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ARTIFICIAL INTELLIGENCE

Computer Simulation Systems for Development of Knowledge Bases of Onboard Online Intelligent Systems of System-Generating Core of Anthropocentric Object

A. V. Romanenko and B. E. Fedunov

Moscow Aviation Institute (Technical University), Volokolamskoe sh. 4, GSP-3, A-80, Moscow, 125993 Russia
FGUP GOSNIIAS (State Research Institute of Aviation Systems, ul. Viktorenko 7, Moscow, 125319 Russia

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Abstract—Classification and pattern of computer simulation systems is presented; these systems provide improvement of knowledge bases of onboard intelligent systems at particular stages of their development. For intelligent information system (first global control level of anthropocentric object) "Situation awareness of the crew", the presence of a man–operator in the simulation loop is mandatory, and for onboard online advisory expert systems for typical situations of functioning an anthropocentric object (second global level of object control), the simulation of the operator work by a special situation control block is admissible.

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INTRODUCTION

An *anthropocentric object* is a shell with a set of macro-components implemented in it (board of the anthropocentric object):

(i) onboard measurement devices receiving information on external world in which the anthropocentric object operates, and its onboard world;

(ii) *system-generating* core of the anthropocentric object in which three global control levels are distinguished: online targeting (I global control level), determination of method for achieving online-assigned target (II global control level), realization of this method (III global control level). In the system-generating core the main role belongs to the team of operators (crew);

(iii) onboard actuators acting on external and onboard world.

It is convenient to describe operation of any anthropocentric object by the calculated set of its operation sessions; each of these sessions is characterized by the general task of the session and the semantic network of typical operation situations; in turn, each of these typical situations is represented by the semantic network of problem subsituations of this typical situation. All above makes the content of the model "General task–global control level" which is used in development of onboard algorithmic and indication support of modern anthropocentric objects [1, 2].

The practice of application and development of modern anthropocentric objects requires the creation of onboard intelligent systems supporting the crew in the course of solution of problems of the first and second global control levels.

1. STRUCTURE OF OPERATOR ACTIVITY ON BOARD TECHNICAL ANTHROPOCENTRIC OBJECT AND CLASSIFICATION OF ONBOARD INTELLIGENT SYSTEMS OF ITS SYSTEM-GENERATING CORE

The activity of the operator (crew) on board the anthropocentric object is represented in terms of the following components. The operator makes decisions on online problem, realizes its solution, and participates in different tracking operations as the element of the tracking system [3–8]. All information necessary for operator activity is presented to him on indicators of information–control field of the crew cockpit and/or supplied to him via cockpit voice devices. The realization of decisions and participation in tracking operations is performed by the crew via control organs of the information-control field. In the framework of the model "General task–global control level" all elements of operator activity are represented in the integrated way by the graph of operator decisions. The estimation of feasibility of the whole volume of this activity described in operator decisions graph is performed using the computer system "operator decisions graph estimation" [9].

Let us consider the capabilities of estimation of the time necessary for the operator for each component of his activity.

Each operator decision is related to one of the following types: π *decisions* (perceptive–identification), ρ *decisions* (speech–mental), and π–ρ *decisions* (heuristic) [4, 7].

Each π-*decision* is characterized by the instantaneous reaction of the operator on a certain signal-stimulus. Time expenses of the operator on making such a decision consist of the time spent for detection and recognition of the corresponding signal-stimulus. These decisions are represented in the operator decisions graph [8]:

(i) by the composition of information or speech message (signal-stimulus) which are necessary for the operator to make decision;

(ii) by the output information: composition and sequence of manual operations necessary for realization of the made decision by the operator.

Upon estimation of the time on information perception and comprehension by the operator information is represented in the form of the set of online perception units which are separated as elements of a particular information frame on the information–control field indicator.

The time estimates necessary for it are introduced into the computer system "operator decisions graph estimation" from [3–9].

Each ρ-*decision* is characterized in the operator decisions graph by the following:

(i) input information including information of the information–control field of the cockpit according to which the operator should make this decision; the composition and duration of speech message supplied to the operator by the cockpit speech device which is used in decision making;

(ii) structure of decision described by the number and composition of online perception units according to which the decision is made; the composition and sequence of elementary acts of making decision described in terms of indication symbols of information frames on indicators of the information–control field;

(iii) output information represented by the composition and sequence of manual operations necessary for realization of made decision.

The necessary time estimates are introduced into the system "operator decisions graph estimation" from [3–7].

Each π–ρ *decision* is heuristic. Upon design of the operator activity, it is characterized in the operator decisions graph as follows:

(i) input information represented by the composition of information in the information–control field of the cockpit according to which the operator should make this decision; composition and duration of speech message transferred to the operator by the cockpit speech device which is used for making this decision;

(ii) time for making this decision (estimated experimentally);

(iii) output information characterized by the composition and sequence of manual operations necessary for realization of made decision.

Algorithms of operator activity connected with his participation in *tracking processes* [6] at the stage of development of specifications of onboard algorithms are described in a rather general form. For estimation of the time spent by the operator on the tracking process the following assumptions are made. It is assumed that upon execution of tracking operations the operator works in discrete–continuous regime, terminating the tracking operation for the time of making and realization of decision (decisions). After that the operator again returns to the tracking process and eliminates the tracking error accumulated during the time of his diversion. Time instants of operator diversion to tracking operations cannot break the decision making process and the process of its realization.

The time spent by the operator for the tracking process is represented by the dependence $\tau_{track} = f(\tau_{div})$ of the time of correction of the tracking error (τ_{track}) by the operator accumulated during the time of his diversion from the tracking process on the time of this diversion (τ_{div}). The operator decisions graph can contain several tracking types, each of these types is characterized by a separate dependence $\tau_{track} = f(\tau_{div})$. Tracking processes can be nested in each other.

Finally, all above elements of operator activity are united by the *conceptual model of operator behavior*, online change of this model by the operator in the course of his activity requires certain time. This time is characterized by one quantity for all conceptual models.

For development of the situation control block whose description will be given below the following is required in the considered typical situation:

(i) first develop the operator decisions graph for this typical situation;

(ii) then use this graph to estimate the time necessary for the operator to realize it;

(iii) separate the semantic component of the operator decisions graph realized in the situation control block;

(iv) determine the parameters of time delays of supply of control signals produced in the situation control block to onboard actuators for particular situation control blocks.

2. DEVELOPMENT OF OPERATOR DECISIONS GRAPH AND CALCULATION OF TIME SPENT BY THE OPERATOR FOR REALIZATION OF RECOMMENDATIONS OF ONBOARD ONLINE ADVISORY EXPERT SYSTEM FOR DISTANT AIR FIGHT OF FIGHTER AIRCRAFTS

The initial information for development of the operator decisions graph for distant air fight 1 × 1 are:

(i) a set of formalized scenarios;

(ii) a system description of information–control field of the cockpit;

(iii) a system description of onboard equipment.

It is convenient to begin the development of the operator decisions graph from the analysis of problem

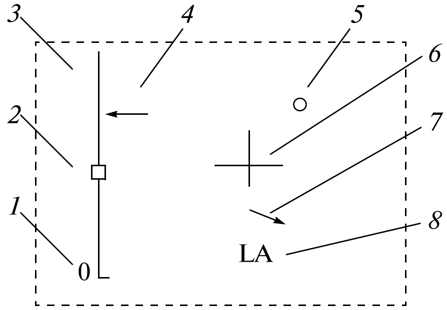


Fig. 1. Information in problem subsituation “Attack” in typical fight situation distant air fight 1 × 1 presented to the operator at the cockpit information indicator. The following notation is used: (*1*) beginning of the range scale between F1 and F2; (*2*) range of R(F1) launch recommended by onboard online advisory expert system for distant air fight 1 × 1; (*3*) range scales between F1 and D2; (*4*) current distance between F1 and F2; (*5*) presentation of error of keeping given flight trajectory by aircraft automatic control system (in the absence of error the symbol is at the center of the indicator); (*6*) center of indicator; (*7*) type and direction of F1 maneuver recommended by onboard online advisory expert system for distant air fight 1 × 1; (*8*) possibility of launch R(F1).

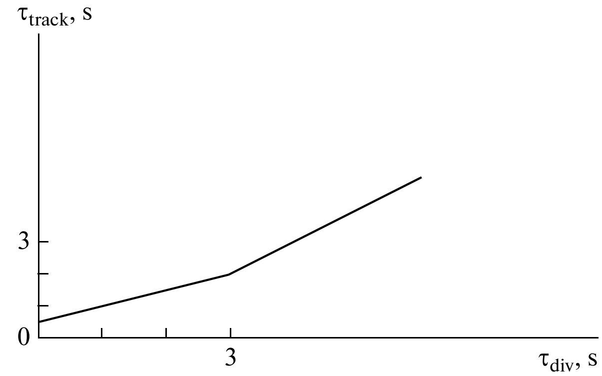


Fig. 2. Experimental dependence $\tau_{track} = f(\tau_{div})$.

subsituations. Each such subsituation corresponds to a set of possible (admissible) methods of its solution. The formation of such sets is performed by the expert based on the analysis of capabilities of onboard equipment and the character of the problem subsituation. The next step of development of the operator decisions graph is the separation of preferable or optimal decision among possible decisions. Often this separation can be performed only after preliminary study of the problem subsituation using the corresponding mathematical model of making decisions. The choice of the preferable decision in development of the operator decisions graph includes the simultaneous solution of the problem of distribution of functions between the operator and the onboard equipment. The methodological ground of this separation is the assumption that the correctly designed man-machine system should solve problem subsituations in the best way. The operator and onboard equipment should add each other, rather than be opposed to each other.

Upon development of the operator decisions graph, following the causal sequence of problem subsituations in the formalized scenario necessary operator decisions are found. The target of solution of the problem subsituation is refined and formalized. Complex problem subsituations are studied by investigation of corresponding mathematical models of making decisions. The calculation of time necessary for the operator to realize the designed operator decisions graph is performed using method [8].

Example of operator decisions graph for typical fight situation of distant air fight 1 × 1. The operator decisions graph in the typical fight situation is made based on the technical document “Logics of operation of the system “Operator—Onboard equipment—Anthropocentric object” which represents the natural language test structured according to global control levels I and II.

Let there exist such document concerning the typical fight situation “Distant air fight of confronting fighters F1 and F2”. Fighter F2 is equipped by the onboard online advisory expert system for distant air fight 1 × 1 with the structure of the knowledge base described in [10].

Onboard online advisory expert system for distant air fight 1 × 1. Let us mark the fragment of the document describing the problem subsituation “Attack” for F1 which occurs in the conditions when the missile launch R(F1) from F1 is possible and the enemy F2 has not yet launched its missile R(F2).

For development of the fragment of operator decisions graph of this problem subsituation, it is necessary to have the following:

(i) the fragment of technical document “Logics of operation of the system "Pilot—Onboard equipment—Aircraft” in the typical fight situation “Distant air fight”;

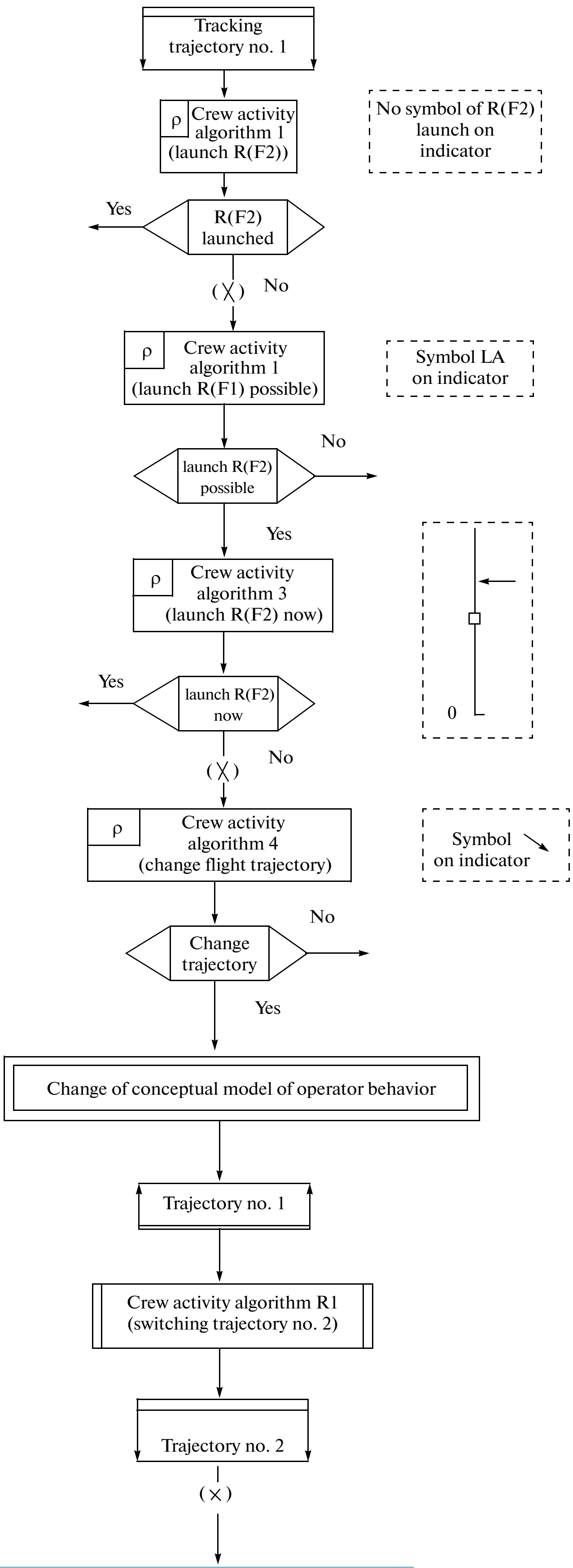
(ii) the fragment of description of information—control field of the crew cockpit, as regards information necessary for solution of the tasks of this problem subsituation;

(iii) the dependence $\tau_{track} = f(\tau_{div})$ for the considered flight trajectory.

Let the mentioned fragment of information—control field be represented in the form of information frame of the cockpit indicator (Fig. 1).

The characteristics of the aircraft automatic control system influencing the process of operator tracking in the considered flight regime are taken into account in the experimental dependence $\tau_{track} = f(\tau_{div})$ shown in Fig. 2.

Let us develop the operator decisions graph for F1 in the typical flight situation distant air fight 1 × 1. Let at the current time instant F1 possess the capability of forestalling launch of R(F1) toward the enemy (sym-



bol LA (launch allowed) on the indicator, see item *8* in Fig. 1). The fact of absence of enemy missile R(F2) launch is detected by the operator by the absence of the corresponding symbol on the indicator (not shown in Fig. 1). Based on these facts, the operator concludes that the problem subsituation “Attack” takes place. In the operator decisions graph this conclusion is made after execution of crew activity algorithms 1 and 2. In this problem subsituation the operator has to make the decision on the range of his missile launch R(F1) (crew activity algorithm 3) and if necessary change the flight trajectory (crew activity algorithm 4). The operator decisions graph shows the operator decision of transition to another flight trajectory (trajectory no. 2); the signal for realization of this decision is produced by crew activity algorithm R1.

These features are also used by the onboard online advisory expert system for distant air fight 1 × 1 to activate this problem subsituation in the knowledge base and produce, presenting to the operator in the information–control field, the following information:

(i) recommended range of R(F1) launch marked by symbol (item *2* between symbols of items *1* and *3* in Fig. 3) on the range scale between F1 and F2;

(ii) recommended type and direction of maneuver (item *7* in Fig. 1).

Let us estimate the operator time spent for realization of the presented fragment of operator decision graph (Fig. 3). The required time is determined separately for each algorithm of activity using the method and time for each fragment of the algorithm collected from corresponding published data in [8].

Crew activity algorithm 1. Detection of enemy missile launch (ρ-decision). Operator noted the absence of the symbol “Launch R(F1)” on the indication.

Composition of crew activity algorithm 1. The latent period and perception inertia, search for the known symbol in the known place of the screen (one online perception unit): mathematical expectation of

Fig. 3. Fragment of operator decisions graph in problem subsituation “Attack” in typical flight situation distant air fight 1 × 1: the branch of operator decisions graph in which the operator performs discrete–continuous tracking for keeping given flight trajectory is surrounded by rectangles with two horizontal lines and downward side arrows (beginning of tracking segment) and upward side arrows (end of tracking segment), crossbuck in brackets shows places in which the operator begins continuous tracking; plane rectangle marks the operator decisions; marker in the left upper corner shows the type of decision; abbreviation CAA with the number of decision and the text characterizing the content of decision are placed inside the rectangle; fragment of information on the indicator according to which the operator makes the decision is shown near each decision; rectangle with double-line side edges shows operator actions on realization of made decision; if several operations are necessary their number is put near this rectangle; abbreviation CAA-R with the number and name of realized decision is placed inside the rectangle.

operator time for execution $\tau_{CAA1} = 0.2$ s, time mean square deviation $\sigma_{CAA1} = 0.3\tau_{CAA1}$. The total time spent by the operator for execution of this operation is:

$\tau_{\Sigma CAA1} = 0.2 + 0.3 \times 0.2 = 0.26$ s.

Crew activity algorithm 2. Determination of the possibility of launching own missile (ρ-decision). Search by the operator of the symbol "LA" on the indication.

Composition of crew activity algorithm 2. The latent period and perception inertia, search for the known symbol in the known place of the screen (one online perception unit): mathematical expectation of the operator time for execution $\tau_{CAA2} = 0.2$ s, time mean square deviation $\sigma_{CAA2} = 0.3\tau_{CAA2}$.

The total time spent by the operator for execution of crew activity algorithm 2 is:

$\tau_{\Sigma CAA2} = 0.2 + 0.3 \times 0.2 = 0.26$.

Crew activity algorithm 3. Determination of recommended range (time instant of launch) of own missile (ρ-decision). Search by the operator of the symbol (item *2* in Fig. 1) on the range scale.

Composition of crew activity algorithm 3:

(a) Detection and perception of two segments (from arrow, item *4* in Fig. 1) to the beginning of range scale (item *1*) and segment starting with the symbol (item *2*) on the scale to scale beginning (one online perception unit): $\tau = 0.1 + 0.3$ s;

(b) Elementary act of making decision: comparison of two segments, as regards their lengths (one feature). Mathematical expectation of execution time for elementary act of making decision $\tau = 0.7$ s, mean square deviation $\sigma_{CAA3} = 0.3\tau_{CAA3}$.

The total time spent by the operator for execution of crew activity algorithm 3 are

$\tau_{\Sigma CAA3} = 0.1 + 0.3 + 0.7 + 0.3 \times 1.10 = 1.43$ s.

Crew activity algorithm 4. Change flight trajectory (ρ-decision). Search by the operator of the symbol on the indication (item *7* in Fig. 1).

Composition of crew activity algorithm 4:

(a) Detection and perception of the symbol of item *7* (one online perception unit): $\tau = 0.1 + 0.3$ s;

(b) Elementary act of making decision: accept recommendation of onboard online advisory expert system for distant air fight 1 × 1 of changing the flight trajectory (of maneuvering).

The total time expenditures spent by the operator for execution of crew activity algorithm 4 are:

$\tau_{\Sigma CAA4} = 0.1 + 0.3 + 0.3 \times 0.4 = 0.52$ s.

Change of conceptual behavior model. The operator prepares for preserving trajectory no. 2. Mathematical expectation and mean square deviation for operator time of changing the conceptual behavior model is

$\tau_{con.m.} = 1.2$ s, $\sigma_{con.m.} = 0.2$ s (both tabulated parameters).

The total time spent by the operator is $\tau_{\Sigma con.m.} = 1.2 + 0.2 = 1.4$ s.

Crew activity algorithm R1. Realization of recommendation of changing flight trajectory. One manual operation.

$\tau_{CAA\text{-}R1} = 0.50$ s, $\sigma_{CAA\text{-}R1} = 0.15$ s (both tabulated parameters averaged over all manual operations),

$\tau_{div} = 0.50 + 0.15 = 0.65$ s.

Tracking operations. The operator works in the regime of discrete–continuous tracking, diverts for execution of crew activity algorithms on making decision τ_{div}, and then returns to eliminate the error of keeping the flight trajectory accumulated during the time when the operator did not monitor the tracking process. Time instants of possible return of the operator to the tracking process are marked on the operator decisions graph by a "crossbuck" in brackets.

The operator time τ_{track} depends on the accumulated error (time when the operator did not monitor the tracking process) and is determined using the experimental dependence $\tau_{track} = f(\tau_{div})$ obtained for each flight regime. For the considered flight regime (trajectory no. 1), this dependence is shown in Fig. 2.

Let the operator return to the tracking process for each corresponding marker in the operator decisions graph from the beginning to the solution of crew activity algorithm R1 inclusive. There are two such return instants (see Fig. 3): after the decision for crew activity algorithm 1 for which the operator terminated the tracking process during $\tau_{div} = 0.26$ s and after the pair of decisions for crew activity algorithms 2 and 3 for which the operator terminated the tracking process during $\tau_{div} = 0.26 + 1.43 = 1.69$ s. Using the dependence shown in Fig. 2, we estimate the time spent by the operator for the tracking process.

(i) after terminating due to crew activity algorithm 1, the operator returns to tracking and spends $\tau_{track} = 0.6$ s;

(ii) after terminating due to crew activity algorithms 2 and 3, the operator returns to tracking and spends $\tau_{track} = 1.30$ s.

All operator time intervals are summarized in Table 1. It follows from this table that for realization of this fragment of operator decisions graph for distant air fight 1 × 1 the operator spends 6.42 s.

3. CLASSIFICATION OF ONBOARD INTELLIGENT SYSTEMS

According to [11, 12] let us briefly describe onboard intelligent systems supporting the process of solution of problems of global control levels I and II. Let us consider the solution of problems of global control level II by the crew: online designation of the current target for the operation session (online designation of typical situation). The motivation for this designation cannot be completely formalized, the smaller part of these motives is weakly structured, and the larger part cannot be even verbally indicated. For making such decisions the crew uses heuristic π–ρ *deci-*

Table 1. Composition of operator activity algorithms

Crew activity algorithm (see Fig. 3)	Time spent by the operator for execution of crew activity algorithm, s	Time of operator diversion from tracking process τ_{div}, s
CAA-1	$\tau_{\Sigma CAA\text{-}1} = 0.26$	
Tracking (after CAA1: in place of crossbuck in Fig. 3)	$\tau_{div} = 0.6$ (see Fig. 2)	$\tau_{track} = 0.26$
CAA-2	$\tau_{\Sigma CAA\text{-}2} = 0.26$	
CAA-3	$\tau_{\Sigma CAA\text{-}3} = 1.43$	
Tracking (after CAA2 + CAA3: in place of crossbuck in Fig. 3)	$\tau_{div} = 1.30$ (see Fig. 2)	$\tau_{track} = 0.26 + 1.43 = 1.69$
CAA-4	$\tau_{\Sigma CAA\text{-}4} = 0.52$	
Change of conceptual model of operator behavior	$\tau_{con.m.} = 1.40$	
CAA-R1	$\tau_{\Sigma CAA\text{-}R1} = 0.65$	
Total time spent by the operator for the sum CAA + tracking (Fig. 2): delay of control signal for changing trajectory	$\tau_{\Sigma change\ of\ trajectory} = 6.42$	

sions. These decisions are informationally supported by the information model of external and onboard situation shown in the information–control field. This model is created by the *onboard intelligent information system "Situation awareness of the crew"* [13].

Problems of global control level II, as a rule, are solved by the operator using π decisions and ρ decisions which makes it possible to develop for these problems *onboard online advisory expert systems for typical situations of operation sessions which supply the crew with the method of achieving the current target of operation session in real time (problems of global control level II)* [14, 15].

4. CLASSIFICATION OF SIMULATION SYSTEMS FOR TESTING AND DEVELOPMENT OF KNOWLEDGE BASES OF ONBOARD INTELLIGENT SYSTEMS OF SYSTEM-GENERATING CORE OF ANTHROPOCENTRIC OBJECT

Development of onboard intelligent systems has the following three stages:

(i) design of algorithmic shell of intelligent system adequate to problems of the subject domain of a certain class of anthropocentric objects;

(ii) filling algorithmic shell of intelligent system by particular knowledge for its operation on board of this class of anthropocentric objects. As a result, the basic sample of intelligent system oriented on generalized (as a rule, most "rich") information medium of anthropocentric objects of this class is obtained;

(iii) adaptation of basic sample of intelligent system to onboard information environment of a particular anthropocentric object of this class. As a result, the adapted sample of the intelligent system is obtained.

At the stages of creation of basic and adapted samples of onboard intelligent systems of anthropocentric object, it is necessary to test and develop their knowledge bases with the help of professional operators. For this purpose, expensive scaled-down simulation complexes with elements of real onboard systems and full-scale information–control fields of the crew cockpit are created. Examples of such scaled-down simulation complexes and their partial description can be found in [1]. Creation of scaled-down simulation complexes requires large financial and labor costs, and their application for development of basic intelligent systems is difficult both due to large duration of work on a basic sample and limited possibility of participation of highly qualified operators.

These considerations force developers of onboard intelligent systems to design computer simulation systems which simulate operation of onboard intelligent system and in a number of cases the operation of the crew (operator) of anthropocentric object.

Two classes of computer simulation systems of are developed based on technical documentation of the simulated anthropocentric object:

Simulation system of global control level I for intelligent information system "Situation awareness of the crew" with necessary inclusion of professional man–operator in the simulation loop.

Simulation system of global control level II for each onboard online intelligent control system for typical situation with simulation of operation of professional man–operator via situation control block.

5. COMPUTER SIMULATION SYSTEM OF FOR DEVELOPMENT OF KNOWLEDGE BASES OF INTELLIGENT INFORMATION SYSTEMS "SITUATION AWARENESS OF THE CREW"

For onboard intelligent systems "Situation awareness of the crew" the specific features of simulation systems are:

(1) online operation;

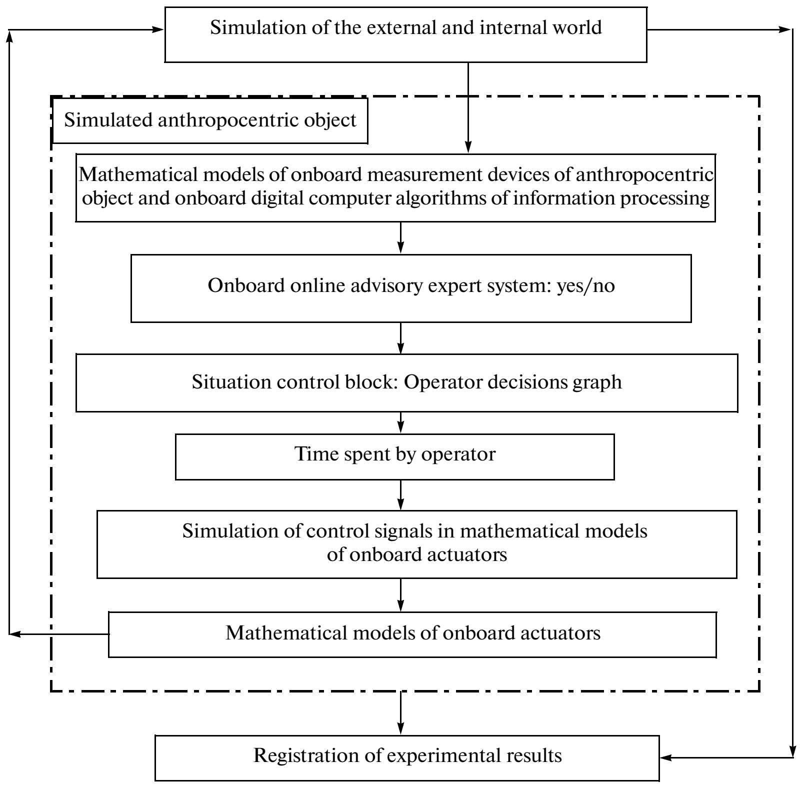


Fig. 4. Functional blocks of simulation system for typical situation.

(2) simulation on a computer display of information frames of the crew cockpit designated for situation awareness;

(3) representation of dynamics of occurrence and development of threats with important events marked on them in the information frame;

(4) simulation on computer keyboard of control organs on anthropocentric object and its onboard equipment used by the crew in solution of problems of global control level I;

(5) *presence of operator in simulation loop*.

These systems will be called simulation systems for global control level I. The functional blocks of simulation systems for global control level I are: external environment and onboard world; anthropocentric object with: (a) onboard measurement devices, (b) simulation of onboard algorithms which submit information to information model of external and onboard environment presented to the operator in the information–control field of the cockpit; (c) information–control field of the crew cockpit as the working place of man–operator; (d) man–operator, (e) block of registration of experimental results.

Since the main types of solutions by the crew of problems of global control level I are heuristic solutions, the presence of the operator in the simulation loop is mandatory.

Upon simulation by the simulation system for global control level I the correctness of assignment by the operator of typical situation, convenience of perception and comprehension of the model of external and onboard environment presented in the information–control field are estimated.

6. COMPUTER SIMULATION SYSTEMS FOR DEVELOPMENT AND TESTING OF KNOWLEDGE BASES OF INTELLIGENT SYSTEMS PROVIDING THE CREW WITH SOLUTION TO PROBLEMS OF GLOBAL CONTROL LEVEL II [17]

Solution of problems of global control level II in which design application by the operator of heuristic solutions is not assumed, is executed by the onboard online advisory expert system for typical situation without a participation of man–operator. The structure of such onboard online advisory expert systems and the technology of their development were discussed in [14–18].

For testing and development of knowledge bases of onboard online advisory expert systems for typical situations, a simulation system for the corresponding typical situation is designed in which the activity of man–operator is represented by the mathematical situation control block.

The functional blocks of the simulation system for typical situation are shown in Fig. 4.

Functional block of the simulation system for typical situation "External and onboard environment" simulates external environment for the onboard online advisory expert system for typical situation and coordinates of SV(typical situation—Problem subsituation); the world corresponding to calculated and expected conditions of use of the anthropocentric object in the considered typical situation. This block simulates external and internal onboard threats occurring in this typical situation, including from similar anthropocentric objects with or without onboard online advisory expert systems for typical situations with knowledge bases of different depth.

Functional block of the simulation system for typical situation "Anthropocentric object" consists of:

(i) mathematical model of the object;

(ii) mathematical model of onboard measurement devices represented by domains of external space (zones) of obtaining information on external environment and recording in these zones the part of information received by anthropocentric object from each measurement device on board. Information is supplied to the input of the onboard online advisory expert system for typical situation and to the coordinates of the situation vector SV(typical situation—problem subsituation) simulating regular information frames of information–control field available to the operator of real anthropocentric object.

In the simulation system for typical situation onboard measurement devices and algorithms realized on onboard digital computers which produce conditional symbols for regular information frames of the information–control field are simulated by:

(i) the fact of presence of such onboard measurement device on board of the anthropocentric object, zone of information collection from external environment, composition of information received by the device from this zone;

(ii) simulation of onboard digital computer algorithms supplying information which is used by the operator in this typical situation to indicators and speech devices of information–control field;

(iii) simulation of onboard digital computer algorithms supplying information to the input of the current typical situation processed by onboard online advisory expert system;

(iv) large-scale onboard online advisory expert system for typical situation;

(v) situation control block simulating necessary for typical situation onboard algorithmic and indication support of the system-generating core and algorithms of activity of man–operator, time spent by the operator on perception, comprehension, and realization of recommendations provided by onboard online advisory expert system for typical situation. The time expenditures spent by the operator are preliminarily calculated [8, 9] and input into the situation control block as corresponding parameters;

(vi) mathematical model of onboard actuators of anthropocentric object simulating their action on external environment according to control signals received from situation control block.

The functional block "Registration of experimental results" records the time evolution of the external environment and recommendations of onboard online advisory expert system for typical situation.

The following is estimated upon simulation using the simulation system for typical situation in the onboard online advisory expert system for typical situation:

(i) completeness of recommendations of the onboard online advisory expert system for typical situation presented to the operator and the value of efficiency criterion for operation of anthropocentric object in the considered typical situation;

(ii) algorithms of operator activity simulated in the situation control block including the operations of detection and comprehension of recommendations of onboard online advisory expert system for typical situation, separation of the part of recommendations which should be realized at the current time instant.

In the absence of an onboard online advisory expert system on board the anthropocentric object, algorithms of operator activity simulated in situation control block include, along with the above components, operations on recognition of problem subsituation, making the decision on this problem subsituation, separation and realization of the part of produced decision which should be realized at the current time instant.

In both cases, the operator should function as the part of tracking processes scheduled for him.

7. EXAMPLE OF SIMULATION SYSTEM FOR TYPICAL SITUATION OF ANTHROPOCENTRIC OBJECT OPERATION

Let us consider the subject domain, distant air fight of enemy fighter aircrafts 1 × 1. Hypothetic fighter F1 equipped by the onboard online advisory expert system for distant air fight 1 × 1 opposes hypothetic fighter F2 not equipped by an onboard online advisory control system for distant air fight 1 × 1 [18].

7.1. Composition of Functional Blocks of the Simulation System for Typical Flight Situation Distant Air Fight with Enemy Fighter

Simulation system for distant missile fight of opposing fighters F1 and F2 is developed for hypothetic composition and characteristics of onboard equipment and weapons of F1 and F2: active noise stations, onboard radar stations, and devices for determination of launch instant; "air–to–air" missiles. In the simulation system for distant air fight 1 × 1 the initial conditions of distant fight are determined: the spatial

Table 2. Functional blocks of F1 in simulation system for distant air fight 1 × 1

Aircraft F1, as the carrier of onboard equipment, crew, weapons; actuator for realization of trajectory of chosen by the crew; situation control block	
Onboard measurement devices	
Object	Mathematical model of object and its properties
1. Onboard radar station with the fact of presence of algorithms of primary and secondary information processing	Model of determination of the fact of presence of F1 aircraft in the zone of onboard radar station. Measurement of spatial coordinates and velocity vector of F2 aircraft $x_2, y_2, z_2, \vec{V}_{F2}$. Constraints on tracking angles of ORS, φ_h and φ_v (h, horizontal, v, vertical)
2. Device for determination of launch instant with the fact of presence of algorithms for primary information processing	Model of all-directional determination of the fact of bearing and time instant of enemy missile launch R(F2)
3. Piloting–navigation complex with the fact of presence of algorithms for primary and secondary information processing;	Model of identification with measurements of flight navigation complex of spatial coordinates and velocity vector of F1 aircraft $x_1, y_1, z_1, \vec{V}_{F1}$
4. Onboard digital computer algorithms producing information to information–'control field and direct control signals to onboard actuators;	Models of onboard digital computer algorithms simulating their structure
5. Information–control field (indication; speech messages)	Model of composition and content of current information in information–control field (F1), fact of receipt of this information by situation control block (F1)
Algorithms of system-generating core	
1. Onboard online advisory expert system for distant air fight 1 × 1	Full scale model of Onboard online advisory expert system for distant air fight 1 × 1
2.Situation control block	Model of simulation of pilot operation with recommendations of onboard online advisory expert system for distant air fight 1 × 1 with account of time spent by the pilot
Onboard measurement devices	
1. Spacecraft	Mathematical model of fighter ATAMAN (F1)
2. Automatic control system (regime of direction control)	Mathematical model of automatic control system is simulated by the presence on windshield indicator of direction signals of flight trajectory chosen for realization and experimental dependence $\tau_{track} = f(\tau_{div})$, obtained for each type of flight trajectory
2. Missile R(F1) on board, in air	Mathematical model of missile on board. Approximating mathematical model of "air–to–air" missile [21] AMM(F1)
3. Active noise station	Mathematical model of active noise station (time of action of noise cycle τ_{ANS} and probability of failure of enemy missile guiding P_{ANS} for ANS(F1)

coordinates and velocity vector of F1, $x_1, y_1, z_1, \vec{V}_{F1}$, and the spatial coordinates and velocity vector of F2: $x_2, y_2, z_2, \vec{V}_{F2}$.

In practice initial information for simulation models of onboard equipment and simulation of results of operation of algorithmic and indication support are the descriptions of elements of onboard equipment, information–control field of the cockpit with the composition of control organs and symbols in the information frames used by the pilot in distant air fight 1 × 1. In development of real algorithmic and indication support, engineers are oriented to crew activity algorithms in distant air fight 1 × 1 of class of ρ and π decisions [7, 8].

For description of the simulation system for distant air fight 1 × 1 the composition of onboard equipment of F1 is represented in Table 2. For aircraft F2, a similar table is formed including the composition of onboard equipment and

(i) algorithms realized in onboard digital computers producing information to information–control field and direct control signals to onboard actuators;

(ii) information–control field;

(iii) presence or absence of onboard online advisory expert system for distant air fight 1 × 1;

(iv) crew activity algorithms;

(v) onboard actuators.

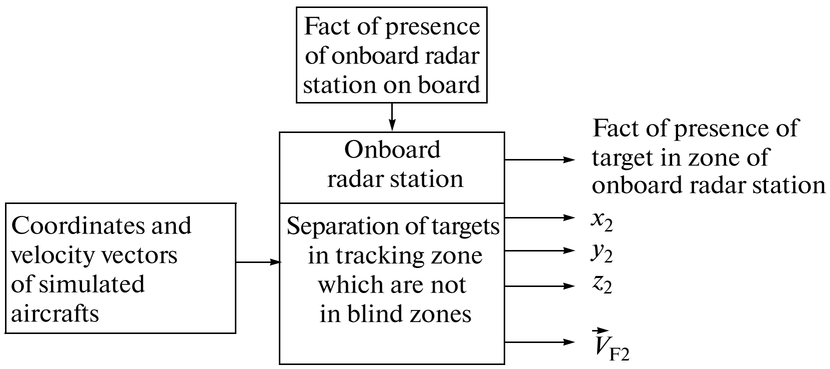


Fig. 5. Schematic diagram of inputs/outputs of onboard radar station in simulation system for distant air fight 1 × 1.

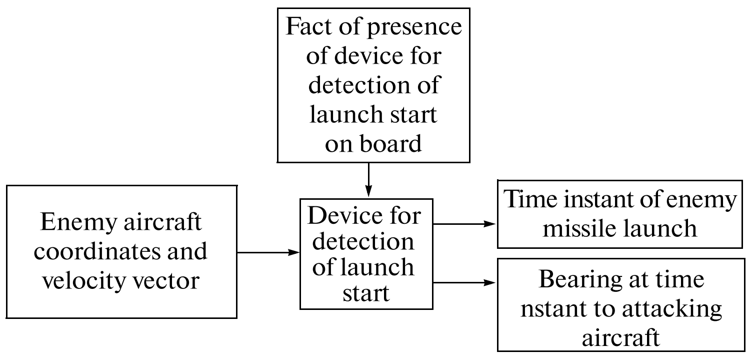


Fig. 6. Schematic diagram of inputs/outputs of device for determination of launch start in the simulation system for distant air fight 1 × 1.

7.2. Functional Block of the Simulation System for Distant Air Fight 1 × 1 *"Fighter Aircraft"*

In the simulation system, the aircraft is simulated as the carrier of onboard equipment, crew, weapons, and as an actuator. In the model of the aircraft as the carrier of onboard equipment, crew and weapons, the presence of measurement devices, onboard digital computer algorithms, crew (pilot) activity algorithms, actuators (i.e., all that is indicated in Table 2) is simulated.

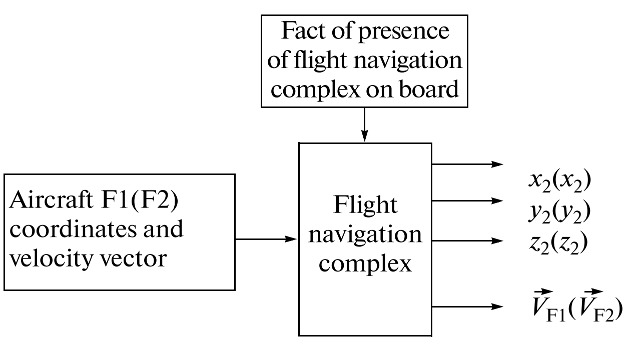


Fig. 7. Schematic diagram of inputs/outputs of flight navigation complex in the simulation system for distant air fight 1 × 1.

7.2.1. Onboard measurement devices. (A) *Onboard radar station* and algorithms of primary and secondary information processing:

(i) equipment of the aircraft by onboard radar station is simulation by the presence of the signal on coordinates of enemy aircraft $x_2, y_2, z_2, \vec{V}_{F2}$ in the tracking zone of onboard radar station;

(ii) onboard radar station provides detection of air targets, determination together with recognition system of their state affiliation, instantaneous capture and auto-tracking of the target that got in the tracking zone of onboard radar station;

(iii) in the model, the tracking zone is described by the segment of the sphere with the radius D_{track} and half-opening horizontal φ_{hor} and vertical φ_{ver} angles. The axis of the segment coincides with the aircraft velocity vector.

The schematic diagram of inputs/outputs of onboard radar station in simulation system for distant air fight 1 × 1 is shown in Fig. 5.

(B) *Device for determination of missile launch*. The equipment of the aircraft by the device for determination of launch instant is simulated by the presence of the signal on the time instant of enemy missile launch and information on direction (bearing) at the time instant of missile launch toward the attacking enemy fighter that launched the missile. The schematic diagram of inputs/outputs of the device for determination of missile launch in the simulation system for distant air fight 1 × 1 is shown in Fig. 6.

(C) *Flight navigation complex*. The equipment of the aircraft by flight navigation complex is simulated by the presence of signals on aircraft coordinates and the velocity vector $x_1, y_1, z_1, \vec{V}_{F1}$. The schematic diagram of inputs/outputs in the simulation system for distant air fight 1 × 1 is shown in Fig. 7.

7.2.2. Onboard digital computer algorithms producing information to information–control field and direct control signals to onboard actuators. The simulation of onboard digital computer algorithms used by pilot of F1 in distant air fight 1 × 1 is recorded as the fact of presence of these algorithms on board the corresponding aircraft. In the simulation system for distant air fight 1 × 1 the operation of such algorithms is provided by supply to the input of onboard online advisory control system for distant air fight 1 × 1 of the information that is sent from imitators of onboard measurement devices at the current time instant. Onboard online advisory control system for distant air fight 1 × 1 provides the pilot with all necessary information for distant air fight 1 × 1 in the form of recommendations on the method of achieving the target of distant air fight 1 × 1.

For F2 in the case when it is not equipped by onboard online advisory expert system for distant air fight 1 × 1 it is necessary to simulate onboard digital computer algorithms which supply information in distant air fight 1 × 1 to pilot of F2. Depending on the composition of such algorithms, on board of the assumed enemy, onboard digital computer algorithm of calculation of maximal range of its missile launch D(R(F2)) and possible other typical launch ranges [19] is simulated, as well as onboard digital computer algorithm for trajectory control of F2 in distant air fight 1 × 1. Simulation of these onboard digital computer algorithms should correctly reflect the structure of algorithms realized on board F2, providing the composition of information available in F2 information–control field and control signals sent to imitators of onboard actuators of F2. Information taken at the current time instant from simulators of onboard measurement devices is supplied to the input of simulators of onboard digital computer algorithms.

7.2.3. Fragment of situation control block of problem subsituation "Attack". Typical flight situation distant air fight 1 × 1. Input signals to the fragment of situation control block are:

(i) enemy missile launch R(F2): yes/no. Signal is supplied from the onboard measurement device;

(ii) missile launch R(F1) possible: yes/no. Signal is supplied from the imitator of corresponding onboard digital computer algorithm;

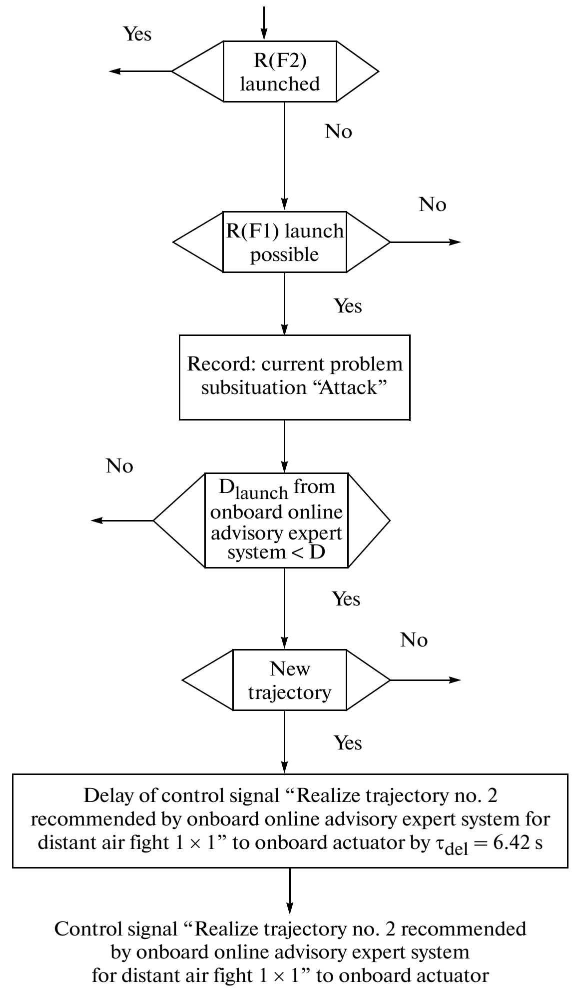


Fig. 8. Fragment of situation control block for problem subsituation "Attack" in typical flight situation distant air fight 1 × 1 of F1 fighter.

(iii) current distance D between fighters F1 and F2. Signal is supplied from corresponding onboard measurement device;

(iv) recommended missile launch range R(F1). Signal D_{launch} is supplied from onboard online advisory expert system for distant air fight 1 × 1.

(v) recommendation for changing flight trajectory (maneuvering). Signal is supplied from onboard online advisory expert system for distant air fight 1 × 1.

The parameter "Delay time of supply of control signal to onboard actuator"(τ_{delay}) is calculated in advance and introduced into situation control block after each crew activity algorithm R (Fig. 8).

7.2.4. Onboard actuators. The composition of onboard actuators simulated in the simulation system for distant air fight 1 × 1 is:

(A) aircraft as actuator;
(B) automatic control system;
(C) "air–to–air" missile;
(D) active noise station.

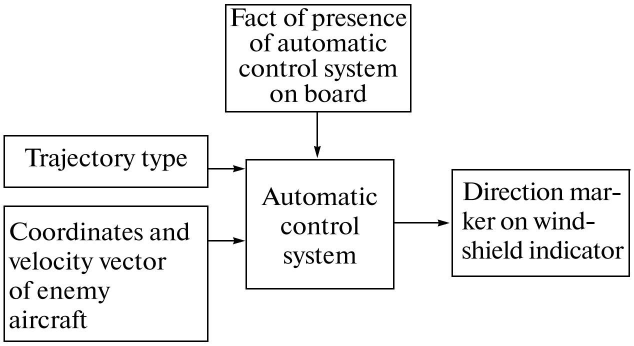


Fig. 9. Schematic diagram of inputs/outputs of automatic control system in the simulation system for distant air fight 1 × 1.

(A) *Model of aircraft as actuator (mathematical model "ATAMAN")*. The model of fighter aircraft [20] (F1 equipped by onboard online advisory expert system and F2) contains blocks for calculation of initial state, power unit, calculation of altitude–velocity parameters, aircraft trajectory motion, control of engine thrust, autopilot, piloting loop and data base of the aircraft. The mathematical model of the aircraft is presented by the module of automation of trajectory maneuvering "ATAMAN", which provides simulation of aircraft motion in space during the time interval ΔT along the trajectory fragment determined from situation control block. If the mathematical model is used for simulation of aircraft F1 and enemy aircraft motion, the corresponding parameters are requested from the "Block of characteristics of F1 aircraft" and "Block of characteristics of enemy aircrafts". The structural diagram of mathematical model "ATAMAN" is taken from [20].

(B) *Automatic control system (direction control regime)*. The equipment of the aircraft by the automatic control system is simulated by the presence of direction signals of flight trajectory chosen for realization on windshield indicator. The schematic diagram of inputs/outputs of automatic control system in simulation system for distant air fight 1 × 1 is shown in Fig. 9.

The characteristics of automatic control system influencing the process of operator tracking in the considered flight regime are taken into account in the experimental dependence $\tau_{track} = f(\tau_{div})$ (Fig. 2).

(C) *Functional block of the simulation system for distant air fight 1 × 1 "Air–to–air" class missile.* Two states are separated:

(i) missile on the carrier (the fact of presence of the missile on board the carrier is simulated). The missile coordinates and velocity vector until the time instant of its launch inclusive coincide with the coordinates and velocity vector of the carrier);

(ii) missile in air.

C.1. Model of missile on the carrier. The fact of presence of the missile on board the carrier is simulated. The coordinates of the missile and its velocity vector until the time instant of launch inclusive coincide with the coordinates and velocity vector of the carrier.

C.2. Model of missile in air. The model of missile simulates ballistic capabilities of "air–to–air" class missile [21]. The approximating mathematical model makes it possible to calculate spatial position of the missile ($X_m, H_m, Z_m, V_m, \psi_m, \theta_m$). In the approximating mathematical model guiding using the method of "proportional navigation" is simulated. For description of a particular type of missile the following parameters depending on the missile launch conditions are used:

p is the thrust of the missile engine on the active leg (constant quantity);

t_a is the time instant of the end of missile engine operation (duration of active segment);

T is the missile drag coefficient depending on the launching conditions (described by two constant quantities, T_a for $t \le t_a$ and T_m for $t > t_a$);

T_i is the missile inductive resistance coefficient, depending on the launching conditions (described by two constant quantities T_{ia} for $t \le t_a$ and T_{ip} for $t > t_a$);

missile guiding method: proportional approach;

τ_{aut} is the duration of autonomous leg of missile flight (begins after the attacked target is captured by the self-guiding head of the missile);

P_{ground} is the "ground" probability of hitting the target.

Outputs of the approximating mathematical model are: phase coordinates of the missile, missile flight stage.

(D) *Model of active noise station*. The model represents the estimation of the influence of active noise on the process of enemy "air–to–air" missile guiding. Active noise stations on board fighters are represented by the two-parametric model: τ_{ANS} is the duration of the noise cycle in seconds, P_{ANS} is the probability of guiding failure of attacking missile for one complete noise cycle.

7.3. Block of Recording Results of Performed Fight

This block is designated for storing and presentation of results of performed fight.

7.3.1. Information for fight process analysis. For each performed fight the following is recorded:

(i) parametric characteristics participating in the given fight of F1 and F2 aircrafts;

(ii) parametric characteristics of R(F1) and R(F2) missiles;

(iii) composition of onboard equipment of F1 and F2 and its characteristics;

Table 3. Fragment of knowledge base of onboard online advisory expert system for distant air fight 1 × 1 of F1 fighter for one pair of trajectories in problem subsituation "Attack" for F1

F2	F1							
	$D_{(0)\text{virt}}$	$D_{(1)\text{virt}}$	$D_{(2)\text{virt}}$	…	$D_{(i)\text{virt}}$	…	$D_{(n-1)\text{virt}}$	$D_{(n)\text{virt}}$
$D_{(0)\text{virt}}$	$F_{0,0}$							
$D_{(1)\text{virt}}$	$F_{1,0}$	$F_{1,1}$						
$D_{(2)\text{virt}}$	$F_{2,0}$	$F_{2,1}$	$F_{2,2}$					
…								
$D_{(j)\text{virt}}$	$F_{j,0}$	$F_{j,1}$	$F_{j,2}$		$F_{j,i}$			
…								
$D_{(n-1)\text{virt}}$	$F_{n-1,0}$	$F_{n-1,1}$	$F_{n-1,2}$		$F_{n-1,i}$		$F_{n-1,n-1}$	
$D_{(n)\text{virt}}$	$F_{n,0}$	$F_{n,1}$	$F_{n,2}$		$F_{n,i}$		$F_{n-1,n-1}$	$F_{n,n}$

(iv) initial conditions of the fight (spatial positions and velocity vectors of aircrafts).

At each pre-determined time instant of the given fight the following information is recorded in the simulation system for distant air fight 1 × 1 from the knowledge base of onboard online advisory expert system for distant air fight of F1 equipped by the onboard online advisory expert system for distant air fight:

(A) Current problem subsituation activated in the knowledge base of the onboard online advisory expert system for distant air fight 1 × 1 and recommendations produced for this problem subsituation. Recommendations for optimal strategy of F1 behavior and expected strategy of enemy F2 behavior. They are represented by the system in the form of the table (matrix) of values of the *criterion of estimation of fight result* $F = P_2 - P_1$, where P_i is the probability of fighter F_i defeat for different combination of trajectories of F1 and F2 aircrafts. This table for one pair of trajectories in the problem subsituation “Attack” for F1 from the knowledge base of onboard online advisory expert system for distant air fight 1 × 1 is given below (Table 3). Vertical columns are marked by virtual (D_{virt}) missile launch R(F1) ranges for F1 aircraft, and rows of the matrix are marked by virtual ranges of missile launch R(F2) for F2 aircraft. Table cells contain the values of the criterion $F = P_2 - P_1$ (difference of probabilities of defeat for F2 and F1). Table cells are connected with the following information:

(i) for F1 recommended type and direction of F1 trajectory, missile launch range, number of noise cycles of the first and second attempts;

(ii) for F2 expected type and direction of F2 trajectory, missile launch range, number of noise cycles of the first and second attempts.

Optimal trajectory strategy for each of the aircrafts is sought and recorded; the search is performed using a series of experiments for different combinations of trajectory strategies produced by the block of construction of trajectory strategies in onboard online advisory expert system for distant air fight 1 × 1.

(B) Actually realized flight trajectory of F1 and F2 and trajectories of launched missiles, ranges of executed missile launches R(F1) and R(F2), time instants and number of noise cycles for F1 and F2.

7.3.2. Estimation of performed fight. For each performed fight actually realized strategies of enemy behavior are used to calculate the following factors which provide estimation of the fight efficiency:

(i) probabilities of defeat of F1 and F2, P_1 and P_2;

(ii) conditional probability of defeat of F2, keeping F1 safe;

(iii) probability of mutual defeat of F2 and F1;

(iv) relative probabilistic criterion $F = P_2 - P_1$.

After simulations in the simulation system of different altitude levels and fight beginning conditions the integral estimate of fight efficiency is calculated (for studied targets) for the particular altitude level; and the degree of influence of recommendations of the onboard online advisory expert system for distant air fight 1 × 1 on the result of the fight for each level is analyzed.

7.4. Preparation of Initial Information for Simulation

Efficiency of distant air fight 1 × 1 should be estimated with account of onboard equipment of simulated aircrafts used in distant air fight 1 × 1 and onboard algorithmic and indication support of both enemies. For simulation of distant air fight of chosen fighters, the following information is preliminarily collected:

(i) composition and characteristics of onboard equipment of fighters used in distant air fight 1 × 1;

(ii) characteristics of both aircrafts;

(iii) type and characteristics of “air–to–air” missiles;

(iv) composition of onboard indication support of distant air fight and control organs on information–control field used by pilots in distant air fight.

Table 4. Explanation of rows of dialog window shown in Fig. 11

X, m	Cartesian coordinates of aircraft
H, m	Same
Z, m	"
V, m/s	Absolute value of aircraft velocity
ψ	Aircraft course angle, degrees
θ	Aircraft pitch angle, degrees
γ	Aircraft bank angle, degrees
Horizontal trajectory before launch [0...3]	Horizontal component of aircraft maneuver before launch of own missile
Vertical trajectory before launch [0...3]	Vertical component of aircraft maneuver before launch of own missile
Horizontal trajectory after launch [0...3]	Horizontal component of aircraft maneuver after launch of own missile
Vertical trajectory after launch [0...3]	Vertical component of aircraft maneuver after launch of own missile

The following operations are executed according to the collected material:

(i) parametric mathematical models of carriers of their onboard radar stations, active noise stations, "air–to–air" missiles for each of the enemy fighters are parametrically adjusted for those units which are included in the equipment of the corresponding fighter;

(ii) onboard online advisory expert system for distant air fight 1 × 1 is used in full scale in the mathematical model;

(iii) situation control blocks reflecting the specific features of indication support of distant air fight and the composition of control organs in indication–control field used by the pilot in the distant air fight are parametrically adjusted for the particular fighter.

Determination of these parameters requires preliminary development of the pilot decisions graph (see Section 2) and estimation of time spent by the pilot for execution of crew activity algorithms.

The set of initial conditions for beginning of distant air fight 1 × 1 important for the fighter is formed, and, according to this set, experiments for elucidation of the influence of each factor on the result of the fight and estimation of the contribution of onboard online advisory expert system into this result are performed.

8. COMPUTER REALIZATION OF THE SIMULATION SYSTEM FOR DISTANT AIR FIGHT 1 × 1

The form of the simulation system for distant air fight 1 × 1 described in Section 7 was used to develop the computer realization of the simulation system with account of [22].

8.1. User Manual of the Program of the Simulation System for Distant Air Fight 1 × 1 (version 1: Distant Air Fight 1 × 1-T)

The program realization of the simulation system for distant air fight 1 × 1-T is the first version of realization of the simulation system for distant missile air fight. In this system, distant air fight 1 × 1 can be simulated for given initial fight conditions and assumed characteristics of aircrafts and their actuators and obtain at the output recommendations on optimal active noise stations, missile launching range, flight trajectory, and assumed enemy behavior at the current fight instant for the given aircraft coordinates $(x_1, y_1, z_1, \vec{V}_{F1}, x_2, y_2, z_2, \vec{V}_{F2})$.

The simulation system "Distant air fight 1 × 1-T" consists of several executable modules (exe files):

(i) AMM.exe is the mathematical model of motion of the controlled "air–to–air" missile (approximating mathematical model);

(ii) Fighter.exe is the mathematical model of controlled aircraft motion (mathematical model "ATAMAN");

(iii) ILS.exe is the simulation of frames of windshield indicator;

(iv) IUP.exe is the simulation of information–control field;

(v) SIM.exe is the main module of the simulation system;

(vi) SOK2Matrix.exe is the console application (without graphic user interface) for conversion of results of operation of the simulation system in the file format convenient for further analysis;

(vii) BOSES_DBV_Exp.ini is the simulation system settings file (initial position of aircrafts, missile types, etc.);

(viii) BOSES_DVB1 × 1_read_sok_v2_(2000).mcd is the MathCad 2000 file for construction of plots using files obtained as a result of operation of the simulation system (in folders of "SOK20090413192154" type).

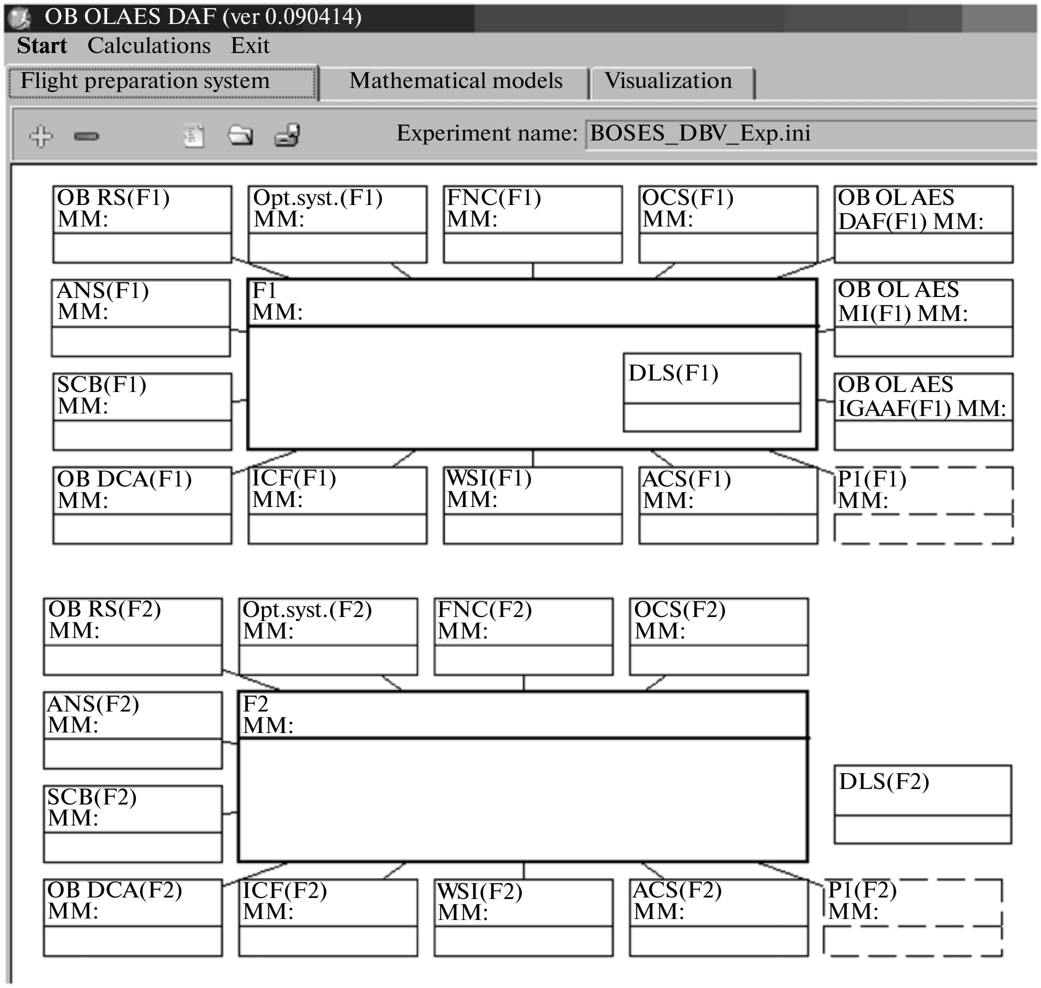


Fig. 10. Composition of onboard equipment of F1 and F2 for simulation in the simulation system for distant air fight 1 × 1-T. OB RS—Onboard radar station; MM—Mathematical model; FNC—Flight navigation complex; OCS—Object control system; OB OL AES DAF—Onboard online advisory expert system for distant air fight; ANS—Active noise station; SCB—Situation control block; OB DCA—Onboard digital computer algorithm; ICF—Information–control field; WSI—Windshield indicator; ACS—Automatic control system; OB OL AES MI—Onboard online advisory expert system for MI; OB OL AES IGAAF—Onboard online advisory expert system for introduction of AG into air fight; DLS—Device for detection of launch start.

8.2. Order of Operation with the Simulation System for Distant Air Fight 1 × 1.1

(1) Run main file of the simulation system SIM.exe. In the bookmark "Flight preparation system" press the open button for loading the file of BOSES_DBV_Exp.ini type which is situated in the same folder as SIM.exe. The file of BOSES_DBV_Exp.ini type can be renamed if desired, but the file name should contain only Latin letters and numbers without blanks and special symbols (like ",", ";", etc.).

(2) After execution of item *1*, the image shown in Fig. 10 should appear on the screen.

Parameters of each block shown in Fig. 10 are changed by double click of the left mouse button on this block. In this version of the simulation system, parameters can be changed only in blocks of F1 and F2 aircrafts, their missiles R(F1), R(F2), and their active noise stations ANS(F1), ANS(F2). Figure 11 shows the form of dialog window for adjustment of aircraft parameters. Table 4 gives the explanation of the rows of dialog window in Fig. 11. Codes of horizontal and vertical components of aircraft maneuver are used:

0—means the flight with constant course and pitch (for horizontal and vertical component of aircraft maneuver, respectively);

1—means attack curve;

2—means the maneuver "tactical turn";

3—means the maneuver "guaranteed turn".

Adjustment of missile parameters is shown in Fig. 12.

Adjustment of parameters of the active noise station of F1 fighter is shown in Fig. 13, explanation of rows is given in Table 5. Similar adjustments are made for F2 fighter (missile and active noise station adjustment).

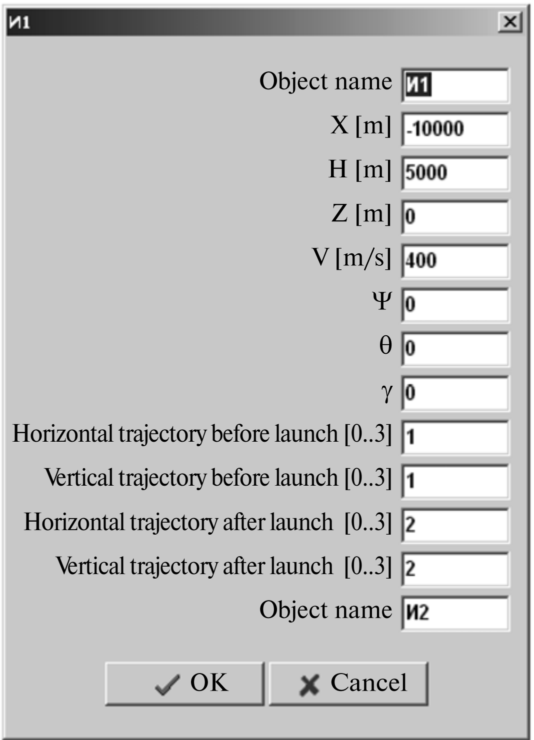


Fig. 11. Dialog window of the simulation system for distant air fight 1 × 1 for determination of initial aircraft position and adjustment of its situation control block (in this case, fighter F1 is considered; rows are explained in Table 4).

After the complete cycle of calculations the column file BosesDBV1 × 1SOK_csv is formed, which contains information on realization of each variant of distant air fight. Explanation of several columns in this file is given in Table 6.

This file should be reduced to the matrix form using the program SOK2Matrix.exe. For this purpose, it is necessary to drag the file BosesDBV1 × 1SOK.csv on the file SOK2Matrix.exe. As a result the file BosesDBV1 × 1SOK_.xls is obtained. In this file the efficiency factor of distant air fight 1 × 1 is denoted by $F = P2 - P1$.

We recall [10] that in the knowledge base of the onboard online advisory expert system for distant air fight 1 × 1 the obtained matrix is used to find maxmin and minmax in corresponding semi-matrices for the problem subsituation “Attack” and “Defense with Attack”. The strategy corresponding to max(maxmin, minmax) is optimal.

(3) If any changes are made in editor windows, they should be stored. For this purpose in the bookmark “Flight preparation system” the storing button should be pressed and the folder containing the program SIM.exe should be selected.

(4) The main menu of the program contains three items: Start, Calculations, and Exit. The first item (“Start”) is designated for single simulation of distant

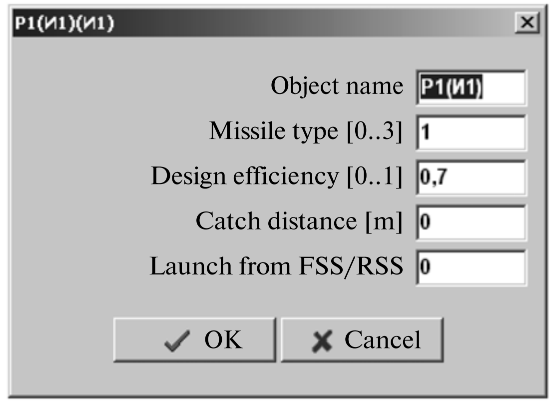


Fig. 12. Adjustment of missile parameters F1 fighter.

air fight. The item “Exit” makes it possible to close the application. The item “Calculations” contains subitems “Results of distant air fight 1 × 1”, “Save signals”, and “Write SOK”.

(5) Choose the item “Calculations|Results of distant air fight 1 × 1” in the main menu of the application SIM.exe for running calculation of the onboard online advisory expert system for distant air fight 1 × 1. Calculations are performed for the current aircraft position only. Automatic movement of aircrafts one step forward is impossible in this program version. After launching this menu item series of distant air fights 1 × 1 are shown on the computer screen in fast time scale. After the end of calculations, the message “Calculation is over!” is shown.

(6) After the end of calculations, according to the item “Calculations|Results of distant air fight 1 × 1” the folder with the name of SOK20090414183705 type (current date and time of program launch) is formed in

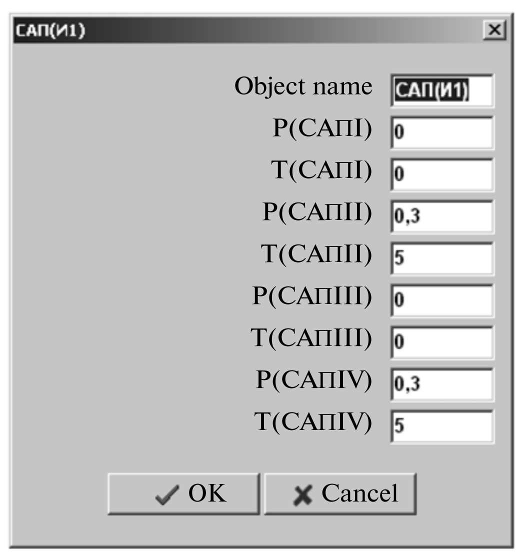


Fig. 13. Adjustment of parameters of active noise station of F1 fighter (explanation of rows is given in Table 5).

Table 5. Explanation of rows of dialog window shown in Fig. 13

P(Automatic control system I)	$P_{ACS\ I}$ – Probability of action of one noise cycle of first attempt
T(Automatic control system I)	$\tau_{ACS\ I}$ – Duration of one noise cycle of first attempt
P(Automatic control system II)	$P_{ACS\ II}$ – Probability of action of one noise cycle of second attempt
T(Automatic control system II)	$\tau_{ACS\ II}$ – Duration of one noise cycle of second attempt
P(Automatic control system III)	$P_{ACS\ III}$ – Probability of action of one noise cycle of third attempt
T(Automatic control system III)	$\tau_{ACS\ III}$ – Duration of one noise cycle of third attempt
P(Automatic control system IV)	$P_{ACS\ IV}$ – Probability of action of one noise cycle of fourth attempt
T(Automatic control system IV)	$\tau_{ACS\ IV}$ – Duration of one noise cycle of fourth attempt

Table 6. Final file of fight result

Column name	Explanation
Dpusk(R1), Dpusk(R2)	Missile launch range
Dend(R1), Dend(R2)	Missile undershot
Tbeg(R1), Tbeg(R2)	Missile launch time (t_0 is the beginning of simulation)
Tgsn(R1), Tgsn(R2)	Time of target capture by self-guiding head
Tend(R1), Tend(R2)	Time of missile flight end
RsapI(F1), RsapI(F2)	Number of noise cycles of first attempt of application of active noise stations of F1 and F2 fighters
RsapII(F1), RsapII(F2)	Number of noise cycles of second attempt of application of active noise stations of F1 and F2 fighters
RsapIII(F1), RsapIII(F2)	Number of noise cycles of third attempt of application of active noise stations of F1 and F2 fighters
RsapIV(F1), RsapIV(F2)	Number of noise cycles of fourth attempt of application of active noise stations of F1 and F2 fighters
Flags	Flags characterizing missile processing; the column contains the row of six items filled by pluses (+) and minuses (–): 1 bit launch R1, 2 bit capture of target by self-guiding head of R1, 3 bit hitting target by R1, 4 bit launch of R2, 5 bit capture of target by self-guiding head of R2, 6 bit hitting target by R2
PopType(R1)	Type of F1 missile hitting: SimHit simultaneous hitting, DelHit delayed hitting, PreHit pre-emptive hitting, NoHitR2 R2 missed target, NoHitR1 R1 missed target, NoLaunchR2 R2 missile not launched, NoLaunchR1 R1 not launched, NoHitR1R1 both missiles missed targets, NoLaunchR1R2 both missiles not launched
P(R1), P(R2)	Missile efficiency in conditions of information counteraction
P(F1), P(F2)	Fighter defeat probability F = P(F2) – P(F1))
F(F1)	Efficiency factor of distant air fight F = P(F2) – P(F1) changes in the range
Effect(F1)	Efficiency of distant air fight changes in the range [0…1]

the folder in which SIM.exe is situated for preventing the loss of results.

(7) For constructing plots using the files of "Dp(C1)= 20615_Dp(F2) = 20615.sok" type the file BOSES_DVB1 × 1_read_sok_v2_(2000).mcd situated near the main file SIM.exe in the folder of "SOK20090414183705" type should be launched. The folder name (of "SOK20090414183705" type) and the name of the necessary file of "Dp(C1)=20615_Dp(F2)=20615.sok" type should be determined in the first lines of mcd file.

Table 7. Enemy missiles

Missile characteristics	F1	F2
Missile type	2	2
Ground efficiency	0.7	0.7
Capture range of self-guiding head, m	4000	4000
Launch hemisphere	Front hemisphere	Front hemisphere

Table 8. Mutual position of enemies at the beginning of distant air fight 1 ± 1 and fragments of their trajectories

Fighters	F1	F2
X, m	0	40000
H, m	10000	10000
Z, m	0	0
V, m/s	400	400
Course, degrees	30	180
Pitch, degrees	0	0
Bank, degrees	0	0
Horizontal trajectory before launch	CA	CA
Vertical trajectory before launch	0	0
Horizontal trajectory after launch	Tactical tur	Tactical tur
Vertical trajectory after launch	0	0
Missile type	2	2
Missile ground efficiency	0.7	0.7
Capture range of self-guiding head, m	4000	4000
Launch hemisphere	Front hemisphere	Front hemisphere

The name of folder of SOK files (near SIM.exe) is dirSOK:=SOK20090414183705".

The name of SOK file in this folder is fnSOK:=Dp(C1)=20615_Dp(F2)=8615.sok".

Then the item of main menu of MathCad "Math|Calculate Worksheet" should be chosen for updating information in mcd document. After that features of defeat of F1 and F2 fighters in the document can be analyzed,

kill_F1 = 0, kill_F2 = 1 are the features of defeat of F1 and F2 fighters, respectively.

This document also contains several plots with the following notation:

(i) F1, F2 are fighters 1 and 2, respectively;

(ii) msl F1, msl F2 are missiles of F1 and F2 fighters;

(iii) Fly_end is the status of flight of missiles of F1 and F2 fighters (–1 missile is not launched, 0 missile is launched, 2 missile hit the target, >0 missile ended flight);

(iv) X, Y, Z are Cartesian coordinates (in km) of the Earth's coordinate system in which the plots of flight trajectories of F1 and F2 aircrafts and two missiles launched from F2 are constructed;

(v) PSI, TETA are the course and pitch angles, respectively (positive direction is clockwise);

(vi) Time is the current time (in s) of aircraft and missile flight;

(vii) V flight velocity (in m/s).

8.3. Some Results of Simulation of Operation of the Onboard Online Advisory Expert System for Distant Air Fight 1 × 1 in the Simulation System

Let us simulate distant air fight 1 × 1 of hypothetic fighters F1 and F2.

8.3.1. Composition of onboard equipment installed on fighters F1 and F2.

Aircraft F1:

(1) onboard radar station;

(2) device for determination of launch instant;

(3) flight navigation complex;

(4) situation control block = Onboard online advisory expert system for distant air fight 1 × 1;

(5) "Air–to–air" missile R(F1) described by the parameters $P, t_a, T_a, T_m, T_{ia}, T_{im}, P_{ground}, \tau_{opt}$ (taken from [2]) and Table 7;

(6) active noise station: τ(ANS(F1), P(ANS(F1)).

In the simulation system for distant air fight 1 × 1 the aircraft model "ATAMAN" is adjusted for the parameters of the fighter described in [2].

Aircraft F2. Similar to composition of F1; the difference is in the situation control block: situation control block = simulation of onboard digital computer algorithms providing indication of distant air fight 1 × 1 of F2 aircraft (see [2]).

The parameters of onboard devices are taken from [2].

In the simulation system for distant air fight 1 × 1 the model of F2 aircraft "ATAMAN" is adjusted for the parameters of enemy fighter [2].

The mutual position of aircrafts at the fight time instant t_0 (left column for F1 and right column for F2) is given in Table 8.

The distance between the fighters D = 40000 m. Until the fight time instant t_0 the enemies did not use weapons (for both fighters situation TVT or "Attack"). Information presented in Fig. 11 and Table 6 is supplied to the knowledge base of the onboard online

Table 9. Recommendations of onboard online advisory expert system for distant air fight 1 × 1 at fight instant t_0

Problem subsituation "Attack" recommended for F1	D_{opt}(F1)	F
Information	34000	0.07

Table 10. Expected actions of the enemy produced by onboard online advisory expert system for distant air fight 1 × 1 at fight instant t_0

Problem subsituation "Defense with attack" recommended for F2	D_{opt}(F2)	F
Information	31000	0.07

advisory expert system for distant air fight 1 × 1 of F1 fighter. Figure 11 shows the trajectory strategies of enemies which are generated in the "Block of generation of hypotheses" in the knowledge base of the onboard online advisory expert system for distant air fight 1 × 1.

8.3.2. Some results of simulation. Recommendations on optimal range and time instant of launch of F1 missile produced by the onboard online advisory expert system for distant air fight 1 × 1-T at the fight time instant t_0 are given in Table 9.

Thus, at the time instant t_0 the simulation system of the onboard online advisory expert system for distant air fight 1 × 1-T the following recommendation is produced: to launch missile first from a distance of 34000 m, i.e., realize problem subsituation "Attack". In this case, the onboard online advisory expert system for distant air fight 1 × 1 also calculates the assumed strategy of F2 at this fight time instant t_0 (Table 10). It is expected that F2 aircraft will perform delayed launch from a distance of 31000 m, i.e., will apply problem subsituation "Defense with attack".

For the current fight time instant t_0, calculations for virtual missile launches from different ranges and fixed trajectory strategies of enemies chosen from the "Block of generation of trajectory strategies" are performed in the knowledge base of onboard online advisory expert system for distant air fight 1 × 1. For each combination of ranges of virtual launches, the following is calculated:

(i) number of noise cycles which can be realized by enemies;

(ii) value of the criterion F;

(iii) type of missile hitting time instant.

Table 11 gives the prediction of fight estimate for different missile launch ranges D(F1)/D(F2) from F1 and F2 fighters, respectively, produced by the onboard online advisory expert system for distant air fight 1 × 1 using trajectory tactics of fighters presented in Table 6 and application of noise before and after the launch of the first missile (see [10] for explanations.

Table 11 gives the value of the criterion $F = P_2 - P_1$ for each combination of virtual launch ranges and its optimal value for the problem subsituation "Attack" found for the case in which the enemy missile has not been launched yet.

Figure 14 shows the predicted trajectories of fighters and their missiles since the time instant t_0 (trajec-

Table 11. Criterion F for problem subsituation "F1 attack"

D(F1)/D(F2)	40000	37000	34000	31000	28000	25000	22000	19000	16000	13000	10000	7000	4000
40000		0	0.58	0.66	0.69	0.69	0.7	0.7	0.7	0.7	0.7	0.7	0.7
37000			0.56	0.7	0.7	0.7	0.7	0.7	−0.7	0.7	0.7	−0.7	0.7
34000				0.07	0.11	0.13	0.14	0.14	0.14	0.15	0.14	0.14	0.14
31000					0.03	0.06	0.06	0.06	0.07	−0.7	−0.7	−0.7	0.07
28000						0.02	0.03	0.03	0.03	0.03	−0.7	−0.7	−0.7
25000							0.01	0.01	0.02	0.02	0.02	−0.7	0.02
22000								0	0.01	0.1	−0.7	0.01	−0.7
19000									0	0	0	−0.7	0
16000										0	0	0	−0.7
13000											0	0	−0.7
10000												0	0
7000													0

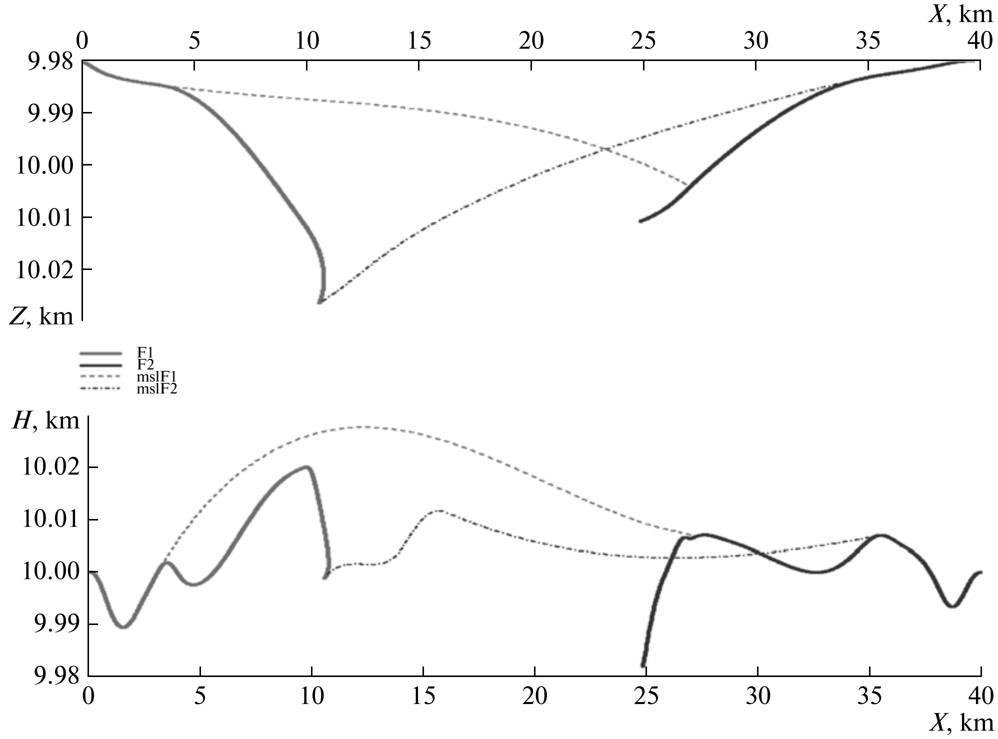


Fig. 14. Fight development for problem subsituation "Attack of F1"–"Defense with attack of F2" (projections of trajectories on the horizontal plane are shown in the upper part of the figure, projections on the vertical plane, in the lower part).

tories for F1 and its missile R(F1) are shown on the left, and those for F2, on the right).

Results of simulation of distant air fight 1 × 1 at the current fight time instant t_0. At the current fight instant t_0, the onboard online advisory expert system for distant air fight 1 × 1 on board F1 produced the following recommendations:

(1) realize problem subsituation "Attack" (since the value of the criterion F is larger than in the case of the fight in the problem subsituation "Defense with attack", i.e., it is recommended to perform the launch first from a distance of 34000 m for assumed range of reply enemy launch from 31000 m);

(2) recommendation for noise initiation: three cycles in the first attempt for the expected active noise station of the enemy with two cycles in the first attempt;

(3) determined trajectory: before the launch (attack curve), after the launch, tactical turn; assumed trajectory strategy of the enemy: attack curve before the launch and tactical turn after the launch.

CONCLUSIONS

The practice of application and development of modern anthropocentric objects requires creation of intelligent systems of two classes for its system-generating core:

(i) *intelligent information system "Situation awareness of the crew" creating information support of the crew for online designation of the current target of operation session*;

(ii) *onboard online advisory expert system for typical situation which present the crew with the method of achieving the current target of the operation session in real time*.

For testing and development of knowledge bases of these systems two classes of computer simulation systems are developed:

(i) simulation system for global control level II and intelligent information system with necessary inclusion of professional man–operator in the simulation loop;

(ii) *simulation system for each onboard online advisory expert system for typical situation with simulation of operation* of professional man–operator by situation control block.

The simulation system for typical situation makes it possible to estimate and improve the knowledge base of the onboard online advisory expert system for typical situation without direct participation of qualified professional operators, and leave this resource for the stage of development of the adapted onboard online advisory expert system for typical situation. These simulation systems are developed based on technical documentation of simulated anthropocentric object on information and control components of information–control field, its onboard measurement devices, actuators, composition and structure of onboard digital computer algorithms.

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