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FACULTY OF AIR NAVIGATION, ELECTRONICS AND TELECOMMUNICATIONS
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(EXPLANATORY NOTES)

FOR THE DEGREE OF MASTER

SPECIALITY 173 'AVIONICS'

Theme:**'Spectra of autocorrelation functions of aircraft flight parameters during landing approaches'**

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ABSTRACT

Explanatory notes to qualification paper ‘Spectra of autocorrelation functions of aircraft flight parameters during landing approaches’ contained __ pages, __ figures, _ graph, __ references.

Keywords: AIRCRAFT, HUMAN FACTOR, ERROR, ERGONOMICS, PSYCHOPHYSIOLOGICAL PRESSURE, FLIGHT SAFETY, AUTOCORRELATION FUNCTIONS, SPECTRUM, WARNING SYSTEM, COGNITIVE LOAD.

The object of the research - the process of studying the use of spectra of autocorrelation functions of aircraft flight parameters during the landing approach

The subject of the research - spectra of autocorrelation functions derived from aircraft flight parameters observed during landing approaches.

Purpose of qualification work – studying the occurrence of the phenomenon of psychophysiological load of the pilot during the landing approach by calculating the spectra of autocorrelation functions.

Research Method –employs a multidisciplinary approach, integrating theories from statistics and information theory. It utilizes the method of expert judgment to interpret findings and comparative analysis to contextualize results within existing knowledge. This comprehensive methodology ensures a robust analysis of the autocorrelation function spectra.

Scientific novelty –proposes novel recommendations aimed at mitigating the adverse effects of human factors during the approach phase of flight. These recommendations are grounded in the application of autocorrelation function spectra calculations, offering a new perspective in understanding and managing pilot stress and workload during critical flight operations.

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5.2.2 Protection against electric shock.................**Error! Bookmark not defined.**

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LIST OF ABBREVIATIONS

ACF – Autocorrelation Function

AFCS– Automatic Flight Control System

AI – Artificial Intelligence

ATC – Air Traffic Controller

AWOS – Automatic Weather Avoidance System

EFB – Electronic Flight Bag

EGPWS – Enhanced Ground Proximity Warning System

FAA - Federal Aviation Administration

HF – Human Factor

HRV – Heart Rate Variability

ICAO – International Civil Aviation Organization

ILS – Instrument Landing System

PNS – Parasympathetic Nervous System

PPE – Personal Protective Equipment

SID – Standard Instrument Departure Route

SNS – Sympathetic Nervous System

TCAS – Traffic alert and Collision Avoidance System

INTRODUCTION

Actuality. Human error is a predominant factor in the majority of aviation accidents and incidents. Statistical analysis of recent aviation accident and incident data indicates that human factors frequently contribute to these occurrences. The integration of human and machine processes is fundamental in mitigating the likelihood of such incidents.

The landing approach phase is particularly critical in flight operations. It demands high levels of pilot concentration and involves the consideration of numerous factors, including meteorological conditions, air traffic, aircraft's technical status, and instrument readings. Effective management of these factors is crucial for safe aircraft operation during this phase.

Addressing human-machine interaction challenges during landing approaches is essential for reducing aviation incidents. A comprehensive study of the autocorrelation functions of aircraft flight parameters during this phase can provide valuable insights into the dynamics at play. By analyzing these functions, patterns and correlations in flight parameters that potentially impact pilot decision-making and flight safety can be revealed.

Autocorrelation functions offer a systematic approach to examining the interplay among various flight parameters, such as velocity, pitch, and altitude. Understanding these relationships is key to developing strategies for enhancing flight safety and operational efficiency during landing approaches.

Therefore, the research on "Spectra of Autocorrelation Functions of Aircraft Flight Parameters during Landing Approaches" is vital for advancing aviation safety and optimizing flight operations. This study aims to propose methods for minimizing the influence of the human factor on piloting quality and enhancing the effectiveness of pilot decision-making in critical situations. Utilizing the data derived from the analysis of flight parameters, analyzed through autocorrelation functions, is a strategic approach. Integrating this data into pilot warning systems for avionics malfunctions can significantly aid pilots in managing stress and focusing on resolving avionics issues, thereby contributing to safer and more efficient flight operations.

Purpose of the work - studying the occurrence of the phenomenon of psychophysiological load of the pilot during the landing approach by calculating the spectra of autocorrelation functions.

Following tasks should be done to achieve this purpose, the:

1. Review existing literature on human factors and their impact on aviation safety.
2. Investigate common issues related to human factors in pilot operations and their root causes.
3. Assess current methodologies for evaluating pilot cognitive load during landing.
4. Develop recommendations for assessing the influence of human factors on flight using autocorrelation function spectra analysis.

The object of the research - the process of studying the use of spectra of autocorrelation functions of aircraft flight parameters during the landing approach
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Scientific novelty –proposes novel recommendations aimed at mitigating the adverse effects of human factors during the approach phase of flight. These recommendations are grounded in the application of autocorrelation function spectra calculations, offering a new perspective in understanding and managing pilot stress and workload during critical flight operations.

Validation of obtain results was wrote in the following articles:

Influence of the pilot's psychophysiological pressure on the quality of the flight piloting technique / Y. Hryshchenko, T. Pinchuk, V. Romanenko, O. Slobodian. *Electronics and control systems*. 2022. Vol. 3, no. 73. P. 65–73.

CHAPTER 1

GENERAL INFORMATION ABOUT HUMAN ERRORS DURING LANDING APPROACH

1.1 Basic concepts of human factor impact on aviation

For many years, one of the fundamental issues in the aviation sector has been flight safety and the development of all possible methods to eliminate errors that may occur during a flight, including human error. The growth of technology, a large number of scientific studies and a thorough analysis of previous aviation incidents have helped experts develop a number of innovative approaches to eliminating many errors at various stages of aircraft preparation for flight. Nevertheless, the human factor remains one of the most complex and unpredictable phenomena in the aviation.

According to statistics from recent decades, the human factor is responsible for more than 70% of aviation incidents and accidents. Knowledge about human factors remains chief for its application in optimising the relationship between people and systems. That allows for a better understanding of human behaviour and performance, and improves overall flight safety and reliability. Basic concepts of human factor impact on aviation

Human factors in aviation are the consequences of human states as stress, fatigue, overconfidence, inexperience, lack of proper communication, and other aspects of human behaviour that can affect flight safety and efficiency. These factors can directly affect pilots' decisions during the flight, cause poor concentration, and create errors in the execution of procedures. The leading negative manifestation of the human factor is pilot misconduct. Due to high tension, excessive fatigue, unhealthy physical condition or stress, crew members may make incorrect decisions and deviate from generally accepted procedures in the event of a hazardous situation in flight.

Qualitative research in relation to human factors requires a lot of studies on human capabilities, their limitations, and specific data for certain situations, including physiological, psychological, and social aspects of interaction between people and aircraft. It is also essential to collect and analyse data from real-life situations and errors during pilot training in a flight simulator to understand how people react to different scenarios and how their performance and safety can be improved.

However, it is worth noting that humans are still an significant part of aviation safety. Despite the large percentage of incidents that are caused by human error, it is also the human who resolves these errors and makes aircraft one of the safest modes of transport.

1.2 General description of the flight process and its stages

Difficult flight phases are another reason for potential risks and unforeseen situations in the pilot's work. Certain phases of flight, such as take-off, landing or manoeuvres in confined spaces, can cause stress to the pilot, as they require special vigilance, attention and quick response. In the case of a critical situation, the pilot should adhere to specific procedures, effectively handle stress, and be ready to make prompt decisions.

Within aviation practice, there are six stages of flight, which cover the entire process of an aircraft's operation from take-off to landing. Each of these stages is important and has its own tasks, and together they demonstrate the whole sequential course of an aircraft's flight. The entire progression of the aircraft flight stages is shown in Figure 1.1.

Fig. 1.1 Stages of an aircraft flight

Taxiing is the initial stage that an aircraft undergoes from the commencement of its movement. During this stage, the aircraft moves along the taxiways and shift around the airport from one place to another. During taxiing, the airplane must follow clearlydefined yellow lines to avoid collision with other aircraft or buildings. During this stage, the pilot must limit the speed of the patch.

The aircraft is powered by the thrust provided by its jet engines or propellers. The control process is performed by turning the nose and tail wheels or rudder. Before starting their own engine, aircraft are pushed away from buildings by a special vehicle, this is due to the possible risk of a jet explosion that could damage airport terminals. [1]

Take-off is the next stage of flight, where the aircraft moves from moving on the ground (taxiing) to flying in the air. The take-off process usually starts from the runway. During this stage of the flight, the aircraft's engines operate at maximum power, and then the airplane stops at the start line on the runway. An essential criterion for flight preparation is to test the engines, especially piston engines, at full power to identify possible problems in their operation.

At the stage when the pilot releases the brakes, the aircraft begins to gain speed quickly, which is necessary to reach the required speed for take-off. There is no specific figure that can describe the exact value of this speed, as the take-off speed depends on factors such as air density, aircraft weight, aircraft configuration, etc.

After the takeoff phase, before reaching the cruise phase, the aircraft needs to attain a certain altitude where it can fly safely. Altitude gain is achieved by increasing the lift of the aircraft's wings; it is necessary for this lift to exceed the weight of the aircraft. The aircraft climbs to altitude until lift and weight become equal. Changing the angle of attack of the wings, increasing engine thrust, enlarging the wing surface area, or modifying its shape are all factors and methods for creating greater lift during flight. The most common methods involve changing the angle of attack of the wings and increasing engine thrust.

As the aircraft gains altitude, lift gradually decreases due to reduced air density. When this lift equals the weight of the aircraft, the altitude gain ceases, and the aircraft transitions to horizontal flight at a constant altitude. During altitude gain, the sound of the engines diminishes gradually as engine revolutions decrease.

Additionally, a change in the tone of noise during altitude gain may be observed, associated with the retraction of flaps.

Cruise is the fourth phase of an aeroplane flight, and it is the most efficient. Cruising is the longest of the other flight phases, as it makes up the majority of the journey. Statistically, this phase of the flight consumes the most fuel because it makes the aircraft much lighter. The cruise flight ends when the airplane is approaching its destination, after which the descent phase begins, as well as preparation for landing. In addition, during cruise, the aircraft is in a stable state, which increases passenger comfort and reduces the likelihood of turbulence.

Descent is the penultimate part of the aircraft flight cycle. This stage is critical because it precedes the landing phase. However, throughout the flight, the pilot may decide to descend in certain areas from time to time for various reasons. These reasons may include avoiding obstacles, adverse weather conditions, wind gusts, or other factors.

The most common descent occurs when the aircraft has a constant pitch angle and a constant airspeed. To maintain a constant airspeed, pilots control engine power and monitor the angle of descent. During this manoeuvre, engine noise tends to decrease as the number of revolutions at which the engines operate decreases.

Landing approach and landing are the final stages of a flight, when an aircraft returns to the ground. The runway on which aircraft usually land is made of asphalt, concrete or gravel. To land an aircraft, the pilot needs to slow the airplane down smoothly, thereby reducing the rate of descent and touching down smoothly. To reduce the speed of the aircraft, it is necessary to reduce its thrust or create more resistance, which can be achieved by using flaps, landing gear or braking.

The pilot needs to continuously engage the landing gear as they approach the ground to ensure a smooth landing. Despite the fact that pilots undergo special training where they learn how to perform landing operations, a significant number of airports have "instrument landing systems" (ILS). The main purpose of these systems is to help pilots land their aircraft accurately. An ILS is an aid used by pilots to precisely guide an aircraft as it lands on a runway. This system can use marker beacons and runway lights as aids in the operation of the system. ILS uses a combination of radio signals and intense lighting to land safely during instrument meteorological conditions (IMC), such as reduced visibility due to rain or fog.

During the landing process, passengers may hear the landing gear doors open, creating additional drag. Once the aircraft touches down, its speed slows down as the engines reverse thrust, redirecting the airflow forward. When the aircraft's speed is sufficiently low, it enters the taxiing stage and heads for the airport in this way.

The full cycle of an aircraft's flight process - from take-off to landing - is complex, sequential, and requires high skill and attention from pilots. Each of these stages has its own peculiarities and risks, which is why all pilots must always be prepared for unforeseen situations and possible errors. Support systems and the availability of technological solutions such as ILS help to make flying safer and reduce the impact of possible negative factors. However, this does not diminish the importance of pilots in the process of flying an aircraft, as they remain a significant factor in aviation, able to respond to problem situations in a timely manner, think critically and make effective decisions. Such challenging stages of flight as the approach and landing phases require pilots to be able to overcome all possible risks and be prepared to make essential and correct decisions to ensure passenger safety.

1.3 Analysing aviation incident statistics by flight phase

Analysing previous mistakes that have already been made and being able to draw the right conclusions is an important step in improving the effectiveness of future experiences. Despite all the efforts made and the technical improvements offered by the latest technology and engineers, aviation incidents and accidents are still part of reality. The only aspect we have control over is the ability to respond appropriately to past mistakes and the ability to learn from them, taking all possible steps to avoid repeating the same experience.

An important step in preventing aviation incidents is to conduct a clear analysis of the incident, evaluate it and examine all available factors that led to the event. An equally important step is to develop a strategy to prevent similar situations from happening again in the future, and it is an in-depth and accurate analysis of past experience that helps to establish this strategy.

In this section, I propose to review the general statistics of aviation incidents in recent years, their causes and at which stages of flight they occurred most often.

According to the ICAO website, we can review and analyse the statistics of aviation incidents in recent years around the world, starting from 2013, in Figure 1.2 [2].

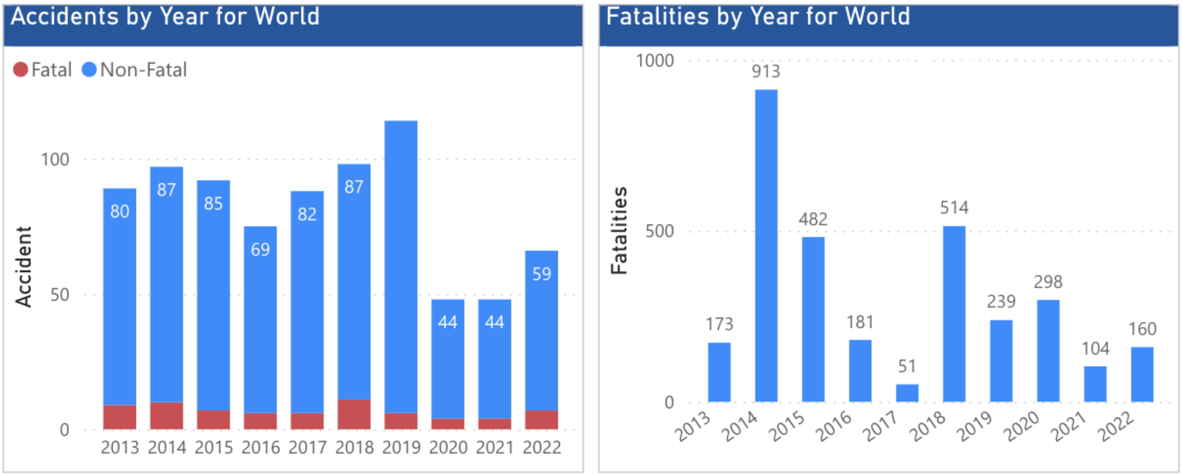


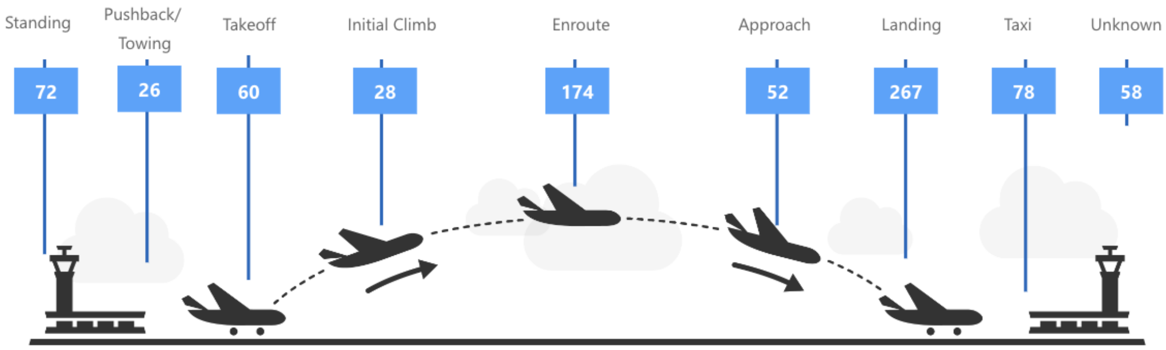
Fig. 1.2 Total number of air accidents and aviation incidents from 2013 to 2022

We can see that the number of fatalities in aviation has decreased in recent years, as 3,600 such incidents were reported between 2013 and 2017, and 1,315 such incidents were reported between 2018 and 2022. This positive trend shows that the work in the field of aviation safety and technology improvement is indeed leading to an improvement in the situation.

The reduction in the number of fatalities may be the result of a combination of many different factors. Improvements in pilot training programmes, technical innovations, procedural improvements, updated cockpit design and strict enforcement of safety standards are examples of areas where changes have occurred that have led to positive developments in aviation safety. However, it is worth noting that for a more sustainable development of aviation safety, the progress made must be constantly developed and not interrupted, as minimising hazards is an important task for the aviation industry.

Another important component of analysing aviation accidents is to classify them according to their flight phases. Figure 1.3 shows statistics on aviation accidents and incidents broken down by flight phase to determine which phase accounts for the majority of accidents.

Fig. 1.3 Total number of air accidents by flight phase



According to the statistics, the most dangerous part of the flight is the landing, and if calculated as a percentage, the approach and landing phases together account for 39% of the total statistics. According to the above data, the majority of aviation incidents occur during the final approach and landing phase. Despite the fact that an aircraft spends most of its time in the air, only 20% of accidents occur during this stage. This data underscores the importance of improving the approach and landing processes, as these phases of flight involve a large number of complex tasks and actions for the pilot.

During landing, the pilot is exposed to the highest psychophysiological stress due to the need to perform a large amount of work. This includes constant changes to the aircraft configuration, interaction with air traffic control and the need to constantly monitor flight parameters. This volume of information and actions during landing increases the likelihood of unforeseen situations and increases the risk of aviation incidents.

The general statistics and analysis of aviation accidents in recent years are evidence of the fact that air travel safety has undergone positive changes. Despite the fact that airline accidents continue to occur and accidents cannot be completely avoided, statistics show a decline in the number of tragic incidents. Landing remains the most risky stage of the flight, as it is during this phase of the flight that the pilot experiences the greatest stress and psychophysiological strain due to the high load on the nervous system. Thus, the landing process needs to be improved and optimised to ensure that in the event of critical situations, the pilot does not lose vigilance and does not get lost in the large amount of information from various sensors and instruments.

1.4 Examples of aviation incidents during the landing approach and landing phases

Table. 1.1

Examples of aviation accidents caused during the landing approach and landing phases

№	Aviation accident	Date	Reason	Consequences
1	Asiana Airlines 214, Boeing 777	06.07.2013	The crew switched off the automatic control mode too early during the landing, which resulted in insufficient control over the aircraft's speed and vertical position. The pilots did not adequately respond to difficult weather conditions and unexpected changes in the situation, which led to a critical descent of the aircraft.	A Boeing 777 aircraft landed too low and too fast, crashing into the end of the runway. The incident resulted in the deaths of three people and numerous injuries to passengers.

2	Southwest Airlines Flight 345, Boeing 737	22.07.2013	Despite the incorrect configuration of the aircraft during the approach, the captain of the aircraft decided to continue to descend, although any landing should be aborted if the aircraft is not in a proper configuration to land at least 1000 feet in the air.	The aircraft landed on runway 4, touching the nose landing gear in front of the main landing gear. The nose section of the aircraft collapsed upwards into the body of the aircraft, causing significant damage to the avionics compartment in the fuselage.
3	Turkish Airlines 1951 (2009), Boeing 737-800	25.02.2009	The aircraft crashed during landing as it descended down the glide path with the autopilot and thrusters engaged. At an altitude of 609.6 metres, the left radio altimeter showed an incorrect altitude, which led to the thrust control switching to low power mode. The radio altimeter malfunction triggered an audible alarm, which is activated when the engines are reduced to low power without the landing gear extended, but the pilots did not notice. When the engines were switched to high power, it turned out to be too late to avoid a disaster.	This led to a loss of speed, a collision with the ground and a crash.

4	Air France 358, Airbus A340	02.08.2002	After receiving a warning from air traffic control that the aircraft in front of them had reported poor braking on the runway, the crew of flight AF358 decided to disengage the autopilot and manually control the aircraft for landing. However, the crew misjudged the distance and speed. When it became apparent that the automation was not adapting to the conditions, the crew did not resume manual control. The delay in applying the brakes and inadequate speed control led to the incident.	The aircraft flew off the runway and caught fire after landing.
5	Emirates Flight 521, Boeing 777-300	03.08.2016	During the landing, the aircraft was travelling at too high a speed. The crew decided to resume the landing procedure, but this resulted in the aircraft losing altitude and colliding with the ground. The reason was a mistake by the pilots, who did not take into account critical aspects of the landing situation. Additional reasons include weather conditions and visual limitations due to high levels of fog.	The plane hit the ground during landing and caught fire.

6	Garuda Indonesia Flight 200	07.03.2007	The pilot-in-command decided to land from a high altitude and at a high airspeed, ignoring the aircraft's ground impact warning system and the first officer's advice to enter the second circle for landing.	The aircraft left the runway, crashed through the perimeter fence and crossed the road. It crashed into an embankment before coming to rest in a rice paddy. The aircraft's fuel caught fire.

1.5 Landing approach as the most difficult phase of flight

The most difficult phase of flight, which consumes a lot of energy and resources from the pilots and requires full concentration on actions and procedures, is the approach and landing phase. This phase is the final phase and completes a clear sequence of carefully planned actions in the flight cycle. It is at this stage of the flight that the largest number of aviation accidents occur; according to the statistics of the American aircraft manufacturer Boeing, this stage of the flight accounts for more than 50% of air accidents [3]. This stage of the flight takes about 4% of the total flight time, but this is the reason for such a large number of unfortunate incidents, as pilots have very limited time to make decisions. It is much easier to accelerate and send an aircraft into flight than to stop it in time for landing.

The above circumstances are possible causes of increased stress levels in pilots, in line with the changing environment. That is why it is so important to be able to manage your emotional state and remain alert even in unforeseen situations. Stress can lead to overreactions and negatively affect decision-making accuracy, as well as lead to incorrect reactions, so developing psychological resilience and emotional management is a necessary component of creating a safe environment in flight.

Figure 1.4 shows some of the possible errors that can lead to unforeseen situations during an aircraft commander's approach manoeuvre.

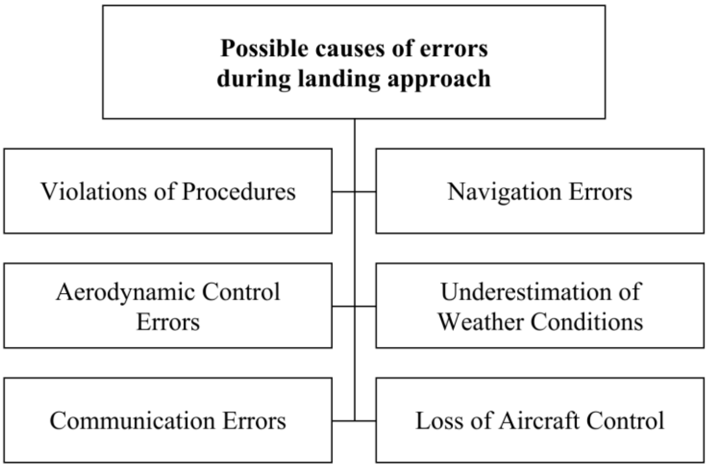


Fig. 1.4 Possible causes of errors during landing approach

Violation of landing procedures is one of the most common mistakes pilots can make during this phase of flight. Stress, psychophysiological tension and the large number of tasks that need to be performed can lead to deviations from the standard procedures that pilots are trained to follow.

For example, a breach of procedures may include such aspects as skipping important steps, poor monitoring, changing course or altitude without proper planning, inadequate response to emergency situations, etc.

In addition, the pilot may make navigation errors by entering the wrong course or altitude. Such actions can lead to danger during landing. Navigation during landing requires special attention to accuracy and compliance with the procedure.

Errors in aerodynamic control are another possible cause of dangerous situations during an approach. Pilots must be able to respond quickly and effectively to changes in flight parameters. Errors in aerodynamic control can include failure to change the angle of attack, flap settings, and violation of aerodynamic limits.

Underestimating weather conditions and communication problems can also be possible causes of errors. Stress can lead to misunderstandings or miscommunication between the pilot and air traffic controller or between the pilot and pilot, which can affect landing safety. The aircraft commander may underestimate weather conditions, which in turn may lead to an incorrect choice of landing procedure or underestimation of visibility requirements.

Of course, the worst possible consequence of stress during the landing phase is a complete loss of control of the aircraft. This can be a step towards a serious aviation accident.

1.6 The impact of stress on the physical and psychological state of pilots

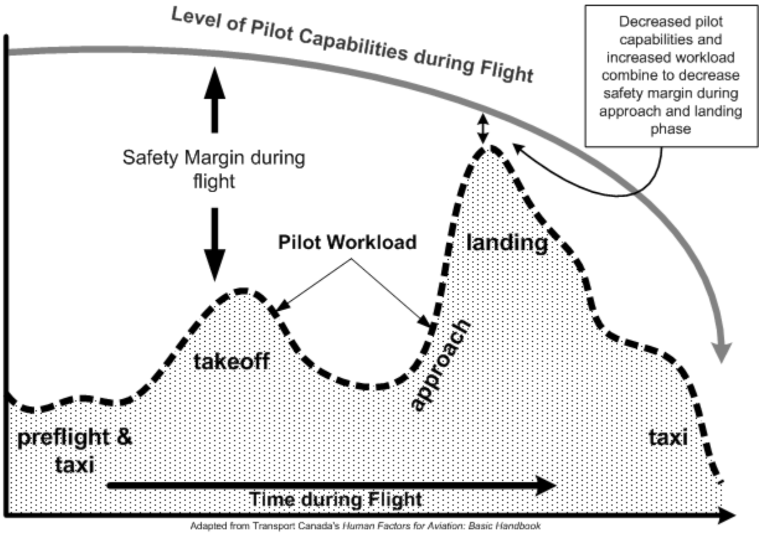
Despite significant technological advances in the aviation sector over the past decades, the human factor remains a factor in flight safety that is difficult to influence and predict. That is why it remains important for the aviation industry to find all possible options to help reduce the negative impact of the human factor. First of all, in order to improve interaction in an ergonomic environment, it is necessary to ensure that the physical and psychological condition of pilots meets the standards, and when pilots undergo anti-stress training on simulators, it is necessary to take into account all possible irritants and prepare the crew to be able to cope with emotional components while working at the helm of an aircraft [5].

Stress refers to the body's reaction to a specific stimulus that can disrupt a person's "normal" physiological balance. In the context of aviation, stress is seen as a state of physical, emotional or mental tension caused by some internal or external stimulus.

At present, stress is seen as the inability of a person to meet certain requirements because they exceed his or her capabilities. Thus, in order to prevent the occurrence of stress, it is necessary to create conditions where the requirements meet the level of human capabilities.

In the aviation sector, the concept of stress also requires some research. By understanding the factors that can cause stress in pilots, it is possible to significantly increase their productivity and efficiency. It is important to note that the same stimulus can cause different reactions in different people. This understanding can help to control a situation that can quickly spiral out of control if a person has a negative reaction.

Figure 1.5 shows the level of a pilot's capabilities during a flight, which directly affects his workload and can cause stress [4].



Adapted from Transport Canada's *Human Factors for Aviation: Basic Handbook*

Fig. 1.5 Level of pilot capabilities during flight

According to statistics, most accidents occur at the end of a flight, and this image confirms this fact, as the workload and fatigue factor of pilots reaches a critical level during approach and landing. Thus, the stress level increases significantly during this phase of the flight and it is very important for the crew to be able to cope with this stress.

Stressors can be of different nature and can be divided into the following types:

- Physical stressor: arises from an unsatisfactory physical condition, such as intense physical activity, insufficient sleep, fatigue, pain or the need for emergency medical care.
- Environmental stressors: arise from the external environment, such as noise, vibration, extreme weather conditions (such as high temperature or humidity), and abnormal gas concentrations.

- Emotional stressor: comes from intense emotional states associated with life events, such as exams, social roles, criticism, injustice, relationship breakdown, job loss, etc. In addition, traumatic memories can cause intrusive thoughts that affect the psychophysiological state of a person.
- Mental stressor: occurs as a result of the mental effort caused by a task in terms of memory and attention allocation or the complexity of the task (e.g., limited time, confusing instructions).
- Chronic stressor: arises from a long-term life condition, such as severe financial hardship, unstable employment, chronic illness or disability of the individual or family members, or marital difficulties [6].

CHAPTER 2

STUDY OF EXISTING AIRCRAFT WARNING SYSTEMS AND THE USE OF SPECTRA AND AUTOCORRELATION FUNCTIONS IN DATA ANALYSIS

2.1 Modern technologies for creating

The development of technology and the significant leap in technological progress have not been spared from the aviation sector, making aircraft increasingly safe and efficient. Over the past decades, a large number of innovations have been developed, ranging from on-board sensors to new cabin designs and new security systems. Thanks to the large amount of data that airlines store about their aircraft, it is possible to identify potential safety issues in advance and take preventive measures to prevent them from becoming more severe.

To better understand the impact of the development of aviation security technologies, let's look at examples of the latest technologies that will make the aviation industry safer or have already made it safer.

Artificial intelligence technology has taken over every possible space in the 21st century. Artificial intelligence is able to generate the necessary images, websites, create texts, process large amounts of data, and much more. AI technology is very widespread and has an incredible number of functions, including the ability to improve the safety of aircraft flights. One example of how AI can be used in aviation is predictive maintenance planning, which uses available data from aircraft instruments and maintenance records to analyse when an aircraft might fail and prevent it. Real-time monitoring of systems also helps to prevent risks associated with malfunctions of aircraft systems. Artificial intelligence technology can also help pilots make decisions in situations of high stress and psychophysiological load. Autonomous flight is another opportunity to use AI within aviation to develop automatic flight systems that can operate without human intervention.

Automatic flight control systems (AFCS) play an important role in ensuring flight safety. The technology behind the system uses special sensors and software to monitor flight parameters and aircraft characteristics throughout different parts of the flight. The main benefits of using AFCS are a reduction in the number of human errors during an aircraft flight and a reduction in the negative impact of the human factor. The system is capable of diagnosing the aircraft avionics, its flight parameters and detecting malfunctions or other problems that may occur during the operation of various aircraft systems.

Weather conditions have a significant impact on flight performance and safety. That's why the use of Automated Weather Avoidance Systems (AWOS) greatly facilitates the work of pilots during a flight, assists in making critical decisions and helps to avoid dangerous flight conditions. AWOS is an advanced technology that provides the crew with real-time weather data. The system can detect hazardous weather conditions, such as thunderstorms, storm locations, cloud accumulation, and wind shifts. If necessary, AWOS can automatically change the flight route to avoid hazardous weather conditions that could threaten the safety of passengers and crew.

Electronic Flight Bags (EFBs) have revolutionised the safety aspects of aviation by providing pilots with quick access to a wealth of information. These digital devices, which usually take the form of a tablet or computer, allow pilots to view flight instructions, maps and meteorological data on a touchscreen. This reduces the need for large folders of documents, making it easier for pilots to make decisions and improve their efficiency.

The EFB can also be used as a digital logbook for maintenance and flight records, which allows for more efficient monitoring of aircraft performance. Another advantage of digital records is the ability to quickly share them with other maintenance and crew departments.

The Enhanced Ground Proximity Warning System (EGPWS) is an advanced technology designed to improve the safety of aviation operations. The main function of the system is to provide information about possible hazards such as approaching terrain or obstacles. The system uses a variety of methods, such as satellite navigation, radar altimeters and terrain databases, to detect ground proximity hazards. When a hazard is detected, EGPWS informs the pilot with audible warnings [7].

The technological advances in aviation that have been made in recent decades have resulted in an undeniable success in the development of air transport safety. Statistics show a sharp decline in aviation incidents and air crashes since the 2000s. However, in order to create a fully safe flight environment, it is necessary to constantly improve and develop the aviation sector and make the aircraft as ergonomically comfortable as possible for the pilot, so that the human-machine communication is not interrupted and the human factor does not lead to fatal consequences.

2.2 The concept of workload in the pilot's work environment

Flying an aircraft is not a simple job and requires a lot of strength, concentration and stress management. During a flight, an aircraft commander has a large number of tasks and functions to perform during the flight, and the number of these tasks and workload may vary depending on the stage of flight the aircraft is in.

The level of workload determines how quickly the pilot will be exposed to stressors and whether the crew's vulnerability to errors will be increased.

Workload has an impact on both the cognitive and mental abilities of pilots during flight. To ensure safe flight, the level of workload on pilots should not exceed their capabilities.

The main stages when the workload reaches a high level are as follows:

- Engine start and reverse, taxiing, take-off and climb, and the standard instrument departure (SID) procedure;
- Descent, landing approach and landing itself, especially when re-entering the second circle;
- Critical or abnormal situations such as equipment malfunctions or adverse weather conditions;
- Emergencies;
- The pilot training process.

The ability to control and keep the workload within normal limits is extremely important for the pilot, as it directly affects his performance and the adoption of adequate decisions whose consequences will not endanger the lives of passengers and crew. Proper distribution of psychophysiological workload increases the pilot's concentration and enables him to react in advance to possible system malfunctions. Thus, workload management helps to reduce errors and increases flight safety.

If the increase in the overall workload on the pilot's psychological and physical condition is not monitored in a timely manner, it can contribute to critical and dangerous situations during the flight.

For example, due to the high workload of the airport, the runway is changed, but due to the excessive workload, the flight crew does not have enough time to repeat the full procedure, which results in the aircraft following the wrong standard departure route according to the instruments for the changed runway, or the pilot may not have time to react and send the aircraft on another circle in time for the landing.

Another example of a critical situation arising from excessive workload on the crew is the misinterpretation of messages from the controller, which can lead to consequences such as approaching an active runway or using an inaccurate route during the approach. In addition, misunderstanding the words of the air traffic controller (ATC) can lead to the pilot starting an unauthorized approach or climbing to an altitude above the flight level during take-off [8].

From the above possible negative factors of the impact of an inadequate workload, it can be concluded that it is extremely important to maintain a healthy level of psychophysiological stress on the pilot by all possible means and not to cause situations of excessive or, conversely, too little stress on the crew. Creating an optimal balance between high and low levels of workload on the crew is an important aspect of creating flight safety conditions.

2.4 Existing warning systems for civil aviation safety

2.4.1 Ground Proximity Warning System (EGPWS)

The introduction of the Ground Proximity Warning System (GPWS) in the early 1970s led to a sharp decline in the number of aviation incidents, which led to an increase in overall flight safety.

The main task of this system is to detect the proximity of an aircraft to the ground or other obstacles, after which the system notifies pilots of possible corrective actions to avoid a critical situation. The system calculates the distance between the aircraft and the ground using radio waves. Visual and audible warnings show the pilot that the aircraft is flying at too low an altitude or is descending too fast. These warnings give pilots time to react in time to prevent the risk of irreparable consequences.

However, further development of the system and the introduction of the Enhanced Ground Proximity Warning System (EGPWS) has made the aircraft an even more reliable mode of transport. Studies conducted by the Flight Safety Foundation have shown that the installation of EGPWS in commercial aircraft has led to an 85% reduction in the number of accidents caused by ground impact over the past decades.

EGPWS uses the following aircraft inputs:

- geographical position;
- orientation
- altitude
- ground speed;
- vertical speed;
- deviation from the glide path.

Along with the input data, the database of terrain, obstacles and the airport isanalysed, and this principle of operation allows predicting the possibility of potential conflicts between the aircraft flight path and the terrain or obstacle.

List of databases contained in EGPWS:

- Geographic location database - a global database of geographic locations with different levels of detail;

Obstacle database - information on known obstacles 100 feet or more in height;

Runway Database - information on runways 3500 feet or longer (2000 feet or longer in some EGPWS models) [9].

In addition to these basic functions, the system warns of severe glide path deviation, wind shear, low flaps in the wrong configuration for landing, and provides information on pitch and altitude outliers based on system settings.

Nevertheless, despite the significant improvements associated with the development of GPWS and EGPWS, it is important to understand that the systems are not perfect and can fail. Pilots should always be prepared for the risk of unforeseen situations and rely only on themselves and their experience to make the best decisions.

The ground proximity warning system has contributed to a significant increase in aviation safety by alerting pilots to important information about approaching terrain. As the aviation industry continues to evolve, the development and implementation of advanced safety systems such as GPWS remains essential to ensure the highest level of protection for passengers and crew.

2.4.2 Traffic Collision Avoidance System (TCAS)

The continued increase in air traffic and airlines has led to a growing concern about the possibility of aircraft colliding while flying in the sky. Ground-based radar and airborne hand control are no longer considered sufficient to ensure flight safety as the number of aircraft in the airspace increases every year.

The Traffic Collision Avoidance System (TCAS) is an onboard airspace monitoring system that uses radio signals to monitor the surrounding airspace. If one aircraft approaches another at an unsafe distance, the system warns the pilot by means of sound signals and cockpit indicators. To detect other aircraft in the vicinity, TCAS sends requests at a fixed frequency throughout the time and uses a receiver to receive responses to these requests. The received radio signals are processed to determine the distance, azimuth, and altitude of the aircraft. Information about the location of other aircraft is displayed in the form of symbolic notations on the navigation screen.

TCAS operates independently of air traffic control, using the transponder signals of other aircraft to predict possible mid-air collision threats and warn pilots.

The system creates a three-dimensional map of the airspace, taking into account the route of each aircraft. Using the signals received from other aircraft's transponders, TCAS can predict potential collisions based on their speed and altitude.

If the system detects a possible collision, it automatically notifies both aircraft in the danger zone. In this case, TCAS automatically designs a mutual avoidance maneuver, which includes informing the crews of the respective aircraft through audible and visual signals. This information indicates to the crews how to change their altitude to avoid a collision when the trajectories of both aircraft intersect.

Figure 2.1 shows a graphical representation of the TCAS system: using a transponder, the system sends a request to another aircraft and displays the image of the oncoming aircraft on the computer screen, and sends evasive maneuvers to anticipate potential collisions [10].

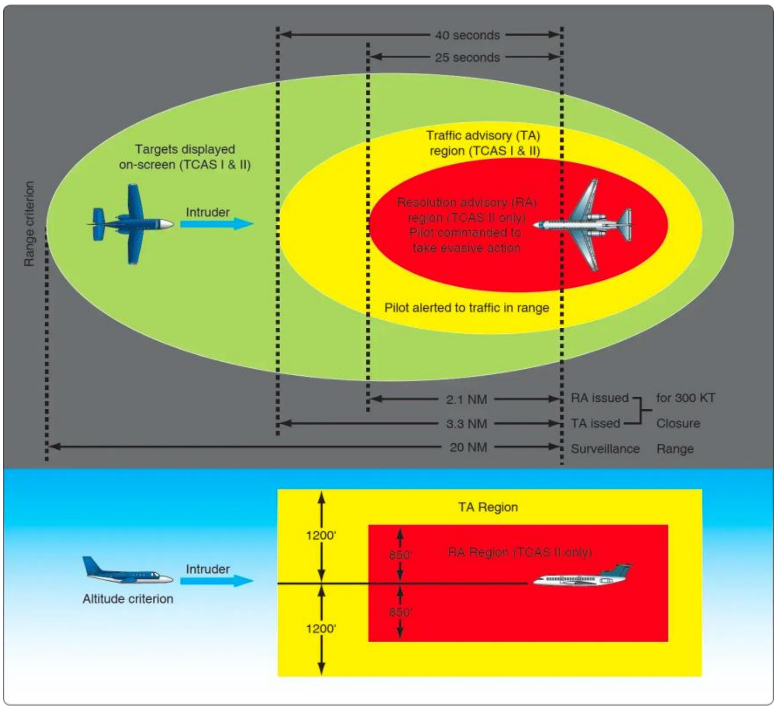


Fig. 2.1 Visual representation of TCAS system operation

Based on the above information, it can be concluded that TCAS is undoubtedly an important component of aviation safety. Using aircraft transponders and computer analysis of the data, TCAS provides pilots with alerts about the presence of other aircraft in the immediate vicinity. The reliability and efficiency of TCAS allow pilots to respond quickly to potential threats, thereby increasing the level of safety in aviation.

2.4.3 Automatic Flight Control System (AFCS)

An integral part of the modern aviation industry is the automatic flight control system (AFCS), which has made it possible to implement complex electronic solutions to support and automate aircraft control. The main advantage of AFCS is that it reduces the workload on the flight crew, optimizes flights, and increases the overall level of aviation safety. The system consists of a large number of sensors, the interaction of which creates the conditions for flight automation and reliability for optimized aircraft control.

Depending on the model and purpose of the aircraft, the system may contain additional subsystems and synchronized sensors designed to control the aircraft at different stages of flight, namely

- Autopilot
- Autothrottle
- Flight control computers (FCC)
- Estimated Position and Heading System (EPHS)
- Onboard inertial data reference system (ADIRS)
- Flight Management System (FMS)

The modern AFCS integrates an automatic throttle system and an autopilot with glide modes to create automatic landing conditions. The system also includes an advanced computer architecture for the autopilot, and the functionality is divided between different interconnected computers and uses intelligent servos to calculate error corrections. The servos interact with the avionics and display computers via a control panel.

The principle of operation of the automatic flight control system is shown in Figure 2.2 [11].

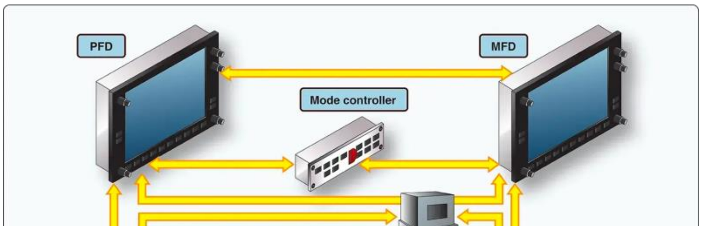


Fig. 2.2 Automatic Flight Control System (AFCS) of the Garmin G1000 glass cockpit instrument system for general aviation aircraft

Thus, AFCS is one of the key elements of technological development in aviation, making aircraft control safer and avoiding many errors associated with heavy workload and human error.

The integration of this system with other digital orientation and navigation systems makes it possible to significantly improve the automation of various aspects of flight at different stages of flight, from takeoff to landing.

2.5 Definition and main characteristics of autocorrelation functions and spectral analysis

2.5.1 Basic concepts of autocorrelation functions

As mentioned earlier, air safety is a key area of development for the aviation industry. Developments and innovations in this important aspect guarantee not only protection for passengers and crew, but also ensure the stability and efficiency of aviation operations. The use of autocorrelation functions in aviation research can help in understanding the occurrence of pilot psychophysiological stress. In the case of a special system for warning and recommending avionics failures during a flight, the analysis of autocorrelation functions can be the key to solving issues directly related to the human factor.

An autocorrelation function is a statistical representation for analyzing the degree of similarity between a time series and its shifted version. The autocorrelation method allows you to compare current data values with previous values. For the autocorrelation method, researchers use the same time series and compare it with the same version, but delayed by one or more time periods. Analyzing the strength of the correlation between these two versions can reveal trends and patterns that allow us to assess the degree of their relationship between several variables.

The calculation of autocorrelation functions is widely used in the technical sciences and can have various applications. For example, in physics and engineering, these functions can help scientists measure and understand the behavior of light and sound waves.

In the context of studying the application of autocorrelation functions in the aviation field, autocorrelation functions can be used as a powerful tool for analyzing the impact of the human factor on the course of a flight, in particular, the impact of psychophysiological stress. Understanding the characteristics of these functions will make it possible to identify certain patterns of behavior and changes in movements when a stressor affects the pilot.

The autocorrelation function (ACF) generates a graph of the correlation coefficient as a function of delay. This graph is a visual representation of autocorrelation. For example, the ACF with a lag of 3 is calculated as the correlation between a time series (Yt) and the same series with a delay of 3 time periods (Yt-3). Thus, for each lag, the correlation is calculated and shown on the graph.

In the case of a partial autocorrelation function, such a function determines the direct correlation between a time series and its lagged version. For example, when regressing a signal S with delay t (St) with a signal with delays t-1, t-2, and t-3 (St-1, St-2, St-3), the partial correlation between St and St-2 determines the degree of correlation between St and St-3 without explaining their mutual correlations with St-1 and St-2 [12].

Figure 2.2 shows an example of how to calculate and graph the autocorrelation function for a certain numerical data set. The example shows a graph in two dimensions, which displays the delay value along the x-axis and the correlation on the y-axis in the range from -1 to 1.

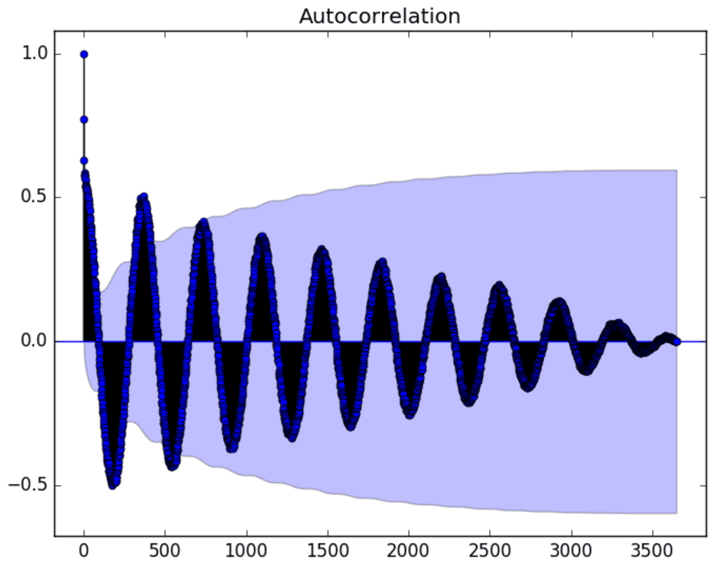


Fig. 2.2 An example of an autocorrelation graph of a data set

2.5.2 Spectra and spectral analysis

Spectral analysis refers to the process of decomposing a signal or a set of data into its component frequencies, usually represented as a power spectrum or frequency distribution. The main purpose of spectral analysis is to identify the main characteristics of a signal, such as periodicity and dominant frequencies. Due to its capabilities, spectral analysis can provide important information about signal frequencies regarding its nature and behavior.

The main characteristics in spectral analysis are:

- Frequency;
- Power spectrum;
- Windows;
- Resolution.

Frequency is the number of repetitions of an event or complete cycles of a wave per unit of time, the frequency is measured in hertz (Hz). Power spectrum is a graphical representation of the distribution of power or energy at different signal frequencies. A window uses a mathematical function to smooth or reduce spectral leakage in a signal. Resolution is the ability to distinguish between different types of frequencies in a signal.

In addition to the above-mentioned components of spectral analysis, other important concepts include Fourier analysis, the process of decomposing a signal into sinusoidal components, and the Fourier transform, a mathematical method for transforming a signal from the time domain to the frequency domain.

Spectral analysis is now a powerful tool and method for analyzing and understanding signals and data sets. The use of this method of information analysis can help in making informed decisions and be useful for processing frequency data. The spectral analysis technique allows you to divide a signal or data set into separate frequency components in order to get an idea of its main characteristics. The application of spectral analysis extends to various fields, including acoustics and astronomy, providing important information for research and practical use.

For example, in the field of acoustics, spectral analysis can be used to analyze the frequency components of a sound wave, identifying its pitch, harmonics, and other characteristics. In finance, spectral analysis can be used to analyze stock prices and identify patterns or cycles in data.

Spectral analysis can be used to analyze such phenomena as autocorrelation functions, which leads to a deeper understanding of the properties of signals or time series. By combining these methods, you can get comprehensive information about the structure and nature of the signal.

Figure 2.3 shows an example of a graphical representation of autocorrelation functions and their spectral analysis [13].

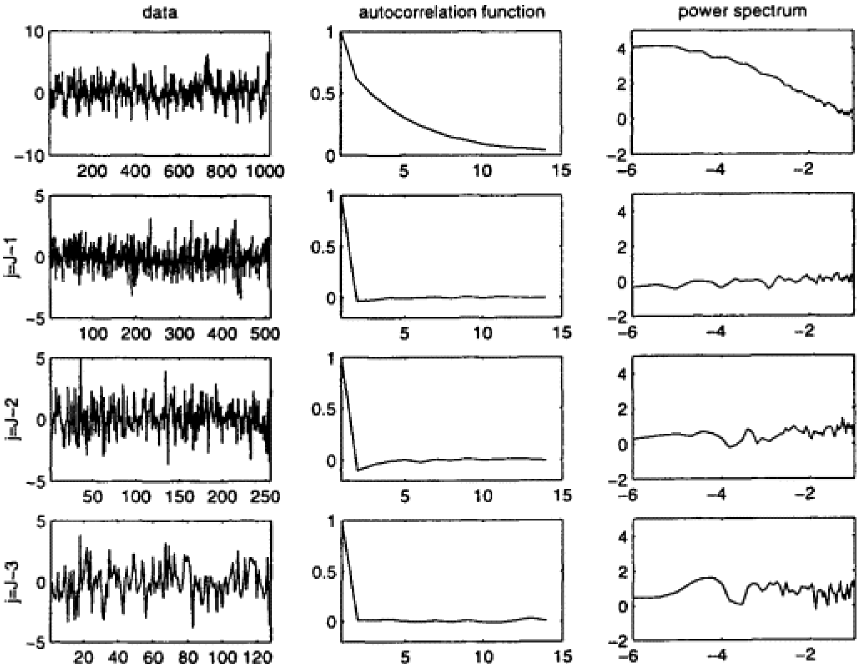


Fig. 2.3 An example of a graphical representation of autocorrelation functions and their spectral analysis

Autocorrelation identifies periodic structures, and spectral analysis indicates the fundamental frequencies of these structures. This allows you to detect complex patterns and accurately determine signal characteristics that may go unnoticed when using each method separately. The combination of these methods helps to refine the analysis of time series and get a more complete picture of the nature of the signal [12].

2.5.3 Interaction in the calculation of autocorrelation functions and spectra

Using the example of the principle of operation of electroencephalogram signals, let's consider the principle of operation of autocorrelation functions and spectral analysis of these functions. An EEG is a measurement of electrical activity of the brain, which is performed using electrodes placed on the surface of the participant's head to record EEG signals.

The autocorrelation of a time function f(t) is the temporal average of the product of f(t+τ) by f(t). Even when considering real functions, it is convenient to use complex time representations. In such cases, autocorrelation is defined as the average of the product of f(t+τ) by the value associated with f(t). Regardless of whether we are dealing with real or complex functions, the power spectrum of f(t) is determined by the Fourier transform of its autocorrelation.

To implement the autocorrelation process, it is necessary to have a mechanism that regulates the reading of the tape during a certain time interval. When a recording segment of duration A passes through a device with two consecutive reading heads, two identical signals with a time offset are generated. This time offset depends on the distance between the heads and the speed of the tape, and it can be controlled as we choose. By denoting one signal as f(t) and the other as f(t+τ), where τ is the time offset, we can obtain their product using quadratic detectors and linear mixers.

$$4ab = (a+b)^2 - (a-b)^2 \quad (2.1)$$

Let's discuss the method of obtaining a brain wave spectrum from autocorrelation. Let C(t) be the autocorrelation of f(t). Then C(t) can be written as

$$C(t) = \int_{-\infty}^{\infty} e^{2\pi i\omega t} dF(\omega) \qquad (2.2)$$

Here, F is always non-decreasing or at least does not affect the decreasing function of ω; this is known as the integral spectrum of the function f. In general, this integral spectrum consists of three elements. The linear part of the spectrum increases only at a limited set of points. After its removal, a continuous spectrum remains, which can be represented as the sum of two parts: one of them increases only on the set of points of degree zero, and the other is absolutely continuous and represents the integral of the positive function to be integrated.

Let us assume that the first two components of the spectrum - the discrete part and the continuous part, which grows at infinity on the set of zero measure - are absent. In this case, we can express.

$$C(t) = \int_{-\infty}^{\infty} e^{2\pi i\omega t}\phi(\omega)d\omega \qquad (2.3)$$

де φ(ω) - is the spectral density. If φ(ω) belongs to the Lebesgue class, then it can be written:

$$\phi(t) = \int_{-\infty}^{\infty} C(t)e^{-2\pi i\omega t}dt \qquad (2.4)$$

There are methods for transferring harmonic analysis to the region around the zero frequency that significantly reduce the amount of work.

Note that

$$\phi(\omega - 10) = \int_{-\infty}^{\infty} C(t)e^{20\pi it}e^{-2\pi i\omega t}dt(2.5)$$

In other words, if we multiply C(t) by e^(2πit), the new harmonic analysis will result in a band around the zero frequency and another band around the +20 frequency. Thus, if we perform such a multiplication and eliminate the band around +20 using averaging techniques equivalent to applying a wave filter, we will reduce our harmonic analysis to a harmonic analysis in the vicinity of the zero frequency.

But

$$e^{20\pi it} = cos\, 20\pi t + i\, sin\, 20\pi t(2.6)$$

Analyzing a curve that has a fundamental energy near a frequency of 10 Hz, we multiply this curve by a cosine or sine with a frequency of 20πt to obtain a curve that is the sum of two components. When averaging the second curve over an interval of 0.1 seconds, we get zero. Averaging the first curve, we get half the maximum height. Thus, by smoothing the results for C(t) cos 20πt and iC(t) sin 20πt, we get good approximations for the real and imaginary parts of a function that has all its frequencies near zero. This function will have a frequency distribution near zero similar to the part of the spectrum of the original curve C(t) near 10 Hz.

Denote the smoothing result for C(t) cos 20πt as K1(t), and for C(t) sin 20πt as K2(t).$\int_{-\infty}^{\infty}[K_1(t)+iK_2(t)]e^{-2\pi\omega t}dt=\int_{-\infty}^{\infty}[K_1(t)+iK_2(t)][cos\,2\pi\omega t-$ $-i\,sin\,2\pi wt\,dt]$(2.7)

The expression (10.07) must be real, since it is a representation of the spectrum. Thus, its value will be equal to

$\int_{-\infty}^{\infty}K_1(t)\,cos\,2\pi\omega tdt+\int_{-\infty}^{\infty}K_2(t)\,sin\,2\pi\omega tdt$(2.8)

In other words, if you take the cosine transform from K1 and the sine transform from K2 and add them up, you get the shifted spectrum of the function f. It can be shown that K1 is an even function, while K2 is an odd function. So, knowing the cosine transformation of K1 and adding or subtracting the sine transformation of K2, we get the spectrum to the right and left of the center frequency at a distance ω, respectively. This procedure allows us to analyze the spectral characteristics of the function f and determine their distribution relative to the center frequency [12].

Based on the information presented in this section, it can be concluded that spectra and spectral analysis of autocorrelation functions are very important for data analysis and processing, including data that can have a direct impact on identifying factors in pilot behavior that can warn of stress.

In this case, the spectral analysis of autocorrelation functions can help to consider the frequency dependencies of the internal structures of time series of psychophysiological flight parameters, for example, changes in pitch angle. The calculation of autocorrelation functions and the subsequent transformation of these functions into a frequency image allows you to identify repeating structures and their frequency components. As a result, the analysis of the frequency characteristics of autocorrelation functions can reveal features associated with changes in the pilot's psychophysiological state.

Thus, the use of spectral analysis of autocorrelation functions in the study will help to provide information about the cognitive and emotional state of the pilot during the flight at different stages. These methods can further improve stress management strategies and increase the overall safety of aviation operations.

CHAPTER 3

SPECTRA OF AUTOCORRELATION FUNCTIONS OF FLIGHT PARAMETERS DURING LANDING APPROACH

3.1 Experimental studies of pilot stress measurements during an airplane flight

The study of the impact of psychological and physical stress on the safety of the aviation industry is a rather relevant topic that is actively discussed and studied, since the human factor and pilot errors are the most common cause of aviation incidents and airplane crashes. Studying the topic of the psychophysiological workload that occurs during an airplane flight for the crew can significantly affect the further development of safety in civil and military aviation.

This section will review the research and what methods of stress measurement they propose. It will be analyzed which of them are the most rational and effective for further implementation and application on all airliners.

The first study that will be reviewed was conducted in 2021 by the Center for Product Design and Manufacturing, Indian Institute of Science (IISc) in Bengaluru, India, and is concerned with the development of methods for assessing pilot cognitive workload and studying its correlation with conventional physiological measurements.

Cognitive load has a direct impact on pilot performance. A high level of workload can lead to a decrease in concentration on tasks, while a low level of workload can cause a pilot to feel bored and can negatively affect his or her overall performance. The study notes the importance of taking these features into account when developing an aircraft interface to improve the ergonomic component of the cockpit display. The article also uses the analysis of certain physiological indicators to assess the crew's workload: electroencephalographic signals, eye parameters, and quantitative indicators.

The first study includes two experiments. In the first experiment, three tests were conducted: the auditory N-back test, the visual N-back test, and the auditory arithmetic test. The aforementioned psychometric tests were conducted to assess ocular metrics focused on the subject's pupils and gaze. The main obstacle was performing the tasks in the dark and under dynamically changing light conditions. This experiment confirmed the fact that performance decreases as task complexity increases. During the experiment, the growth of such coefficients as L1 Norm of Spectrum, Standard Deviation of Pupil, Low Pass Filter was monitored. The results showed the stability of ocular parameters in determining cognitive load under variable light levels [14].

The second experiment was conducted on the NALSim flight simulator and included three levels of tasks from C1 to C2, which varied from lower to higher levels of complexity. The results of the research presented important conclusions about human information processing when the level of tasks has significantly different complexity. As in the previous experiment using psychometric tests, the result of this study showed that an increase in task complexity leads to a decrease in performance.   The main methods used to determine the cognitive load assessment were EEG, eye tracking, and pilot performance.

The first study used standard methods of statistical hypothesis for comparative analysis of the results. The first stage of the study assessed the effect of the effectiveness of ocular parameters on the cognitive load of pilots in the conditions of tasks of varying complexity and changing lighting. The second stage of the study compared three methods for assessing cognitive load, taking into account different levels of task complexity and the influence of secondary factors.

Thus, the results showed a significant increase in cognitive load when performing secondary tasks, which became known through the use of these metrics. The findings of the study indicate the possibility of assessing the cognitive load of pilots using their physiological indicators.

The level of workload on the pilot can also be determined by the current phase of the flight and increase in the case of instrument flight (IFR), and decrease in the case of visual instrument flight.

The main goal of the second study was to measure the workload of five pilots of different experience by comparing heart rate variability parameters. The measurements were conducted on the L-410 UVPE flight simulator and tested how the level of cognitive load changes when pilots performed a standard approach using the Non-Directional Beacon (NDB) and Instrument Landing System (ILS) systems, and also measured the pilots' performance during a state of relaxation. This study made it possible to identify the difference and compare the psychophysiological load on the pilot in the conditions of different methods of landing the aircraft.

The level of heart rate variability of the pilots during the experiment was measured using the HRV CorSense ELITE device, which was attached to the pilot's fingertip. This device was chosen for the study because it minimally restricts pilot movement and does not interfere with concentration. The key indicators of data measurement were the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) indicators. The results were presented graphically in Figure 3.1.

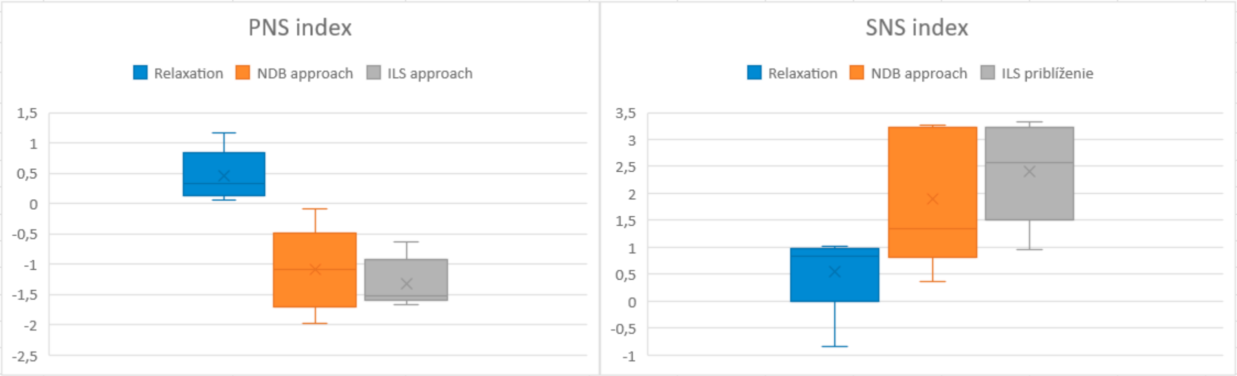


Fig. 3.1 ComparisonofboxplotswithPNSandSNSindexvaluesduringexperiment

Based on the data obtained, it is possible to trace the tendency that the load on the pilot's nervous system increases during the measurements. Measurements of the PNS index showed that the cognitive load increases significantly in both cases, both with NDB and ILS approaches. The SNS index showed an increase in workload relative to the resting state only in the case of ILS, which may indicate a connection with the number of flight hours and training.

Changes in heart rate variability may be an indicator of stress and workload, as it is known that mental stress and physical activity contribute to heart rate increase. This fact contributes to the effective use of this physiological parameter to measure pilots' workload [15].

The latter study, like the previous one, is related to the measurement of heart rate. Psychological and physiological factors such as noise, fever, hypoglycemia, and fatigue were chosen as additional stress parameters. These factors are best suited for an experimental study because they can easily simulate unfavorable conditions for the pilot. Auxiliary flight tasks were added to increase the workload and allow for a clear assessment of the effectiveness of secondary tasks in strenuous flight conditions.

To create a state of hypoglycemia, sugar consumption in the pilots' diet was limited before the study. Increased noise exposure was caused by a high level of noise load during the operation of the aircraft engines, during which it was necessary to maintain communication with the air traffic controller (ATC). Fatigue was caused by a lack of sleep for 24 hours before the experiment. A factor in the high temperature conditions in the cockpit was the use of special heating equipment, which caused the temperature to rise to 47°C.

Table 3.1 shows how the heart rate of the pilots participating in the experiment changed, while the normal heart rate variation is from 60 to 100 beats per minute.

Table 3.1

Results of heart rate measurements in pilots under various adverse conditions

Pilot	**Flight hours**	**Hypoglycaemia**	**Fatigue**	**Heat**	**Noise**
Pilot 1	300	84.52	87.04	96.7	80.44
Pilot 2	50	91.31	87.05	99.02	94.13
Pilot 3	150	102.99	93.98	115.67	108.65
Pilot 4	160	71.84	73.47	87.52	74.82
Pilot 5	160	135.64	137.83	104.29	115.45
Pilot 6	150	94.28	98.52	99.52	95.36
Pilot 7	50	111.34	119.47	121.43	93.21

According to the results presented in the table, it can be concluded that the most significant factor affecting pilot efficiency and performance during the flight was the heat in the cockpit, as this parameter provoked an increase in heart rate variability to the maximum level in most of them. The factor that had the least impact on the pilots' workload was noise. The study found that the biggest problems with concentration loss occurred during the last approach, as during this stage pilots had to perform a large number of flight tasks in a minimum amount of time.

In general, the number of flight hours of different participants in the experiment does not confirm their ability to cope better with cognitive load, as the key role in this is played by the physical and psychological states of a person in a particular period of time. Since pilot 5 with a large number of flight hours performed worse than pilot 2, who had significantly fewer flight hours [16].

Thus, three different studies were reviewed to determine the impact of adverse conditions on the level of pilot psychophysiological stress during flight. All of these studies have shown that situations that go beyond the standard ones provoke a state of stress in the pilot. Pilots experience the greatest stress during the landing phase, as this stage of the flight requires a high level of concentration and focus.

3.2 Influence of the pilot's psychophysiological load on the quality of aircraft piloting technique

The analysis of aviation incident statistics in recent years shows that there are a large number of aviation accidents caused by pilot errors. Fatal accidents can be the result of wrong decisions, lack of special training, little experience, lack of situational awareness and stress. However, the main cause of most of these factors is the physiological and psychological conditions in the pilot's body during flight missions.

In order to improve air traffic safety and reduce the negative impact of the human factor, it is extremely important to prevent the occurrence of physiological and mental stress in pilots and to teach the crew to control their psycho-emotional state. The dynamic nature of the aviation environment requires continuous improvements in safety systems to ensure effective interaction between the aircraft and the pilot in an ergonomic environment.

A key feature of determining the pilot's effectiveness as an operator at different stages of the flight is the assessment of his piloting quality. The analysis of piloting quality allows for a deeper understanding of the critical stages of the flight, the most frequent problem areas, and the development of measures to prevent the occurrence of such situations during piloting.

A sharp change in the psycho-emotional state can significantly affect the flight parameters of the aircraft, its smoothness and overall stability. Changes in the pilot's mental state can lead to fluctuations in such pilot characteristics as altitude, roll, pitch, flight course, etc.

The disclosure of the pilot's psychological and physical limitations in the conditions of flying an aircraft plays an important role in the analysis of the human factor. The results of the research conducted to study these human limitations can help improve pilot training conditions by applying special techniques and solve the problems of aviation incidents that are directly related to the human factor. An equally important aspect of using the results may be the creation of comfortable and safe conditions for pilots to work productively in their work environment.

Further research will examine the impact of changes in flight parameters, in particular changes in pitch angle dynamics, on the quality of aircraft piloting technique and how it relates to pilot psychophysiological stress.

Often, the occurrence of psychophysiological stress goes unnoticed by the pilot and can be accompanied by an increase in the amplitude of the aircraft's flight parameters. The occurrence of stress can lead to accelerating and sudden movements on the part of the captain, and the lack of a timely response to stress, in the worst case, will cause critical angles of attack and can create conditions for losing control of the aircraft.

The optimal method for assessing the quality of piloting technique is to analyze flight data by determining their autocorrelation functions. Changes in the amplitude of aircraft parameters have a direct interaction with changes in the pilot's psycho-emotional state and may indicate the level of his workload. Conducting a comprehensive analysis of the function can help identify changes in the pilot's cognitive state and assess the level of his training to prevent such situations.

3.3 Application of spectral analysis of autocorrelation functions to measure pilot psychophysiological stress

In this work, the analysis of the calculation of the autocorrelation function and the spectra of autocorrelation functions was used to measure the pilot's workload indicators. The autocorrelation function, by its characteristics, allows us to assess the degree of relationship between certain elements of the time series; in our case, this value is the pitch angle amplitude during real flights on the B-737 NG in the vertical plane by pitch angle on the glide path under normal flight conditions [17].

The use of autocorrelation analysis with changes in flight parameters provides a more detailed characterization of random processes and significantly expands the possibilities for collecting statistical data on the movement of aircraft in the sky. This method explains the interaction between various flight factors and the pilot's psychophysiological state more broadly. High correlations reveal at what point in time a period of increased workload occurs, which contributes to a decrease in productivity and loss of concentration. It is extremely important for an aircraft pilot to be able to manage his or her stress and remain alert in critical situations. Analyzing flight parameters in this way helps to develop effective strategies for managing the psycho-emotional state of the crew.

Autocorrelation allows us to determine the degree of correlation between individual elements of a time series represented as a random process. In our study, these elements are the pitch angle amplitudes.

The appearance of the first negative values of the modulus amplitudes is a characteristic sign of an increase in the pilot's stress level. This is a dangerous phenomenon, as further development and aggravation of the crew's emotional state can lead to an incorrect reaction to unforeseen situations and affect the control of the aircraft. Negative values of modulus amplitudes can be the first sign of the risk of reaching critical angles of attack and cause the aircraft to stall in the future.

In our calculations, we used graphs of actual flights on a Boeing 737 NG airplane. The first step in calculating the autocorrelation function was to determine the amplitude of pitch angle changes during four flights. After determining the amplitudes, the main task was to calculate the normalized autocorrelation function:

$K(t) = \frac{1}{\sigma N}\sum_{i=0}^{N-t-1}[(\theta_i - m)(\theta_{t+1} - m)]$,(3.1)

where N is the number of observations in the time series t, θi is the pitch angle amplitude, i = 1, 2, 3; m is the mathematical expectation, σ is the standard deviation.

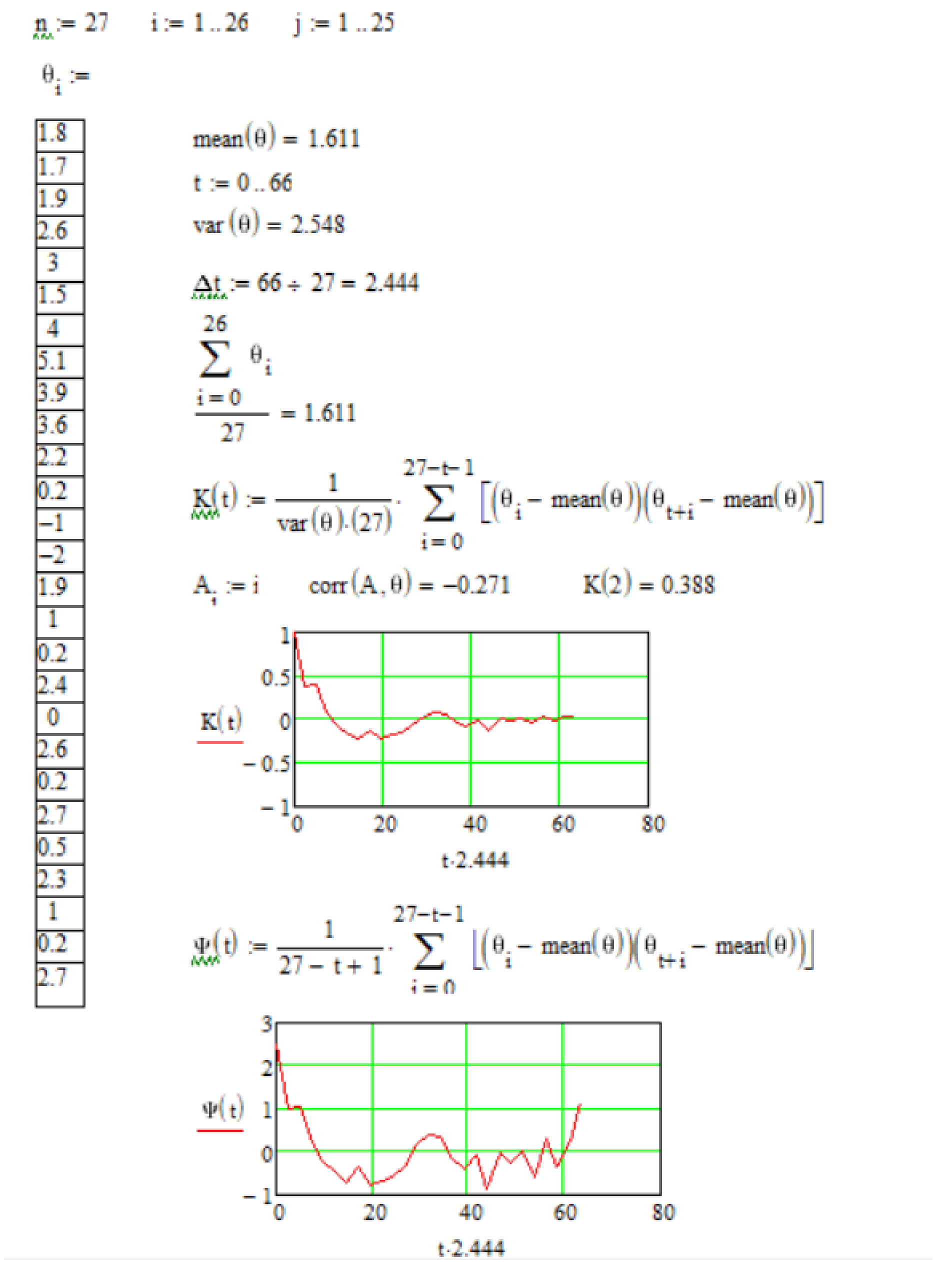
After that, the non-normalized autocorrelation function was calculated:

$\psi(t) = \frac{1}{N-t+1}\sum_{i=0}^{N-t-1}[(\theta_i - m)(\theta_{t+i} - m)]$(3.2)

To calculate the spectra of autocorrelation functions θ from discrete values, it is necessary to use the formula of the Fourier integral:

$S_t = \sum_{i=1}^{N-1} K_i e^{\frac{-i2\pi it}{N}}$(3.3)

There are the calculation of pitch angle autocorrelation functions for flight parameters #1. Figure 3.2 illustrates the calculation of normalized and non-normalized autocorrelation functions.



$n := 27 \qquad i := 1..26 \qquad j := 1..25$

$\theta_i :=$

1.8
1.7
1.9
2.6
3
1.5
4
5.1
3.9
3.6
2.2
0.2
−1
−2
1.9
1
0.2
2.4
0
2.6
0.2
2.7
0.5
2.3
1
0.2
2.7

$\mathrm{mean}(\theta) = 1.611$

$t := 0..66$

$\mathrm{var}(\theta) = 2.548$

$\Delta t := 66 \div 27 = 2.444$

$$\frac{\sum_{i=0}^{26} \theta_i}{27} = 1.611$$

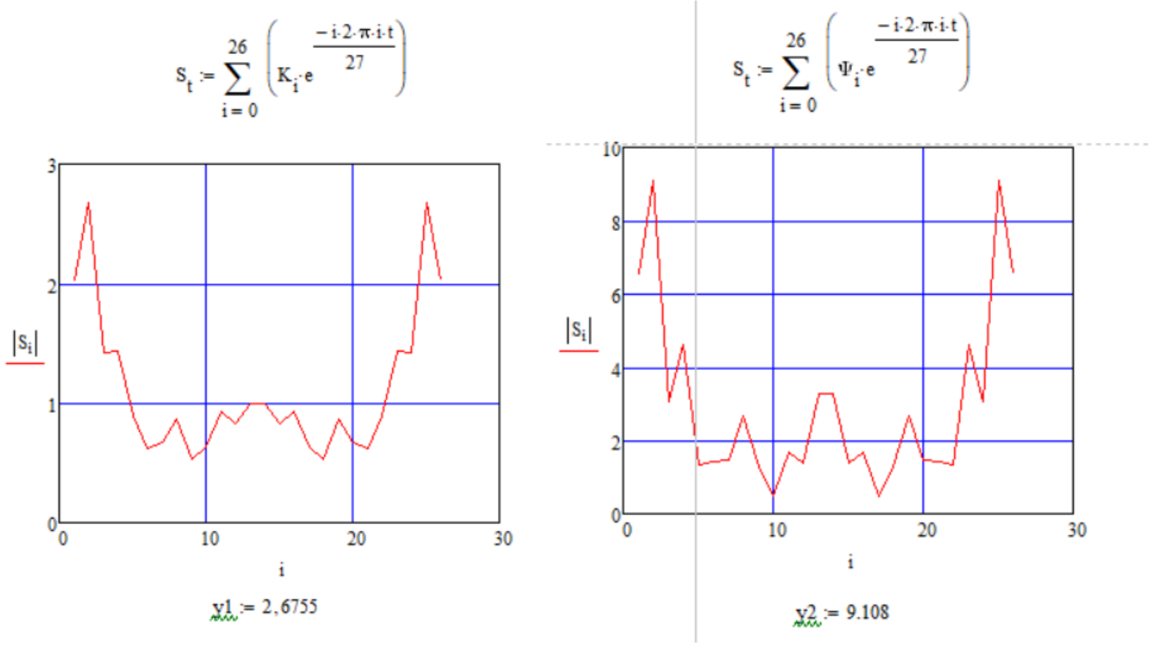
$$K(t) := \frac{1}{\mathrm{var}(\theta)\cdot(27)} \cdot \sum_{i=0}^{27-t-1} \left[\left(\theta_i - \mathrm{mean}(\theta)\right)\left(\theta_{t+i} - \mathrm{mean}(\theta)\right)\right]$$

$A_i := i \qquad \mathrm{corr}(A, \theta) = -0.271 \qquad K(2) = 0.388$

$$\Psi(t) := \frac{1}{27 - t + 1} \cdot \sum_{i=0}^{27-t-1} \left[\left(\theta_i - \mathrm{mean}(\theta)\right)\left(\theta_{t+i} - \mathrm{mean}(\theta)\right)\right]$$

Fig. 3.2 Listing of calculation of normalized and non-normalized autocorrelation functions

After calculating the normalized and non-normalized autocorrelation functions, it is necessary to calculate the spectra of these functions. Figure 3.3 shows how the spectra were calculated for flight 1. In this case, the maximum values of the amplitudes of the spectra of the normalized and non-normalized autocorrelation functions were 2.6755 and 9.108, respectively.



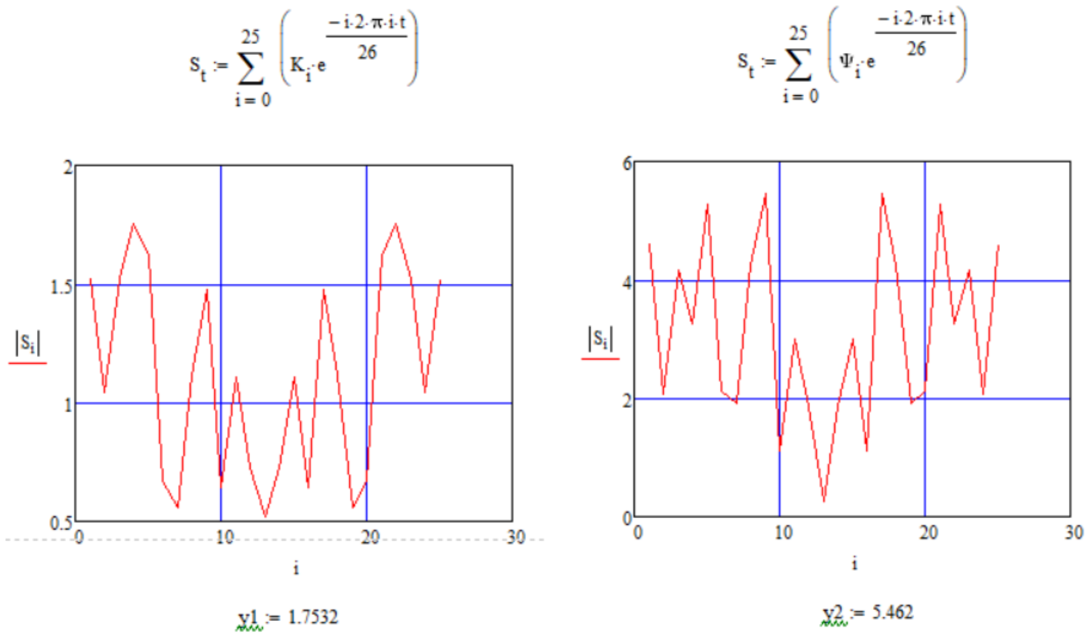
$$S_t := \sum_{i=0}^{26} \left(K_i \cdot e^{\frac{-i\cdot 2\cdot \pi\cdot i\cdot t}{27}} \right) \qquad S_t := \sum_{i=0}^{26} \left(\Psi_i \cdot e^{\frac{-i\cdot 2\cdot \pi\cdot i\cdot t}{27}} \right)$$

y1 := 2,6755

y2 := 9.108

Fig. 3.3 Listing of the calculation of the spectrum of normalized and non-normalized autocorrelation functions for flight #1

After calculating the spectra for flight #1, it is necessary to perform the same calculations for flight #2. In this case, the maximum values of the normalized and unnormalized autocorrelation functions are 1.7532 and 5.462, as shown in Figure 3.4.



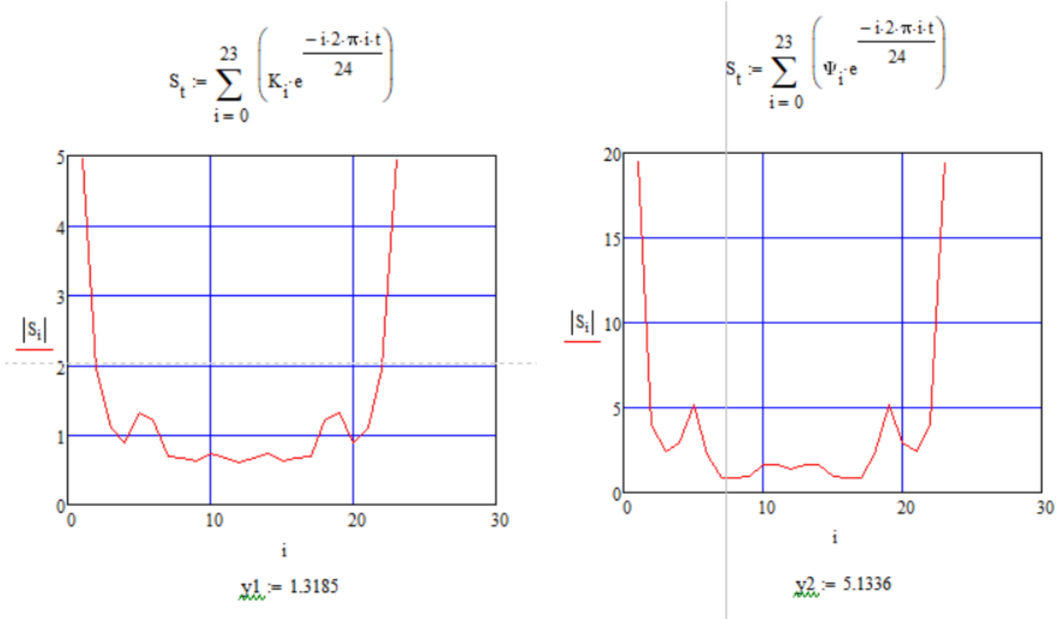
$$S_t := \sum_{i=0}^{25} \left(K_i \cdot e^{\frac{-i\cdot 2\cdot \pi\cdot i\cdot t}{26}} \right) \qquad S_t := \sum_{i=0}^{25} \left(\Psi_i \cdot e^{\frac{-i\cdot 2\cdot \pi\cdot i\cdot t}{26}} \right)$$

y1 := 1.7532

y2 := 5.462

Fig. 3.4 Listing of the calculation of the spectrum of normalized and non-normalized autocorrelation functions for flight #2

Fig. 3.5 graphically shows the results of calculating the spectra of flight parameters of flight No. 3, the maximum values of the amplitudes of which are 1.3185, 5.1336.



$$S_t := \sum_{i=0}^{23}\left(K_i \cdot e^{\frac{-i\cdot 2\cdot \pi\cdot i\cdot t}{24}}\right)$$

$$S_t := \sum_{i=0}^{23}\left(\Psi_i \cdot e^{\frac{-i\cdot 2\cdot \pi\cdot i\cdot t}{24}}\right)$$

$y1 := 1.3185$

$y2 := 5.1336$

Fig. 3.5 Listing of the calculation of the spectrum of normalized and non-normalized autocorrelation functions for flight #3

Table 3.2 presents the results of the analysis of normalized and non-normalized spectra of pitch angle autocorrelation functions conducted during the approach phase of a B737NG aircraft based on 3 different flights.

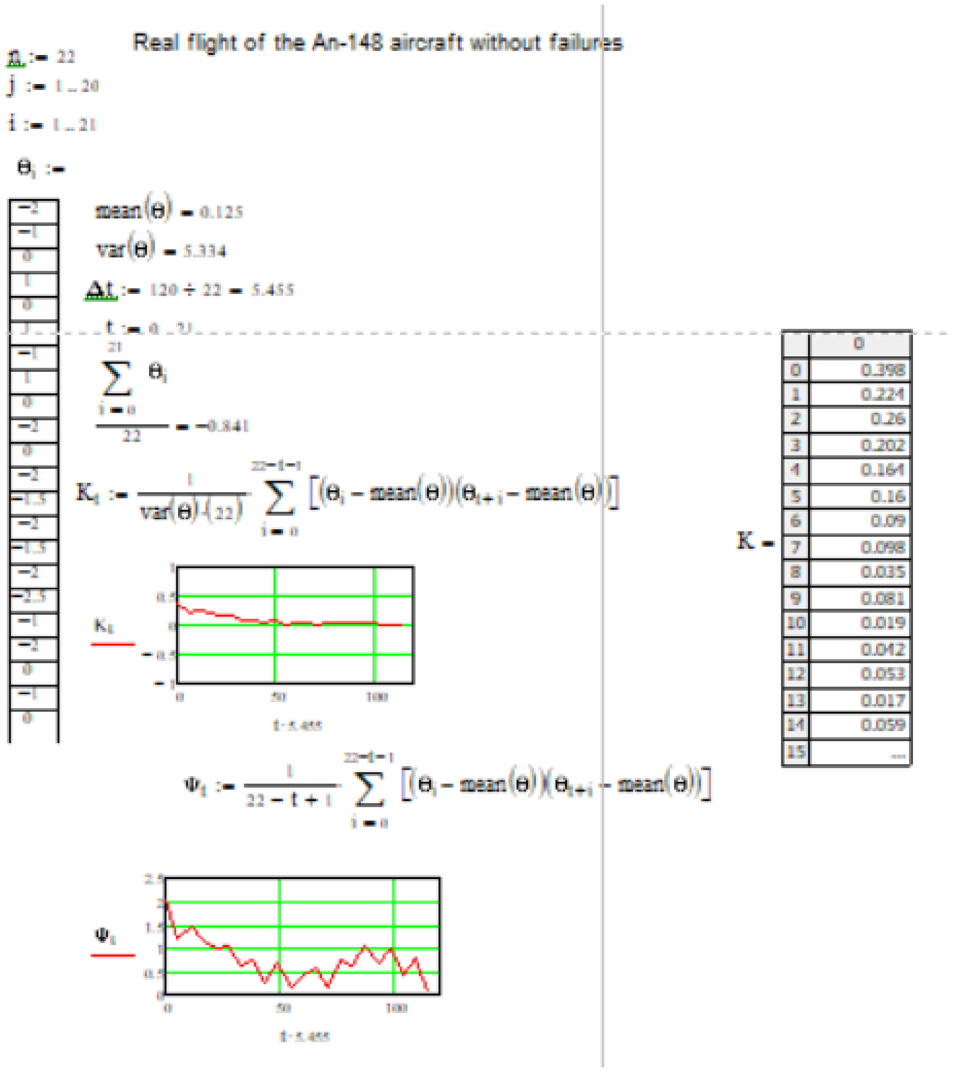
Table 3.2

Results of the analysis of normalized (y1) and non-normalized spectra (y2) of pitch angle autocorrelation functions

№ flight	**y1**	**y2**
1	2.6755	9.108
2	1.7532	5.462
3	1.3185	5.1336

As a result of the analysis of the quality of piloting techniques, it was determined that the pilots of all these flights were in a normal psychological state and had satisfactory piloting techniques. The best result was shown by the pilot of flight #3.

The next study will be based on the analysis of data from a real flight without failures on the AN-148 at the glide stage. Figure 3.6 shows the results of calculating the autocorrelation function.



Real flight of the An-148 aircraft without failures

$n := 22$

$j := 1 .. 20$

$i := 1 .. 21$

$\theta_i :=$

−2
−1
0
1
0
2
−1
1
0
−2
0
−2
−1.5
−2
−1.5
−2
−2.5
−1
−2
0
−1
0

$\mathrm{mean}(\theta) = 0.125$

$\mathrm{var}(\theta) = 5.334$

$\Delta t := 120 \div 22 = 5.455$

$t := 0 .. 21$

$$\frac{\sum_{i=0}^{21} \theta_i}{22} = -0.841$$

$$K_t := \frac{1}{\mathrm{var}(\theta)\cdot(22)} \sum_{i=0}^{22-t-1} \left[(\theta_i - \mathrm{mean}(\theta))(\theta_{t+i} - \mathrm{mean}(\theta))\right]$$

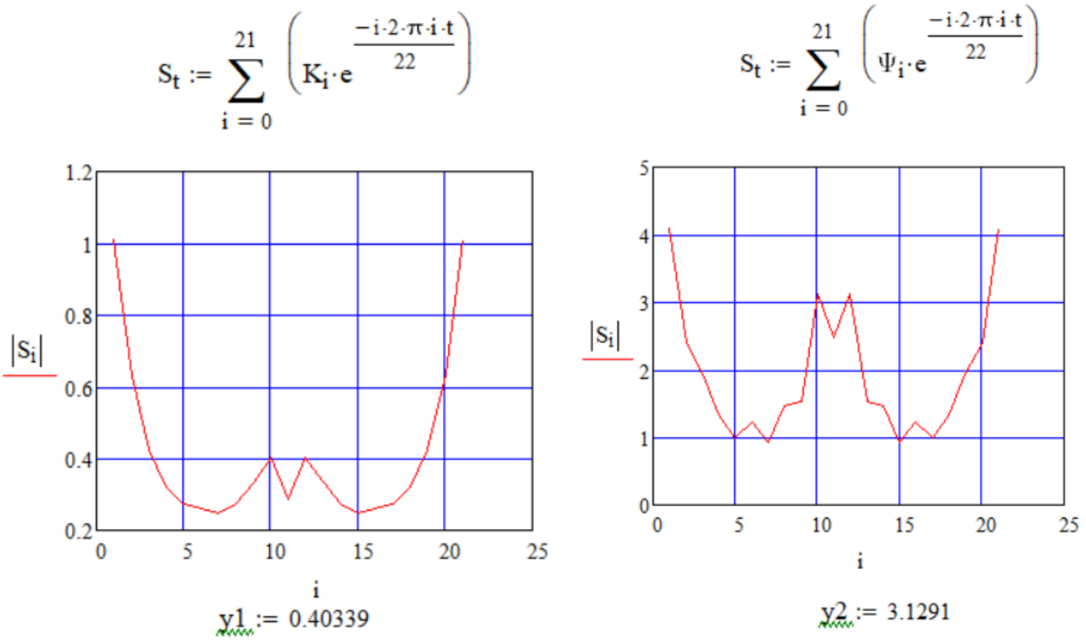
	0
0	0.398
1	0.224
2	0.26
3	0.202
4	0.164
5	0.16
6	0.09
7	0.098
8	0.035
9	0.081
10	0.019
11	0.042
12	0.053
13	0.017
14	0.059
15	...

$K =$ (table above)

$$\Psi_t := \frac{1}{22 - t + 1} \sum_{i=0}^{22-t-1} \left[(\theta_i - \mathrm{mean}(\theta))(\theta_{t+i} - \mathrm{mean}(\theta))\right]$$

Fig. 3.6 Listing of calculation of normalized and non-normalized autocorrelation functions

The graphical results of calculating the spectra of these functions are illustrated in Figure 3.7, the results of the calculations showed that the spectra of the normalized and non-normalized autocorrelation functions for this flight are equal to 0.40339, 3.1291.



$$S_t := \sum_{i=0}^{21} \left(K_i \cdot e^{\frac{-i\cdot 2\cdot \pi \cdot i\cdot t}{22}} \right) \qquad S_t := \sum_{i=0}^{21} \left(\Psi_i \cdot e^{\frac{-i\cdot 2\cdot \pi \cdot i\cdot t}{22}} \right)$$

y1 := 0.40339

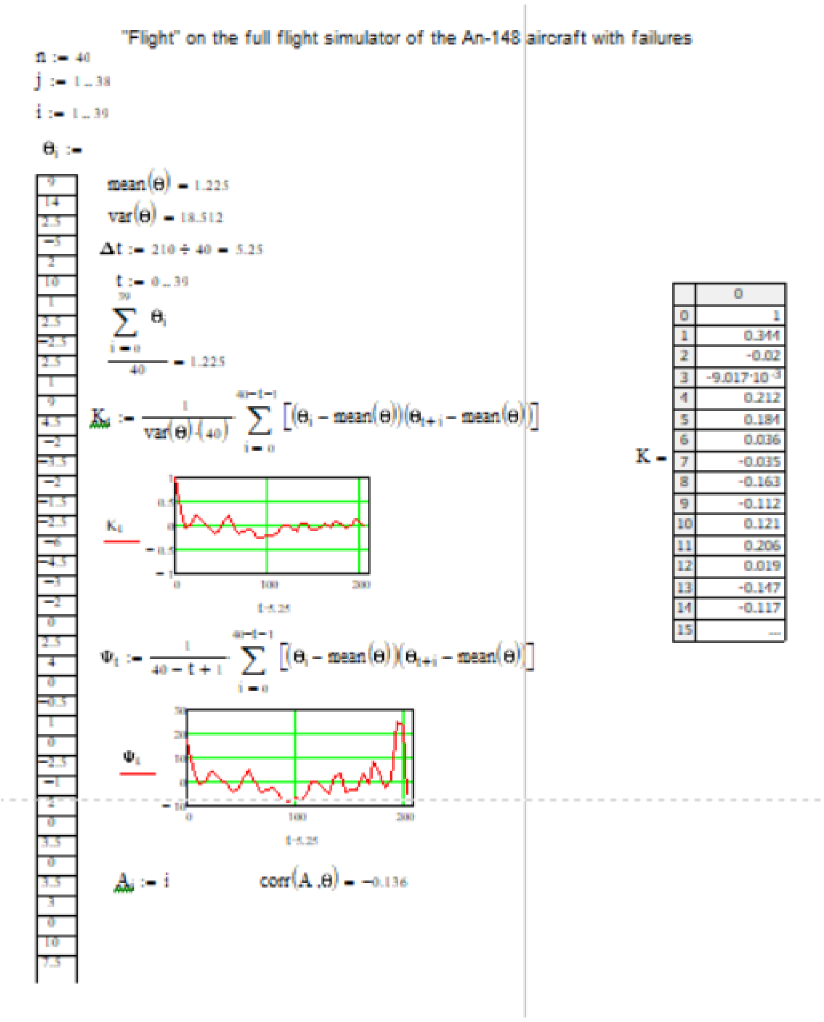
y2 := 3.1291

Fig. 3.7 Listing of the calculation of the spectrum of normalized and non-normalized autocorrelation functions

Based on our studies, we observe a relative coincidence of the results of spectrum analysis on Boeing 737NG and An-148 aircraft, the reason for this phenomenon being that both flights were conducted under normal conditions without failures.

To compare the positive results of the assessment of the quality of piloting technique on aircraft with a negative assessment of the quality of piloting, we will perform additional calculations of autocorrelation functions on the AN-148 CTS.

Fig. 3.8 shows the calculation of autocorrelation functions for a flight without failures on the AN-148 airplane.



"Flight" on the full flight simulator of the An-148 aircraft with failures

$n := 40$

$j := 1..38$

$i := 1..39$

$\theta_i :=$

9
14
2.5
−5
2
10
1
2.5
−2.5
2.5
1
9
4.5
−2
−3.5
−2
−1.5
−2.5
−6
−4.5
−3
−2
0
2.5
4
0
−0.5
1
0
−2.5
−1
2
0
3.5
0
3.5
3
0
10
7.5

$\mathrm{mean}(\theta) = 1.225$

$\mathrm{var}(\theta) = 18.512$

$\Delta t := 210 \div 40 = 5.25$

$t := 0..39$

$$\frac{\sum_{i=0}^{39} \theta_i}{40} = 1.225$$

$$K_t := \frac{1}{\mathrm{var}(\theta)\cdot(40)} \sum_{i=0}^{40-t-1} \left[(\theta_i - \mathrm{mean}(\theta))(\theta_{t+i} - \mathrm{mean}(\theta))\right]$$

K_t

$$\Psi_t := \frac{1}{40-t+1} \sum_{i=0}^{40-t-1} \left[(\theta_i - \mathrm{mean}(\theta))(\theta_{t+i} - \mathrm{mean}(\theta))\right]$$

Ψ_t

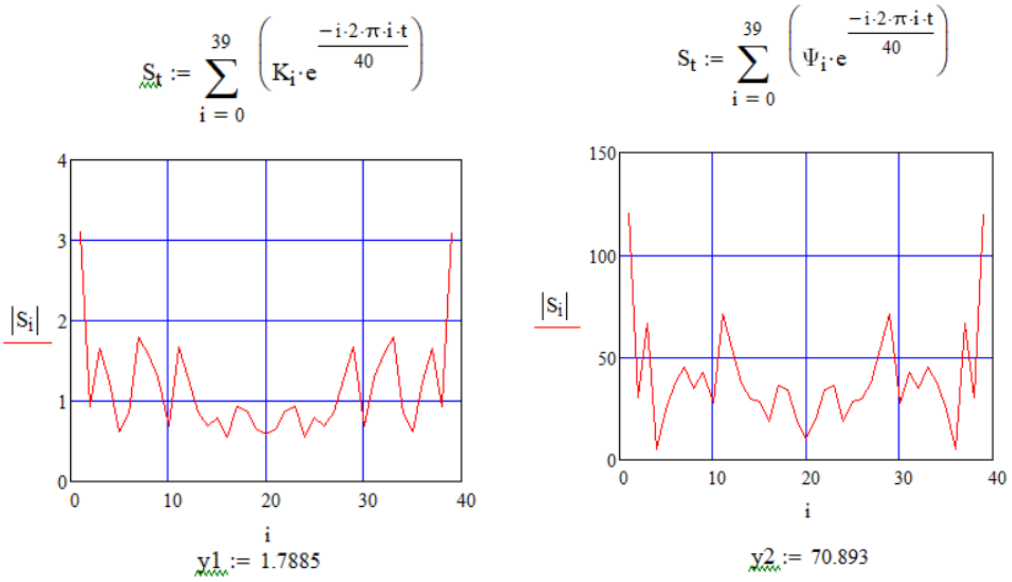
$A_i := i$ $\mathrm{corr}(A, \theta) = -0.136$

K =

	0
0	1
1	0.344
2	-0.02
3	$-9.017\cdot10^{-3}$
4	0.212
5	0.184
6	0.036
7	-0.035
8	-0.163
9	-0.112
10	0.121
11	0.206
12	0.019
13	-0.147
14	-0.117
15	...

Fig. 3.8 Listing of calculation of normalized and non-normalized autocorrelation functions

The calculation of the spectra of normalized and non-normalized autocorrelation functions for this flight, which are equal to 1.7885, 70.893, is shown in Figure 3.9.



$$S_t := \sum_{i=0}^{39} \left(K_i \cdot e^{\frac{-i \cdot 2 \cdot \pi \cdot i \cdot t}{40}} \right)$$

$$S_t := \sum_{i=0}^{39} \left(\Psi_i \cdot e^{\frac{-i \cdot 2 \cdot \pi \cdot i \cdot t}{40}} \right)$$

$y1 := 1.7885$

$y2 := 70.893$

Fig. 3.9 Listing of the calculation of the spectrum of normalized and non-normalized autocorrelation functions

The values of the maximum amplitudes of the non-normalized spectra of autocorrelation functions in the case of a flight on the AN-148 without failures and in the case of a flight with complex failures on the AN-148 complex simulator differ by a factor of 22.656.

To improve aviation safety conditions, it is necessary to conduct special training for crew personnel, and the use of a special warning system for failures and increased psychophysiological stress in flight can help to cope with the psychophysiological load in flight [17].

3.4 Optimizing crew decision-making with a special avionics failure warning system

In the face of system failures and avionics malfunctions, it is very easy for pilots to lose control of their psycho-emotional state and react to critical situations with excessive emotion. This is one of the reasons why the human factor is such a widespread problem that has negative consequences for the crew and passengers.

The development of a special system that could monitor the deterioration of a pilot's psycho-emotional state by analyzing his or her piloting technique could greatly simplify the process of transition from psychophysiological stress to a normal state.

Such a system is not limited to visual warnings of failures, but also warns the aircraft commander of changes in his nervous system that can provoke excessive stress, which in turn can lead to an inappropriate response to external stimuli. Thus, in the event of a malfunction, the system will not only notify the pilot of the location of the malfunction, but also provide specific recommendations for solving the problem.

The main purpose of this system is to help calm the pilot and return him to a normal psychological state, which will help him to understand the problem faster and make a more effective decision to solve it.

One of the problems of being in a state of high psycho-emotional stress is that most often the pilot does not realize that he is under stress. The state of psychophysiological stress causes various consequences and can provoke uncontrolled movements in the pilot and lead to an increase in the amplitude of flight parameters. It is important to be able to control this condition and avoid its aggravation, as unresolved stress can lead to critical angles of attack and loss of control of the aircraft.

In our study, the calculation of normalized and non-normalized autocorrelation functions, as well as their spectra, is used to determine the quality of piloting technique. An increase in the amplitudes of flight parameters characterizes an increase in the pilot's psychophysiological stress. Conducting a comprehensive analysis of flight parameters by applying autocorrelation functions in the calculation can help determine the pilot's psychophysiological state and show his level of training.

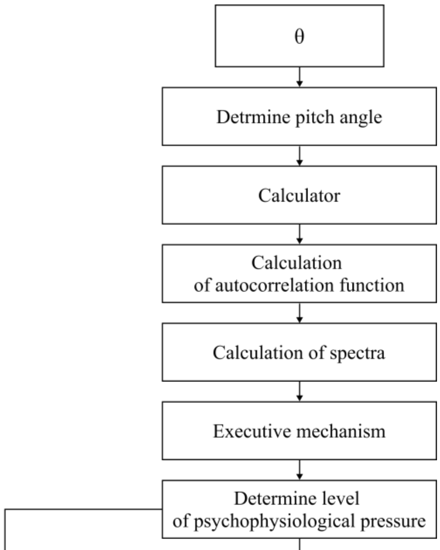


Fig. 3.10 Schematic representation of the principle of operation of a special warning system for increasing psychophysiological stress of the pilot

Let's take a closer look at how the warning system works. The first step to launching the system is to determine the pitch angle of the aircraft and the amplitude of changes in its parameters using aircraft telemetry data. Such indicators are necessary to provide information on the smoothness of the aircraft's movement. The input data of pitch angle amplitudes are required to calculate the autocorrelation normalized and non-normalized functions, and then to determine the values of the spectra of these functions.

After the functions are calculated, the amplitude values are calculated modulo using their graphical representation; if this value is negative, it may indicate a critical condition of the pilot; if the value remains positive, the pilot is in a normal state with no psychophysiological stress. If negative modulus amplitudes are detected, the system is activated and provides the pilot with special recommendations to improve his or her psycho-emotional state and directs the pilot's attention to information that will help return the aircraft to a safe position.

Thus, further development and application of the system can help to better control the pilot's psychophysiological state, increase his productivity and decision-making efficiency in emergency situations. Its application will help to optimize crew performance, reduce stress, and improve the overall safety of the aviation environment.

CONCLUSION

Thus, after analyzing the safety of the aviation sector and the impact of the human factor on air transportation safety, we can conclude that the aviation industry has made significant progress in safety development over the past few decades. A large number of new technologies have been introduced that have had a positive impact on the overall flight dynamics. However, the human factor is still an unpredictable and uncontrollable phenomenon that can have both positive and negative effects on the flight.

The study found that the most dangerous stages of a flight are the takeoff and landing stages of an aircraft. According to statistics, it is during these phases of flight that aviation incidents most often occur. This can be explained by the fact that during these phases of flight, the pilot must interact with a large amount of information and perform many flight tasks.

The use of existing warning systems proves the positive impact of technology on the development of aviation safety. This is evidenced by the analysis of such automatic warning and alert systems as EGPWS, TCAS, AFCS. Their use in modern civil aviation aircraft helps to avoid many hazards and reduces the risk of aviation incidents and air crashes.

The study shows that understanding the concept of workload and improving the working environment of pilots are important steps to ensure their optimal performance. The search for advanced methods of monitoring and studying pilots' physiological reactions is still relevant. Given the importance of improving safety and eliminating possible human errors, this issue becomes even more significant. Workload monitoring can have a positive impact on optimizing the work process, improving rest regimes, and maintaining the optimal mental state of crews. This, in turn, contributes to improving overall safety and efficiency in the aviation sector.

The paper emphasizes the importance of introducing additional warning systems to reduce the impact of the human factor and offers recommendations for the development of such a system. Integration of spectra and autocorrelation functions for analyzing data on the quality of piloting technique is a promising direction for identifying the psychophysiological state of pilots. This can serve as the basis for the development of intelligent systems that adapt to the pilots' workload in real time and provide recommendations to maintain their performance and reduce the impact of stress on decision-making during the flight.

In general, the combination of technological innovations, understanding of the workload and psychophysiological state of pilots opens up new prospects for creating highly efficient and safe aviation control systems. Combining technological solutions with a focus on human resource development in the aviation sector is an important step towards achieving maximum safety and efficiency of aviation processes.

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