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MODELING OF THE HUMAN – OPERATOR IN A COMPLEX SYSTEM FUNCTIONING UNDER EXTREME CONDITIONS*

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Abstract

Problems, related to the explication of sophisticated control systems of objects, operating under extreme conditions, have been examined and the impact of the effectiveness of the operator's activity on the systems as a whole. The necessity of creation of complex simulation models, reflecting operator's activity, is discussed. Organizational and technical system of an unmanned aviation complex is described as a sophisticated ergatic system. Computer realization of main subsystems of algorithmic system of the man as a controlling system is implemented and specialized software for data processing and analysis is developed. An original computer model of a Man as a tracking system has been implemented. Model of unmanned complex for operators training and formation of a mental model in emergency situation, implemented in "matlab-simulink" environment, has been synthesized. As a unit of the control loop, the pilot (operator) is simplified viewed as an autocontrol system consisting of three main interconnected subsystems: sensitive organs (perception sensors); central nervous system; executive organs (muscles of the arms, legs, back). Theoretical-data model of prediction the level of operator's information load in ergatic systems is proposed. It allows the assessment and prediction of the effectiveness of a real working operator. Simulation model of operator's activity in takeoff based on the Petri nets has been synthesized.

Introduction

Human activity under the conditions of space flight is a specific type of labour, carried out in unusual and sophisticated conditions, requiring high activity, readiness for reaction to sudden vague situations and ability to bear

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loads, weightlessness, isolation, and possession of a particular system of knowledge, skills and habits. He/she performs various functions – piloting, monitoring, communication, repair, ergatic reserve, etc., which require high creativity, purposefulness and efficiency. Routine and smooth reactions of human-operator (HO) after failure of technical equipment give way to sometimes forgotten, unusual and rare operations that has to be carried out in extreme situation and deficit of time and with consequences for the safety of humans, transport vehicles, material and natural values.

The formalization, modelling and analysis of the man in the sophisticated ergatic systems (ES) in that regard turns out to be *important interdisciplinary scientific problem*, requiring the use of theory and methods in many branches of science: the Cybernetics, Physiology, Ergonomics, Mathematics (fuzzy sets, mathematical linguistics, semi-markov processes, etc.), system analysis, biomechanics, computer sciences etc. [1-6]. When analysing the function of such sophisticated systems, it becomes increasingly evident, that reliable results cannot be obtained without taking into account the human factor, because a person is an active part in them, who defines to a large extent the achievement of its objectives in its operation and development. The man, as an element of the control, participates in every stage of its formation – perception, recognition, prediction, adoption of a decision and implementation [7].

Problem Formulation

Research and experimental work on the creation of unmanned aerial vehicles (UAV) in the 21st century has become a priority topic for the aviation and in particular – for military aviation and services for public protection from accidents and natural disasters. Due to the large number of such aircrafts, the preparation for UAV pilots became a separate problem. It takes special equipment, separate airbases for pilot’s training and special control systems for control of UAV. The airspace is one for everyone and the air traffic control assumes new dimensions and philosophy.

HO is separated from the machine not only in functional (as in the case with supervisory control, e.g. during piloting Airbus), but in literal sense: he has not direct contact with the machine, there is no additional sensory information from the flight’s point function, he is “out” of it, and in this sense the “dimensionality” of his sensory space decreases. UAV pilot is immersed and works in a new virtual environment and in a sense he practices his profession in a virtual workplace. All these new circumstances put many new challenges to researchers and designers of ergatic control systems and to the modelling of HO, now as a man as a control system (MCS).

In the specialized literature the concepts UAV (Unmanned Aerial Vehicle) and RPV (Remotely Piloted Vehicle) are distinguished. Unmanned aerial complex (UAC) or the system (UAS) consists of UAV and ground control station – the radiotechnical system, compulsory elements on which are radio channel to transmit current target information and the ground control station in control radio channel for control of RPV and its service load. Exactly in the interaction of RPV with the ground control station and its main element – human-operator, the main feature of RPV – the interactive control is realized [8, 9, 10]. In such a way, RPV is an automated interactive drone, capable to perform flight on a preset route and to maintain its orientation in the space without human intervention, but at the same time is ready to respond to the controlling impact of human-operator. As a rule, UAV performs a flight under program set into its onboard control complex, with receipt or transmission of target information on the customers radio channel. Moreover, the multifunctional and intellectual nature of such technical complexes provide for change of the flight's program in a real time scale. The availability of automatic pilot of UAV, along with remote control devices outside of the area for visual or radiotechnical visibility, distinguishes it from the simple sport aeromodels.

Considering the system approach, the structure of organisational-technical system of unmanned aviation can be represented as a three level’s hierarchy (Fig. 1). The complex technical systems with UAV are on the first (lowest) level, the unmanned aerial complex (UAC) is on the second level and on the third – the technical unit combines with ergatic. Besides UAV, the structure of UAC consists of the devices for: communication and control, the aircraft ground handling, launching, landing, saving, transportation and storage. This representation of the unmanned aviation's structure allows the treatment of different concepts and their component elements of common positions by seeking their interconnection.

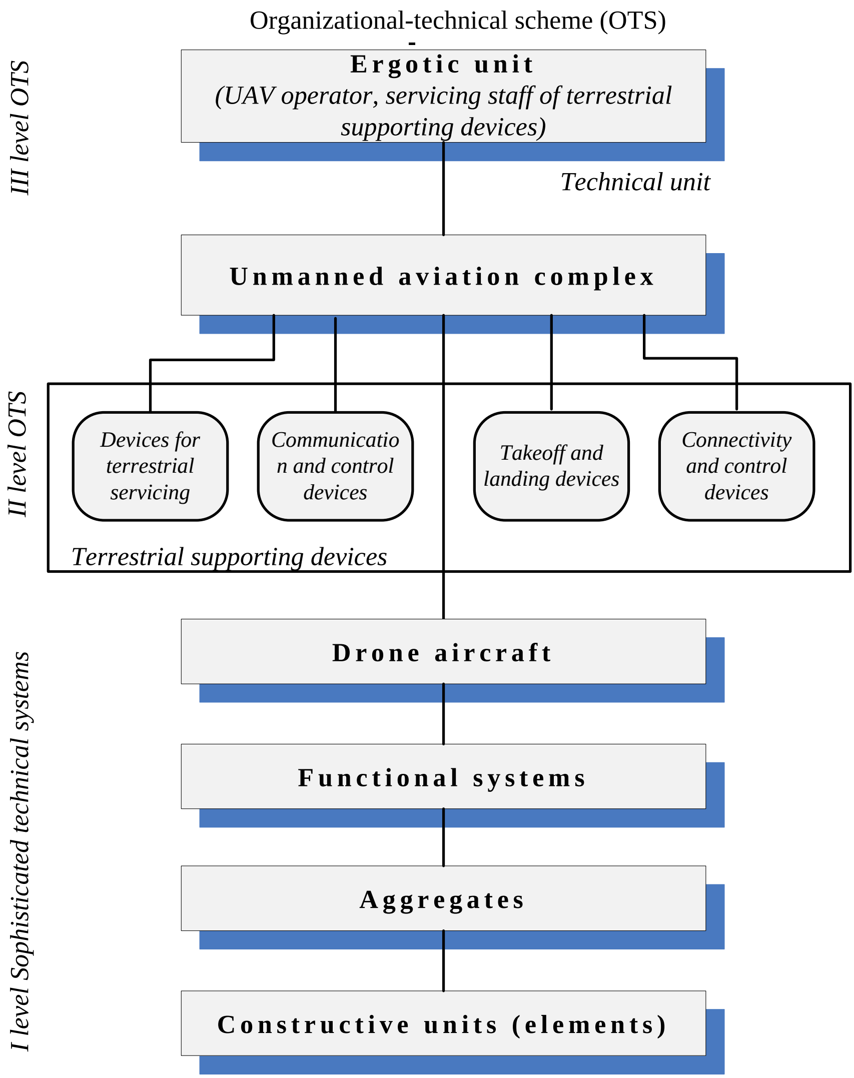

Fig.1. UAC organizational-technical scheme

Main purpose of the intelligent onboard systems is the collection and processing of data coming from technical devices and the creation of models of the process in real time. In general, the formation of the control model and its display on screens is implemented in the following order:

- data collection from peripheral sources and processing by the system;

- creation of models of the controlled process based on incoming information;

- representation of invented models in a form, convenient for perception and highlighting of the most significant risk events [11].

The indicated sequence of actions shows that the system creates a base of knowledge for monitoring and control which is initial for control activity of the operator. This is the reason the “UAV – operator/s” system to be considered as a class ergatic system.

Modelling of the man in ergatic system

Researches on the human brain activity are focusing on the fact that a reasonable person copes with unfamiliar situations and makes rational decisions because he can extract new knowledge from existing experience and can consider the consequences of those decisions. People analyse not only accurate, predefined data, but also incomplete information which often has not a numeric expression. This means that a person meets challenges of unstructured type with non algorithmic solution on daily basis; the quantities he operates with cannot be set in numerical form; their solution requires processing of information which is ambiguous and changes dynamically; purposes of the mathematical problem cannot be expressed by exact objective function.

The human intellect is complex biological phenomenon and it is not limited only to problem solving, structured or unstructured. But in the present level of knowledge and instrumentation not all types of human reasoning are well studied and therefore it is impossible to be modelled (for instance like creativity, intuition, imagination).

Conceptual and computer model of the Man as control system (MCS) and his subsystems

The man as a control system (MCS) is complex multi-parametric and multilayer system and can be seen, formalised and modelled in different sections (in different qualities and parameters). With a high degree of abstraction, MCS can be seen as a hierarchical system of three levels: mechanics, control, intellect, united into one conceptual model (Fig. 2). Each subsystem and the system as a whole has two faces, two areas of functioning and manifestation: internal and external [12,13,14].

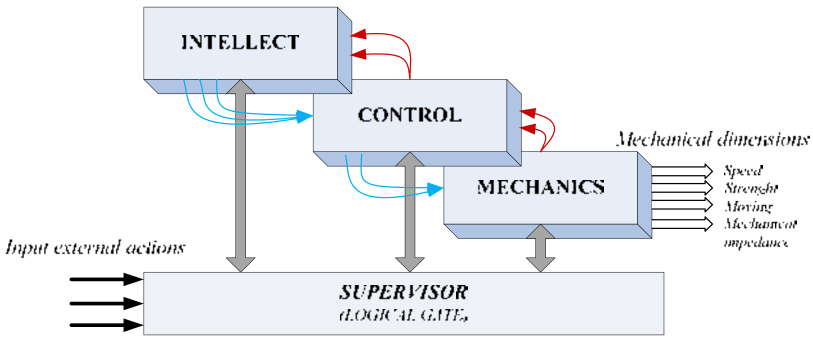

Fig. 2. Systematical representation of MCS

Level *mechanics* of high degree of abstraction can be defined as a sophisticated mechanical system of solid bodies with a large number of mobility degrees. The executive human organs are determined, i.e. they have as a rule more than necessary degrees of freedom to perform a movement. This enables alternative selections, great flexibility and thereby –optimization in the organization and control of each motion. This subset of mechanical system's elements defines efferent (executive) organs of MCS.

Mechanical human system becomes vital due to a *level of management*, containing a range of different programming modules, functionally organized in two levels:

− Local subsystems – closed systems to control the mutual position of a group of solid bodies (bones) with their own autonomous endo sensors, regulators (nerve ganglia) and efferent executive organs (muscles). Each subsystem has channels of communication with the upper level;

− Central subsystems – for coordinated control of ensembles of local subsystems. Regulators of this level are located in the central nervous system. There are located "the libraries" of standard motor programs for coordinated control of the local systems and implementation of various structural and functional compositions from them.

While the first level (mechanics) is a "hardware", the intelligence level is "software" or "bio-software". In this sense it is "the most hidden" level and can be summarized as an capability to receive, preserve and process a database – an information processing; capability to receive, preserve and process a knowledge base – knowledge processing; capabilities to create of mental (reflective) models (MM); capability of internal off-line reflective analysis of MM's functioning and performance of adjustments to them based on the stored results from real human actions; opportunities for mental operational and long-term prognosis and evaluation of the results of the scheduled upcoming action; opportunity of criteria adjustment of the lower control level; opportunity to control the strategy choice (risk level); opportunity of self-regulation of the internal information processes (informative regulator) depending on the uncertainty, danger, responsibility of the upcoming action.

Software "MATLAB –Simulink" is used for computer realization of the algorithmic models and it is suitable for formal presentation and modelling of cognitive activity of Man as a control system, as well as Fuzzy Logic environment for modelling of fuzzy systems [15].

Models of the following subsystems were developed and experimented: subsystem for fuzzy evaluation of the input signals by triple overlapping of triangular membership functions (MF) as an example for fuzzification and fuzzy logic; subsystem input signals – perception of position, velocity and acceleration from MCS; a subsystem for switching of various generators for input stimuli; subsystem for interval estimation of input signals, comprised of 25 blocks in 5 subsystem levels; "Training" subsystem – model of "variable (stochastic) conduction" in a knot of self-learning matrix; "Exit" subsystem – model of fuzzy-exit of MCS of stochastic type, comprised of 14 three-level subsystems.

Models are implemented in an accelerated time scale. Real time step depends on the hardware platform. However, it does not affect the dynamic characteristics, logical and numerical results, as they are scaled accordingly and on the graphs, as time functions are read real units (to man) – usually seconds.

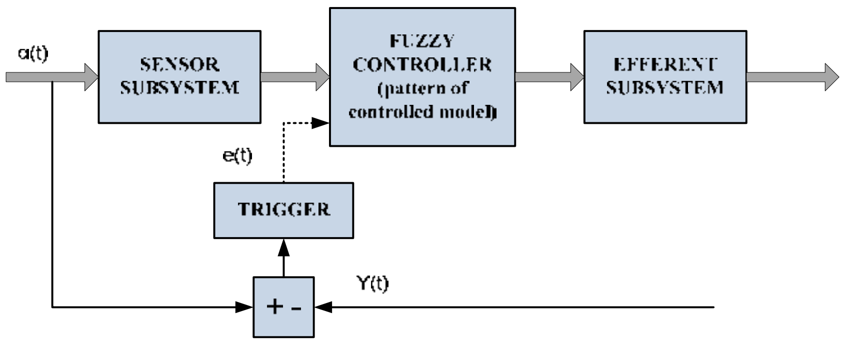

Fig. 3. Conception model of MCS

An original computer model of a Man as a tracking system (MTS) is also implemented in one-dimensional mode of accompanying tracking (fig. 3). Synthesized model of MTS has multi-layer structure, implemented and tested on Simulink by MATLAB (fig. 4). Models are synthesized in heuristic way. In systematic aspect Simulink environment is virtually the laboratory and experimental environment in which the system as a whole and its various subsystems are built and verified:

- sensor subsystem;
- subsystem subjective evaluation of target's dynamic. The subsystem consists of 11 subsystems for each channel for random interval evaluation, each of which – by another subsystem of third line;
- model of the central subsystem of PTS in an accompanying tracking mode;
- subsystem for generating random sequences with uniform and Gaussian distribution.

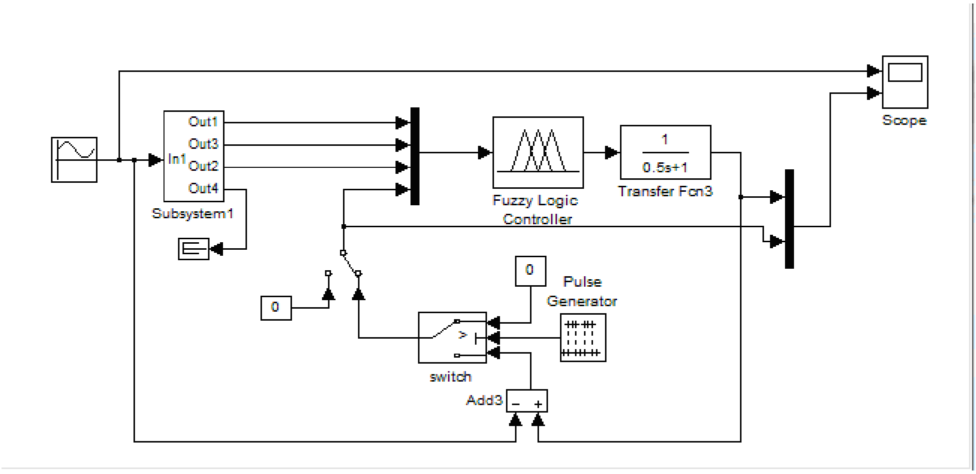

Fig. 4. Computer model of MTS

Subsystems are working and are synthesized with existence of a large number of parameters which can be set to different values and a very large number of experiments (virtual) can be produced. Results can be used for data verification from experimental researches of real operators. Synthesized computer models can be build with subsystems of higher grade and can be modelled MTS systems with possession of part of "human" qualities and capabilities.

In Fig. 4 is shown the computer model of a man as tracking system in a concomitant track. Visual information for tracking object – *the target* enters at the inlet.

Subsystem has four outputs – target position (S), moving speed of the target (V), acceleration of moving (a) and direction of moving sign. Four signals entry as four input values in the Fuzzy Controller Fuzzy Logic Controller, the action and set value of which are described above. In this case the object of control (tracked object – *the cursor*) is represented as an inertial unit of first tier [16].

3.2. Model of unmanned complex for training of operators and formation of a mental model of emergency situation

Operator's work in the control loop of unmanned complex differs from the work of the pilot in a real aircraft, in the manner of determining the position of the aircraft in space. Operator, especially in absence of direct visibility of the aircraft (in autonomous flight outside the field of vision) works on the device's data in the control panel. Based on the indication of the complex of devices, he forms mental image of flight (also called "mental" model) and monitors it by comparing this picture with indications of the devices. When this is fixed mode in the performance of type programmed mission, this process usually does not pose much difficulty and is learned relatively successful after a cycle of trainings and piloting of real flights. The situation is completely different with the formation of mental picture on the aircraft behaviour after failures – in an emergency situation.

Countering of failures in control system of a drone is practically fruitless task, although for some retarded situations after passive failures it is possible (according to data modelling) to respond promptly and to attempt to save the aircraft. As a rule, after emergency identification the pilot should activate the emergency rescue system in order to avoid the aircraft's destruction, as well as objects on the route of collision. The only reliable method with a minimum research costs for the behaviour of the aircraft, its trajectory and continuation of the situation, and the operator's capabilities in the conditions of time shortage is the development of computer models, visualization of the flight on simulative device's panel and its multiple repetition with monitoring of the situation on the devices [17]. For the research of formation process of imaginary (mental) picture (IP) of emergency was developed pattern, reflecting the specific features of the drone with capabilities for modelling different types of failures in the control system with the help of program product “Simulink”.

In the basis of the *flight model* development are subsystems of lateral and longitudinal motion and connections between them, model of the control system with automatic pilot and manual mode for adjustments (i.e. combined mode) [18,19]. Upon active failure of the ailerons the motion loses stability, resulting in vigorous rotation around the longitudinal and transverse axes. The reason for this is the work of the steering wheel after the ailerons active failure. Before the intervention of the pilot-operator to shut off the automatic pilot in third second, the aircraft is on the critical angles of attack (over 200) due to the deflection of steering wheel for height in end position «on toss bombing» from the working pitch channel of the automatic pilot and has significant sliding to the right. The spatial position of the drone in runoff auger is – the aircraft is on its back, but with supercritical angle of attack. The available time for the operator is very short ($t_{av} \leq 2$ s). If the operator succeeds to turn off the automatic pilot during this time and auger does not occur, the aircraft performs spiral motion to the right with drooping down nose. This is an adverse failure with a very high probability of an unfavourable outcome. From a practical point of view, it cannot be averted during a flight outside the field of vision. At sufficient flight height a parachute system could save the drone from destruction. The destruction is possible even before the fall of the aircraft due to the high values of normal overload even in the first 5 - 10s if the operator does not intervene.

If the device readings by emergency situation could be visualized the picture will show the following: the aviation horizon rotates and fluctuates by pitch in the zone of negative pitch angles. Iteration of the modelled situation forms a flight’s image in the operator’s mind of the type “monitoring of the aircraft from the ground”, which is necessary for quick identification of the situation and activation of the emergency parachute system.

Model of the pilot. During a flight every crew member performs the tasks, appointed to him by the flight’s program, but in the loop for direct piloting of the aircraft, constantly in a manual mode of piloting is included the aviator – pilot. Various mathematical models are used for his actions with controls in the cockpit during the study of closed loop.

As a unit of the control loop, the aviator can be seen simplified as a system for automatically adjustment, comprising of three basic, interconnected subsystems: sensitive organs (perceiving sensors); central nervous system; executive organs (muscles of the arms, legs, back). The central nervous system (CNS) is a base of knowledge and behaviour models in each particular situation. As a result of training and drills there are created and maintained the ideas of pilot for correct and safe flight (mental models). Function of information processing and decision making resulting from a comparison of real flight parameters to the mental images of pilot for the flight is performed in the central nervous system. Movements of the executive organs and the efforts, developed by them, are an output signals in the control loop. Through motive (kinaesthetic) receptors the information about the muscles action is transmitted back to the central nervous system. Thus are formed internal connections in the organism, similar to the reverse connections in the automatic adjustment systems. Thanks to these reverse connections, the aviator can dose the control levers motion, as according to effort and displacement.

Modification in an effort are better felt than moving of the control levers and accuracy of dosing according to efforts is bigger than in moving, therefore among the features of controllability of the aircraft, priority have those in efforts. If the pilot does not feel the changes of efforts in moving the control levers, he deprives himself of a very important part of information and this leads to large mistakes in piloting even to complete loss of stability of the control loop.

Modelling program for takeoff and the pilot's actions in implementing of the program through motions of the control lever in this case is an imaginary (mental) model of the pilot for takeoff, realized by Simulink's devices. The most important features of pilot's MM are safe takeoff (observing of the aircraft's limitations, defined by its aerodynamics and a short distance and profile of the flight after detachment which ensures the passing over the obstacle at a safe height (min 50 m above it)).

These particulars are developed in the process of flight preparation on the basis of knowledge of aerodynamic characteristics of the aircraft, which are studied by the pilots on theory [20].

Block "Step input Programme_pitch 110 s_1-0" eliminates the mental model of takeoff and prepares the model of pilot for implementation of the horizontal flight and landing.

Modelling of pilot's work in control loop during takeoff and landing. Flight program is modelled by considering an aircraft type with following characteristics: mass = 10252 kg; area of the wing $S_W = 34\ m^2$;

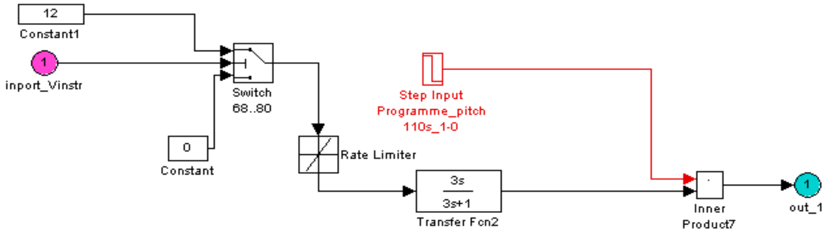

Fig. 5. MM of the pilot in detachment of the aircraft from the runway

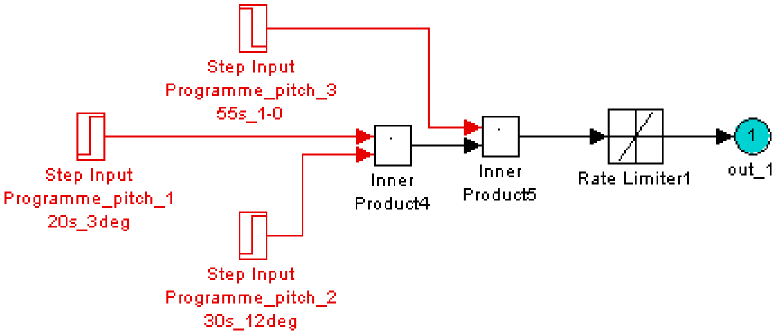

Fig. 6. MM of the pilot on the phase of initial climb

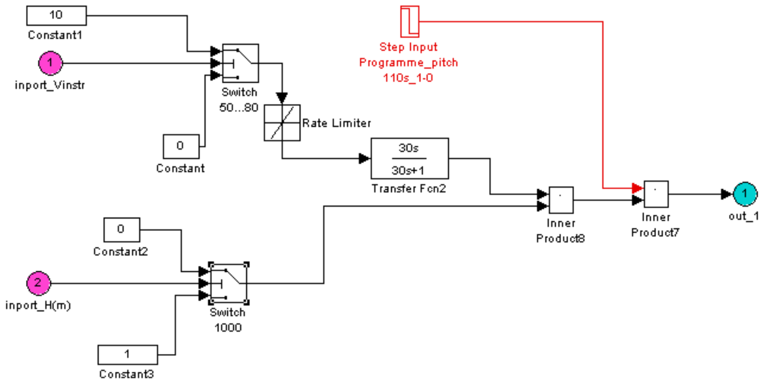

Fig. 7. Detachment of the aircraft from the runway and the initial climb are connected

average aerodynamic chord b_a = 4.16 m; wingspan l_w = 9.3 m; body length L_m=10 m; inertia moment about the axis OZ (for pitch control) I_z= 111593 kgm^2; coefficient characterizing the efficiency of controllable horizontal stabilizer m_z^{φ} = −0.91; range of deviation of controllable horizontal stabilizer "on toss bombing"φ_{bomb} = –150; maximum coefficient of elevating force $C_{y\ max}$ = 1.2 (without flaps); increase in coefficient of elevating force from flaps C_y = 0.5 (flaps).

Model of closed loop illustrates the capabilities of "Simulink" product for simulating of sensomotoric activity in single-channel control by pitch. The operation of closed loop is presented by the devices of "Simulink" based on three main hypotheses. The first one – in takeoff and landing the pilot works by pitch because the speed pressure is low and the reaction of the aircraft in deviation of control means is more sensitive to the angles and angular velocity of pitch and lower on normal overloading.

This fact is well-known and is established by engineering-psychological research and flight tests and it is attached as a key hypothesis in the work of the pilot. Another hypothesis which is ground the work of the pilot to be simulated through model, are known facts and research of the methods for building of mental model for the development of the flight in the future, which in the control loop is the flight's program.

Logical operations for the beginning and the end of different phases of the control process (point of support) and the assessment of impedance mismatching between set and actual value of monitored parameter are carried out in it. The third hypothesis is from the information theory: if a constantly varying value (e.g. pitch) is observed with discreet perceptions (alternating phases of observation and breaks between them), then the operator (pilot) by the discreet perceptions under certain conditions may form the mental model of constantly varying parameter.

Modelling results indicate that the pilot's model performs the flight program safe in compliance with the basic restrictions imposed by the characteristics of the object for control. The object for control is a manoeuvrable aircraft with resistance and navigable characteristics which under the conditions of time and space scarcity can provoke emergency and catastrophic development of flight situation as a result of pilot's errors.

The model of pitch control developed by the pilot implements the mental models set in the program for the flight and landing. The typical stages in observance of safe flight conditions are reflected.

3.3. Modelling of information interaction of human-operator in an ergatic system

Terrestrial information systems are this part of equipment with which the UAV's operator directly interacts. Based on the information received, he creates a mental model of the control process he uses his activity. That is why the effective implementation of such systems is impossible without detailed analysis of relations in examined complex "man – machine" (in this case "HO/pilot – aircraft").

Increasing the efficiency and throughput capacity of the interface is particularly important task, related with the modification of the human component on the one side, which is more difficult, and of the other – by adapting and improving to HO of the second component – the information system. In this case it is necessary the capabilities and limitations of the pilot to be known, as well as the conditions of his work to be taken into account.

Relations "pilot – information system" are part of the broader and general relations "pilot – aircraft", including, if necessary, the UAV control, and of the other – the informing of the pilot about the condition of the object for control and the surrounding environment by the on-board information systems (generally accepted term is pilot-vehicle interface) [9, 10].

Theoretical-data model of the operator activity. As we noted so far, the operator's activity differs from the other type of activity with this that he resolves issues on control, management, transmission or transformation of information, interacting with the external environment or technical devises not directly, but by the assistance of various means to display the information and by the relevant control authorities. General characteristics of the activity of all operators is the collection, evaluation and processing of information for technical equipment, technological and other processes, dynamic objects; taking the relevant operator's decisions based on the evaluation of information; actions on their implementation; monitoring of the effectiveness.

In the proposed model, in which the operator monitors several devices simultaneously, the viewer is represented as a non-stationary discrete communication channel with discrete time.

It is appropriate to assume that in the operational and long-term memory of the operator is stored information about the purposes of functioning and quality assessment of the activity, i.e. there is a certain "instruction" and setting for the task implementation.

In the general case, the tasks of human-operator (HO) are presented as prescribed image of the area of input impacts L_x on the space of the acceptable responses L_y. Thus in set or known characteristics of the permissible ability of the operator in terms of sensor input and motor output the actual and perfect information load of the operator must be assessed. This problem cannot be solved by conventional methods of information theory, since the properties of the operator in resolving of specified tasks are non-stationary in the usual sense. Multiple data from the area of general and experimental psychology for cognitive processes, results of psychophysiological experiments and modern theoretical understanding of the structure of sensory-perceptual processes convincingly confirm the specified status.

In order of the evaluation of work characteristic of the operator upon receipt and processing of the information, has been introduced the concept model unit of functioning of the operator (MUF). Under this concept is understood all the operations and activities of operator, related to search, finding and knowledge of a certain signal – element of L_x, and also its logical processing and formation of response reaction – element of L_y. Essentially, MUF can be regarded as some elementary unit of the operator's activity, with a limited spatial and time duration. In terms of quality it is natural for MUF to be characterized firstly by ultimate continuity in time and secondly with certain information, i.e. with this amount of information, processed by the operator in its implementation [21].

Using MUF in such a manner, the operator's functioning as a process is described as stochastic sequence of disjoint unit of functioning. Then each final time interval of operator's functioning can be represented as a total sum of incidental number incidental augends, corresponding to discrete time intervals of MUF implementation in order of their following, starting from *t = 0.*

Based on the accepted limits and the examined structure the mathematical model of the operator's activity is described for unspecified MUF υ:

(1) $$P(Y;\upsilon) = \Psi\left[P(X;\upsilon),\upsilon\right],$$

where Ψ in general case is a symbol of non-stationary transformation of discrete sequences of distinct states of the information panel (elements of space L_x) in a discrete sequence of the recognizable for the object controlling impacts of the operator (elements of space L_y). Physical meaning of this transformation is that in the absence of errors in formation and implementation of the controlling impact, the operator is obliged in response to every x_j state of the information panel with probability one to realize the set the corresponding control action y_j. On the basis of this functional dependence of MUF's number arises an opportunity for reading of such specific operator characteristics as adaptation to situations, adapting to work, tiredness, ability for improving the activities in the learning process, etc.

(2) $$P(Y;\upsilon) = P(x;\upsilon)\,M(\upsilon) ,$$

where $M(\upsilon)$ is the matrix of conditional probabilities with dimension $N \times N$, satisfying all conditions of stochastic matrix, since all its elements are non-negative, does not exceed one and the elements sum in each row is equal to one. This matrix is specific for each operator in a sense that it reflects his individual characteristics associated with the intake and processing of information within the examined structure of activity.

The proposed theoretical-data model allows selection of basis for comparison of real operators with the perfect one according to matrices type $M(\upsilon)$ and assessment of work quality by comparison of the matrixes $M(\upsilon)$. Thus, a summary model which reflects the integral characteristics of the operator's activity can be used for normative assessment of both operators and information models in systems for control and managing of complex objects.

Perspective opportunities for application of the proposed approach presumes further development and application of the method for integrated data assessments with subsequent complication of the communication channel, inclusion of the memory and after-effect in the channel. This method provides an opportunity to be built a satisfactory description of the reliability and efficiency of operator's work in the real control and management systems; and to provide comparable descriptions of the functioning of the “human” and “technical” part of the entire system.

In the presence of sufficiently complete empirical material – engineering-psychological and experimental-psychological data on the operator's work in receiving and processing of signalling information, the method set forth herein provides an opportunity for effective prognosis of the actual information loads of operator in the systems.

An algorithmic model of operator activity is formalized and studied. The model of the process is set by the interaction of three structures (Fig. 8), which may be described, respectively, graph of the objectives, graph of operations and graph of indicators

The objectives are divided into final, characterized the results of the activities described in the working procedures and intermediate, which are stages upon reaching of the main ones.

The indicators contain assessments of various aspects of the operator's activity in the process of reaching of the final objective, set by the procedure.

When modelling with Petri nets a graph of indicators can be formed, in which transitions have certain weight factors. For the time parameter the summary coefficient at any point is equal to the time of achieving the task [22, 23].

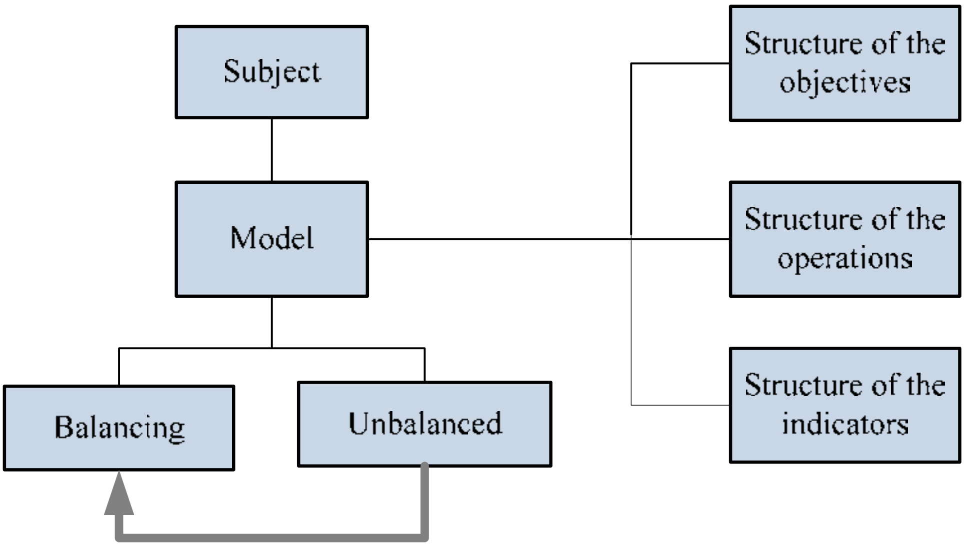

Fig. 8. Process model

The algorithmic model for actions of the operator is developed and it is presented with two graphs with Petri nets – graph of the objectives and graph of the operations, as it is accepted that each objective ends with operation to implement the taken decision. Graph of objectives describes the structure of sequential actions in time, oriented to achievement of the final objective.

Implementation of the model of procedure with graph of objectives is formalized in the theory of Petri's nets as a script (fig. 9).

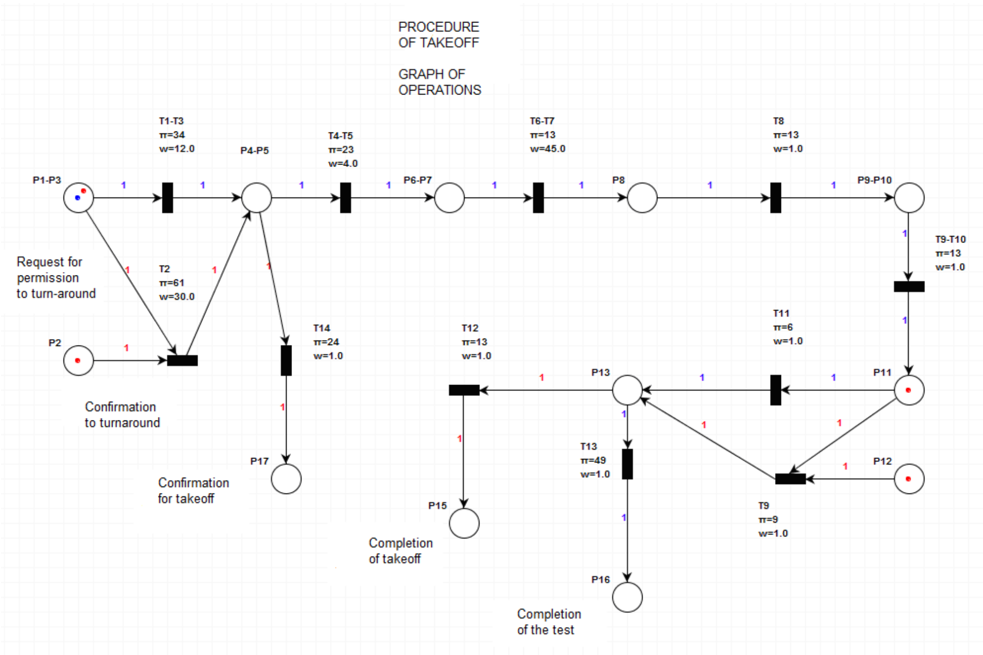

Fig. 9. Operations graph

The model of operation includes a graph with Petri nets with the sequence of actions (operations), performed by the operator. In practice the target model's development precedes the development of model for the operations and they are created independently of one another. In this graph the positions corresponds to the operations and for each point of the graph is drawn a table with description of the achieved objectives and current status of the indicators. Current indicators in the case are the time, necessary for performance of certain operation, reducing the working capacity of the operator, alteration of technical parameters of the flight (speed, altitude, fuel consumption).

Conclusion

Within the framework of the implemented project of FNI DTK 02-59/1913 “Study of the functional efficiency of man under work in extreme conditions”, Contract DTK 02/59 (2009-2013) were developed a concept and methodology for assessing of man in the structure of ergatic systems. Computer models of human-operator with possibility of different applications have been implemented.

Algorithmic model of MCS is synthesized, which is considered as a complex hierarchically organized control system at three levels: mechanics, control, intelligence. Organizational-technical system of the unmanned aircraft complex as sophisticated ergatic system has been described.

Computer realization of the main modules of the algorithmic model of the man as a control system has been implemented and software for data processing and analysis has been developed, including: 1) Model of unmanned training complex of operators and formation of the mental model in an emergency situation, implemented in “Simulink”. This model reflects the specific features of the drone aircraft and has the capacity to model different types of failures in the control system. 2) Flight model.

At the base of development of the model stand subsystems of lateral and longitudinal motion and connections between them, model of the control system with automatic pilot and manual adjustments mode (i.e. “combined mode”). Modelling has been done for specifically adopted characteristics of small drone. 3) Pilot’s models. As a unit of the control loop, the pilot (operator) is simplified viewed as an autocontrol system consisting of three main interconnected subsystems: sensitive organs (perception sensors); central nervous system; executive organs (muscles of the arms, legs, back).

Models of the system aircraft-operator-automatic pilot under different modes of operation are presented in detail. Operation of the pilot in closed loop during takeoff and landing in “matlab-simulink” environment is modelled. Results of the modelling of flight with takeoff, horizontal flight and landing are shown. Characteristic stages in observance of safe flight conditions are presented.

Theoretical-data model for prediction of the level of operator’s information load in erratic systems is proposed. It allows the assessment and prediction of the effectiveness of a real working operator. Simulation model of operator’s activity is synthesized based on the Petri nets. The sequence of the actions of HO are given by the algorithm of activity, including consecutively performance of elementary operations to solve of the given task.

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МОДЕЛИРАНЕ НА ЧОВЕКА – ОПЕРАТОР В СЛОЖНА СИСТЕМА, ФУНКЦИОНИРАЩА В ЕКСТРЕМНИ УСЛОВИЯ

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Резюме

Разглеждат се проблеми, свързани с експликацията на сложни системи на управление на обекти, работещи в екстремни условия, както и влиянието на ефективността на операторската дейност върху системата като цяло. Обоснована е необходимостта от създаването на комплексни имитационни модели, отразяващи операторската дейност. Описана е организационно-техническата система на безпилотен авиационен комплекс, като сложна ергатична система. Осъществена е компютърна реализация на основните подсистеми на алгоритмичния модел на човека като управляваща система и е разработен специализиран софтуер за обработка и анализ на данните. Реализиран е изследван оригинален компютърен модел на Човек като следяща система. Синтезиран е модел на безпилотен комплекс за тренировка на оператори и формиране на менталният модел на аварийна ситуация, реализиран в “matlab-simulink” среда. Като звено от контура за управление, летецът (операторът) е разгледан опростено като система за автоматично регулиране състояща се от три основни, свързани помежду си

подсистеми: чувствителни органи (възприемащи датчици); централна нервна система; изпълнителни органи (мускули на ръцете, краката, гърба). Предложен е теоретико-информационен модел за прогнозиране на нивото на информационното натоварване на оператора в ергатични системи, който позволява да се оцени и прогнозира ефективността на реално работещ оператор. На база мрежите на Петри е синтезиран информационен имитационен модел на операторска дейност при излитане.