, pilots should focus on the correct distribution of attention and regularly monitor all instruments.



Graph 3. Torque

The combination of inadequate training with fatigue can result in excessively long reaction times, which in some cases can lead to tragic consequences.

9. CONCLUSION

In the thesis we tried to find out to what extent fatigue can affect the reaction time of a pilot. It all depended on attention, which is what fatigue affects the most.

In the beginning, we focused on the current situation in terms of aviation safety, where we analyzed the decreasing accident rate caused by pilot error. We also analysed research by other experts on the same topic. They concluded that reaction time speed increases approximately and spatial orientation decreases after the age of 40.

In the chapter on psychological aspects, the human nervous system is described, which is the control system of the entire organism of the human calf and thus transfers stimuli received from the external environment by means of the sensory organs to the brain. From this point of view the different sense organs

are explained in detail. Sensory organs like sight and hearing are indispensable for piloting a transport aircraft and therefore pilots must be in hundred percent health both physically and mentally. In order to make the harmony work between the human factors with each other and with the machine, which in our case is the aircraft, the SHELL model was invented and put into practice. The decision-making process is influenced by various factors such as attention, stress, knowledge, experience or, for example, increasing age. In this chapter we have tried to summarize the whole process of decision making, from the initial impulse the pilot receives to some of his reactions, whether right or wrong. Cockpit ergonomics is developing and moving forward very rapidly in the aviation industry. Outdated instrument panels with analog instrumentation are slowly disappearing and being replaced by modern electronic screens. Pilots must therefore adapt to these changes and undergo new training on these new systems on board transport aircraft.

Fatigue is one of the factors that negatively affects air transport safety, especially for pilots. For this reason we have chosen this topic, which some pilots underestimate and overestimate their strength. If a pilot is tired and makes a bad decision in the simulator, nothing will happen to anyone, he will only be warned and he will be careful the second time, but if he makes a mistake during the flight when he is in a single-pilot aircraft, i.e. alone, it can have fatal consequences. He may harm not only himself and possibly some passengers he has on board, but also the people on the ground. Quality sleep or sufficient rest is essential. The pilot should enter the cockpit of the aircraft for the intended flight rested. Fatigue is a feeling of exhaustion and lack of rest that is difficult to detect by another person if they have only interacted with the pilot for a short time. He or she would have to spend more time with him or her and notice a yawn, subtly impaired body motor skills, or reduced attention when communicating together, for example. Caffeine provides a supportive substance that has the ability to suppress the feeling of fatigue and provide energy for a certain period of time. Its positive and negative effects are discussed in the next section of the thesis. The analysis and investigation of fatal accidents where pilot fatigue was part of the cause of the accident is important to prevent similar disasters in the future. In this thesis we have mentioned 3 transport aircraft accidents. Legal regulations are also broken down, giving the exact maximum time a pilot can spend at work, or the minimum amount of rest a pilot must take.

In the fourth chapter we have broken down information about reaction time and the difference between short-term and long-term memory. Also important is the cooperation between pilots and the exact division of the tasks to be performed so that there is no chaos between pilots. This cooperation between pilots is called CRM.

The measurements were carried out on a Flight L-410 Turbolet simulator from a safety point of view. During the measurements and their evaluation we came to the conclusion that creating conditions like in a real aircraft and then measuring the reaction time affected by fatigue is not as easy as it may seem at the beginning. This was influenced by factors such as the pilot's not being very familiar with the aircraft itself and the cockpit indications, the limited time for the research between 8 am and 4 pm. It is at night that fatigue affects pilots' attention and reaction time the most. Also, the pilots were not as tired in a few hours in the simulator as they would have been if they had been piloting the aircraft for, say, six hours, but even the repeated indication of a given error reduced their reaction time quite a lot, as they knew what was coming and were not caught off guard and surprised as they would be during a normal flight when it might occur.

As a recommendation, we would therefore suggest that pilots get sufficient rest and thorough preparation before the planned flight and do not overestimate their strength. In particular, a good quality and especially regular pilot training, where pilots regularly repeat and practice their knowledge and experience, has a positive effect on reaction time and decision making.

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