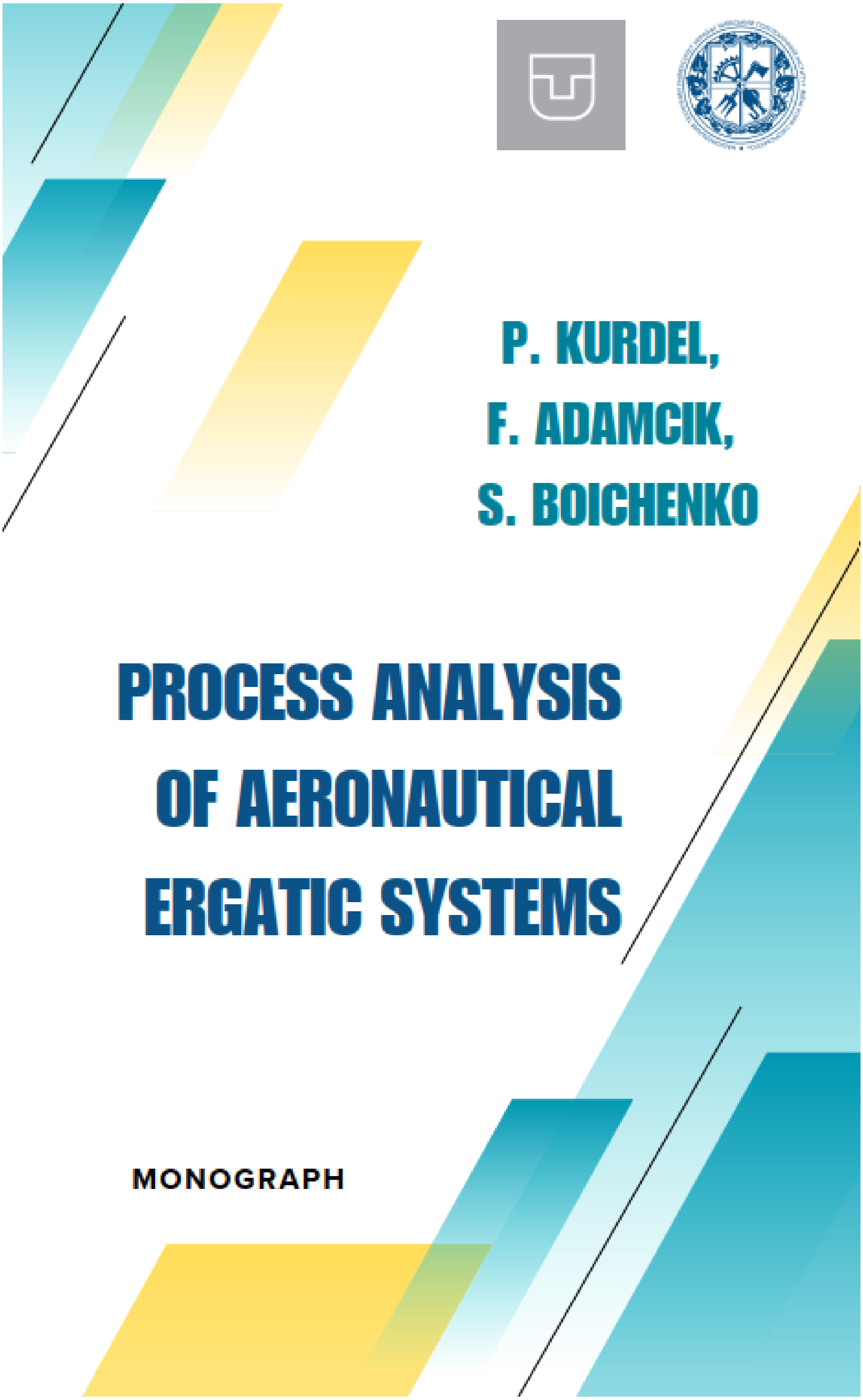

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PROCESS ANALYSIS OF AERONAUTICAL ERGATIC SYSTEMS

MONOGRAPH

Ministry of Education and Science of Ukraine
National technical university of Ukraine
«Igor Sikorsky Kyiv Polytechnic Institute»

P. Kurdel, F. Adamcik, S. Boichenko

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Monograph

Recommended by the Scientific Council of
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«Igor Sikorsky Kyiv Polytechnic Institute»

Kyiv
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The focus of the monograph is on the results of the research aimed at creating conditions for the use of the navigation ergatic complex. The determinants include the applicability criteria of methods for defining the efficiency of autonomous navigation ergatic complex. From the point of view of the systems approach, the applicability of target precision efficiency, which is relationally defined by probability, is discussed. The process-controlled movement of the flight control system on the specified flight path is determined in time by the probability of not leaving the specified flight airspace without process control by the operator-pilot. The criteria for the applicability of the methods for defining the efficiency of autonomous navigation ergatic complexes are a prerequisite. The applicability of target precision efficiency defined by probability is also discussed.

The monograph is recommended for professionals, researchers and young scientists in the fields of electrotechnics, electromechanics and aeronautics.

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CONTENT

INTRODUCTION

Intensive development of science and technology in the second half of the 20th century, at the end of the XIX century, caused great interest in the activities of ergatic systems. Under this name we understand systems in which a person - an operator - acts together with the technical equipment and equipment of the system. A high degree of automation removed the human being from the direct impact on the object, but at the same time it burdened his psychological abilities with a hierarchical responsibility for the safe performance of tasks. When we ask (Area of successful control - ASC) selves how to design ergatic systems, we also need to know the answer to the following problems:

1. how to optimally combine human activity with part of the machine system,
2. how to best organise human cooperation in the assembly of a single ergatic system,
3. How to evaluate the quality of human work in the ergatic system and the efficiency and safety of the system as a whole.

Answers to these and other questions can be found in the process of long-term observation, using analytical methods that allow us to evaluate the quality of work in complex systems. For this reason, there was a need to create a publication whose content is the evaluation of ergatic systems and processes.

Systems in which people work together with technical equipment, i.e. ergatic systems, fulfil their intended purpose, which has been studied in the past and has become an area of interest in engineering psychology. Based on observations, several analyses and publications have been developed that deal with the activities of operators in complex management systems. The greatest expansion of ergatic systems has occurred in areas where special conditions apply to the use of these systems, especially in the field of cosmonautics. The systematic processing of valuable knowledge from analysis results in the control of spacecraft and highly sophisticated aircraft was only possible in cooperation with pilots, aircraft operators, ATO and cosmonauts. These participants in aviation knew how to properly combine the acquired knowledge in the manifestation of complex management functions with theory. Based on these results, it was then possible to further model the dynamics of ergatic systems in modern aircraft.

In some chapters, the model structure is used to estimate the quality of the ergatic process, without which it is impossible to determine the technical and tactical capability of the ergatic system. So far, man has been forced to adapt to parts of the machine system. The complexity of the technology characterises the current situation and its use determines the mutual adaptation of man and machine to parts of machine systems.

The theory of optimal systems, which is successfully used in automatic control, can be used to optimise the operation of the machine. So, how should we look at the process of optimising the connection between the machine and the human being (the operator)? Is it necessary to adjust the adaptation of a person to successful work in the assembly of a given system for the fulfilment of assigned tasks? This view changes the management tasks assigned to the operator, e.g. the control of the processes of stabilisation of the positions of the flying apparatus is promoted to the monitoring and correction of the indicators of the quality of the operation of the assembly of the given system.

How is it possible to estimate the quality of the ergatic process? From a practical point of view, statistical criteria are suitable for estimating the quality of the ergatic process, which are applied to the processing of the parameters of the tasks performed, realised in a set of cycles of the ergatic process. The position of the human operator as a member of the ergatic system is manifested in a special kind of self-realisation associated with learning, when the result is the creation of new algorithmic procedures for controlling the object (e.g. learning. a sophisticated flying machine). The tool for evaluating the described method of implementation are statistical methods, which allow to estimate the quality of the ergatic process. The basis of this applied statistical method is the information that we get not from the final results of each cycle of the process, but from the results about the course of activity of the ergatic system in contact with the limits of the cycle. This method of "local estimation" (between limits) allows us to determine the probabilistic characteristics of the ergatic system for each individual cycle of the ergatic process, and according to them, it is possible to compile an information learning curve consisting of successful and unsuccessful cycles of the process.

In the final chapters of the monograph, the issue of learning of a person - operator in both standard and non-standard modes of work is elaborated. This makes it possible to stabilise the indicators of the quality of the process, to make a statistical assessment of the cycles and to implement the statistical modelling of the ergatic process as a targeted assessment of the reliability of the system as a whole.

The concept of reliability of ergatic systems is understood in the monograph as a non-local concept. Methods of estimation allow to take into account factors that distinguish a person from a machine, such as motivation, emotional tension, and responsibility for the fulfilment of the task. The importance of the use of these factors comes to the fore in the implementation of unique systems operating in the special conditions of aviation and cosmonautics. Statistical modelling of the ergatic process allows to imitate both standard and non-standard modes, so that reserves in the self-realisation ability are found.

When imitating ergatic regimes, it is sometimes necessary to perform a dangerous action (risky for a person), which is contrary to the ethical principle. Therefore, it is necessary to implement such a mode of work of the ergatic system, which corresponds to motivations and emotional tension with a level not lower than in the case of the action of extreme conditions. A significant part of the publication is devoted to the mathematical description of the human operator as a member of the ergatic system. As a rule, the described models always correspond to the research model, which is based on the type and method of imitation of the process carried out at the Department of Avionics of the Technical University of Košice. Therefore, it is necessary to determine in advance the prerequisites for the design of the ergatic system with the possibility of implementing the estimation method after each stage of the achieved level of quality and stability of the performed tasks. In addition, the principle instability of the human operator's characteristics and his learning ability at the stage of setting the model requires corrections to the methodology in which the control procedures are synchronised with the achieved results of the ergatic process. This method requires non-interactive one-step adaptation, taking into account the adaptation criteria and variability of model parameters.

Constructing the model of the ergatic system lets us explore conflicts in the modeling process. It is then a reflexive ergatic process that can be realised in the design of trainers. In this way, the art and habits of a person-operator, acquired at the previous stages of his activity, can be fully realised.

CHAPTER 1

ERGATIC SYSTEMS-CONCEPTUAL IDENTIFICATION

A system is a purposefully defined set of elements and relationships between them, which together form a relatively closed whole in relation to their environment and determine its properties. The acting elements are connected in such a way that they can be divided into groups in which they can work autonomously, i.e. independently.

The definition of a set of elements in a system often depends on objective factors, which are understood by how the observer chooses the boundaries of the selected set, depending on the goal of a particular observation.

Ergatic systems can be objects and views as well as their totality. All the elements of the system that are in the object and that we are going to deal with in the next section are physical. A control system is a physical set that has the following characteristics:

1) has its function (management),

2) can change the parameters of the elements to influence their function (it is controllable).

The ergatic system (Fig.1) is functionally dependent on human action. All physical systems controlled by humans are ergatic systems. The man-machine system in the narrow sense of the word is understood as the connection of the human operator with the machine, through which the operator realises himself. A machine in a system connection with a human operator can perform the functions for which it is intended using the technical means used by the human operator. Thus, a human-machine system is an ergatic system in which a human operator controls a machine, while in a broader sense, it can also control other people as well as collectives [1,2].

The object of activity in the ergatic process is any object with which a person works at a certain stage under certain conditions in order to change the properties of the object. A person must know the ergatic process to be able to realise the desired changes in it through his actions. The operator must have certain habits which enable him to carry out the task for which he is responsible. To fulfil these conditions, certain professional qualities are required of a person. Man-operator, as an element of the ergatic system, realises himself in the ergatic system, interacts with other people and, under the influence of the external environment, acts through the information model and management bodies. The information model represents the algorithm of the system's operation, compiled according to the rules by which the object of the ergatic system's activity accepts the influence of the external environment, as well as the interaction of other elements of the ergatic system's circuit.

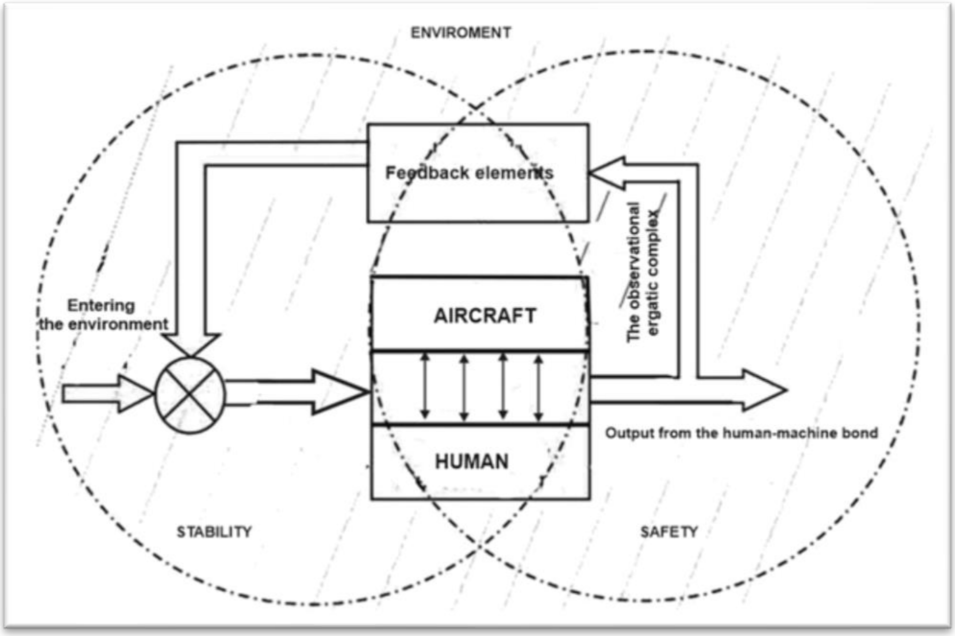


Fig. 1 Ergatic system, human-machine connection

The information model allows a person-operator to obtain knowledge about the behaviour of the object which he controls, and which is functionally dependent on his control activity. By the term of quality of ergatic process in the following, we will understand the totality of its functions, by which the usability of the system for solving certain tasks or their class is expressed. Estimation of usability (in ASC case estimation of the state of e.g. an aircraft) represents a summary of the necessary activities, a summary of the output quantities and a summary of the control activities performed over time.

By the concept of the goal of the ergatic process, we will understand the achievement of a defined boundary of the desired task, which is realised procedurally. The goal is long-term (in terms of the system's operating period), i.e. it is the desired result, which cannot be achieved in given time intervals, but which the system must approach. Achieving the desired result in the shortest possible time is realised for the period of activity of the ergatic system, which is called a step. In the following we will refer to all the successful solutions achieved as the goals of ergatic system management [3].

By the term quality of the ergatic system, we will understand the set of its characteristics, which determine its ability to solve certain tasks or a class of tasks. The evaluation of the system's capabilities often includes the period of operation of the aggregate input activities, a summary of output quantities (indicators) and a summary of management activities. The quality of fulfilment of the task of the ergatic system can be evaluated as some tangible function determined by the set W, which gives a picture of the efficiency of the ergatic system [4].

The concept of the theory of quality assessment of the ergatic process implies the need to divide the process into individual isolated operations. An operation is the functional completion of the parts of the ergatic process, the purpose of which is to achieve the desired result. The activity of a person-operator represents the functional sequence of the implementation of its elements related to the achievement of the desired management goal. This function of the operator (pilot) is called doctrine in the literature. The level of doctrine depends on the level of training. When changing the doctrine, i.e. when changing the level of training (readiness), the objective does not change (remains the same). From this, it follows that the readiness of the pilot-operator is such a state of the ergatic system that depends on the professional readiness of the person-operator. As already mentioned, under this term we understand his ability to perform the specified activities with the required quality, which is connected with the level of special knowledge, skills and habits [5].

1.1 Indicators of the ergatic system

The ergatic system consists of two different physical elements (systems). The first part includes mechanisms, equipment and other parts that operate without human intervention for a certain period of the time (e.g. between repair intervals). The second part includes elements that are designed to carry out commands given by the human operator. In this way it is possible to separate non-allergenic elements from each other. The term "ergatic" refers to the system together with the human-operator model that controls and manages the aircraft:

- with instruments and displays,
- with controls,
- with auxiliary controls,
- and the person himself, the operator.

The quality of the ergatic system is assessed by analysing the phase trajectory image. Each point of the phase trajectory reflects a certain state of the system, the coordinates of which determine the position of the system in the phase space.

A cycle is a sequence of states of an ergatic system in which a given point is represented repeatedly.

1.2 Adaptation of the ergatic system

The concept of the ergatic system is closely related to the concept of adaptation, which speaks of adaptation to the conditions of activity. Adaptation of the ergatic system is a characteristic that is expressed in the ability of a person-operator to change the inherent structure of models and parameters of his activity to increase the quality realised by the ergatic process.

Indicators of adaptation of the ergatic system are:

- Speed of change of the quality indicator,
- Threshold of readiness, which is the minimum value of the quality indicator that

the system reached by the system in each time interval or for a given number of repeated cycles,

- The dispersion of the quality indicators at the threshold level,
- Significant rate of change of the functional quality.

When studying the adaptation of the ergatic system, the following concepts are important.

Motivation of the ergatic system - is a property expressed in the ability to regulate the intensity of change of adaptation indicators when changing the goal of the ergatic process.

Interaction - is a complex ergatic process in which a change in the activity of one person-operator causes (or stimulates) changes in the activity of another or several operators, which ultimately affects the content of the dependence of the ergatic system on their activity. Interaction can be divided into two basic classes:

- Interaction with the same interest,
- Interaction with different interests.

Interaction with the same interest - this form of interaction assumes the existence of functional interaction, which tends to a certain extreme in the interaction of certain actions of participants of the system. It can be different:

Interaction in cooperative conditions, in which two or more ergatic systems carry out an activity aimed at achieving a goal under different conditions,

Interaction in competitive conditions, where two or more ergatic systems carry out activities related to each other, aimed at achieving a single goal, which is realised in the same conditions (with the same modes of work of the system and its part).

Interaction with different interests - in such interaction the system cannot influence each other (non-reflexive interaction). Reflective interaction assumes that the operators have an idea of the work of models of other systems involved in the process of interaction. This creates the possibility of influencing their activities through managerial intervention [6].

CHAPTER 2

NAVIGATION ERGATIC SYSTEMS

Navigation ergatics systems (NEC) combine oriented air navigation with systems providing spatial navigation according to PRNAV and BRNAV rules. The role of ergatics is to accurately identify the reliability of navigation systems that are interconnected with space or ground segments. These segments provide accurate navigation, but the input and diversity of the external (environment) and internal (aircraft) environment change the accuracy according to the laws of the environment.

The main strategic directions for the development of general navigation are.

1. Transition to zonal navigation methods with different RNPs in the airspace of all ECG countries;
2. Implementation of the concept of "Free Routes" - Free Sky;
3. Granting the right to fly on aircraft with lower navigational characteristics, down to technical parameters where possible;
4. Implementation of 4D RNAV procedures to ensure the transition to ATM organisation;
5. Provide location and navigation information in the correct format - in the formats required to support the different CNS / ATM infrastructure systems;
6. The targeted development of the rationalisation of the ground support infrastructure, allowing the transition to GNSS navigation in all phases of flight, in accordance with ICAO recommendations [8].

The "concept" of the navigation ergatic complex includes the process connection of the physical information system of an object (aircraft) and a person (operator-pilot), which is realised by the transfer of a given track or a newly created event with known coordinates (x_0, t_0) to the desired (or specified) aircraft position $s_0$with coordinates (x, y, z) at time $t \geq t_0$ with known accuracy and safety in advance.

In recent years, manufacturers of aeronautical equipment have paid considerable attention to ensuring accuracy and safety. The problem of this relationship becomes more complicated when we extend safety to the concept of reliability, which reflects and influences the characteristics of a person. A person perceives safety as a measure of the smooth operation of the navigation system. If the navigation system does not perform its functions correctly, it is necessary to ensure that it has entered a safe state. The concept of reliability is defined by the probability that the navigation system will perform its functions correctly. But reliability does not solve the problem of what happens when the system fails. In this case, a human operator – pilot (OP), enters the navigation process, which usually resolves the following three statistically defined cases. They are determined by the conventional coefficients of the crew-object (aircraft) relationship:

$$c_{ds} = \frac{n_{dm}}{n_{cds}}; c_{hs} \frac{n_{es}}{n_{ds}}; c_{cs} \frac{n_{cs}}{n_{es}} \qquad (2.1)$$

where: c_{ds} - coefficient of dangerous situations, c_{es}- coefficient of emergency situations, c_{cs} - coefficient of catastrophic situations, n_{dm}- the number of dangerous manifestations that have occurred, n_{cds} - the number of complex dangerous situational, n_{es} - the number of emergences that have arisen n_{ds} - the number of dangerous situations that have arisen, n_{cs} - the number of catastrophic situations that have arisen, n_{dm} - the number of manifested situations.

Probability of occurrence of f ASC strange situations:

$$P_{sp}= \frac{n_{sp}}{N}\frac{p_{hs}}{N}; P_{es}\frac{n_{hs}}{N}; P_{ks}\frac{n_{cs}}{N} \qquad (2.2)$$

where N is the number of flights in the observation period [9].

Substituting (1) into (2), we obtain a probabilistic mathematical model for the probability of a catastrophic situation:

$$P_{cs}\times c_{cs}c_{hs}c_{ds}c_sP_s \qquad (2.3)$$

where we interpret it as the probability of difficult flight conditions P_s.

It follows from relation (2.3) that even if a high probability of P_{cs} not occurring is achieved, there may be a condition in the crew-object relationship where one of the constants is exceeded beyond the specified limit. In this case, the P_{cs} value will decrease. However, a decrease in this value may not be the cause of the non-fulfilment of the flight task, but the quality of its fulfilment will decrease. The acceptable quality of the task performance has its measure, which we will call efficiency. In the observed case, equation (2.3) acquires the value of the effective probability of occurrence of a catastrophic situation. The practical significance of the consideration is that the chosen criteria of flight safety in the crew-object-aircraft system can be used as a tool for estimating the quality of the reciprocity functions of the flight apparatus operator (pilot). The importance of these considerations is also obvious in the economic field. From the point of view of the need for the formation of models of ergatic systems, we can also use this consideration to study reciprocity using set theory. Let the set B represent the events that act on the crew-flight equipment system. Let the set C represent the external actions or adaptations. Flight without the action of special situations can be described by the interaction of: $B_0 = \mathrm{B} \cap \mathrm{C}$

where ∩ it represents the unification (penetration) of factors (both factors, i.e. j. B, C occurred at the same time) or that one of the events, e.g: C=$C_1 \cup C_2 \cup$...........$\cup C_n$,

The validity of negations (i.e. they will reinforce each other:

$\overline{B_0}$ =$\bar{B}\cup\bar{C}$, ale= $B_0\cap\bar{B}$=∅ , which is an empty set.

The probability of an event is:

$$\mathrm{P}(\bar{B})= \mathrm{P}(\bar{B})+ \mathrm{P}(\bar{C})-\mathrm{P}(\bar{B}\cap\bar{C}) , \qquad (2.4)$$

The expression P (C) in (4) expresses e.g. adverse weather conditions or non-existent control by the flight controller, etc. The criterion used for these adverse effects is:

$$\mathrm{P}(\bar{C}) \approx 0.12\ \mathrm{P}(\overline{B_0}) \qquad (2.5)$$

In this case, criterion (2.5) is an example of the choice of the performance criterion for ensuring flight safety of the crew/aircraft system. Any similar criterion can be used as a standard. This method can also be used to predict the effectiveness of flight safety assurance at all stages of flight and air traffic. Applying the accepted method to the first equation (2.2), it is possible to state that:

$$P_{sp} = 1 - P(B), \tag{2.6}$$

This relationship can be used to estimate the probability of a complex flight situation and subsequently influence the elements of the crew/aircraft system. It can also be used for flight planning with prescribed efficiency.

Suppose that the objectivity of the crew-flight (*cf*) apparatus system (in the next_P_{cf} ⊥ A) depends on the efficiency of other parts: construction, propulsion, radio equipment, piloting, and navigation system. Then it is practically impossible to conduct research from the position of a systemic approach of all structures and schemes of the object in question. The problem becomes even more complicated if we add to the research on the effectiveness of a complex system the competence of the operator-pilot (hereinafter OP). To simplify the task of each on-board equipment system with multifunctional ergatic elements, it is appropriate to divide them into simple target ergatic complexes, according to certain assumptions that are important to accept in the research.

1. Each target complex must provide the solution of the defined tasks separately, without backup.
2. If even a single complex ceases to fulfil the given task, then P_{cf} ⊥ A does not fulfil [10].
3. The probability of flight task completion by P_{cf} ⊥ A must be accompanied by a conditional probability of task completion by each ergatic complex.

The validity of the above rules is realized on board ⊥ and by fulfilling the following functions:

1. By converting the energies contained in their carriers into engine thrust and supplying energy to other appliances.
2. Shaping a safe space-time flight trajectory.
3. Carrying out control of the aircraft around its center of gravity on a specified time-space trajectory.
4. Creating living conditions for people.

The listed functions can be placed in individual ergatic complexes:

1. Energy complex, Drive complex P_{cf} ⊥ A;
2. Navigation complex;
3. Pilot complex;
4. Local environmental complex. Each of the complexes listed is characterised by several internal links and structures, which are distinguished by their links and tasks. Model-wise, the distribution of events into complexes can be solved as follows.

$$B = B_1 \cap B_2 \cap B_3 \cap B_4, \quad B \cap \bar{B}_i = \emptyset, \; i=1,2,3,4,\ldots.. \tag{2.7}$$

where $\bar{B}_i$ are events affecting the performance of the tasks assigned to the energy, navigation, pilot and local environment complexes.

From the point of view of evaluating the objectivity of the ergatic complex, it is possible to use and propose criteria derived from its scheme. For the scheme in Fig. 1, an appropriate criterion is the independence of the energy complex from the elements of the other parts of the scheme, which in turn depend on its function. We evaluate the expression of such security in its language as event A_1. That is, if we express the probable safety of the ergatic complex P(B_1), then its manifestation will be the eventA_1, which we denote by the notation zápisom P(B_1)= A_1; other probabilities (Fig.1) depend on P(B_1).

The equation can express the probability interaction:

$$P(B)= P(B_1)P(B_2/B_1)\ P(B_3/B_1 \cap B_2)\times P(B_4\ /B_1 \cap B_2 \cap B_3), \qquad (2.8)$$

where P (B_i) are the conditional (dependent) probabilities of solving the tasks by the target ergatic complex characterised by the probability P(B).

By accepting the laws of commutativity of sets and events, following the rules of probability multiplication, it is possible to decompose the form (2.8) on equality:

$$P(B_1)\ \ P(B_2/B_1)\ P(B_3/B_1 \cap B_2)P(B_4\ /B_1 \cap B_2 \cap B_1)$$
$$P(B_2)\ P(B_3/B_2)P(B_4/B_2 \cap B_3)P(B_1/\ B_2 \cap B_3 \cap B_4\ )$$
$$P(B_3)\ P(B_4/B_3)P(B_1/B_3 \cap B_4)P(B_2/\ B_1 \cap B_3 \cap B_4)$$
$$P(B_4)\ P(B_1/\ B_4)P(B_2/\ B_1 \cap B_4)P(B_3/B_1 \cap B_2 \cap B_4) \qquad (2.9)$$

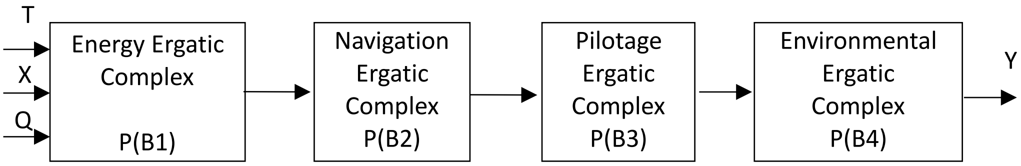


Fig. 2 Schematic for determining the flight safety assurance efficiency of an aircraft crew system

Legend:

T-Flight time, X - Finite set of input variables, Q - set of random variables, Y - Finite set of outputs

Using deduction, let's analyze the circuit safety probability based on Fig.2 and the file (g). We assume P(B_1) =A_1=0,995,, and the requirement is P(B)<A=0,85 (see (2.6)).

Solution:

From the theory of probability, it is known that the conditionality of phenomenon A, provided that phenomenon B occurred, is defined by the relationship:

$$P(A/B)\frac{A \cap B}{P(B)} \qquad (2.10)$$

Phenomena (events) are called independent if:

$$P(A\cap B) = P(A)P(B) \qquad (2.11)$$

From the monotony of probability it follows that if at least one of the elements p of events has zero probability then phenomena A, and B are independent.

For independent events (phenomena), if: P (A)≠0, P (B) ≠ 0, then:

$P(A\cap B) = P(A)P(B)$ (2.12)

That is, the probability of events A under condition B (respectively, A) and B (respectively, B) the probability of phenomenon B under condition A) is equal to the unconditioned probability of events A (respectively, the probability of the occurrence of a)). events (B).

Fusing criteria (2.8) for events conditioned by the phenomenon P (B_1), (see equations (2.10), (2.11), (2.12) satisfies the first equation of the system (2.9)

$P(B)=0{,}995\times 0{,}995\times 0{,}995\times P(B_2)\times 0{,}995\times P(B_2)\times P(B_3)=0{,}85$

After adjustment we get

$0{,}995^4\ P(B_2)^2\ P(B_3)=0{,}85$.

In a similar way, we express the other shapes of the system. The modified equations of the system (2.9) take the final form:

$P(B_2)^2 \times P(B_3) = 0{,}8672$

$P(B_2) \times (B_3)^3 \times P(B_4)^2 = 0{,}8542$

$P(B_2) \times P(B_3)^2 \times P(B_4)^3 = 0{,}8542$

$P(B_2)^2 \times P(B_3) \times P(B_4)^4 = 0{,}8542$

The first and last equations make it possible to calculate the probable safety of the ergatic environmental system: $P(B_4) = 0{,}9969$.

Let the pilot ergatic complex (PEC) be characterized by reliability P (B_3) =0.999. Then from the navigation ergatic complex it must be distinguished by a safe function with a value (see the third equation of the example):

$P(B_2)=\frac{0{,}8542}{0{,}999^2}\times\frac{1}{0{,}9969^3} \doteq 0{,}8666$

When for the validity of the conditions of the specified example, a minimum is required (see the first equation of the set of the Solved Example):

$P(B_2)=\sqrt{0{,}8672/0{,}999} \doteq 0{,}9211$

The solution of the example shows that the resulting safety of the ergatic complex must be characterized by values of P (B_i)≥0.85. It also means that the member of the ergatic complex with the lowest value has the greatest influence on the resulting safety. Additionally, the general structural scheme in Fig.1 indicates that during the flight, there will be no special event that can be expressed by the probability of safety (certainty) (2.6). This is because, in the case of: $P_{sp1} = 1-0{,}8672 = 0{,}132$, and in other cases, it is equal to: $P_{sp2,3,4} = 1-0{,}8542 = 0{,}1458$

When we increase NEC security to P $(B_2) = 1,$ PEC increases to $P(B_3) \doteq 0{,}869$, given $P(B_1)=0{,}995$.

The method of deductive analysis used also indicates the appropriateness of the set (2.8). This is also because (2.8) allows the measured parameters of ergatic complexes to be used to create qualified representations of safety fuses [11].

We all are aware that the concept of polyergic systems represents a multi-member crew, which precisely defines the concept of the ergatic complex. Under the above term, we will further understand how crew members - and operators control the interplay of interacting systems with different characteristics during the flight. They solve tasks to ensure that the flight task is performed in the desired goal or area. This area is called the Successful Solution Area (SSA). The introduction of the above concepts is a prerequisite for the use of methods applied in the field of monitoring for the estimation of efficiency. Efficiency criteria require knowledge of ways of solving flight tasks that burden crew members - operators, the economy of air traffic, and also make it possible to estimate the economy of flight safety assurance. The above method of analysing the principle of reciprocity of crew-aircraft systems in its entirety covers the energy, navigation, control, and environmental systems. From the above, it follows that it is important to know the method of research from the point of view of the emergence of a manifestation of a decrease in the safety of those parts of the ergatic complexes that are influenced by the crew. In this case, it is NEC, PEC.

The increase in speed and density of air traffic required accurate and reliable measurement of navigation parameters. The new requirements have led to an increase in the number of navigation measurement systems. These systems use different measurement principles and methods. However, they all share one common requirement: to solve navigation tasks. The complexity of the tasks required the use of new types of computers and the display of output data as the demands for accuracy increased. In this way, the increase in the number of indicators, displays and signallers forced the creation of architectures of automated navigation complexes (ANC). Their generalised structure is shown in Fig. 3.

The automated navigation complex differs from the previous ones in that it optimises the measured navigation parameters based on additional information received from several independent sensors, automates a large part of the calculations and logical operations on the data and recasts the navigation data from the commands controlling the position and speed of the aircraft [12 - 14].

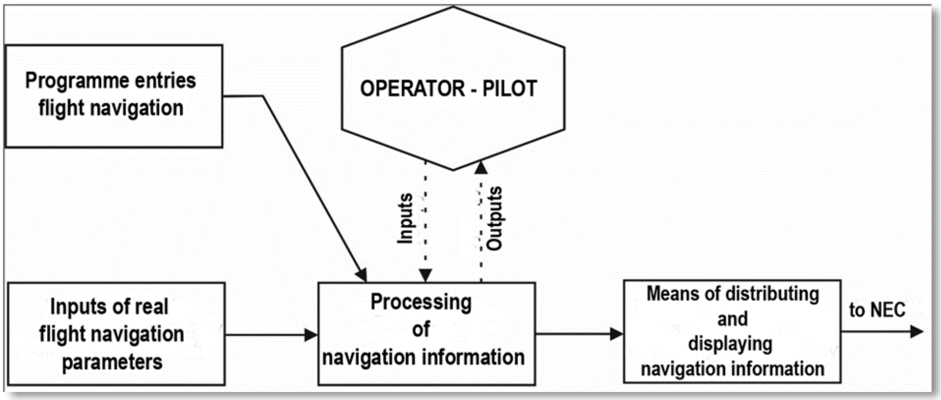


Fig. 3 General architecture of the automated ergatic navigation complex

Differences in their composition and how they are processed by the operator allow automated navigation systems to be divided into the following groups ergatic complexes of automated control of the aircraft along parts of the flight path, when on its partial parts automatic correction maintains the flight on a given runway under the effect of wind in a set course. In this type of complex, the operator enters into the navigation computer the flight programme for each leg of the flight (as a rule, the coordinates of the point and the angle), as well as other related tasks [15].

Ergatic complexes of automated flight control on the flight path along its entire length. They also have an automatic correction of the calculated coordinates according to the automatic evaluation of the wind parameters. Tasks of the operator:

a. Manages the work of coordinate measurement systems;
b. It solves logical tasks in the correction of flight coordinates and flight course;
c. It measures wind parameters and chooses the position of the aircraft in relation to its parameters;
d. Other tasks of an unspecified nature.

NEC with full automation of navigation processes, performing solutions of complex logical tasks and management of navigation information measurement systems. The operator in this kind of complex performs a check on the state of the NEC systems and, if necessary, introduces corrections to the functions performed.

2.1 Navigation ergatics systems target efficiency criteria and mathematical modelling methodology

In accordance with the concept of the target navigation ergatic complex, which is a link between the crew and the aircraft, attention is focused on the navigation ergatic complex, which represents the naturalness of its internal relationships. This naturalness is linked to the specific position of the NEC in space-time. The position of the complex is determined by the control skill of the operator, who sets it according to the known flight plan. This fact also allows a feeling of security (psychological well-being, flowing, fear ours security) to arise in the human operator. This feeling of security is lost if it is disturbed by an unwanted change in the trajectory in space-time. The reasons for the emergence of threats and the loss of well-being indicate the lack of activity of the navigation information elements, including the operator.

For this reason, it can be argued that the general navigation task assigned to the Pilot Ergatic Complex (PEC) currently requires the provision of information on the safe coordination of the deviation that has occurred, in order to restore a sense of security (certainty of non-threat). The content of this information can be considered as events to be implemented in order to compensate for the error:

$$B_2/B_1 \cap B_3 \cap B_4 = A_1 \cap A_2 \cap A_3 \qquad (2.13)$$

The following must also apply:

$(B_2/B_1 \cap B_3 \cap B_4)\ \bar{A}_i = \emptyset$ (2.14)

where: A_1 is an event expressing the competence of the work of the operator of the navigation and power navigation complex.

The A_1 event represents the assurance that the tasks assigned by the operator-navigator (OP) are fulfilled.

A_2 is an event with the content that system errors and malfunctions are solved with the required accuracy.

A_3- is an event with the meaning of certainty that if the OP is sufficiently skilled and works within the time limit of the navigation system, he will reliably solve the navigation task.

$\bar{A}_i$, i =1,2,3 indicates opposite events.

In such a case, equation (2.13) points to an empty set, NEC is not adapted to the navigation task to be solved, equation (2.14) allows one to construct a mathematical model that has the meaning of the general suitability criterion, i.e. j flight safety in space-time:

$P(B_2/B_1 \cap B_3 \cap B_4) = P(A_1)\ P(A_2/A_1)\ P(A_3/A_1 \cap A_2) = E(t) = P_i(t)\phi_1(t)\ R_i(t)$ (2.15)

where: $P(A_1) = P_i(t)$ is the probability of trouble-free work of the NEC, which is applicable to solve the task at the specified time t.

$P(A_2/A_1) = \phi_1(t)$ - expresses the probability that the error of the system and the acting solution allows solving the specified task, defined in a specific(local) space-time, with the required accuracy under the condition A_1((i.e. NEC is technically and energetically adapted to the task.$A_1 P_i A_2 A_1\ \ \phi_1$

$P(A_3/A_1 \cap A_2)$ =R(t)) expresses the probability that a time deficit will not arise under the action of the above two events and a skilled operator.

R(t) - also expresses that the psycho-physiological state of ON makes it possible to fulfill a given navigational task.

The rules of formal probability allow (2.15) to be written in the form (see (2.12)) in the form:

$$\begin{aligned} &P(A_1)\ P(A_2/A_1) P(A_3/A_1 \cap A_2) = \\ &= P(A_2)\ P(A_3/A_2)\ P(A_1/A_2 \cap A_3) = \qquad (2.16) \\ &= P(A_3) P(A_1/A_3)\ P(A_2/A_1 \cap A_3) \end{aligned}$$

The readiness of the OP to solve navigation tasks must be accompanied by its readiness and sufficient motivation. Obviously, equation (2.16) is counterbalanced with safety P(B). The level of safety in the navigation process is a time function:

$U_{bn} = 1 - K_{ds}(1 - E(t))$ (2.17)

where: E(t) represents the target efficiency of the navigation ergatic complex, where E(t) is characterized by shaping (P(i=1,2,3) a safe space-time trajectory over the flight period. This means that under the term target safety of the NEC we can also mean its capability to solve tasks that are assigned during flight. A frequent task of navigation is to maintain the specified flight trajectory without deviation and deviation, e.g. the normative values for permitted yaw are:A_i

Route width [km]:	± 5	± 10	± 30
Previous requirements:	0,95	0,9995	0,9999
Current requirements:	0,99	0,9999	

NECs, unlike automatic ones, cannot work without the participation of the operator. In this case:

$A_2/A_1 \cap A_3 = \emptyset$ (2.18)

Requirement (2.18) places increased emphasis on the characteristics of NECs, the structure and precision of whose work must accept the psycho-physiological characteristics of a person and his intellectual characteristics [16].

2.2 Navigation ergatics systems navigation tasks

The complexity of the navigation tasks solved by the NEC requires certain simplifications to be made, the aim of which is to allow descriptive analysis to be carried out using mathematical methods. General features of navigation tasks are included:

1. within time limits; all navigation tasks are deterministic in nature with a strong probability accent,
2. in the requirement to transmit information in a language that emphasizes the demands on the intellectual qualities of ON.
3. in that the solution of navigation tasks is associated with logical operations, if the performance is realized in the final output, which is the movement of management bodies,
4. in that the output information of the NEC requires parameter control, which is implemented in the system.

The main task of the NEC is to check the correctness of the position of the center of gravity of the aircraft on the specified flight path.

Let the navigational task of the NEC be the realization of a system of equations written in the form:

S_z(t) - S(t) = ΔS(t) ,Z_z(t) - Z(t) = ΔZ(t) ,H_z(t) - H(t)= ΔH(t) (2.19)

where: S,Z,H- are the instantaneous coordinate values of the position of the aircraft at the time of measurement.

t, S_z , Z_z , H_z –specified coordinate values at the measured time.

When the final position of the aircraft is taken, i.e. when ΔS(t), ΔZ(t) , ΔH(t) =0, holds, a final state is reached where (19) represents zero values, i.e. a state in which the flight mode is equilibrium. The above descriptive example also shows the main sequences of solving the task of the NEC:

1. measurement and calculation of instantaneous position coordinates,
2. comparison of instantaneous coordinates with program (entered),

3. calculation of the parameters of the required navigation mode,
4. shaping and sending a directive to the PK, which performs the required navigation mode.

The above sequence is valid in general and also applies to automatic navigation complexes, where the sequence of programs is indicated and determined by the function of the on-board computer. The second main task of the NEC is to ensure flight safety. Essential importance in solving this task lies in observing the horizon. Observation is carried out by locators that provide information (visually) about the meteorological and air situation. If they see something bad outside, pilots usually choose a new direction to fly or find the closest runway. This task, together with the previous ones, is one of the most important. The task of observing, in particular, the front hemisphere of the flight horizon is compulsorily performed by several crew members [17].

2.3 Classification of navigational ergatic complexes

Of the total number of classes of navigation complexes, only those which, in their function, are in connection with a navigator-operator or a kind of operator who performs this function constantly or interruptedly, shall be listed below. This group also includes automated navigation systems whose function puts a workload on the crew member. From the above point of view, NEC can be classified into the following classes (Fig.4):

1. NEC with direct instrumental navigation,
2. NEC with partial automation of navigation task solving,
3. automated NEC.

In general, all NECs include the following technological equipment:

1. The environment for entry programmes;
2. Means of measuring the position and movement of the aircraft;
3. Means of processing navigational information.
4. Means of transmission and indication of navigational information.

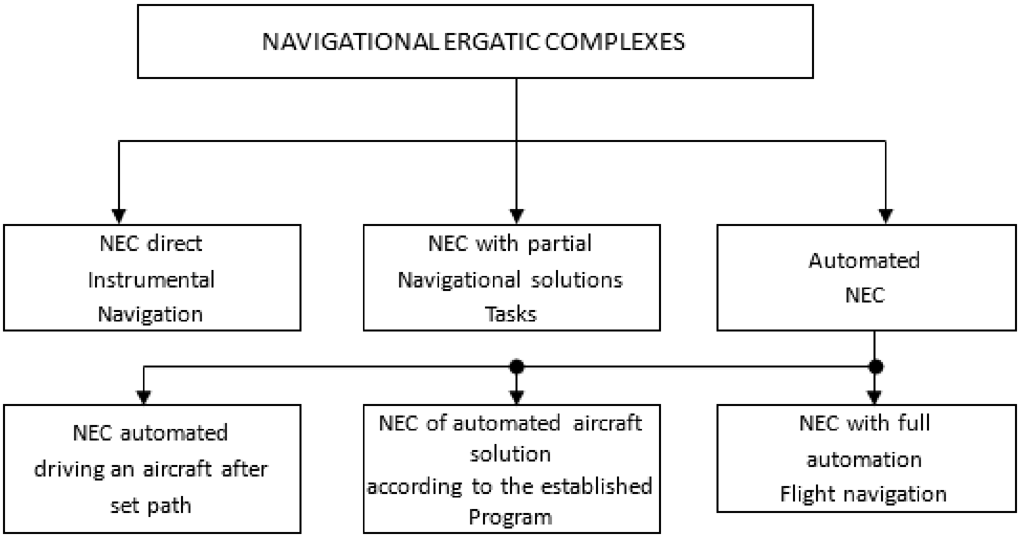


Fig. 4 NEC sorting diagram

The NEC of direct instrumental navigation (Fig.3) is an operator classified as a serial element between blocks of measurement and transmission (distribution) of navigational information. In such a connection, NO solves the following tasks:

1. It receives from measurement systems up-to-date navigation information that characterizes the position of the aircraft in space-time.
2. It compares the obtained visual information with the calculated values and then manually feeds them into the computer program; It compares outputs and establishes a sector of disagreement with program coordinate values.
3. It shall decide empirically whether to induce a navigation mode that creates a correspondence between the actual (factual) coordinates of the aircraft and the programmed ones. The result can be, for example, a comparison of factual parameters of aircraft movement (e.g. line speed, route angle β, wind speed W, specified vertical speed V_{vs}) and parameters specified by the program (β_z ,W_z , V_{vz}) [18].

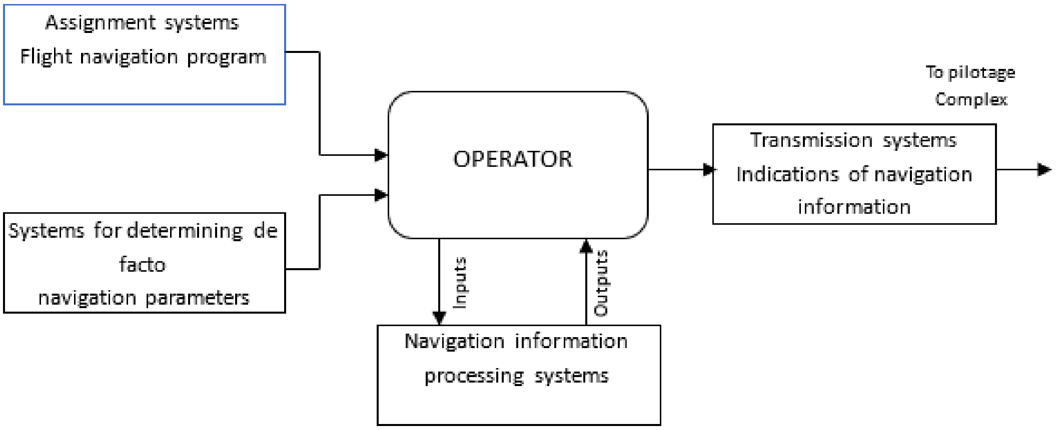


Fig.5 General scheme of direct instrumental navigation

The match is then the result of the management effort shaped by PEC and its manifestation takes the form:

$$\Delta\beta = \beta_z - \beta = 0 \Delta W = W_z - W = 0 \Delta V = V_{vz} - V_v = 0 \qquad (2.20)$$

The NEC diagram with partial automation of navigation task solving is shown in Fig. 6

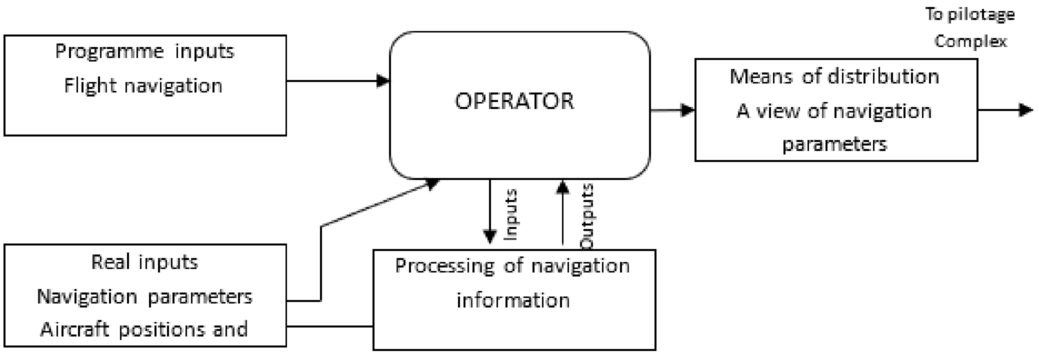


Fig. 6 General scheme of the complex with partial automation of the solution of navigation tasks

Navigation complexes with partial automation of solving navigation tasks according to Fig.6 contain elements of the direct navigation complex. However, they differ in that part of the solved tasks is distributed to the PEC, i.e. their solution is not performed by the operator. The NEC architecture, with partial automation, makes it possible to solve complex variants of navigation tasks enabling flight along a defined path (route), as well as instrument landing even in difficult meteorological conditions [19].

2.4 The structure of navigational ergatic complexes

The architecture of the NEC differs according to the operational characteristics of the aircraft, the manner of use, the speed range, flight altitudes and conditions of operation. Their design is the result of technological progress of production and aviation science. In general, the most frequently solved navigation tasks, which are common to all types of aircraft, determine the architecture of the NEC in the following range:

1. sensors and vertical speed measurement,
2. sensors and measurement of line speed and its components,
3. sensors and indicators of direction, angular velocities, orientation around world coordinates, e.g. course indicator, course angle of radio beacon (KUR), azimuth, nose angle,
4. coordinate computers.

An example of the arrangement of the NEC of direct instrument navigation is shown in Fig.7. Its architecture includes:

1. variometer for measuring vertical air velocity $V_{y,}$ which is used for the speed of ascent to a specified flight level,
2. altimeters (barometric, radio technical) for measuring absolute and relative flight altitude H,
3. instrument or actual air speed speedometer V,
4. thermometer for measuring ambient air temperature t_{ov} (it is important for altimeter and speedometer corrections).

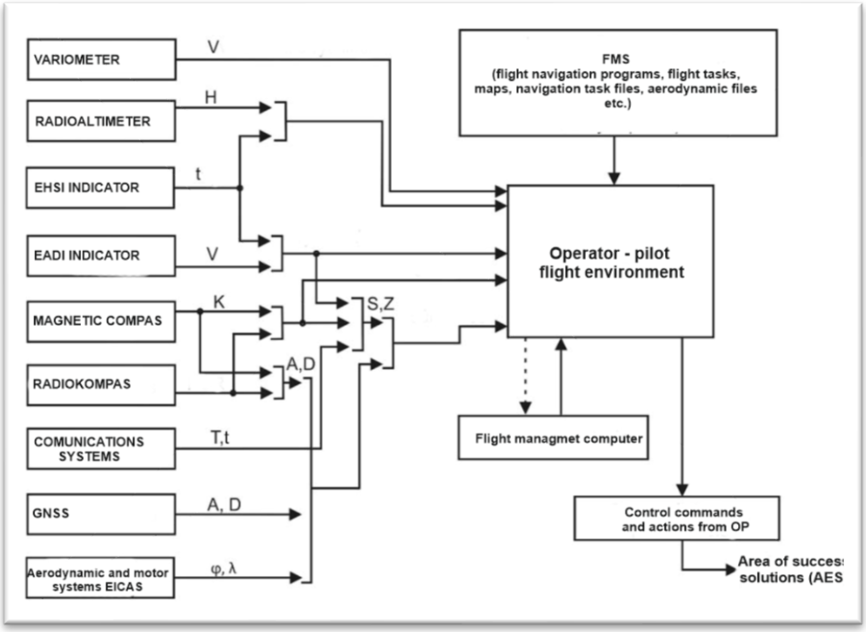


Fig. 7 Structural diagram of NEC direct instrument navigation

Measurement of the direction of flight is carried out using compasses (magnetic, gyroscopic or their combination). The output is magnetic course data (world coordinates), relative rate K. The radio compass allows you to measure the course angles of the supply radio beacons (KUR), which allows calculate the nose angle and also the coordinates of the aircraft using a map.

The radio station allows communication, the content of which is service reports on the movement of the aircraft in the air. The radio allows you to receive and give information about coordinates/azimuth and distance D, wind parameters, as well as flight mode information and more.

Navigation coordinators – natural or artificial are objects placed on the earth's surface, recognizable by the crew from the deck of the aircraft. The coordinates (coordinates) of these points are known as geographical and are denoted by φ, λ.

The clock measures astronomical time T and track time $_{t\,t}$. According to the above data as well as known navigation parameters of aircraft movement (speed and direction of flight), it is possible to calculate the position of the aircraft and solve other navigation tasks.

The navigation programmes of NEC flight tasks include maps in which control orientation coordinates (points) are plotted, as well as a flight navigation notebook indicating the time of flight over each control point, as well as other necessary information.

The processing of navigational information and air navigation parameters for direct navigation NECs shall be carried out manually by the appropriate operator. To perform this function, the operator is adequately trained and works with tools to ensure that the flight task is performed when reaching the specified area.

The NEC architecture with partial automation of navigation task solving contains all NEC elements with direct navigation. The architecture also includes a flying orbit calculation system. For this calculation, the data from the airspeed sensor and the manually determined direction and speed of the wind, as well as the angle marked on the map, are used. Wind data is provided by the onboard radar. The structure of the described complex contains two automatic radio compasses due to the need to measure the course angles of two different radio beacons. By their layout, it is possible to determine the position of the aircraft [20-24].

The peculiarity of the structure of complexes with partial automation of solving navigation tasks is the use of course systems (CS), which represent a combination of magnetic, astronomical and gyroscopic course instruments. These instruments allow automated measurement of magnetic, proportional or orthodromic (conditional) courses. They also allow you to measure the actual airspeed of flight without the need for calculation on the navigation ruler. It also includes an air signal system (ASS) that automatically counts methodological errors in barometric altitude, air velocity, outdoor air temperature as well as selected pilotage parameters.

To solve the tasks of the spatial trajectory in the landing process, course and glisade radio beacons are used in the described complex. The flight over characteristic points on the descent trajectory shall be carried out according to a data-marking radio beacon (signal). Entered descent signals in the course and glisade are automatically distributed to the PEC.

Automated navigation complexes (ANC) are characterized by a significant number of sources of diverse navigational information (Fig.7). They include Air Signal System (SVS), Dopler Route Speed and Nose Angle Measurement System (DISS), Radar Station (RLS), Astronavigation System (ANS), Near Navigation and Landing Radio Technical System (ILS), Navigation Radio technical System (DVOR) and Inertial System (IS).

The processing of the outputs of navigation measurements and the calculation of the parameters of the ANC navigation mode are calculated in the navigation computer. In order to increase the accuracy and credibility of checking the correctness of navigation systems, statistical methods are used in the ANC.

The connection between measuring systems (centrals) and navigation computers (NC) can be one or two ways. For example, the IS sends information about the parameters of measuring the movement of the aircraft to the NC and receives only its corrections from the computer. The use of logical terms in the NC architecture makes it possible to statistically evaluate the results of measuring navigation parameters perform estimates of their plausibility, and then select the most likely value. In the calculation of solved tasks, it is possible to include calculations of distance and time, which divide the position of the aircraft from the specified area of successful solution (ASC). Such a calculation shall include the calculation of the required fuel stock and fuel consumption. In ANC, the navigation computer reduces the load on the operator, relieving him of the need to perform mathematical operations that are necessary for calculating distance, speed, wind direction, flight altitude, and reducing the weight of the aircraft due to the fuel consumed.

In addition to radio stations, connecting systems also contain radio transponders, which are designed to cooperate with active terrestrial radars. The content of the radio transponder information is: aircraft number, flight altitude, fuel reserve and, if necessary, voice information.

The navigation mode of flight in the vertical plane on all NECs is realized using aerometric parameters and altimeters, which make continuous measurements of flight altitude, direction and flight speed value, their indication. These parameters are used in PEC. In the case of prospective (now partially implemented) ANCs, four-dimensional navigation tasks are solved, where onboard numerical computers (FMC) solve navigation tasks of flight altitude, and vertical speed, whose signals are distributed to PEC, which controls the position of the aircraft in the vertical plane [25,65].

2.5 The interaction between the level of automation and the characteristics of the complex navigation systems

Aviation operational practice has confirmed that a reliable system is not the ultimate guarantee of flight safety. It is also known that the high accuracy of the navigation complex is not always profitable and does not dominate safe flight operations. This means that excessive and advanced automation can harm flight safety. This also applies to NECs. This is because characteristics such as accuracy, reliability and degree of automation are largely incompatible. Their installation on board aircraft shows the technological level achieved by the manufacturer, but they are unusable in certain operating conditions. For this reason, the task of optimising the operating characteristics of each dedicated aircraft system from the point of view of its efficiency stands out. This means that optimising the characteristics of a purpose-built aircraft is not only a technical problem but also an economic problem, as well as an ergatic problem in terms of solving specific light tasks. Figure 8 illustrates the relationship between these factors and the NEC operational characteristics of the purpose-built aircraft.

The accuracy of the NEC is bilateral. Signals enter the block:

1. Flight navigation requirements
2. Accuracy of the automated complex.

The higher the accuracy of the NEC, the lower the operator's workload in solving navigation tasks with the required accuracy. Conversely, the less accurate the NEC is, the greater the operator workload will be for flight protection with such accuracy. This means that the degree of automation should reduce the operator's workload (stress). The operator workload is connected to the system reliability fig.8. To solve navigation tasks, the operator needs working time, which also includes a time reserve in case the automated system becomes unreliable. In such a case, the operator solves the navigational tasks with the help of reserve means, with which he can eliminate disturbances during the flight. The operator is also required to propose the elimination or resolution of the malfunction. In such cases, the operator's professional qualifications are required. It is clear that when searching for ways to eliminate malfunctions, he interrupts his action and does not engage in navigation, since he is performing control and search functions, which usually involve the need to send service reports to other crew members or the appropriate ground centres.

The search for faults and elimination of their causes is only effective if the control system (block 7) implements a fault search programme and the operator is sufficiently capable of eliminating the fault by his solution within the required time.

It should be emphasised that the operational way of finding and eliminating an error during flight places new demands on the automation of navigation and, in this context, also requires new skills of operators for its operation and management. The development of operator functions calls for the use of micro-miniature, sufficiently reliable equipment, the control of which in ground (pre-flight) conditions cannot provoke and anticipate the occurrence of faults that can manifest themselves only in flight conditions. However, the main task of the operator is to be a double member of the automated system, since even a multiply booked system does not exclude the possibility of interruption of its activity or transition to a system whose output is inaccurate data. In this case, each member of the crew becomes an operator-navigator. Any malfunction or inaccurate, indefinite navigational data leads to an increased workload for all crew members. The interaction of the reliability of navigation equipment increases the financial costs of its development, production and operation [26,11].

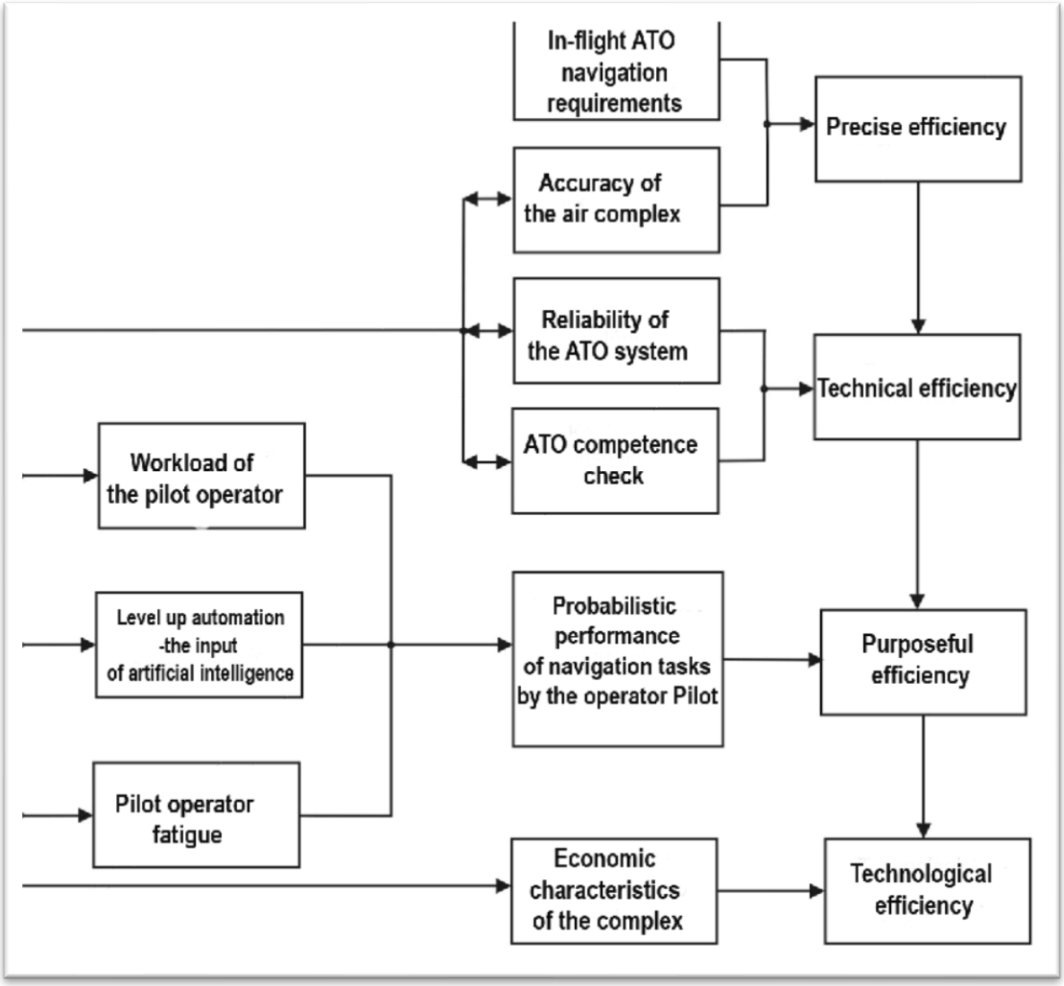


Fig. 8 Interaction of NEC characteristics

From the results of the solved example, as well as from the description in Fig. 8 and before, it follows that the efficiency indicator is the fault-free function of the ergatic parts of the navigation complex. Let us introduce the concept of general efficiency W. Under this term, we will understand the functions of the process parts of the circuit (Fig.8) and its inputs. Let be (in relative quantities) the own function defined by the equation:

W = W [C, P, R, A, ...] (2.21)

where:

C – the quality of the management functions of the NEC system and its elements,

P – comprehensive system reliability (in the sense of ergatic),

R – development costs;

A – operating costs.

Let's describe the significance (2.21) of the interactions illustrated in Fig.8. It is clear that the primary parts of the NEC are technical systems, which are represented by blocks 5, 6, 7 (Fig.8). The financial costs of maintaining their reliability of P, together with the payment for the energy insurance of their operation, require constant financial attention to the connections and their renewal. Failure to comply with this requirement means loss of meaning of the NEC. Let us concentrate (accepting the meaning just mentioned) blocks 5, 6, 7 (Fig.8) into a single block C (see 2.21), the elements of which are $c_{i,j}$ Let all elements work with reliability P, and let these values form a matrix C. Each element $c_{i,j}$ (its probability) has the value of cash deposits necessary for their operation. This means that for the operation of integrated blocks in matrix C, funds proportional to the value of K are required, to maintain the operational reliability of P. For the stated reason and the number of elements $c_{i,j}$ is matrix K its elements are $k_{i,j}$. If we consider that the operator has a finite amount of funds, then the following applies:

$O = C \times K$ (2.22)

Let d represent a set of random causes that affect the reliability of P and act capitally on the total volume O. The financial coverage of these coincidences is expressed by elements $d_{i,j}$ where j is constant. A with elements and $a_{i,j}$ with demands on the volume of funds $A \times K = b$. Operation is always carried out with restrictions (limits) from below lb (level b) and from top ub (up b). The described situation of reciprocity can be illustrated by an illustrative diagram (Fig.9).

Based on hypothetical inputs, let us solve the optimization of capital inputs in order to ensure the process functions of the technical part of the NEC. The requirement of effective reciprocity is the confirmation of certainty that the amount of funding A×K exceeds or is sufficient to cover the operation of the NEC and the reliable operation of P. Then: $|C \times K - d|^2 \leq A \times K \leq b^*$ (2.23)

where the left part (21) represents the criterion value of the comparison K. The quadratic criterion function significantly suppresses small values (below zero) and highlights values above zero [27,19].

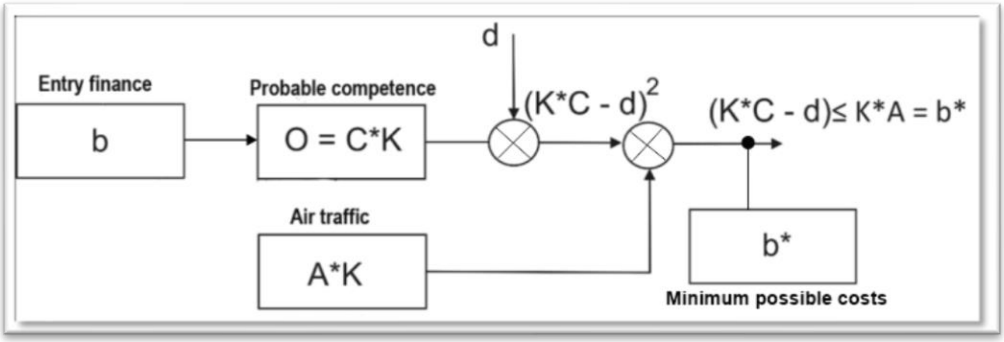


Fig. 9 Interaction of economic, technical and operational links in NEC

where K - is the matrix sought, b^* - is the chosen matrix that freely enters the algorithm:

<u>Interaction of stages in navigation ergatic systems</u>
Aggregate value probability:
C =[0.985 0.9976 0.9961 0.9994; reliability of energy sources;
0.9923 0.9945 0.9791 0.9935; reliability of sensors
0.9606 0.9960 0.9821 0.9816; reliability of signal processing
0.9848 0.9829 0.9973 0.9741; display reliability
0.9989 0.9994 0.9987 0.9989]; the reliability of the control system;
Contingencies (in unit cost scale):
d = [0.0578, 0.3528, 0.8131, 0.0098, 0.1388];

Coverage of costs planned in calendar terms (in unit cost scale) (e.g. A = 4 months):
A =[0.1202 0.2721 0.7467 0.4659
0.1987 0.1988 0.4450 0.4186
0.3603 0.0152 0.9318 0.8462
0.1356 0.2167 0.8327 0.6235
0.1852 0.3468 0.7843 0.6268];
The first column sums up the unit/unit capacity. Others accept variability in reliability. The volume of funds (Fig.8) is also needed to ensure the operation [A] will cover:
b =[0.5251; 0.2026 ;0.6721; 0.4265; 0.3114];
The necessary amount of funds (Fig.9) to maintain eligibility [C], [A] is determined by payment with the amount of C*K-available capital while accepting the selected limitations:
lb = 0.1*ones(5,1),ub = 2*ones(5,1),(lb-minimum required).
Calculation of comparison coefficients, i.e. matrix "K" at lb=ub=0
The model for calculating a matrix that minimizes the result of comparison is:
K=lsqlin(C,d,A,b,[ ],[ ],lb,ub), minimization (columns): MATLAB program;

Starting from the scheme of the model of minimizing necessary costs (Fig.9), it is possible to indicate:
q=(C*K-d); Q=q.^2, square squares.
A*K,
Condition (K*C-d)_<A*K, is true.
A*K=b* is a real result of minimizing the costs of maintaining the operation of the NEC.

CHAPTER 3

MONITORING THE SAFETY OF THE AEROSPACE ERGATIC COMPLEX

The control of complex systems in which a human operator operates is linked to the need to solve tasks generated by a functional machine-intelligent system. The regular harmony of the intelligent connection between man and machine creates a special arrangement, which will be referred to in the following as the ergatic complex. The movement of an aircraft, as an unruly body, i.e. in the simplified sense of an inflexible body, consists of two components, which are generally expressed in the Earth's coordinate system:

1. motion around the centre of gravity (rotational motion);
2. movement of the centre of gravity (translational motion).

Each of these motions is characterised by three degrees of freedom so that the resulting motion is determined by certain degrees of freedom, which requires the use of six coordinates when creating its dynamic model. A more detailed analysis shows that this concept is inaccurate because it does not take into account the influence of aerodynamics and the environment in which the aircraft is moving.

A detailed analysis of the forces and moments acting on the aircraft shows that to describe its movement in free space by an abstract mathematical model with state variables, we need an infinite number of degrees of freedom [28,4].

3.1 Aircraft Situational Flight Dynamics Modelling

The described situational dynamics of an abstract model are only valid under the assumption that the environment under consideration is also abstract, physically undisturbed, and free of other material bodies. In spite of the simplified dynamics of the above model of the flight space, which represents the presence of another body, we conclude (from the point of view of flight safety) that it is necessary to take into account the interaction of real situational dynamics of two bodies, for which it is desirable to create a new, again simplified, mathematical model. The concept of situational uncertainty describes the complexity of the problem with an idea of its magnitude, which is important and often unidentifiable in the assessment of aviation safety, as well as in the search for the causes of aviation accidents. An equally important concept is cognitiveness, i.e. the cognitive ability of an aircraft and a human operator to perceive a situation and to adapt with a certain degree of dynamism to changing situational conditions. Contemporary aircraft manufacturers provide users with aircraft equipped with various levels of intelligence, which, with their utility value and embedded expert experience and ideas about the desired behaviour of the aircraft, create the prerequisites for providing information that reduces the entropy of situational flight dynamics. A graphical interpretation of the problem is shown in Figure 10.

3.2 Model of situational flight dynamics realised in two adaptation spaces

Let us now consider the flight of an aircraft whose purpose function is determined by the activity of groups of people, the concept of man-operator [generalises whose action1]. It is generally impossible to determine the degree of freedom of its situational dynamics. The common abstract space of both situational dynamics realised by machine and human-operator in cyber-machine bond is situational space D, which simply represents a physical space for aircraft and space D' for human-operator.

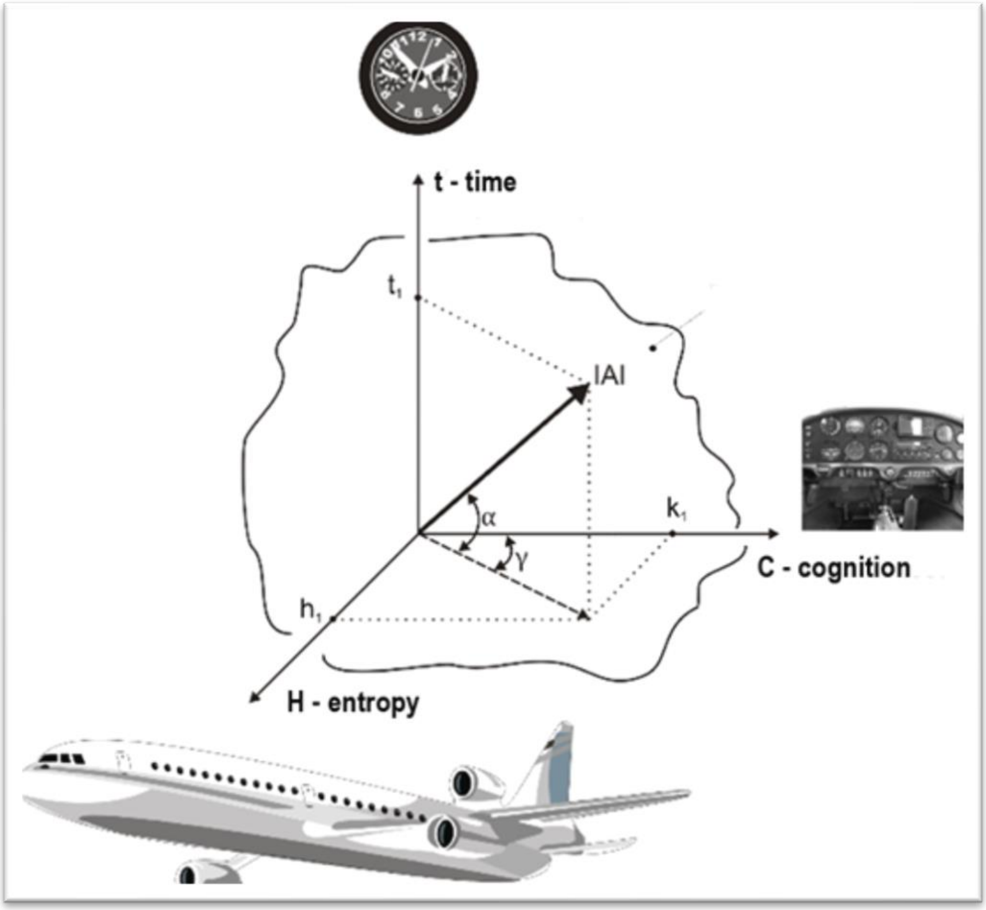


Fig. 10 Model situational flight dynamics in space of physical adaptation

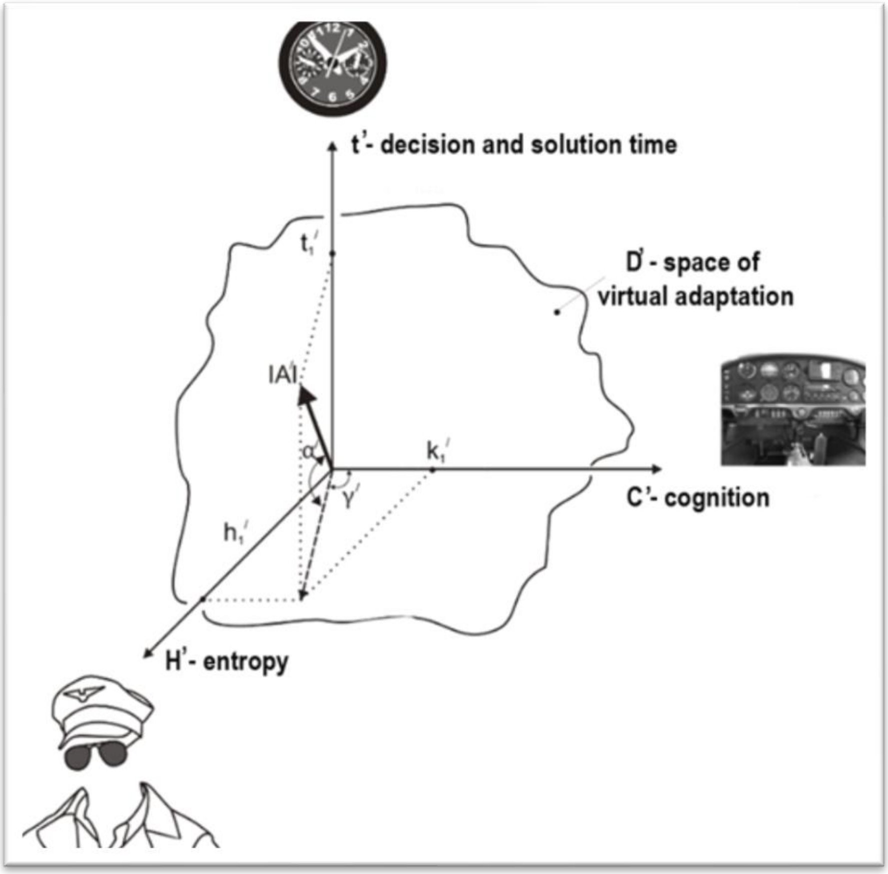


Fig. 11 Model situational flight dynamics in virtual pilot adaptation space

Computer science, which represents the intelligent properties of the aircraft and the learned, trained skills of a human operator, constrains each of these spaces. Another non-binding fact in creating an idea of situational dynamics is the virtual and physical knowledge that is fixed in his consciousness by real practical experience, shaped by flight training, e.g. on flight simulators, as well as by the educational environment. Here we also include the influences of fixed personal images and emotional elements, which complete the content of the adaptation scene D'. We can further increase the complexity of considerations, e.g. disinformation with dominant interference effects, operating in the sphere of adaptation D and adaptation scene D'. For safe flight, the equivalence D = D' must apply, which is reflected in the new representation (5). This represents the new safety coordinate system shown in Figure 12.

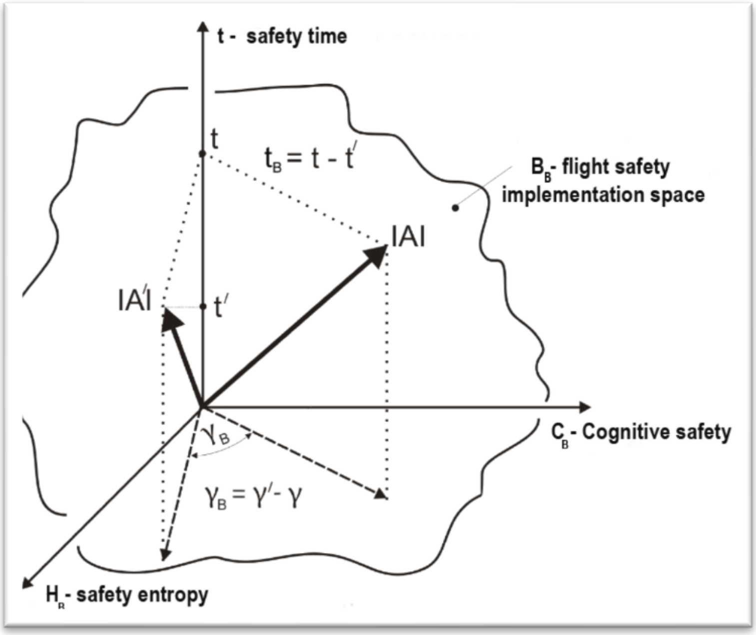


Fig. 12 Coordinate flight safety system

for $t_B > t = t - t'$ → prognose of decision
for $t_B < t = t - t'$ → stress,
for t = t‘→ balance flight

A difference of $D \neq D^1$ creates the conditions for a stress situation to arise. They are induced by shifting the resulting module towards the coordinate that is dominant for the flight situation. A negative value of the distance between the modules $|A_D|$; $|A_D^1|$ generates a stress S that reduces the cognitive capacity of the whole system and defines a permanent limited safety. The legitimacy of the considerations made can be documented by real records of air disasters (black boxes), which confirm the above assertions (1). The evolution over time of the record shows, to a reasonable extent, changes in the characteristics of the aircraft and in the results of the decisions taken by the crew, which led to interventions in the control system, as well as to aberrant functions that ended the flight catastrophically and irregularly. Research in this area will aim to determine the critical angle γ kr beyond which return to the safe flight zone (γ_B) is impossible [29,39].

A transparent interpretation of the problem of degradation of aircraft flight safety is intended to show that an isolated assessment of a safety problem is generally unjustified. An unambiguous indication of the cause of the degradation of the safety of the ergatic complex almost always leads to an isolated assessment of the emergence of the final consequences, regardless of their development. The dynamics of causes and the number of aviation accidents in Figure 12 distinguish the origin of their occurrence caused by human operators and aviation technology.

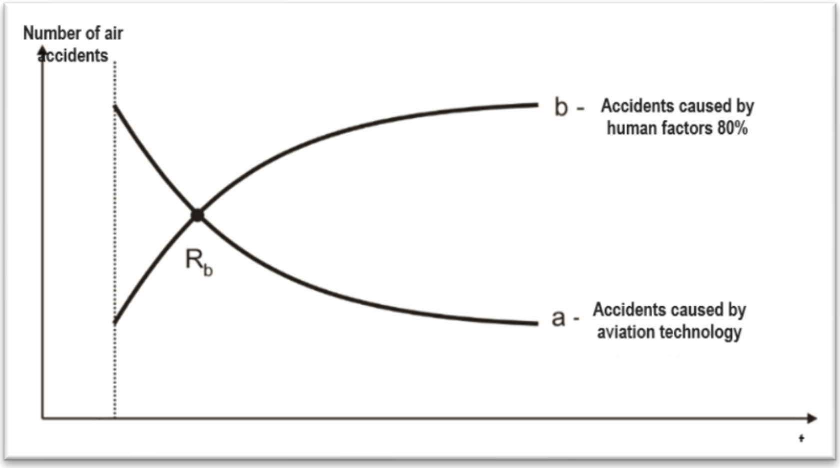


Fig. 13 Dynamics of aviation accident development

The increase in the distance between curves a, and b in Figure 13 is considerable and reasons can be given for the non-decreasing steepness of the line b. The common point R b where the lines intersect is critical and suitable for further research. According to ICAO statistics, the human factor is responsible for 80% of air accidents. Of these, 25-30 % are due to deficiencies in professional training. The unsatisfactory state of training of aviation professionals in university training centres (9) is due to their lack of training. To overcome this, ICAO has developed a special programme called "TRAINER", which aims to improve the safety and efficiency of air transport. The effectiveness of training for aviation professionals is directly related to the research work of training centres [30,54].

3.3 Capability for rating operators of autonomous means in air transport

The initial hypothesis for identifying the skills of operators who control the aerospace ergatic system is to show by measuring the control elements of autonomous systems on possible mathematical models. By simulating them, it is possible to carry out a certain process evaluation of the individual profession of operators to control an air transport object (ATO). Verification of the validity of this hypothesis presupposes conducting research in at least three areas:

1. In relation of operators to the characteristics of the aeronautical ergatic system (AES).
2. In the issue of the cognitive abilities of the operator and in his improvement (learning) of his professional competence to drive an airborne autonomous vehicle (ATO).
3. In the assessment of the achieved state of the ability to identify and forecast one's own skill to guide the ATO along the track. This shall be consistent with maintaining

the professional motivation of operators and in conjunction with flight safety and effective identification of their own skills.

The complexity of the problem and the interaction in the action of the listed areas can be illustrated by the diagram in Fig. 14.

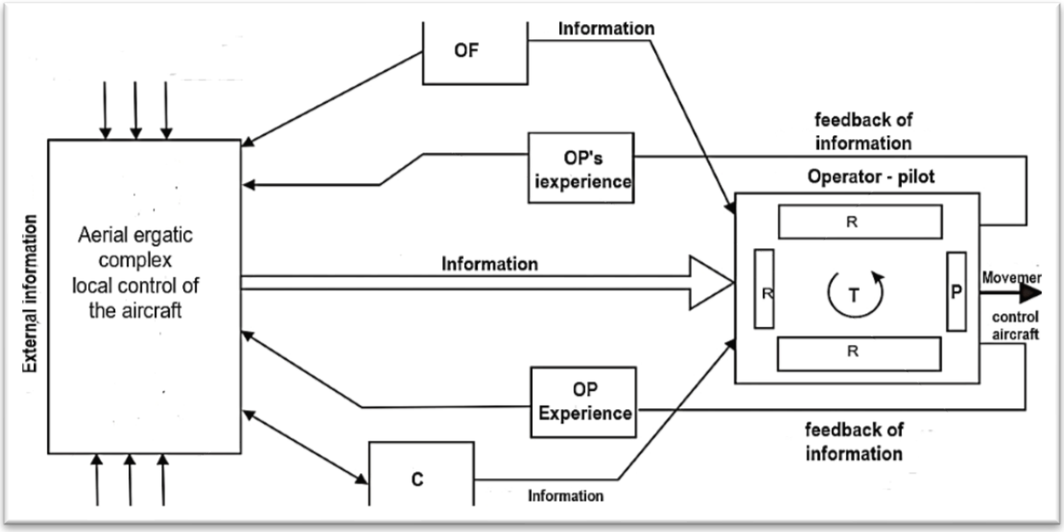


Fig. 14 Scheme of interaction and influence of AES control by ATO operators

Meaning of symbols:

OS - objective fact and its informative picture;
C - cognitive ties and influences of mutuality;
R - operator-pilot receptors through which it receives and perceives information;
T - transformation of information received by operators, pilots, and their decision-making
P - power components operator - pilot, reaction
OP experience - experience of operator – pilot, current awareness of the situation manifested in the skill of controlling the AES.

The interaction of environmental influences, in which the ATO and the operator are located, emphasises the two-way interaction of human characteristics (possible bionics) and the machine connected to the aircraft ergatic system, especially when the control activities of the operator - the pilot - are influenced by external information flows. Then we are talking about the aerospace ergatic complex Fig.15.

The theory of optimisation of avionic systems, which is successfully applied in the theory of automatic control of aircraft, can be used to design the optimal operation of an airborne object. It is possible to observe the process of optimisation that takes place in the field of interconnections and links "aircraft - operator - pilot". To apply this approach to this problem, it is necessary to monitor human adaptation and create space for its design as a mathematical model for ATO management. It is crucial to manage the successful flight activity of a given aircraft to accomplish the assigned flight task. This view changes the ATO control tasks assigned to the operator, where the control of the processes of stabilising the positions of the aircraft is promoted to the monitoring of the subsequent corrections. These corrections are indicators of the quality of the operation of the whole assembly of the aeronautical system.

How can the quality of an aeronautical system be assessed? From a practical point of view, the most suitable criteria for assessing the quality of an ergatic process are statistical criteria applied to the analysis of the parameters of the flight tasks performed in a series of cycles of an aeronautical ergatic process [31].

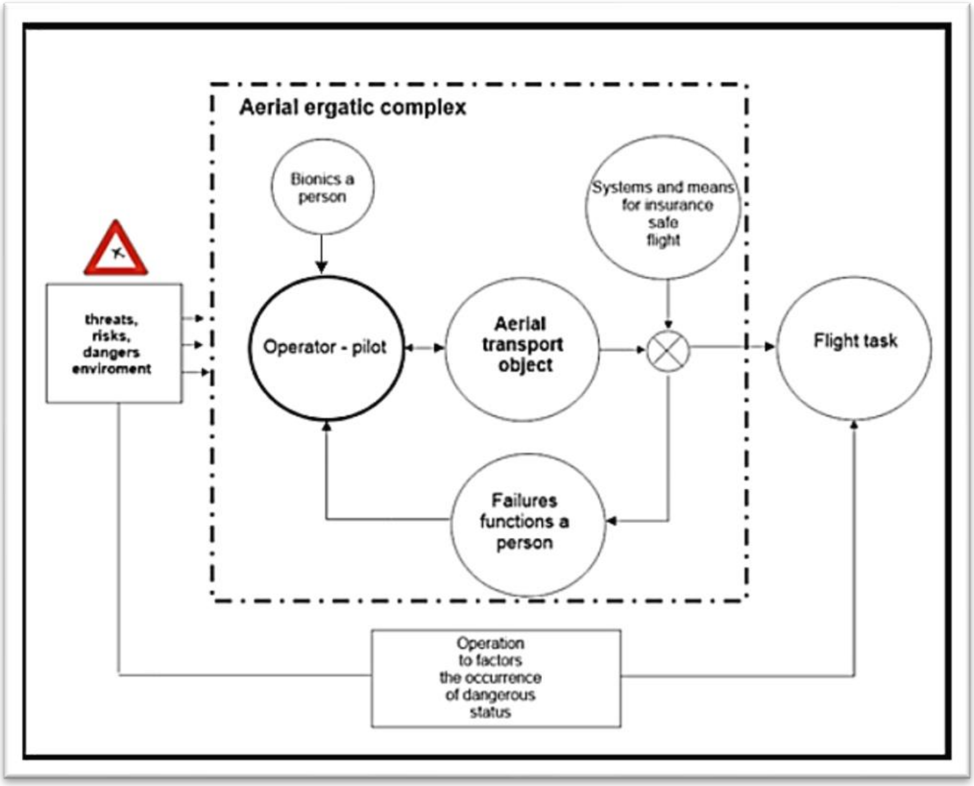


Fig. 15 Aerospace ergatic complex

The position of the man-operator as a member of the aeronautical ergatic system is manifested in a special kind of self-realisation of the implementation of control processes, which is connected with learning to control an airborne transport object. The result is the creation of new algorithmised procedures for controlling an airborne transport object (e.g. a sophisticated aircraft) Fig. 16.

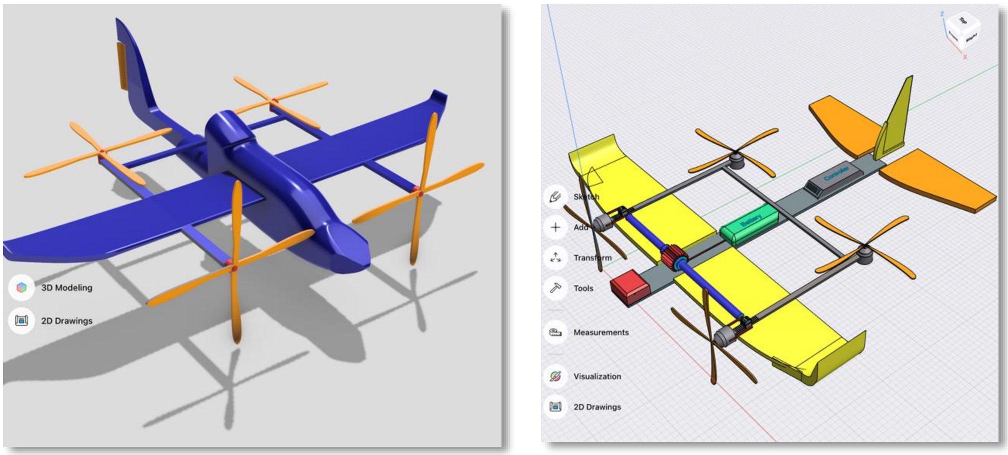


Fig. 16 Sophisticated flying apparatus with avionics formed at LF TUKE

Statistical methods are used as a tool to evaluate the way of implementation of ATO control and management and allow to estimate the quality of the aeronautical ergatic process. The basis of the applied statistical method is the information obtained not from the final results of each cycle of the control process, but from the results of the course of the manifestation of the operation of the aeronautical ergatic system in contact with the limits of flight safety. This method of local estimation (between safety limits) makes it possible to determine the probabilistic characteristics of an aeronautical system for each cycle of the ATO control process. It is then possible to draw an information curve and subsequently correct the operator's control method [32].

Any control of modern autonomous objects is carried out according to errors. This means that the operator assumes the role of a supervisor who compensates for control errors that have been programmed according to the flight trajectory. Such learning to control a flying object by errors during flight performance consists of successful and unsuccessful cycles in the process of controlling an airborne object. It is this learning, based on the ATO operator control process in both standard and non-standard flight modes, that makes it possible to perform a systemic statistical assessment of the quality indicators of the ATO management process. It takes place in cycles and is realised based on statistical modelling of the aeronautical process as a targeted estimation of the system's reliability [33].

The reliability of AES is understood as a non-local concept. Reliability estimation methods allow us to take into account the factors that differentiate the operator's motivation to manage the ATO from the emotional tension and responsibility to perform the task. The scales of influence of these factors come to the fore in the implementation of unique systems operating in the special conditions of aerospace. Statistical modelling of the aeronautical ergatic process allows imitation of standard and non-standard flights so that reserves in the operator's self-realization ability and forecasting of his activity when changing the functions of the ergatic system can be determined.

When imitating ergatic modes, it is necessary to simulate dangerous functions of AES (hazardous to humans), which is contrary to the ethical principle. When observing the dangerous states of the ATO and the mode of work of the ergatic system, it corresponds to motivation and emotional tension and a level not ours than in the case of the action of boundary flight conditions determined by the characteristics of the air apparatus [34].

Many works are devoted to the mathematical description of the operator as a member of the ergatic system. As a rule, the described models are always consistent with the research model, which is based on the type and method of imitating the management process. Therefore, it is necessary to establish in advance the prerequisites for the design of the aerial ergatic system with the possibility of implementing the estimation method after reaching a certain level of quality of the performed tasks. In addition, the fundamental instability of the operator's characteristics and its ability to learn at the stage of model construction require correction methods. In ATO control, the control procedures are synchronized with the manifested results of the aeronautical ergative process. The correction is usually accompanied by a multi-stage asymptotic adjustment of the variable parameters of the AES model.

The presence of a full-fledged automatic control system such as AES is what essentially distinguishes, for example, an unmanned UAV from a helicopter. Any of the UAV subsystems (surveillance, communication, power, power) is derived from a related branch of technology, adapted to the application to one degree or another. Any automatic control is based on a simple sequence: measuring, comparing and averting the disturbing influence. The function of measuring system status in a modern professional aviation navigation and control complex is usually performed by a small integrated inertial system (MINS). The system, which is composed of a triad of inertial sensors (micromechanical gyroscopes and accelerometers), as well as a barometric altimeter and a three-axis magnetometer and combines the data of these sensors with the data of the GPS receiver, develops complete navigation. solution in terms of coordinates and orientation angles [35].

The skill in such control increases the efficiency, safety, and economy of the flight. Let us analyze a simple mathematical model of OP placed in the cockpit of the system shown in Fig. 17, expressed as a transfer function with a variable delay. The display information monitor displays the data of the unmanned aircraft with which the operator identifies (Fig. 17) - supervisor control. The ability to demonstrate conformity is expressed in the term operator-pilot skill [5].

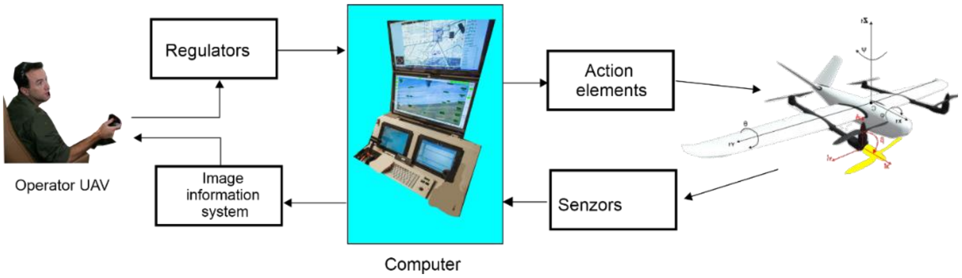


Fig. 17 Principle of supervisor control of UAV with unmanned aerial vehicle

Model of the construction of the UAV complex during its control with known avionics for VTOL.

The content of the technical term "symbiosis" refers to the manifestation of the quality of reciprocity of the skill of the operator - the pilot (OP) in controlling the aircraft. [11] Assume that the image information monitor (IM) solves the situational task of tracking the target (e.g. approach to the line of contact on the VPD). The diagram in Fig. 18 represents the movement of the center of gravity of the LES described by the transfer function of the aircraft movement.

$$F_{LES} = K_0 / s^2$$

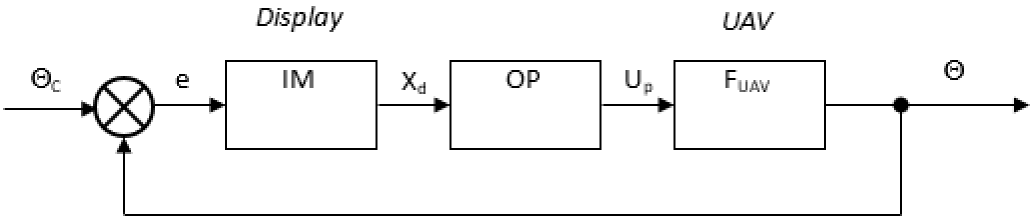


Fig. 18 Illustrative diagram of the UAV tracking process during landing from horizontal to vertical flight

Legend: Θc - desired position of the target, Θ - controlled position angle of the object (aircraft), e - control deviation caused by the different value Θc and the current value Θ, Up - direct control by the operator without correction

Solving the situational task of tracking the target is connected with the need to shape control commands ahead of time. Feedback from the angular velocity [7], the content of which provides the relevant necessary information is provided to the operator to the operator also includes the property of the object Fig. 19. Structure of the mathematical model of symbiotic bonds:

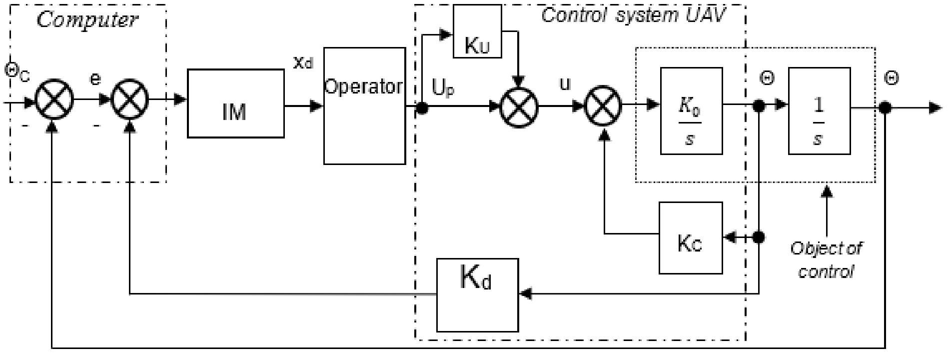


Fig. 19 The structure of the mathematical model of UAV control

Legenda: Θc - required angular position of the UAV (input quantity),e- the difference between the measured input quantity and the actual position UAV Θ , OP-operator – pilot, Ku - corrective member of direct control, K0 - integration constant of the process, Kc - stabilizing member Kd- feedback coefficient, u - flight process control UAV, Up – direct control of the UAV by the operator without correction, Θ - position angle, Θ - angular velocity

The complexity of the problem requires dividing the task into sequences, that is, steps that enable understanding of symbiotic dependencies [3] Transmission of the UAV automatic control system function

Open loop transfer function:

$$W(s) = \frac{K(s)}{f(s)} = \frac{K_1 \, W_y(s)}{s\,(T_s + 1)}$$

$$s^3 + 1.21s^2 + 12s + 0.6976$$

S (0,13 + 1)

closed system transfer function:

$$\Phi_0(s) = \frac{W(s)}{f(s)} = \frac{W(s)}{1 + K(s).W(s)}$$

$$\frac{\frac{1.863s^2 + 0.104s}{s(0.13s + 1)(s^3 + 1.121s^2 + 0.6976}}{\frac{1.863s^2 + 0.104s}{s(0.13s + 1)(s^3 + 1.121s^2 + 0.6976}}$$

Proportional control law components were introduced to ensure accuracy. To ensure the stability of the control system and improve the transient response.

$$\delta_\varepsilon = K\,(K - \,\omega req) + \,K_{\omega z} + \omega z$$

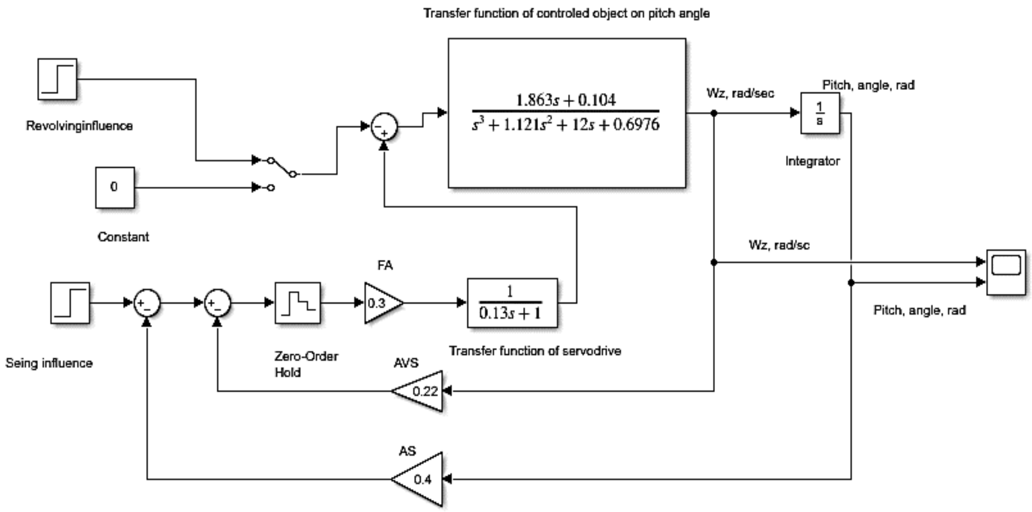


Fig. 20 Model of the UAV control system in the longitudinal channel

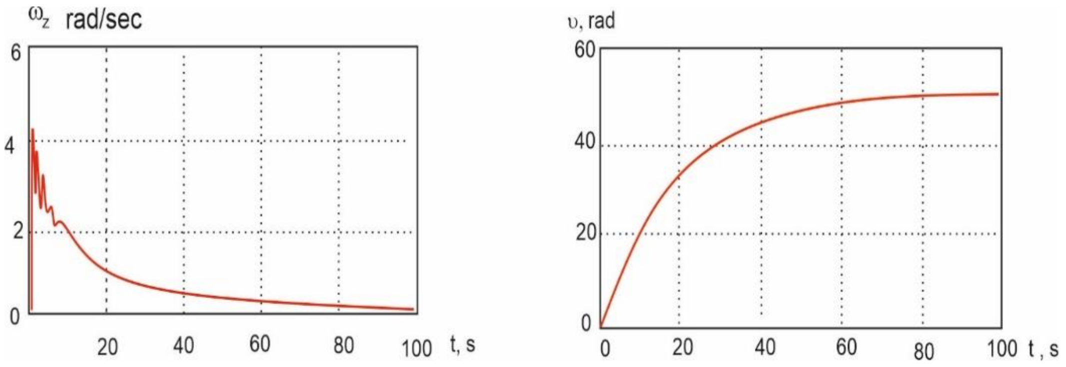


Fig. 21 The response of a closed system to the action of a gradual input

Figure 21 shows the simulation results.
a) dependence of angular velocity on time
b) dependence of the inclination angle on time

Based on Fig.21, the investigated closed system in the longitudinal channel is stable, but its qualitative indicators (especially the steady-state time) do not meet the requirements of the specifications. Therefore, it needs improvement. To create frequency responses, Matlab commands were used: Bode - for a closed system and Reserve - for an open system.

It shows the results of the obtained frequency characteristics in Fig.22.

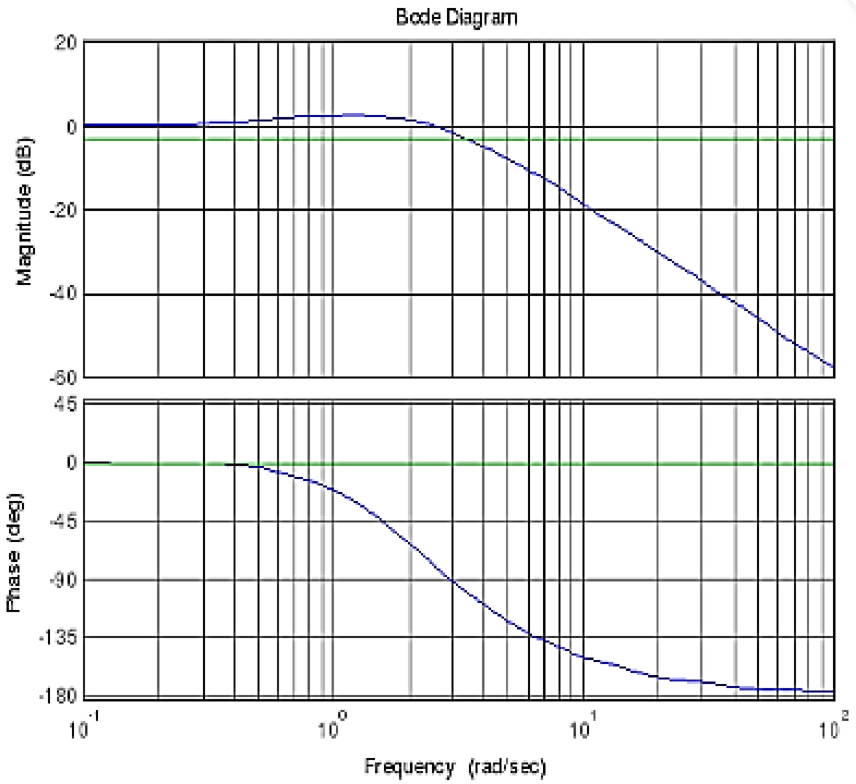


Fig. 22 Transition characteristic of the manifestation of horizontal flight

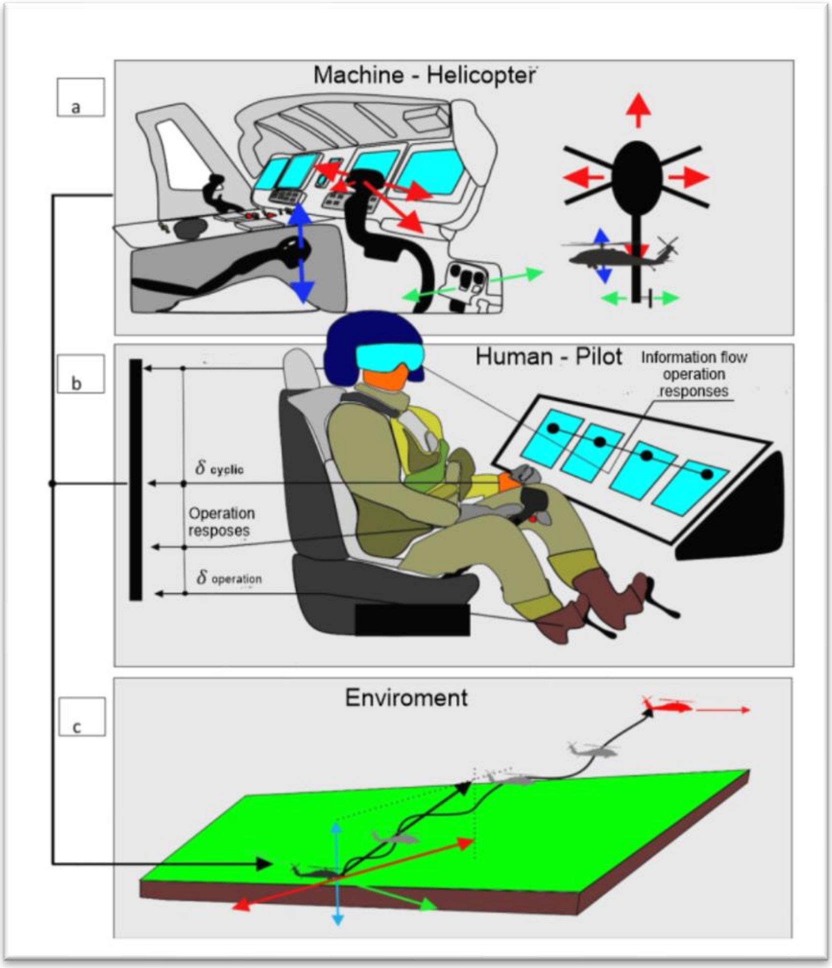


Fig. 23 Reflective ergatic process in ATO control

The second architecture of the model of the aeronautical ergatic system makes it possible to realise an interesting process of simulating the emergence of conflicts. This is a reflective ergatic process that can be carried out using specific identifiers of the operator's skill. In this way, the operator's skills and habits acquired during the different phases of the activity can be fully realised (Fig. 23).

The creation of habits for precise control of the ATO (helicopter) 16a is the automation phase of a complex ergatic system. This is the basis for the best possible pilot response 16b. As a result, the musculoskeletal and vegetative functions are aligned and balanced, and uncertainty in control is lost. This phase is characterised by further consolidation of the feeling of self-confidence and positive expressions of confidence during the flight. The output is the pilot's ability, assuming the development of his abilities and the prediction of time changes of emerging phenomena and orientation in the flight environment of (Fig. 23) [34].

CHAPTER 4

COGNITIVE PROPERTIES OF AERIAL ERGATIC COMPLEXES

The capabilities of current AES are close to those of intelligent beings. The perception of scenes, the recognition of images of the environment and the creation of programs of their activities distinguish them. Cognitive AES(K) is its own management, cognitive, and decision-making activity, which is concentrated in the structure of Fig. 24.

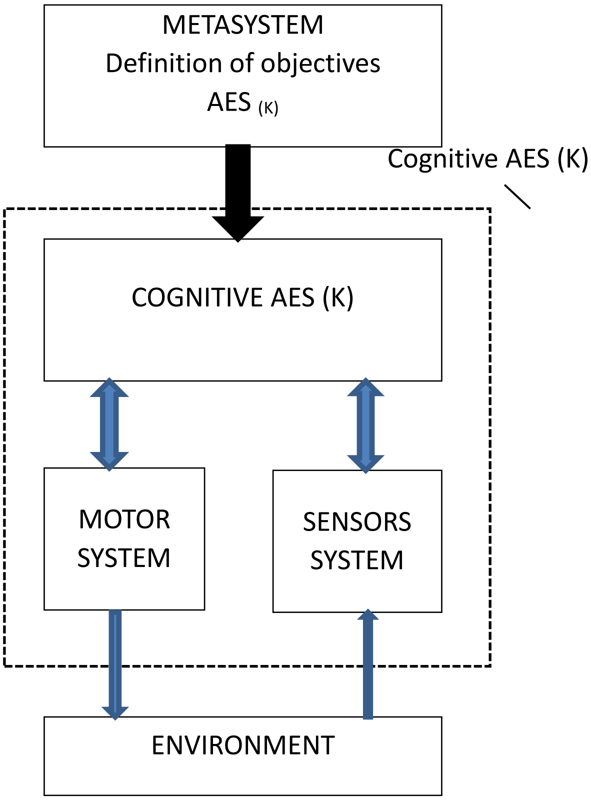


Fig. 24 Basic structure of cognitive AES(K)

Powerful computers provide the cognitive AES(K) function but may not be a necessary part of the airborne equipment. The external computer can be connected to the AES via a suitable data transmission system, e.g. wire AES, which controls the on-board sensor and motor system. It is also possible to use one computer to control several separately flying AES(K).

The sensory system is designed to respond to changes in the situational patterns of the environment and the internal states of the AES(K). It actively influences flight situations in the environment through the motor system. The relationship between the cognitive AES(K) and the environment has a feedback character. The interaction in the action and flow of information in the internal structure of the AES(K) with cognitive properties is shown in Fig.24, which incorporates the idea of Fig.25.

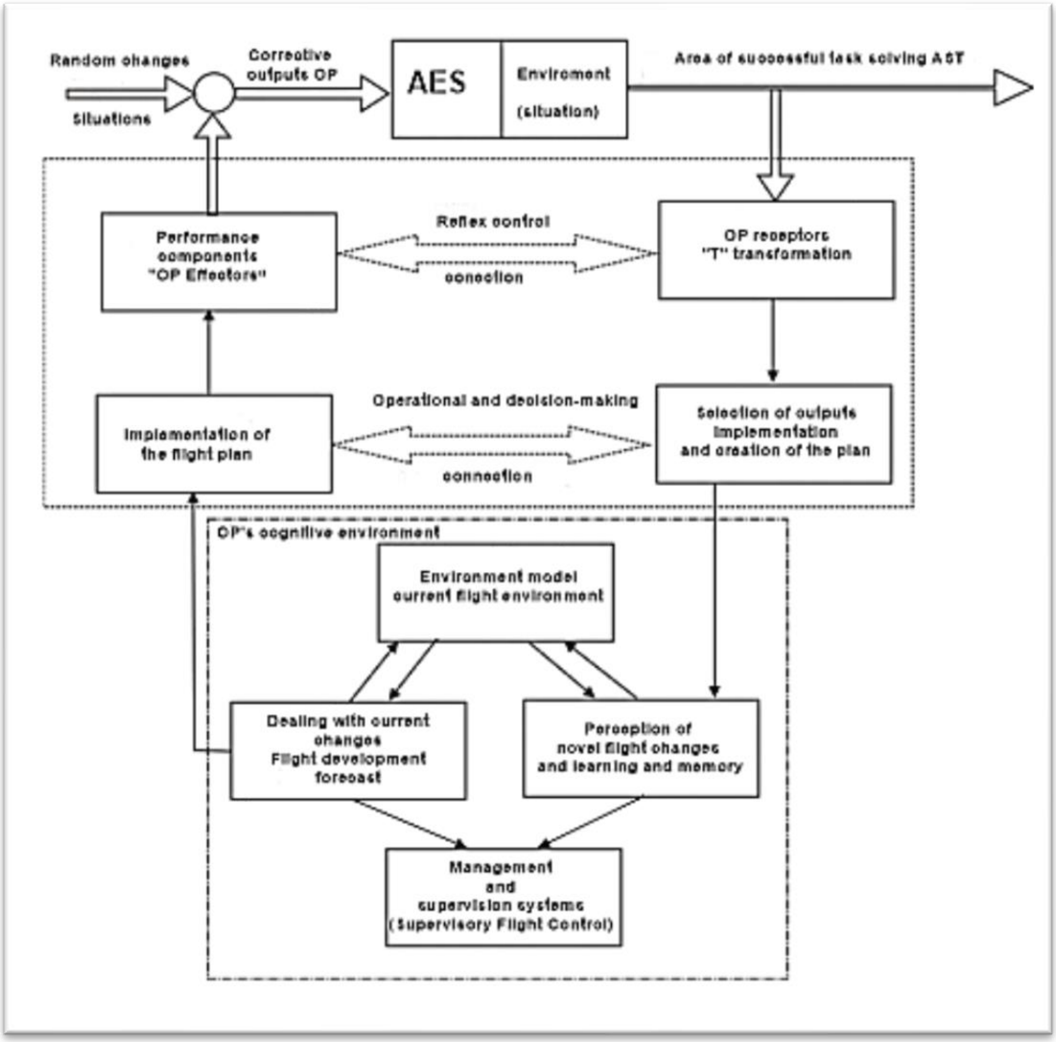


Fig. 25 Structural control schemes of AES (K) with cognitive properties

The shown structural diagram in Fig. 25 shows that an aeronautical aerospace ergatic system with cognitive properties sufficiently emphasizes the dominance of the operator in its ATO process control. In other considerations within this publication, let us consider any flying apparatus marked with the shape of the AES as cognitive. Cognitiveness (Fig. 25) in verbal expression combines the intelligent control of the operator's AES with the artificial intelligence of the air object in the mutual supporting process of changing situations. $AES_{(K)}$ [35].

4.1 Aerospace Ergatic System Quality Assessment–Factor Model

The evaluation of the quality and efficiency (25) of the aeronautical ergatic system (AES) shall use criteria linked to the estimation of the following parameters:

1. Accuracy;
2. Reliability;
3. Durability (durability, usefulness, efficiency...).

These parameters are the subject of much research. In this publication, we are only interested in specific issues related to the professional evaluation of operators and pilots. This means that the quality of the aeronautical ergatic process will be understood as the interaction of the range of parameters mentioned, the output of which is the usefulness of the solved task embedded in the metasystem.

The basic method of quality estimation is applied statistics, with which the realisation of a type of task is connected. When experimenting, it is important to know the characteristics (see below) of the operator - the pilot, whose experience in operating the AES (K) is based on professional experience, training and educational level. The resulting manifestation of professionalism is then the ability to control the aeronautical apparatus (aircraft, UAV), in which the feedback information flows make it possible to gain knowledge of the object's behaviour. The latter is controlled and predicts flight sequences with a certain degree of flight safety. Estimation of the skills of the aircraft operators is an integral indicator of the quality of the AES and contributes significantly to the construction of the architecture of the individual operator-pilot factor model [36].

The input requirement for building a factor model is an estimate of the relationships between AES and environmental influences. The combination of the terms AES and ENVIRONMENT is represented by the next symbol, AES(K). In a general sense, control of the AES by the operator-pilot represents the desired change in the sequence of achieving specified coordinates by changing its parameters. Control sequences accept the reception and processing of information. The analysis of the operator-pilot control process makes it possible to separate the following control actions and operations, which include

1. implementation of the metasystem programme,
2. control of aircraft movement and dynamics,
3. stabilization of the AES position on a specified (selected) trajectory.

The required flight safety (the main task of the metasystem) is ensured by measurement and observation, which generally represent random scalar fields determining the movement of the aircraft in Fig.26. These include the density of the environment *(atmosphere) ρ, temperature* T*, turbulence (vector quantity)* W, which *changes randomly in the real atmosphere, depending on the coordinates [x, y, z] and time* t. Random factors, the arguments of which are vectors, are called spatial random fields. The stated parameters of the air atmosphere are arguments of the coordinates of space [x, y, z] and therefore we call them *spatial.* If the random field also changes at time *t*, then we are talking about a time-space field. Spatial and temporal-spatial fields can be scalar and vector. The density of the atmosphere *ρ (x, y, z, t)* and the temperature *T* (x, y ,z, *t*) are scalar time-spatial fields. The turbulence of the atmosphere W *(x, y, z,* t*) is a vector space-time field, since the velocity of wind gusts exerted on an aircraft in a turbulent atmosphere* W *is a vector characterized by three components [.*w_x, w_y, w_z].

Let us analyse the motion of an operator-pilot-controlled AES in vector space-time, in which a complex of forces and moments acts, the resultant of which determines the position and speed of the AES. It is then possible to describe such a state of the AES, where at any time t there is a comparable vector U(x). Its argument x is also a vector containing the three coordinates of space [x, y, z] and time t. Let the enumerated quantities belong to the specified space-time region D (Fig. 26). We call this specified area the area of successful management (ASC). The function u is also a vector whose components are projections into the coordinates [. The projections are determined by the operator-pilot through the control and are the sum of three scalar fields. The statistical description u(x) is synchronous, equivalent in time to the statistical description by the vector field ρ, T, W. Let us suppose that it is continuous in next section. Let us denote the result of the action of random forces on the AES by the symbol of forces and moments L [37,40].

The action L on the vector [u] can be described by the equation:
$[\, u_x, u_y, u_z u_x\ (x), u_y(x), u_z(x) t_0, \infty]$

$$L.u = Q \tag{3.1}$$

Q – element of space (for others, see Fig.26)

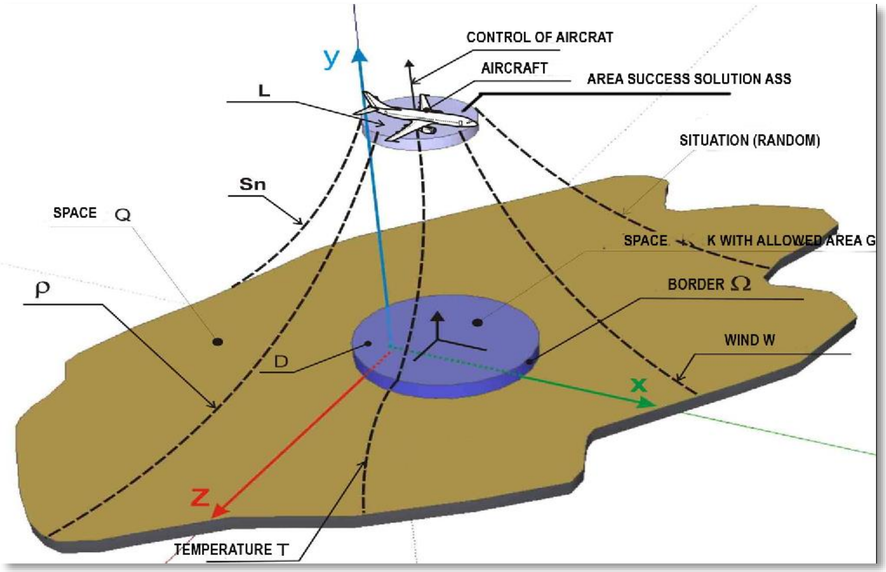


Fig. 26 Position of AES in the area of successful solutions (ASC) and elements of space-time

Equation (3.1) represents the model of the element ASC, which has reached AES (symbol L) through process control by the operator-pilot in space D.

The uncontrolled process has an evolutionary character at time t (Fig. 27 a). Let us denote the control vector [u] in conjunction with the time u(t). The trajectory of the phase space U (Fig. 27b) represents the geometric picture of such an action. The actual technical conditions for the use of an ergatic system represent certain physical limitations, given the operational characteristics of the AES, which are a basic prerequisite for maintaining flight safety. We assign to the operational characteristics a vector k belonging to the quality space K (Fig. 27c), forming the subspace Q. The set of permissible states in the space K represents the range of permissible values of Ω (Fig. 27c), which in principle remains open. The boundary of the Ω domain is called the permissible domain, denoted G in the following. The first penetration of the vector of the permissible area G into the secondary (open) area represents the degradation of flight safety. The described reasoning is illustrated in Fig.27. $k_{(t)}$

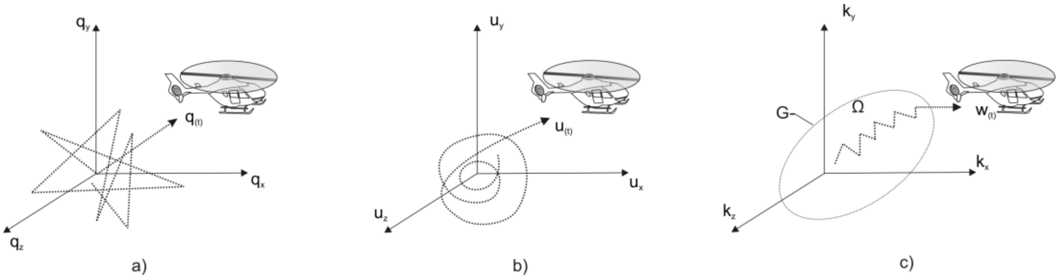


Fig. 27 Prognosis of flight safety evolution in spacetime

Let us observe the evolutionary development (Fig.22a) described (1) in periods. Let the results of observation (measurement) be an analogue of safety and be a vector quantity with $t_1 \dots\dots t_k$. Ôo components [$\check{Q}_{1;}$Ô$_{2\dots\dots}$Ô$_n$] Fig.22a. The components of this vector are characterized by the synergy of random forces and moments, i.e. parameters q(t). For reasons of simplification, we will use the designation for the set of times and Ô $T_k = \{t_{1\dots\dots} t_k\}T_k$ () = In the next suppose there is such a control U (AES that causes the transition from evolutionary control to deterministic (Fig. 28b).

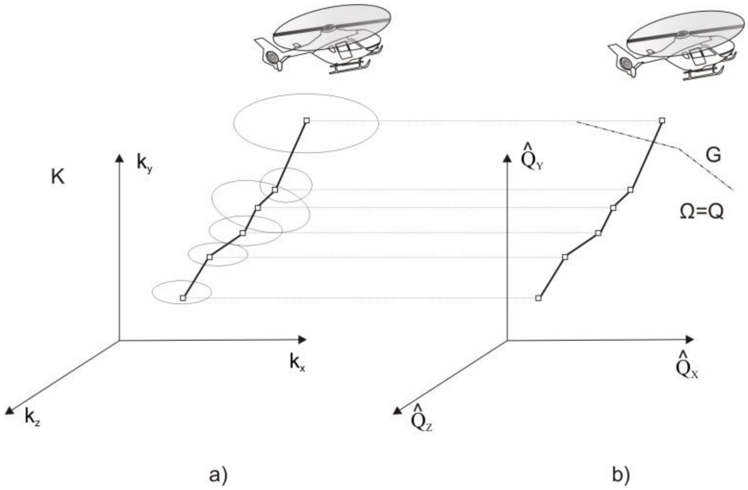


Fig. 28 Graphical determination of the time forecast for the development of flight safety inside the area

As shown in Fig.21, the area of permitted Ω values is located in space (Fig.28b). The illustration shows that control continues according to the prognosis of the development of Q (t / T_k) process Q (t) pre t > t_k. It follows from the above that the system is safe for t and is unpredictable (dangerous) in time, provided that $t_{k+1} > t_k$ applies.Q (t/T_k) ∈ Ω.

The described management process justifies the development of cognitive-ness and the development of the skill of controlling the AES operator-pilot [42].

4.2 Single-factor aeronautical ergatic system control

A multifaceted function completes the process of placing AES in ASC by control. The I/O relationships, in addition to the prescribed quality of assuming a designated position within the ASC, are generally unknown. The reason for this is the randomness of the manifestation of the environment and the psychological-physiological peculiarities of the operator-pilot, which affect the tactics of the method of control. Simulation, i.e. working with the AES control model, requires certain simplifications that accept the nature of positioning in space (Fig.26) of the AES from handlebars controlled by the operator-pilot. The experiment schemes presented in Fig.29 accept the one-factor principle [43].

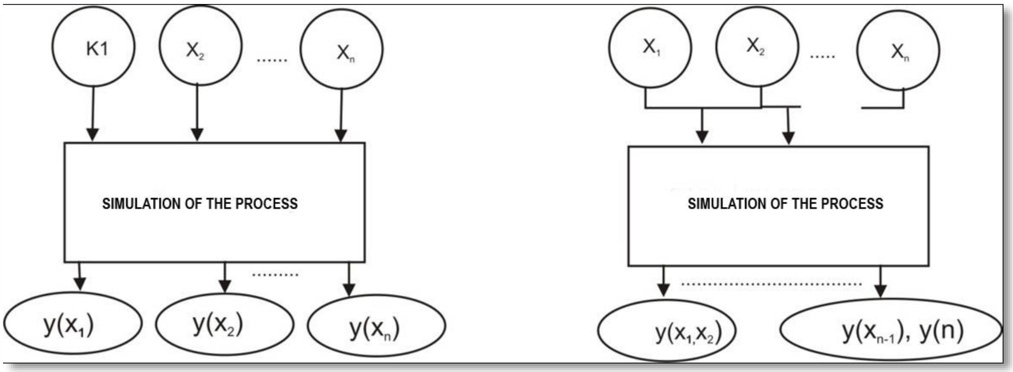


Fig. 29 The principle of simulation of single-factor AES controls by operator-pilot

When controlled by the AES operator-pilot, the influences of the cross-couplings of the handlebars (rudders) act, which, by changing the action of forces and moments on the physical body of the AES, make its movement in the coordinate system (Fig.27, Fig.28) difficult [44].

The scheme of allows you to analyze the linear laws of relations input (x_1,$x_{2,}x_u$), y (x_1), y (x_2), y (x_1), y (x_2), y (x_7) independent factors from each other. As an example, the thrust of the AES power unit can be chosen, which, in addition to changing flight speed, does not provoke a change in other factors. Therefore, we call this method of choosing a simulation (experiment) a one-factor.

An example of a multifactor simulation is shown in Fig. 23 b. Each input-output session can be defined by different laws of change expressed e.g. by exponential, stepped, linear, etc. functions. The resulting resulting position $'y'$ LES into ASS is then determined:

y = f (x_1,x_2,....x_u) (3.2)

4.3 Informative function of the ergatic system

The concept of the informative function of the AES control skill of the aeronautical ergatic system includes in this publication the transformation of acquired experience, skills, decision-making, and speed of information processing, enhanced by professional motivation and responsibility. For the reasons listed, the growth of the informative function of operator-pilot skills is the main prerequisite for air safety assurance. From the listed attributes, its manifestations are obvious, which are reflected in the profession of an operator - pilot in the ability to:F_z

1. Perceive observed changes in the character of "in", "ex";
2. Create a situational abstract (thought) model of the environment;
3. On the basis of the environmental model (in internal representation, i.e. "in" and in accordance with the metasystem, decide on the further interaction of the aeronautical ergatic system;

4. Communicate with the assisted support environment in flight safety monitoring in natural or artificial language;
5. Accept the physical laws of influencing the environment.

It follows that the structure and technology of the aeronautical ergatic system should correspond to the skills listed. In terms of inputs, i.e. control of "u" AES, it is a technique that ensures the choice of program when performing a task by the metasystem. This is necessary to check the maintenance of steerability and subsequent stabilization of the AES. The abstract structure of the content of the informative function of skill is shown in Fig. 30.

The informative function of the operator-pilot concentrates on management, cognitive and decision-making activities, which in aggregate results in a limited one. When controlling the AES, the operator-pilot continuously enters and maintains the flight mode in order to perform the tasks of the metasystem in a given environment (Fig.30).

The specific function of the operator – pilot in controlling the aircraft is associated with the receipt of information, it is processing with the forecast and the decision on the further direction of the AES. The schematic process of processing instrumental information by the operator-pilot when controlling the aircraft is shown in Fig. 31 [46,33].

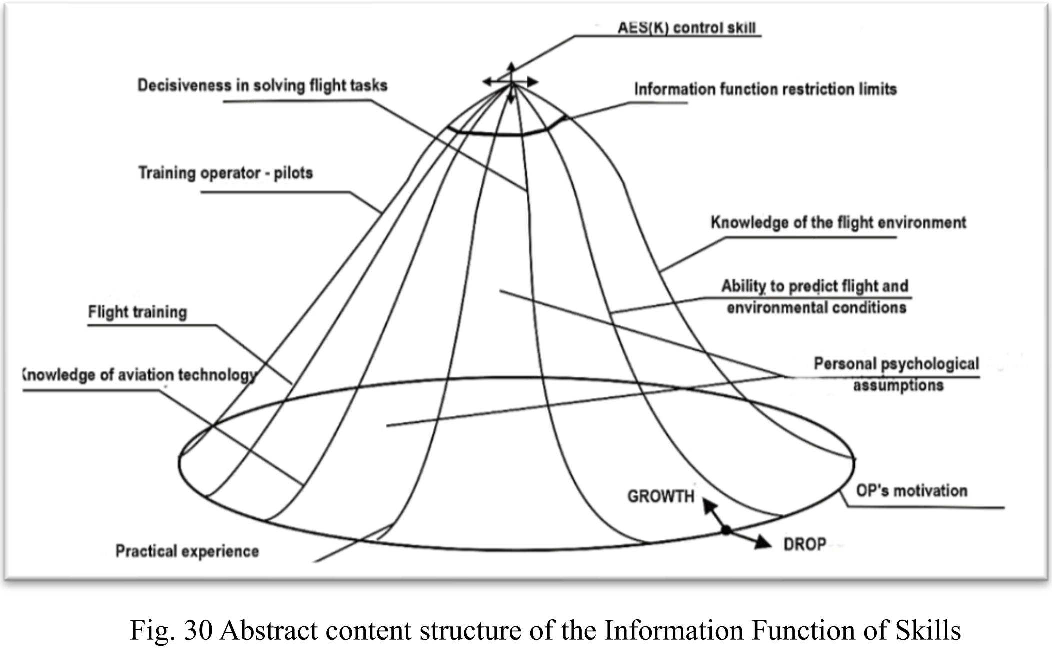


Fig. 30 Abstract content structure of the Information Function of Skills

For the operation of the operator-pilot in controlling the AES, the following operations are important:

1. receiving information about a change in the flight situation,

2. estimation of the position of the AES and its solution, which is a manifestation of the knowledge and experience of the operator-pilot about its physical manifestation,
3. practical implementation of the decision taken,
4. control of the consequences caused by the movement of the handlebar.

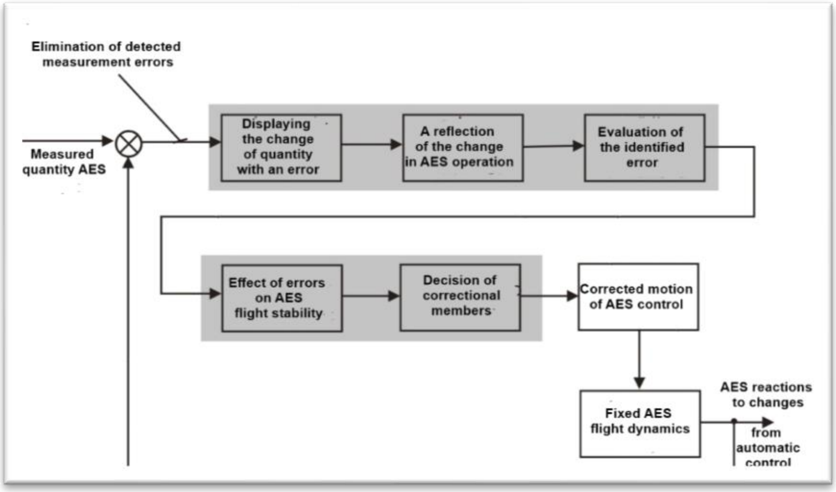


Fig. 31 Example of a structural diagram of the process of processing instrumental information by an operator-pilot

The above description of the activities of the operator-pilot has methodological meaning. The reception and processing of information takes place as a single sensor-logical process, from which it is problematic (it is not even possible) to eject any of the named operations. The purpose of the reflection is to point out the time sessions of operator-pilot reactions, which are important for understanding the context illustrated in Fig. 32, and Fig.33.

The response time of the pilot operator required to complete one logical operation t_{op} can be expressed by the algebraic sum of:

$$t_{op} = t_p + n.t_{str} + t_{pr} + t_M + \mathrm{t_k} \tag{3.3}$$

The concept of control (see below) is associated with manual or foot steering, where:

t_p – the time required for the signal to be read perceptively;
n – number of symbols on the display or instruments;
t_m – mean notification time of expression of information;
t_m – the time needed to make a decision;
t_{mp} – period of motor executive activity;
t_c – the time required to check steering performance.

The literature gives the following values:
$t_p \cong 0{,}1s$; $t_m \cong 0{,}4s$; t_m ; $\cong 4-5s$ $t_{mp} \cong 0{,}5s$

In order to complete the evolutionary process of movement of the AES in space-time, the first intervention in the control is important, in response to the received information. Fig. 32 illustrates the range of motor activity of the operator-pilot, expressed in a unit of time [s], which depends on the number of received and processed signals [47,3].

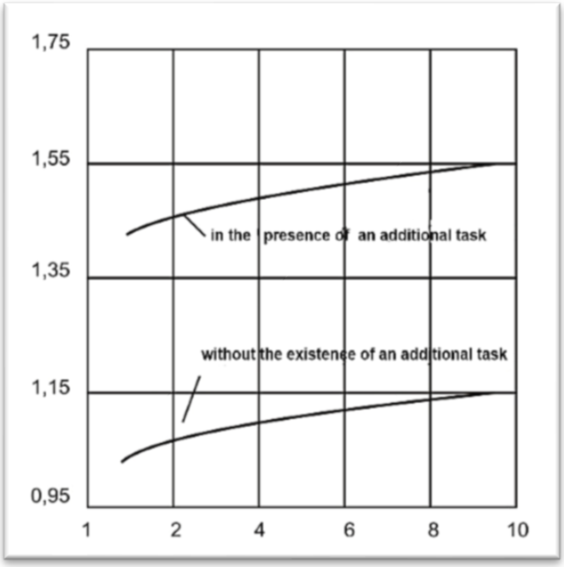


Fig. 32 The dependence of the time of the first activity of the pilot-operator on the number of signals

The graphical representation in Fig.32 can be approximated by the analytical expression:

$$t = a.\sqrt{(n)} + b \tag{3.4}$$

Where:

t – period of first activity; n – number of signals; a – 0.057 , (applies to a skilled pilot operator);

b – constant (0.92 for the first case; 1.33 for the second).

One of the peculiar characteristics of a person is his reaction to random warning signals. The danger factor evokes his senses and increases the speed of reactions, which translates into a reduction in the time of motor operator interventions (Fig.33).

Time deficit is the factor with the greatest influence on the occurrence of aircraft control errors. From the point of view of flight safety significance, these are mainly errors (see Table 1):

1. in the control mode,
2. in the estimation of the aircraft control response,
3. in the reception and processing of instrument signals.

The highest number of errors (more than 80%) occurs in the estimation and processing of information, which seriously affects the quality of management at a critical safety stage. A detailed analysis of pilot-operator errors is given in [48,23].

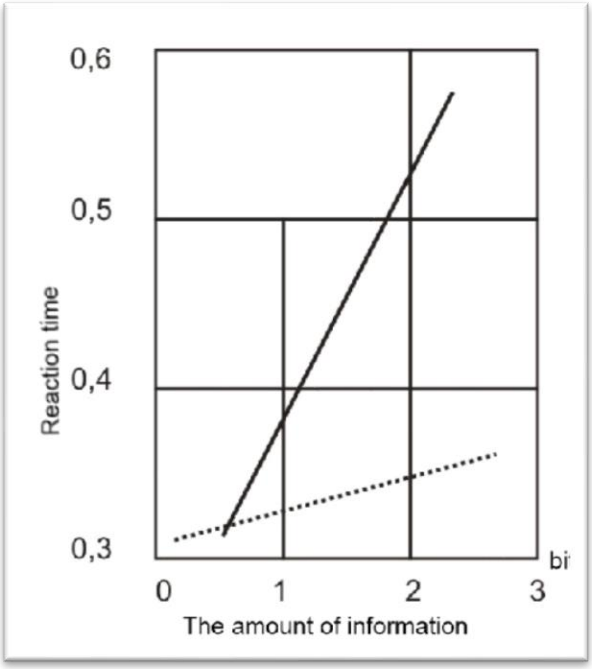


Fig. 33 Dependence of the operator's reaction time on the amount of information received

Table 1 Analysis of pilot-operator errors in critical mode

Task	**Nature of errors**	**Count**	**Σ**
Find a signal	Non-reading of instrument information	4	26
	Reading the information on another instrument	13	
	Using the wrong device	9	
Signal recognition	Incorrect reading of instrumental information	14	

	for reasons of difficulty in distinguishing Incorrect reading of instrumental information for reasons of complexity in distinction and identification Data Misinterpretation of read information	18 6	38
Signal identification	Oscillation of symbols on the display or hand Pointer	17	17
Situational estimate	Incorrect evaluation of signals	5	5
The choice of method of operation	Incorrect response to the signal	14	14

The final operation in the control of AES by the operator-pilot is the control of the consequences of the corrective intervention. A successful outcome is associated with a series of satisfactory/motivating self-realisations. Failure is associated with a critical evaluation of the state, which includes:

1. consideration of the criteria for correct flight behaviour of the aircraft at the time of the malfunction;
2. continuously compare the instantaneous flight progress information with the criteria of point 1;
3. identify the malfunction which caused the deviation from normal flight and determine its location;
4. localise the causes of the development of the malfunction;
5. assess the complexity of the situation and decide how to control the airplane;
6. adjust the position of the control wheel(s);
7. in accordance with the decision and check the response of the aircraft to the movement of the steering wheel(s) [50,62].

The mindset of the operator-pilot is burdened the most by points 2, 3, 5, and 7, which are demanding on time consumption. Time is dominant, especially in a critical situation. Let's mark the time required to carry out the above procedures. Durability indicates the manifestation of the operator-pilot's skill, temperament, psychological state, etc. This time is different not only for a group of operators – pilots, but also for an individual who works in different conditions. Practice shows that the value is also largely dependent on the flight mode, e.g. when a malfunction occurs t_{POT}.

It has now been established, on the basis of statistical methods, that:

$t_{POT\ \mathrm{min}} = 2\mathrm{s}$ → for flight modes performed at low altitudes,

$t_{POT\ \mathrm{min}} = 5\mathrm{s}$ → right arrow for flight modes performed at high altitudes.

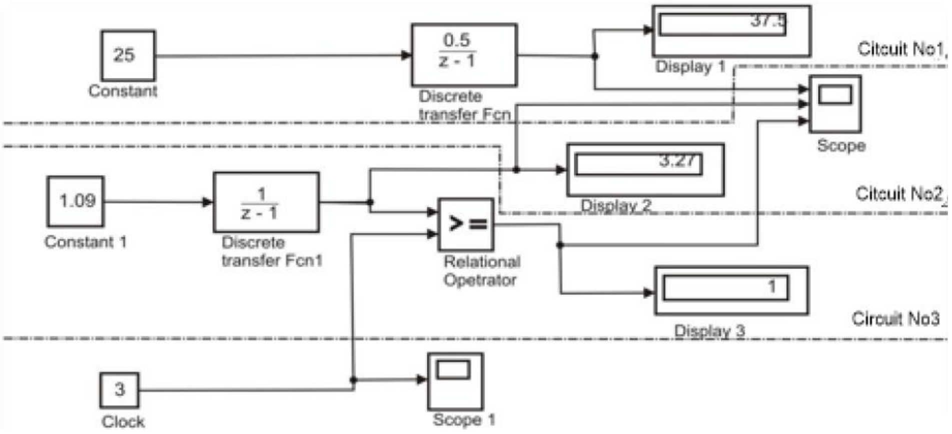
By equipping aircraft with early warning alarm systems, it is possible to reduce the transition time to spare $t_{POT} = t_{prep} = 1\mathrm{s}$. When designing automatic control systems, $t_{prep} = 2 \div 5\mathrm{s}$ is used as a calculation value $t_{prep\ \mathrm{min}}$. Other methods of shortening assume that the smallest possible values are achieved. For this purpose, methods of fully automated control systems that operate throughout the flight are used. No AESs important are the methods that reduce the complexity of the solutions of operations referred to in points 2, 3, 5, and 7. For this purpose, it is possible to use special control blocks that measure flight parameters according to specified algorithms, the outputs of which are processed by the appropriate computer [48,14].

Suppression of the values of the 5th operation can be achieved by using command information, with which it is possible to restore the original flight mode. An example of a simulation of operator-pilot readiness to respond to a relevant signal, e.g. early warning, can be performed using the simulation model in Fig. 34a, which was implemented in the MATLAB/SIMULINK environment [49,67].

4.4 Demonstration of the operator-pilot's reaction to new information

Circumference No.1 (Fig.34b) measures the aircraft's drift path while reading information. The difference between the set value of 25 and 37.5 is 12.5 units of length in one second. Circuit no.2 (Fig.34c) records incoming information for the operator – pilot when changing the data on the display. If t 1, display no. 3 shows the value "0". Circuit no.3 (Fig. 34, b, c) determines the number of changes to the information on display no.3.

Fig.134b - measures the real-time set in the window of the respective "untitled" measured by an oscilloscope. The clock symbol Fig.34 does not contain. Sequence numbers 1,2,3,4 - illustrate oscilloscope measurements of values and data on displays. As an example of the transition from the abstraction of the listed concepts to the conditions of flight reality, consider an artificial scene or situation in which an indefinable process develops evolutionarily in parallel with the flight (which we can call "safe"), which manifests itself in a threat to flight safety. The operator-pilot is particularly sensitive to this manifestation when such a scene occurs in landing mode. The OP perceives the manifestation of the malfunction as an illegal function of the on-board automatic control system (FMC). The development of a possible adverse condition is illustrated in Figure 35.



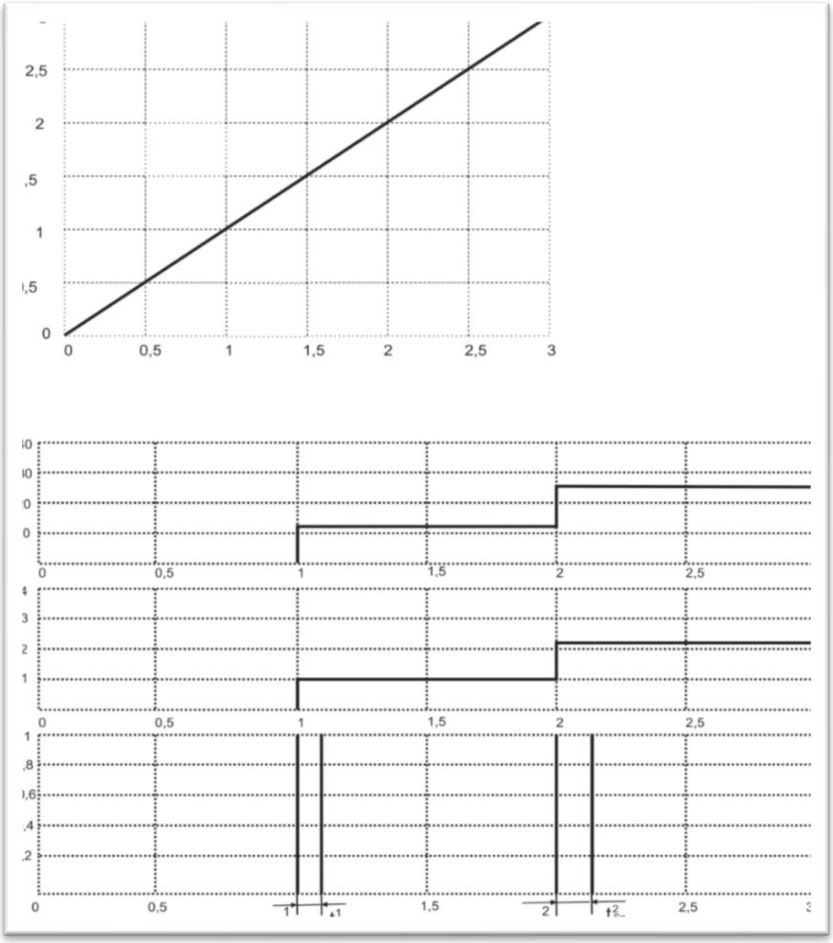


Fig.34 Simulation of operator-pilot time required to distinguish the change in information on the display

A – simulation scheme, B – real time, 2c – simulated flight path proportional to the time length during the reading of the signal on the display, 3c – changes in the information, 4c – readout of operator-pilot information, values t_{str}^{1}, $t_{str,}^{2}$ the delay is the time needed to recover feelings and become aware of the possible consequences of the expression of information on the further development of AES $t_{str,}^{2}$ [50,9].

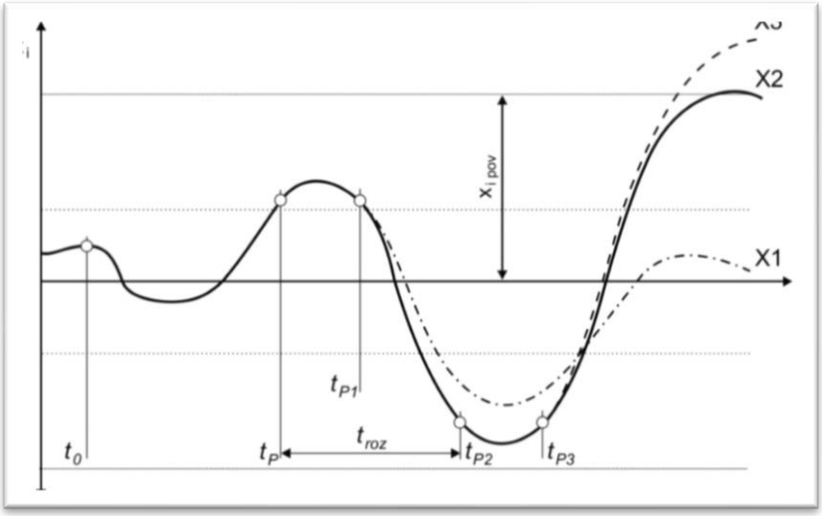


Fig. 35 Influence of the moment of the entry of the OP into the control after the manifestation of the occurrence of a malfunction

In Fig.35, the designations X1, X2, X3 represent changes in flight parameters after the gradual entry of the pilot into control at times tp1, tp2, tp3. Delayed responses to stimuli extend the AES stabilization periods. Thus, for example, at a discord signal frequency of 0.5Hz, a delayed OP input of 0.2s means a delay in the phase of 36º, and at a frequency of 1Hz the phase delay is up to 72º. If we consider that in current aircraft these values increase in some flight modes (in heavy aircraft they exceed values of 0.5 Hz, in light aircraft they reach values up to 1 Hz), then it becomes clear why the mismatch in the control of such OP aircraft is noticeable. The ergatic link OP is illustrated in Fig. 36 [60,43].

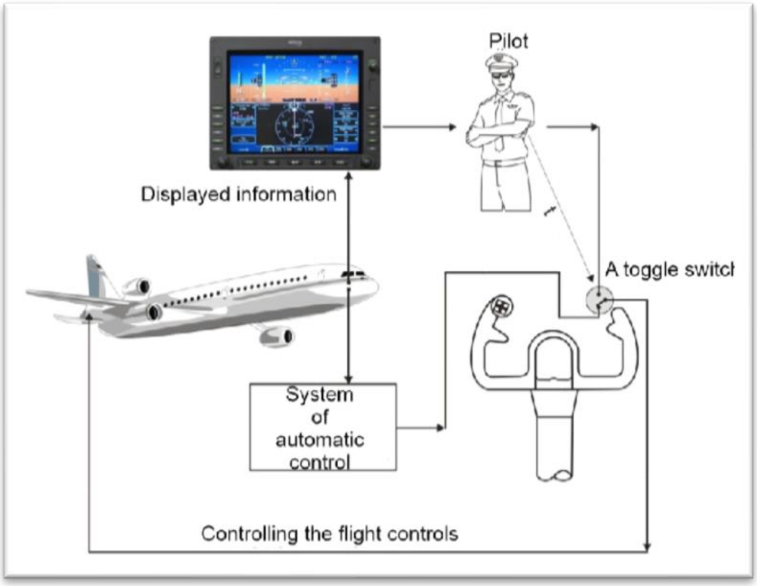


Fig. 36 Diagram of ergatic coupling AES – FMC OP

The described state is also analyzed by an automatic control (diagnostic) system, which "alarms" the pilot-operator of the need to disable the FMC (Fig.36). The situation in which the control of the AES OP is realized is illustrated in Fig. 36. The resulting situation in which the control of LBK operators is realized is called the technogenic environment (Fig. 37).

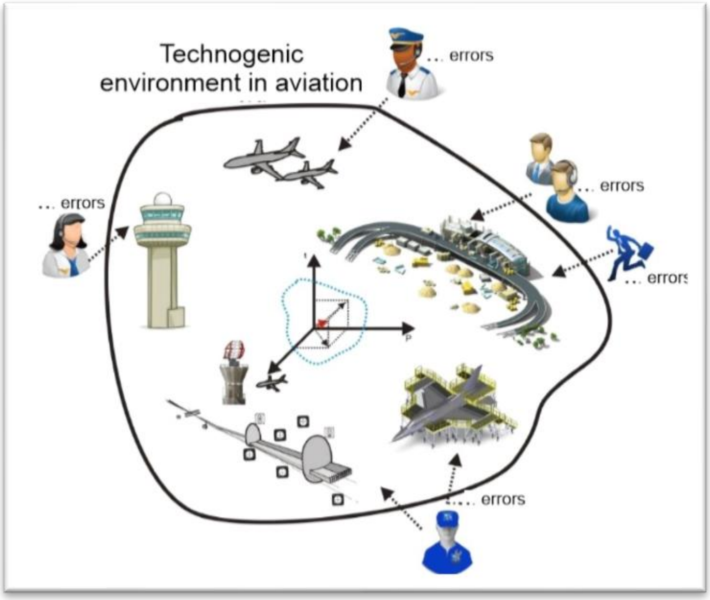


Fig.37 Technogenic environment

Nodal values t (Fig.38) is perceived as dominant information quantities, limiting the reinforcement of the contradictory duality of the mono-ergatic system (ES). The characteristic time moments of reaction are:

t_0 – the moment of manifestation of the malfunction, diagnosed and signalled by the alarm system,

t_P – the moment of recording the manifestation of the disorder in receptors and central nervous system, OP

t_L – reactions of OP effects, disconnection of FMC and control input.

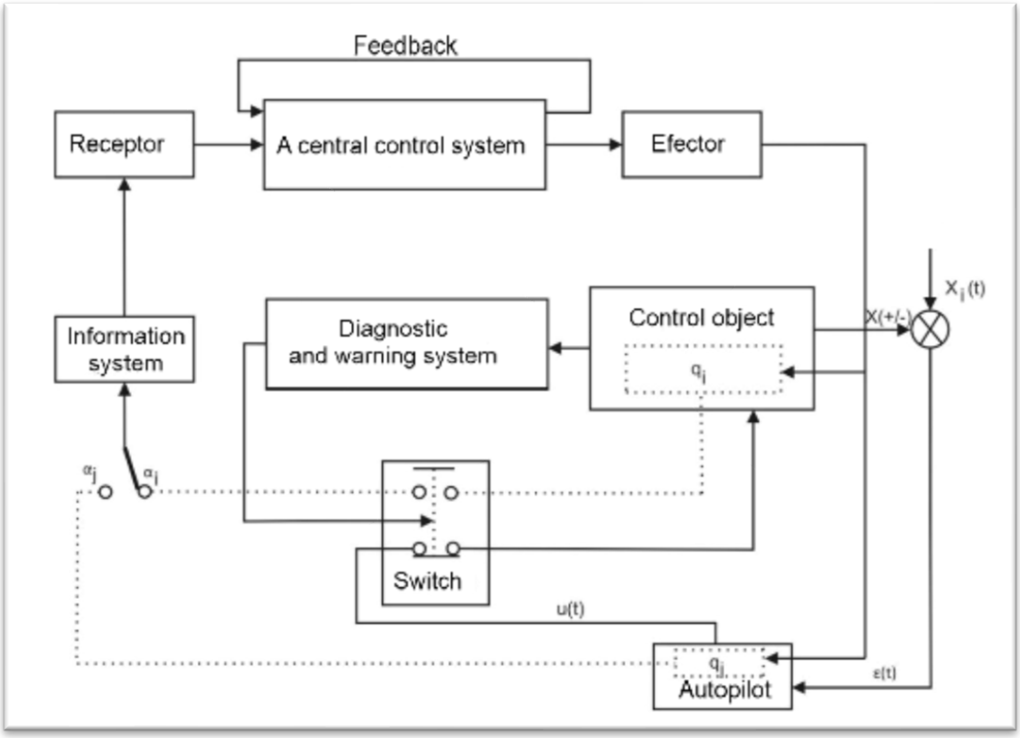


Fig.38 General block diagram of a mono-ergatic system

Where:

PARS – on-board automatic control system;

α_i – an indicator of parameter q_i of the control object;

α_j – an indicator of parameter q_j of the controller (Fig.38).

With the pilot-operator input, the parameters of the ergatic system have changed. In landing mode, where the distance to the point of contact with the RWY is shortened, e.g. at a speed of 75 $\mathrm{ms^{-1}}$, fast and accurate responses are required to ensure the correct position of the aircraft on the descent line (Fig.39) [61,18].

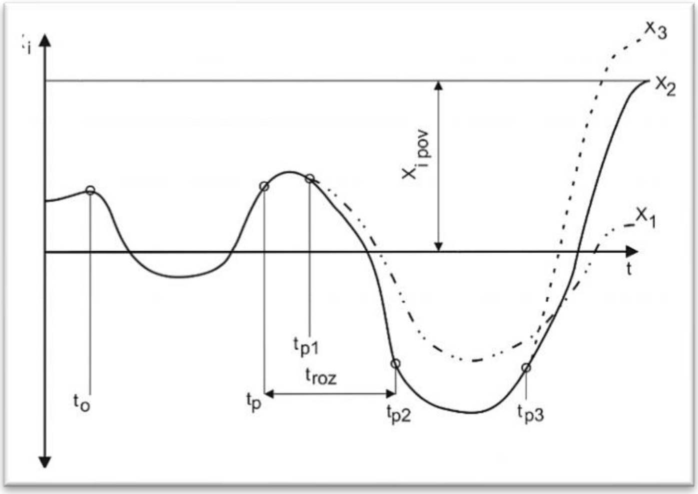


Fig.39 Limits of permitted deviations from nominal flight path to point of contact with RWY

4.5 Situational mathematical model, simulation

The starting point is to simulate the effect of delayed pilot inputs to the control in the cases shown in the hypothetical situation map in Fig. 40. The final analysis aims to show, graphically and numerically, the influence of delayed OP inputs on the control and, in the cases shown in Fig. 40, the pilot's decision to divert to another airport C due to an aeronautical error.

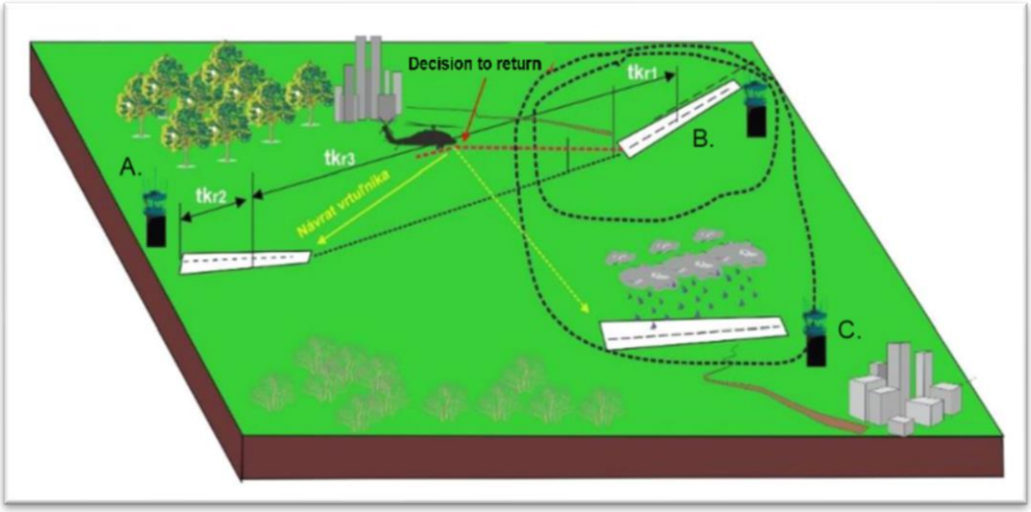


Fig.40 Dependence of the extension of the critical section on the size of the zone in which the decision is taken

The assumption that the Destination Airport B segment is critical includes the critical time of the tkr1 decision. The conditions of this stage are
- constant duration of the critical leg;
- zero probability of departure for an alternative variant when flying the critical leg;
- the possibility of successful completion of the flight in the event of information system malfunction;
- a statistically certain probability of the pilot switching to manual control;
- a pilot decision influenced by the dispersion of information system data. The decision that the pilot makes at tkr1 is determined by knowledge of conditional probabilities:

$Q_{bez} \approx q_{kr}(t_B/t_0) + q_{kr}(t_0).p_1(t_B/t_0)$ (3.5)

Where:

t_0 – the start time of the critical section;

q_{kr} (t_B/t_0) — conditional probability at the critical section, according to which a critical part of the control component of the helicopter will also fail; $t_B t_0$

$q_{kr}(t_0)$ — probability of failure of a critical part of the helicopter's control branch on a non-critical section (after reaching time t0);t_0

$p_1(t_B/t_0)$ — the conditional probability of on-board information systems functioning correctly.$t_B t_0$

Assume:

$p_1(t_B/t_0) = 1, \qquad q_{kr}(t_0) = 0$ (3.6)

Then the equation moves to the form:

$Q_{bez} = q_{kr}(t_B/t_0)$ (3.7)

From this shape of the equation, it follows that pilot control, which we want to call safe, is conditioned by the correct functioning and trouble-free operation of the control system. In helicopter pilot control mode:

$Q_{bez} = 0$ (3.8)

In the diagram described below, the OP, which is part of the flying apparatus (AES), procedurally recognizes and perceives the following picture of the flight situation. When operating, for example, unacceptable meteorological conditions overlapping destination B airport and alternate C, we will lay a critical section at the point at which the OP decides to return to take-off airport A, or proceed in flight to destination airport B.t_{kr3}

The decision of the pilot includes consideration of all the features of the ergatic complex. Because of critical periods, the pilot's decision will be conditioned by the entropy value (scattering) of the information systems data. Next, let us assume that the section at destination airport B will be critical. The critical period of the decision, represents the acceptance of the conditions:

1. the critical period of time is constant;

2. in the event of failure or malfunction of the information systems, the pilot has the possibility to successfully terminate the flight;
3. when flying on a critical leg, the probability of a successful departure for an alternative variant is zero;
4. the probability of switching to autonomous (manual) driving is equal to the unit.

The pilot-operator decision in a point is determined by knowledge of conditional probabilities.

Equation (3.6) solves the control safety of the non-energetic part. As can be seen from Fig.42, it remains to determine the state of the duality part, i.e. OP, a model that contains a time (also called traffic) delay. The implementation of this feature was included in the transmission function of the rotational speed of the aircraft around the Z-axis, which follows the angular adjustment of the glisade. The variation in said speed was determined by a tilt model that included pilot time delays of T = 0.15s; 0.45s; 0.8s; 1.0s; 1.2s; 1.4s assuming a landing speed of 75 ms^{-1}, Fig. 41.

Then, at given time delays, the intertwined paths are: = 11.25m; = 33,75 m;S_1, S_2, S_3 = 60m.... A simplified mathematical model of angle control derivative on both triple vectory and critical sections, accepting the given parameters, is for an airliner with a weight category t_{kr1}
G = 153. kg given by the equation (mathematical model) [62-70].

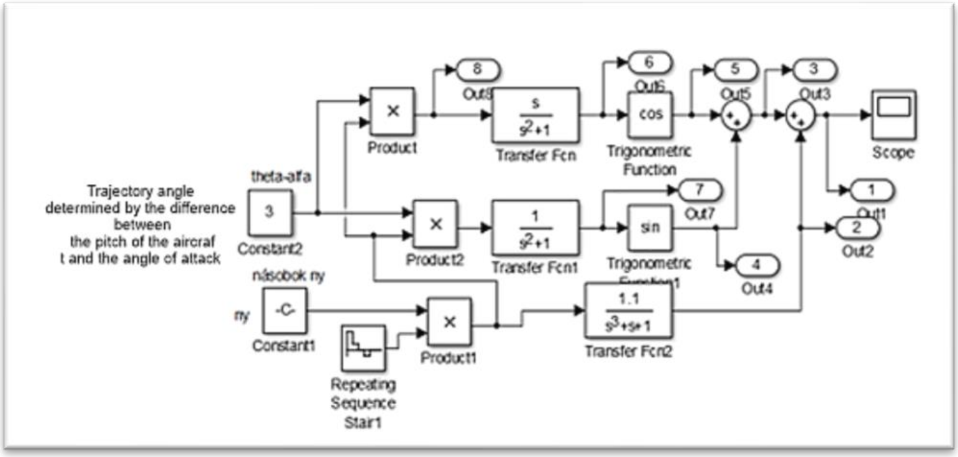


Fig.41 Rotational angular velocity of real descent of UAV in vertical plane instead of aircraft UAV

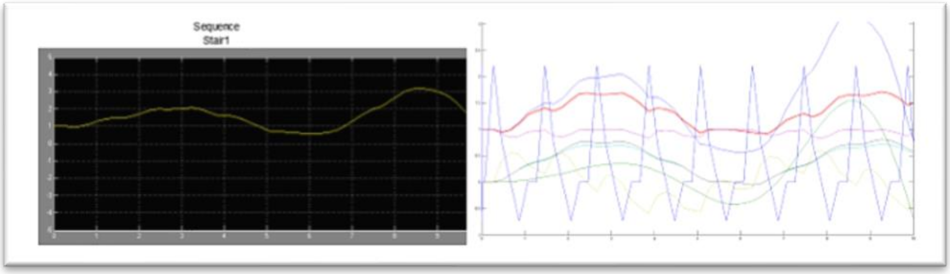


Fig. 42 The simulation model in the MATLAB-SIMULINK environment

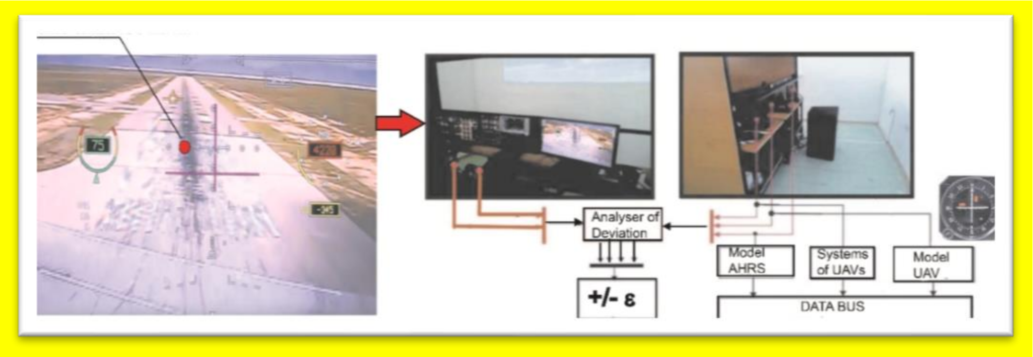


Fig.43 Simulation scheme of ATO flight according to the selected trajectory

Simulation parameters:

Input: = U_A = 0,15⇒8,5° handlebar deflection (left-right)

Period: T_p = 8s; $T_{p/2}$ = 4s

Table 2 Table of measured values

$T_{delayed}$[s]	**0**	**0,15**	**0,45**	**0,8**	**1,0**	**1,2**	**1,4**
0[rad/s]	-0,08	0,30259	0,226	0,45	0,565	0,68	0,7708
0^{γ}[°]	32,88	31,6	29	26	24,28	22,56	20,84

Measurements were made at the beginning of the half-period, which is always postponed by a time delay. The successively set values on the delay element (see Fig. 43) determined the time of intervention of the aileron-steering model (D_{kr}) in the dynamics of change in the angle of the velocity vector 0^{γ}, the value of which was read at the end of the half-period. The numerical value corresponded0^{γ} to the corresponding phase (see Fig.43). Obviously, in a limited time shortened by the delay value $T_{delayed}$ the aircraft dynamics did not "didn't align" the control deviations from the set 0 altitude rudder. The error is obvious from the graph in Fig.42.

The measured values include not only the pilot's traffic delay, but also the time needed to start the dynamics of the angle model, the values of which 0^{γ}can be changed during modeling, which allows for various variations that are useful for estimating the quality of control (skill) performed by the OP. The setting of time limits achievable by proper management interventions can generate a certain psychological tension, the value of which is measurable and usable for the overall establishment of the picture of the existing duality of security. The research results are a prerequisite for testing OP models [71,32].

4.7 Physical assumptions of feasibility management and stability of the ergatic complex

The meaning of the terms used so far is explained in the relevant sections of the publication. This section presents terms and names used by the authors of the monograph when performing experiments in the MATLAB environment. The commands used in this environment do not always correspond to normalised concepts. In the terms and phrases presented below, they accept the need for comprehensibility of performance and simulation content that is more related to mathematical abstraction transformed into aeronautical issues. For example, the dynamics of AES in the atmosphere are perceived by the authors as a part of mechanics, by which we mean the action of mutual influences of the atmosphere and a flying body. We have named the complexity of such mutuality AES(K), where "K" stands for the complex. On the other hand, the dynamics of AES (without the addition in the atmosphere), in the authors' reasoning, represents its controlled but also uncontrolled motion.

The concept of controlled motion is such a motion of the AES, which in the observed period of time is determined by the operator-pilot (OP) by moving the handlebars, by which he changes the geometry (configuration) of the AES and the work of its power units.

Uncontrolled movement is a type of movement that is carried out in a period with the OP's handlebar position unchanged and with the AES configuration unchanged for its entire duration. In this type of motion, the thrust of the drive does not change and there are no external influences.

The term flight mode summarises the computational (drawing) characteristics of the controlled movement of the AES at the time when the OP (or automaton) keeps one or more flight parameters (e.g. speed, flight altitude, pitch angle, course, elevation angle, side angle, etc.) unchanged. The flight mode is divided into steady, quasi-stable, constant, main, transient, boundary, rectilinear, curvilinear, flat, and spatial. By analogy with the above terms, mathematical models of regimes are also referred to. The term AES mode combines characteristic, stable forms of uncontrolled movement of the aircraft, which occur under certain flight conditions due to the action of the external environment or when the control stick of the OP is deflected. All known AES modes can be divided into two groups:

1. Uncontrolled movement observed under operating conditions,
2. Critical (dangerous) uncontrolled movement occurring outside the permissible limits of normal operating conditions.

The term flight capabilities of the AES combine all indicators that represent boundary (extreme, limited) states in time and space. It also includes conditions that determine the independence of the AES from external conditions. The term also refers to ideal stability, manoeuvrability, reliability and the skill and technique of AES control. External factors with which the listed factors are compared are weather, operating time regularity of information processing with ground (and global) navigation systems, control centre, airport operational capabilities [33,34].

The marginal characteristics of the aircraft include the aerodynamic performance of the engines and their characteristics, structural strength, control surfaces, braking efficiency, fuel reserves, etc.

By flight safety, we understand the conditions of flight operation of AES and such methods of its protection, in which the probability of overlap of operational restrictions and manifestation of dangerous modes is AESs than the recommended level.

The concept of control accuracy expresses the accuracy of the aircraft movement determined by the control laws of the AES OP. In order to achieve the maximum precision of AES(K) control, it is necessary to create suitable conditions (comfort) for the OP, which also include such characteristics as transition processes, speed of assuming the specified AES(K) position without overshooting, as well as its other properties ensuring independent (OP) automatic systems. From these characteristics, two important concepts in the simulation processes are presented: the stability of the AES movement and its controllability [35,36].

CHAPTER 5

STABILITY AND STEERABILITY OF THE AERONAUTICAL ERGATIC SYSTEM

It follows from the foregoing considerations that comfortable effective control of the AES by the operator-pilot occurs when all transient processes induced by his inputs to the physical equilibrium state terminate spontaneously, i.e. uncontrollably. With this type of control of the AES, the OP feels satisfaction, which manifests itself in a motivating self-fulfilment.

By stability of movement, we mean the ability to maintain spontaneously, without the operator's participation, the position defined by the AES through its control, and also to adopt the standard flight mode at the end of the action of the forces and moments acting on the handlebars.

The concept of steerability is then the ability of the AES to realise the intentions of the pilot, expressed in the movements (first factor) of the handlebars and the application (second factor) of muscular effort. In this case, the manifestation of the comfort of the OP control is the optimal handlebar lift in relation to the required time and the optimal value of muscular energy (effort).

The concepts of aircraft steerability and flight control are different. The former is determined by the physical characteristics of the AES that characterise the end result of the control process in conjunction with the manner in which the control operation is performed. These include the availability of control, ease of control, and informativeness of inputs to the control process. The second term expresses the operation of the OP, the ground operators, the programmed airborne equipment and the dynamic characteristics of the AES propulsion units.

Stability and manoeuvrability are important physical characteristics of the AES. The content of these terms has a significant impact on flight safety, they determine the design (synthesis) of AES control circuits and, in summary, their flight characteristics. The required parameters of stable motion are oscillation with rapid damping and small oscillation value or its aperiodic cASCse with zero value of the transition process.

The stability of current fast aircraft is determined by the following manifestations:

1. aerodynamic compositions and particularities in weight distribution, particularly for large-capacity aircraft,
2. changes in flight parameters (speed V, height H, number M, angle of attack, side angle,β
3. shape geometry in the context of structural flexibility,
4. intelligent control (using smart automatons) and intelligent assistance systems of manual control of the OP,

5. method of fixation of control levers OP,
6. modes of work of power units.

The flight stability of the AES is influenced by the OP and the environment. Changes in stability are achieved by OP deflection of the rudders, changes in engine thrust, air brakes, changes in wing geometry, and extension of the landing gear. The environment affects stability: atmospheric turbulence and convection in general. These changes in stability are part of the concept of dynamic stability. The term static stability is also used, which gives an idea of the sign (sigma) and magnitude of the effect of aerodynamic moments on the course of pitch, yaw and roll of the AES. The course mentioned above, together with the term static stability, characterises the deviations from the specified flight mode under the action of external influences. By changing the value of the listed course, the OP compensates (balances) the effect of the external angle and course. This creates stabilising aerodynamic moments in the longitudinal, vertical and lateral axes, which characterise the longitudinal, lateral and directional static stability [52].

The manoeuvrability of the AES is conditioned by its stability and is easier the faster its spontaneous movement (uncontrollable by the pilot) disappears. Stability determines the quality and agility of the AES during its control of the OP, reduces the time of delayed reactions, and increases the feeling of self-realisation of the OP, which occurs after the successful result of a controlled steering intervention in conjunction with the subsequent dose of expended energy [54].

5.1 Cognitive manageability of aeronautical ergatic system

The effective management of current forests is determined by:

1. the level of energy consumption for control and control;
2. the information flexibility of the control system, which accepts the energy consumption of OP and its influence on the effective deflection of the handlebars (rudders, flaps, forewings, air brakes, etc.) in the execution of the metasystem programme;
3. characteristics of assistance systems and stability automatons;
4. amplitude-phase characteristics of control systems including OP.

The effective level of energy consumption (effort) to control the AES is provided by power systems (hydraulic, electric, etc.) with which the OP deflects the rudders as well as other aerodynamic controls. Control systems are also used to realise a change of flight mode in two phases (i.e. by rudder deflection and effort of the pilot). Current, mainly supersonic, aircraft with rudder suspension torques have steering forces that are sensitive not only to changes in the position of the control stick but also to the speed at which it is moved. The effort (energy) required by the OP to control the AES is realised by means of load mechanisms, the characteristics of which ensure pilot comfort. The requirements for frequency and amplitude characteristics are quite stringent and must be met not only by the steering wheel drive, but also by the assistance systems. [Complex flight conditions require a change in characteristics, the range and accuracy of which are determined by a system with a cognitive control architecture. The purpose of such an AES control arrangement is to allow the operator to easily transition from one mode to the next and to compensate for the effects of the external environment [55].

The cognitive responses of the AES to changing flight conditions shall be performed by

1. Quickly change the engine operating mode;
2. Qhanging the configuration of the AES;
3. Transferring control to the backup control in the event of failure of the main system;
4. Ensuring and controlling the reliable operation of critical architectural units of the AES;
5. Fast compensation of the influence of external conditions on the change of the AES property.

Composition (integral) of propulsion characteristics into characteristic manifestations of steerability and stability of AES requires in particular:

1. Adjustment of the change in the aerodynamic centre of gravity of the AES in relation to the position of the engines (motor), including the acceptance of the input and output characteristics of the motor,
2. Acceptance of the gyroscopic moments of the engines (motor), in particular when nominating the AES.
3. The comfort of the operator-pilot in controlling the AES is a cognitive assessment of the static control of the assistance systems, whose function is reflected in the self-realisation and its mental load.

In mathematical models, within the framework of research on asymptotic learning and OP skill, the following quantitative indicators of static manoeuvrability are implemented.

1. For small and slow deflections of the handlebar by the OP from the initial value corresponding to the equilibrium state of the AES. In this case, when the handlebar is moved, the configuration of the AES does not change, its weight, centre and flight are not performed at the performance limit.
2. When flying at the limit of the flight envelope, if the pilot moves the stick in the configuration of the AES, its centre drives and balancing systems remain in the cruising flight mode position.
3. With a rapid change in the configuration of the AES, its weight, centage and operating modes of the drives.

In each of the above cases, the directability indicator has a different evaluation principle. The indicator is estimated during the first test according to the generally accepted principle:

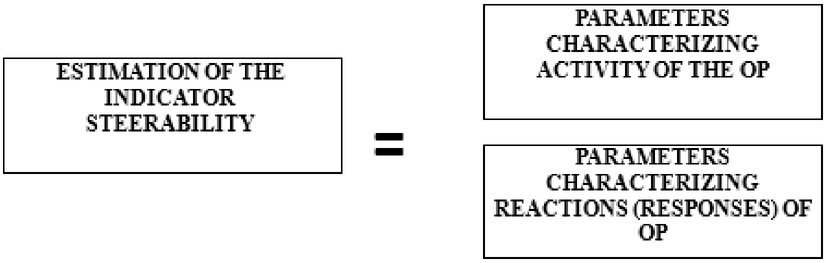


Fig. 44 Summary of parameters affecting the steerability of the AES

When analysing the longitudinal static steerability of current aircraft, two types of controlled movements are analysed:

1. A sharp change in the angle of inclination of the flight path at a constant speed of the AES;
2. Acceleration and deceleration of the AES in straight flight.

When analysing the lateral and lateral stability of the control characteristics, the control characteristics shall be assessed according to the following AES movements

1. Lateral deviation of the AES in level flight at constant speed;
2. Rotation of the AES about its longitudinal and vertical axes at a constant speed.

The result of the estimation of the OP parameters is the ability, which we analyse for changes in the energy (effort) applied to the handlebars, and the balance characteristic, which we obtain by measuring the positioning of the handlebars. The responses of the AES to the OP control are manifested in a variation of the speed V, the number M, the multiple (n_y, n_z) of the inclination an AES, the side angle and the angular speeds ω_z, ω_y, ω_x.

The estimation of static steerability in the second and third cases is based on a different principle:

1. The estimation of the static steerability of the AES is carried out during manoeuvres in conjunction with the transition to boundary parameters such as permissible angle of attack, M-number, thrust, speed v, and heel angle. The control is performed by the main circuit, maintaining the equilibrium state of the rudder position is a balancing system.
2. In order to estimate the static steerability of the AES under modified modes of operation of the AES engines and modification of its centrifugal mass configuration, the measurement of the movement of the control stick by the OP is used, which is necessary to maintain unchanged flight speed and normal acceleration [56,34].

ESTIMATION OF THE MANAGEABILITY INDICATOR = THE MAGNITUDE OF THE NECESSARY CHANGE IN THE PARAMETER THAT CHARACTERIZES THE ACTION

Fig. 45 Indicators control of AES

The second set of steerability indicators includes the effort (energy) required by the pilot to control the rudder in order to maintain the initial flight speed parameters and the normal multiplier AES associated with the performance of the following operations:

1. Maximum variation of engine thrust (engine);
2. Deploying and retracting the air brakes;
3. Wing geometry deployment and retraction;
4. Landing gear extension and retraction;
5. Landing gear jettison.

5.2 Steerability in the profile of aeronautical ergatic system control skills by the operator-pilot

As shown by the pattern of reciprocity and influence in the control of the AES, the only measurable output of the OP is the movement of the control stick, which transforms his professional skills. The professional gift is concentrated in the unique (biological) functions of a person in conjunction with an ergatically designed environment. It is the primary prerequisite for the interpretation of the personal ability that evaluates the manageability of the AES.

The movement of the handlebars and the energy expended (effort) are indicative of his research method, which reduces applied cybernetics to the methods of control theory. This simplistic view makes it possible to include this control manifestation in the steering circuit as an element of the circuit. In order to reconcile the physical steerability of the AES and its effective control of the OP, it is necessary to indicate their interactions [57,12].

The transformation of both characteristics is realised in the feeling of the necessary dosage of the expended OP energy during the handlebar deflection, which creates the expectation of a response (reaction) of the AES. If the rider does not feel a change in effort when the handlebars are moved, he loses an important part of the information about the change in the flight mode of the AES.

This leads to steering errors and, in some cases, a loss of stability in the steering circuit. As research in this area has shown the loss of stability of the steering circuit is not only due to a loss of effort but also to values that are too small, as shown in Fig. 46.

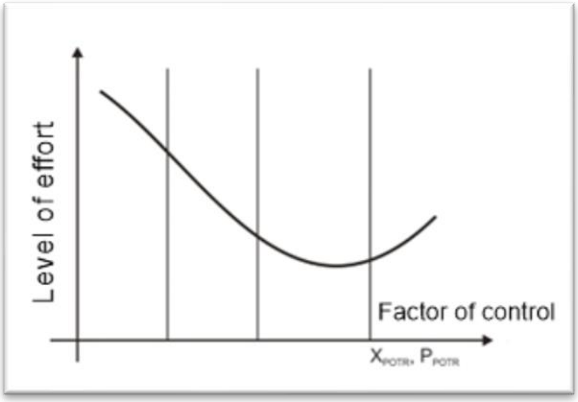


Fig. 46 Graphical representation of the measure in the movement of the AES handlebar (the effort applied X necessary, handlebar deflection needed, P necessary – OP effort value required)

The graphical representation of the control factor measure changes the parameters of AES movement in space in different ways. These temporal changes can be expressed by $Zi(t) = \alpha(t), M(t), V_{iz}(t), H(t), \ldots, \omega_x(t), \omega_y(t), \omega_z(t)$, in n – dimension euclid area E, which can be divided into a number of characteristic zones. The characteristic zones together form the environment of possible parameters Z_i, aircraft movement [58,44].

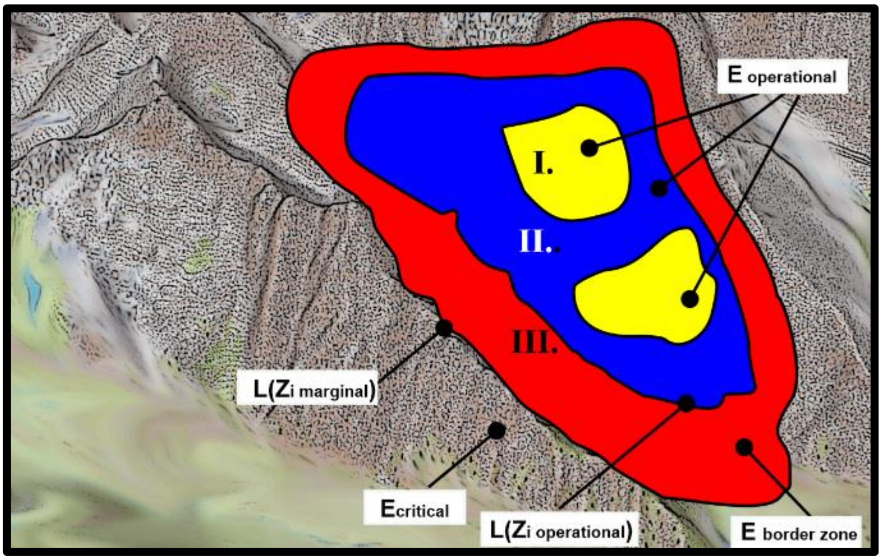


Fig. 47 Distribution profile of possible flight parameters Z_i, AES under the action of control factors OP

Legend: I — main zone, II — operating zone, III — boundary zone separated from the operational zone by the permitted values.

Area $\mathbf{E}^{\mathbf{op}}$ — operating values of those parameters to which it applies
$|Z_i(t)| \leq |Z_{i\ alowed}|$
Area $\mathbf{E}^{\mathbf{m}}$ — **marginal**values of limit parameters determined by inequality
$|Z_{i\ marginal}| < |Z_{i(t)}| \leq |Z_{i\ critical}|$
Area $\mathbf{E}^{\mathbf{crit}}$ – values of parameters that are dangerous for the AES flight mode when exceeded.
$|Z_i(t)| > |Z_{i\ limited}|$

As can be seen from Fig. 47, external profile limits L (ξ marginal) indicate the potential emergence of critical flight modes, L (Z_i allowed) – is the implementation area of normal operating parameters. The inner part of the EZ_i^{Pr} section, which is enclosed by the boundary point ($Z_{i\ \mathrm{permitted}}$), contains all possible values achievable in normal flight operation for which a non-sharp inequality applies $|Z_i(t)| \leq |Z_{i\ permited}|$ $and\ is\ include\ area$ E(I) a E(II). V – speed, H – flight altitude, $n_{x.y.z.}$, – acceleration, angle of attack, which are a necessary condition for the performance of the flight task. The second area contains the parameters allowed in the boundary operation of the AES.

The surface area that fills the inner and outer areas shall contain only those AES parameters that correspond to boundary flight modes E(III). These include limits of speed, angle of attack, and flight altitude, exceeding which will provoke acute danger.

The outer enclosed space belongs to the steerability area to the left of the L boundary ($Z_{i\ \mathrm{marginal}}$) - it represents a profile of dangerous critical dynamic states. When looking for solutions to increase steerability (controllability), it is necessary to accept the characteristics of Fig. 47 in order to meet the requirements of operation, weight of AES and requirements of fulfilling specifically defined tasks.

Aircraft capability standards define stability and manageability levels to ensure that the Successful Control Area (ASC) is achieved at every flight stage, i.e. from take-off to landing. The emerging complexity of interactions acting in a complex machine-human bond points to the need to apply cognitive principles, the introduction of which into aviation practice requires knowledge of model creation and simulation [59,17].

5.3 Heuristic model of cognitive aeronautical ergatic system

Aircraft capability standards define the levels of stability and controllability, so that achieving the area of successful control (OUR) is ensured at each flight stage, i.e. from takeoff to landing. The apparent complexity of interactions between a complex machine and a human shows the need to apply cognitive principles, the implementation of which in aviation practice requires knowledge of model creation and simulation.

Heuristic modeling determines the behavior structures of the system on the basis of conclusions obtained by the method of induction and observation. The heuristic modeling process consists of:

- From the investigation of the functional laws of the modeled system;
- Creation of algorithms from elementary information processes from which functional laws are formed;
- Model corrections according to observation results until satisfactory results are obtained.

The analyzed heuristic models of the cognitive LES accept the profile area E^{op}, E^{m}, $E^{tcritc.}$ euclidean space E. The basic elements of the created models are changes in the dynamic and aerodynamic characteristics of the LES, which have the greatest impact on OP skill. They belong here:

- Changes in the number M, flight height, periods of longitudinal and lateral oscillations, damping time of the resulting unbalanced state caused by the failure of the overshoot time of the acceleration multiple;
- The influence of the angle of attack on the static stability (in particular the lateral static stability),
- Significant changes in longitudinal stability at speeds close to the speed of sound;
- Significant changes in track static stability at near sonic speeds;
- Decrease in steering efficiency at supersonic speeds;
- Increase in rudder hinge moments at reverberant supersonic speeds.

This appointment (as well as others not mentioned due to the research needle) brings specificity to the control of the LES, which allows a skilled surgeon to improve his professional skills.

5.4 Analytical-synthetic method of stability and controllability of the heuristic model aeronautical ergatic system

Let us describe an analytical-synthetic method for determining the stability and controllability of the heuristic model AES in a mathematical laboratory environment (MATLAB).

The dynamics of the ergatic complex are determined by vector equations

$$\frac{D_x}{dt} = A_x + B_u + B_p(w) \tag{4.1}$$

$$y = C_x + G(u) \tag{4.2}$$

State vectors: x = [flight speed change (DV), angle of attack change, angle change derivative (υ dtheta)]

Scalar quantity designated for operator-pilot: w

The stabilization system is a compensator described by vector equations:

$$U = K_{1x} + K_{2x} + K_{3x}.(w) \tag{4.4}$$

$\frac{D_x}{dt} = K_{4z} + K_{5y} + K_{6w}$ (4.5)

Dz/dt = K4z + K5y + K6w (4.6)

Flight mode AES steady-equilibrium, flight level: 7000m, number M=0.8, flight speed Vo=250m/s.

The dynamics of the ergatic complex are determined by vector equations:

dx/dt = A*x + B*u + Bp*w (4.7)

y = C*x + G*u

State vectors: x = [flight velocity change (DV), angle of attack change (Dalfa), theta angle derivative (DER.theta), theta angle change(Dtheta)]. Control functions are specified by OP (operator-pilot): w

The stabilization system is a compensator described by vector equations(8),[9]:

u = K1*x + K2*z + K3*w, (4.8)

dz/dt= K4*z + K5*x + K6*w.

The specified values of deviations from the equilibrium state in the matrix form are:

A = [-0.013 -0.346 0 -2.349; -0.001 -0.932 0.994 0; 0.0004 5.887 -0.927 0; 0 0 1 0]

B = [-1.347 -0.568; -0.126 0.151; -17.89 -4.473; 0 0]

C = [1 1 1 1; 0 0 1 1]

Bp = [-1, -0.25];

- height rudder deflection 'D_{vk}', flaps 'D_{kl}'.

The system of equations (P2) contains six K-matrices of amplification coefficients. For example, matrix K1 contains measured values:

K1=[0 0.048 0.258 0.121; 0 -0.002 0.045 0.035]

Let's simplify the task by the existence of a condition:

K2=K3=K4=K5=K6=0, which is highlighted by introducing the symbol K1=C1

Then: C1=[0 0.048 0.258 0.121; 0 -0.002 0.045 0.035]

The G-matrix represents a system that allows direct entry of the operator-pilot into the control of the AES by the w function. For the above inputs: G = [0 0; 0 0]

Connection of matrix blocks expressed by equations (P1), (P2).

5.5 Analysis of the mathematical model

Vector equations (P1), (P2) are a MIMO (multi input-multi output) model that we create in the MATLAB-SIMULINK environment.

By opening: A, B, C1, G we get:

```
A = [-0.013 -0.346 0 -2.349; -0.001 -0.932 0.994 0; 0.0004 5.887 -0.927 0; 0 0 1 0]
B = [-1.347 -0.568; -0.126 0.151; -17.89 4.473; 0 0]
Bp = [-1; -0.25]
G = [0 0; 0 0]
```

As can be seen, matrix C= [1 1 1 1; 0 0 1 1] does not intervene in the compensation of instability of the ergatic complex. Let's name the state quantities of the vector x:
DV-dimensionless speed increment, Dalfa-attack angle increment, DER.theta - trajectory angle velocity change, Dtheta-trajectory angle change.

```
states= {'DV' 'Dalfa' 'DER.theta' 'Dtheta'};
inputs= {'Dvk' 'Dlk'};
outputs= {'DER.theta' 'Dtheta'};
sys_mimo=ss (A, B,C1,G,'statename',states,'inputname',inputs,'outputname',outputs);
```

We find GMK, we take an analysis:

```
axis(gca,'normal'), h = pzplot(sys_mimo), setoptions(h,'FreqUnits','rad/sec','Grid','off'),
```

The model is unstable, as evidenced by the following characteristics:

```
impulseplot(sys_mimo,20),
tf(sys_mimo),
```

Select the input-output 'ss_MIMO' for analysis
input (Dvk) - output (DER.theta),which represents 'ssSISO'.
Let's mark Dvk-DER.theta with the symbol 'sys11'.
Then

```
sys11=sys_mimo('DER.theta','Dvk'),h=bodeplot(sys11),setoptions(h,
'FreqUnits','rad/sec','MagUnits','dB','PhaseUnits','deg'),
```

The transformation of ss11 into a transfer function is: tf(sys11),
An unstable model expressed by the above transmission function requires a compensation circuit,
the design of which is the subject of synthesis.

5.6 Synthesis of stabilization (compensation) circuit by GMK method

We will simplify the procedure by introducing a label: h11=sys11

```
R = rlocusplot(h11), setoptions(R,'FreqUnits','rad/sec')
```

The distribution of zeros and AES on the graph is an expression of the positive gain values 'k'.
For a negative 'k' we get the area R = rlocusplot(h11), setoptions(R,'FreqUnits','rad/sec'),

```
R = rlocusplot(-h11), setoptions(R,'FreqUnits','rad/sec'),
```

The requirement for frequency, reregulation value, position of zeros and poles decided to choose:

```
k=-3.51,
```

The GMK method accepts this amplification in the internal feedback loop. Its transfer function, designated Hsv, is of the form: Hsv=tf(-3.51,[0,1])

The transmission function of the direct (unstable) branch is HPV=h11

The instability compensator of the aircraft model (non-energetic part) works in anti-parallel wiring.

```
cloop=feedback (HPV,Hsv)
tf(cloop)
```

The calculated transmission function of the monitored DERtheta/Dvk circuit indicates the stability of the circuit with a compensator. The compensator belongs to the class of linear time-invariant systems (TIS).

Transition characteristic:

```
sys_lti(:,:,1,1)=(cloop)
steppe(sys_lti)
```

Impulse characteristic:

```
impulseplot(cloop,5),
```

Gyromagnetic compass:

```
R = rlocusplot(cloop), setoptions(R,'FreqUnits','rad/sec')
bode (cloop)
```

The compensator stabilises the model at the proposed gain in a narrow stability band. The proposed function of the compensator can be used in the ergatic system of training and education of operators. When monitoring flight safety, the compensator requires determination of the range of allowed changes and their instrumental ensure [60,34].

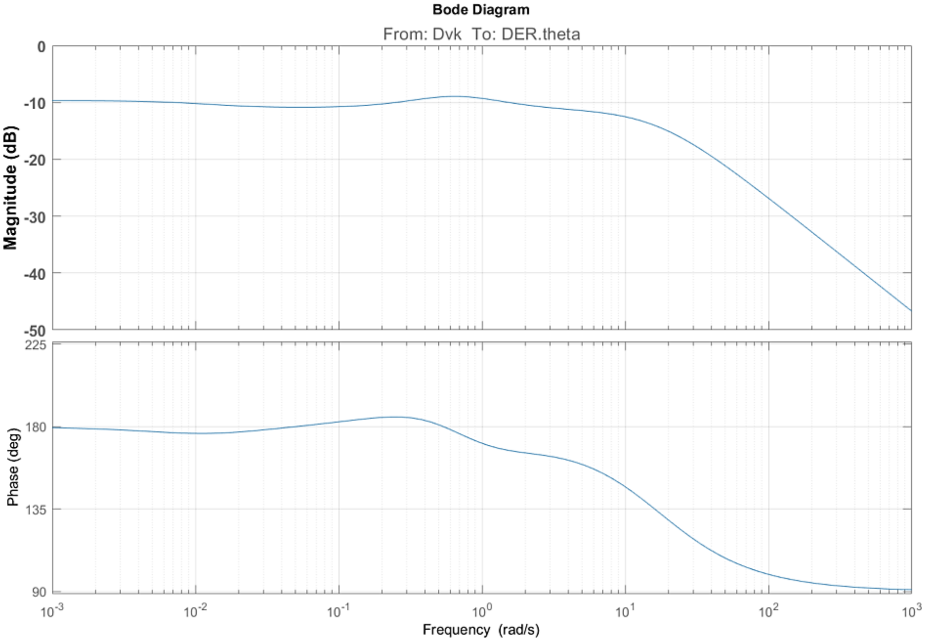


Fig. 48 Output transient characteristic of a point diagram

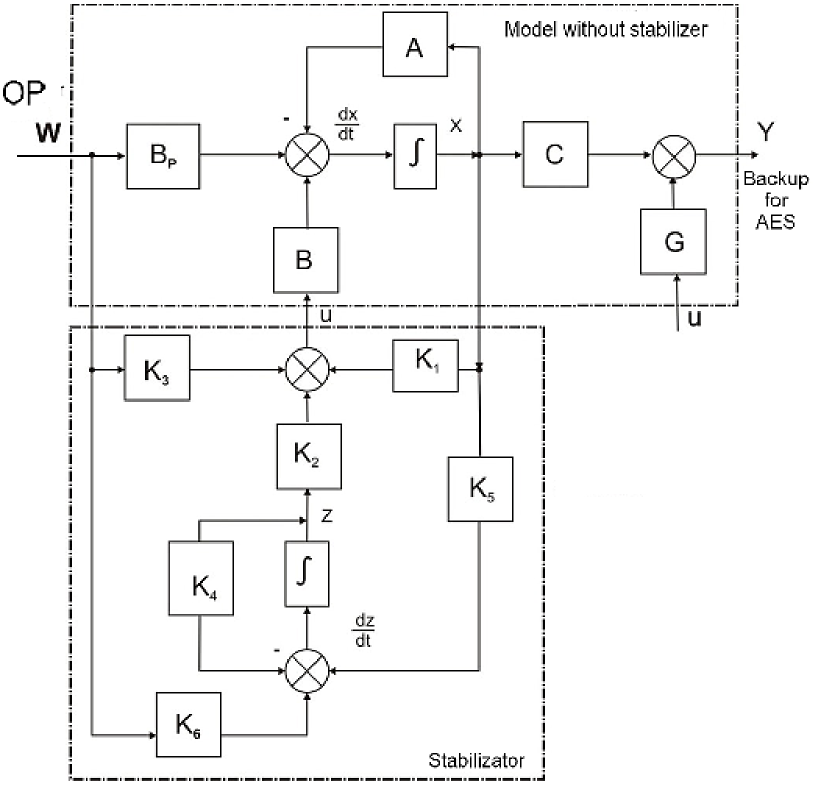


Fig. 49 Heuristic model of AES stabilization

The operator piloting control characteristics of the analyzed heuristic model can be found as a sequence, simulating a variant of the matrix K of equation [P1].

When the configuration (P1) accepted the coefficient C1 = K1 = [0 -0.048 -0.258 0.121 0 -0.02 0.045 0.053] at values: K2 = K3 = K5 = K6 = 0 , then the configuration C2 will be:
C2 = K1 = [0 0,129 0,244 0,122 0 0,018 0,057 0,023] at K2 = K3 = K4 = K5 = K6 = 0
C3 configuration:
K1 [0 0,329 0,942 -0,028 0 0,073 0,232 0,007]
K3= [-0.746 -0.187] , K2 = K4 = K5 K6 = 0
C4 configuration:
K1 = [0 -0,508 2,336 0 0 0 0 0]
K2 = [1 0 0,106 0 0 -1]
K4 = [0 0 7,66 0 0 0 7,66 0 0 0 0]
K5 = [-1 1 0 0 0 0 0 0 -1]
K6 = [-2,085 -3,066 0,241]

5.7 Analytical-synthetic method of controllability of the heuristic model of side movement aeronautical ergatic system

The lateral movement of the AES is the result of the forces and moments generated by the movement of the handlebar(s) and steering wheel, induced by the movement of the handlebar(s) and steering wheel with which the operator controls the inclination. In this motion is described by f_{ASC} differential equations, which summarise the effects of aerodynamic forces and moments in conjunction with the mass and initial characteristics of the AES. Current aircraft are characterised by small values of damping decay, especially at high speeds and altitudes, an increase in lateral stability at large angles of attack, as well as an unacceptable change in the moments of inertia associated with the x-axis, y. The manifestation of this problem explodes into the environment, especially in aircraft characterised by a small wingspan. The manifestation of these peculiarities is an increase in the oscillation of the lateral movement, accompanied by a sharp change in the pitch with its weak damping. The unfavourable characteristics of the lateral movement make it difficult for the pilot to control it and reduce its accuracy, resulting in a reduction in both accuracy and control [61].

Despite the inappropriateness of these characteristics in lateral movement, measurements show stability and acceptable manoeuvrability that can be corrected. The fact that current aircraft are in isolated motion can be described by a precise first-order function (pitch) and oscillating member yaw (second-order transfer function) demonstrating that AES will be stable in motion. It shows that in all cases the difference between the amplitudes of the oscillations decreases with time (in longitudinal and lateral motion), only at the final value do they stabilise (in time) at a stable value. This means that the aircraft has stopped in time, provided the pilot is no longer controlling it. The AES will only become unstable if the pilot intervenes. Handlebars with appropriate power and feedback circuits also contribute to the induced instability. Ultimately, the frequency characteristics of today's AES are determined by its composition, the OP and the control system. If the characteristics of these circuit elements are unsatisfactory, the control of the AES by the operator-pilot can cause it to become unstable [62].

The stability of the operator-pilot control of the AES is variable, and multifactorial, depending on flight conditions and flight role. The variability of the OP trait, which is subject to the influence of personality factors, can be fixed by learning and training (in contrast to the AES). The above reasons show that it is not possible to project the control system as a personality trait of the AES if we do not know the characteristics of the OP. An illustration of the interaction between the OP control and the AES is given in Example 6, whose information data was taken from the MATLAB programme. The modified interpretation of the computational algorithms makes the original content of the program transparent and solves the problem of the controllability of the AES, which, even in the monitored case, bears the unwritten attribute of cognitiveness.

Dynamics of change trajectory 'Dtheta' (DESIGNING COMPENSATORS).
Method: separation of relaxation and fugoid oscillations.
Tool: MATLAB-SIMULINK program environment.
(Used designation in the next - Control System Toolbox). Object model(G)-movement of the AES in a vertical plane.

```
A = [-0.013 -0.346 0 -2.349;-0.001 -0.932 0.994 0; 0.0004 5.887 -0.927 0; 0 0 1 0]
B = [-1.347 -0.568;-0.126 0.151;-17.89 -4.473; 0 0]
C1 = [0 0.048 0.258 0.121; 0 -0.002 0.045 0.035]
D = [0 0; 0 0]; matrix of direct output control.
states= {'DV' 'Dalfa' 'DER.theta' 'Dtheta'}
inputs= {'Dvk' 'Dlk'} %sets the operator-pilot (OP)
outputs= {'DER.theta' 'Dtheta'}; %output (measured values) AES
Sys_mimo=ss(A, B,C1,D,'statename',states,'inputname',inputs,'outputname',outputs)
sysG=sys_mimo('Dtheta','Dvk')
```

5.8 Model analysis

```
g = bodeplot(sysG),setoptions(g, 'FreqUnits','rad/sec','MagUnits','dB','PhaseUnits','deg'),
sisotool(-sysG),
```

sys(G), (i.e. the non-ergatic part of the AES) is unstable.
Synthesis of Dtheta stable circuit.
The directive 'sisotool(-sysG)' displays the control circuit design assumption. Click on View and then "DESIGN PLOTS..." we open synthesis procedures,G=tf(sysG);

```
sisotool(-sysG);
```

By judicious analysis of sequential steps, we set the correction term "C", to which the program assigns the constants "H=1","F=1". The synthesized G transfer function is corrected by a correction member whose transfer function is presented by 'Viewer':

C=tf ([0.019 1.659], [0.0769 1])

The transmission function of the closed circuit (contains blocks: F, C, G, feedback member H is determined based on the data given on the information "Viewer".

The result (after shortening similar two-members) is:

W = tf ([1 1.708 0.757], [1 22.55 309.6 50.62 54.468])

The following operations will verify the "satisfaction" of the solution:

sisotool(W)

zpk(W).

The result of the analysis indicates the need to separate oscillations relaxing from fugoid. Decomposing the transfer function W into partial fractions, we get:

W1=tf ([-0.146 -1.211], [1 0.152 0.178]); - fast (relaxing) oscillations.

W2=tf ([0.146 493], [1 22.4 306]); - fugoid oscillations.

Recommendation: In both cases, determine damping (d), and frequency (OMEGA). The realized synthesis determines the character of the inner loop. The device property can be adjusted, for example, by the heuristic method or by using the Viewer. In the analytical-synthetic solution, we can continue to apply the state space method.

Then: [a, b,c,d]=tF2SS([1 1.708 0.757], [1 22.55 309.6 50.62 54.468])

We get a comfortable reduced Frobenio shape. Recommendation:

1. connect the input circuit to operator-pilot signals 'w' via matrix Bp.
2. establish the limits of the applicability of the circuit and establish the safety stability zone.
3. state the relation of Dtheta with the change of Dalf, multiple 'ny',DER.theta,-detail the procedure for invoking the Viewer
4. to show the informational, exploitable potential contained in the GMK method.k

Flight in spatial coordinates

Input assumption: The aircraft model (non-energetic part) is characterized in time:

1. unchanged stability,
2. characteristic steerability,
3. limited rudder deflections.

Longitudinal channel

The dynamics of aircraft movement around the centre of gravity is described by the transmission function:

S_{11}=tf([0.4245 0.7827],[1 7.84 31.36])

omZ/Fp={0.4245(rad/s^2)*(s+1.844)}/(s^2+2*(0.7)*(5.6)*s+5.6^2)
When:
o$_{mZ}$- represents the angular speed of rotation of the aircraft about the "Z" axis,
F$_p$ - the necessary effort exerted by the pilot for control, after modification and equality of symbols S$_{11}$=omZ/Fp, we get the form:

```
[a,b,c,d]=tF2SS([0.4245 0.7827],[1 7.84 31.36]).
```

The program returned the notation of the equation of state in canonical form, which allows control using matrix 'd' (direct control, matrix c = 0; See matrix Bp above).
In a mode close to horizontal, where the equality of kinematic angles holds, we determine the temporal change of the trajectory angle by integrating the function S11:

The notation of the equation of state in canonical form allows control by means of the matrix 'd' (direct control, matrix c = 0; See matrix Bp in the previous section).
In flight mode, close to horizontal, where the equality of kinematic angles applies, we determine the temporal change of the trajectory angle by integrating the function S11:

```
Ut=int(S11)
```

The Laplace transform shows the integral with the symbol 1/s. Then:

```
Ut=tf([tf([0.4245 0.7827],[1 7.84 31.36 0]);
```

Analysis and synthesis of the problem
Know:
tf([0.4245 0.7827],[1 7.84 31.36 0]),then multiplied by 1/s will be:
Ut=tf([0.4245 0.7827],[1 7.84 31.36 0]); We will use the directive:

```
sisotool(-Tue).
```

As a result of the integration shown on the "VIEWER", the pole is placed at the origin of the complex plane. In another, the Evans method of compensator design is used, which is broken down into programmed sequences. The scheme used: compensator C in series with object G. The antiparallel branch has the term 'H'. By analyzing the synthesized outputs, we decide on the values of the compensator 'C' 'H' [61,44].

Conclusion:

1. Compensator C in the gain range 1, ensures stability.
2. The extent of compensation can be defined by a saturation-type limiter.
3. Relaxation oscillations can be determined by an outer loop.
4. We can control with zeros and poAES.

Aircraft propulsion dynamics

```
(T/G)/Dpom=tf (2,[1 3 4]),
```

where:

T-thrust of the engine, G-weight of the aircraft, D_{pom} - throttling of the engine, which is a function of the position and speed of movement of the POM.

Let's mark:

```
P=tf (2,[1 3 4 ]);
```

Alysis-synthesis.

```
sisotool(-P);
```

The "Viewer" display allows the control of aircraft propulsion through both zeros and poles of the transmission function P. AES propulsion as tilt angle stabilizer.

Use:

1. stabilisation of the AES track position, especially at high altitudes;
2. stabilization of the position of the AES in the vertical plane in landing mode.

Reason: In the listed flight modes, rudder control of the AES is ineffective.

```
s*Dpom=0.174*k*Ut;
```

Circuit architecture, description of antiparallel wiring blocks. Straight branch: signal generator, summation coupler, Ut block.

Observation and analysis is carried out by analyzing the characteristics of the aircraft (non-ergatic part), according to the data of the attached oscilloscope.

```
sys_f=feedback (tf([0.4245 7827],[17.8431.360]), tf(153,[134]));
SmUt=sys_f;
sisotool(-SmUt);
```

The controller model was designed using the procedures of the set "TOOLS". Model architecture:

```
s=sym('s');
C=6.16*(0.27-1/s+0.9*s);
```

The transfer function is:

```
tf ([5.544 -1.66 6.16],[1 0]);
```

Applies:

```
C=tf ([5.544 -1.66 6.16],[1 0]);
tf(C*SmUt);
```

The shape of the "zpk" of the transfer function is:

```
zpk(C*SmUt);
```

By separating members:0.63555(s+1.844)/(s+1.074), we get the transmission function C , which accepts the position of the working point "o" of the SmUt function:

```
Co=tf ([2.353 4.34],[1 1.074 0]);
G=tf ([1 3 4],[1 9.765 48.3875 73.4483 111.4802]);
```

We perform the arrangement of Co, G members according to the first display of the "Viewer" after using the "sisotool" directive, which we will also use to analyze the work of the circuit.

```
sys_f=feedback (TF ([0.4245 0.7827],[1 7.84 31.36 0]),TF(153,[1 3 4]));
```

A direct solution is also possible:

sys_f=feedback (TF([2.353 4.34],[1 1.074 0]),TF([1 3 4],[1 9.765 48.3875 73.4483 111.4802]));

Let's mark:

tf (Co*SmUt);

Lateral movement of the AES

The transmission function of the lateral movement of the AES is:

Gs=tf([0.016940.3123],[14.5510.56]); dimension:[rad/s^2/m],Gs=Oy/Dped,where:

Oy-rotational angular velocity of the AES about the 'y'[rad/s],Dped.-movement of the aircraft control pedals

Clone control is defined by the transfer function:

Oy-rotational angular velocity of the AES about the 'y'[rad/s], Dped.-pedal movement [m]. Control effort: 2690N/m.

Note: foot control is not dominant during flight.

Clone control is defined by the transfer function:

sys_tfdelay=tf (4, [0.0075 0.175 1],'inputdelay',td); Meaning of symbols: td-delay

Time constant with values td = (0.15,0.25,0.45 0.8) suitable for sequential modelling.

For td = 0.15s, the model is:

sys_tfdelay=tf (4,[0.0075 0.175 1],'inputdelay',0.15);

Let's mark:

Gkl=Pkl/Fkl, where:Pkl-projection of the angular velocity vector on the longitudinal axis "X",

Fkl-pilot control effort when tilted.

Let's name:

Gkl=sys_tfdelay;

The notation will allow selecting flight modes and the influence of traffic delay td on the accuracy of the control of the lateral movement of the AES. The influence of tilting on the dynamics of longitudinal movement of the AES. The significance of the influence is unpleasantly manifested in landing mode, for which the following applies:

DER.theta=cy*57.3/m*q*S*cos(gamma)-57.3/V*g;

Meaning of symbols.cy-buoyancy force coefficient, m-aircraft weight, q-thrust pressure, S-wing area, V-track speed.

When solving, we do not consider the influence of wind. In the equation below, the equation in numerical form is a model of a large-capacity aircraft.

The values of the members of the written equation are:cy=0.84[],m=1.523*10^-6[kg],S=330[m^2],

q=2812[Pa], V=75[m/s). By calculation, we get:

DER.theta=9*cos(gamma) -7.64;

Let's analyze: the transfer function Gkl shows the rotation(angular) velocity of the AES about the axis(X). DER.theta transverse axis (Z). Gkl=Pkl/Fkl=(gamma)/dkr.

If Gkl=Pkl/Fkl is angular velocity

then by integrating it we get (gamma)/Dkr=1/s*Gkl.The installation in the DER.theta transmission function will be:

DER.theta=9*cos(1/s*Gkl*Dkr)-7.64; where Dkr-angular deflection of the wings.

Task: perform modeling for known 'T' values by browser library blocks; The simulation showed a change in the angular speed of rotation of the AES around the 'Z' axis when tilted [62,29].

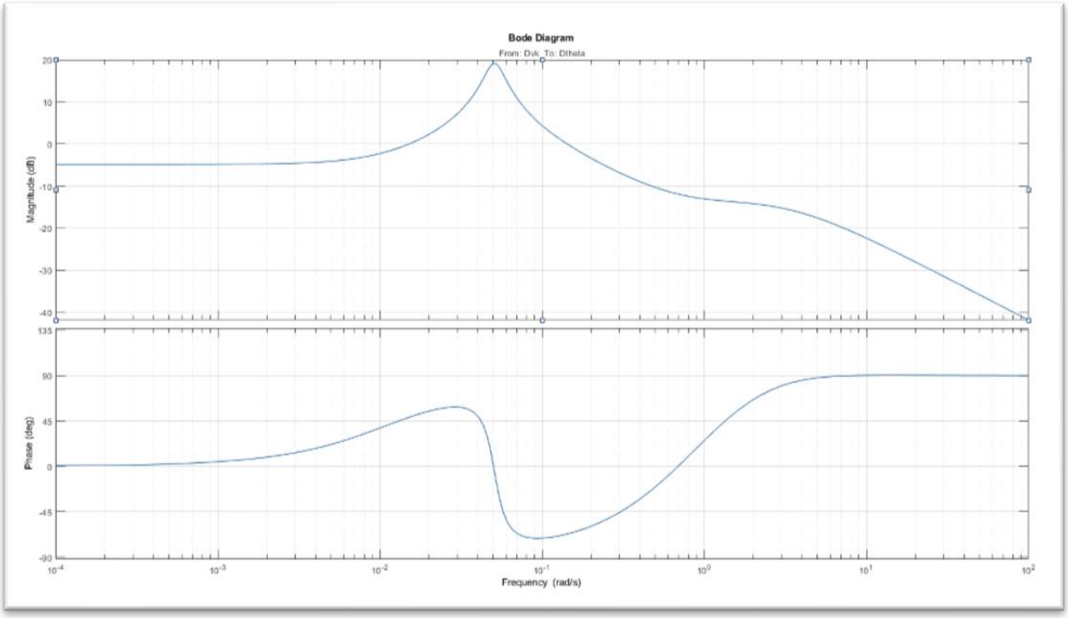


Fig. 50 Modeling pilot handlebar responses – Bode diagram

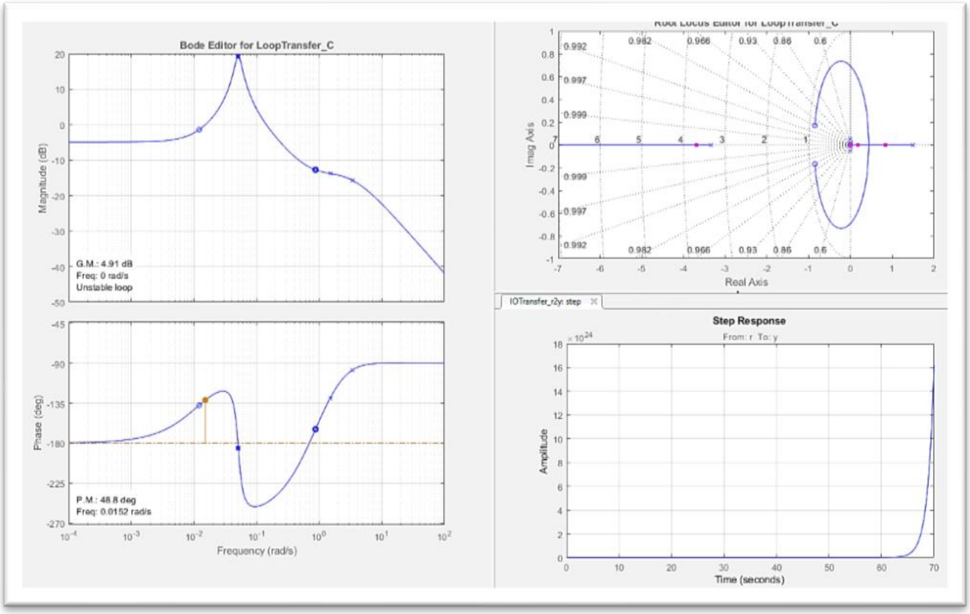


Fig. 51 Point diagram showing the magnitude of the response to pilot control

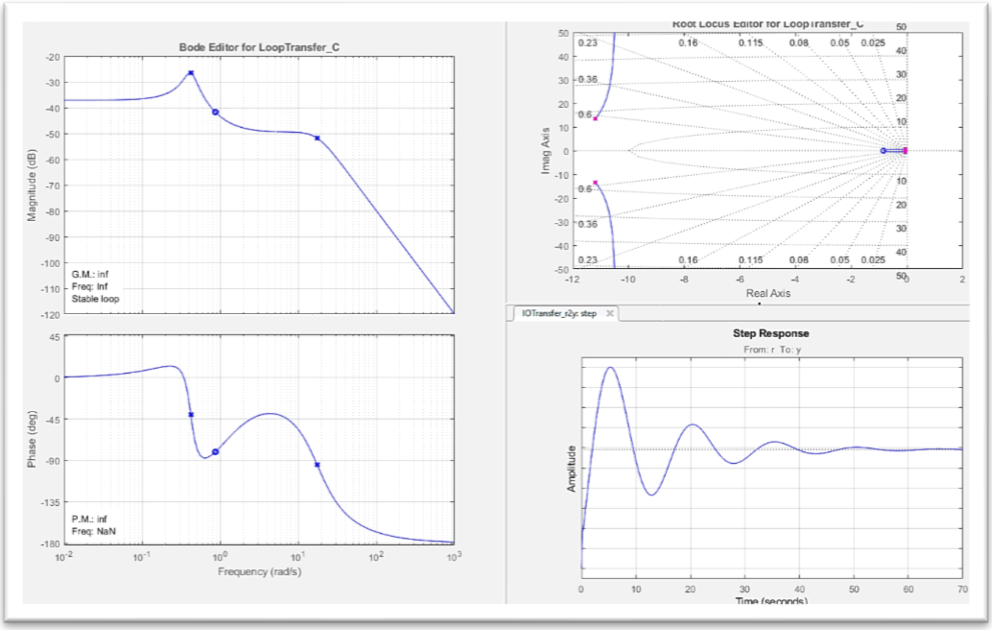


Fig. 52 Phase control response from pilot simulink

5.9 Synthesis of aeronautical ergatic system control with assured reliability in an exact environment

The appearance of a disturbance in the symbiotic system will provoke a non-standard situation that will change the process of controlling the AES. By the term non-standard situation, we understand the state of the AES in space, in which its position can be corrected by the OP control system [63].

The method of research of this problem is based on the principl AES of the theory of asymptotic learning in the occurrence of the disturbance outside the AES or in its local parts. The occurrence of any failure (subjective or objective) requires a change in the positioning control algorithms of the entire system. The above reasoning shows that the reliability of the observed object in reaching the ASC will change. Any decrease in reliability (triggered by a failure) induces an extreme condition that cannot be used in standard methods to achieve ASC. To better understand the problem, let's use the concepts of AES uptime and OP resistance [13].

Uptime is a term that expresses the property of the AES to maintain the working capability of its non-energetic part for the period specified by the manufacturer. OP resistance is an intellectual property to find a way to adapt the ability of the ATC to perform a flight task during and after the occurrence of a malfunction of the non-energetic part of the ATC.

If the management of the operator's activities changes to a non-standard state, then the manifestations of the ergatic complex must also change. The described speech shows changes in the position of the area of successful solution and subsequently the perception of a new OP relationship. A new manifestation of the change in the management rules is induced by changes: If the management of operator activities changes to a non-standard state, then the manifestations of the ergatic complex must also change. The described speech shows changes in the position of the area of successful solution and subsequently the perception of a new OP relationship. A new manifestation of the change in governance rules is induced by changes:

1. feelings of need to match a skill with the characteristics of AES;
2. the need to change the algorithms of AES control in the conditions of manifestation of the causes of
the failure;
3. adaptation to the position of the AES, i.e. its coordinates in phase space Q(F), the manifestation of which due to disturbances affects the control of the operation of the OP.

The established non-standard area and its relation to OP management requires the use of AES reliability methods. It is important to point out a certain contradiction in the understanding of the concept of AES reliability and asymptotic learning of OP, which is measured by its quality. Reliability is generally understood as the ability of the AES to perform flight tasks while maintaining its characteristics as defined by the flight envelope over time, which is also defined under extreme loads affecting the OP. The last part of the sentence indicates a certain contradiction. Estimating the reliability in a given case means determining the stability of the characteristics achieved by the system at the moment of failure. Until the moment of failure, the laws of asymptotic learning apply. And the OP applies the learned ability of AES. At the moment of failure, the standard situation changes to the non-standard situation. This is the law of asymptotic learning, where it takes on a new character in new conditions, and then new control algorithms already apply with the desired decision to change or select a new ASC. This means that the period between the beginning of the expiry of the used law of asymptotic learning and the emergence of the need to change it is the period that the OP will use to create a new law of asymptotic learning that compensates for the manifestation of the disturbance. It follows from the above that for estimating the probability of periods of OP input into the control, it must not exceed the period in which disturbances can be compensated. The perturbation compensation algorithm is usually part of the OP learning curriculum. The difficult task is to establish a new ASC domain for non-standard flight task fulfilment [66,19].

In the following, we will focus on creating a model for estimating the quality of standard control in the Matlab environment. We start the principle of model design by evaluating the change in the success of the ergatic process, which can be described by the well-known equation:

$$y_i = a \,.\, y_{i-1} - (1 - \mathrm{a})\mathrm{q}(i) \qquad (5.1)$$

where, in relation to the connection to the ASC, the following applies:

$$\mathrm{q(i)} = \begin{cases} = 1 \text{ when } \mathrm{F} \subset Qour \text{ is success} \\ = 0 \text{ when } \mathrm{F} \subset \text{ is a failure } Qour \end{cases} \qquad (5.2)$$

Where F is the coordinate vector of the system in relation to ASC, a is the operator parameter Q with which OP or AES is connected to the ASC position with the time constant t0 and with the handlebar positioning time t. ΔSuppose that for success and failure of reaching ASC, the probabilities hold:

$$P_{rav}\,(\mathrm{q(i)} = 1) = \mathrm{u(i)} \qquad (5.3)$$

$$P_{rav}\,(\mathrm{q(i)} = 0) = 1 - \mathrm{u(i)}$$

It shall be evaluated by the differential equation of estimation of the quality of control: $T_0 y + \dot{y} = \dot{q}$,

Where the point on q represents the change in perception of ASC.

$$T_0 = \frac{\Delta t}{1-a}, \qquad (5.4)$$

Where Δt is seen as a period of discretization of POL positioning

The parameter a represents an abstraction of the relationship OP vs. AES. To the new ASC, which changes according to empirical law:

$$a = 1 - \frac{4\,\tau_{q=0}}{T}, \qquad (5.5)$$

Where $\tau_{q=0}$ is the minimum residence time of the AES at the boundary of the new ASC. This time is determined by the properties (manoeuvrability of the object and the skill of the OP)

T – cycle period of the standard ergatic process

Solution (5.4) for leads to the convolutional integral $q \doteq 1$

$$y(T) = \frac{1}{T_0} \int_T^0 \exp\left\{-\frac{T-x}{T_0}\right\} q(x)d(x), \qquad (5.6)$$

Where x is the critical transition time to a non-standard flight.

Let's show how the success of the ergatic process y(T) changes with the known parameter a = 0.8, discrediting $\Delta t = 1$. Let's calculate parameters (5.4) and (5.5).

$$T_0 = \frac{\Delta t}{1-a} = \frac{1}{1-0{,}8} = 5s$$

For the estimated time of stay of the AES outside the ASC area, $\tau_{q=0} = 1$ s will be (5.5)

$$T = \frac{4}{1-a} = \frac{4}{0{,}2} = 20 \text{ s},$$

The solution of the convolutional integral (5.6) in shape was performed in the Matlab environment:

syms x notation of function shift in Matlab symbolism,
T=sym(20); periods of the AES cycle
yT=0.2*int(f,x,0,20), calculation command,
f=exp(-(20-x)./5); convolution , x is the transit time n non-standard flight,
yT=0.2*int(f,x,0,20), calculation command,

The AES property, determined by the time constant (T0=5s, a =0.8), allows Prav to be reached in the cycle T=20s. ASC = 0.9817

In the next, notice how it changes (5.6) when switching to non-standard mode when the phase trajectory of the system goes beyond the boundaries of ASC. In this case, the function (5.6) changes due to Q=0 - failure, (5.2). In the idea of the OP, this will manifest itself as a situational change to compensate, for which time consumption is required: T* = t* + Tn.

Where:

Tn represents non-standard time and t* is added time consumption (time consumed).

Note: Switching from standard to non-standard mode requires compensation, which postpones the total time, i.e. period time, by the necessary compensation period.

However, knowing the threshold level, the success rate, and the 'i' threshold 'y' threshold, we can construct the boundary function of success $y_{\text{n.limited}}$.(t), which has the same parameters as the standard function y_{w} (t). The shape of the functions is:

and $y_s(t)1 - exp\left\{-\,(\,1 - a)\,\frac{t}{\Delta t}\right\}$ (5.7)

b, for a non-standard flight

$y_n(t) = \ y_n exp\left\{-(1 - a)\,\frac{t_i}{\Delta t}\right\},$ (5.8)

Where v (5.8) represents ti= t* consumed to implement the correct solution of OP, Δt – discrediting interval y_n – the value of the variable at the moment t* when the need for a non-standard flight mode solution arises. The equation for estimating the limit value of the non-standard mode function can be determined by the equation:

$y_{n.thr.}(t) = 1 - exp\left\{-\,(1 - a).\,(t_i - \ t_h)\,\frac{1}{\Delta t}\right\},$ (5.9)

An illustration of the local estimation used in the reliability analysis of an ergatic system is performed in the following example, where the basic inputs of equation solutions (5.7), (5.8) are used:

```
t=0:1:30; a = 0.8;
dt=1; ys=1-2.718.^(-(1-a).*t);
hold on;
plot(t,ys,'k'),hold on,
yn=0.6; ti=2.668:1:13; a = 0.85;
dt=1;
ynt=yn.*2.718.^(-(1-a).*ti);
hold on;
fence(ti,ynt,'r'),
yn=0.8; ti=10:1:30; dt=1; th=10; a = 0.8; th=10;
ynht=1-2.718.^(-(1-a).*(ti-th));
fence(ti,ynht,'rd:'),
t1=13:1:30; a = 0.87; dt=1;
ys=1-2.718.^(-(1-a).*(t1-13))+0.089;
fence(t1,ys,'c'),
hold off,
```

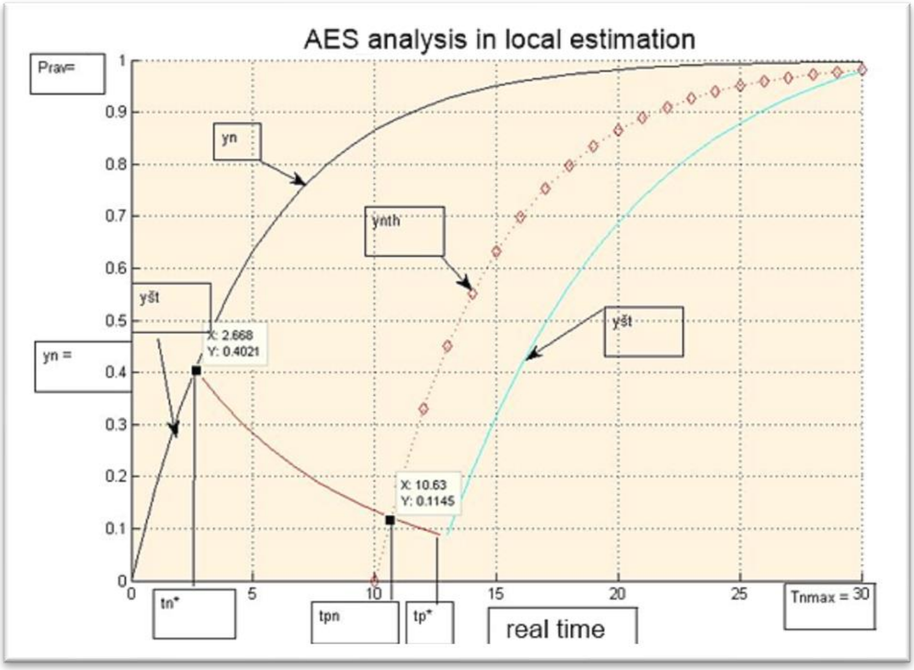


Fig.53 Illustration of AES reliability after switching from standard to non-standard flight

Legend:

ys(t) — standard estimation function,
yn(t) – estimation function on the resolution of a non-standard situation,
Ynth – boundary estimation function at the maximum allowable solution cycle non-standard tasks of the situation,
Tnmax - the maximum period of finding and relaxing the correct solution of a non-standard situation according to the chosen AES control doctrine,
TNX* - the immediate time value of finding a solution for the implementation of a new doctrine according to equations (5.7),(5.8)(5.9), the time required to compensate for the failure (Δt = 1) can be determined:

$$t_{k.n} = \frac{\ln(c_1 + y_n)}{1-a}, \qquad (5.10)$$

Where:

$c_1 = \exp\{(1-a)t_n\}$, nsa yn set for fig. 53. Xy where th = 10.63 , yn = 0.1145, a = 0.8, will be c1 = 2.718^ 0.2 * 10.63 = 8.44 then:

$$t_{k.n} = \frac{\ln (8.44+0.12}{1-0.8} = 3.75\text{s},$$

Then the success of compensation for the malfunction by the ergatic system will be determined by inequality:

$t_i \leq t_{pn}$ (5.11)

And that the difference will be – to you $(t_{pn} - t_{p1})$ (5.12)

Then, in the continuing analysis, we get a value (t_i is the value chosen by 10.63 – 10 = 0.6s), which represents the time element of forecasting the sequence time of successful completion of the compensation cycle. The mathematical models (5.12) mentioned in the previous section can be realized by electronic circuits [67-70].

5.10 Precision efficiency of autonomous air navigation ergatic complexes

The current issue in the research of unmanned vehicles is the methodology and flight characteristics when it is required that they move in the selected corridor. Especially in cases where there is a large absence of crew systems. In combining these areas, the assumption of the need to create legislation regulating this area is also addressed. The first technical requirement for applicability is to specify the movement of an Air Transport Object (ATO) in each corridor. The aim of the initial research is to create a hypothesis of the applicability of the navigation ergatic complex NEC. A prerequisite for the solution is the applicability criteria of methods for defining the efficiency of autonomous navigational ergatic transport complexes (NECs). Using a systems approach, the question of the applicability of probabilistically defined target accuracy efficiencies is investigated. The process-controlled movement of an Air Transport Object on a given trajectory is determined over time by the probability of not leaving the corridor. This probability can be expressed by the ratio of the number of 'n' - ATOs that have not disturbed the boundaries of the corridor to the number of 'N' moving in a controlled manner in the section. The speed of movement of the observed objects, as well as the conditions of the technosphere, do not change. With a total number of 'N', 'n_1' ATOs returned to the corridor after making a correction at the border. This means that the boundary of the corridor has been reached or left for a short time by the 'N-n1' ATO. Conclusion: at the time of observation t (0, T) of the number of ATO 'n1' beyond the corridor 'n3' had passed and 'n4' had returned. In the final total, T k was at the exit of corridor 'n_2' ATO and outside 'N-n2'. Then: n1 + n4 = n3 + n2, [72,66].

The relative number of ATO at the observed time t (0, T) was:

$(n_1 / N)*(1-n_3 / n_1)$;

After adjustment, we obtain the probabilities P1, P3.

Difference: f / F = Pp. e = P 1 - P3 can be defined as a criterion of accuracy efficiency where:

$P_1 = \frac{n_1}{N}$; $P_3 = \frac{n_3}{N}$; (5.13)

The criterion used: P2 = n2 / N increases the value of the accuracy efficiency of the NEC:

$P_2 = P_p . e + P_4$; (5.14)

The use of the criterion: 1 - P3 (probability of not crossing the corridor boundary from within) will also increase the estimation of the accuracy efficiency of the NEC:

$(1 - P_3) = P_p \,.\, e + (1 - P_1)$ (5.15)

Physical significance of the above results:

After substituting (5.14) in (5.15) and after modification, we get

$P_1 + P_4 = P_2 + P_3$ (5.16)

Probabilities (5.16) by their indices express the longitudinal and lateral movement of the ATO in the observed corridor. Longitudinal movement is the content of further research. Content (5.16) may be premises about the prestigious efficiency of autonomous ATOs as carriers of NECs. The criteria of accuracy efficiency (hereinafter used to replace the symbol $f\ /F\ =\ P_p.ef\ /F\ =\ F_i, F_j\Phi$), meet the requirements and are solved further using statistical analysis. The aim is to demonstrate the applicability (5.16) in determining the probabilistic characteristic of an ATO that moves within a corridor and whose width is 'c'.

Process navigation is carried out with NEC and together with ATO they create an intelligent autonomous "SCOPE = Sky Control Object Power Environment". It accepts the natural and local features of the corridor, which are subject to legislation and rules of movement of air bodies as well as rules of flying regulated in the relevant legislation. The process NEC was used to measure deviations in ATO movement within the corridor c = ±0.2km. Sensor errors were accepted for measurement. Environmental impacts have been neglected. The accuracy of the measured data was objectively determined by the technological level of the systems [34].

Approximations of characteristics and their adjustment were carried out in the MATLAB program environment. The need to reduce the time required was solved by applying the procedure for calculating probabilities P1, P2 to the applicability of the described method, which represents two-dimensional densities of spatial displacement of ATOs in the corridor.

Let P1 be the probability of random movement of ATO at the level of +c (from the centre of the corridor upwards) and P2 the probability of random movement at level - c (from the centre towards the lower limit) [74].

The calculations were carried out at the time of observation t. Then:

P1=FI[c/sigmaz(t)]; (5.17)

P2=FIi[c/sigmaz(t+T)]; (5.18)

where Fl is a function of the normal normed distribution.

sigmaz (t), sigma (t+T) - are mean quadratic deviations in the first section and subsequently in the time-shifted section of the corridor.

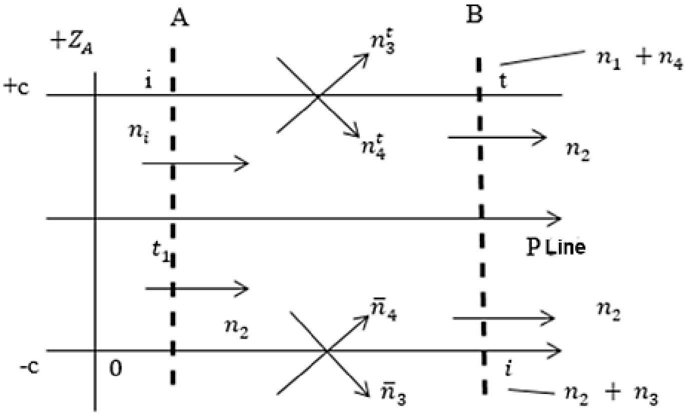


Fig. 54 Page ATO movement

In another, the following were used:

1. models mean quadratic deviation *'sigmaztm'* which is the square root of dispersion Dz(t)
2. manifold Dz(t), which contains measured values, sensor errors, and correlations.
3. NEC error interactions are significant for the following kinds of errors:
4. *ssigmazk* - the initial value of the system error measuring side deviation,
5. *ssigmapsi0* - course system (CS) system error,
6. *ssigmaus* - system error measuring the angle of nose,
7. *nyomega* - a measure of the influence of a random quantity on flywheel leakage,
8. *sigmaomega* - flywheel error CS,
9. *nyus* - a measure of the influence of a random quantity on the angle of the nose,
10. *alphaomega* - tracking speed of the CS inertial system platform,
11. *alphaus* - observed value of the nose angle after single integration,

<u>Calculation procedure in the MATLAB environment</u>:

Calculation of P1

Observation time: *t=0:0.5:5;*

```
sigmaztm=5.4e-006.*t.^2+0.034.*t+0.14;
figure,1; stem(t,sigmaztm,'g:','LineWidth',2),grid on,
title('Record sigmaztm page deviation values','FontSize',12),
ylabel('Sigmaztm[km],'FontSize',12),
xlabel('Observation Time','FontSize',12),hold off,
```

Tabular values:

```
[t; sigmaztm],
```

Quantification (5), for +c=0.1[km]:

Using [6],we find FI=P1 in turn:

u=(0.1./[sigmaztm]),
P1=[0.76 0.73 0.71 0.70 0.68 0.67 0.66 0.65 0.64 0.63 0.625];
Graphical presentation of the probable location of a ATO using the following NEC parameters:
figure,2; stem(t,P1,'k','LineWidth',2),grid on
title('Probability of VOD P1 entering corridor','FontSize',12),
ylabel('Probability values P1','FontSize',12),
xlabel('Observation Time','FontSize',12),

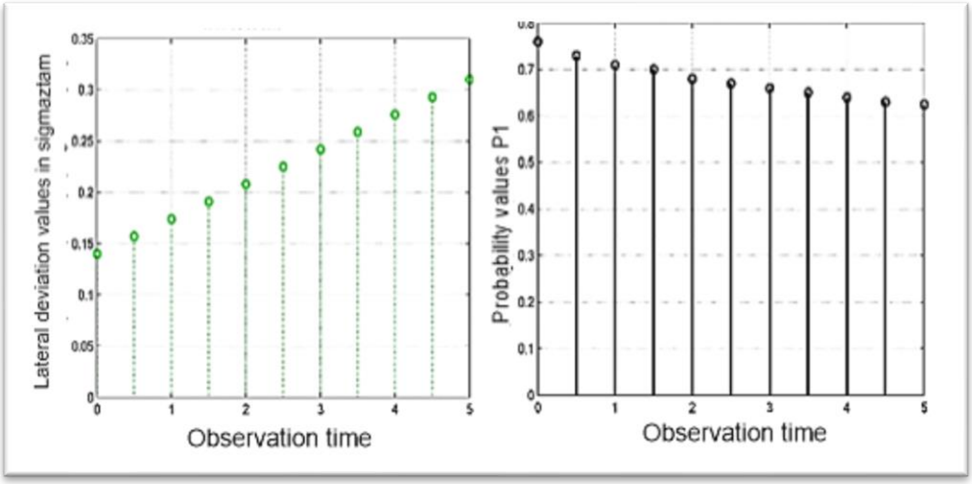


Fig. 55 Record of values on reciprocity of deviations and probability of ATO flights in the corridor

Calculation of P2.
Probability of ATO flight in 'c' exit from corridor P2.
After the NEC correction was made, the probability P2 of the position of the flight path ATO in the specified corridor at time t+T was determined, It was necessary to determine such a probability at a known time: T=3; [min];
The current flight time was:
ta=0:0.8:8; Page errors change to:
*sigmaztam=5.4e-006.*ta.^2+0.034.*ta+0.14;*
figure,3; stem(ta,sigmaztam,'b','LineWidth',2),grid on,
title('Record sigmaztam page deviation values','FontSize',12),
ylabel('Sigmaztam side deviation values [km]','FontSize',12),
xlabel('Observation time ta','FontSize',12),hold off,
Tabular values:
[th; sigmaztam],

At a known width of the corridor:

c = 0.1; will be the argument to the normal normed distribution FI :
u=c./sigmaztam;
P2=[0.57 0.25 0.03 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00];
figure,4; stem(ta,P2,'m','LineWidth',2),grid on
title('Probability of VOD P2 entering corridor','FontSize',12),
ylabel('P2 probability values','FontSize',12),
xlabel('Observation Time','FontSize',12),

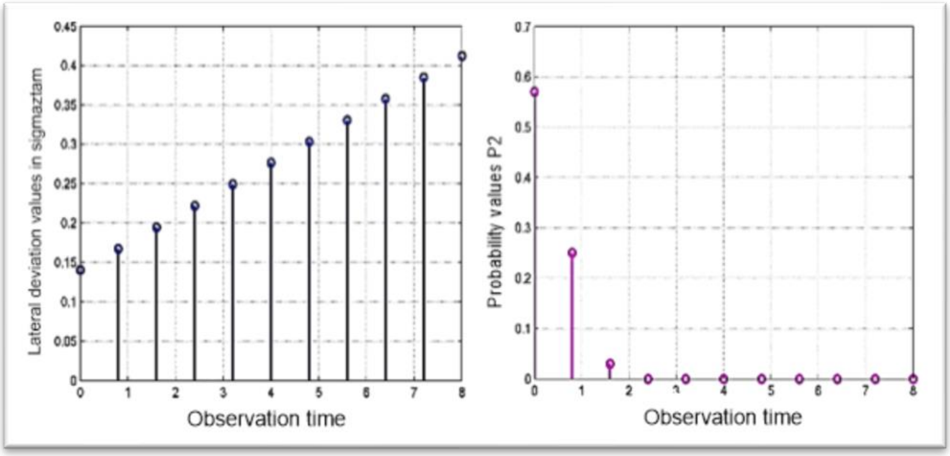


Fig. 56 Recording of ATO side deviation values and probability of ATO entering the corridor

The aim of the solution was to perform an analysis of the accuracy efficiency of the NEC, which consists of a Doppler, aerometric and inertial complex in a flight corridor with a width of +c = 100 m. The width of the corridor at the appropriate time as well as the correction of the inertial system carried out significantly affected the accuracy of the ATO navigation. Ongoing research has shown that for +c=800m and observation time t=0:5:60[min], the probability at the entrance to the corridor (estimated to two decimal places) will be:
P1= [1 0.99 0.95 0.89 0.83 0.78 0.75 0.72 0.70 0.68 0.66]
The observed value at the exit of corridor P2 at the shifted time T=3 min was:
P2= [1 0.99 0.94 0.87 0.82 0.77 0.74 0.71 0.69 0.670 0.66 0.64]
According to the known method [2],[3] the probability of not crossing the corridor boundary was calculated:
P3= [1 1 1 0.99 0.91 0.83 0.72 0.57 0.44 0.30 0.2]
In this case, according to (3), the value of the accuracy efficiency shall be:
Ppe=sum((P 1-1)+(1-P3))
Ppe = 0.9900; efficiency value.

Using this method to determine the accuracy of a VOD line in a selected NEC corridor requires knowledge of its statistical parameters and corridor quantities. Data on predictability characteristics are inputs for the calculation of technical efficiency.

The estimation of the quality of work, especially in the case of built-in complex systems, is assessed using various methods. The chosen method assumes the use of efficiency indicators of performed reliability tests when introducing tests of new complex systems into the basic ergatic complex. The results of the tests produce a characteristic from which it is possible to estimate the degree of conformity of the costs incurred for their actual operation. The decisive parameter is therefore the optimisation of the financial costs of maintaining the reliability of the above-mentioned systems, assuming that their optimisation can be estimated at unforeseen costs for the operator, e.g. an airport base system [78].

There are several peculiarities associated with the calculation of the efficiency of ergatic base complexes in their technical tests, the nature of which is determined by their technical specification and quality. In order to take into account, the quality of airport base systems, special methods are selected for their optimal management in the area where they can be evaluated. A prerequisite for effective assessment of their quality is also the state of the environment in which they are located and the management capabilities of operators with specific skills.

The main prerequisite for determining the beginning of quality is their functionality and price, which can be evaluated by means of set tests of their effective operation. An effort is made to achieve a minimum number of tests based on the number of airport systems in the LBS. Due to the complexity of airport base systems and the need for their "tuning" (the integrity of all technical systems), it is necessary to carry out an inspection of the relevant parts of the LBS or the effectiveness of structural modifications. The information resulting from the inspection is of a diverse statistical nature, which is difficult to analyse. The above facts limit the use of calculations of estimates of the effectiveness of the experiment by classical methods. The complexity of basic ergatic systems also requires the use of other calculation methods, which can estimate the effectiveness of the system on the basis of a priori information and compare it with the values (estimates) of previous tests [79,80].

Based on the considerations made, important parameters are time and price, which determine the validity of the basic ergatic complex or ergatic system. Validity is a value determined by the specified efficiency and depends on factors including efficiency models. The accuracy of the models is important because of the price. The more accurate the mathematical model, the smaller the number of technical inspections required for real testing of technical systems. Simple proportionality is particularly important for models expressing efficiency dynamics. For this reason, knowledge of model design is an important factor in the analysis of the results obtained in the course of all tests, which must include a qualitative assessment of the functionality of the basic ergatic complex. The formation of an accurate mathematical model of efficiency dynamics depends on the programme and methodology of the tests. Most models are created from empirical equations. This leads to problems with the implementation of measured data into model parameters (e.g. ergatic navigation systems of the airport, etc.) Since in some cases this is almost impossible, the following procedure is used [82].

The structure of the model is determined a priori and then, based on the test results, the parameters of the model can be estimated and an adequacy check can be performed. The accuracy of such a model depends on the amount of statistical information that can be processed. In general, the amount of measured information obtained during measurements is known, and therefore it is possible to focus on the dominant values, from which an appropriate set is formed. The next step is to choose a method of calculating the efficiency that gives an idea of the regularities of its evolution without demanding high accuracy. The input to this procedure is a method which does not require a specific analytically described model and which can only be used to follow the trend of regularity [83,12,19].

CHAPTER 6

STATISTICAL METHODS FOR EVALUATING THE ERGATIC BASE COMPLEX

By scientific fact, we understand any phenomena, processes, or facts that exist or take place independently of the observer. From the logical-gnoseological point of view, the fact is understood as substantiated knowledge, obtained by describing selected fragments (ergatic base complex).

Let the programme of concrete inherent test effectiveness presuppose *N* stages, in each of which a group of identical objects (airports) is tested. According to the test results, we record the defects that have occurred, which we also remove. This procedure ensures that each subsequent exam has the same entry prerequisites, and each is independent of the previous one. At each stage during the test, random failures may arise „ρ_i" as well as manifestations of design defects (defects) „f_i". Let's denote the number of successful exams „m_i" and the general number of exams „n_i".

Let's indicate the probability of manifestation of a random failure q_o, which we will consider a constant valid for all stages. Let us denote the probability of manifestation of structural defects at the q_i. stage. In this case, the probability of trouble-free work, which we will name efficiency, where the index "i" represents the stage number will be: $q_{o,}q_i, W_i$.

$$W_i = 1 - q_0 - q_i = 1 - (q_0 + q_1) \qquad (6.1)$$

The notation (6.1) is analogous to the notation of a loss function for t=0. For the estimation of effectiveness, the enrolment has the importance of the independence of each subsequent test. Consequently, due to the specified number of structural failures in the measured ergatic base complexes (if their number does not exceed a specified amount), the quantity q_i is not increasing, i.e.: $q_1 \geq q_2 \geq \cdots \ldots q_i,$ i = 1,2, ... n. (6.2)

Satisfying condition (6.2) shows that the inherent efficiency W_i has a non-decreasing value. The estimation of efficiency in the first approach is made using the maximum efficiency estimation method, where $W_{max} = m/nm$ is the number of successful tests and n – is the number of tests performed, which for the functional efficiency model of the whole complex (elements are included in series [1]) is shown by the maximum probability function of the monitored case in the form:

$$L\ (\varepsilon_1 f_1 m_1 f_2 m_2\ ; \ldots \ldots ; \frac{\varepsilon_n f_n m_n}{q_0 q_1} \ldots . q_n) = \prod_{i=}^{n} \frac{n_i!}{\varepsilon_i! f_i! m_i!}\, q_0^{\varepsilon_i} q_i^{f_i} (1 - q_0 - q_i)^{m_i} \qquad (6.3)$$

An estimate of the maximum value of probabilities q0 and q_i is obtained by deriving successively (6.3) and comparing it to zero**.**
Gradually, we get:

$$q_0 = \frac{\sum_{i=1}^{n} \varepsilon_i}{\sum_{i=1}^{n} n_i} \tag{6.4}$$

$$q_i = \frac{(1 - q_0) f_i}{f_i + m} \tag{6.5}$$

Estimates (6.4), (6.5) were determined regardless of condition (6.2). Let us check the validity of condition (6.1). When, at any stage, this condition is not fulfilled, i.e. if $q_i <$ qi+1 does not hold, then *the ith* and (i +1*)* stage merge. The quantity q_i for such a connection is determined according to (6.5). The connection of stages continues until the desired condition is met: The estimation of the effectiveness of the system is then consistent with the dispersion when the following applies:$q_i \ \geq \ q_{i+1}$

$$E\,[D_2^2 - D^2] < E\,[D_1^2 - D^2] \tag{6.6}$$

where: E is the mean value of the assay, D dispersion of the test sequence: i = 1,2,

In the method described below, it was used to imitate a practical test, which was oriented towards a hypothetical manufacturer of a new ergatic system in an ergatic base complex. Efficiency was determined by the floor of situational frames, the success or failure of speech of which was assessed by dichotomous states: (qi = 0 - failure, respectively. 1 - success).

Maximum probability function

```
Gi = [0 0 0 1 0 0 0 1 4]
```

Vector of random quantities induced by the technical environment of the base complex (airport)

```
q0 = 0.12
```

The influence of external conditions; Constant for all tests of the new system

```
mi = [1 0 0 0 3 0 3 2 9 10]
```

Number of successful phased trials

```
fi = [1 1 1 1 1 1 1 1 1 1 1]
```

number of faults eliminated during tests (functionality)

```
ni = [2 1 1 2 4 1 4 3 11 21]
```

Number of tests

```
qi=(1-q0). * fi./(fi+mi)
```

Probability of structural failure (1:5:32)

```
L=(factorial(ni)./(factorial(gi).*factorial(fi).*factorial(mi)).*(q0.^gi.*qi.^fi.*(1-q0-qi).^mi));
```

Maximum probability function. The sequence of tests:

```
i=1;    gi=[0];; mi=[1]; fi=[1]; ni=[2]; qi=(1-q0).*fi./(fi+mi),
```

```
L1=(factorial(ni)./(factorial(gi).*factorial(fi).*factorial(mi)).*(q0.^gi.*qi.^fi.*(1-q0-
qi).^mi));
i=2;    gi=[0]; q0=0.12; mi=[0]; ni=[1]; qi=(1-q0).*fi./(fi+mi),
L2=(factorial(ni)./(factorial(gi).*factorial(fi).*factorial(mi)).*(q0.^gi.*qi.^fi.*(1-q0-
qi).^mi));
i=3;    gi=[0]; q0=0.12; mi=[0]; fi=[1]; ni=[1]; qi=(1-q0).*fi./(fi+mi),
L3=(factorial(ni)./(factorial(gi).*factorial(fi).*factorial(mi)).*(q0.^gi.*qi.^fi.*(1-q0-
qi).^mi));
i=4;    gi=[1]; mi=[0]; fi=[1]; q0=0.12;; ni=[2]; qi=(1-q0).*fi./(fi+mi),
L4=(factorial(ni)./(factorial(gi).*factorial(fi).*factorial(mi)).*(q0.^gi.*qi.^fi.*(1-q0-
qi).^mi));
i=5;    gi=[0]; q0=0.12; mi=[3]; fi=[1]; ni=[4]; qi=(1-q0).*fi./(fi+mi),
L5=(factorial(ni)./(factorial(gi).*factorial(fi).*factorial(mi)).*(q0.^gi.*qi.^fi.*(1-q0-
qi).^mi));
i=6;    gi=[0]; q0=0.12; mi=[0]; fi=[1]; ni=[1]; qi=(1-q0).*fi./(fi+mi),
L6=(factorial(ni)./(factorial(gi).*factorial(fi).*factorial(mi)).*(q0.^gi.*qi.^fi.*(1-q0-
qi).^mi));
i=7;    gi=[0]; q0=0.12; mi=[3]; ni=[4]; fi=[1]; qi=(1-q0).*fi./(fi+mi),
L7=(factorial(ni)./(factorial(gi).*factorial(fi).*factorial(mi)).*(q0.^gi.*qi.^fi.*(1-q0-
qi).^mi));
i=8;    gi=[0]; q0=0.12; mi=[2]; fi=[1]; ni=[3]; qi=(1-q0).*fi./(fi+mi),
L8=(factorial(ni)./(factorial(gi).*factorial(fi).*factorial(mi)).*(q0.^gi.*qi.^fi.*(1-q0-
qi).^mi));
i=9;    gi=[1]; q0=0.12; mi=[9]; fi=[1]; ni=[11]; qi=(1-q0).*fi./(fi+mi),
L9=(factorial(ni)./(factorial(gi).*factorial(fi).*factorial(mi)).*(q0.^gi.*qi.^fi.*(1-q0-
qi).^mi));
i=10;   gi=[4]; q0=0.12; mi=[10]; fi=[1]; ni=[21]; qi=(1-q0).*fi./(fi+mi),
L10=(factorial(ni)./(factorial(gi).*factorial(fi).*factorial(mi)).*(q0.^gi.*qi.^fi.*(1-q0-
qi).^mi));
i=1:1:10;  To write calculated data in a table:
q=[0.4400 0.8800 0.8800 0.8800 0.2200 0.0880 0.2200 0.2933 0.0880 0.0800];
L=[0.3872 0.8800 0.8800 0.2112 0.2530 0.2530 0.2530 0.3029 0.1424 NaN];
[i;q; L], Maximum Probability Table.
fence(i,q,i,L),hold on,
xlabel('Test stages i','FontSize',10),
ylabel('New system failure probability values','FontSize',10'),
grid on,
title('Maximum probability function of estimating efficiency in tests','FontSize',10'),
hold off.
```

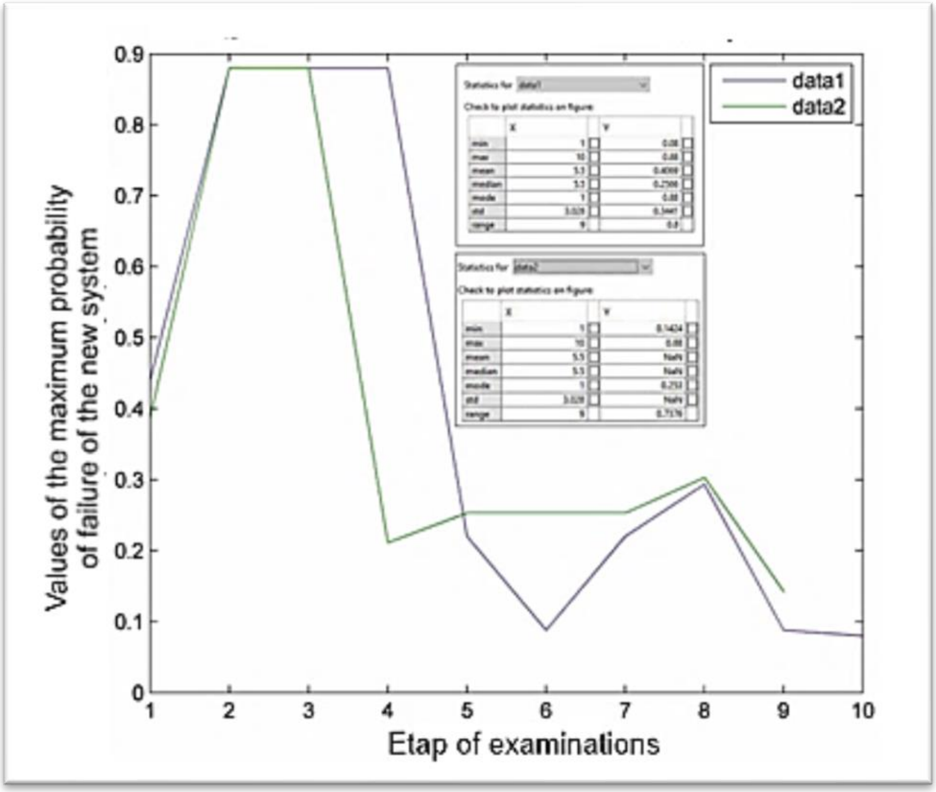


Fig. 57 Maximum probability function of estimating efficiency in flight tests
Legend: data1 – qi, (equation 5), data2 – maximum probability function (equation 3)

Figure 51 shows that the number of tests in determining the complex inherent efficiency of the base complex is 9, and with each subsequent test, the system behaves stably. This method has the possibility to predetermine the behavior of ergatic base complexes during their introduction into the environment (e.g. airports), where we want to determine its technical efficiency (technogenic functionality). Using statistical methods, it is possible to quantitatively evaluate the sequence of individual processes in the test stage [22].

6.1 Procedure for determining the cost of tests carried out

Let us selectively select from the object a dominant, proprietary subsystem significantly affecting E-safety (e.g. landing navigation systems). The financial costs of maintaining its reliability and energy consumption require constant financial readiness of the operator (e.g. airport). Failure to meet this condition creates prerequisites for the emergence of E-imbalance. Let us denote a certain technical device with the symbol "C" and its elements $c_{i,j}$ ($i \neq j$) which together form a matrix. Elements $c_{i,j}$ have the meaning of capital contributions. To operate "C", funds X are needed, which individually will cover the energy consumption and economics of reliable work of elements $c_{i,j}$. The matrix X is columnar, its elements are$x_{\mathrm{i,j}}$, where j = const. The volume of financial costs is then: $O = C \times X$.

Let "d" represent a set of unforeseeable causes that are capitally influenced by elements $d_{i,j}$, that j = konšt. airport operator covers the necessary financial costs by matrix "A" with elements and i,j with the required volume: A*X=b. The value dimension of volume "b" is limited from below "lb" and from above "ub".

The task will be to optimize "X" so that the quadratic criterion condition is met:
||CX-d||^2<_AX=b;
The left side of the equation represents the quadratic criterion for the deviation of financial cost management.
MATLAB sets: lsqlin=||C*X-d||.

The following financial volumes represent hypothetical estimates.
Matrix "C" of capital contributions:
C = [0.9501 0.7620 0.6153 0.4057; 0.2311 0.4564 0.7919 0.9354; 0.6068 0.0185 0.9218 0.9169; 0.4859 0.8214 0.7382 0.4102; 0.8912 0.4447 0.1762 0.8936),
Unpredictable expenses:
d = [0.0578, 0.3528, 0.8131, 0.0098, 0.1388],
The costs of quality assessment (planned) are covered in each quarter (fASC months):
A =[0.2027 0.2721 0.7467 0.4659; 0.1987 0.1988 0.4450 0.4186 ;0.6037 0.0152 0.9318 0.8462],
The first column represents the unit volume in total. Others accept variability in reliability.
The volume of funding to which the optimization requirement applies is:
b =[0.5251, 0.2026 ;0.6721],
Constraints:
lb = -0.1*ones(4,1),ub = 2*ones(4,1),
Determination of the optimal value of "X" at lb=ub=0:
X=lsqlin(C,d,A,b),
Let's apply to the conditional equation:
q=(C*X-d),
Q=q.^2
The other two rows of matrix Q can be ignored. Then, indeed, the following applies: Q<_b.
When accepting lb and ub:
X=lsqlin(C,d,A,b,[ ],[ ],lb,ub) represents cost optimization for maintaining the reliability of the ground navigation complex.
q=(C*X-d),
Q=q.^2,

The result indicates an increased "density" of optimal control, but the requirement of the equation is met.

Further evaluations are based on the following conclusions:

1. Environmental safety management for a specific aviation the operator is current and possible;
2. The complexity of the task can be reduced down to elements of capital contributions (matrix "C");
3. The quadratic criterion is purely selective;
4. Environmental risk can be valued by capital contributions to the dominant item;
5. Successful solution of the task requires high-quality input data.

The statistical method used indicates the possibility of its use for monitoring the ergatic base complex in direct use in practice and in connection with the funds spent on maintaining its high reliability. Acceptance of the effectiveness the reliability of the ergatic base complex emphasizes the randomness that needs to be covered with the planned additional means. The maximum probability estimation method has a loosely structured structure that accepts the current state of its decline in confidence by the predicted number of tests performed. The estimation of effectiveness is monitored by the dispersion criterion. It allows graphic-analytical recording of sequence and subsequent evaluation using statistical methods. The cost-effectiveness method used, based on the principle of quadratic assessment, makes it possible to monitor apriori the development of effective reliability of the ergatic base complex. It can be used by operators of complex ground-based air ergatic complexes in connection with optimizing the financial criteria of its operation.

CHAPTER 7

ADAPTATION OF THE AERONAUTICAL ERGATIC SYSTEM TO ITS MALFUNCTIONS

The control and guidance structure of complex airborne aircraft systems is a set of logically arranged elements performing alternative functions related to the stabilisation and guidance of the aircraft itself at all stages of flight. A separate position in the structure of functional arrangement of airborne aircraft complexes is occupied by self-control systems with specified reliability. In accordance with the principles and architectures of the applied automated aircraft control and guidance systems, it is possible to separate various purpose-built subsystems from each other, taking into account the exact useful properties of the aircraft with its parameters and taking into account the overall economy of operation.

An important area of the above problem is the solution to reliability issues of the Aeronautical Ergatic System (AES), the operation of which is affected by failures. It is a solution to the task connected with control of aeronautical ergatic complexes when parameters of their reliability are defined expressed by mathematical models. It is also necessary to know the problem of control of aircraft by the operator-pilot and thus intuitively create a possible hypothesis about the applicability of definitions of control of airborne systems using compiled algorithms. Mathematical models can be solved using differential equations, which implicitly give a picture of the complexity of controlling on-board information systems. They make it possible to solve the problem of stabilisation of aircraft control, which is one of the important criteria for eliminating the occurrence of a possible malfunction in the aerospace ergatic complex. Such a malfunction provokes a non-standard situation. A non-standard situation changes the algorithm of the entire continuous control of the AES. When an abnormal situation occurs as a result of a malfunction, the state of the AES also changes within the range in which it can be corrected by the aircraft control systems and the skill of the operator-pilot following the established procedures for troubleshooting during flight [13,76,45].

7.1 Method of research of OP skills by asymptotic learning in solving non-standard situations

One of the many methods of research into OP skills is based on the principles of the theory of asymptotic learning of operator-pilots when a fault occurs in the AES or its local parts. The occurrence of any error (subjective or objective) requires a change in the management rules of the entire AES. This implies the assumption of a change in the reliability of the observed object (defective aircraft system) in achieving the desired final domain of successful control of the aircraft by the operator-pilot (safe landing with failure).

Any decrease in the reliability of the AES (induced by failure) induces a boundary condition that affects the operation of the OP in controlling the aircraft to successfully achieve a safe landing. The concepts of AES reliability and OP quality are related to this issue.

Uptime is a term that expresses the property of the AES to maintain the serviceability of its non-energetic part for a period of time specified by the manufacturer of complex aircraft systems. The quality of OP is also understood to be the intellectual property of a person (OP) to find a way to adapt his ability to perform a flight task during and after the occurrence of a malfunction.

If the sequence of operator actions changes to a non-standard state, then the manifestations of the ergatic complex must also change. This indicates a change in the position of the AES in the area of successful resolution and the consequent perception of a new relationship between aircraft and operator. New manifestations of change in the control sequence are mainly provoked by:

1. The need to adapt the skill to the characteristics of the AES.
2. The need to change the control procedures of the AES in the conditions of the manifestation of the causes of the failure.

The adaptation of OP to the change in the position of the AES due to failure, i.e. the change in AES coordinates in phase space Q(F) affected by the control of the aircraft OP along the track, is shown in Fig.58.

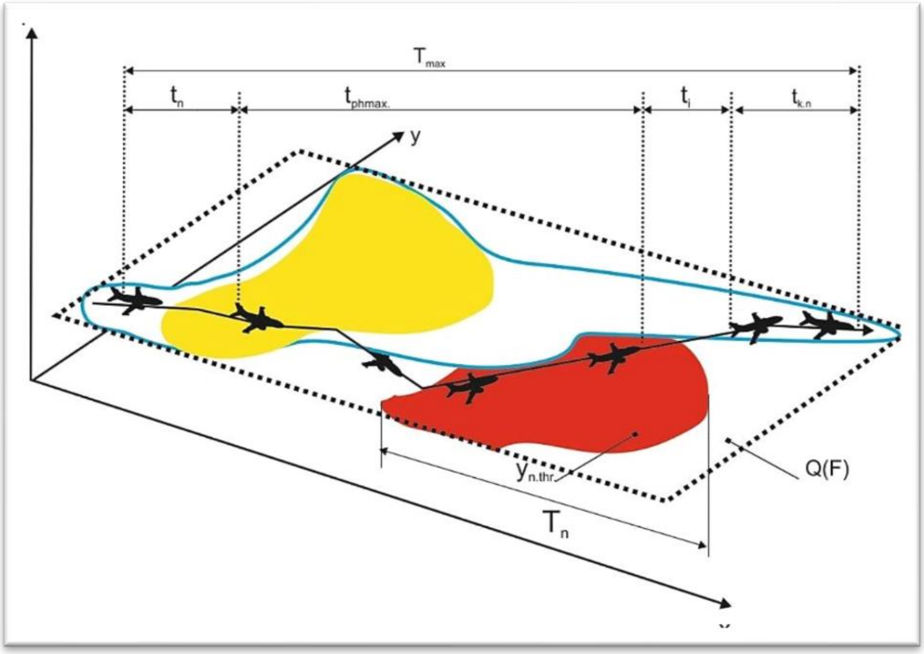


Fig.58 Illustrative description of phase space

In the specified non-standard area and binding to the management rules (i.e. choice of control) of the OP, the use of AES reliability methods is required. It is important to focus on a certain contradiction in the understanding of the concepts of AES reliability and asymptotic learning of the OP, which is measurable. Reliability is generally perceived as the ability of an AES to perform flight tasks while maintaining its characteristics over time as defined by the flight envelope, which is also defined under extreme operator-pilot loads. Estimating the reliability of aircraft systems means determining the stability of the characteristics of the AES achieved by that system at the time of failure. Up to the moment of failure, the laws of asymptotic learning apply, and the OP applies the learned skill of AES management. At the moment of failure, the standard situation changes to a non-standard situation. This is the law of asymptotic learning when a new character of management occurs. In the new conditions, new control algorithms are applied with the necessary decisions to change or choose a new terminal area - landing at a foreign airport. This means that the time between the beginning of the expiry of the applied law of asymptotic learning and the emergence of the need to change it is the period that the OP will use to create a new law of asymptotic learning. The latter compensates for the manifestation of the disturbance. It follows from the above that, to estimate the probability of the periods of input of the OP into the control, it must not exceed the period in which the disturbance can be compensated [85].

The AES disturbance compensation algorithm is usually part of the OP learning curriculum. A difficult task here is to establish a new range of successful control q(i) for non-standard flight task fulfilment. Let's create the necessary model for estimating the quality of standard control and its simulation in the MATLAB environment. Let us consider a change in the success of the ergatic process due to a malfunction, which requires the validity of the following differential equation:

$$y_i = ay_{i-1} - (1-a).q_i; \qquad (7.1)$$

Suppose that for success and failure of reaching the end control area, the probabilities hold:

$$P(q_i) = 1 = u(i), \qquad (7.2)$$
$$P(q_i) = 0 = 1 - u(i).$$

The probability of q(i) being achieved shall be evaluated by the differential equation for estimating the quality of control in failed driving, where the change (fault response) time is expressed by the member:Δt

$$y_{i+\Delta t} = y_{i+1} = ay_i - (1-a)q_{i+\Delta t} \qquad (7.3)$$

y - represents the derivation (change) of the perception of the disorder in the current tense with the learning value $"a"$. It is then possible to determine the quality of the rapid estimation of the OP failure at its very quality:

$$T_0 = \frac{\Delta t}{1-a} \tag{7.4}$$

Where:

T0 – time constant OP. The expression of the quality of OP by the value $"a"$ in the next is perceived as an entropic abstraction of the OP versus AES relationship, which can also be interpreted as the OP*'s ignorance of the state of the* AES (impossibility of identifying the disorder).

The OP comes to a new area of successful solution according to a change in empirical law:

$$a = 1 - \frac{4\,\tau_{q=0}}{T} \tag{7.5}$$

where $\tau_{q=0}$ is the minimum permissible residence time of the AES at the margin of safety (failure manifestation) when detecting an OP failure. This time is determined by the characteristics and norms in maintaining the position of the AES on the flight surface, as far as time for decision-making allows.

T is the period of the standard ergatic process control cycle that is selected or specified.

The solution (7.6) leads to a convolutional integral, which concentrates in the resulting solution the parameters a$q \doteq 1$ $_{,T0}$, T and Δt.

$$y(T) = \frac{1}{T_0} \int_0^T \exp\left\{-\frac{T-x}{T_0}\right\} q(t)d(t), \tag{7.6}$$

Where: $"q"$ is the function sought, which, in the above interpretation, indicates the process skills of the OP in detecting faults in complex AES on-board systems. We also interpret equation (6) as a weighting function, the solution of which expresses the quality of OP in the phase space of the AES control in the current situation and in solving complex fault conditions [88].

In the following, let us point out the changes in expression (7.5) that occur when the flight mode switches to a non-standard mode, i.e. when the phase trajectory changes in a short moment of time $\tau_{q=0}$. Non-standard mode represents a flight outside the boundaries of a successful landing solution. In this case, the function (6) indicates a non-standard state, q = 0. In the idea of the OP, this fact manifests itself as a situational change to compensation, which requires the need for a set time:

$$\mathrm{T} = \mathrm{t} + \mathrm{T}_n \tag{7.7}$$

The member Tn represents the non-standard flight time with the failure and t the added time consumption (time consumed) to resolve the failure. The transition from standard to non-standard mode requires compensation, which shifts the total time, i.e. the period period by the necessary compensation period [89].

If we know the threshold of success $y_{\text{threshold}}$, we can construct a limit function of success $y_{\text{n.hram.}}(t)$, which has the same parameters as the standard function y(t).

1. The shape of the standard function is:

a) $$y_n(t) = 1 - exp\left\{-(1-a)\frac{t}{\Delta t}\right\}, \tag{7.8}$$

2. The shape of the standard function for extraordinary flight

b) $$y_n(t) = y_n exp\left\{-(1-a)\frac{t_i}{\Delta t}\right\}, \tag{7.9}$$

where ti = t is the time consumed to implement the correct solution of OP, Δt discretization interval, y_n value of the variable at the moment *t* when the need for a non-standard flight mode solution arises.

Thus, the equation for estimating the limit value of the function of a non-standard flight mode with failure can be determined in the form:

$$y_{n.thr.}(t) = 1 - exp\left\{-(1-a).(t_i - t_h)\frac{1}{\Delta t}\right\}, \tag{7.10}$$

A possible approach for evaluating the probability of achieving the area of successful aircraft control in the event of a AES failure is shown by illustrating the local estimation used in the reliability analysis of an ergatic system, using the basic inputs of solving equations (7.8, 7.9):

```
t=0:1:50; a = 0.9;
dt=1; ys=1-2.718.^(-(1-a).*t);
hold on;
plot(t,ys,'k'),hold on,
yn=0.6; ti=2.668:1:13; a = 0.85;
dt=1;
ynt=yn.*2.718.^(-(1-a).*ti);
hold on;
fence(ti,ynt,'r'),
yn=0.9; ti=10:1:50; dt=1; th=10; a=098; th=10;
ynht=1-2.718.^(-(1-a).*(ti-th));
fence(ti,ynht,'rd:'),
t1=13:1:30; a = 0.87; dt=1;
ys=1-2.718.^(-(1-a).*(t1-13))+0.089;
fence(t1,ys,'c'),
title('Outputs of the pilot doctrine of the transition from standard to non-standard
mode','fontsize',14),
xlabel('Real time and its components in the pilot decision-making during AES control
','fontsize',14),
ylabel('Probabilities of reaching the area of successful flight control','fontsize',14),
```

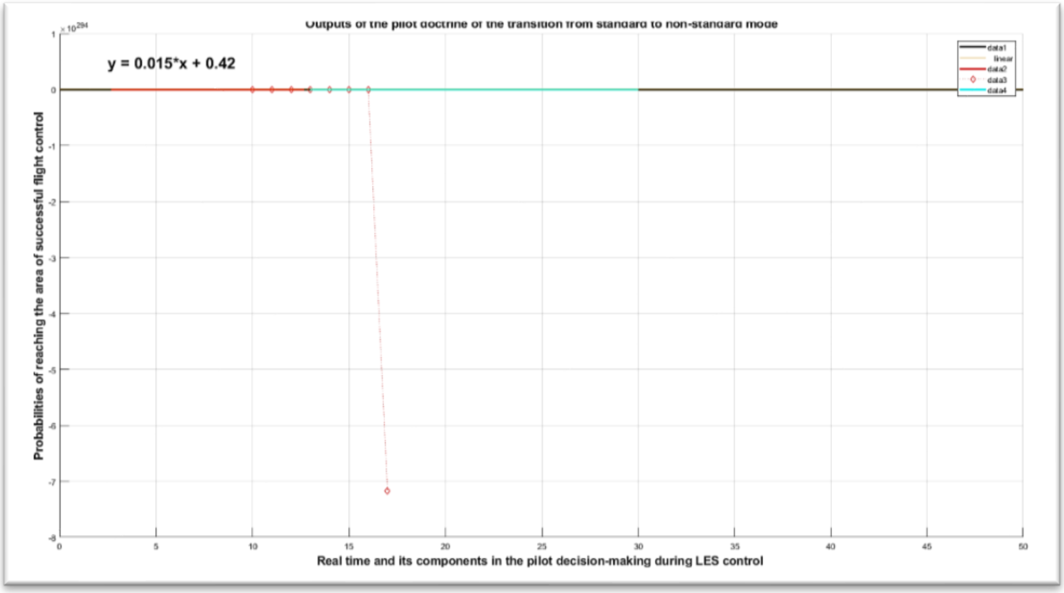


Fig. 59 Illustration of outputs of doctrinal decision-making on OP entry into AES control after a random error occurs

Each of these probabilities (7.2) represents a random process. For further elaboration of the problem, it is necessary to determine the set of states of the random process of solving the control of the AES with a fault and to determine the dominant elements for reaching the range of successful control. Changing the mode of operation of the aircraft ergatic system in the event of a fault leads to a change in the state, which in the OP can provoke a change in the quality of control when a fault is detected. This is due to regime changes triggered by physiological and psychological processes in response to the need to change one's own personal activities. The induced motivation to solve the situation in the aircraft caused by a malfunction is a subjective manifestation of the effort to solve the flight task in the given possible failures. The unspecified type of malfunction and the OP's reaction to its effects or the length of time it takes to manifest is the ability to have perfect knowledge of the aircraft's control functions. Such problems do not operate in isolation. Existing interactions result in an outcome that translates into dominance in the control of the AES. Depending on the given local measure, the OP can then compare the time period t n with the time period t_i, i.e. the time determined by the distance of the boundary from the position tph. The time deficit in troubleshooting causes factors in the control of the AES which directly affect the motivation of the operator-pilot to control the AES [92].

7.2 Helicopter control convolution and quality estimation

The method of managing modern helicopters and monitoring their controlled flight is associated with monitoring the effective operation of control systems and system integration of specialised airborne systems. The control structure of helicopter airborne systems is a complex of logically arranged elements that perform alternative functions related to the stabilisation and steerability of the helicopter itself in all phases of flight. The functional arrangement of the onboard complexes of the next generation of conventional helicopters has a fixed task of self-control with specified accuracy and with a precise flight task to guide the helicopter into the area of successful control. In accordance with the principles and architectures used in these intelligent systems, it is possible to separate various purpose-built subsystems, which take over the exact useful characteristics of a conventional helicopter with its parameters and with regard to the overall economics of its operation. Many solutions that contribute to the quality of control of a conventional helicopter are located in the environment of the helicopter cabin. At the same time, the helicopter's technogenic environment is being designed to focus more on cognitive systemic flight situational awareness in front of the helicopter. The aim is for the systems to operate with at least the lowest probability of failure. The autonomy of the helicopter control system itself will come closer to that of unmanned vehicles as it develops. Autonomous navigation systems will solve their decisions according to a priori calculations, which will control the helicopter according to commands and predicted information from the control centres. Based on these considerations, part of the design of the control of helicopter complexes in their various modes and stages of flight will be the solution of the issue of their reliability, which can also be expressed by mathematical models [55].

For this purpose, it is necessary to have knowledge of helicopter control with a certain degree of intelligence, and thus intuitively form a possible hypothesis about the applicability of information on the control of on-board systems using built-in algorithms (Fig.60). Again, applicable solutions to mathematical models can be obtained using differential equations, which implicitly provide solutions to the complexity of controlling on-board information systems. They are used to solve the stabilisation of the helicopter by the autopilot and the helicopter stabilisation systems in their specific hanging mode. In this mode, the self-control consideration is the highest, i.e. with the highest value of the probability of failure not occurring.

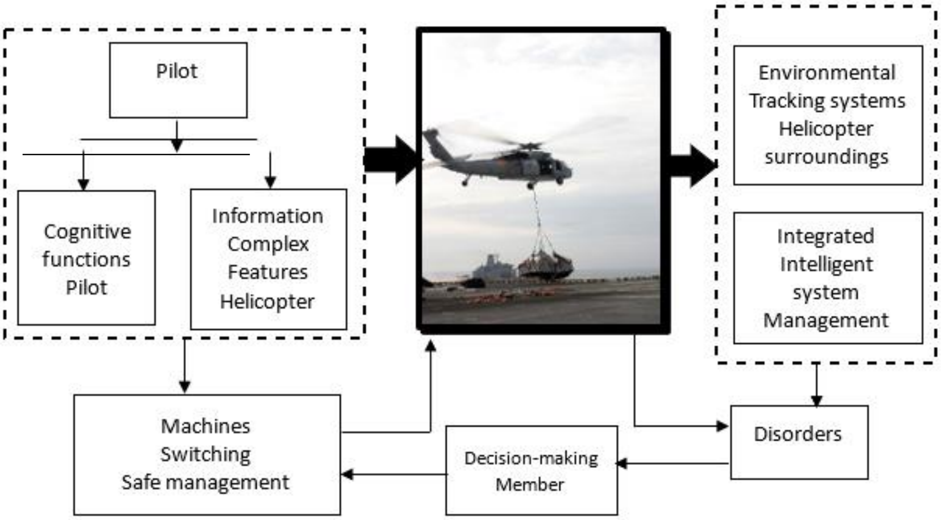


Fig. 60 Configuration of a conventional helicopter with prediction decision member

In the most complex mode, "hanging", every part of the helicopter's engine, propulsion and airframe is stressed with a high probability of possible malfunction. For this reason, this mode is often tested before the helicopter attacks the chosen route. The pilot checks the stability of the helicopter through his observation skills and by reading the sensory information elements to ensure the correct operation of the systems in this mode. Any malfunction in this mode can reach a pre-critical or critical state, resulting in an aviation incident. Thus, any malfunction provokes a non-standard situation which, unlike an aircraft, is characteristic of this mode and leads to a catastrophe. A possible non-standard situation also changes the rules of the entire continuous control of a conventional helicopter. Thus, the non-standard situation caused by the failure represents a change in the state of the entire Aeronautical Ergatic System of the helicopter. In an area where a given fault can be corrected by the helicopter's control systems and pilot skills according to established troubleshooting procedures, there is only a 30% success rate [77,98].

7.3 The effectiveness of helicopter control quality estimation in solving non-standard situations

One of the many research methods in the field of helicopter control is based on the principles of the theory of asymptotic learning of the pilot in the occurrence of a malfunction in non-standard situations or in its local parts. The occurrence of any malfunction (subjective or objective) requires a change in the system of principles (doctrine) of control of the entire helicopter. The above consideration suggests the assumption of a change in the reliability of the observed object (faulty helicopter system), while achieving the desired range of successful termination of control of the helicopter by the pilot (safe landing with failure).

Any decrease in helicopter reliability (induced by a malfunction) will trigger a boundary condition that will affect the pilot's control performance to achieve a safe landing.

By the ability of a pilot to fly a helicopter in non-standard situations, we also understand the intellectual property of finding a way to adapt his skill to solve this problem when a malfunction occurs.

When a malfunction causes a change of flight mode, a non-standard situation arises in which the manifestation of the helicopter control doctrine points to changes in the position of the helicopter itself and to estimates that the pilot, without a predictive system, must solve in order to reach the areas of success within the required (unset) time. A priori estimates for helicopter control changes are triggered by:

3. feelings of the need to adapt the pilot's skill to the characteristics of the current state of the helicopter in which he finds himself;
4. correct estimation of the need to change the way of controlling the helicopter in the conditions of manifestation of the cause of the malfunction.

The above way of estimating the successful handling of a failed landing is carried out by observing the convergence of the entire AES aeronautical ergatic system with the helicopter metasystem using the following aspects of the search

5. the mean position of the helicopter's cyclical control stick;
6. the corresponding position without the inertial AES affected by the fault;
7. the desired value of the probability of performing the helicopter metasystem tasks for a successful landing [44].

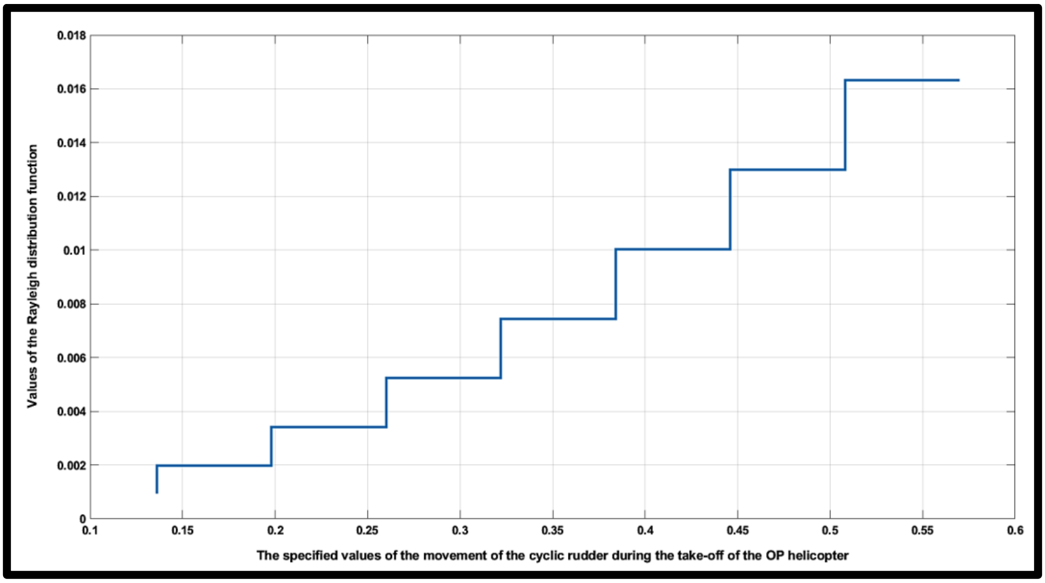


Fig. 61 Rayleigh probability function of successful landing with failure

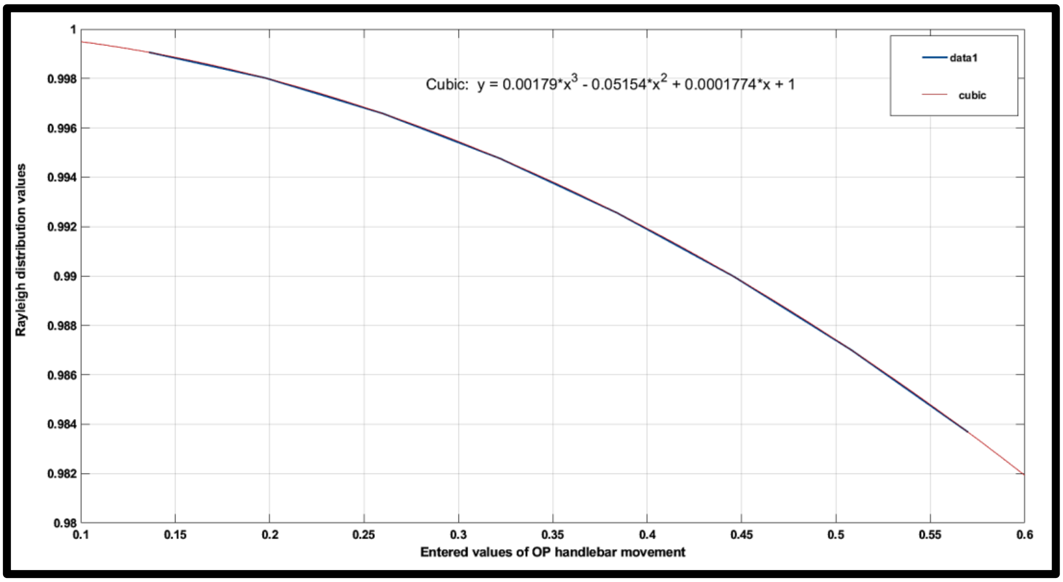


Fig. 62 Rayleigh's distribution of pilot skill in successfully achieving landing

cdf=1-pi; convergence condition: cdf = 1; when 1, then cdf=0.
E=(x.*pi); mean values of the elements of the Rayleigh distribution.
D=(x.^2.*pi)-E.^2; dispersion.
ES=sum(x.*pi); summarized mean,
DS=sum(x.^2.*pi)-E.^2; summarized dispersion.

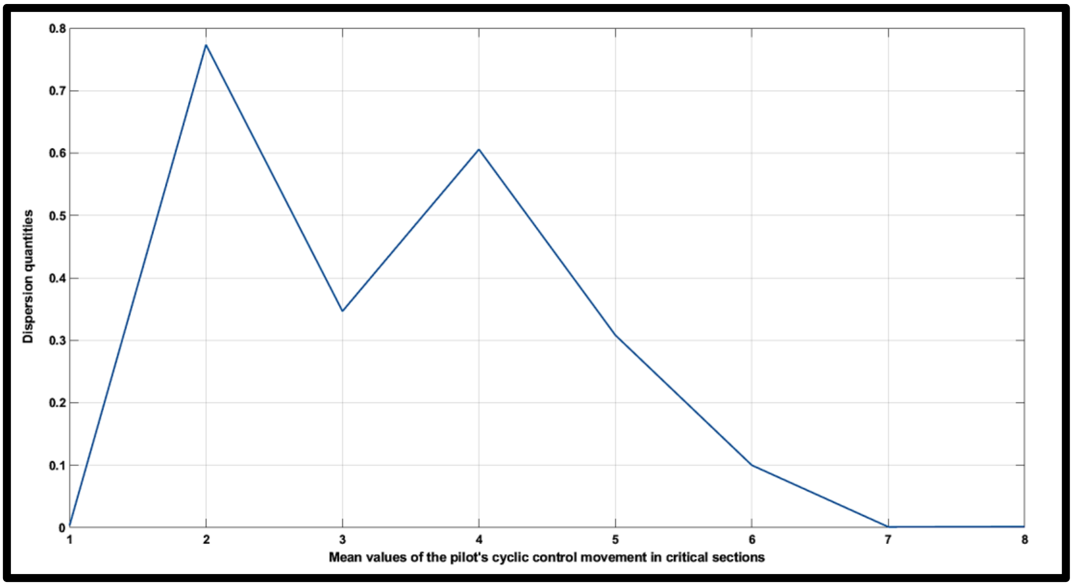


Fig. 63 Estimation of fault dispersion for helicopter behavior

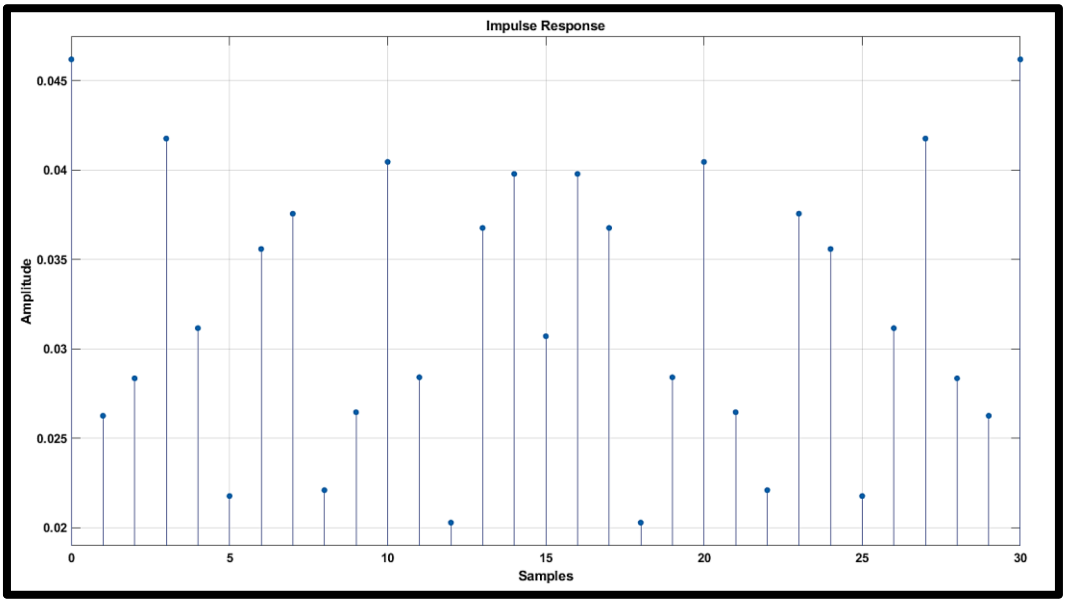


Fig. 64 Rayleigh distribution function of probability growth of pilot failure skill

The dispersion graph shows the effectiveness of the local AES quality estimation method.

7.4 Time variability of delay in pilot control of aeronautical ergatic system helicopter

Alternates n=[0 1 5:5:35],are placed in cyc AES. N=0:9;
The mean values of handlebar positioning by the pilot are:
y=[0 0.2225 0.4338 0.4598 0.0823 0.0392 0.0360 0.0345 0.0119 0.012];
Achieving AES control skills is asymptotic, the mathematical model of which is:

$$x = \left[\left(1 - \frac{1}{2.718^{yN}}\right)\right] \qquad (8.1)$$

The selected time delay value is one tenth of the cycle:
d = (N+1)/10;

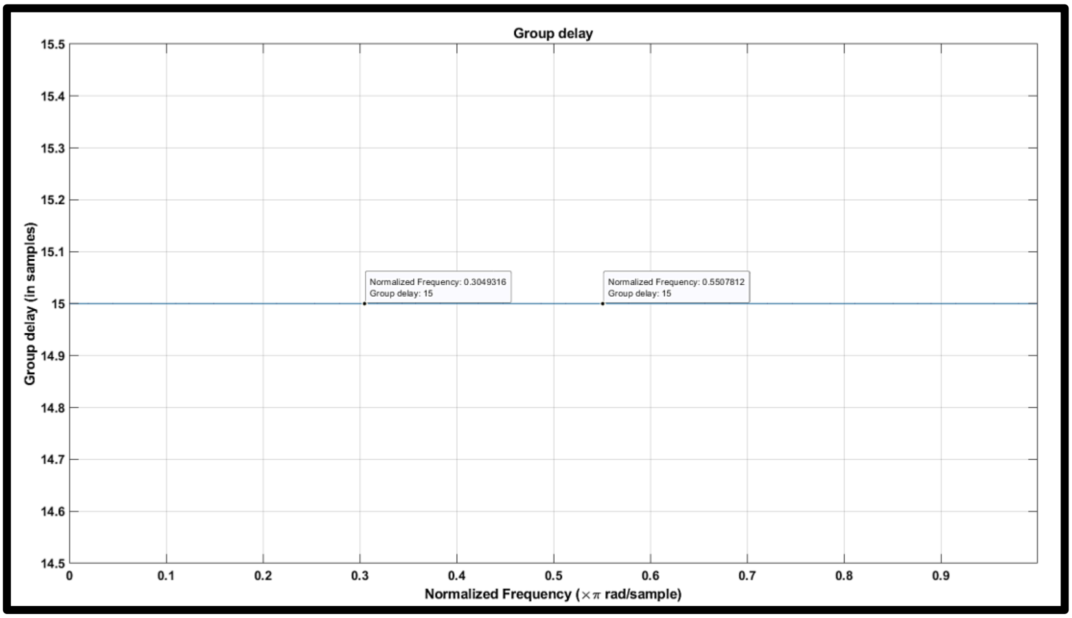


Fig. 65 Variable delay in controlling a malfunctioning helicopter

7.5 Analytical solution of gradual solution of decision division function in solving and correcting a conventional helicopter

To analyze the asymptotic learning process, the solved example uses the Butterworth filter and its normalized (standard) response frequencies from the control of the helicopter by the pilot. The input to the solution is the frequencies of the deflected cyclic handlebar by the helicopter pilot on the STA training simulator. Let 35 be the length of the frequency band; the number 10 represents the measured frequency in the ASS section of the helicopter. Then:
[L, M] = rat (35/10), L-interpolation factor, M-decimation factor.
f = fdesign. polysrc(L,M,'Fractional Delay','Np',1); %number 1-represents the upper limit of handlebar deflection, Np-program determined by the order of the Butterworth polynomial.
Hm = design(f,'lagrange');
t= [0 1 5:5:35]; convert frequency to time session.
Y= [0 0.2225 0.4338 0.4598 0.0823 0.0392 0.0360 0.0345 0.0119]; operator-pilot P3.
Asymptotic learning:
x= (1-1. / (2.718. ^(Y.*t)));
y = filter (Hm,x);
Record:
stem (t,x,'g'),hold on,
title ('Determining the degree of time delay'),
xlabel ('time slots'),ylabel('handlebar positions'),

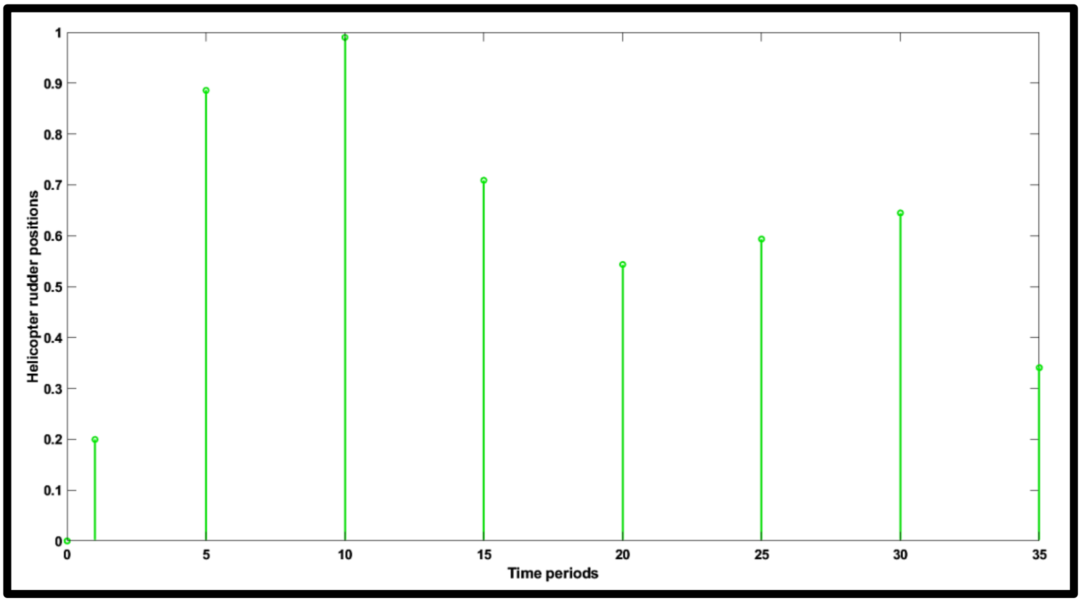


Fig. 66 Determining the degree of response time delay from helicopter cyclic control

Analysis:

```
d = fdesign. lowpass(0.3,0.5,1,16);
hd = design(d,'butter','matchexactly','passband');
fvtool(hd);
t1= [1 5:5:35];
Y1= [ 0.2225 0.4338 0.4598 0.0823 0.0392 0.0360 0.0345 0.0119];
x1=(1-1. /(2.718.^(Y1.*t1)));
y1 = filter(Hm,x1);
stem(t1,x1,'r+'),
title ('Determining the degree of time delay'),
xlabel ('time slots'),ylabel('handlebar positions'),
d = fdesign. lowpass(0.3,0.5,1,16);
hd = design(d,'butter','matchexactly','passband');
```

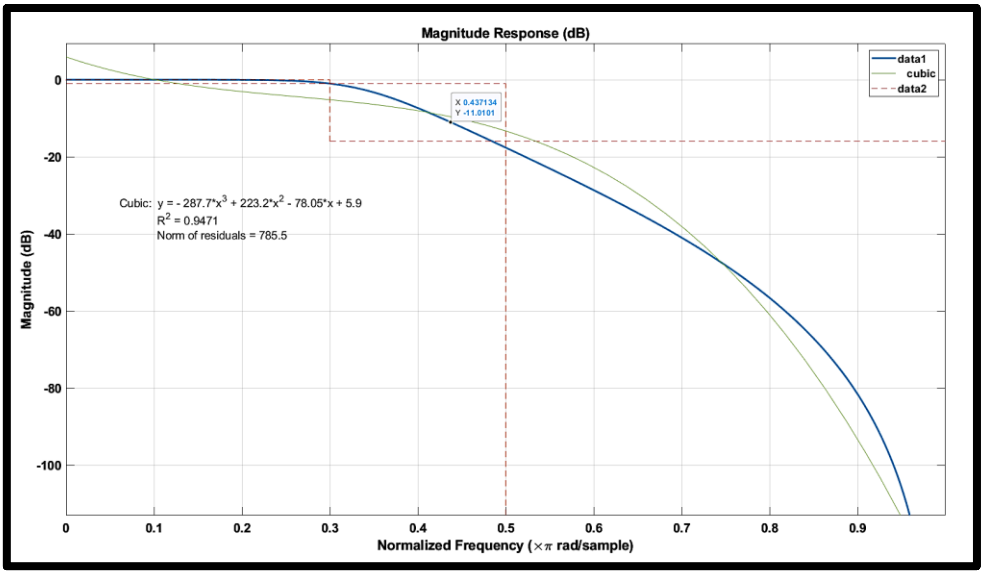


Fig. 67 Helicopter control frequency response

7.6 Analysis of parameters of cognitive Operator-Pilot skill in local estimation from the outputs of the ergatic system

Concepts, symbols; Status: Sa -pilot-operator successful, Sb-pilot-operator unsuccessful.
Alternatives for Status: Sa

1. Alternative 1 – continue training,
2. Alternative 2 – repeat training.

Input assumptions of analysis. Consider the skill of the P1 operator-pilot:
y= [0.0273 0.5722 0.3064 0.4532 0.2851 0.1524 0.0160 0.018];
By selecting the mean value of the Rayleigh distribution, we determine the probability density]:
fy=0.1286. /2.718. ^(0.1286.*y);
The pilot operator has a probability distribution in sections: 1,..,8,probability distribution:
P1(1:8) =[0.1281 0.1195 0.1236 0.1213 0.1240 0.1261 0.1283 0.1283];
Sum of probabilities P1(1:8) =[1],
Mean:
E=1/0.1286;
Requirement: Status: Sa, Alternative 1 allows you to divide P1(1:8) into:
PSa1= [p11 p12]=[0.6 0.4], Sum of transition probabilities:0.6+0.4=1.
PSa1= [0.6, 0.4]; PSa-transition matrix. In the top sixth of the function, 'y' is the biggest contribution (profit 'r11' difference.
r11=0.4532-0.0273;

r11=0.1195-0.1283; the highest drop (loss)in p11 of the PSa1 transition matrix.
In the other three digits there is a difference:
r12=0.1283-0.1261;
The profit vector then is:
RSa1= [-0.0086 0.0022],
For alternative 2 we choose:
PSa2= [0.7 0.3],PSa2=[p11(2) p12(2)];
In the first seven of the function, 'y' is the largest whistle (gain 'r11')
r11=-0.0086,
In the other two digits there is a difference:
r12=0,

Status: Sb, Alternative 1.

1. Alternative 1 – get a successful pilot operator from a competing company.
2. Alternative 2 – Accept a beginner operator-pilot training.

Alternatives 1.2 make it possible to design vectors:
PSb1= [0.4 0.6]; PSb1=[p11(1) p12(1)];
PSb2= [0.5 0.5]; PSb2=[p21(2) p22(2)];
RSb1 gain vectors:
r21=0.1195-0.1281; r22=0.1283-0.1261;
RSb1= [r21 r22];
RSb2 gain vectors:
r21=0.1283-0.1195; r22=0.1283-0.1261;
RSb2= [r21 r22];
Limit limit (discount factor) of ASS reachability:
ro=0.9;

Determination of cognitive parameters.
The beginning of the solution requires the display of states expressed by vectors v(i, d0).
The display is:

I	D0(i)
1	2
2	1,

When the alternatives i = 1,2 hold, we can construct a mathematical model:
v (1, d0) =q1(2) +ro[0.7*v(1,d0)+0.3*v(2,d0)],
v (2, d0)=q2(1)+ro[0.4*v(1,d0)+0.6*v(2,d0)].

The solution of the above equations presupposes knowledge of the values of q(ij). Let's calculate step by step; For calculation reasons, let's denote: q1(1) =Q1,

q1(2) =Q2, q2(1) =Q3, q2(2) =Q4;
Q1= (0.6*(0.1195-0.1283) +0.4*(0.1283-0.1261)),
Q2= (0.7*(-0.0086) +0.3*(0)),
Q3=0.4*(0.1195-0.1281) +0.6*(0.1283-0.1261),
Q4=0.5*(0.1283-0.1195) +0.5*(0.1283-0.1261),
Let v1=v (1, d0); V2=v(2,d0),then:
V1=0.2975+0.9*(0.7*V1+0.3*V2),
V2=0.1495+0.9*(0.4*V1+0.6*V2);
The solution gets: V1=v (1, d0)=2.427; V2=v(2,d0)=2.224, Display d1.

Let's calculate:
Q1+ro*(p11(1) *V1+p12(1) *V2),
Q2+ro*(p11(2) *V1+p12(2) *V2),
Q3+ro*(p21(1) *V1+p22(1) *V2),
Q4+ro*(p21(2) *V1+p22(21)*V2);

After substituting the calculated values, we gradually get:
-0.0044+0.9*(0.6*2.427+0.4*2.224)
-0.0060+0.9*(0.7*2.427+0.3*2.224)
-0.00212+0.9*(0.4*2.427+0.6*2.224)
0.0055+0.9*(0.5*2.427+0.5*2.224)

The analysis of cognitive skill as an output of asymptotic learning shows maximum value: 2.1235 for the state of Sa, alternative: Redo training; Subsequently: 2.1068 for the state of Sa, alternative: Continue training.

Table 3 The result of program calculations exemplary for pilot training analysis

RSa1 = -0.0086 0.0022	RSa1 = -0.0086 0.0022
PSa2 = 0.7000 0.3000	PSa2 = 0.7000 0.3000
r11 = -0.0086	r11 = -0.0086
r12 = 0	r12 = 0
Q1 = -0.0044	
Q2 = -0.0060	
Q3 = -0.0021	
Q4 = 0.0055	
ans = 2.1068	ans = 2.1068
ans = 2.1235	ans = 2.1235
ans = 2.0726	ans = 2.0726
ans = 2.0985	ans = 2.0985

7.7 Analysis of operator-pilot quality in dichotomous control of aeronautical ergatic system

A prerequisite for the analysis is the transformation of the numbered positions of the handlebar into dichotomous states. Let's determine the degree of skill of the operator-pilot P3, the content of which is determined by the model of the exponential function. Learning as well as skill is procedurally evaluated by dichotomous states: 'successful', and 'unsuccessful'. The development of skill, and learning, has an asymptotic character. The object of analysis is the characteristic of the Operator-Pilot 'P3' (hereinafter referred to as OP): YN= [0 0.2225....0.012] and alternates with the period 'T'. For sections [0 1 5:5:35], let's formally allocate time to regulations:

t=0:9; where are the periods Ti= [0 2 2.5 2.5 2 1 0.5 2 1],i=1,2...,9.

The skill of OP is expressed by the period 'T': YT=Yi/Ti,i=0.1,...,9;

YT= [0 0.1112 0.1735 0.1839 0.04160 0.0392 0.0720 0.01725 0.0119 0.012];

The criterion function of achieving ASS establishes the method of asymptotic learning,

where the exponential term dominates:

x=(1. /(2.718. ^(YT. *t)));

The numerical form is:

x= [1 0.8948 0.7068 0.576 0.8467 0.6492 0.8863 0.9092 0.8976];,

Let us determine with the calculated values 'x' representative points. The first three periods represent the OP's decision on the choice of tactics to achieve ASS. Therefore, the final stage of development of asymptote is subjected to analysis, the ordered numbers of which by size form a matrix:

F=[0.5760 0.6492 0.8220 0.8863 0.8976 0.9092]; A vector 'which has the meaning of 'measure'.

The handlebar positions [0.5760 0.6492] represent the quality of the OP decision and grow skills with weight [1 1]-SUCCESS. In the end part of the asymptote, the OP moves the handlebar at least-with weight [0 0 0 0].

Let's make a matrix:

A = [1 1 0 0 0 0]; A - asymptotic dichotomous rate. (Vibration vector).

It follows from the considerations made that the development of skill has a discontinuous (discrete) character. However, the idea of the quality of skill development fits a continuous function. Let us transform the vector 'F' into the form of a Chebyshev polynomial, which has unit coefficients (see row 'A'). Let's use the Chebyshev polynomial to construct a pulse (weight) filter. Let the weighting function for the row symbol pairs "F","A" be the vector:

W=[2 1 1]; The response to a command is an impulse characteristic. (Balance vector).

The length (orders) of a digital filter is:
N=35; Filter order - proportional to the number of patterns of handlebar movement.

By the command 'accepting the errors (err) of the respective coefficients 'b' we obtain successively records that can be analysed both qualitatively and quantitatively:

```
[b,err]=firgr(N,F,A,W);
hfvt = fvtool(b);
```

The AES dichotomous measure method is suitable for monitoring and classifying operator-pilots in an ergatic system. The condition for its usability is knowledge of the flight characteristics of the AES, with which steerability is especially important.

CHAPTER 8

RELEVANCE OF AERONAUTICAL ERGATIC SYSTEM MODELING

The shaping of OP signals is performed in a time-space in which the AES stabilization process proceeds continuously. The subject, i.e. OP, performs control by AES under the influence of internal and external states. The diversity of processes (discontinuous – continuous) has a significant effect on the quality of AES stabilization, which is induced by the control of the OP and is a source of disparity between stability and steerability. Differences (differences) are also caused by the need to use type functions on identification-intelligent equipment, which under their influence enters stationary and non-stationary states. In general, models of any structure can be used. For example, a linear model with a parametric interfering compensation structure allows:

1. By measurement, determine the compensatory abilities of different OPs under conditions of asymptotic (i.e. according to exponential) real-time learning,
2. Provide information and recommendations on the change of skills of OP in specific (variant changed flight conditions)
3. Set limits on skill and skill quality.

It follows from the above that even if the estimated quality criterion of the OP skill meets the flight conditions, this does not mean that the model chosen is adequate for the original AES. This ambiguity arises from the fact that the heuristic model used cannot express the effects of non-linearities, the presence of which compensates for OP in given AES working conditions. Hence the need for condition correction. The problem is not the model-object relationship, which is technically solvable [66].

8.1 Search for results to determine the heuristic model

In the process of learning OP, the contradiction arising from the relationship between two subjects - the learner and the teacher (the object of the experiment - the experimenter) is often resolved. The experimenter is authorised by the ability to analyse the results, i.e. to correctly assess the achieved professionalism (skill) in controlling the AES, the authority of the experimenter is a manifestation of his individual skill which he applies to the examinee (learning OP). It follows from the above that each flight activity is a process function realised in time. The adequacy of the heuristic AES model (i.e. the OP aircraft) is not a complementary problem, but a fundamental one. This problem can be solved in the following way.

Suppose that the process of asymptotic learning (i.e. the growth of knowledge according to the exponential model) is realised on an intelligent identification device (IID) that imitates the properties of the AES. In the process of performing an elementary ergatic operation (cycle), the OP performs a one-factor control operation. Let this operation be performed by the IIZ element, which is its model.

Let this model be described by the transfer of the OP function. At the end of the execution time specified by the experimenter (without informing the OP under test), he switches the circuit (Fig. 68) from the operator to the OP model [86].

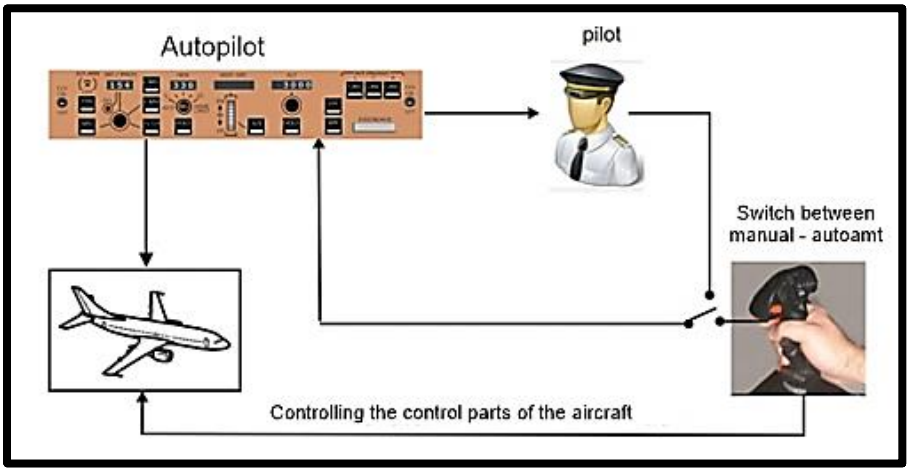


Fig. 68 Aircraft-autopilot ergatic coupling diagram – OP

The estimated time at which the OP did not respond (delay) can be used as a valued stimulus of subjective skill. In management theory, delayed response is called time, and sometimes traffic delay.

Fig. 69 shows a diagram of the implementation of the described problem. In the explanatory notes presented under Fig. 69, data are written that characterize the OP for controls, especially spacecraft, but they can serve as input parameters of the OP in the general case [35]

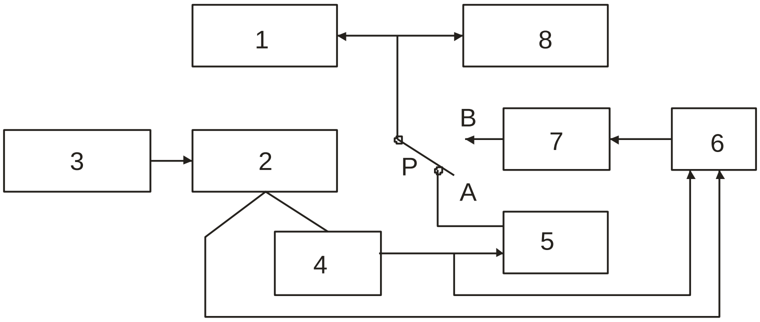
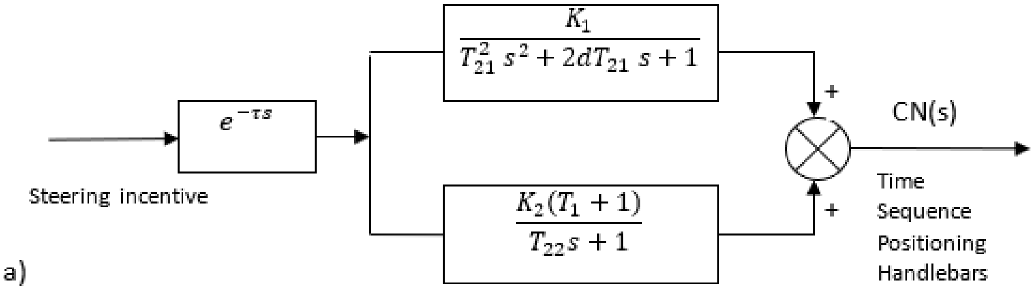


Fig. 69 Examples of models of OP transfer functions

Legend:

1 – dynamics of the control object, 2 – indicator observed by OP, 3 – external fault model, 4 – OP, 5 – AES control, 6 – software for time delay measurement, 7 – OP transmission function (model), 8 – adequacy criterion estimation block. P - mode switch, A - control from OP, B - control from model OP

The time delay marked as 6 is a fiction that results from the psychological-biological conditions of OP. In the real attitude of the OP (person), especially if he is burdened with decision-making, maintaining psychological stability is unlikely. The number of factors that influence the change of the marked constants is largely dependent on the progression of time [79].



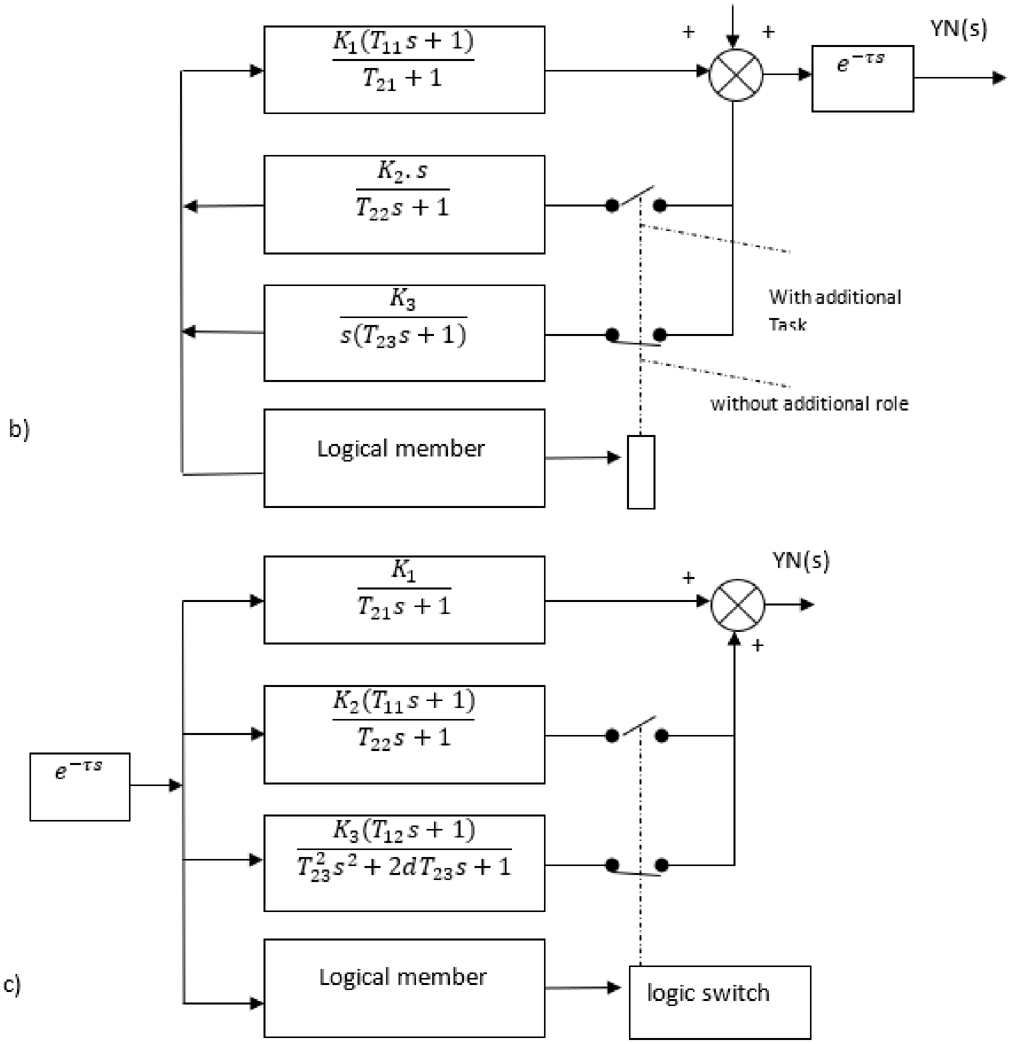


Fig. 70 Examples of OP transmission function models

Legend:

A – diagram of a disconnected model with parallel blocks with the determination of the compensation of fault quantities, time constant T21 = 2.14s, time delay (OP reaction), τ = 0.21s (OP – he is well skilled), gain coefficient K1 = 0.87 – characterizes the amplitude of unstable oscillations in response to the input signal W(s), K2 = 4.2 – effort coefficient required to position the handlebar, time of perception of the derivative (change) of the input signal, T1'0.64 s, - muscle time constant, T 22 = 0.61s, d = 0.22 – damping coefficient, advance time constant T11 = (0.25 – 2.5)

B – disconnected model with variable structure and non-linear term for solving complex compensation tasks, C – closed model with variable structure and nonlinear term. The circuit is designed for flight tracking mode. The logic block solves switching circuit members when changing the disturbance compensation mode and pursuing the goal of the OP [65].

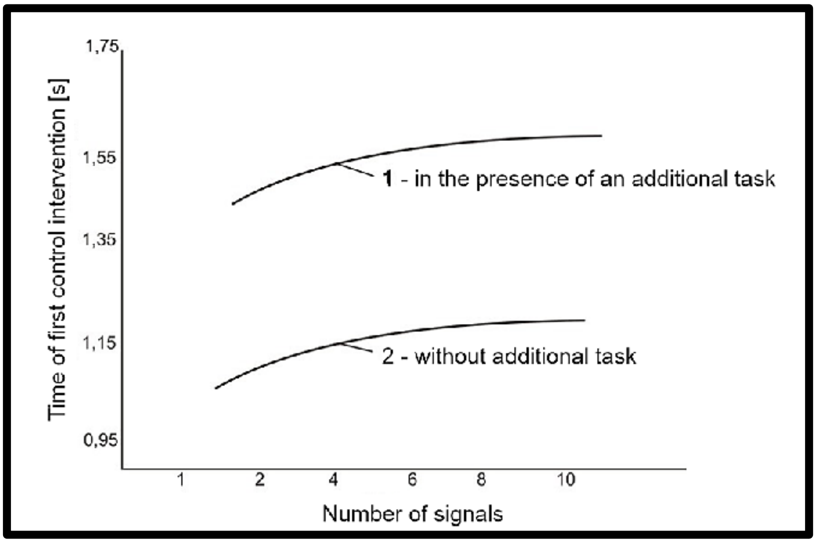


Fig. 71 The dependence of the time of the first activity of the pilot-operator on the number of signals

8.2 Concretization of the heuristic model in a program environment

The following example illustrates the effect of a set traffic delay constant that shifts the OP input to the AES control on a time sequence scale. The content of the solution is a disconnected OP model, designed to compensate for fault quantities acting on the AES during flight. The input into the solution is the design of the control pulse generator. In terms of content, it is a representation (analogy) of the model. The analogy is crucial for the construction of AES control incentives [23].

The stimulus of the OP for controlling the AES is information about the mismatch of its position with the specified position. Restoring the original position presupposes the application of an exponential law, made visible by positioning the handlebars. Supervisor has a program of sequence:

```
YN=[0 0.2225 0.4338 0.4598 0.0823 0.0392 0.0360 0.0345 0.0119 0.011 0.008];
```

It compensates for the change in AES position triggered by a malfunction. The supervisor's program is implemented in the OP control mode, for which it has become an incentive. As follows from the sequence, the following applies:

```
N=0:10;
```

The law of control (compensation process) has a model:

```
x= (1-1./(2.718. ^YN. *N));
plot(N, x),hold on,
```

```
title(‘fault compensation line'),
xlabel(‘order of fault compensation cycles'),
ylabel(‘handlebar adjustment values'),
```

The incentive for control is the handlebar positions resulting from the 'fence(N,x)', which are:

```
W= [0.1995 0.676 0.7895 0.7697 0.8077 0.8392 0.862 0.8765 0.8901 0.9008];
```

Endurance(pulse width - sample):

```
si=3;
```

Simulation of the transfer function of the created heuristic model OP for the mode of compensation of the influence of the fault quantity on the AES is shown in Fig. 72 [65].

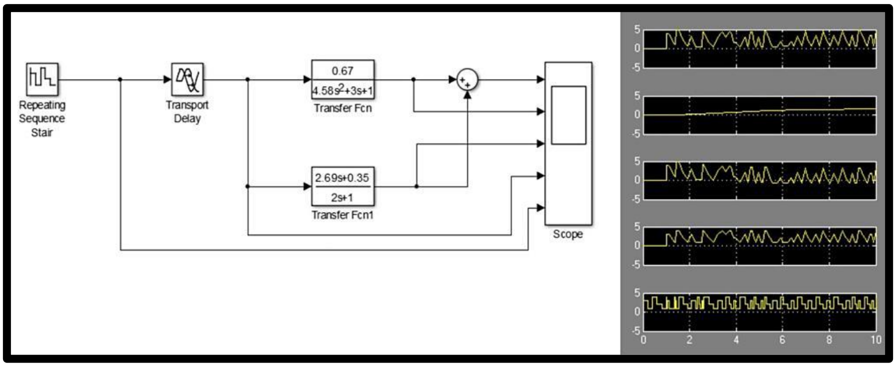


Fig. 72 Heuristic model of OP in AES fault compensation mode

The parameters of the OP are determined by the requirement of the supervisor program, which supervises the correctness of the control sequence. In analogy with Fig. 72a, the parameter values are as follows: K1=0.67 T21=2.14s d=0.72 K2=0.35 T22=2s;

The effect of traffic (line) delay is strongly felt in cases where the endurance (pulse width) of the handlebar positioning changes. The increase in the value of the time delay requires a quick decision by the operator in the control process (determined by the time limit) and an increase in the frequency of the handlebar positioning [100].

The denominator of the transfer function TF1 Fig. 72 indicates the emergence of instability (uncertainty) of the OP, where the document d = 0.72 qualifies the ability of the OP to transform it into productive (psycho-physiological) control.

The transfer function TF.1 expresses the ability to react and the realisation of the internal tension resulting in the movement of the handlebars. The conformity of the models indicates the skill of the OP and the correct adaptation of the characteristics of the AES expressed in the supervised programme of the cognitive system.

The solved example P7 shows the possibilities of applying considerations on the effectiveness of the creation of heuristic models of the operator. It is clear that their creation is possible only for a specific flight situation and always in interaction with the object of control. An effective OP model can only be developed when the OP has reached a certain level of readiness to deal with a specific task. Any creation of a physical model must be confronted with the fundamental idea of cybernetics, which is based on the unity of animate and inanimate nature.

The creation of the AES model at the level of dynamic principles is based on the application of differential equations, which make it possible to realise the theory and techniques of their calculation in today's well-developed apparatus. When constructing such a model, it is necessary to assess the temporal scope of the result obtained. Any transfer function (Fig. 73) provides a usable result only for a relatively short period of OP of the activity for which immutable facts are defined in a given section. It is known that complex multi-block models, which require high financial demands for their implementation, are a source of potential errors and, as a rule, are also inaccurate. However, their main drawback is the loss of the psychological-physiological essence of the OP function [20-28].

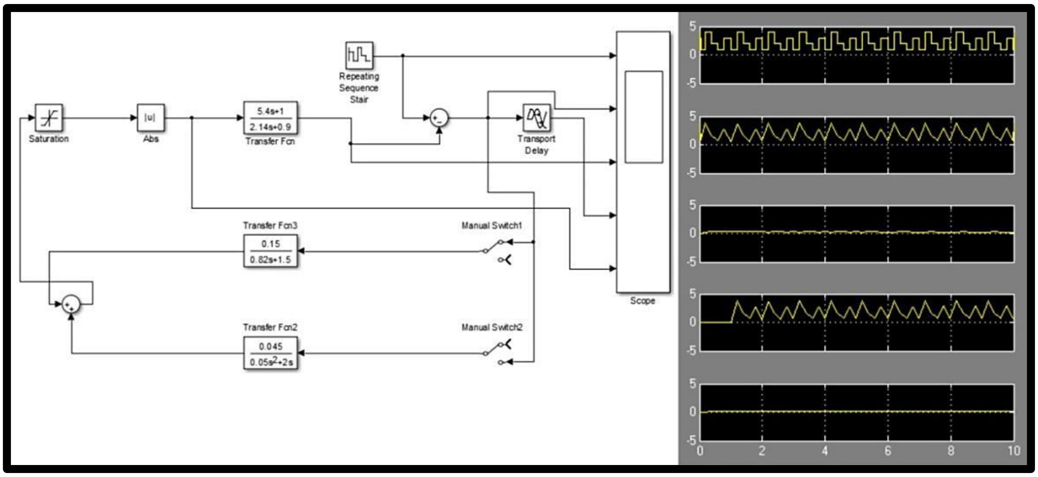


Fig. 73 Simplified simulation model

The input to the scheme is a generator with values that model the positioning of the handlebar OP in the ascent mode and in its descent part. The diagram in Fig.73 includes two switches that switch (for methodological reasons) manually. The principle used confirms that the TF 2 is a suitable complement to the transmission function in the OP handlebar positioning mode. The transmission function of the TF 3 completes the heuristic model of the OP when the handlebar moves apart. The interpretation of the obtained graphs allows you to create an idea of the effort expended and the movement of the handlebar of the OP. In a similar way, it is possible to continue the consideration in simulating the scheme in Fig. 73.

In general, the design of OP models as an element of the circuit of an ergatic system is based on the use of statistical results. This method is inherent in many methods of modeling. Experience from the previous way of creating models:

By researching the reactions of OP to a specified stimulus, a hypothesis of the structure of the heuristic model is formed, i.e. the order of the differential equation is determined, from which the transfer function is formed (see examples P5, P6....). In the simulation process, the parameters of the model are gradually set and a member is included in series with it, which imitates the traffic delay in positioning the control OPs. It is convenient to set (tune) the simulation scheme in the following ways:

1. using known experimental methods of object identification and analysis of OP and system output signals,
2. using known (or specified) criteria, e.g. system sensitivity to parameter changes; it is advisable to find dominant values of increments that are induced by a hypothesized transfer function or deviations from the specified value,
3. using models of complex structure, which are connected to the main circuit, depending on the ability of a person to adapt to a given system subject to modeling.

The stability of the characteristics of OP, which is the content of the heuristic model of AES, is a statistical concept. The ergatic process is defined as a stationary function, and so the heuristic model is similarly named. The quality of functions and the effectiveness of identification can then be determined by the methods used in control theory. The following characteristics are specially used:

1. qualification characteristics of familiarity with OP [30-38],
2. the minimum level of local quality rate of OP readiness, of which Ymin and Yth - threshold shall not exceed the sharp imbalance defined as:

$$|Y_{min} - Y_{th.}| < K_Y \tag{8.1}$$

3. The minimum oscillation of local circuits at threshold values must not exceed:

$$\left|\varepsilon_{max} - \varepsilon_{min}\right| < k_{\varepsilon}; \tag{8.2}$$

k_{ε}- the permitted value (variable amplitude) of oscillation.

4. External faults F(T) shall be compensated so that the relevant parameters of the model are provided within a specified quality range:

$$\left|\chi(q_i) - \chi(f)\right| < k_q; \tag{8.3}$$

k_q- permissible failure compensation inaccuracy.

5. The period EP TP of elimination of external failure must be within the range:

$$\left|\chi(T_P, q_i) - \chi(T_P, f)\right| < k_T; \tag{8.4}$$

k_T – permissible inaccuracy of external failure compensation.

8.3 Air transport object random error analysis model in zonal navigation

In this case, the technological combination of control and navigation accepts in principle the possibilities of the programmable inertial navigation system (INS) ATO. The initial phase is controlled by an operator who, using a supervisor, directs the flight with the required accuracy to the designated corridor. Accuracy analysis is performed only in the zone of approximation with the area of successful solution (ASS) of the assigned flight task. In this flight section, the ATO control enters its autonomous (programmed) navigation control function, influenced by the random, e.g. windy manifestation of the mountain environment. The limits of ATO precision in the convergence zone are also presented in the article in the form of graphs, which are the output of the method used in the Matlab environment.

The method used to analyze ATO errors in its approximation with ASS is carried out by mathematical tools that are used in the theory of random processes. The INS ATO determines in real-time the flight trajectory according to the law of specified deviation sigma(z)=a*S,

Where: a - the percentage of the ATO position taken is determined,
S - is the distance travelled after correction.

The requirement 'a', its percentage determination, allows applying the theory of stationary random processes. The reason for such a statement is the physical concept of the INS, the accuracy of which is determined by the corrected position of the ATO position sensors, its speed and the aerometry of the movement of air masses in its vicinity. A prerequisite for placing the ATO in the percentage-defined band is the exact program of work of its computer, in which the positional data measured by the sensors are compared. The resulting errors sigma(z), in the band 'a', the distance travelled S and the known third coordinate (height H) form the zone of ATO motion in continuous time.

Let us name the movement navigated and controlled in this way by flight in a zone in which the resonant vector is determined by zonal navigation. The concept of zonal navigation makes it possible to formulate a probabilistic criterion as the probability that the ATO will not pass beyond the zonal boundary at the time of flight. This criterion allows you to analyze the accuracy of zonal navigation [60-69].

8.4 Zonal navigation model design

The content of the proposal accepts the movement of ATO on a trajectory in zone II (Fig.74), which represents the convergence of ATO with ASS. The existence of air currents (forces and moments) is assumed, the action of which is compensated by the shifting system with the permissible error. As an accuracy criterion, choose deviations from the airborne INS program designated zone and known geodetic points whose altitude position does not penetrate the flight zone [46].

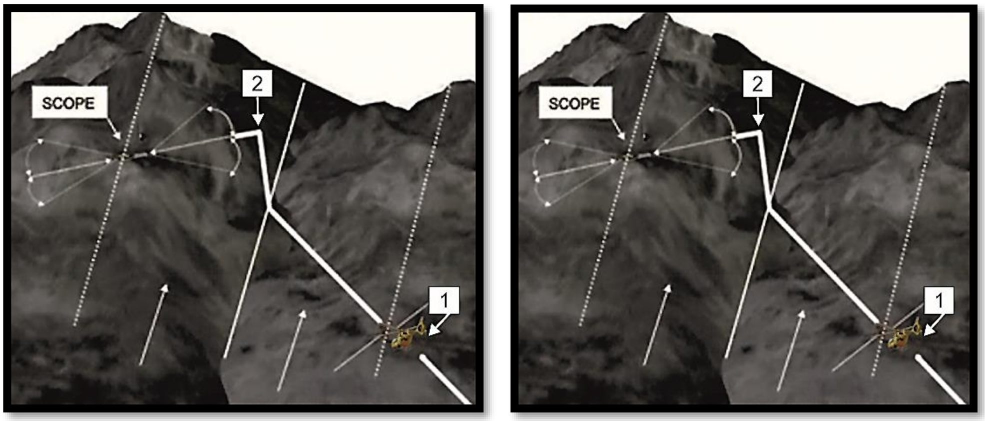


Fig. 74 High Tatras - 3D model of the local area

The model accepts height deviations of ATO with values of H = 100, 60, 30, 15 m. According to similar control measurements carried out on landing systems, accuracy graphs were made, which are shown in Fig.74. The accuracy graphs represent a mathematical hope:

m^[x]=1/n*sum({i=1; n}xi; (8.5)

Deviation: sigma^[x]=((1/(n-1))*sumsum({i=1; n}(x-m^)^2)^0.5; (8.6)

where: x-is the value of the random quantity measured in the ith phase of measurement, n is the number of realizations.

The approximation of the statistical distribution was carried out by the method of moments. In accordance with it, the parameters characterizing the theoretical distribution are calculated so that they are comparable with the normal probability distribution:

pdH=(1/(sigmadH*2.5)).*2.718.^(-0.5.*(((n-mdH)/sigmadH).^2); (8.7)

Simulations in the MATLAB program environment

To illustrate the method used, flight altitudes were used: H = 100, 15 m. Two moments are accepted in equation (8.4): the mathematical hope mdH, and the dispersion of the statistical distribution: sigmadH.

The models analysed are:

Instantaneous value of approach height: H = 100[m];
n=(-100:10:0:10:100); number of simulated measurements when converging with ASS,
mdH=-1; [m], mean of deviation of ATO from the convergence line.
sigmadH=2; [m], the standard deviation of the normed distribution [36].

The last two data represent statistics of individual measurements. Estimation of the length of the measured instantaneous height vector:

deltah=(-8:0.5:0:0.5:6); [m], linear deviation in height from the convergence line with ASS.
datah=normrnd(-1,2,100,1); statistics of measured data of "sensors".

Distribution of the probability of deviation from the specified height at H100:

```
pdH100=(1/(sigmadH*2.5)).*2.718.^(-0.5.*(((deltah-mdH)/sigmadH).^2); Look at (8.4),
figure(1),fence(deltah,pdH100,'r')
title('Probability distribution of linear deviation from the height of the convergence line,','FontSize',14),
ylabel('Variance Probability Distribution Values','FontSize',12),
xlabel('Linear deviations from the convergence line','FontSize',12),
figure(2),bar(deltah,pdH100),grid on,
title('Histogram of the probability distribution of deviation from the height of convergence',' FontSize',14),
xlabel('Linear deviations from the convergence line,m','FontSize',12),
ylabel('bin-shaped probability distribution values','FontSize',12'),
```

Analysis of statistical measurements using the invoked command:

```
dfittool,
```

Instantaneous value of the approach height: H = 15[m];

n=(-100:10:0:10:100); number of simulated measurements when converging with ASS,

mdH=-0.4; [m], mean of the terminal deviation of ATO from the convergence line sigmadH = 0.6; [m], standard deviation of the normed distribution.

Estimation of the length of the measured instantaneous height vector:

deltah=(-8:0.5:0:0.5:6); [m]

DATA100=NORMRND(-1,2,100,1); Statistics of measured data of "sensors".

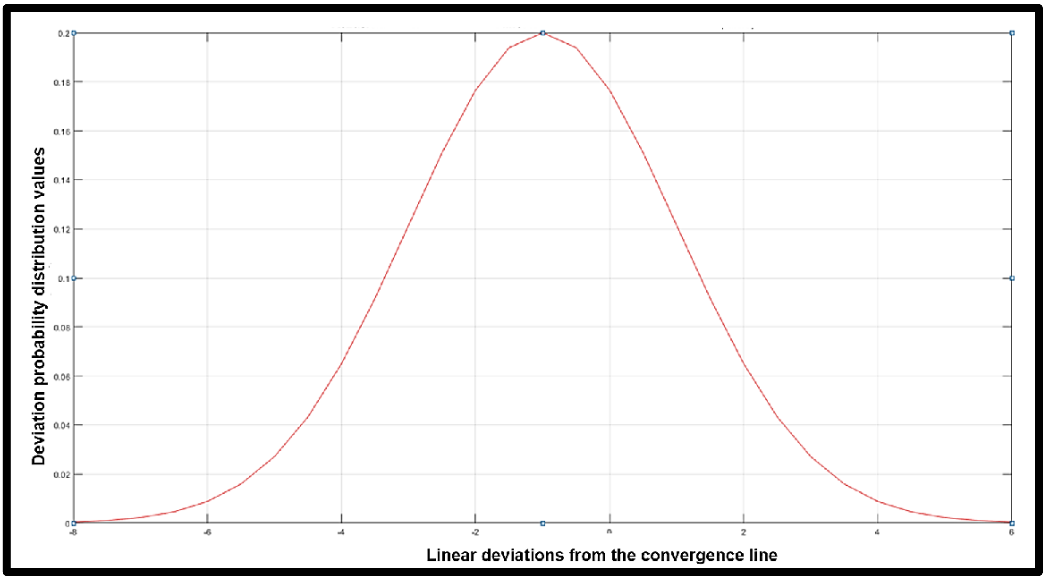


Fig.75 Probability distribution of linear deviation from the height of the convergence line

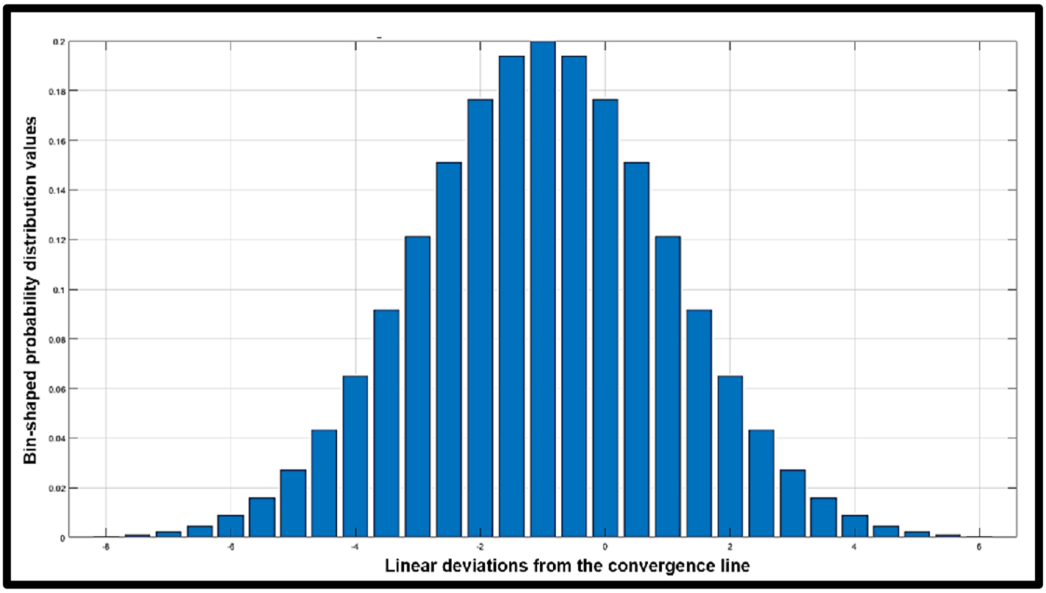


Fig.76 History of the probability distribution of deviation from the height of convergence

The distribution of the probability of deviation from the specified height in point H15:

```
pdH15=(1/(sigmadH*2.5)).*2.718.^(-0.5.*(((deltah-mdH)/sigmadH).^2);
figure(3),plot(deltah,pdH15,'r'),grid on,
title('Probability distribution of linear deviation from converging line
height,[m]','FontSize',14),
ylabel('Probability distribution values,[m]','FontSize',12),
xlabel('Linear deviations from the convergence line','FontSize',12),grid on,
figure(4),bar(deltah,pdH15),grid on,
title('Histogram of the probability distribution of deviation from the height of convergence',
'FontSize',12),
xlabel('Linear deviations from the convergence line,m','FontSize',12),
ylabel('bin-shaped probability distribution values','FontSize',12),
dfittool;
```

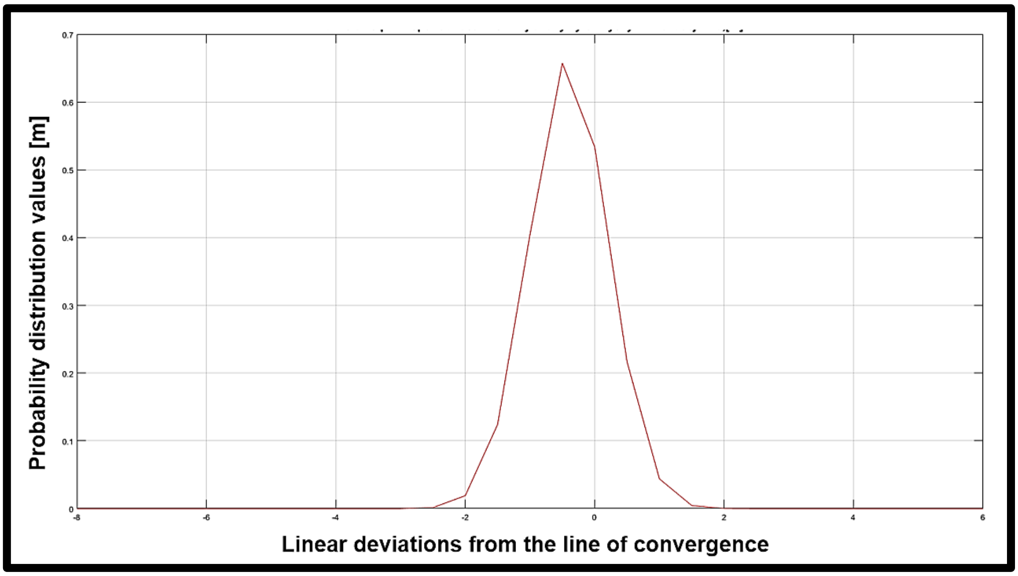


Fig.77 Probability distribution of linear deviation from the height of the convergence line

The outputs of the solution as well as the relevant waveforms, including histograms that align the curves, point to the assumed alignment of the theoretical curves of the statistical distribution. This also confirms the hypothesis of the normal distribution of parameters H. The analysis of the influence of random quantities on the accuracy of the side movement of the ATO was carried out by flyovers over the corridors of the High Tatras (+/-4)'c' [98].

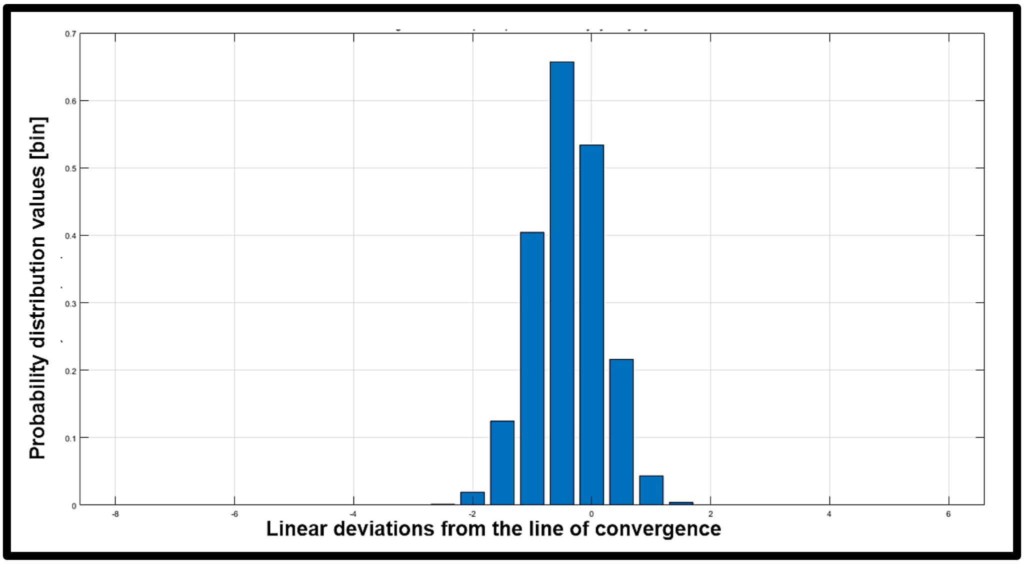


Fig. 78 Histogram of the probability distribution of deviation from the height of convergence

Decisive are the aerometric data of sensors, the errors of which are separately analyzed. Data (coordinates) of the landing point or hang are accepted. In the first case, the vertical speed is calculated, in the second, the side deviation is also controlled. The chosen methods of dealing with landings accept asymptotic learning.

The method of analysis used has a targeted character, in the core of which the technological character of interacting systems that influence each other disappears. The aim was to show the theoretical and practical application of statistical methods that give ATO users their rating. Statistical criteria are based on the probabilistic principle of manifestation of random quantities, on which depends the accuracy of the work of ATO systems as well as the recoverability of its functions, especially in boundary bands where control correction is required. This means that when flying in a designated zone, the criteria characterize the probability that the ATO will converge with the ASS [46].

CHAPTER 9

AIRPORT ERGATIC COMPLEXES AND THEIR IDOLATRY

Airport processes, consisting of econometric and information databases, are implemented in all areas of air traffic through the operator control of aviation personnel. Today, the knowledge and application of econometric processes provide a significant competitive advantage in solving technical problems in the implementation of new systems in aviation. The stable position of the airline as the executive arm of the aviation complex in the market creates the ability to evaluate the efficiency of its internal processes a priori and a posteriori. However, the pursuit of rapid development, acquisition of new technologies and efforts to implement them in aviation processes and complexes often lead to failures and worse results. According to statistics, only 10% of developed aeronautical information systems fully satisfy the work activity at airports. There are many reasons for this finding. One of them is the poor quality of information outputs (aeronautical information systems, etc.) with information value (e.g. altitude, aircraft speed - IFE systems, etc.) [11].

Until recently, almost no airport had a uniform approach, methods and requirements for assessing the relevance of the quality of its operations, such as its own information systems and available software for aviation personnel. In many ways, the efficiency of established aviation processes has required developers to create feedback loops for passengers to have sufficient information to solve their problems at the airport. The most important part of gaining relevance is setting clear requirements for the parameterisation of systems and then evaluating their knowledge. At present, the passenger needs clear and high-quality user systems, but this depends on the final price of the ticket and the cost of the flight itself.

The cost of an information system, in addition to the price of design, development and implementation, includes the cost of maintenance throughout the life cycle of the airport system implemented in the airport complex. Aviation regulations often contain brief information on methods for evaluating and measuring the quality of aviation complexes. The perception of their effectiveness depends to a large extent on the information provided to passengers, who demand quality information in return for their payment. The efficient operation of systems can change over time, which is related to the degenerative entropy of estimated airport complexes, e.g. the design of an airport geosystem. The main components of such information are

- properties of the object,
- the conditions under which the object is evaluated.

Accordingly, it is possible to speak of defined quantitative expectations in the form of objective characteristics of the airport environment - technogenic. More abstractly, it is possible to imagine the concept of efficiency as a measure of passenger satisfaction and the specific needs it requires today. The topicality of this issue is due to the fact that the development of air transport in Slovakia has been slowing down or even stagnating at some airports. This has increased the need for a scientific contribution to active incentives for the development of operators of aircraft complexes and aircraft and for an objective criticism of their evaluators on how they use the received funds for their development. In the case of the evaluation of current complexes in the field of air transport, the evaluation of the quality of air transport is a motive for introducing new aviation systems in the field of creative management and observation of the effectiveness of the work of aviation professionals at the airport and in the airspace of the Slovak Republic (pilots, ATC operators) [67-79].

It is important to point out the mutual implementation of real econometric assessment in various areas of aviation, which is also defined in aviation legislation. The method of graphical-statistical conclusions can be used to monitor selected processes at the selected airport. It is based on the analysis of the airport's own environment, in which the operator and the controlled system are located. From the measured outputs identified, it is then possible to define ways of evaluating them in order to address their structure from a management perspective [19-22].

Aviation complexes are made up of aviation units (the sum of individual airports, aircraft systems, aviation personnel and airport systems) that are interconnected with functionally related structures, usually with dimensional and measurable effects from several interconnected parts and sets of objects, systems, aviation groups and organisations.

An aircraft system is composed of interconnected subsystems which, when considered as a whole, exhibit one or more characteristics (behaviour between possible characteristics) that are not clearly visible from the characteristics of the constituent parts. This property of any system is called emergent and applies to any system, not just the complex system of which it is a part.

The complexity of aviation can be understood as an organised continuity, with the aviation system itself (with a limited number of subunits) exhibiting emergent properties.

The modern theory of aviation complexes allows us to conclude that the characteristics of the aviation system and the environment in which it operates (airspace, airport) exist and determine the degree of sophistication of the operators' use in controlling it [54].

The complexity and operation of an aviation system in an environment is mutually assembled from the features and interactions between them. It is determined by the environment in which it creates another environment of its own, which, in turn, has the opposite effect on the system. A system cannot be upgraded unless its environment can be changed, upgrades cannot be implemented in it, and vice versa [25].

The most important concept of aircraft systems is their complexity, which is open and expressed using the concepts of nonlinearity, instability, integrity, and self-recruiting. Each aviation complex has the following characteristics:

1) Complexity, as a set of elements of a connected aircraft system of non-trivial, original interconnection with each other; There is a dynamic network of elements, for example in an aircraft (elements are linked to aircraft systems).
(2) Diversity of the system, whereby its elements or subsystems change flexibly depending on the changing situation (ATM airspace management).
3) Multi-level system (there is an architecture of complexity) - aviation complexes are larger than the sum of their parts, systems of any size, so they need to be analyzed in terms of the hierarchy of interactions. At the same time, one part may be more complicated (for example, a person more complex than an airline), so this part can carry all the system characteristics, but at the same time has its own, complicated modes of activity.
4) Open system, i.e. exchanges energy and/or information with the environment. The boundaries of the aviation complex in certain cases are difficult to determine (the vision of its boundaries depends on the position of the observer).
5) Emerging phenomena (properties). New, unexpected properties are displayed at the dynamic level of the system as a whole, which cannot be identified from the analysis of the behaviour of individual elements. But even an object/system that has become part of a whole can be transformed and its new properties demonstrated.
6) Phenomena with hysteresis change in active air traffic mode.

An aviation complex can be defined as:

1. Which is highly structured - showing deviations,
2. The development of which is highly sensitive to initial conditions and changes,
3. Which is understandable and verifiable by its design (airport) and its functionality,
4. In which there are many interactions between many distinct components,
5. Which continuously evolves and develops over time.

An airport system can be characterized as individual interconnected airport structures that are part of an orderly whole. The way they are organized is legislatively determined and may be partially internally divided into management subgroups.

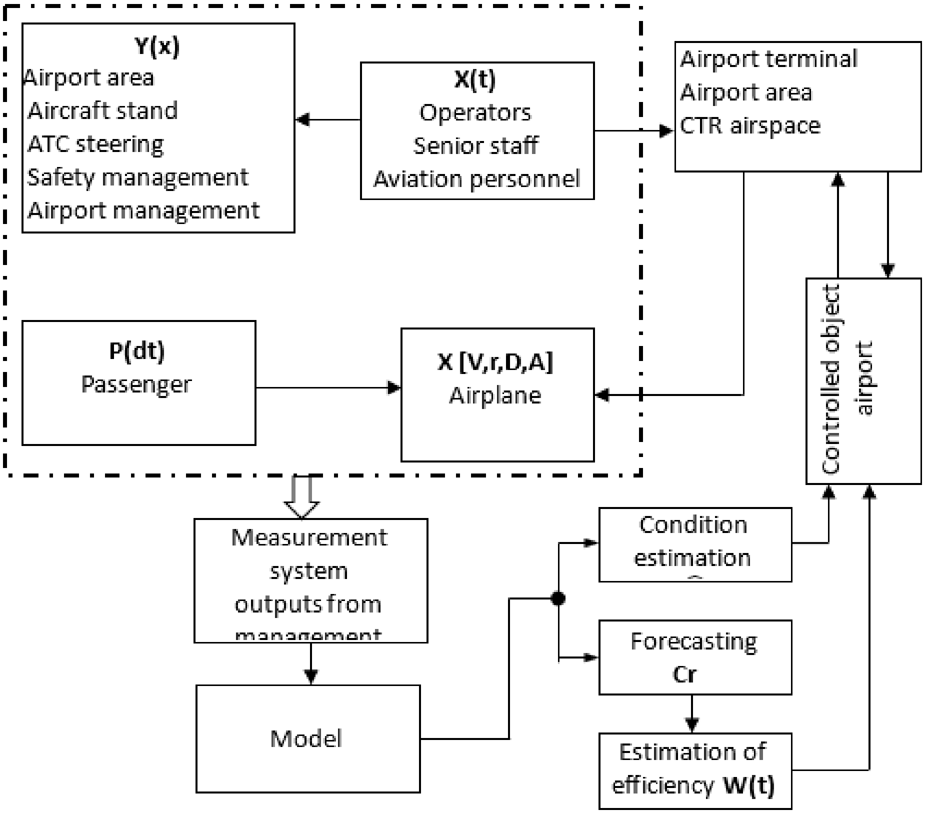


Fig. 79 Interconnection airport control system

The main characteristics of the airport system:

- The characteristic (purpose, function) of the airport system is different from the sum of the characteristics of its elements; the set of characteristics of the elements of the system does not represent a general characteristic of the system, but creates its new characteristics;
- The existence of a specific structure of flight activity that cannot be directly deduced from the way in which the airport operates;
- It evolves, starting from the past and continuing into the future.

An airport system, as a kind of aviation integrity, consists of interdependent elements and meets the following requirements:

1. the operation of each element of the system has an impact on the behaviour of the airport system and on its essential characteristics [59],
2. the behaviour of system elements and their influence on dependent elements and on their inherent properties of the elements of the system,
3. features or links of the system with other systems (subsystems); properties, behaviour or state of its constituent elements.

A complex aeronautical system is therefore made up of elements with a heterogeneous relationship between them. The characteristics of these systems require:

1. the existence of a complex composite system, the simultaneous existence of different aircraft subsystems;
2. the simultaneous existence of aircraft structures in an aeronautical system (e.g. airport, flight school, aeronautical industry, international or national aeronautical administration, functional aeronautical organisational units, etc.);
3. (3. the use of different types of aviation professionals for operations, analysis and structures in aviation;
4. subsystems, e.g. in aircraft construction (technological diagrams, manufacture of aeronautical products), determination of regulatory legal acts and their control (air transport personnel).

In any aircraft system, control exists as a set of interrelated control elements, where there is a way to implement control technologies that include state and process characteristics on an object [62].

9.1 Control levels of airport ergatic systems

Management levels (levels or types of management) are classified within aviation organisations according to the scope of responsibility, decision making and duration of the aviation activity. They can be divided into three basic levels:

- Top management, known as the strategic level. It consists of representatives of the owners and senior managers of the airline, such as the airline's director and other top managers (known as the C-level). Their role is to plan, decide and manage in the long term, about 2 to 5 years. They create strategic plans and generally coordinate the organisation and operations at the airport. This level of management is also known as strategic management.
- Middle management, also known as the tactical level (also in military aviation). It consists of middle managers, who are usually managers in charge of larger organisational units or specific areas, such as quality managers, financial managers, etc. Their role is to plan, decide and manage in the medium term, from a few months to two years. This level of management is also called tactical management. Middle management in small and medium-sized aviation organisations is usually carried out by top management.
- Lower management, first-line management, also known as the operational level. It consists of foremen, supervisors, project managers and managers with a narrow range of responsibilities. Their role is to plan, decide and manage in the short term, from a few weeks to a year. This level of management is also called operational management.

Each level of management must use a control system with all management methods. (technological, logical, economic, professional).

The control system used in control and automated driving includes the following main elements

- Mechanisms for collecting information on the status of the controlled object,
- A subsystem for collecting and transmitting information between aircraft systems to aircraft complexes,
- an information processing and display subsystem (aeronautical information systems, etc.)
- the control measures subsystem,
- Resources (energy, human, financial) [19].

When analysing individual functions of airport systems and their elements, it is possible to use

- Proposals that deal with structured problems; they cannot be solved, but if there is an ongoing problem or technological progress (aeronautical scientific institutes), they can be solved by individual formal or mathematical methods,
- Scientific view of current problems in aviation,
- Qualified opinions on problems in aviation, formal analytical methods, but also methods of qualitative analysis [21].

9.2 Aeronautical ergatic system and internal information systems

The aeronautical system is an aeronautically organised entity that is significantly influenced by the way a group of aviation professionals manage it. Their activities are consciously coordinated to achieve a common goal, which is located in the area of successful solutions. The characteristics of each aeronautical organisation in terms of the systems management approach depend on the external environment, internal variables and the efficient operation of the subsystems. Each aeronautical organisation requires the achievement of specific end states or results (required transport of passengers by contractual routes). The airline organisation is part of the aeronautical complex, the so-called ergatic system. Most aviation organisations are multipurpose (passenger transport, aircraft MRO, instruction (part). Their goal is to achieve the desired effect of air transport. In general, it is the transformation of resources (aviation professionals) to achieve final results (final air transport). The main resources used by the organisation are:

1. Aviation professionals (human resources),
2. Material resources,
3. Modern technologies and acquired information.

The dependence of an aviation organisation on the external environment results from the very nature of the definition of interconnected aviation structures (aircraft production - operation - spare parts supply). Therefore, an aviation organisation is an open dynamic system characterised by interaction with the external environment. The external environment includes:

- Indirect effects - economic conditions, passengers, unions, government laws, legislation, competing airline organisations, value system in society, communities, attitudes, etc., political factors, relations with local organisations (cities, villages - reason for air traffic), equipment and technology and other components;

- International environment - factors of the international environment (economy and political situation interest in flying to areas with unstable government or government structure).

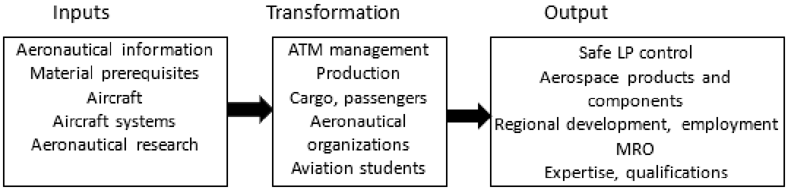


Fig. 80 Open aviation system model

For the entry of an airline organization, information is received from the environment, which, after transformation, creates benefits for the airline. All these components are called inputs (Fig.80). In the process of transformation, the aeronautical organization processes these inputs and converts them into output products or services. These products and services are outputs of the aviation organization that contribute to the development of air transport. If the managing organization is efficient, then during the transformation process additional input costs are incurred. As a result, many other outputs appear, such as profit, increased market share, increased sales (in the airline business), responsibility, passenger satisfaction, etc [33].

The structure of an aviation organization is a logical relationship between levels of management and functional areas. It is built in a form that allows you to achieve the goals of this organization most effectively [35].

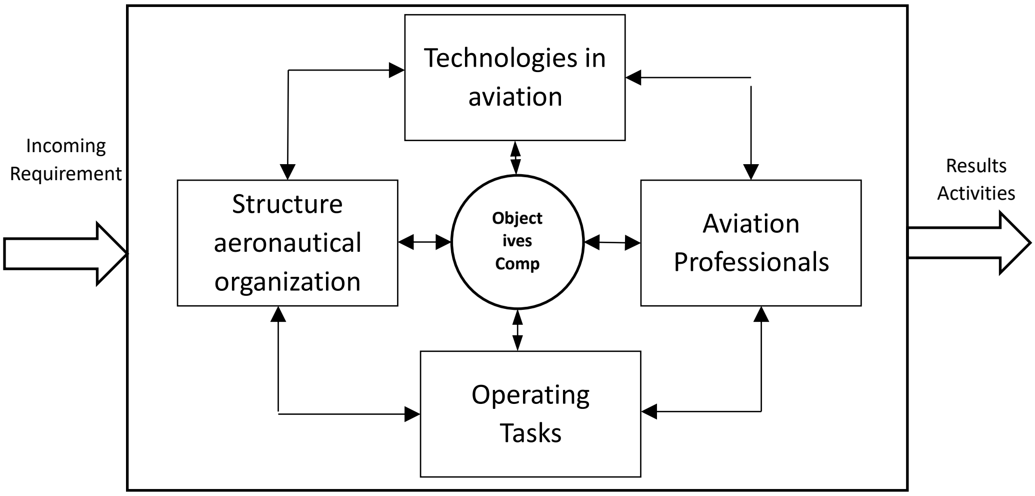


Fig.81 Interaction of internal variables of aviation organization

One of the tasks of the aviation organisation is to carry out prescribed work and a series of resuscitation work that must be carried out on aviation equipment in a prescribed manner and at a prescribed time. From a technical point of view, the tasks and prescribed works of an aviation organisation are different for each type of aircraft. The tasks of the aviation organisation are divided into three categories: work with aviation professionals (pilots, technicians); work on aircraft (machines, tools); and work with information (about the aircraft) [65].

The role of the aviation organisation as a whole is basically to work with aviation professionals. At the same time, however, it deals with information related to aviation technology. The technology used is a means of transforming, for example, students - aviation professionals, information or materials - into the desired products and services. In a broader context, each technology is a combination of skills, equipment, infrastructure, and tools necessary to perform the required technical tasks by aviation professionals - aviation operators. Tasks and technologies are closely related. The processing of a given patch - task involves the use of a specific technology as a means of transforming the incoming problem (failure) into the format obtained at the output (repair - information output). Thus, the most important part of the technology is the process of preventing system failures. Other expected benefits may be prolongation and optimal use of the service life of equipment and devices, improvement of the operational safety, an increase of the readiness of the equipment to perform the required function, optimisation of the operational processes, reduction of the number of failures, planning of the operating costs of the equipment [11].

Maintenance carried out by an aeronautical organisation is particularly important when the failure of technical aircraft systems directly endangers human life. In these cases, maintenance is controlled by modern information systems or their delegated subsystems. Aircraft maintenance, for example, is highly regulated and therefore requires a highly accurate flow of information (Flight Management Information Systems, FMS).

The term aeronautical information system in a broad sense refers to the interaction between processes, e.g. between aircraft and airport (control of aircraft in airspace) and the technologies used; in a narrower sense, it refers to the interaction between air operators, processes, information and the technologies used. In the case of aircraft control, it is the pilot and the ATC operator; in the process of air traffic control, it is information about the movement of the aircraft in space (altitude, speed, squawk).

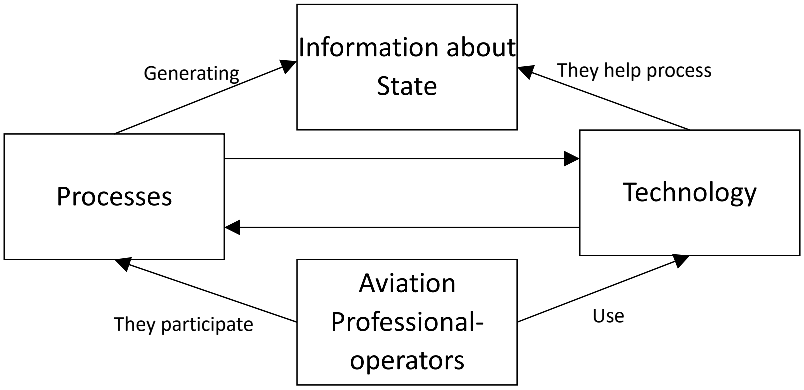


Fig. 82 Concept of aeronautical information systems

In order to evaluate the effectiveness of aircraft systems, using information (econometrics) and specific technologies (professional procedures and knowledge), it is necessary to use mathematical formulations with methods of solving tasks, models and algorithms (information, physical, chemical, etc.). In a functional system, mathematical software is implemented as part of the software. In the description of IS, the following types of structures are used, differing in the types of elements and interrelationships (Table 4):

Table 4 Structures of aeronautical information systems

State of the structure	**Elements**	**-**
Functional	Functions, tasks, operations	Information
technical	Aeronautical equipment	Automated
Organizational	aviation professionals, operators, operating personnel	Information
Algorithmic	Algorithms	Information
Program	Program moduAES	Information and management
Information	Forms of information in the system	Information processing operations in the system
Economic	models, mechanisms,	Market

In the process of development, each aeronautical system is associated with the requirement of a defined interconnection with aeronautical users and end users, for which an aeronautical organisation is legally assigned in air transport. If we want to know exactly what stage each structure of the aeronautical system is at, it is necessary to be able to measure it [75].

A similar measuring principle can be applied to the creation of the control system itself when we implement these systems in today's modern airports. One such structure, which is part of the programme and algorithmic structure, is the Chief System Integrator for ICT (Information & Communications Technology) Operational and Control Systems for Airports. The integration involves more than 20 subsystems. For example, at airports with autonomous structures (OSS). The content of the OSS is:

1. Airport
2. Airport area
3. Logistics area
4. Residential areas
5. Commercial space

By integrating different airport systems into management-level networks, real-time data is analysed to achieve significant cost reductions in airport operations. The multi-purpose integration of ecosystems and airport facilities with different monitoring and shifting protocols with their own management framework serves to ensure real-time management of the entire airport infrastructure [73].

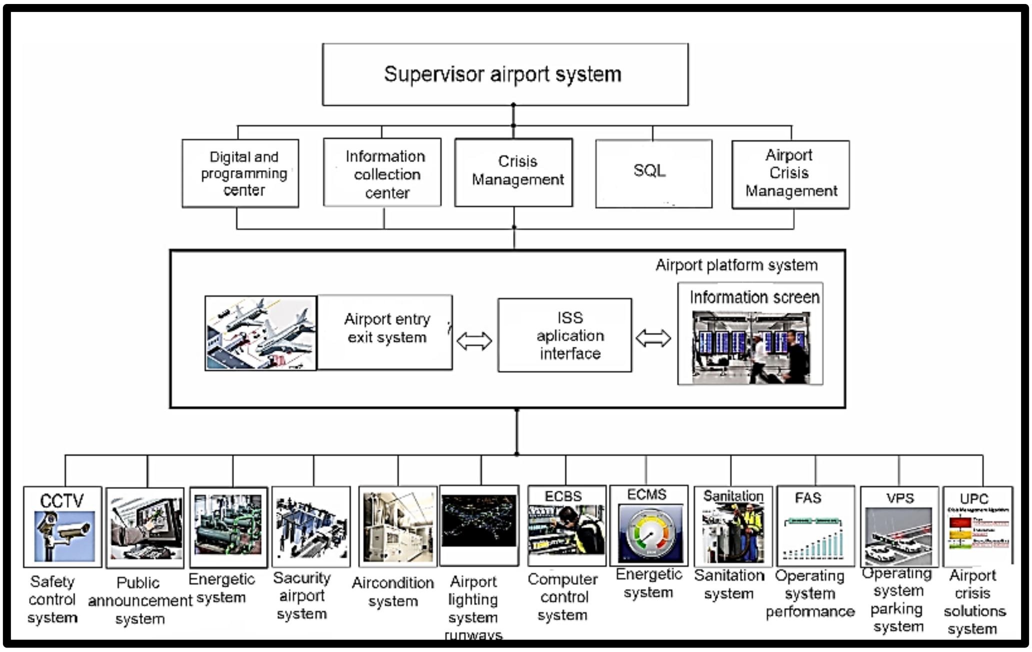


Fig. 83 Conceptual airport system

9.3 Airport phase complex expressed in dimensional parameters

The airport phase complex is intended to serve:

1. a steady reduction in public service costs through the monitoring of state-of-the-art airport systems,
2. collecting reports from remote airport infrastructures and processing them to reduce human source and total operating costs of the airport,
3. monitoring and analysing energy data to reduce energy consumption and maintenance downtime,
4. to increase operational efficiency.

The inherent system in question in its structure further significantly divides the LS into other subsystems:

1. BIS (Building Integration System),
2. FAS - BIS interface,
3. LCMS - BIS interface, the technology was used to create and graphically report the status on two main runways (Laser Crack Measurement System),
4. Interface FGS - BMS - FGS - BMS (Baggage Management System) flight control system, significantly improves the delivery of the passenger's luggage to the destination in time; It also helps the airline easily track where luggage is throughout the flight journey.
5. SAB Systems airport buildings,
6. Building management system,
7. Fire alarm system,
8. Lighting control and monitoring system,
9. Safety and access control system,
10. Power supply management unit,
11. UPS
12. Central battery emergency system,
13. Conveyor control system – HVTS,
14. Conveyor control system - Integrated aircraft stand system,
15. MATV (Master Antenna Television Network) – it is a network of cables and specially designed components that process, amplify and distribute TV and FM signals,
16. SMS (Safety Management Systems) - a complex system designed to control safety features in the workplace [12].

The conceptual structure of the airport has other major architectures that affect the operation of the airport system:

Fig.84 Conceptual sub-architecture of the airport

Airport integration: the act of merging into an integral whole.
Airport interface: A hardware or software link that connects one device or system to another device.
Airport protocol: AES governing the format and transmission of data [49].

SAB Systems airport buildings:

1. Building management system
2. Fire alarm lighting control and monitoring system Safety and access control system
3. Power Management Unit
4. UPS
5. Emergency Central Battery System
6. Management information system

9.4 Testing of airport ergatic systems models

Recently, the issue of complexity and complexity in aviation, in the process of decision-making, control and testing of airport systems has become topical. The expenses for the implementation of these processes are associated with modern airport objects and architecture, which are constantly affected by the consequences of incorrect solutions that are becoming increasingly sensitive (for example, information flow and protection).

In the theoretical field of methods of management, diagnostics and design of new airport structures and their formalization into individual procedures, it is possible to assemble a modern sophisticated airport capable of recognizing complex situations using new elements, sensors and technologies. The establishment of a control chain for the implementation and execution of airport systems takes the form of control cycles. Each cycle belongs to the structure of algorithms in the sense of logical and causal coupling.

The issue of control and its testing at each stage of its development is becoming one of the most important tasks in effective airport management. High investment costs are only justified if the equipment is fully utilised in terms of capacity and time. The requirements for organisational airport solutions are growing much faster than their testing and the scale of their production. Airport systems can be used for the control and management of any airport subsystem, with their main field of application being those where the heuristic approach is based on experience and intuition of predictive error solving. Every major airport system is controlled by airport subsystems in which human errors (economic, environmental, etc.) are introduced [10].

The most common use of airport systems is in the dispatching of operators, who must constantly monitor the airport's energy, transport and telecommunications systems, etc. Diagnosis and situation management of airport complexes are possible only if effective models of exact types are created. Each of these models must be tested for a period of time that determines the specified reliability value before it is included in the feasibility calculations. The completeness of the test plans prepared is determined as a percentage of the coverage of the requirements by the tests performed for the introduction of new aircraft systems. There is a correlation between the evolution of the reliability requirements of these systems and their management. In the context of control, different aspects are used to model an aircraft system [20].

A given aspect of the system, combined in a single model, needs to be analysed in a structured manner using methods best suited to processing airport information. The simulation method helps to analyse and define the requirements by which the aircraft system should perform its operations, using its own requirements (stakeholder requirements), user-defined scenarios such as UML diagrams, cos (class diagrams), sequence diagrams, message sequence graphs and static graphs.

With changing system requirements, for example in data archiving, the performance aspect of the created aircraft system becomes more important. In this case, different types of models can be used to demonstrate whether the chosen architecture (test solution of the chosen system) is functional even with some non-functional requirements.

As mentioned above, requirements are closely related to testing. When testing an aircraft system, measures are taken to identify and prevent emerging failures in the system where the deviation error exists. In addition, classical test methods can be created in parallel using models. Testing begins with the development of the system specification (design) and consists of checking the reliability of the system and verifying the specifications [95-101].

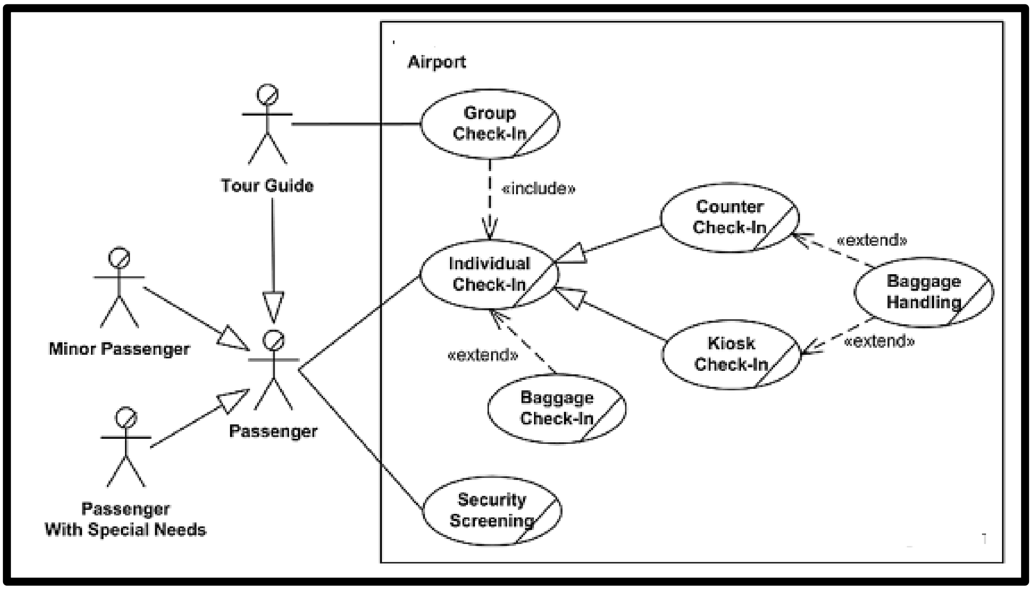


Fig. 85 Conceptual subarchitecture airport system

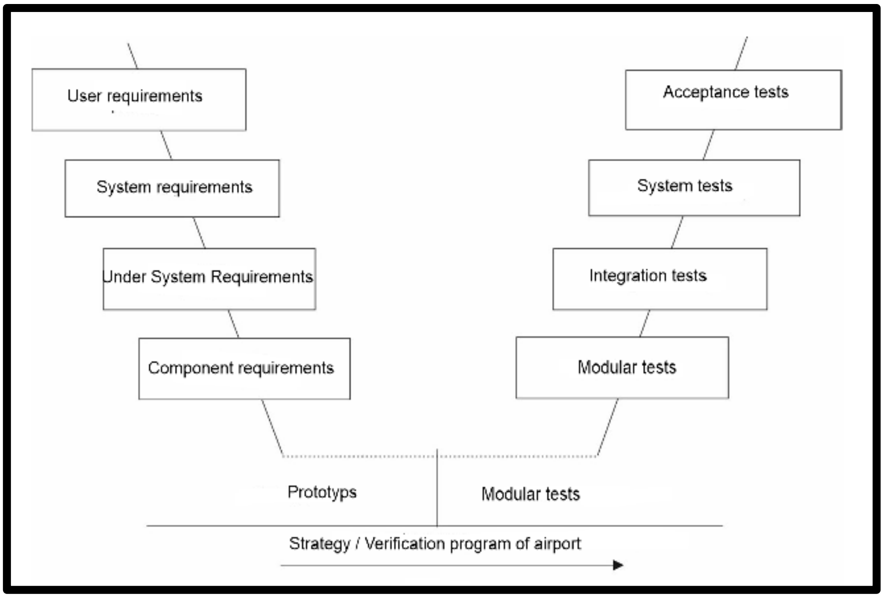


Fig. 86 System validation strategy in line with the development cycle

The design of tests for each system is an important process for the operation of airport systems, as it helps to minimise losses due to inefficiencies in each area. The area of responsibility for deciding on the initial stage of development is divided into the "problem area" and the "successful solution area". It is necessary to include in the problem area: - the reaction of the systems to failures,

- the modalities of use of aircraft systems,
- own requirements.

The problem of selecting the most suitable aircraft systems is focused on the regularities of the dichotomous theory describing the resulting malfunction of the aircraft system in its local parts. Failures require new advances in the localisation of the functionality of the whole system [102]. Such a direction shows that then the reliability of the observed system in reaching the area of successful solution - ASS - will change. If the functional reliability (triggered by a failure) decreases, a critical condition occurs that affects the operation of the aircraft system when the requirement to achieve an area of successful resolution is required. At airports, it is clear that the highest possible uptime value must be demanded from the systems in use.

Each aircraft system, by its composition, represents a serial series of subsystems implemented in it, which belong to the aeronautical complex.

Let us give an experimental example, which has the character of further monitoring the reliability of the aviation system. This theoretical plane clearly indicates in which direction reliability needs to be set. Unambiguously, this is only possible by mathematically expressing the technical problems expressed by probability theory with the necessary imagination to show their application to aviation practice. Any such system needs to be addressed in the aggregate for the description of flight safety [103].

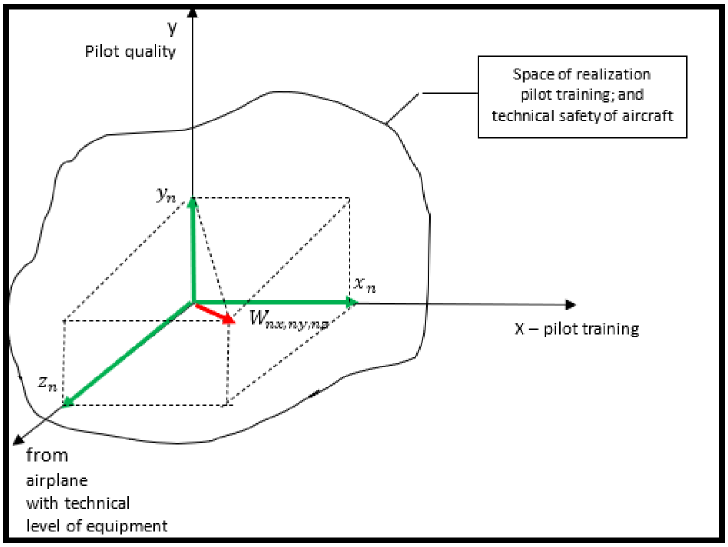


Fig. 87 Flight safety in the model

For example, the design and implementation of electronic circuits in aircraft systems, which are essential for the operation and control of aeronautical technology and its reliability, are primarily associated with the field of avionics, which makes it possible to apply their practical reality on the basis of calculations.

It is also the basis of cybernetics, the computer algorithms to which aviation professionals have become accustomed and which have introduced concepts such as the relationship between artificial and natural intelligence into aviation. A branch in the field of aviation has become aviation systems in the technogenic environment, the dominant element in the position of supervisor for controlling the operation of aircraft systems. Such a system in a technogenic environment exhibits many deviations of operation, different from a system operating in a permanent environment without dynamically changing environment [17].

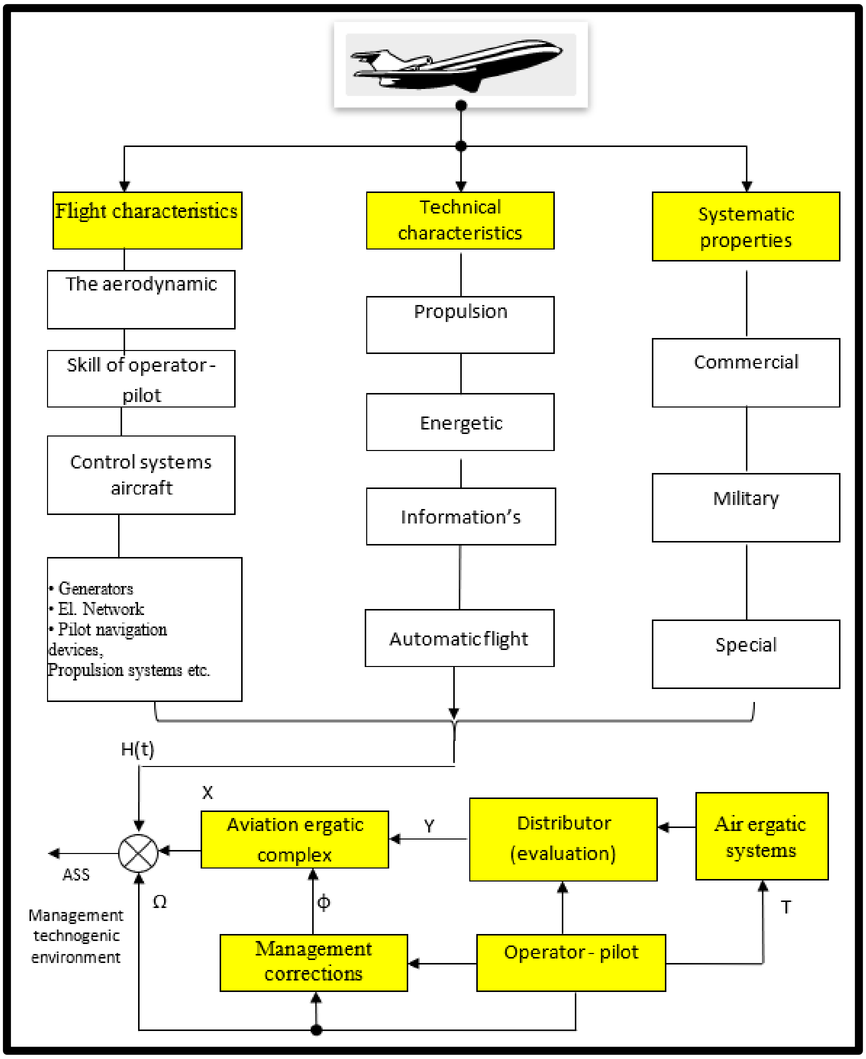


Fig. 88 Technogenic environment with object failures

Legend:

ASS – Area successful solution, T – is the finite set of observations of the aircraft ergatic system at a given time, X – is a finite set of input control signals and Y – is a finite set of *output values of the behavior of the aircraft ergatic system. Ω - is a set of possible controls implemented by the operator (system control), H(t) – changes in properties (failure) of aircraft objects.*

The end solution of the operation of the aviation system is its performance and efficiency in solving assigned tasks, which were compiled from a lot of information and reached the area of successful solution (ASS). The quality of operators' control of aircraft systems determines the overall efficiency. The termination of operator activity can be evaluated as successful if the initial conditions t0, which determine the quality of the system, are met, and unsuccessful if the quality conditions of the operator's control $t_{\text{n are not met}}$. Since the quality of activity represents the interaction of the internal links operating in the aviation system, we will use the term local quality estimation. The local estimation shall be linked to one cycle of operation of the aircraft system from n-numbers of controls and system use, for which:

$$\hat{P}\left\{X_q \le Q_{OUR}\right\} \to \mathrm{P} \tag{9.1}$$

Xq – are the coordinates of the AES position in Q_{OUR}

Q_{OUR} - area of successful solution of the task

P - position probability achieved Q_{OUR}

$$\boldsymbol{q}(\boldsymbol{i}) = \begin{Bmatrix} 1,\ ke\text{ď}\ Xq \in Q_{OUR},\ t.j.\ \text{ú}spech \\ 0,\ ke\text{ď}\ \ Xq \notin Q_{OUR.}\ \ t.j.\ ne\text{ú}spech \end{Bmatrix} \tag{9.2}$$

The described ideas about the quality of the aviation system are represented by a sequence of variable N-cycles (interventions in a certain activity of the aviation system) in the scope of the aviation complex.

$$Y(i) = a(i)(\,i-1) + (1-a).\,q(i) \tag{9.3}$$

Where:

$y(i)$ - je ukazovateľ úspešnosti zásahov operátora

$q(i)$ - je prvok úspešnosti vyriešenej úlohy v oblasti Q_{OUR}

a - parameter kvality operátorov leteckých systémov, kde $a \in (0,1)$.

At the same time, the effect of the environmental environment and the operator on the aircraft system is a mathematical expression of the interconnection of changing parameters of the aircraft system so that the output shows the desired parameters. The output figure achieved has the importance of estimating the impact of the likelihood of achieving reliable operation of the aircraft system.

This number assesses the professional performance of the aircraft system.

a=0.8;

a = 0.8; T = 4/(1-a),

T = 20.0000;local consumption rate of the control time (cycle) of the aircraft system.

T0=1/(1-0.8),local operator time constant.

```
T0 = 5.000;
syms x notation of function offset in MATLAB symbolism,
T=sym(20);
f=exp(-(20-x)./5);convolution, x-time transition to critical activity,
yT=0.2*int(f,x,0,20),calculation command,
yT =-exp(-4)+1;
yT = 0.9816;rate of local estimate of the probability of continuous work LS,
a=0.85
new value.
a = 0.85; T = 4/(1-a),
T = 26.6667;
t0=1/(1-0.85),
T0 = 6.6667; T0^-1
T0 = 6.6667;
syms x notation of function offset in MATLAB symbolism,
T=sym(26.7);frequency of the aircraft system's operating cycle,
f=exp(-(26.7-x)./5);convolution, x-time transition to critical activity,
yT=0.2*int(f,x,0,20),calculation command,
yT=0.15*int(f,x,0,26.7),calculation command,
yT = 0.7464;
a=0.9;
a = 0.9; T = 4/(1-a),
T = 40.0000;
T0=1/(1-0.9),
T0 = 10.0000;
syms x notation of function offset in MATLAB symbolism,
T=sym(40);period per aircraft system operation cycle,
f=exp(-(40-x)./5);convolution, x-time transition to critical activity,
yT=0.1*int(f,x,0,40),calculation command,
0.5*(1-exp(-8))
yT = 0.4998
ai=[0.8 0.85 0.9]; Ti=[20 26.7 40]; T0i=[5 6.7 10]; yTi=[0.9816 0.7464 0.4998];
[ai; fi; T0i; yTi],
plot(ai,Ti,'bo',ai,T0i,'kd',ai,yTi,'rs'),
title('Characteristic exponential weighting functions of an air operator's activity on an
aircraft system'),
ylabel('Characteristic values of operators:T; T0; yT'),
xlabel('Aircraft System Critical Activity Values:a')
```

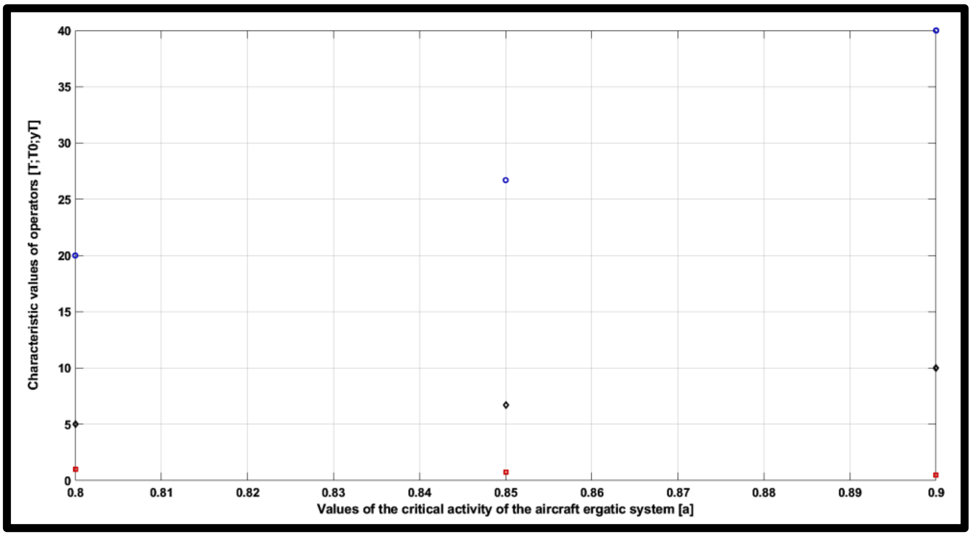


Fig. 89 Characteristic exponential weight functions of the activity of an air operator in an aviation system

The change in the dynamic properties of the aircraft system is characterized by its reaction to the nth cycle of the operator, who by his interventions activates functions with which various activities of the aviation system can be expressed, creating incentives for work, for example, the conveyor system of luggage at the airport. The response of an aviation system to, for example, a unit pulse defined by the function f(t) is called the weighting function h(t), by which it is possible to characterize the operation of the aircraft system. It is clear that the course of action needs to be recorded graphically, whereby accurately expressing changes are supported by an integral course. The above integral is the division of the input signal into individual pulses with the subsequent determination of the output signal by summarizing the number of responses of the operator to the aircraft system.

Thus, the weight function h(t) and the frequency transmission H(i) are bound together by the Fourier transform:

$$h_{(t)} = -\frac{1}{2\pi}\int_{-\infty}^{\infty} H(i\omega).e^{i\omega t}.d\omega \qquad (9.4)$$

$$H(i\omega) = \int_{-\infty}^{\infty} h(t).e^{i\omega t}.dt \qquad (9.5)$$

The weighting function h(t) expresses the operator's response to one aircraft system cycle by an expressed characteristic.

The efficiency of an airport is reflected in the criterion of the proper management of the airport's activities, i.e. its effective strategic planning. This is based on the basic concept of managing legal aviation entities. Each organisational unit of an airport can be affected by the measures currently being taken. Strategic planning requires a review of both existing and potential challenges facing an organisation. It is necessary to develop a vision of what the airport will look like in the future and to define the steps and actions to be taken to achieve it. The strategic planning framework includes the following key elements:

- Outcomes that define the purpose of the airport and its core values, which can also be created;
- Goals for the future of the airport, which outline future objectives for the airport and its coordinating organisations;
- Identification of the airport's strengths and weaknesses, as well as the threats that could affect it;
- Definition of effective criteria to be addressed in the course of future planning;
- A set of general and broad strategies, long and short term goals, action plans that provide a roadmap for addressing the situation between the airport's current state and its vision;
- Define the airport's key performance indicators (measures and targets) and evaluate progress towards achieving the long and short term objectives.

In recent years, corporations, nonprofits, academic institutions, and government entities have adjusted airport operations to meet specific needs. Over the years, a number of professional publications have been created designed for airports to plan their conceptual activities at the level of *"How To"*. Special manuals for airport operators in the process of their effective management have been published.

The aim is therefore to present a proposal for the creation of models for some objects at the airport, in order to show how differently the activities of airport managers and aviation professionals can be approached professionally. This information can be used for process development applicable to selected airports.

Strategic planning at today's airports consists of several elements to ensure passenger safety and security, but also to achieve a strong financial performance of the airport. When an airport system, or multiple planned systems, anticipates a future vision, that system determines the strategy and goals for its growth and prosperity (including the types of products and services it should provide) and also defines visions for how this will be achieved.

The elements that influence the process of the primary product offered by airlines for all airports are addressed by the infrastructure of the airport system and the transport hubs to it, which facilitate the safe and efficient movement of people and goods from 'point A' to 'point B'. The product evolves over time, but its purpose remains fundamentally the same. Similarly, airlines provide a similar product (i.e. transporting passengers from their point of origin [point A] to their point of destination [point B]).

Simultaneous planning in an airport environment is possible, but many factors, including differentiating products, affect the loss-making process. Some of these factors are similar to those that apply to businesses and non-profit organisations, while others are specific to the airport industry. The views of stakeholders, which are generally diverse in the airport process, need to be taken into account when planning an airport management strategy. Corporations and not-for-profit organisations also involve a range of stakeholders in the implementation of their strategic plans. The strategic planning process involves airport representatives from the local community, such as local governments, business and community leaders, and local public interest organisations.

An airport serves a broad and diverse group of customers, consisting of two main categories: airport tenants (airlines, concessionaires, fixed-base operators (FBOs), operators and other business owners at the airport, and passengers, supporters and other businesses or individuals who are users or, depending on the status of the airports, users). These entities must consider the needs and priorities of their customers when defining the vision for their airports.

Unlike businesses, an airport serves the local community as a whole and is generally established as an economic development engine for the communities it serves (cities, states). Airport operators must be sensitive to the needs of both their customers and their communities. At present, the management of a company can decide which type of customer it is interested in. Moreover, local authorities today cannot operate an airport if the evolution of their decisions may or may not be in line with local needs and priorities that affect the future of the airport. In contrast, local communities usually have more control over the operation of airports than general state corporations.

The competitive environment in which airports operate in Slovakia is not uniform. In some cases, competition comes from other airports in the vicinity (Vienna) or from an airport offering better services or prices (Košice vs. Poprad). In other cases, it would be preferable to connect central airports (Žilina-Sliač) according to a consolidation strategy that would depend on the airline, which may lead to competition for new opportunities and services between them. In addition, other modes of transport and economic factors such as fuel costs may influence the competitive environment (advantage of Sliac airport, where military aviation is also operated).

Strategic planning in the airport industry is challenging because the aviation industry is constantly changing. It is difficult to participate in structured airport maintenance for the future. Events such as airline bankruptcies and restructurings, economic slowdowns, the introduction of new regulatory requirements, the emergence of low-cost carriers or the consolidation of airlines through mergers mean that the airport must constantly be managed in such a way as to at least maintain its flexibility and adaptability. Nearly two-thirds of respondents to an online survey conducted as part of ongoing research said they were trying to create a variety of events that could affect the future of their airport as part of the fundraising and promotion process [32].

Future airport traffic planning also requires an assessment of the airport's regulatory environment. In planning for the future, the airport seeks to match its capacity with the demand for air travel. At the same time, airport operators must ensure that they comply with the complex regulatory requirements imposed by federal, state and local agencies and authorities.

International regulatory bodies such as EASA, the Department of Transport and transport authorities are of particular importance to the airport sector. In accordance with various state and local regulations, they protect airports and the surrounding communities from incompatible developments and define the conditions under which the airport can operate in the environmental field. This influence on the development of the airport is particularly noticeable at Poprad Tatry Airport, where the environmental protection component of TANAP and others have a constant influence on the growth of air traffic in the area [22].

Slovak airports differ in size, location, type of operation and number of passengers. Each airport also has its own values and culture. This uniqueness creates a problematic comparative environment. Because of this uniqueness, airports in the future must be designed in such a way that each airport has its own individual characteristics. Achieving this goal is necessary for their effective evaluation and development. The basic points of optimisation, which can be considered from a broader perspective, include:

1. airport - historical context in terms of air transport, vision, and fundamental values;
2. the indoor and outdoor environment in which the airport operates;
3. strategic issues in airport development to create competitive advantage;
4. long- and short-term solutions to the objectives set and the action plan that must be implemented for the vision of the airport;
5. an evaluation plan using key performance indicator.

The approach to address the current situation of airports cannot be objectified without the necessary output data from airport sections to optimise or identify their inefficiencies. In order to be able to compare and contrast airports or to assess the quality of a given airport, it is necessary to describe partial experiences and to create a professional description of the situation. The system of comparing the quality of airports is one of the ways of creating a sufficiently healthy competitive environment, which has the effect of encouraging all those involved in the airport complex to create a level of quality, not only by evaluating their own experience, but also by using sound means of optimisation (e.g. education). This comparison can be approached mainly through the subjective creative activity of researchers, whose recognised results are actually documented and supported by the methodology of their creation. The method of comparison represents a certain specialisation, characterised by the fact that its main method is the comparative method. In addition to the use of this method, it is characterised by a certain similarity in the way problems are seen, and in the way past and present conditions are viewed [30].

Comparing airports is the essence of examining past knowledge of errors in order to gain new knowledge. The result of this process is not a simple statement of agreement and difference between the objects compared, but their explanation and evaluation. It is a complex process that takes into account a number of factors, including historical development, geographical advantage and defining social processes. For airports to function effectively, it is essential that their dependent and independent activities are optimally evaluated. In particular, an airport should be able to analyse changes in these activities, identify a so-called emergency area and take timely corrective action when it comes to dynamic processes in its management. The evaluation of the airport's performance (also strategic) helps to prepare realistic plans for the future and to set specific objectives in the respective management areas. The discrepancy between different airports is clear and it is difficult to make only a heuristic comparison, which is to some extent dangerous [35].

The main criteria for the selection of airport activity indicators may include the ability to retrieve time data for events and activities at the airport relatively easily. The data should be simple enough to help passengers make decisions about the quality of the airport, and the results should be obvious to both professionals and the public who are not involved in the day-to-day operations of the airport. The data obtained must not be influenced by factors unrelated to the airport being evaluated. The inability to provide data on a wide range of different aspects of airport management is one of the criteria for an airport to be in decline.

The organisational structure of an airport should also be taken into account when making a specific assessment of its quality. Section managers should be aware that responsibility for the quality of the assessment is an element in assessing the overall active safety of the airport. Any objections to specific acceptable corrective actions shall be removed if required by the efficiency of the airport system. The efficiency of the operation of the airport system and its assessment should be part of the action plan.

The other main units of evaluation are financial indicators. These include, in particular, revenue, which can be broken down into direct expenditure on the operation of airport systems and technical facilities, and administrative or economic costs [44].

ICAO documents recommend how to evaluate the functional efficiency of an airport according to the proposed structure, using the following factors:

$$Xp = [\ I, C, O, P, N_P, WP, TP, CC, CA,] \qquad (9.6)$$

- revenue per passenger; [I]
- energy consumption per passenger; [C]
- operating profit per passenger; [O]
- air revenue per passenger; [P]
- non-aeronautical revenues per passenger; [NP]
- the cost of the employee's work per passenger checked in; [WP]
- total revenue per employee; [TP]
- capital costs per passenger; [CC]
- net assets per employee. [CA]

In domestic practice for assessing airport performance, this list should be supplemented by:
- the share of international freight and passenger traffic;
- freight consignments;
- the number of consignments sent by the airport in question and more.

These indicators are considered to a greater extent as peculiarities of airport operation. By examining important philosophical issues in the concept of airport operating efficiency, depending on market efficiency or transitional conditions, it is necessary to form correlation conclusions with which each element can be corrected with the XP set. The category "efficiency" also includes a sophisticated detection system in which the influence of research and the command economy of labour is basically absent. Until recently, the terms "airport economy" or "efficiency of airport operations" were difficult to accept because they were self-supporting departments within an airport. Within the economic and legal independence of airport functionality, some evaluation methods are not appropriate. In developing precise methods for assessing the efficiency of airport operations, it is necessary to identify how the new economic category should respect the evaluation characteristics in the general airport operating system of an airport [51].

These characteristics and the term "airport economic efficiency" (as a new economic category) mean the economically independent and stable state of the airport, the constant and regular cooperation with other objects of the operational process, the implementation of an optimal volume of commercial and technical operations, a certain system of measuring the economic indicators of the airport, which together define the state.

The transition of the Slovak economy to a market economy has resulted in the establishment of indicators for assessing the quality of passenger and cargo air transport at airports. New requirements have arisen for airports, which have to develop and implement new organisational processes:
- demonopolization, separation of combined airlines,
- privatisation assets,
- the development of a competitive environment establishing the optimal quantity and position of existing airports.

The process of demonopolization of air transport required the separation of airports and air transport, i.e. the creation of two equal companies of airports and airlines. The separation of airports and airlines was necessary not only because of their different functions, but mainly because of their different revenues and profits. Their revenues are in direct contradiction - the airport's revenues are loss-making, the airlines' and vice versa. In simple terms, an airport can be seen as a section of road that generates high economic value for all sectors of the economy in a given area, unlike, for example, motorways, whose investments exceed profits in the long term. Motorways provide a level of transport comfort that, unlike a railway line, requires a high level of profit on a daily basis. This philosophical view of the airport clearly completes the field of realisation from the point of view of changing opinions on the unity of transport [54-58].

For an airline, the price is artificially reduced by reducing the costs of the airport. This creates a misconception about the high profitability of the airline and the low profitability of the airport. If the independent existence of each company looks for sources of income and cost reduction, then there are opportunities to increase its profitability. From the point of view of control, it is effective for regulation to create means of self-financing, which are provided in normal situations.

The process of separating airlines and their total revenues is complex and requires a preventive approach, so that the financing process is fully completed at many airports. The process of airport unbundling has created opportunities to obtain funding from different entities, which are ongoing and still relevant.

Each division of airport complexes aims to guarantee the efficiency generated by airlines and allows antitrust claims for the monopoly position of airports. Over the years, basic principles have been developed to create objective measurable parameters. For the purpose of determining optimization methods, the following indicators or parameters stand out, which can be measured, evaluated, or generated for modeling and simulation using IATA standards.

9.5 Input measurable parameters of the airport and specifics of air passenger transport

The main static measurable parameters of the airport include:

1. Parameters that depend on airport infrastructure P_s
   - number of stands for aircraft of the critical type concerned,
   - number of check-in counters,
   - number of departure gates in division (Schengen, non-Schengen and gates for departures to third countries),
   - aviation fuel warehouses, capacity + evaluation of expenditure/receipt, slag of logistics (OSA methods).

2. Parameters that depend on the technical handling of aircraft. Technogenic parameters P_{TG}
   - number of boarding stairs,
   - number of LPL tanks,
   - number of GPUs,
   - number of ASUs,
   - number of de-icing vehicles,
   - number of vehicles for filling with drinking water,
   - number of vehicles to operate the toilet system,
   - etc.

3. Parameters that depend on personnel capacity (human resources). Variable parameters P_{VAR}

- number of CKI employees,
- number of aircraft ground handling personnel,
- number of security screening staff,
- number of personnel handling baggage and/or cargo,
- number of personnel balancing aircraft.

4. Parameters that depend on airport capacity (throughput) management. $P_r -$ steering throughput

- to what extent slot coordination is applied,
- evaluation of the throughput of CHECK-IN desks (number of PAX checked in the respective flight per unit of time),
- evaluation of the throughput of security checks,
- evaluation of passport control permeability,
- assessment of the permeability of customs administration.

5. Parameters that are related to the terms and conditions. Time-based parameters - P_{tp}

- the opening time of the CHECK-IN desks of the respective flight before the scheduled departure
- the time of closure of the CHECK-IN desks of the respective flight before the scheduled departure
- number of CHECK-IN desks per flight
- number of boarding stairs depending on the number of arriving/departing passengers
- TRT – Turnaround time -etc.

Parameters that depend on meteorological conditions $\mathrm{P_{Meteo}}$

From the above, the following probabilistic scheme of airport parameters can be determined.

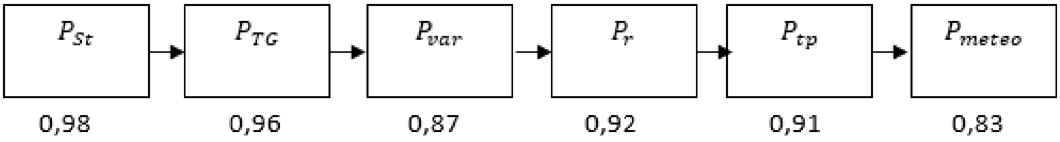


Fig. 90 Airport efficient use block diagram

The efficiency of passenger transport is determined by the final probability (P = 0.568). Any change in probability from normalized is a malfunction. The calculated probability (efficiency) is valid only after the occurrence of the fault in any block P. An important characteristic is the intensity Θ of the disorder i, the manifestation of which may occur over time τ. In this case:

$$W_i = P_{oi} \, . e^{-\Theta_i \tau_i} \quad (9.7)$$

A partial objective of the airport efficiency is to analyse this complex formation and rationalise the management of aircraft ground operations at the airport.

In order to achieve this, the following objectives will be set and addressed

- Analysis of the performance and organisational level of the airport's aircraft control systems,
- Distribution and functional activity of the business units operating at the airport,
- The development of handling at the airport,
- Methodical design of the implementation of ERP systems for aircraft ground handling,
- The concept of a new procedure for the implementation of information systems (IS), resulting in the creation of a single information space at the airport, fully ensuring the process of operational management and resource planning for aircraft ground handling,
- A comprehensive assessment of the proposed activities for the reorganisation of ground handling at the airport [66].

Issues of effective ground management and the possibility of providing information taking into account the specifics of the airport and market requirements remain the subject of research. The Slovak airports (Žilina, Poprad, Piešťany, Sliač, Košice) can be selected as the subject of the research. The aim is to develop methodological, organisational and information support for managerial decision-making in the management of the ground part of airport systems. In the transitional period of restructuring the airport network, as well as in view of the incomplete statistical and financial information for assessing the efficiency of airports, it is possible to use a system of indicators that can adequately contribute to assessing the efficiency of their operations. The most important of these are: profit per passenger, revenue per passenger from airport employees, airport profit per management unit, share of international traffic [99].

The economic efficiency (comparative) of the operation of each airport is evaluated not only individually, specifically by a single index, but also integrally. A maximum or minimum value, which generally means aggregating information on the most efficient airports.

The algorithm for determining the integral index consists of f_{ASS} phases:

1. determination of specific values of indicators, $P_{st} \ldots \ldots . P_{Meteo}$
2. evaluation of each efficiency indicator (10 parameters or another system)
3. definition of effective managed positions at each airport,
4. an assessment of the economic situation of each airport in relation to its total population, summing up the time series on interest in air transport.

The proposed methodological approach will make it possible to identify the airport and determine its forecast for a set period.

Monitoring the efficiency of airport ergatic complexes

Let us apply the observation acceptance scheme to an airport that can be characterised as internally stabilised in order to establish the basis for determining the "airport readiness constant". On the basis of this constant, it is possible to observe the deviations of other airports that lack internal and external development dynamics in the air transport market. In other words, why fly to this airport and for what purpose? The dynamics of the constant is crucial and parametrically indicates the possibilities in which direction to go when evaluating the dynamics of airport efficiency.

9.6 Determination of the standby constant of the transport system

The transport system constant is divided into the airport readiness constant and the readiness constant of the means of transport as the basic determining criteria for assessing efficiency. Efficiency is currently described by generally known AES methods, which are analytical and statistical, which result in the expected functions of the airport system (value close to 1) and whose content is useful for determining the absolute constant and the reliability of the airport.

When constructing mathematical models for determining the airport constant, the observable process is simplified and schematised in the desired way. From the set of factors influencing the formation of a mathematical model for determining the airport constant, only those are taken that can change the reliability of the airport. Such a procedure should result in links between the structure and status of the airport over the period of time in which the airport system is in operation and the technical characteristics, modes of their use and outputs of the passenger transport solution with reliability indicators [65].

The more responsible the choice of the probabilistic model for determining the airport constant, the more accurate the estimate of the reliability of the airport system. The model of the airport constant is always designed separately for each case and differs from the physical model by the formal forms of description used, which bring it closer to the mathematical models. For practical reasons, the model of the airport constant can be assembled according to characteristic symptoms.

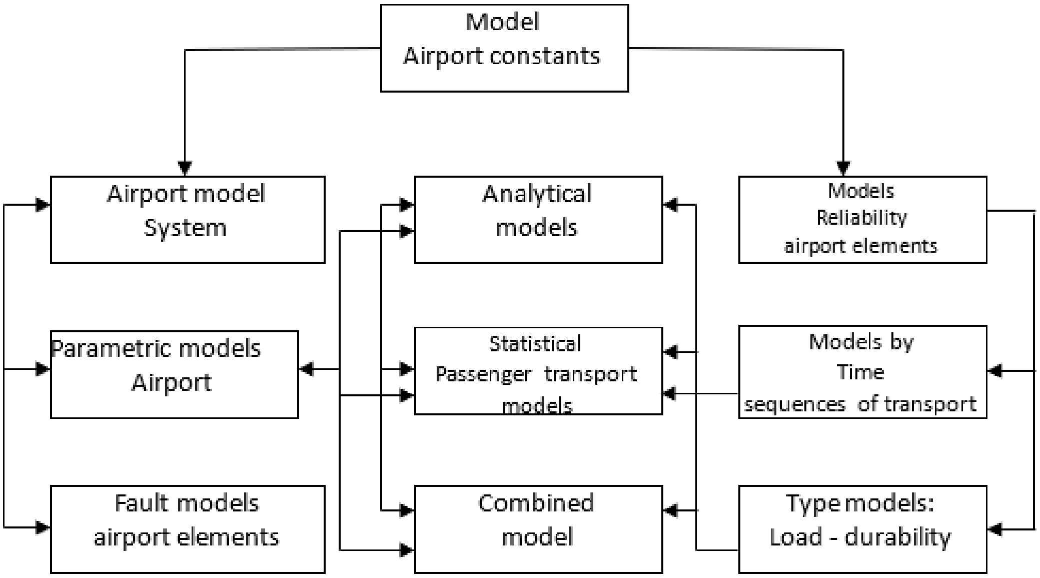


Fig. 91 Classification of reliability models

The first prerequisite for solving this problem is knowledge of the initial reliability of the airport, expressed by the symbol P0. When the airport system works without interruption during the preparation of the aircraft for flight at the airport, then there is no point in proceeding with further investigation. Let us set Ourselves the requirement to maintain adequate reliability.

The manifestation of one malfunction during preparation for take-off of the aircraft at the airport is: Q = 1 – P0, then before the start of the next stage it is necessary to carry out a repair so that the reliability of the airport is maintained. This necessity is determined by the equation after each repair has been made:

$$P_{(i)} = a^i . P_0 + (1 - a^i)P_\infty \qquad (9.8)$$

Where

and is the level of decline (degradation of the reliability of the airport system that produces the need for repair. In general: 0 ≤ and ≤ 1.

I is the number of repairs needed.

For the first correction will apply: P(1) = a1 P0 + (1 - a1) P∞

P ∞ is the achieved reliability P∞ = 1.

The second correction is an equation of the form

P(2) = a2P0 + (1 - a2) . P∞, etc...

The probability of a malfunction occurring at an airport can be expressed by the equation:

$q(i) = 1 - (Pi) = 1 - aiP0 - (1 - a) P\infty$,, (9.9)

where

Q(I) is the number of failures

In equation (2.3), let's introduce: $P\infty = 1 - q\infty$, $P0 = 1 – q0$, then holds:

$q(i) = a^i q0 + (1 - a^i) q_\infty$ (9.10)

The determination of the airport constant presupposes the implementation of the correct decision of all participants at the airport (both controlling and operating), for whom the value of "a" is determined. Number of administrative management decisions characterised by a sequence of i=1. 2,... generates 2i possibilities of reaching the probability P(i) and at the same time determines the nature (shape) of the discrete distribution function F(xi). This means that each value of P(i) corresponds to a specific probability value, which is given by the symbol Ri. In this way, we get the P-split function after completing each correct decision, which makes it possible to forecast the reliability of the airport.

Let (xi) mean the highest reliability of the airport system achieved after the i-th assessment of the correctness of airport management. i.e. P(i) ξ and Ri is the probability of ξ the reliability of the airport after $(\xi_i + 1)$ assessment. The airport system shall have a reliability of P(i) + 1 = a . P (1 - a), P∞ with probability Ri (1 – P(i)), subject to a correction made for the error of decision (coefficient a) after completion (i + 1) of the decision. As long as the reliability Pi with probability P(i) is achieved. R(i) after (i + 1) decision, this means that no corrections have been made.

In the following, the following procedure can be established:

(a) value of the mathematical mean airport reliability value — airport standby constant:

$$M[X] = \frac{P_{(i)} - P_0}{P_{\infty -} P_0} \tag{9.11}$$

(b) forecast of the upper limit of the economic and technical probability level of the airport function:

$$PH_{i\,.prog} \le P_\infty - (P_\infty - P_0)[\,a - (1 - a\,)P_0]^i \tag{9.12}$$

1. forecast of the level of the lower limit of the economic and technical probability of the airport function:

$$PD_{i\,.prog} \ge \frac{P_\infty - P_0 - P_\infty . e^{(\,i-a\,)(\,1-P_\infty)} .(\,1 - P_0)}{P_{\infty\,.}P_0\,. - e^{(1-a)(\,1-P_\infty)^i}(1 - P_0)} \tag{9.13}$$

In the light of the above conclusions, it is necessary to observe the rightness and wrongness of the decisions of the controlling and operating airport operators, which can establish an airport standby constant as to how the airport is able to respond to possible changes in external and internal influences. For example, in terms of airport capacity, if there is an unexpected increase in airport traffic due to a poor decision by the airport management to accept another carrier. Or the inefficient management of the airport when it receives subsidies that are intended for the operation of the airport but not for its development [13].

The issue of airport structures is grouped into complexes, which can be conceptually referred to as airport and aviation complexes. These have their own managerial and technical problems, from which it is possible to create safety indicators. They need to be well managed, so it is necessary to have good management and a technology portfolio that clearly explains the optimisation of internal airport processes. There are different ways of solving this problem. Aerospace technology is one of them, since it is the unit itself that can be analysed by dichotomy. Its indicators have mathematical solutions, the results of which are values with which we can evaluate these elements of the aeronautical structure. The results of the solution are direct and indirect parameters that allow us to estimate the forms of measurability of the quality of the transport processes themselves. The creation of safety models, which are the apex of partial models in the technical and managerial area, allows the identification of individual safety hierarchies. The output of these models are latent control elements that can improve the technique with which we control security indicators in these structures in the airport environment.

2. Airport optimisation is possible according to the following specified areas:
3. Security management at airports and in the local area;
4. Airport processes and how they are implemented into individual structures;
5. Air safety methods;
6. Addressing threats within the airport;
7. Direction and availability of threat solutions;
8. Identification of individual dangerous threats;
9. Methods of dealing with internal security at the airport;
10. Model situations in the penetration of information threats into systems;
11. Model aspects and MIMO airport project;
12. Statistical and probabilistic models of situational security solution.

To solve airport security, it is possible to use:

1. the classical theory of the probability of problems occurring at the airport;
2. statistical AES assessing the status of the airport;
3. random quantities representing the emergence of dangerous situations, the approximation of which to deal by regression with an increase or decrease in dangerous situations;
4. purposeful functions for a specific problem;
5. graph theory.

Today's air transport is unparalleled in terms of speed and ground reach. For many transport users, air transport is important because it quickly connects many places on the ground. For many, this mode of transport has opened up new opportunities for trade and other activities. The combination of modern technology and assured safety makes air travel safer. The area of implementation is airspace and airports. A consistent methodological approach to assessing the relevant functional quality of airport operations can address problems in such a way as to create a safe environment for passengers. This can be ensured through quality in the provision of all services to ensure airport security. The most important factor in determining the relevance of the data is the identification of the relevant requirements. These must be parameterised according to the manuals of airport transport systems, which have a common safety ideological basis. For this purpose, an airport needs appropriate information from the airport systems in order to be able to demonstrably reassure air transport users about the quality of air transport. Parameters associated with the full lifecycle functionality of airport systems need to be systematically archived. Over time, these will be translated into precise aeronautical regulations for assessing and measuring the quality of aeronautical complexes. Monitoring their effectiveness depends on information about the passenger, on the economic costs associated with his flight. The efficiency of airport operating systems can change over time. This is related to reduced activity, which is represented in econometrics by the entropy of the estimated functions of each part of the airport. Here we rank the number of passengers handled at the airport in quarterly seasonal periods. The main measurable processes in the airport complex include:

13. Features of the device (airport),
14. The conditions under which the object is assessed.

The objectification of the results obtained by measurement can be defined in the form of qualitative values. More abstractly, by using passenger satisfaction levels as a key parameter, efficiency results can be used to compare airports within individual components of the assessment [20-26].

9.7 Managed security at airports

When introducing new information security system solutions, preference must be given to a local security solution. In essence, this is the precise support of all components of aviation security management. The entry and exit areas of airports have reached the highest possible technical level and the level of security required by law. Thanks to multi-level security processing, solutions are available for effective monitoring and control of the current status of individual airport complexes. Managed security refers to precise process security management based on statistical data processed from the monitoring and control systems of security information at the selected airport, indicating likely intrusions and potential threats. There are two distinct components of aviation security. The first deals with physical security as a component of aviation security, and the second deals with its assessment. Today it is possible to study safety from the point of view of the internal and external forces that change its shape by identifying the component that makes it up. It can be shown that, in the case of an airport, safety deficiencies create an unsafe environment that must be identified. Their differences have a major impact on how safety is stabilised. The methods used to select different types of safety features for different airport complexes reflect the differences. For example, a linear safety model with a parametric structure that compensates for perturbations can be used:

1. Define, by measurement, the compensatory capabilities of different security systems under conditions of threat occurrence (i.e. exponential) in real time;
2. Provide information and recommendations on the need to modify flight and airport activities under specific (variably modified) conditions;
3. Set limits for evaluating the level of safety and quality of current airport security features.

Today's transport systems, which demonstrate the efficiency of development, are highly reliable. Situations and processes that occur there over time are monitored and, according to the laws of security management, reactions are expected that prevent dangerous threats. Ambiguous information that could affect flight safety must be eliminated through appropriate control. This is mainly in order not to reduce the stability and safety of the airport, which affects the overall flight safety, represented as Y(t). The airport itself is under constant control, adjusting its internal conditions to implement airport protection. If the quantities W(t) - observed external changes prevail, it is possible that there will be an instability of the airport protection and the objectification of the control will have a decreasing manifestation. In order to examine each level of airport protection, it is necessary to know the magnitude of the threat. It is important that the security management has a sufficient degree of stability in terms of knowledge of the intersections that are known at the airport and cannot be removed mechanically or by any other means [16].

$$\mathrm{Y(t)} = (W(t), \mathrm{Ls(t)}, \mathrm{Lz(t)}, \mathrm{H(t)}, R, \mathrm{Q(t)}) \qquad (9.14)$$

where:

Y(t) — Effectiveness of air safety monitoring

W(t) – external security states and threats

Ls(t) – level of activity monitoring area in the airport complex

Lz(t) – area level focused on individual airport structures and systems

R(t) — safety regulators

$H_{(t)}$ – changes in the normal state of safety (degree of danger),

$Q_{(t)}$ – risks of danger

$\sigma_{(t)}$ – internal states of security, defects

$\varpi(t)$ - external manifestations

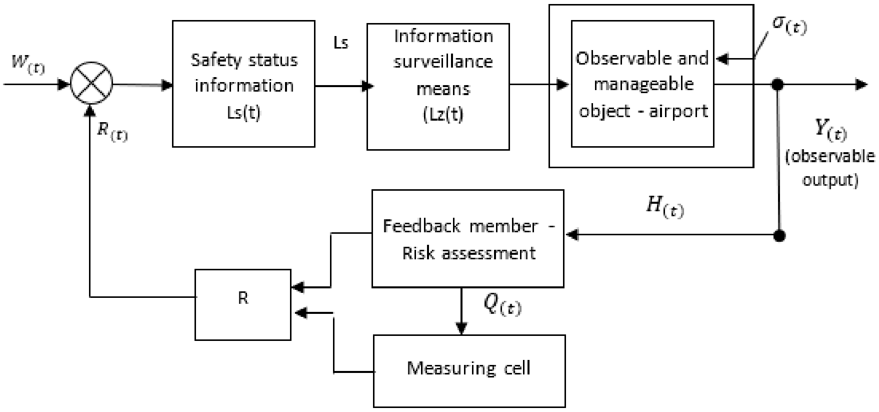


Fig. 92 Local Airport Security Management Feedback

When assessing any risk at a given level of safety, it is necessary to seek R(t) values that will regulate the entire airport complex so that the instability of the airport surveillance system can adequately eliminate potentially dangerous threats W(t). A hazard occurs when the flow of information about a decrease in safety of Ls(t) exceeds the minimum level of safety, which we call the following hazard. The zero value of this result makes the airport an unobservable system with a zero representation of the information flow. The object (airport) becomes not only non-functional but also unmanageable. The non-equilibrium state is the visible manifestation of the dominant vector Y(t) - the general flight safety - which changes the stability of the object's safety - its security. Controllable and observable objects contain changes in internal states accompanied by visible changes in AES stability. The source of the hazard is the airport stability and flight safety system (radar, airport information system, etc.). The hazard always manifests itself at the lowest level of safety in and around it, e.g. the CTR of an airport.

Any unaddressed risk has a negative impact on the positive motivation of the airport's human resources and reduces the stability of the airport's management. At its current stage of development, air transport has to deal with a number of important issues arising from dynamic processes. Current processes in the areas of market and economic globalisation, financial crisis, environmental protection, information and communication, reassessment of the role of the state in society have a fundamental impact on the forms and directions of development of transport systems. The constant growth of the aircraft fleet, international air traffic and its intensity leads to an overabundance of airlines and airports. The high work intensity of modern airports caused by the increase in air traffic has created a "safety" problem. The volume of passenger traffic is increasing and is not expected to decrease in any way (only the COVID period is observable). The aim is therefore to solve the problem of increasing the capacity of airports and the airspace around them without compromising safety. Integration processes in the world aviation community are creating a new global air transport system [90-96].

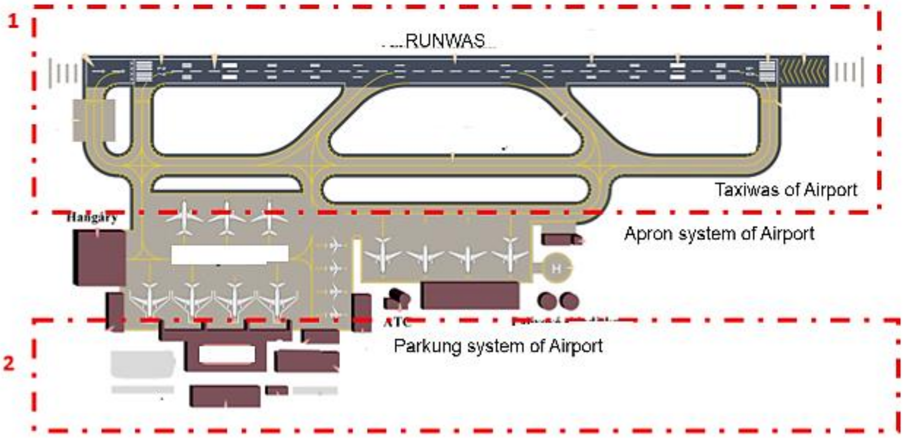


Fig. 93 Airport structure *in – out* safety

The air transport industry must find solutions for an air transport market that is undergoing major changes in terms of the availability and possibilities of commercial and passenger transport. Its main characteristics are relative economic freedom and fierce competition. During the COVID period, the volume of air traffic and aviation labour has decreased significantly and most airlines are in a difficult financial situation that does not allow them to develop and maintain infrastructure. Airlines have undergone a process of corporatisation, splitting into independent airlines and airports. The current regulatory framework for civil aviation hinders the development and functioning of the aviation market and the sector as a whole, leaving it to large companies and effectively integrating it into the global aviation community. In order to operate effectively, airports are generally divided into two distinct areas:

- Airport (flight area), where there is a strong movement of aircraft, their parking and handling, as well as other areas used by customs, immigration and other authorities (departments), including a support system;
- Public space, including airport areas, for free access by the general public.

Access from a public area to aviation activity areas shall be controlled by passenger boarding exit points and checkpoints with physical barriers. At the airport, ASS working areas of the flight zone are distinguished: 1 - runway for ensuring the take-off and landing of aircraft and the necessary ATC equipment for this, 2 - the apron area where aircraft for loading, unloading and ground handling are located, 3 - passenger terminals for handling and handling passengers, 4 - interconnected equipment and equipment necessary for the airport to operate.

Main aircraft ramp maintenance activities:

1. Unloading and loading of baggage carried on aircraft premises.
2. Unloading and loading of freight and mail.

3. Procedures for controlling and controlling loading operations to ensure that the aircraft is correctly cantered.
4. Waste disposal and replenishment of the on-board galley with onboard meals.
5. Technical support procedures for the inspection of aircraft systems and servicing.
6. Cleaning of passenger cabins and maintenance of aircraft toilets, refuelling of aviation fuel, oil and water to aircraft, change and instruction of flight crew.
7. Disembarkation and subsequent boarding of passengers.
8. Supplying an aircraft with electricity and conditioned air during shutdown of its own systems.
9. Procedures for towing and starting aircraft engines.

All the above activities must be carried out in accordance with the technical schedule based on the choice of the optimum time. The organisation of airport management is primarily focused on providing an environment in which civil aviation can effectively operate safely and in a manner that provides the best service to its customers. Therefore, in order to facilitate cooperation in the implementation of airport security procedures, the head of aviation security must understand the role (appointment) and responsibilities in each area of management within his airline, i.e. technologically, procedures for implementing procedures should be developed in full accordance with technology. The solution of specific tasks related to technical procedures for aviation safety, documented by operational procedures, is only possible if some formalisation of the task has been achieved. Some basic aviation safety procedures can be formalised using mathematical models of aviation safety SOPs. Of course, confidence in the absence of interference can be assessed on the basis of the level of aviation safety resulting from expert assessments of the condition of aircraft and airports. The task is therefore framed by the question: At what time intervals is it necessary to perform expert assessments of the level such that the probability of the airport system transitioning to some of the specific states is minimal [77].

Fig. 94 Six-level safety assessment model for airport system classification

The mission of airport security is to prevent the consequences of system process failures in the area of allocation of possible hazardous intrusions in full airport operations. The public part of the airport is an integral part of the mixed part and is the most vulnerable part. Figure 88 shows the security state, the probability of the system transitioning to the state - the state of access violation or the inside of the object mode, for which the respective service is responsible. P - the probability of transition to the state of unauthorised access (difficult situation) - the probability of transition to the state of performed illegal act (catastrophic situation). The task is described by the following system In order to determine the critical time after which the security system enters a dangerous situation, it is necessary to normalise the probability values to the state of interest. Thus, we move to a new concept of aviation safety A_0A_iA_rA_dstandardisation of the level of aviation safety.

The question remains where to get the true transition probabilities. Such statistics do not exist, and that is a good thing because otherwise, safety cannot fulfil its functions. Models describing different situations address the question of when, in the event of a loss of safety, the measures taken have enabled the system to return to its initial state. A system of evaluation equations can be developed for each model. For airport security management, it is essential to determine the probability of a system returning to an operational state in the event of a current or gradual failure. Suppose the airport security system has been ineffective and there has been a breach of the access control or screening regime. This places the system in a state of stress based on the number of illegal entries. It is in a state of illegal access if, at the same time, other services (e.g. screening) are being performed inefficiently [54].

The value level determines the probability of changing the system from one state to another, which is a constant value.$P_i A_0 A_i$.

9.8 Airport systems and their fault rating

The prevention of technical failures is one of the most important things to consider in order to maintain flight safety. Models, which can be expressed in much more precise formulations, can imitate these failures. We need to understand malfunctions because their systematic approach in aviation complexes complements us and allows us to solve them safely. Any approach to fixing a system failure only slows down the process of fixing it quickly so as not to cause a cascade of other system failures. In order to detect a malfunction in the aircraft system, it is preferable to use parallel or serial branches, because other malfunctions do not occur.

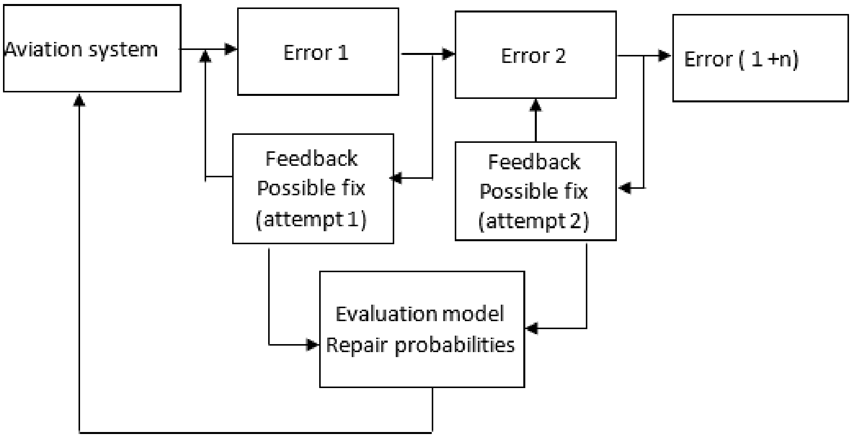


Fig. 95 Serial source of failures with parallel evaluation

The identification of problems on aircraft is solved by the crew at the airports (technical service), who quickly intervene in the course of the problem in order to solve it before the dangerous mode occurs. These serial failures have a major impact on reducing the level of flight safety. For example, automatically measured quantities from technical devices with incorrect parameters can eliminate the process where they manifest themselves in monitoring and during operation. The objective of aerial-aerial monitoring of aircraft systems is to determine their precise limitations that can be stopped for the duration of a safe flight [67]. The measured quantities are continuously variable due to the operation of airport systems or aircraft movement. Considering their value, which can lead to repeated failure, they must be respected in the following respects:

1. Quantitative – assessing the magnitude of failures that have not been adequately monitored;
2. Qualitative – assessing the accuracy of their monitoring within the flight envelope of an aircraft or operational-operational surveillance systems.

3. The accuracy of monitoring failures occurring in aircraft systems can be defined:
4. Directly - a parameter called accuracy rate;
5. Indirectly – through errors that burden the aircraft system.

In order to address the extent and essence of the occurrence of defects in aviation technology, which causes a decrease in flight or technical-operational safety in aviation, it is necessary to address the absolute and relative failure of aviation technology.

1. Absolute – in units of monitoring quantity,
2. Relative – numerical ratio, most often expressed in.

An absolute failure of aeronautical technology "a" is given by the value by which the result of its monitoring differs from the real value, i.e. from the constant that we should observe at a given moment by the pilot or operator of the aeronautical equipment. Thus, the following applies:a_0

$$ai = a_i – a0 \qquad (9.15)$$

The relative error of i-th monitoring is defined by:

$$\varepsilon = \frac{an\ absolute\ error\ \Delta a\ .\ 100}{range\ of\ faults}\% \qquad (9.16)$$

Each result in the ith fault monitoring attempt will depend on the actual value and a_{i0} of the observed fault and on the value of the systematic failure and random failure $v_1\delta_1$ caused by the sequence of failures that have arisen:

$$a_i = a_0 + v_1 + \delta_1 \qquad (9.17)$$

where:

δ_1 - is the total value of the resulting accidental failure detected on the aircraft system.

Partial failures are mass random phenomena that result in their total value of the resulting failure:

$$\delta = \delta_1^{'} + \delta_2^{'} \dots . + \delta_n^{'} = \sum_{j=1}^{n} \delta_j^{'} \qquad (9.18)$$

From the equation % - relative failures, it follows that, which means that the $\xi_i = \frac{absolute\ faults\ \Delta a\ .\ 100}{range\ of\ detected\ faults} v_1 = v_2 = v_3 = v_n$, *value of "i"* in all monitoring results is the same. The absolute disturbance in the i-th measurement can be expressed in the form:

$$\Delta a_i = a_i + a_0 = v + \delta_1 \quad - \quad \text{the sought value of } a_0 \text{ is equal to:}$$

$$a_0 = a_i + \Delta a_i = a_i - (v + \delta_1) \qquad (9.19)$$

To determine is to solve equation (9.19) containing two unknowns. So far a_0 it is an unknown constant, $v\delta_1$it is an unknown value of the variable failure.

In practice, (9.19) is not addressed directly, but gradually. The goal is to rule out systematic disorder and thus convert (9.19) into an equation of one unknown. This is only possible by lining up the aircraft system. It is necessary to quantitatively determine the systematic malfunction, and then eliminate it. For this, control repeated monitoring is used. It is not possible to approach control monitoring without knowing the properties of random failures $\delta_j^{'}$ and from them the characteristics of the resulting random failure δ.

As practice shows, partial disorders arise from various and unrelated causes. Although their number may change with time, it is always considerable. The design of aircraft systems is chosen in such a way that no failure dominates if the effects of some random phenomena were in operation during the design of the airport system. The above selection of properties of partial failures to reveal the property of the resulting failure must be applied as a central limit theorem, which expresses e.g.: sum of elementary failures.

The observed values can be expressed as the sum of the number of independent elements that affect the disturbances, it is then possible to determine phenomena and influences that are statistically dependent and Their influences are comparable, none of them dominates.

When controlling failures by system analysis, e.g. quantities *"A",* it is possible to express for each i-th result:

$$a_0 = a_i - v + \delta_1 \qquad (9.20)$$

where:

a_0 - the known value of achieving the fault operation to be detected is predetermined e.g. engine speed drop below a specified value.

a_i - the result of the ith tracking of engine speed can be converted by n - tracking (the greater the n, the more likely the results):

$$a_0 = a_1 - v - \delta_1$$
$$a_1 = a_2 - v - \delta_2$$
$$a_0 = a_n - v - \delta_n \qquad (9.21)$$

Failures occur in technically complex equipment operating under variable conditions with varying degrees of interdependence while aircraft systems are in operation. When solving failures of devices that do not work or have a minimal relationship with each other, it is possible to resort to methods of indeterminate formulas. We define these failure elements, for example, in terms of constants that are familiar to specialists, but the solution is then of a complex nature:

$$e^{i\pi} + 1 = 0 \qquad (9.22)$$

where: i - (x^2 1=0)

Is there then a solution?

i - will solve what cannot be solved: - 1 $= i^2$,

$e^{ix} = cosx \,.\, sinx, x = \pm\, i$ ....

This is a special case of an important relationship that links the functions sine, cosine and exponential function to explain many problems in electric aircraft systems.

In the process of real problems in aviation technology, it is possible to track malfunctions that arise due to their imperfection over time:

1. the limited sensitivity of monitoring systems;
2. instability of aircraft installations;
3. dependence on stability;

4. incorrect alignment of the overall flight safety task unitary population;
5. caused by a change in the characteristics of the environment surrounding measuring devices (pressure, temperature, humidity, radioactivity, shock).

Failures in aeronautical engineering can be systematic or random. Typically, systematic failures are caused by one or more permanent causes. Accidental failures occur as a result of the action of a larger or larger number of partially accidental phenomena. For example, changes in air pressure due to weather instability, changes in aircraft direction due to gusts of wind, etc. One of the other possible failures in flight safety is the imperfection of the approximation of the shape of the earth's surface. This depends on the accuracy of the position in navigation using GNSS systems. The basis for the existence of this type of error is either the imperfection of the theory explaining a given physical phenomenon, or the intentional and unintentional limitation of the possibilities of this theory by the choice of a certain method [10].

Hidden conditions that can result from failures may be present in an aircraft system long before an emergency occurs. At first, they are not perceived as dangerous, but under certain conditions, they can manifest themselves and their operational level is violated. Such conditions can be created when they last longer and the scope for resolving them is minimal. Hidden conditions in an aircraft system can include both created circumstances and safety levels.

The development of mathematical models to determine the probability of detecting a fault should contribute to the ideal state of an airport. The prerequisite is to obtain accurate data. In this case, for example, emerging complications between ground and airborne ATM systems place increased demands on the booking of planned financial costs for their repair.

The observation of airport security can be carried out using a well-known evaluation method. Classical models are designed to address the optimal security performance of airport systems, especially in numerical evaluation. In the presence of other methods of evaluating the effect, such as the cost of repairing them, it is possible to use the method of least squares to identify faults with the exact nodes and with the measured values in them. A sufficiently advantageous combination of the evaluation of the effects on the reduction of the failure rates and thus on the functional safety is the precise control of the mechanical and electrical airport systems.

The probability of trouble-free operation of an airport system is expressed as:

Right{qi = 1} = p,

Probability of achieving failure when the ith fault occurs in the airport system:

Right{ q = 0} = 1 - p.

Probability of trouble-free operation:

t = time to estimate trouble-free operation up to the fault and time required to resolve:

t = 0:4:40,

DT - Confidentiality interval:

dt = 1,minute,

$t = 0{:}4{:}40,$

$\tau_q = 0{:}1{:}10,$

$T = 40,$

$a = 1 - \frac{\tau_q}{T},$

$T_0 = 1./(1 - a),$

$y_{BP} = 1 - \left(e^{(-(1-a)t/dt)}\right)$

(9.23)

Time of occurrence of the malfunction:

t_{vp} = 10, in 10 minutes, (example).

Value at time :$y_{BP} t_{vp}$

y_p = 0.462, on the Probability scale.

A failure changes the mutuality of the relationships between automatic control and intervention of the airport system operator. The evaluation function shall be determined according to the activity of the system operator after switching to manual control.

Let the uncontrolled control of the airport system be determined by:

$yN = yP\ (\ e^{-(1-a)t})$

(9.24)

$$yN = yP\left(e^{-\left((1-a).*t-.\frac{tvp}{T0}\right)/dt}\right)$$

(9.25)

The experience and operational team of repairing the airport system repaired the airport system using technical fault models. The measured time for estimating and implementing trouble-free operation is:

$t_{Dok} = (t - 18)./T0,$

(9.26)

Control is a function of:

$$y_{Do} = 1 - \left(2.718.^{-\left((1-a)t\frac{dok}{dt}\right)}\right) \qquad (9.27)$$

The limit for repairing an aircraft system shall be:

thr=(t-12)./T0 (9.28)

The boundary function is an evaluation function:

$$y_{hrDo} = 1 - \left(2.718.^{-\left((1-a)\frac{thr}{dt}\right)}\right) \qquad (9.29)$$

Exceeding it reduces the degree of knowledge of the airport system. y_{hrDo}

9.9 Safety limits and their control against the safety models used

Two levels are used in a security assessment solution: General Security Level (UK) and Threat Management Level (BH). The innovation of the procedure is based on an analysis of the concept of qualitative airport security assessment, VB-HB system modelling methods, models of standard and operational procedures for aviation security. The solution lies in the generalisation of the airport safety model and the aviation safety quantification methodology. An important concept to address this issue is:

- The concept of qualitative assessment of the state of aviation safety at airports;
- Safety model of the complex system "VB - HB";
- Qualimetric models of aviation operational procedures safety;
- General model of airport safety quality;
- Methodology of quantitative assessment of aviation safety level.

The practical significance of their use lies in the fact that the results enable the development of an airport quality system with parameters that guarantee the achievement of the required minimum level of aviation safety. The developed models and methods are then translated into technical recommendations in the form of a methodology for quantifying the level of aviation safety at airports.

The analysis of the current state of aviation security issues reveals some discrepancies between the dynamics of service improvement and the pace of development of potential and real threats. The organisation of the aviation security system should be based on an agreed set of requirements of ICAO international standards and ISO 9000-2000. However, it is impossible to solve the problem of aviation security without the use of scientific methods and means. Without an accurate and quantitative assessment of the state of airport security, its improvement is highly problematic. It is therefore necessary to develop the concept of qualitative assessment of the level of aviation security at airports [23].

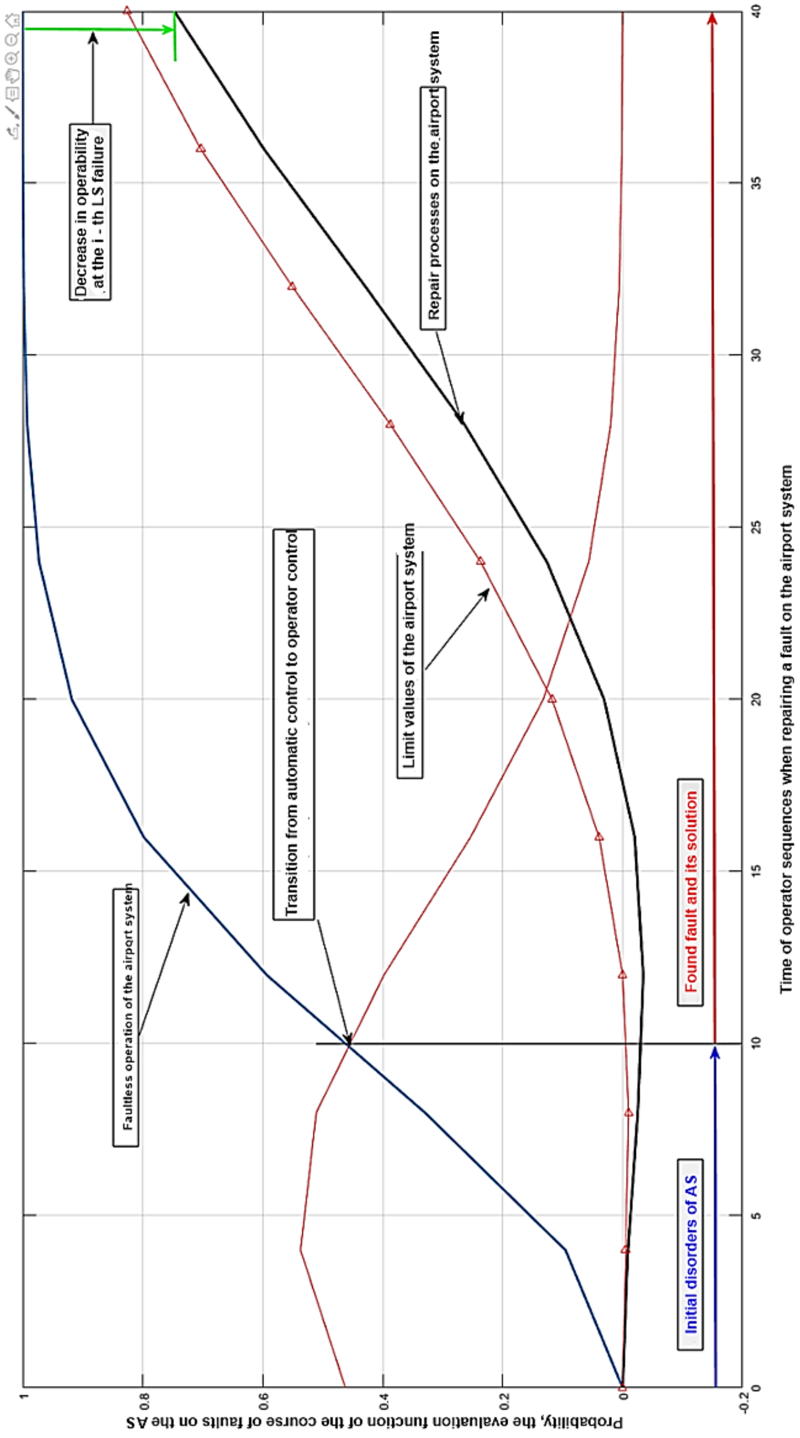


Fig. 96 Quality estimation to analyse the reliability of the airport system

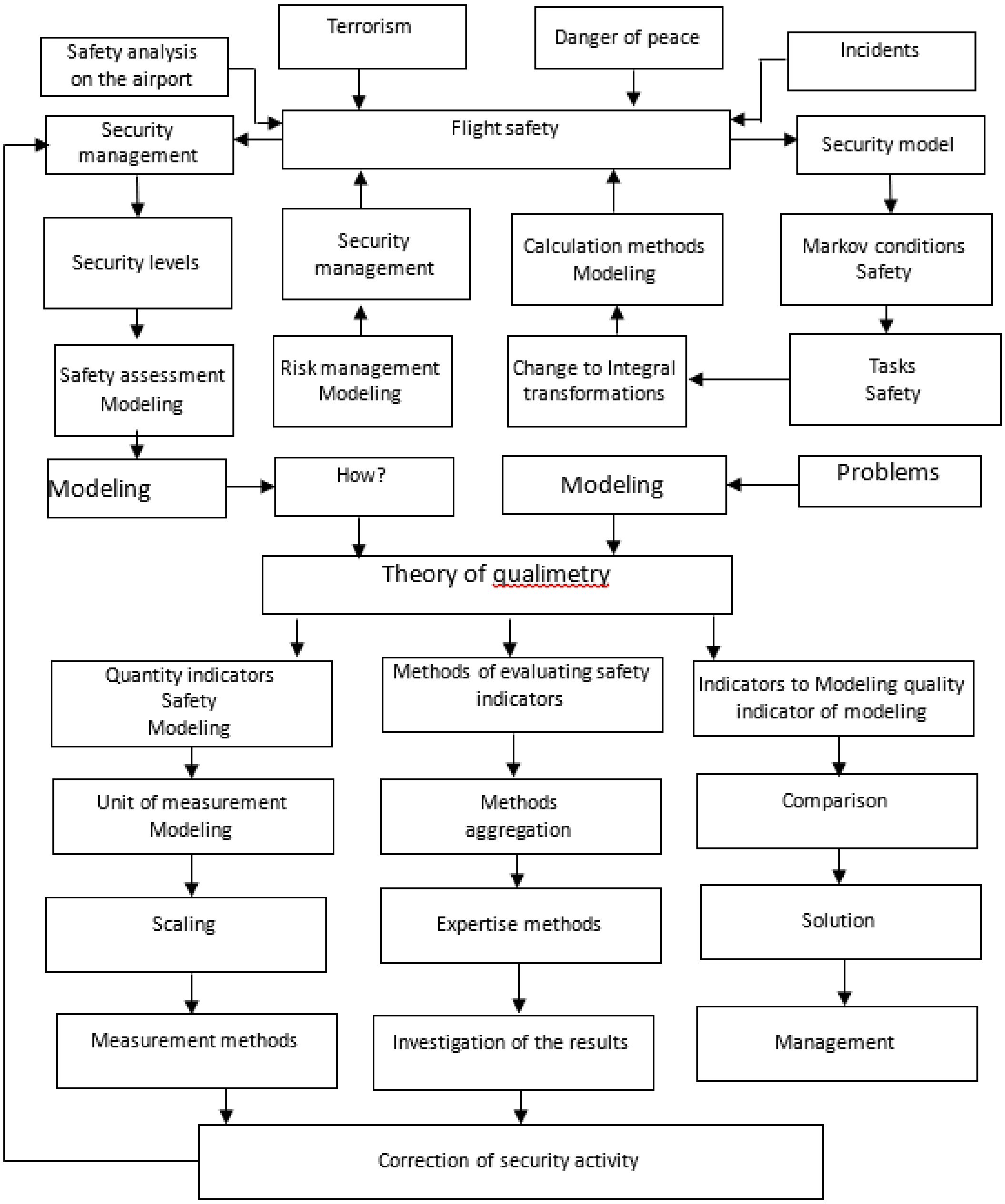


Fig. 97 Qualimetric assessment of airports at the level of own safety [Author]

One solution is to model processes using airport system states. In order to build models, it is possible to design a system of differential equations of the Kolmogorov equation. It can be solved analytically, by direct and inverse Laplace transforms or by numerical methods. The solution consists in determining the probabilistic function of the state of the airport system as a function of time. Theoretically, it is possible to solve this problem if data on the probability of transition from one state to another are available, determined by statistical methods. Such statistics do not exist for the UK, as they would require several hundred implementations. Therefore, the solution to the UK management problem is based on direct statistical methods, which is problematic. There are other methods for determining the probability of transition, using the qualimetric theory [11].

According to this theory, it is necessary to make a list of quality indicators, i.e. to choose methods for measuring and evaluating safety indicators. Interdependent activities aimed at unlawful interference with civil aviation activities must be formalised in three directions:

1. Linguistic modelling;
2. Mathematical modelling;
3. Qualimetric modelling.

Such modeling allows us to identify and describe technological processes occurring in VB and HB systems. This makes it possible to proceed to the mathematical modelling of the generalized system "VB - HB", which belongs to the class of complex systems.

For the VB - HB system, one can proceed from several assumptions that characterize the interaction of its constituent elements:

1. HB elements or subsystems which interact with elements or subsystems shall operate sufficiently autonomously whereby the result of the interaction from the point of view of one need not be positive.
2. HB in the general case can be considered as a multi-element system, the system property of which is determined by its purpose.
3. In the system "VB - HB", the main cause is HB with the element of real threat, i.e. who is the initiator of the danger.
4. Not a single negative result of HB's interaction from a system perspective should be considered as a final act in view of the multifactorial nature of airport security.
5. The total number of threats should be viewed as a stream of events or factors.

Thus, the VB-HB system at any time in one of the possible states, determined by the nature of the interaction of the subsystems and the factors involved, may endanger airport safety. The number of states of the airport system under consideration is determined by the level of fragmentation of the VB to solve a particular problem.

The following security statuses of individual airport systems can be proposed:

0 Normal situation (protected state),
1 Tense situation (violation status),
2 Difficult situation (unauthorized access status) ,
3 Problem situation (trapping status - hijacking or GA general aviation object),
4 Emergency.

Events at other time intervals can be considered as a flow without the subsequent effect of preventive measures. It can also be assumed that all probabilistic characteristics of illegal events at any time are determined only by the time that can be recorded. This property, together with the finite number of states, leads to the conclusion that the process under consideration is a Markov random process.

In view of the above, a mathematical model of a complex system "VB-HB" is proposed Qualimetric algorithm - modelling:

1. Establishment of a list of airport quality indicators using known methods: classification and grouping method, cluster method, analysis, or expert method.
2. Processing the results of the measurements of the airport quality indicators, solving the tasks of constructing a generalised assessment of the significance of the safety indicators. These shall be based on individual or paired comparisons to determine the relative weighting of airport quality indicators.
3. Determine the relationship between sequences. This consists of defining the dependence between sequences, measured by the Spearman or Kendall coefficient of ordinal correlation.
4. The degree of consistency of the expert group's opinions (estimates), such as the dispersion or entropy of the coefficient of conformity (standards and regularities) [99].

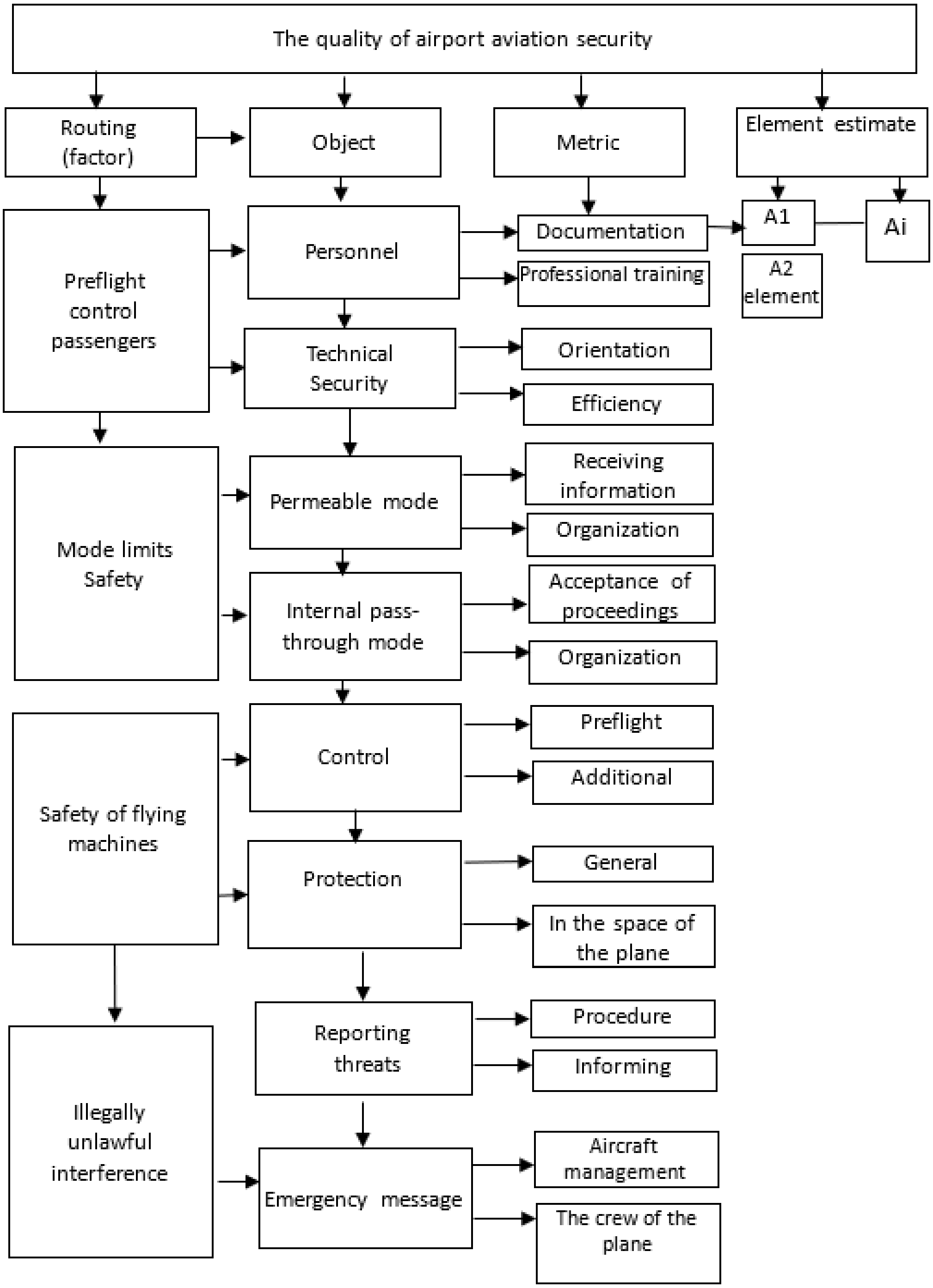


Fig. 98 Airport safety quality model

These methods make it possible to solve the problem of developing techniques for quantitative assessment of the level of airport security. The results of the practical implementation of the qualimetric method of assessing the level of airport security will be the basis for the corresponding methodology and experimental solutions. In accordance with the algorithm, it is also possible to draw up a list of quality indicators of airport security. For this purpose, in the first phase, linguistic models will be identified for UK and HB, which will be transformed into operational procedures for airport security in their areas of activity. They include operational algorithms and regulatory requirements. For each operational procedure, a system will be developed - a quality indicator - which will be combined into a generalised quality model for airport security. In this case, questions about the range of measurements, and weighting coefficients are solved. A procedure for professional evaluation of the quality indicator at the level of elements of evaluation of minimum normative values of indicators is developed [55].

The scientific results obtained allow the following partial conclusions to be drawn:

1. Analyses of the current state of security problems show some inconsistency in the dynamics of improving the technical condition of systems at the airport so that security can withstand the pace of development of potential and actual threats.
2. Airport security management is most effective on the basis of the quality criterion implemented within the system.
3. The research of airport security problems is expedient to be implemented within the framework of a comprehensive system "VB - HB"; a graph model is proposed, through which states and transitions can be solved by mathematical formalisation in the form of a probability system and statistics.
4. A quantitative method of the probability of the operability of airport complexes is possible, provided that there is sufficient information about the probabilities of the transition of the system from one state to another.
5. The concept of aviation safety management, based on quantitative estimates of its level, makes it possible to apply the theory of qualimetry to determine the probabilities of transitions.
6. Qualimetric methods for modelling a safe system are most advantageous when the actual conditions of practical operation provide a quantitative solution based on expert judgement.
7. The developed mathematical models of safe operational procedures make it possible to solve various problems of assessing the state of airport safety. However, this requires initial statistics which are limited.
8. The developed qualimetric models of operational procedures make it possible to generate initial statistics for the formation of mathematical models.

9. The methodology for quantifying air traffic levels and airport safety is based on qualimetric assessment methods. It expands the possibilities and improves the efficiency of the aviation safety quality system [77].

9.10 Forecasting of security situations at the airport

The importance of addressing the likelihood of security situation conditions through airport technology systems allows threats to be identified. The processing of hazard factors and the development of methods to assess the likelihood of hazardous situations arising from their use. It is therefore necessary to collect sufficient statistical data on complex airport problems. Various methods of converting and processing statistical data raise awareness of their technical status. The disadvantage of these methods is that they partially limit experimentation and cannot be used directly to assess the hazard of new airport system technology. The most popular method of assessing hazards is reliability theory.

Reliability is the property of an object to maintain the values of all parameters of the airport system over time and within specified safety limits. This allows it to perform the required functions. Probability values are used to quantify reliability. One of the fundamental concepts in reliability theory is failure. Failure is a disruption of the operational status of an airport technical facility due to a shutdown or sudden change in its parameters. Reliability theory estimates the probability of failure, i.e. the probability that a piece of technical equipment will fail within the specified operating time [34].

Reliability theory makes it possible to estimate the expected lifetime at the end of which the airport technical system will run out of resources and require major repair, upgrade or replacement.

Airport technical assets are monitored through continuous or total periodic work from the start of operations to the establishment of the limit state. Quantitative reliability information is collected during the operation of technical systems and used in reliability calculations. At the same time, characteristics and factors that accelerate or cause decommissioning are identified. Design weaknesses are identified and recommendations are made to improve equipment and its optimum operating modes. Hazard modelling uses formalised concepts [30].

Formalisation is a standardised and organised representation of the objects under study using various physical and geometric elements. Incident statistics, structures and operating patterns of technical systems are formalised.

When shutting down an airport system, it is important to know that, for example, a power failure is sufficient to put the system out of operation. Therefore, for a malfunction to occur (Event A), at least three conditions must be met simultaneously: the absence of electrical power to airport equipment (Event B), the possibility of switching to a backup system if one exists (Event C), and the failure of the backup system (Event D). Event B, in turn, can be a consequence of any of the events, e.g. if it is not triggered. Event C can only occur in situations where the system is in direct flight safety, e.g. when the aircraft is controlled by automatic landing systems in bad weather conditions. Event D can have one of three causes - repair, maintenance or operation of the equipment. The analysis of these problems is to identify the minimum necessary and sufficient conditions for the occurrence or non-occurrence of the main event. The model can provide several minimal combinations of initiating events that together lead to a given incident [18].

The logical structure of such probabilities is such that, in the absence of at least one of the preceding events, no event can occur that reduces flight safety below the limit. Therefore, it is possible to identify potentially hazardous factors that have manifested themselves in previous phenomena. This can prevent a similar event from occurring again [32].

For complex airport systems, the analysis can be carried out using methods where, for example, the diagram in Figure 92 shows events and conditions as logical consequences of other conditions and events.

The advantage of such hazard modelling is the ease and clarity with which mathematical algorithms are used in production processes and technical systems. These are developed and used in practice to model hazardous situations. Estimating the probability of occurrence of a hazardous situation in the human and technical system at the design stage of production, technological and technical systems makes it possible to increase their safety. To this end, programmes are developed to study risk factors and test technical means to meet safety requirements [98].

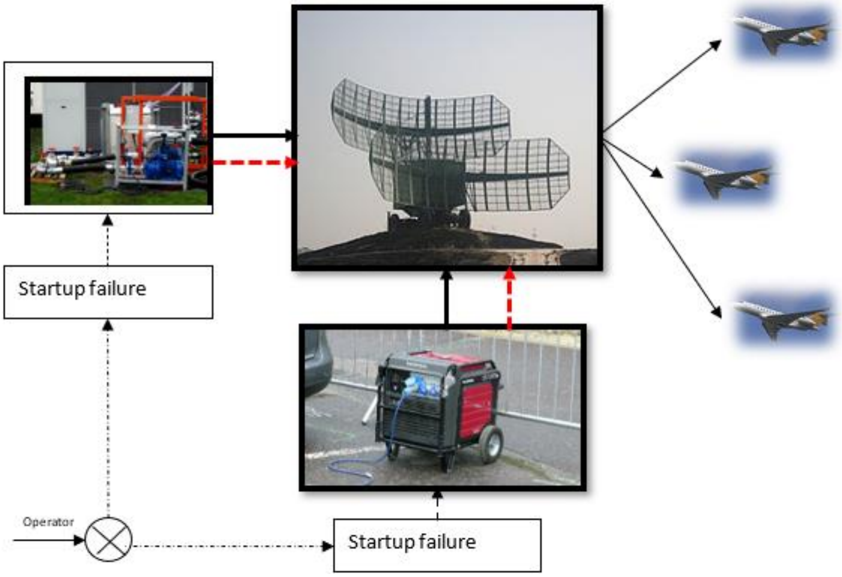


Fig. 99 Logical structure of the operation of backup of airport systems [Author]

Expert assessment methods are used to study rather complex objects, as it is difficult to create reliable models of the operation of large airport systems. These problems can arise due to the complexity and effort required to solve optimisation problems. Also as a result of combining the principles of different scientific fields in technical solutions.

Experts are specialised in specific fields and can provide preferred solutions. To ensure the objectivity of the evaluation, methods are developed to obtain expert information: paired and multiple comparisons and classification. These experts can quantify preferences, analyse and process information using mathematical methods. With their help, it is also possible to carry out systematic studies of the operation of the entire airport and a separate technical unit. The quality control of the designed technical means is carried out by testing prototypes and then during operation by periodic testing of serial samples in conditions close to the real ones with the most negative impact.

Aviation safety can be estimated. The uncertainty of safety situations characterises the probability. For many users of airport systems, safety becomes a major obstacle to ensuring high efficiency. The probability of an event is the likelihood of a particular outcome. A distinction is made between absolute probability, which is clearly assessed in all cases, and statistical probability, which is based on events occurring with a certain frequency.

$$E(x) = P_1X_1 + P_2X_2 + \cdots + P_iX_i \; pri \; \sum_{i=1}^{n} P_i = 1 \qquad (9.30)$$

where E(x) is the expected match,
P - is the probability of the corresponding result,
Xj - a result is possible.

Deviation is the difference between the actual and the expected result. Lack of information reduces security. The higher the fluctuations in awareness in the volume of failures, the riskier and AESs manageable the situation, given the large proportion of the influence of external factors. Indicators known from statistics such as variance, standard deviation and coefficient of variation can be used to characterize deviation. Variance is the weighted average, equal to the square of deviations of the actual results y from the mean value of the expected results y over time period t:

$$\sigma_t^2 = \frac{\sum_{t=1}^{n}(y_t^n - \overline{y_1})^2}{n} \qquad (9.31)$$

Standard deviation characterizes deviations from the mean value of expected results: $\sigma_1 = \sqrt{\sigma_t^2}$

The coefficient of variation V expresses the percentage deviations of the calculated values from the mean value:

$$V = \frac{\sigma_1}{X} \qquad (9.32)$$

Resolving a hazardous situation in a managed safety process using a logistics safety model. Every hazardous situation requires solutions so that their results are sufficient for monitoring. An example of monitoring various hazardous situations is the direct application of methods in practice, where the evaluation is the result of experience and knowledge gained through practice. The second option is to install intelligent controls. To examine the overall situation of safety quality assessment, it is plural to use known descriptive methods to accurately assess the level achieved by the system or complex [76].

Methods of determining safety:
- Quasi-modelling - expresses modelling that approximates the result of monitoring the level of safety in such a way that it can vary a successful intervention according to conditions.
- Application Markov models - stochastic method for randomly changing safety systems that have Markov properties. This means that at the observed time (course of activity at the airport), the following state depends only on the current state and is independent of anything in the past.
- Domino model - modelling the transition of states when a series of specific problems are triggered when a hazard occurs.
- Control system process modelling - adaptation of interrelated activities conditioned by airport security.

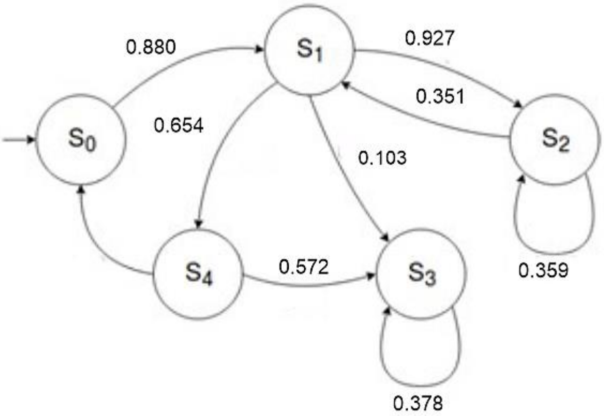


Fig. 100 Markov chain in discrete time

Safety statuses are represented by circles. For airport systems, the statuses typically correspond to the number of problems at the airport. Crossings are marked using arrows with an indication of the probability of passage, they are carried out when aircraft systems interact with each other. The initial state is indicated by an incoming arrow. The displayed Markov string contains 5 states S_0 = (S). The given finite state graphically represents the probability matrix of transition Y. In the matrix, the rows show where the transitions come from, and the columns determine were. S_0, the first row specifies that it is based on the state, and the second column specifies that it goes to a state with probability 1. Similarly with the state. line matrix that it is possible to get into states. This probability is written in the corresponding places, that is, in the 2nd, 3rd and 4th columns. This procedure can be used to assess the quality of air transport. $S_0, S_1, S_2, S_3, S_4 S_0 S_1 S_{1,2} S_2, S_3, S_4$.

$$Y = \begin{pmatrix} 0.8803 & 0.9273 & 0.6540 \\ 0.1038 & 0.5722 & 0.8838 \\ 0.3783 & 0.3064 & 0.6583 \\ 0.3519 & 0.4532 & 0.7819 \\ 0.1524 & 0.2851 & 0.9874 \\ 0.2821 & 0.2524 & 0.6941 \\ 0.0428 & 0.6160 & 0.8678 \\ 0.0261 & 0.4018 & 0.6751 \end{pmatrix} \tag{9.33}$$

9.11 Determination of the level of airport safety in transport infrastructure

Ensuring the functional safety of transport infrastructure means solving a set of tasks and implementing mechanisms to prevent or minimise the negative impact of resources that interrupt or complicate traffic.

Critical situations are those whose interruption or cessation of operation results in:
- Loss of control over traffic in the region.
- Irreversible negative change or collapse of the transport infrastructure, region or community.
- Significant reduction of transport safety in deterministic risk areas. Potentially hazardous systems include equipment.

Ensuring the functional safety of critical and potentially hazardous equipment in transport means improving their control through control systems.

Objectives for ensuring transport and airport security:
- To gain knowledge about the benefits of civil aviation for people.
- Problematic transport systems and air transport processes.
- Acquire knowledge of methods, principles and ways to safely operate air transport, infrastructure and modern systems for the flight environment.
- Develop risk-based thinking on safety issues.
- Acquire practical skills in the use of computer technologies to collect, store, process, analyse and present information on safety levels in order to ensure functional safety and provide protection of potentially hazardous objects in the organisation of air transport processes.

In order to achieve the objectives listed, it is necessary to solve the following tasks:
- Master basic concepts and theoretical information.
- Study the main types of traffic problems in air transport and their processes.
- To study the basic methods, principles and ways of ensuring functional safety at airports.

- Acquire the ability to use computer technologies to collect, store, process, analyse and present information to ensure functional safety in the organisation of air transport processes.

9.12 Assessment of air transport infrastructure quality in time

The assessment of the quality of the transport infrastructure over time can be produced by situational models that are sufficiently feasible to optimise the airport.
Practical mathematics is used to describe such a model. The boundary of the decision is the point of the safety function under consideration, which is defined as a delimited area. In graphical form, it is represented by a change of course, where the character changes according to how the final hazards arising from the entry of threats into and out of the airport area appear. In other words, they are transitions between danger and safety when projected in unconsolidated states. They regroup among themselves. This consolidation has a positive or negative effect on the safety structures represented by the technical systems that ensure the actual operational state represented in the time domain by the frequency of satisfaction. The value of the possible inflection point represents the moment when the overall safety curve changes in the time unit [54].

The quality of air traffic in the process of ensuring flight safety can be sought in the environment when it changes from one layer to another. This point is represented by a point (mathematical expression). In its vicinity there is such a function of safety f, where its derivative f' () at its point there is a probability of P that a series of safety problems will occur.

These are linked to the quality of aviation technology. In the named point x_0 $x_0 x_0$, $x \in P$, $x <$, applies to all points and elements constituting safety. This presents the course of the function f, whose convex values, that is, all values show an increase in safety (respectively, concave - the opposite). Conversely, for all x_0 $x \in P$, $x >$, the safety function f is concave (or convex). In the vicinity of the inflection point, it is required that there is such a tangent of the limit safety level that the function has x_0 *a "spike"* (i.e. it does not have a tangent in it). We do not consider such a point to be an inflection point – air transport is losing its quality [32].

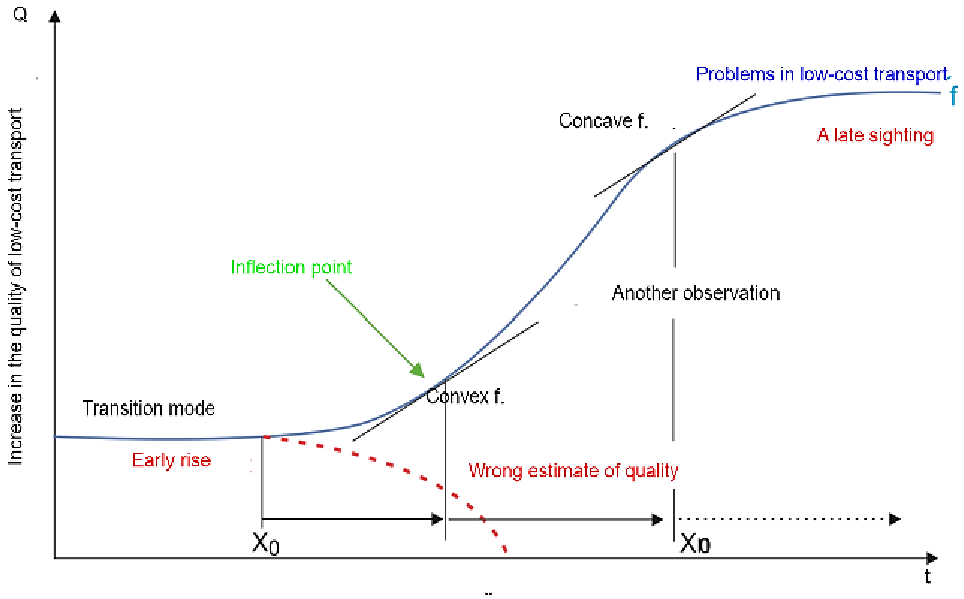


Fig. 101 Graph of functional values presenting the relationship of quality with safety of observed traffic

There are two types of bulk optimal transport that are widely used when comparing turning points. The first are those that are created and capture the vast majority of their transport quality thanks to a single shift. The latter are those that benefit from a number of turning points. The first group of uniform turning points are called transport options (rail), the second (air) [88].

The first mode benefits from accessibility at a time that seems perfect for its growth. This includes several low-cost airlines that were created in the first half of the 20th century and have flourished since the late 1990s. These companies took advantage of the increasing penetration of passengers' desire to travel quickly and cheaply. This opened the idea of regional expansion and dampened further traffic. In recent decades, we have seen airlines at a turning point take advantage of new distribution and transport flight channels, such as social media and programmatic advertising, which allow them to reach passengers on a larger scale. Specifically, at a theoretically lower cost and therefore higher margin compared to existing means of transport. Since then, many low-cost airlines have emerged [23].

In order to achieve the required level of safety, this low-cost traffic is subject to a process of gradual stabilisation of the airport system by means of predefined conditions. These conditions determine the assessment of the airport security quality under a defined final sequence of controlled security protection points at the airport. They are necessary to determine the level of detention in the process of all passenger and aircraft handling so that the security envelope is maintained.

In this role, the airport security service plays a positive role by implementing the functions of the protection complex. It is a generator for controlling all security intervention options for monitoring airport areas. The source of the controls is the difference between the values of the meta-system and the current state of security at the airport. This difference prompts the manager (security services and airport support systems) to implement gradual steps that limit the convergence of the meta-system to a fixed security space-time [13].

The continuous process of necessary compliance is linked to the adaptive monitoring of the security of all the elements that implement it. As a result of confronting the outputs of airport security systems, their state monitoring leads to a continuous improvement of airport security. Realised safety in connection with the knowledge of the character and intellectual capabilities of the object is a manifestation of the quality of the airport. In the intellectual management of complex aircraft and airport complexes, security alone, together with readiness, can carry out operations at the airport as quickly as possible and with the least effort, based on the acquired knowledge.

Demonstration of how it is possible to forecast the inflexion point of the course of danger according to heuristically significant parameters obtained from the airport.

```
t = ([1 5: 5: 35])′,
y1 = [0.0273 0.5722 0.3064 0.4532 0.2851 0.1524 0.0160 0.018]′,
y2=[0.8803 0.2038 0.3783 0.4519 0.2524 0.8821 0.5428 0.6261]',
y3=[0.654 0.8838 0.6583 0.7819 0.9874 0.6941 0.8678 0.6751]',
```

$$y = C_1 e^{-\lambda(1)t} + C_2\, e^{-\lambda(2)t} \tag{9.34}$$

```
t=([1 5:5:35])',
y4=[0.9273 0.5722 0.3064 0.4532 0.2851 0.2524 0.6160 0.4018]',
```

The unique mission of ensuring airport security in the handling and operation of the airport lies in the responsibility for the chosen doctrine set by the program (see example), which derives from the security institutions of strategic companies such as the airport. The interaction between *the airport and the aircraft* completes the idea of a safe system in which the safety process is interconnected and optimizes the transition to normal [56].

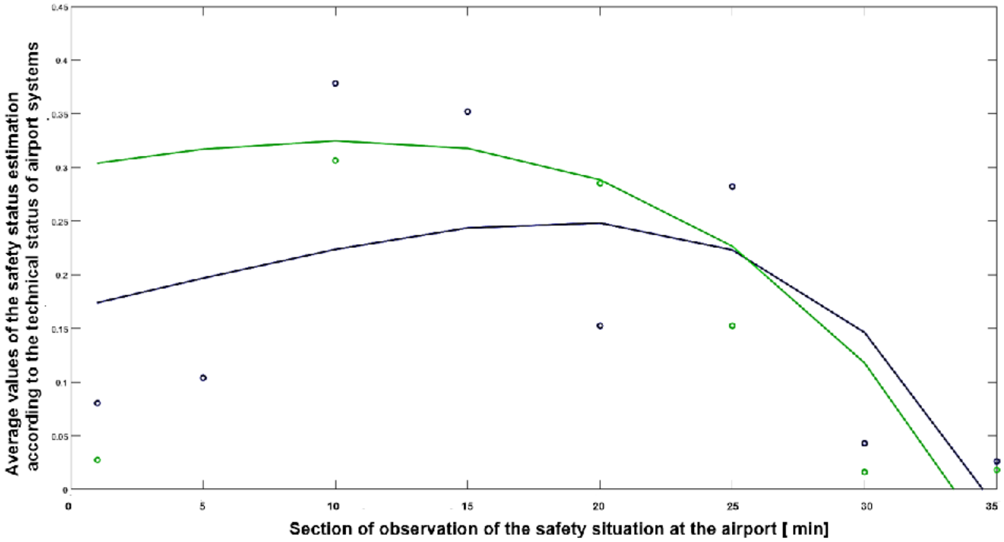


Fig. 102 Safety assessment according to the number of technical safety features over time

9.13 The cognitive informative function of safety

The need to increase informative accuracy about threats at airports is usually of a one-factor nature. In a specific case, the proposed model may have one of the following approximation functions:

$$y_i = a_0 + a_i . x_i + \varepsilon_i, \qquad (9.35)$$

$$y_i = a_0 . x_i^{a_i} + \varepsilon_i, \qquad (9.36)$$

$$y_i = a_0 + a_0 . a_i^{x_i} + \varepsilon_i. \qquad (9.37)$$

It follows from the approximation functions that the awareness of threats is conditioned by the variability of external security factors, which is characteristic of the congested airport. In those cases, it is necessary to include another parameter when the experiment changes from a single factor to a multi-factor character. The security coefficients of the aircraft complex with the object of controlled security control are determined by the number of external factors, which cause synergistic changes due to their reciprocity. In addition, when we compare the number of security levels with each other, we get combinations that e.g. on the reliability of airport security significantly increase the informativeness of the experiment $x_i x_i$.

The whole issue can be narrowed down to the method of controlled security. Assume that responding to threat A changes the security level. Thus, we will further approximate the threat to second-degree polynomials. An experiment aimed at identifying threats, responds sensitively to changes e.g. recording of camera systems with intelligent systems of a modern airport f

The experiment in the given area will therefore be performed in a relatively narrow area of changes in safety factors. The results of the experiment indicate that the idea of using a linear model is adequate only for the local area of the airport "a", in a manner similar to that shown:

$E(x, y) = y_A(x) - y_a(x)$, (9.38)

Where - the difference between the measured value and modelled value $E(x, yyA(x)ya(x)$.

It follows from equation (9.38) that if the variable factors change in the range, then the approximation error approaches the limit by zero. If the factor values are exceeded during the experiment, the approximation error may increase. The result is the recognition that the sensitivity of the model has too narrow a band and it is necessary to use another polynomial, which will expand the informativeness of the performed experiment. However, if the diapason (range) of factor changes is obviously small and the informativeness is not significantly affected, then they may be excluded from further experimentation. The result of security is limited not only by the saturation of information but also by the way it is used, especially in the decision-making and implementation process of the plan on how to perform automated control. The rational use of measurement results makes it possible to solve complex situations even with a small number of safety control devices$inf\, x_{01} \leq x_{01} \leq sup\, x_{01}$. An example of this statement will be provided by examples, the input values of which will be taken from experimental measurements at Košice Airport. Assuming that the set of factors contains sufficient information about the hazards, we can determine the order of importance and thus the need to monitor selected hazard factors that may reach critical states. According to this method, a mathematical model would be created from the observed and modelled situations, which would be assumed to be constant (ideal) for the sake of simplicity of calculation [32].

The source of information is the results of the observations, which we gradually refine into mathematical models. A prerequisite for a successful experiment is reliability, which preserves the level of informativeness of each threat until the first manifestation of a successful attack with the manifestation of the final response to an airport element of the system. However, a change in informativeness does not necessarily imply a change in reliability. In the process of experimental identification, different types of security (in the sense of definition) come to the fore:

- functional safety,
- technical safety,
- economic safety,
- information safety.

9.14 The Coefficients of experimental identification of functional safety

The Experimental identification of the local security of airport systems appears to the observer as a complex of operations associated with observation or surveillance. All similar security control systems are characterized by errors that cause real danger. This has an impact, for example, on the efficiency of airport systems. Every manifestation of error, change of characteristics, the occurrence of danger, reduces the efficiency and utility value of the monitored airport system. The degree of loss of efficiency of these systems is associated with the concept of the loss function, which is determined by time existence and has a notation. For example, the loss function may make an unacceptable difference between the actual output - and modelling situation, which requires the interruption of the tracking action at the moment:

$$\ell(y,t) = \mathit{\Delta} y(t) = y(t) - y_M(t) \tag{9.39}$$

When representing an ideal situation of danger and interfering effect on the control object (its hazard factors) it works. Where the transformation operator of the resulting hazard estimation is projected into the process functions of experimental identification, then the loss function has the form:$y_M(t)\varepsilon_X(t)x_iF$

$$\ell(y,t) = F[x_0(t) + \varepsilon_x(t)] - F[x_0(t)] \tag{9.40}$$

According to (9.40), the effectiveness of the intervention is then affected only by the emerging problems posed by the function. Another example of a loss function is the square of the difference between the real and ideal dangers of a process experiment:$\varepsilon_x(t)$

$$\ell(y,t) = \{F[x_0(t) + \varepsilon_x(t)] - F[x_0(t)]\}^2 \tag{9.41}$$

Equations (5), (6) make it possible to define the loss function of the security efficiency of experimental identification as follows:

When the control task is given to estimate the security of the experimental identification defined by level A, which represents the maximum quality, then we request that the loss function be minimal. In this case, the loss function will be expressed by a mathematical hope in the form:

$$W(t,A) = M[\ell(y,t)]. \tag{9.42}$$

For case (9.42), the functional safety will be determined by the mathematical hope of the error of the output situation (intervention) on the object for time t and case (9.41) by the mean square error.

If the condition for the success of the intervention is the quality of its level, the value of which is known in advance, if the loss function does not exceed its specified level, then the probability of achieving it is chosen as the criterion of functional efficiency.

$$W(t,A) = P\{t,A\} = Probability\,\{\ell(y,t) < l(y,t)_d\}, \tag{9.43}$$

where:

$P\{\ell(y,t)_d\}$ - the value of the loss function is reached.

The criterion of functional safety is of a universal nature. In particular, criterion (9.43) makes it possible to estimate the safety of airport complex systems because physical knowledge of their function is not required for the estimation and is independent of their complexity and interconnectedness. The security of experimental identification also includes airport service systems, which are elements of the efficiency of the airport system. The criterion of mathematical hope of performing experimental identification tasks is not always applicable, because the physical meaning and expression of its level are considerably different for different airport systems that are part of the aviation complex.

Special factors of functional safety

By *"specific security factors"* we mean the quantification of the quality of each process of experimental identification of threats and hazards. The criteria that determine the accentuated functional safety thus directly affect the values of the safety estimate expressed by the calculation of the loss functions of the individual monitoring functions. Experimental identification at such speeches quantifies the quality of the protection of airport systems, the degree of backup protection, and diagnostic and safety alarms.

The coefficients of information security

The entropy of the state of the i-th safe object, when the j-th object is excluded from the efficiency estimate, is determined by the approximate equation:

$$H_{ij} = -\int_{y_{min}}^{y_{max}\int} f_i(y)\, log_2 f_i\,(y)dy,$$

(9.44)

Where - is the density of the distribution of the output coordinate y, of the activities identified object,$f_i(y)$

ymax; y_{min} – the minimum and maximum values of the output coordinate that are reached in the interval. In the practical inspection of the object, it is useful to use an even distribution:$(-\infty\ \ldots\ +\infty)$

$$H_{ij} = log_2(ymin_{max}). \qquad (9.45)$$

The coefficient of informative security of the j-th inspected object, for which the process of experimental identification takes place, is determined by the relation:

$$y_{ij} = 1 - \frac{H_{ij}}{H_{\bar{ij}}}, \qquad (9.46)$$

where:

y_{ij} - the information security factor,

H_{ij} – the entropy of the i-th controlled airport object,

$H_{\bar{ij}}$ the entropy of all airport objects.

It follows from relation (9.46) that the smaller the entropy of the object that is subject to detailed control (),(represents the exclusion of a cooperating object), the higher the coefficient (). The coefficient of information security is usually synthesized from the previous criteria and includes readiness, reliability, serviceability, controllability, normativity, etc. According to the above principles, an informative function is determined, the model of which will be analyzed in the $H_{ij}\bar{j}y_{ij}$*MATLAB Simulink* environment. Let the response to the controlled control be a change in the angle of view of the intelligent systems recording α and the speed in the recording from intelligent surveillance systems is fig.103:

alpha=0:.1:30; V=0:.3:90; Critical and allowed values are:

alfakr=90; degree of control,

```
alphaps=45; degree of control,
Vvkr=4; Mbit/s; speed of recording intelligent systems.
Widow=0.5; Mbit/s; allowed speed of recording intelligent systems.
Then (12) is:
Fneb=1-[1-((alpha-30)./10).^0.5].*[1-((0.5-Vv)./20).^(10./(40-alpha))];
X=real (Fneb);
Y=imag(Fneb);
absFbneb=(X.^2+Y.^2). ^0.5.
%Standardisation:
absFbnebN=absFbneb./1.6221;
Fneb=1-absFbnebN.
Safety:
Fbesp=1-Fneb.
tlg1=0:.1:30; tlg2=0:.3:90;
figure(1); plot(tlg1,Fbesp,'b','LineWidth',3),grid on,hold on,
figure(1); fence(tlg1,Fneb,'r','LineWidth',3),grid on,
title(' Intelligent airport systems' record security information functions,'FontSize',14),
ylabel('Information function values','FontSize',14),
xlabel ('Airport area recording time slots','FontSize',14),
xlabel('Time slots for positioning and switching of airport complex areas','FontSize',14).
```

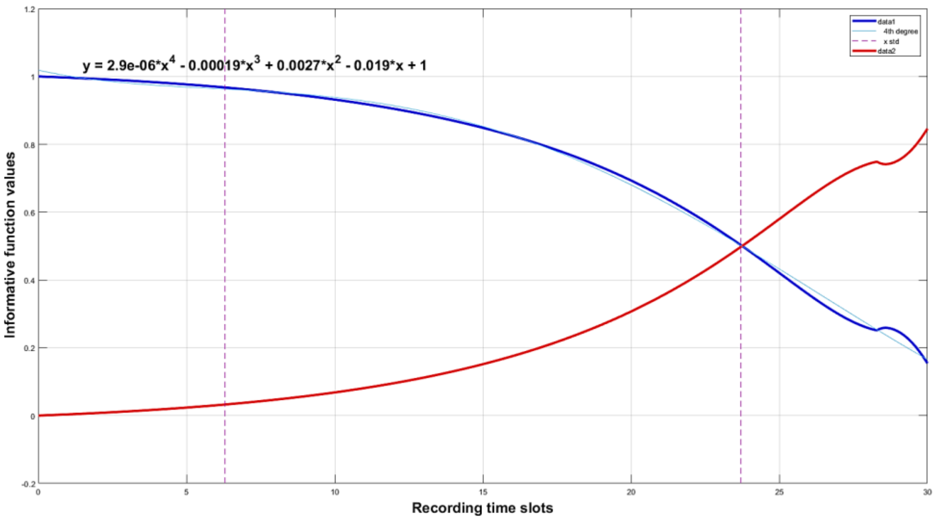


Fig. 103 The intelligent airport systems record security information functions

The analysis carried out is in line with current regulations and the direction of information security, in particular with the precise control of the airport environment. The resulting effect is a methodology for designing models with impossible intrusions into security and their transmission to aviation security control systems. The scientific and technical character of the research subject is concretised and illustrated so that it can be used in pedagogical and aviation practice. The applied methodology of analysis and synthesis points to the principle of the creation of information functions and their transfer through critical areas to ongoing dangerous situations. The information for the procedure is provided by intelligent sensory control systems. The non-thematic models of flight situations in the form of the presented equations accepted the basic properties of airport control systems. The specific contribution of the authors is:

- Theoretical basis of the design of the method of analysis of information insurance of aviation safety
- Methodology of forming informative functions in semilogarithmic coordinates
- Methodology of selection and placement of xi sensors in the situational state of the airport [30-39].

9.15 Model for secure operational management and control at the airport

In control experiments, a safety experiment reflects a precise way of scientifically investigating the objective reality of hazard findings. It is a way of verifying the accuracy of subjective (ASS) judgements about hypotheses and theories supported by safety theories.

Instead of experimental verification, the term control is often used in safety theory and limit state detection. The development and continuous improvement of airport control facilities is inconceivable without carefully performed safety checks. These checks have an impact on the flight safety process, a condition that is encoded in the reliable operation of airport control systems. This fact also underlines the importance of knowing the hierarchy of security. In the course of security research on airport complexes, security checks are carried out, preceded by an inspection plan. The inspection plan is based on the determination of the security level, the manifestation of which requires a specific form of control. Of course, the type of control management must be attributed to the ability of the cognitive way of detecting danger.

The sequence of detection of danger

The safety experiment is reflected in controlled experiments as a way of scientifically investigating the objective fact of finding a hazard. It is a way of verifying the veracity of subjective (ASS) judgments of hypotheses and theories. Instead of the term experimental verification, the term control is often used. The development and continuous improvement of airport facilities are unthinkable without carefully performed security controls. This increases the requirement for flight safety, which is a condition encoded in the reliability of the work of airport control authorities, which underlines the importance of knowing the safety hierarch.

When researching the security of airport complexes, security checks are performed, preceded by a control plan. The control plan assumes the emergence of a degree of security, the nature of which requires a specific form of control. Of course, the type of controls must be assigned to the cognitive way of detecting the hazard. The basic precondition for performing inspections is a set time, which determines the intensity of detection of danger by a certain probability.

The process of finding hazards in the control process is random in nature and can be investigated by the methods used in reliability theory. For example, the time of detection of danger is analogous to the time of its expression. In the previous part, the applicability of the mathematical apparatus in the readiness of the control object for the experiment was pointed out. The control method at each of its levels of the security hierarchy includes several of specific controls, the arrangement of which is presented in Fig.105 [15].

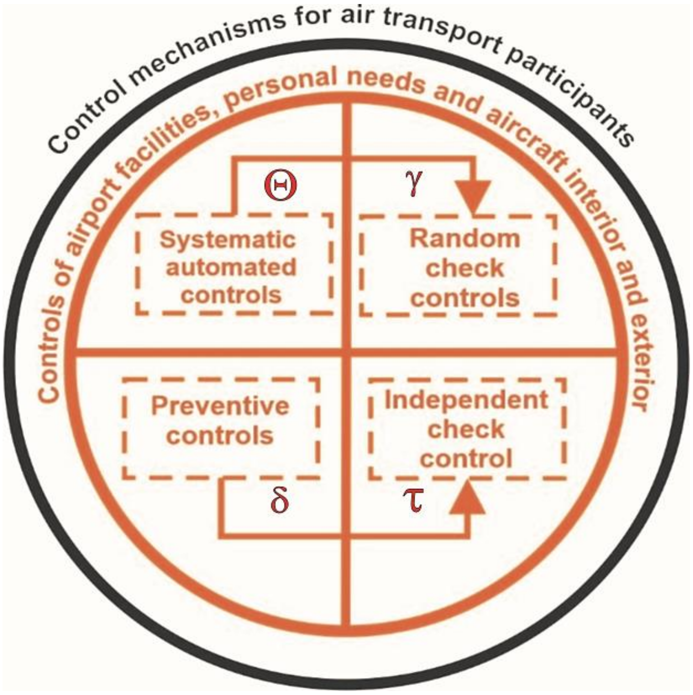


Fig. 104 Hierarchy of security controls

When deriving a mathematical model, we assume that all controlled complexes, and objects are characterized by a certain possibility of detecting (finding) danger. In general, however, this is not the case, as the likelihood of safety-to-hazard also depends on the control method. We also assume that some controls are independent and do not depend on airport security issues in another security system (information security service). To create a mathematical model, determine the probability of hazard detection $\Theta;\ \gamma;\ \delta;\ \tau$ on the time interval upon acceptance of the condition that we carry out a unit check at the specified interval of $\tau \leq t \leq d\delta j - th$ type of control. In the following, we will accept the fact that the danger has not been detected until now. When checking the ($t = \delta\Theta_j\delta$) = constant. Set (t), i tis means the probability that the danger was not detected even after the time $P_j t$ has elapsed, in time units of the process, for example, airport control. From the above statements, it is possible to draw attention to the probability that the danger has not been detected even in time *t + dt*. Then the probability of finding danger will be:

$$P_j(t + dt) = P_j(t)\left[1 - \theta_j dt\right] \qquad (9.47)$$

From equation (2) it is possible to write a differential equation for:

$$\frac{d}{dt} lnP_j = \theta_j \qquad (9.49)$$

The solution (9.49) for P_j (t) has the form:

$$P_j(t) = P_o exp\left[-\theta_j\, .\, t\right] \qquad (9.50)$$

where P_0 - is the probability of finding (non-detection of danger at the beginning of the *j-th* check control. Let us now point out the complexity of fulfilling the safety check carried out on a *k -th* air transport participant, where several individual checks will be used. Let these controls have a durability and be characterized by the intensity of the detection of a security defect θ. In addition, assume that the number of unit checks includes a - combined security checks Θ; γ; δ; τ.

For such a case, fundamental equation (9.49) has notation:

$$\frac{d}{dt}\ln P_j(t) = \begin{cases} -\theta_1, 0 \leq t \leq t_1 \\ -\theta_j, t_1 + \cdots . + t_{j-1} \leq \mathrm{t} \leq t_1 + \cdots . + t_j \\ -\theta_k, t_1 + \cdots + t_{k-1} \leq t \leq t_1 + \cdots + t_k \end{cases} \qquad (9.51)$$

The complete probability of finding a security problem during the security check is described by the equation:

$$P_j(t) = P_{0j} exp\{-\theta_1 t_{1-....-} \theta_k t_k\} \qquad (9.52)$$

Let us denote the general inspection time of a given security system as:

$$\tau_e = t_1 + t_2 + \cdots t_k$$

and relative time values for each *j – th* type of control (protected area, mode area, etc.) as:

$$a_j = \frac{t_j}{\tau_e} \qquad (9.53)$$

In this case, it is possible (6) write in the form:

$$P_e(\tau_e) = P_{0e} exp\left\{-\left(\theta_1 a_1 + \cdots . + \theta_j a_j + \cdots + \theta_k a_{k1}\right)\tau_e\right\} \qquad (9.54)$$

or:

$$P_e(\tau_e) = P_{0e}\; c +\; p\,\{-\theta_e \tau_e\} \qquad (9.55)$$

where:

$$\theta_e = \theta_1 a_1 + \cdots + \theta_j a_j + \ldots + \theta_k a_k \qquad (9.56)$$

In equation (9.55) and (9.56) can be interpreted as the probability of security controls t -th type at any point in time throughout the security screening. Because a number of checks are performed at each security level and many security issues (intrusions) can arise, it is possible to determine (reliably) their intensity of detection for each hierarchical level. For this reason, to create a mathematical model for solutions in the probability of finding a potential degree of danger can generally use a continuous model written.

$$P_{(t)} = a + p\,\{-\,\theta_1\tau_1 - \ldots. - \theta_i\tau_i - \ldots - \theta_n\tau_n\} \qquad (9.57)$$

where:

τ_i- is the security check time at the *i - th* security level.

n - number of checks on in the security hierarchy.

Equation (9.58) allows you to write the probability of finding a hazard at the *i-th* level of security in the form:

$$P_i(t) = exp\{-\,\theta_1\tau_1 - \ldots. - \theta_i\tau_i\} \qquad (9.58)$$

By comparing (9.58) and (9.59) at the *i-th* safety level, we obtain the initial value of the probability of not finding (not occurring or not detecting) the danger at the beginning of the level of control for the duration τ.

$$P_{0i} = exp\left\{-\,\sum_{n=1}^{i-1} \theta_n\tau_n\right\} \qquad (9.59)$$

The first experimental measurement of security checks has confirmed the correctness of control of airport offices and meet the expectations. It has been shown that the use of 5 checkpoints creates conditions for further use of the same control mechanisms. These reliably suppress the impact of dangerous leaks in the environment of airport facilities. In addition, it is possible to create a space for imitating security problems, which I randomly check with signalling control machines for operators of security checkpoints.

9.16 Principles needed to evaluate the input control data for the airport

Designing the modelling of any airport control system is an important process for the safe operation of an airport, as it minimizes risks and hazards on board aircraft. Distinguishing safe zones and initial stages to distinguish the initial danger are another area of concern. Included in this problem area are detection safety sensors that can predictively select:

- responses to basic security intrusions of air traffic controllers from security control systems,
- ways of using aviation security systems,
- own requirements.

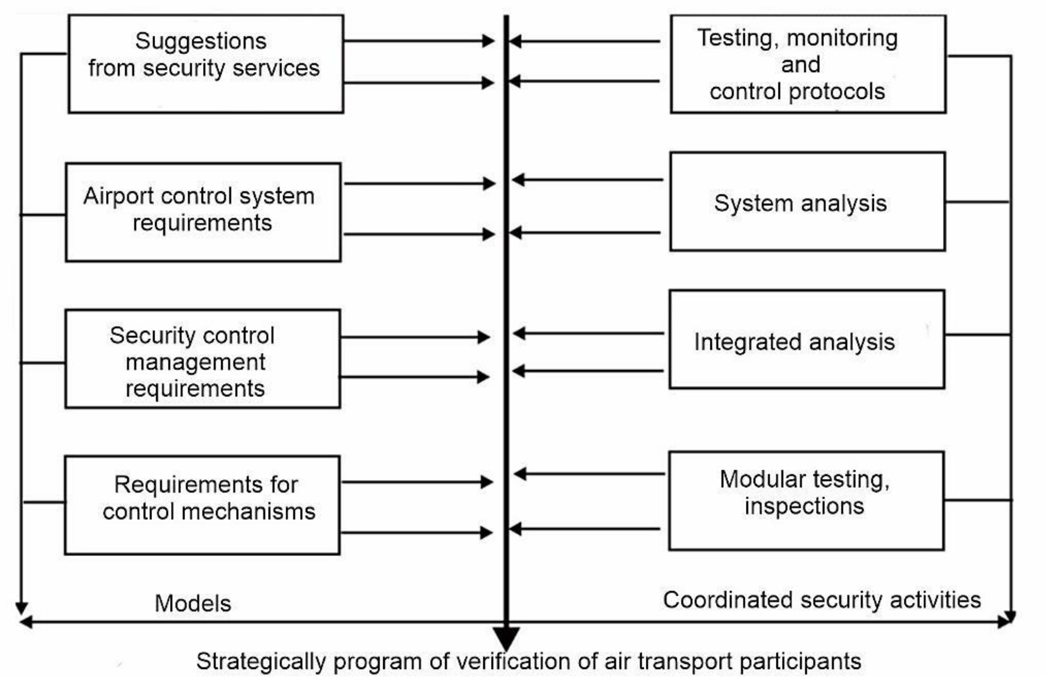


Fig. 105 Verification strategy for air transport participants

The question of research into the selection of the most suitable control mechanisms is based on the regularities of the dichotomous theory of hazard description in the airport complex and in its local parts. Airport security breach requires the creation of new progress in localization functionality of the whole control system. Such a direction shows that then the reliability of the observed (controlled) system will change in reaching the area of a successful solution. If the functional reliability decreases, a critical state arises, which affects the control activity. At airports, it is clear that he needs to ask about the deployed control mechanisms, the highest value of trouble-free operation [28].

Each control mechanism, by its composition, affects the space of the implemented subsystems in them, which we assign to the airport complex. Calls can give one experimental example, which has the nature of follow-up danger. This theoretical level clearly determines in which direction it is necessary to set the security model fig.106. Clearly this is possible only by the mathematical expression of potential problems expressed in probability theory with the necessary imagination, which shows their application. Each such control mechanism needs to be summarized to describe safety [84].

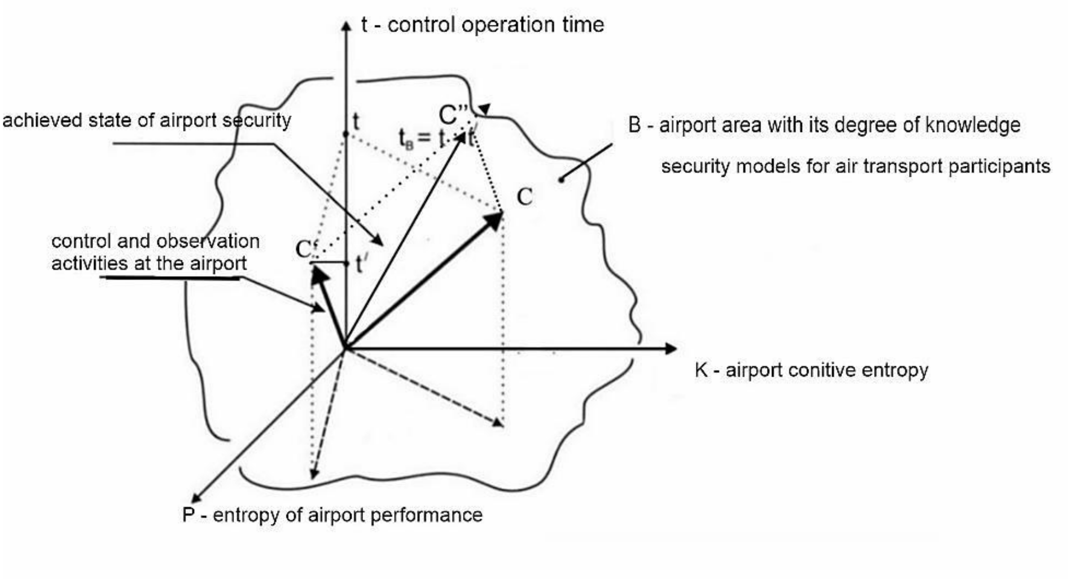


Fig. 106 Entropy for setting conditions for airport security models

The problem of degradation of airport security shows that an isolated assessment of the security problem, in general, is unjustified. The airport area is described in the coordinate system by the entropy of the time of security controls. These checks, based on accurate models, govern their hierarchy in safety theory. For us, it is necessary to be able to investigate the resulting vector *C*. This vector requires knowledge of the required input properties of security mechanisms at the airport. Here we can measure points in space in a given coordinate system, with changing coordinates of the airport security vector, where all coordinates of points in space change. This makes it possible to investigate the clear causes of the security degradation of the airport complex if we have accurate values [24-27].

With a sufficiently long period of security checks at the airport, the probability of finding danger is approaching zero. Thus, even with the position of reality during long inspections, the success of finding danger is accurate. In real conditions, we try to shorten the time of security checks. This is possible mainly at higher hierarchical security levels of airport facilities and complexes. In this case, we approach the value of the lower limit of safety, which can be determined in advance. If that quantity control is known, then the mathematical model of comprehensive security checks will take the form of:

$$P_i(t) = exp\{-\theta_1\tau_1 - \dots - \theta_i\tau_i\} \tag{9.60}$$

The elements of the probability of detection of danger are arranged in series (number of passengers before inspection). In finding the greatest degree of hazard it is interrupted whole series of checks. Control mechanisms are being introduced in the whole area of airport complexes.

Input variables for MATLAB program are:

```
taui=0:3:100; minutes; time of one security check: 3min, number of checks for aircraft A
330: 200 of passengers.
l=5; Number of serially connected passenger security checkpoints; sum of the values found
potentially dangerous elements (pocket knife, scissors, gun etc.) calculated in hASCs of work
during the safety controller, in numerical order airport checkpoints:
S=sum([5 1 6 3 1]./10.^4);
thetat=S.*taui; exponent,
Plt=2.718.^(-thetat);
plot(taui,Plt,'r+'),hold on,
lambda=0.1473; at i=100 minute.
plot(taui,lambda,'k'),hold on,
xlabel('Check time at hazardous element detection level'),
ylabel('Initial probability of subsequent security check'),
title('Probability of safety', 'FontSize', 12),
legend('lambda'),
hold off,
```

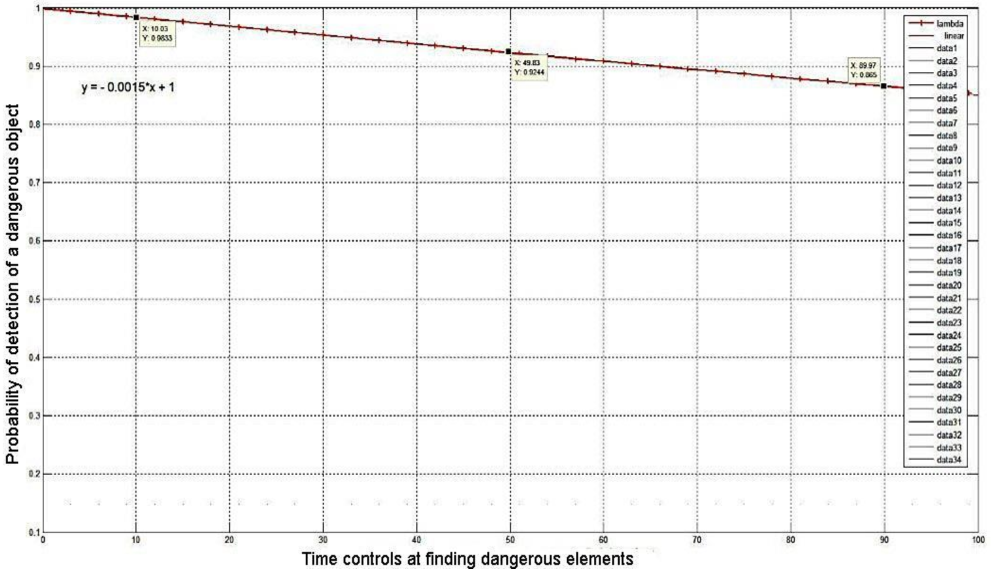


Fig. 107 Probability of safety

The task is to determine the initial value of the probability P_{oi} of not finding (dangerous element). The result shows a simulation of a mathematical model in the MATLAB programming environment, the output of which is also the residual probability in one-time unit.

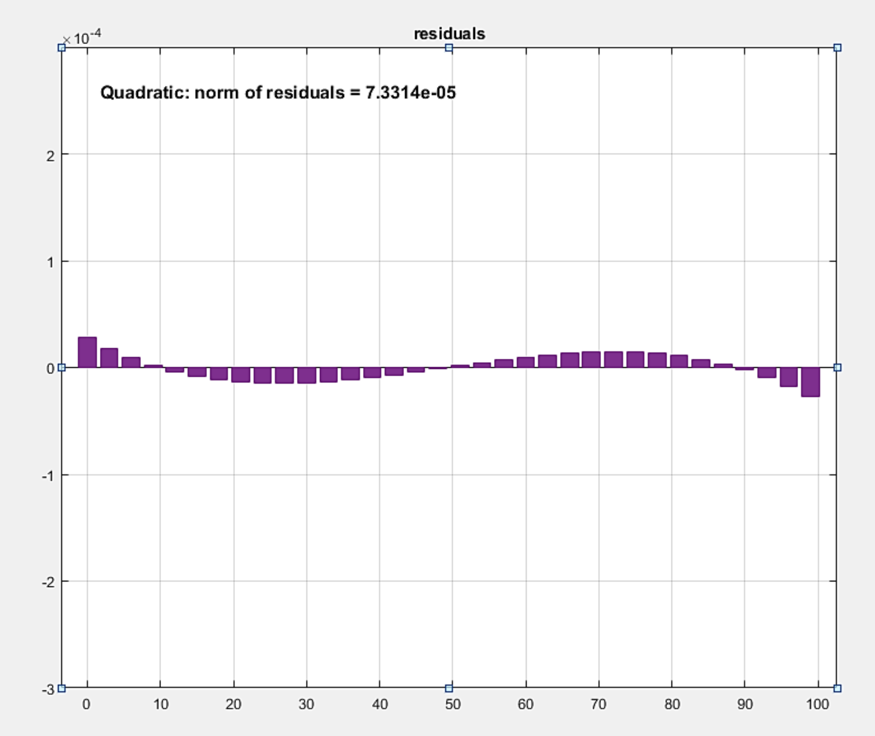


Fig. 108 Residual course of danger when checking passengers on a sample of 100 passengers

As is clear from Fig. 108, when sufficiently large time monitoring and control stations = 5 and more sought probability is close to zero. Control mechanism with the desired probability of non-occurrence of danger at the end of the experiment, i.e. when the control lasts t = 100 min. The mean time of non-danger is: T_{mean} = 10; 50; and 90 minutes for 200 passengers. As follows from the applied MATLAB program, the meantime non-occurrence of danger is at the level of $7.33.10^{-5}$ which is a small, expected value in the number of residues of fig. 108. In real conditions, we try to shorten the time of passenger screening. This is possible, especially at lower hierarchical levels of security with small airports or with a sufficient number of checkpoints. In this case, we bring the value of the probability of security closer to the lower limit, which can be determined in advance and which can be stated in the control program. The control system detects the degree of danger if the elements of danger are different. The required probability of non-occurrence of danger at the end of the control, i.e. when t = t_k = 100 min.

The safety experiment is reflected in controlled experiments as a way of scientifically investigating the objective fact of finding a hazard. It is a way of verifying the veracity of subjective (ASS) judgments of hypotheses and theories. Instead of the term experimental verification, the term control is often used. The development and continuous improvement of airport facilities are unthinkable without carefully performed security controls. This increases the requirement for flight safety, which is a condition encoded in the reliability of the work of airport control authorities, which underlines the importance of knowing the safety hierarchy.

When researching the security of airport complexes, security checks are performed, preceded by a control plan. The control plan assumes the emergence of a degree of security, the nature of which requires a specific form of control. Of course, the type of controls must be assigned to the cognitive way of detecting the hazard. The basic precondition for performing inspections is a set time, which determines the intensity of detection of danger by a certain probability [99].

9.17 Model of information function of irregular airport operation with hazard rate

The use of information-security systems to control the operation of the airport requires the acceptance of the outputs of control-diagnostic devices and devices capable of eliminating the problem. If there is a situation for which the airport operator cannot find a solution, then the airport security system activates critical mode prediction blocks. In accordance with the type and type of airport, the critical parameters have defined standards, which are quantitatively determined for each irregular regime at the airport caused by the intervention of security forces. Identification of the state is then possible with integral informative functions of danger and characteristic data of special situations - x{Hi}, characteristic situations at the airport - x{ni}, permitted airport traffic - x{perm}, critical situation - x{kri}. Airport suitability standards, for example at airports, assign the values of special situations to the above characteristics in the manner indicated in Tab.5. It means that each special situation Zi has a critical parameter xi according to which the inequality can be identified:

Table 5 Models of special situations due to uncorrected failures of safety systems

a)	b)	c)
x_0	Normal operating conditions of the airport	$10^{-9} < P_{OP} < 10^{-6}$,
xu_{DFC}^{UPi}	Difficult flight conditions "DFC"	$10^{-6} < P_S^{FS} < 10^{-4}$,
xs_{CAS}^{Sni}	Complex airport situation "CAS"	$10^{-4} < P_S^{FS} < 10^{-2}$,
x_E^{Sni}	Emergency at the airport "ES"	$10^{-2} < P_E^S < 1$,
x_C^{Sni}	Critical situation at "CS" airport	CS = 1;

Table 5 shows an illustration of the application of the mathematical model of the process control system in the case of a different logarithmic system.

One of the standards that describes this is the SIL standardisation. The use of existing information resources is used to perform control security functions in airport facilities. For effective use of information resources, it is necessary that they meet a certain minimum level of standardisation according to standards. They must be able to perform hazard and risk analyses of processes that create a sophisticated security space. The usefulness of information resources is considered only in relation to the requirements for the effectiveness of security controls. SIL includes all the devices required to perform each control step, from sensors to actuators. The set of applied solutions is based on two basic concepts necessary for its application: "Safety Life Cycle Concept" and "Safety Integrity Levels (SIL) Concept". IS using electrical/electronic/programmable technology uses operating principles for logic devices that use general provisions to ensure that functional safety requirements are met. Sensors and IS actuators are also considered, regardless of their operating principle. For airport processes, the concretisation of the general approach to safety issues establishes an approach that minimises the standardisation of activities for all phases of control and security. This approach has been adopted to implement a sound and consistent technical policy [22].

In most situations, safety is best achieved by designing an inherently safe process. However, where necessary, the process can be supplemented with protection systems to address any identified risk. Protective systems are based on the use of different technologies: chemical, mechanical, automatic, electrical, electronic… All safety strategies must consider each specific safety device in the context of other protection systems. To facilitate this approach, systems must be required:

1. carry out a hazard and risk assessment to determine the overall safety requirements,
2. implement an approach that is applicable to all instrumental measures to ensure functional safety, considers in detail the application of defined safety management measures that can be applied to all methods of ensuring functional safety,
3. covers all stages of the life cycle of the safety system from initial concept development, design, implementation, operation and maintenance to disposal.

CONCLUSION

The monograph presents the authors' view of the operation of aviation systems in connection with a narrowly specialised aviation environment, which they call the ergatic system. The developed question of ergatic systems in connection with the conducted experiments is a manifestation of the relationship between the operators of air systems and the air vehicles themselves. Ergatic systems have many alternatives that can be broken down and included in other scientific fields. Despite this, there is little "comparative information" from which to conclude what is regularity and what is randomness in aeronautical science. In principle, however, each alternative in relation to other fields of science has common methods, the basis of which can be found in mathematics and physical laws. The ergatic connection of both fields with creative human activity gave rise to the possibility of the emergence of a combined field - mechatronics. Mechatronics is a multidisciplinary field that combines mechanics, electronics, computer science and automation. The meaning of this multidisciplinary field of science is the development of mechatronic systems, in which the matches between control and information structures in ergatic systems, including electronic ones, have a replaceable place, as the factor of environmental change acts in them. The given aircraft moves in this environment. Developments in the field of ergatic systems have created the conditions for modern control methods and new approaches on board aircraft that have changed the way aviation professionals think. Computers, algorithms and new technologies have become attributes of mechatronics and cybernetics used by professionals, bringing new knowledge and new applications to the field of aeronautics, especially in the design areas of aircraft systems. Concepts, such as the relationship between artificial and natural intelligence and the use of computer technology in the context of flight and air traffic safety, have led to an explosion of information. The content of the monograph is the specifications and reality that link the interactions between human, biological, technical and environmental systems.

This connection is the core of the focus of the monograph, in which the human being, in the professional term operator-pilot (OP), acts as the dominant element of the ergatic system in the position of the experimenter and executive member. He solves tasks that have the nature of errors of the ergatic system in the air base complex. The necessary professional skill of the operator to eliminate a certain defect in the course of his professional learning has an asymptotic manifestation, which is supported by electronic information systems. In the monograph, the use of electronics in the OP's decision-making process is made visible, which has a positive effect on the emergence of motivation for the use of specific electrotechnical solutions by designers, analysts and aeronautical scientists. These systems then take on a real form in the field of complex management of the operation of aircraft systems.

In the monograph, the authors focused mainly on the control outputs of the OP and the analysis, which, in conjunction with asymptotic learning, creates a control function included in the concept of skill. Special attention was paid to the on-board information systems, which to a large extent replicate the capabilities of the OP. The reason for solving important parts of the management is their observation in the practical environment. In short, it can be stated that all onboard information systems with flying operators have control and information significance and are currently combined into a symbiotic ergatic complex.

In a limited area, the monograph gives an idea of the methods of analysis of a complex information system, which are presented in the form of examples and comments within the framework of individual experimental parts. Simulations bring and complete a characteristic picture in computer simulations. Visualization of solutions of mathematical algorithms is carried out by finite forms at the level of modern aerospace technology using intelligent electronic display systems. Considerations directed to the field of science and experiment, together with methods of solving selected problems, are also included. Application solutions of control information systems in aviation have a level of flight safety assurance represented by functional onboard ergatic complexes of aviation technology.

The content of individual chapters of the monograph has been chosen to distinguish the tendencies of future integrated information management systems and ways of increasing the safety of ergatic complexes. The dominant element remains the electronic display system. The presented methods show that the human operator is a necessary condition for the errors he solves in the assigned tasks. These are graded and different, but always solvable and evaluable.

A systematic interpretation of the efficiency criteria of asymptotic learning and skill is the precise control of aircraft ergatic systems. The reason for this was to establish the scientific premise of the evaluation of the skill, which is the only one that expresses the OP's ability to monitor the set goal together with the information complexes. Then it is justified to summarize the information complexes together with the OP under the term "target ergatic complex". This complex determines the level of safety and efficiency of aircraft and spacecraft research. From the point of view of the system approach, the possibilities of research and experiments with polyergic systems, in which it is possible to include simulation systems, were analysed in individual parts of the work.

The solutions to the formulated scientific problems presented in the monograph were concentrated in the following directions:

1. Definition of efficiency indicators that influence the quality of the professional development of the operator-pilot,
2. Determination of the awareness of the operator-pilot in the existing criteria and conventions for evaluation of the level of his professional quality,
3. Application of used algorithms in aviation practice,
4. Application of the described methods of scientific and experimental application in the research of variants of information control and target functions in the analysis of aviation ergatic systems.

The research methods described in the monograph took into account the current problems of aviation, such as reliability, safety and efficiency. The methods used were made visible in the given areas by mathematical statistics, systems analysis, and parametric and structural synthesis of measurement theory. Examples of imitation modelling and filter theory have also been used. The evaluation of aviation professionals in general is based on the following approaches and solutions:

1. The evaluation methods used are not mutually exclusive with the evaluation process of experts; the mentioned methods are part of the demanding OP education,
2. The methods developed take into account the emergence of emotional tensions of the OP in the management of complex functions (time deficit),
3. The introduction of time variability and time delay in driving, in connection with a specific decrease of the OP's skill, has been theoretically and experimentally justified,
4. A reasoned method of compensatory process in the management of the OP, which, after evoking the state of his emotional tension, will allow him to reach the area of successful management,
5. To develop and illustrate with examples the method of flight tests and their possible effective cost estimation,
6. The use of algorithms of mathematical models, from time series to probabilistic models.

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THE LIST OF ABBREVIATIONS

AES	Aeronautical Ergatic System, Aerial Ergatic Complexes
ANC	Automated Navigation Complexes
ANS	Astronavigation System
ASC	Area Of Successful Control
ATM	Air traffic managment
ATO	Air Transport Object, Approved Training Organisations
BIS	Building Integration System
BMS	Baggage Management System
CS	Course Systems
DISS	Dopler Route Speed and Nose Angle Measurement System
DVOR	Navigation Radio Technical System
SAB	Systems airport buildings
FMC	Flight Management Compute
FMS	Flight Management Systems
GMK	Gyromagnetic Compass
ICAO	International Civil Aviation Organization
ICT	Information & Communications Technology
IID	Intelligent Identification Device
ILS	Near Navigation and Landing Radio Technical System
INS	Inertial Navigation System
IS	Inertial System
LBS	Load Balancing System
CMS	Laser Crack Measurement System
MATV	Master Antenna Television Network
NC	Navigation Computers
NEC	Navigation Ergatics Systems
NECs	navigational Ergatic Transport Complexes
OP	Operator-Pilot

PEC	Pilot Ergatic Complex
PRNAV	Precision navigation
BRNAV	Basic Area Navigation Standards
RLS	Radar Station
SIL	Safety Integrity Levels
SMS	Safety Management Systems
SVS	Air Signal System
UAV	Unmanned Aerial Vehicle

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ABSTRACT

The operation of ergatic systems is conditioned by safety, the assurance of which requires high dynamics of reactions to possible errors generated. The motivation for compensating these errors is the operator functions of the navigational ergatic systems, which together with the environment represent the safety assurance. The dominant element is measured errors, which together with sensory intelligent systems, adjust the functions of the aircraft. These systems, which combine the possibilities of measurement and subsequent compensation of errors, are called ergatic systems. We call the functions of transport systems, which are designed for their practical applicability and adaptability to the human operator, ergatic complexes (EC). Specialized ECs with a defined scope of application in the field of navigation, which ensure operational safety and efficiency, then form navigation ergatic complexes (NEC). Other related concepts used in the analysis of the efficiency and safety of ergatic systems are also presented, knowledge of which is a prerequisite for successful analysis.

Ergatic systems take into account the characteristics of operators-pilots of aircraft objects moving in the airspace while fulfilling the set requirements. The first technical requirement for their applicability is the precision of the movement of the aerial ergatic system. The focus of the monograph is on the results of the research aimed at creating conditions for the use of the navigational ergatic complex (NEC). The determinants include the applicability criteria of methods for defining the efficiency of autonomous NECs. From the point of view of the systems approach, the applicability of target precision efficiency, which is relationally defined by probability, is discussed. The process-controlled movement of the flight control system (FCS) on the specified flight path is determined in time by the probability of not leaving the specified flight airspace without process control by the operator-pilot. The criteria for the applicability of the methods for defining the efficiency of autonomous navigation ergatic complexes are a prerequisite. The applicability of target precision efficiency defined by probability is also discussed.

Key words:

Ergatic system, ergatic complex, navigation ergatic system, aeronautical ergatic system, operator-pilot, unmanned aerial vehicle.

Наукове видання

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Аналіз процесів авіаційних ергатичних систем

Монографія

(Англійською мовою)

Основна увага в монографії приділена результатам досліджень, спрямованих на створення умов для використання навігаційних ергатичних комплексів. Визначено критерії застосовності методів визначення ефективності автономних навігаційних ергатичних комплексів. З точки зору системного підходу обговорюється застосовність ефективності точності наведення на ціль, що реляційно визначається ймовірністю. Керований процесом рух системи управління польотом по заданій траєкторії польоту визначається в часі ймовірністю не покинути заданий повітряний простір польоту без керування процесом з боку оператора-пілота. Критерії застосовності методів визначення ефективності автономних навігаційних ергатичних комплексів є необхідною умовою. Обговорюється також застосовність ефективності цільової точності, визначеної ймовірнісними методами.

Монографія рекомендована для фахівців, дослідників і молодих вчених у галузі електротехніки, електромеханіки та авіації.