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MODELING OF BEHAVIORAL ACTIVITY OF AIR NAVIGATION SYSTEM'S HUMAN-OPERATOR IN FLIGHT EMERGENCIES

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Abstract. *The Air Navigation System is presented as a complex socio-technical system. The influence on decision-making by Air Navigation System's human-operator of the professional factors as well as the factors of non-professional nature has been defined. Logic determined and stochastic models of decision-making by the Air Navigation System's human-operator in flight emergencies have been developed. The scenarios of developing a flight situation in case of selecting either the positive or negative pole in accordance with the reflexive theory have been obtained. The informational support system of the operator in the unusual situations on the basis of Neural Network model of evaluating the efficiency of the potential alternative of flight completion has been built.*

Keywords: informational support, logic determined models, neuronetwork model, reflexive theory, socio-technical system, stochastic models.

Introduction

Air Navigation System (ANS) in conformity to the principles of functioning may be referred to socio-technical systems within which close co-operation between human and technological components occurs [1]. The distinguishing feature of the socio-technical systems is availability of the hazardous kinds of activity as well as usage of the high level technologies in production. Since operations in socio-technical systems generally involve high-risk / high-hazard activities, the consequences of safety breakdowns are often catastrophic in terms of loss of life and property [1]. The more a Human-Operator (H-O) is trying to control a production process being aided by high level technologies, especially in case of distant operation, the more non-transparent becomes the result of the operation of a system, which is accompanied by a high degree risk of causing catastrophic outcomes [2].

Large-scale, high- technology systems such as nuclear power generation and aviation have been called socio-technical systems because they require complex interactions between their human and technological components [1]. Most investigations were conducted with a view to provision of safety in nuclear power production [3; 4]. In the ANS provision of safety is rather actual with the aim of prevention threats on the operational level, for example in the event of technical equipment damage or maintenance personnel faults [5]. The provision of flight safety in the ANS by means of high level technological processes depends primarily on reliability of a H-O as well as his timely professional decisions.

Review of research results

Statistical data show that human errors account for up to 80 % of all causes of aviation accidents [6]. The existing approaches to checking separate aspects (psycho-physiological, behavioural, ergonomic, professional, etc.) do not give the proper consideration to the functional state of H-O in the conditions of the dynamic change of external and internal factors [7].

The environmental conditions determine the reaction of a H-O, while the reaction of the latter, in its turn, changes the environmental conditions themselves. Representation of the ANS in the form of a socio-technical system first of all makes possible to take into account the influence of social, cultural environment of people who make decisions. Culture surrounds people and affects their values, convictions and behavior, which they share along with other members of different social groups. Culture serves to bind us together as members of groups and to provide clues as to how to behave in both normal and unusual situations. The psychologist Hofstede suggests that culture is a "collective programming of the mind" [1]. Thus fatal mistakes can be committed by normal, healthy, highly motivated and well equipped personnel [1; 8]. Russian scientists have used lately the term "departure of conscience" when they analyze the causes of aviation events conditioned by the insufficient development of the appropriate cultural values in a person that makes decisions [6].

One of the possible approaches to the solution of these problems is formalization and mathematical presentation of the ANS operators' activities in the form of a complex socio-technical systems on the base of the systemic analysis. Taking into account in the act of Decision-Making (DM) by a H-O within ANS, besides the separate professional factors (knowledge, habits, skills, experience) also the factors of non-professional nature (individual psychological, psycho-physiological and socio-psychological) [9; 10; 11] enables to predict the H-O's actions on the basis of modelling the foresighting "large-scale" outcomes of individual actions [1] with the aid of the reflexive theory [12].

The systemic approach requires examination of all interrelated different components of the navigation system acknowledging the fact that changes in one sphere may affect the other (probably unpredicted) sphere [1; 2].

For the formalization of the behavioural activity of H-O ANS in flight situations those models seem to be suitable which present the process of appearance of separate preconditions and their development into the causal chain of events in the form of proper diagrams of causal-consequential relations.

Nowadays the most widely spread are the diagrams in the form of different graphs (or current states and transitions), trees of events as well as functional networks of stochastic structure [13-16].

Purpose of work

The purposes of the article are:

– decomposition of the process of DM by H-O ANS, systemic analysis and formalization of the influence of the factors on the DM within ANS treated as complex socio-technical system;

– working-out of models DM by H-O in socio-technical ANS (DM under Certainty, DM under Risk and DM under Uncertainty, Neural Network models);

– working-out of a computer program for optimization of the choice of the Decision alternative of a flight completion for an Aircraft (AC) in unusual situations.

Decomposition of the process DM by H-O ANS and the systemic analysis of factors

In order to take into account the complex of the factors that influences H-O of the ANS in the expected and unexpected conditions of operation of an AC a model of the DM for H-O has been worked out (fig. 1).

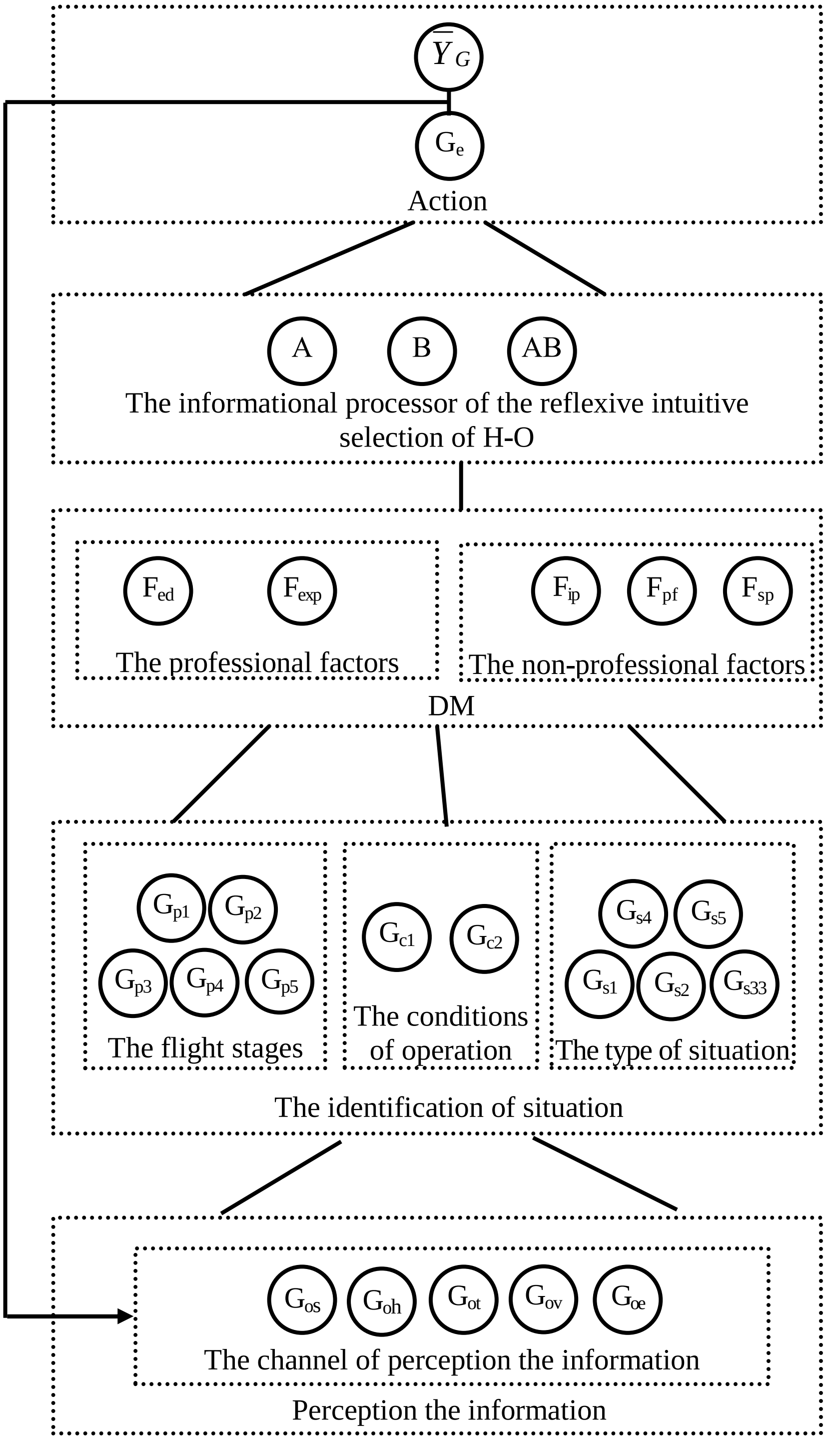
As a result of the previous studies the factors which affect the DM by a H-O ANS have been determined, namely: level of knowledge, skills, abilities, preceding experience as well as the factors of non-professional nature (psycho-physiological, individual-psychological, social-psychological factors) [11].

The systemic analysis which has been carried out as well as the formalization of the factors which affect DM by H-O (individual-psychological, psycho-physiological and social-psychological) in the conditions of the progress of a flight situation from normal to catastrophic to obtain [11]:

– the models of preferences by a H-O under the influence of social-psychological factors;

– the models of preferences by a H-O depending on the significance of individual-psychological factors in the conditions of development flight situations from normal to catastrophic ones;

– the models of diagnostics of psycho-physiological factors at the score of monitoring the emotional state of H-O.



G_e – obtained experience;
$\overline{Y}_G$ – vector of predicted H-O's actions;
A - selection in the direction of positive pole A;
B - selection in the direction of negative pole B;
AB – mixed selection

F_{ed} – knowledge, skills and abilities, acquired operator during training;
F_{exp} – knowledge, skills and abilities, acquired H-O during professional activity;
F_{ip} – individual-psychological H-O's qualities;
F_{pf} – psycho-physiological H-O's qualities;
F_{sp} – social-psychological H-O's qualities

G_{p1} – takeoff;
G_{p2} – climb-out;
G_{p3} – level flight;
G_{p4} – descent;
G_{p5} – landing;
G_{c1} – expected conditions of the AC operation;
G_{c2} – unexpected conditions of the AC operation;
G_{s1} – normal situation;
G_{s2} – complicated situation;
G_{s3} – difficult situation;
G_{s4} – emergency situation;
G_{s5} – catastrophic situation

G_{os} – optic channel;
G_{oh} – auditory channel;
G_{ot} – tactile channel;
G_{ov} – verbal channel;
G_{oe} – preceding experience

Fig. 1. The model of DM by H-O ANS

The analysis of social-physiological factors conducted by the authors allowed to make a conclusion that the activities of pilots are influenced by the own image, the image of corporation as well as by interests of a family.

At the same time respondents – air traffic controllers pay special attention to interests of their families, their own economical status and professional promotion. The analysis of priorities when a pilot and dispatcher are to make a decision together, determined the following model of advantages: social and economic priorities of a person, political views and legal norms of a person, spiritual and cultural orientations of a person as to the influence of individual-psychological factors the most significant of them are health and experience. In the conditions when a flight situation develops in the direction to a catastrophic occurrence, then the temperament and ability to receive information become more significant factors [10; 11]. The research into the influence of individual-psychological and social-psychological factors on the professional activity of H-O ANS allowed to obtain data on such structural components of a personality of an aviation specialist, such as motives or behaviour, values and priorities, hierarchy and development of these dynamic categories on the stages of DM by H-O.

Modelling of the DM by H-O ANS under Certainty, Risk and Uncertainty

The investigation into the processes of modelling the DM by air navigation specialists in the normal and unusual situations enabled to build the following models.

1. Decision Making by H-O in Flight Emergencies (FE) under Certainty. The network analysis of the actions of an AC crew and an air traffic controller in flight emergencies with the aid of the network planning methods gave a chance to obtain [13]:

– structural-hourly table of the actions taken by H-O (controller, pilot) in FE;

– the network graph of taking the actions by a H-O (controller, pilot) in the FE;

– the critical time of taking the actions by a H-O (controller, pilot) in the FE;

– the determined models for a H-O (controller) are presented in tab. 1 and fig. 2, which were obtained in accordance with the adopted technologies of controller's work in the FE [14; 15].

The obtained critical time for performing the operations by a controller in the FE namely: engine failure on takeoff, depressurization of flying vehicle, hydraulic system faults, failure of the electric power supply system, etc. as well as the critical time of the crew actions in case of an engine failure on takeoff and approach to land in the adverse meteorological conditions has been obtained.

2. Decision Making by H-O in FE under Risk. The structural analysis of developing FE and DM by AC crew and air traffic controller in FE with the aid of decision tree enabled to obtain such results:

– graphical-analytical models of FE development and DM by a H-O (controller, pilot) in FE [9; 17];

– stochastic models type GERT network (Graphical Evaluation and Review Technique), decision trees and Markov chains [10; 11; 16];

– reflexive models of bipolar choice in FE under the influence of external environment, previous experience and intentional choice by H-O.

With the aid of the bipolar reflexive model of the behavioral activity of H-O in the extreme situations [12] W-functions of the positive and negative choice have been obtained. The model represents the subject (H-O) who is on the verge of choosing one of the alternatives: A (positive pole) and B (negative pole).

The choice H-O ANS is described by the function:

$$X = f\,(x_1, x_2, x_3),$$

where X is a probability with which the H-O is ready to choose the positive pole A in the reality;

x_1 is a pressure of the external environment on the H-O in the direction of the positive alternative at the moment of the choice:

$x_1 \in [0, 1]$;

x_2 is a pressure of the previous H-O's experience in the direction of the positive alternative at the moment of the choice:

$x_2 \in [0, 1]$;

x_3 is an intentional choice (intention) of H-O in the direction of the positive alternative at the moment of the choice:

$x_3 \in [0, 1]$.

Table 1. **Generalized structural-hourly table of the technology of the air traffic controller work in FE**

Contents of the work	Designation of the work	Set of the operations	Support on the work	Time of the performing the work
Receiving the information from the AC crew about the FE	A_1	$\{a_{11}, a_{12}, \dots, a_{1n}\}$	–	$\{t_{11}, t_{12}, \dots, t_{1n}\}$
Confirmation of receiving the information to the AC crew	A_2	$\{a_{21}, a_{22}, \dots, a_{1n}\}$	A_1	$\{t_{21}, t_{22}, \dots, t_{2n}\}$
Transmission of the information to the appropriate services	A_3	$\{a_{31}, a_{32}, \dots, a_{3n}\}$	$A_1 \cap A_2$	$\{t_{31}, t_{32}, \dots, t_{3n}\}$
Receiving the decision of AC commander	A_4	$\{a_{41}, a_{42}, \dots, a_{4n}\}$	A_1 U A_2 U A_3	$\{t_{41}, t_{42}, \dots, t_{4n}\}$
Provision of the conditions for the safe flight completion	A_5	$\{a_{51}, a_{52}, \dots, a_{5n}\}$	$A_1 \cap A_2 \cap A_3 \cap A_4$	$\{t_{51}, t_{52}, \dots, t_{5n}\}$
Reception of the information from the AC crew about the result of landing	A_6	$\{a_{61}, a_{62}, \dots, a_{6n}\}$	$A_1 \cap A_2 \cap A_3 \cap A_4 \cap A_5$	$\{t_{61}, t_{62}, \dots, t_{6n}\}$

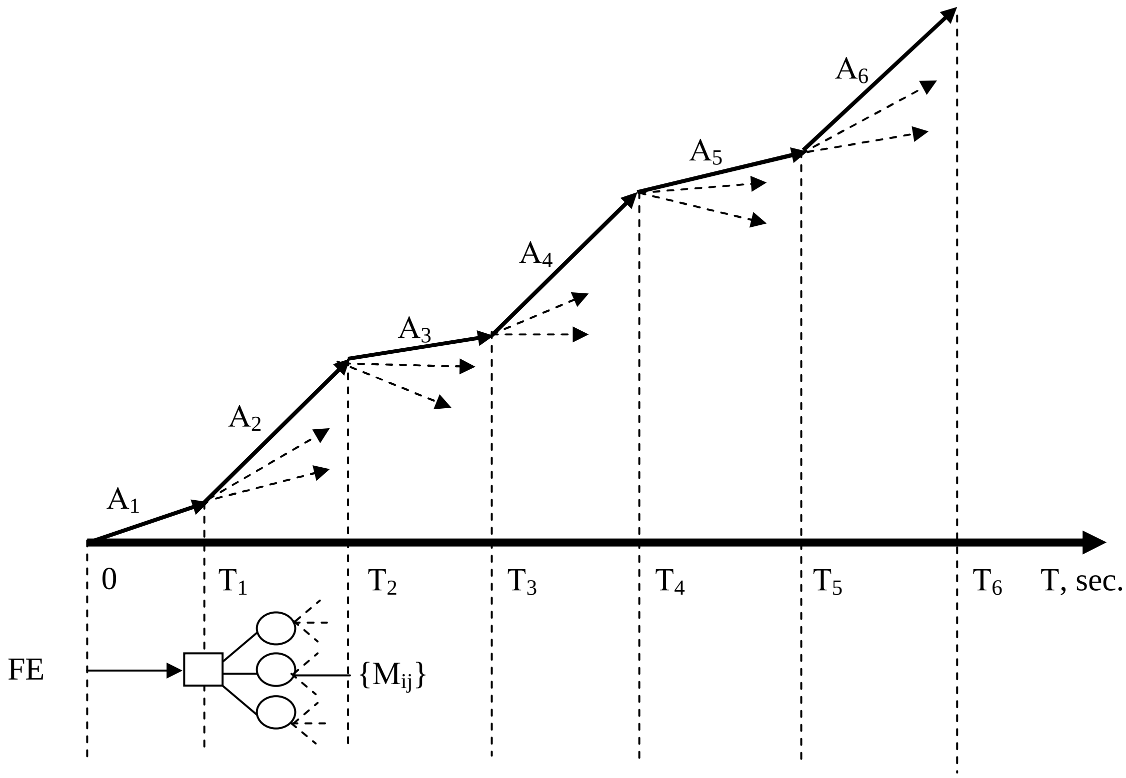


Fig. 2. The network graph of carrying out the actions by an air traffic controller in the ANS:
A_1-A_6 – operations which are carried out by the controller in accordance with approved technology;
$\{M_{ij}\}$ – the set of the scenarios of the development of flight situations in compliance with stochastic model

The expected risks R_A, R_B of making a decision in the ANS under the influence of the external environment x_1, the previous H-O's experience x_2 and the intentional choice of a H-O x_3 have been obtained. The expected risk in the process of DM of a H-O is equal:

$$R_{DM} = \begin{cases} R_A = \min \{R_{ij}\} \\ R_B = \{\gamma, \rho\} \\ R_{AB} = \{X(x_1, x_2, x_3), \gamma, \rho\}, \end{cases}$$

where R_A is an expected risk of the DM for a H-O with taking into account the criterion of the expected value minimization;

R_{ij} is an expected risk for making A_{ij}-decision;

R_B is an expected risk of the DM for a H-O with taking into account his model of preferences;

γ is a concept of a rational individual's behaviour;

ρ is a system of a individual's preferences in a concrete situation of the choice;

R_{AB} is a mixed choice made by a H-O.

The H-O ANS preferences system is influenced by professional $\overline{F}_p$ and non-professional $\overline{F}_{np}$ factors [11]:

$$\overline{F}_p = \{\overline{F}_{ed}, \overline{F}_{\exp}\};$$

$$\overline{F}_{np} = \{\overline{F}_{ip}, \overline{F}_{pf}, \overline{F}_{sp}\},$$

where $\overline{F}_{ed}$ are knowledge, skills and abilities, acquired H-O during training;

$\overline{F}_{\exp}$ are knowledge, skills and abilities, acquired H-O during professional activity;

$$\overline{F}_{ip} = \{f_{ipt}, f_{ipa}, f_{ipp}, f_{ipth}, f_{ipim}, f_{ipn}, f_{ipin}, f_{iph}, f_{\exp}\}$$

is a set of individual-psychological qualities of a H-O (temperament, attention, perception, thinking, imagination, nature, intention, health, experience);

$\overline{F}_{pf}$ is a set of psycho-physiological qualities of a H-O (features of the nervous system, emotional type, sociotype);

$\overline{F}_{sp} = \{f_{spm}, f_{spe}, f_{sps}, f_{spp}, f_{spl}\}$ is a set of socio-psychological qualities of a H-O (moral, economic, social, political, legal).

The computation of one of the scenarios of the flight situation development is presented in fig. 3 (for example – approach performed in bad weather conditions [10; 11]).

The results of the computation of the expected risks in the course of the transition between flight situations and the criterion of the expected value by means of the dynamic programming method are presented in tab. 2.

The example of the computation of the expected risks in the course of the transition between flight situations is presented in fig. 4.

The selection in the direction of the negative pole in compliance with the $S_{1\text{-}2\text{-}3\text{-}4B}$ scenario leads to the maximum expected risk R=1028 conventional units (c.u.). The choice in the direction of the positive pole when the FE occurs at the first stage of DM by H-O ANS (for example, a flight to a reserve aerodrome in the difficult meteorological conditions) has a risk which is 60,5 times lesser: R=17 c.u.

Table 2. **The results of computation of the scenarios of flight situations development**

Scenarios, S	Probabilities, p	Consequences, U	Expected risks, R, c.u.
S_{4B}	0,7	60	597
	0,3	59	
$S_{3\text{-}4B}$	0,7	28	874
	0,3	27	
$S_{2\text{-}3\text{-}4B}$	0,7	12	991
	0,3	11	
$S_{1\text{-}2\text{-}3\text{-}4B}$	0,7	4	1028
	0,3	3	
S_{1A}	0,7	2	17
	0,3	1	

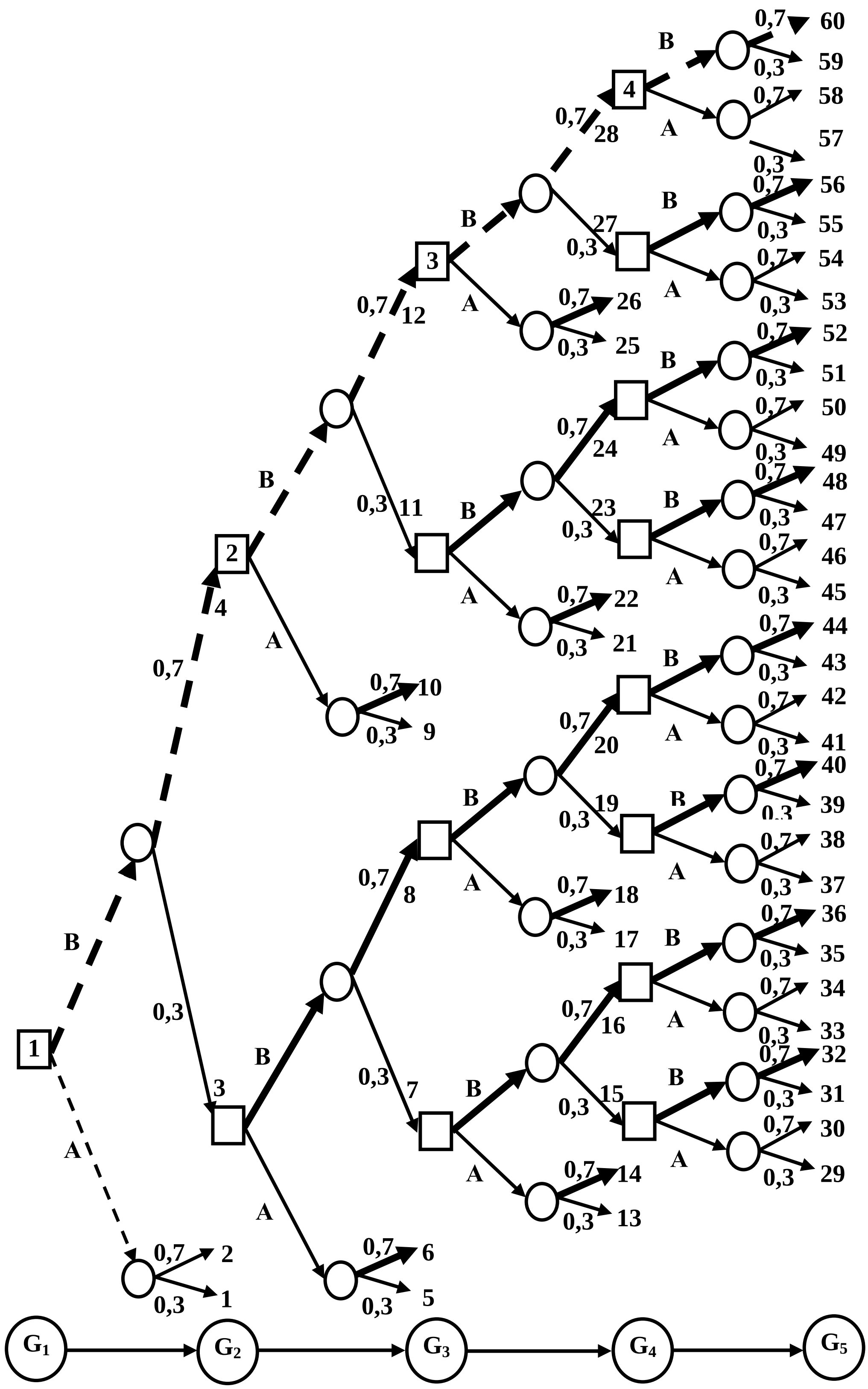


Fig. 3. The example of the computation of one of the scenarios of flight situation development:
A, B – selection in the direction of positive or negative pole respectively;
G_1, G_2, G_3, G_4, G_5 – normal, complicated, difficult, emergency, catastrophic situations respectivel

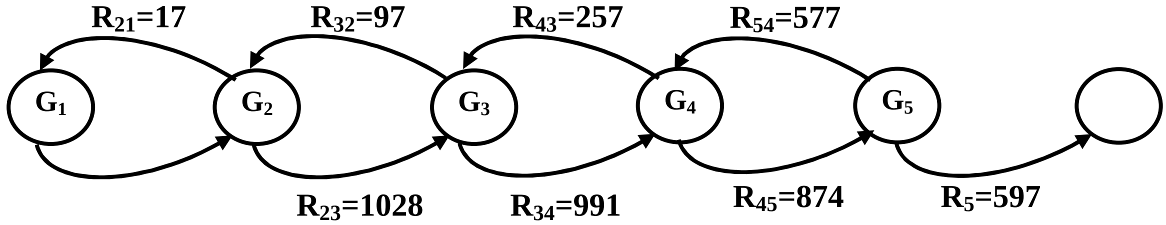


Fig. 4. Markov Chains of the development of flight situations:
G_1 ,G_2, G_3, G_4 ,G_5 – normal, complicated, difficult, emergency, catastrophic situations respectively;
R_{ij} – value of risk during transition between flight situations

3. Decision Making by H-O in FE under Uncertainty. The analysis of FE developing and DM of an AC crew and air traffic controller has been made with the aid of Minimax, Laplace, Savage and Hurwicz criterions which enabled to obtain the DM by H-O models in FE under uncertainty.

The matrix of the possible results of the H-O's DM in the ANS in the FE are presented in tab. 3. The consequences of the flight situation development u_{ij} have been obtained in conformity to the reflexive theory.

It is advisable to employ the models of the development of flight situations as components of the DM Support System which enables a H-O ANS to evaluate numerically the possible versions of FE developing and choose timely the strategy of behaviour with the minimum level of the potential loss in the conditions of the insufficient and uncertain available information.

Computer program for the optimization of choice of an alternative variant

The Neural Network model of evaluating the efficiency of the potential alternative of flight completion on the basis of the two-layer perceptron developed by us (fig. 5) differs from the used ones because it enables to define with a high degree of precision the amount of the possible loss due to the complex taking into account of the influences of various separate factors differing from the point of view of their significance which characterize the potential place for making a forced landing.

The entry parameters of the model in the form of the Artificial Neural Network (ANW) are factors which characterize the potential alternative of the flight completion (tab. 4).

Every entry parameter has a binary vector corresponding to it and reflecting the availability (1) or absence (0) of a certain factor.

The potential loss due to the choice of the certain alternative decision in the conditions of the limited flight continuation serves as the criterion of the efficiency of the alternative variants of flight completion:

$$Y_{Gaer} = f_G([\overline{B} \cup \overline{C}]W_{BC,G});$$

$$Y_{Glf} = f_G([\overline{D} \cup \overline{E} \cup \overline{F}]W_{DEF,G}),$$

where f_G – the activating function which is applied elementarily to the components of a vector-row which is positioned in the brackets.

The efficiency will depend on the type of a potential landing place as well as on the fact which factors characterize it. The optimum variant of the flight completion with the minimum risk is chosen on the basis of the potential loss minimization:

$$Y_{Gopt} = \min f_G(\overline{G}).$$

Table 3. **Matrix of the possible results of the decision making by H-O ANS in FE**

Alternative decisions	Factors		
	Pressure of the external environment on H-O	Pressure of the previous experience of H-O	H-O's intentional choice (intention)
A – choice in the direction of the positive pole	u_{11}	u_{12}	u_{13}
B – choice in the direction of the negative pole	u_{21}	u_{22}	u_{23}

Table 4. **Parameters of the ANW**

Inputs of the ANW – characteristics of the potential places for landing (aerodrome, landing field)			
Aerodrome	$\overline{B}$	$\overline{B}=\{b_i\},\ i=\overline{1,3}$	Technical suitability of an aerodrome
	$\overline{C}$	$\overline{C}=\{c_j\},\ j=\overline{1,3}$	Suitability of an aerodrome with respect to meteorological conditions
Landing field	$\overline{D}$	$\overline{D}=\{d_k\},\ k=\overline{1,1}$	Type of a landing field
	$\overline{E}$	$\overline{E}=\{e_l\},\ l=\overline{1,5}$	Kind of an underlying surface
	$\overline{F}$	$\overline{F}=\{f_m\},\ m=\overline{1,3}$	Suitability of a landing field in connection with the meteorological conditions
Criterion of effectiveness – a potential loss value			
$\overline{G}=\{g_r\},\ r=\overline{1,5}$	g_1	Consumption of fuel – 10 units	Very small loss
	g_2	Incident – 30 units	Small loss
	g_3	Breakage – 50 units	Average loss
	g_4	Accident – 80 units	Great loss
	g_5	Catastrophe – 100 units	Very great loss
Outputs of ANW – alternative variants of flight completion Y_G			
Aerodrome	Y_{Gaer}	$f_G([\overline{B}\cup\overline{C}]W_{BC,G})$	Effectiveness of flight completion at the aerodrome
Landing field	Y_{Glf}	$f_G([\overline{D}\cup\overline{E}\cup\overline{F}]W_{DEF,G})$	Effectiveness of flight completion at the landing field

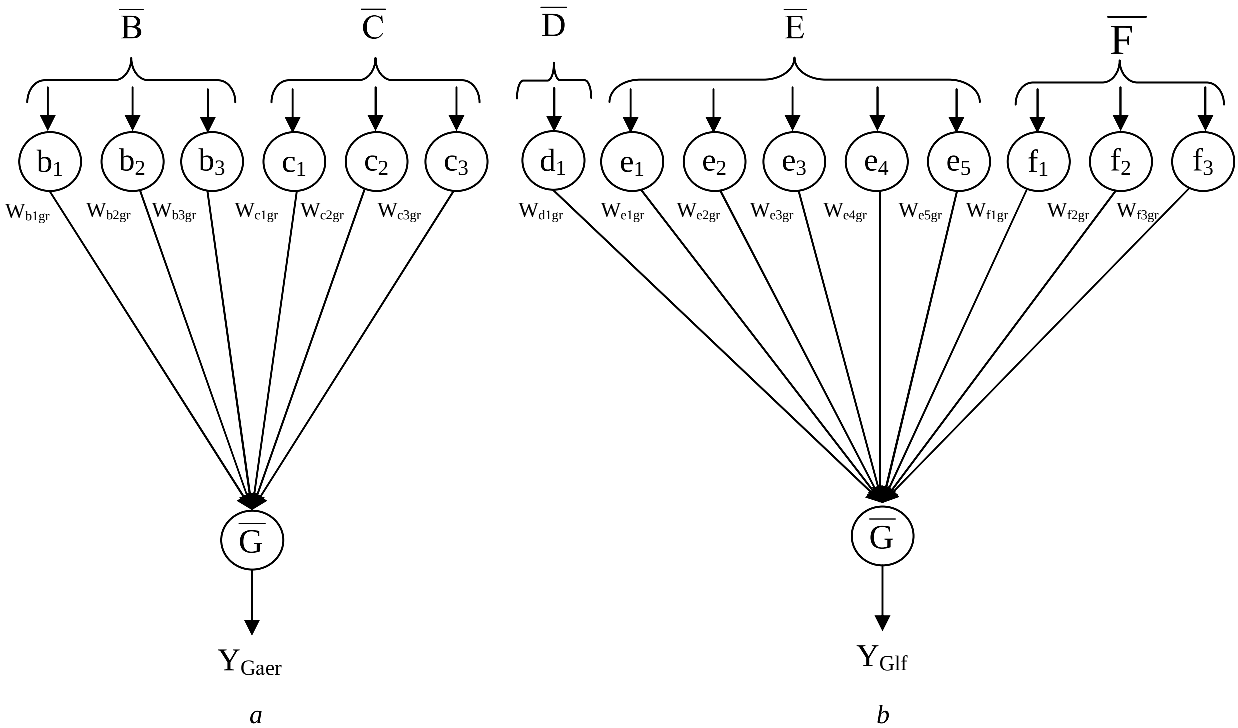


Fig. 5. Neural Network model when potential alternative of the flight completion is an aerodrome (*a*) and is a landing field (*b*):

$\overline{B}$, $\overline{C}$, $\overline{D}$, $\overline{E}$, $\overline{F}$ – characteristics of the potential places for landing;

$\overline{G}$ – potential loss;

W – weight coefficients of neural network;

Y_G – effectiveness of flight completion

For the informational support of an air navigation system to enable it to make operatively a timely decision concerning the selection of the optimum flight completion strategy in unusual situations which require a forced landing the specialized program complex “Prompt” [18] has been created.

The program complex was created with the aid of the visual system for designing programs Delphi 5 which is based on the special version of the programming language Pascal – Object Pascal and supports the main principles of the object-oriented programming.

With the aid of the program “Prompt” the subsystems of forming the strategies of actions, predicting the development of a situation, defining the characteristics of the alternative variants of the flight completion, evaluation of the efficiency of the potential alternatives and building the optimum decision were realized.

The program “Prompt” enables to handle two non-standard situations – an engine failure and fire on board an aircraft.

When the system receives a message about the unusual situation origination, the additional panel for providing the recommendations concerning the possibility of the flight continuation or necessity to execute a forced landing appear on the operator’s monitor. When a type of situation – engine failure – is to be selected the number of the engines which have failed is to be input; when the type – fire – is to be handled, the condition of the aircraft is to be input and the proper advice appears on the monitor (fig. 6).

When the recommendation concerning the necessity to accomplish a forced landing is obtained, the field of approachability for the aircraft is built on the monitor, also values of the potential loss required for selection of a definite flight completion alternative as well as the coordinates of the potential landing sites (azimuth, range) are presented on the monitor. The program envisages the formation of the field of approachability for two extreme cases – the regime of planning and regime of an immediate descent (fig. 7).

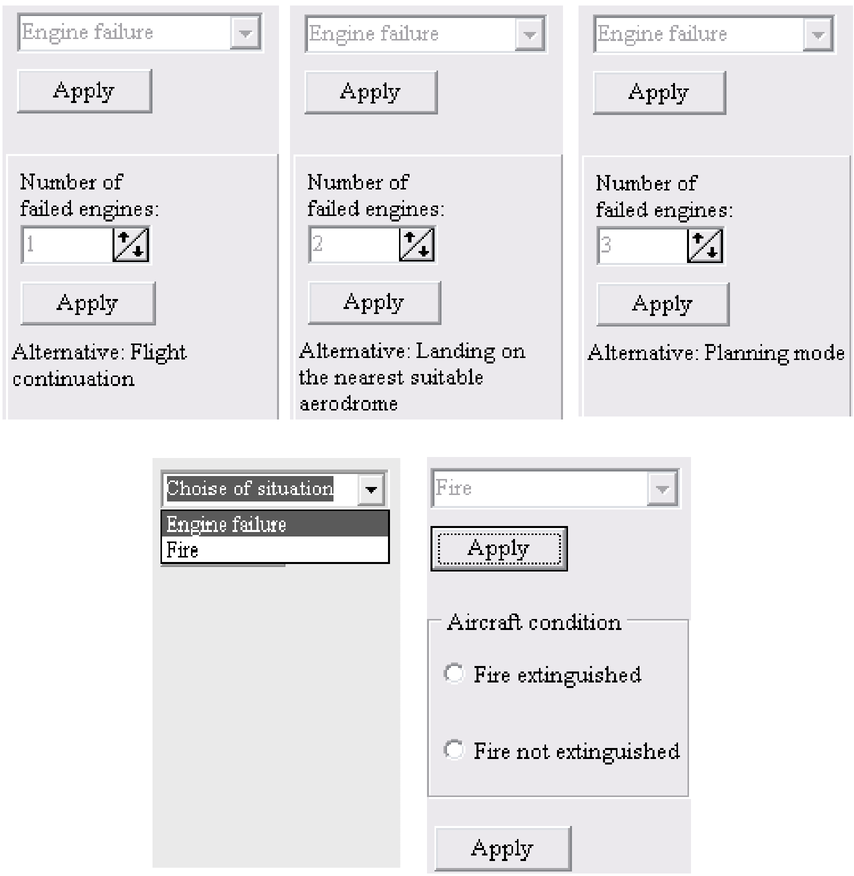
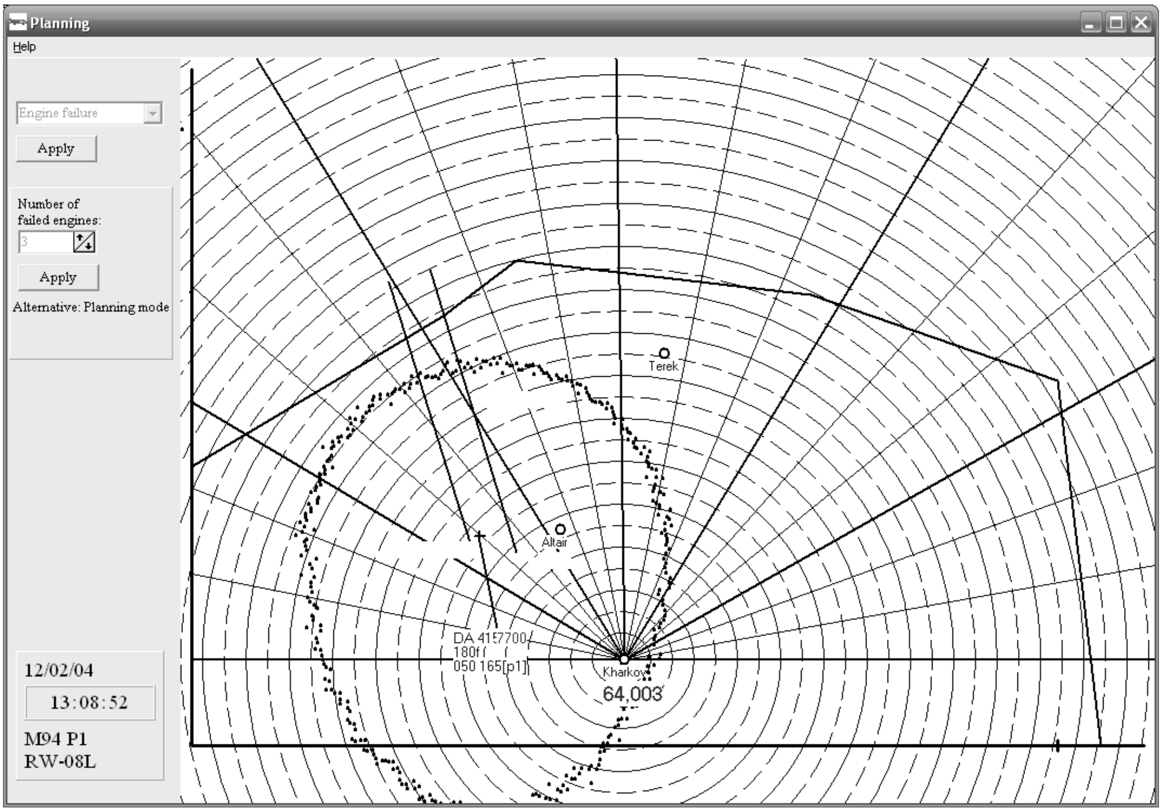
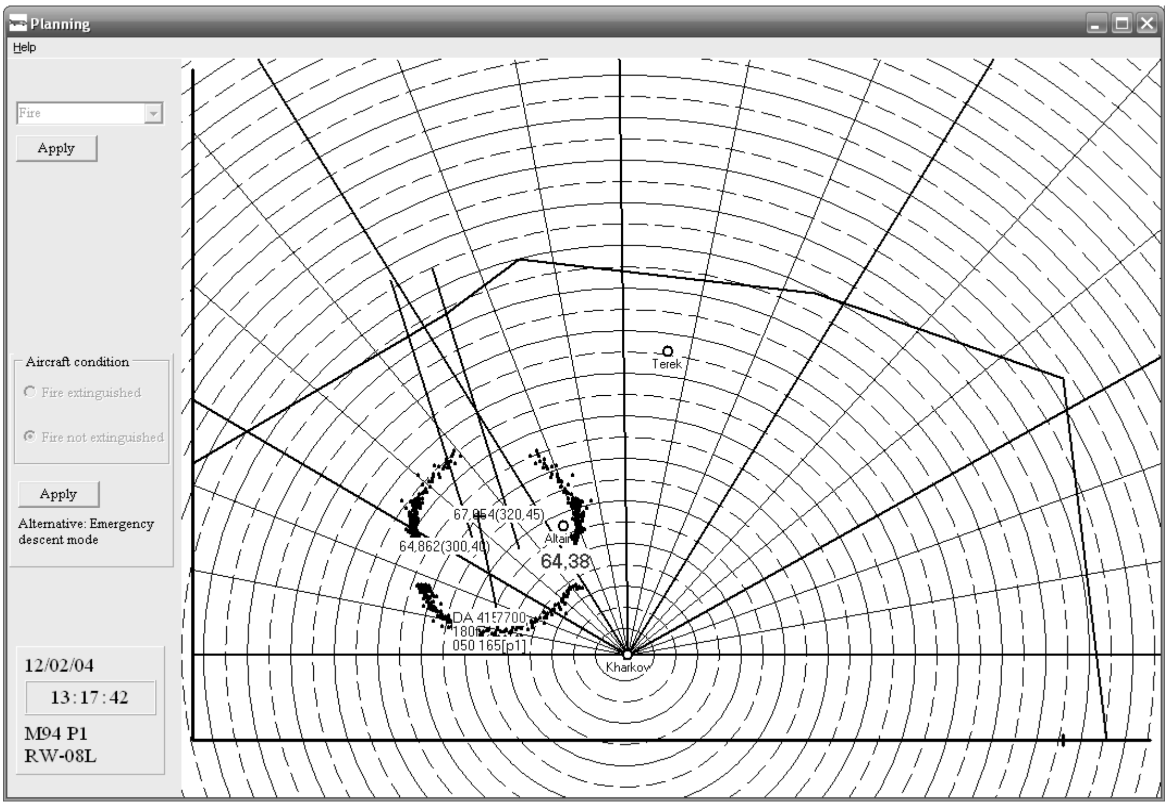


Fig. 6. Realization of the subsystem of forming the strategy of action



a



b

Fig. 7. The field of approachability and defined potential loss for a few variants of the flight completion in the event of the complete failure of the aircraft engines (*a*) and in case of the fire on board the aircraft which was not extinguished (*b*)

The program complex “Prompt” allows:

– to give the recommendations concerning the possibility of the further flight continuation or the necessity to accomplish a forced landing of the aircraft with the aid of the interface suitable for the user;

– to define the field of approachability of the aircraft in case when the necessity to make a forced landing arises;

– to form the evaluation of the alternative variants of the flight completion and define the optimum variant using the potential-loss minimization criterion.

Conclusions

The ANS is presented as a complex socio-technical system. The influence on the DM by H-O of the ANS of the professional factors (knowledge, skills, abilities, experience) as well as the factors of non-professional nature (individual-psychological, psycho-physiological and socio-psychological) has been defined.

The network analysis of the actions of an AC crew and air traffic controller in the flight emergencies has been made with the aid of the network planning methods; also the logic determined models DM by H-O ANS in FE have been developed.

The numerical indices of an expected risk in the stochastic models DM by H-O ANS under Risk and Uncertainty have been defined.

The scenarios of developing a flight situation in case of selecting either the positive or negative pole under the pressure of the external environment, the preceding experience of a H-O and the intentional selection (intention) in accordance with the reflexive theory have been obtained.

To ensure the informational support of an operator of the Air Navigation System with the purpose of assisting him in taking the operative timely decision concerning the selection of the optimal flight completion strategy in the unusual situations which require a forced landing of an aircraft the program complex “Prompt” has been built.

The Neural Network model on the basis of the two-layer perceptron realized in it enables to define with a high degree of precision in the regime of real time the quantity of the possible loss due to the complex consideration of the various factors of different significance which characterize the potential place for accomplishing a forced landing.

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