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ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ
“МАГІСТР”

Тема: ІНФОРМАЦІЙНА ТЕХНОЛОГІЯ ІНТЕЛЕКТУАЛЬНОГО УПРАВЛІННЯ КОНФЛІКТНИМИ СИТУАЦІЯМИ ДИНАМІЧНИХ ОБ’ЄКТІВ У МАСШТАБІ РЕАЛЬНОГО ЧАСУ

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GRADUATE WIRK

(EXPLANATORY NOTES)

GRADUATE OF AN EDUCATIONAL DEGREE
“MASTER”

Theme: INFORMATION TECHNOLOGY OF INTELLECTUAL CONTROL OF CONFLICT SITUATIONS OF DYNAMIC OBJECTS AT REAL-TIME SCALE

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NATIONAL AVIATION UNIVERSITY
Faculty of Air Navigation, Electronics and Telecommunications

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"___"___________2022

TASK

for execution graduate work

Lakhtyr D.A.

1. Theme of bachelor work: «Information technology of intellectual control of conflict situations of dynamic objects at real-time scale», approved by the Rector on «13» September 2022 №1413/ст.

2. Duration of which: from 5 September 2022 to 30 November 2022.

3. Background to the work: Concerns of aircraft flight safety requires development of a new information technology for solving conflict situations and collisions prevention.

4. Content of explanatory notes: List of conditional terms and abbreviations; Introduction; Chapter 1: Method of plotting areas of completely controlled state of a dynamic object; Chapter 2: Information technology for resolving conflict situations of dynamic objects on a real-time scale; Chapter 3: Simulation of information technology for resolving conflict situations of dynamic objects on a real-time scale; Chapter 4: Labor protection; Chapter 5: Environmental protection; Conclusions; References;

5. The list of mandatory graphic material: Graphical presentation of the results of the mathematical modeling of the developed information technology for resolving conflict situations of dynamic objects

6. Planned schedule

№	Task	Duration	Evaluation of the performance
1.	Validate the rationale of graduate work theme	05.09-06.09	
2.	Carry out a literature review	07.09-09.09	
3.	Develop the first chapter of diploma	10.09-24.09	
4.	Develop the second chapter of diploma	25.09-09.10	
5.	Develop the third chapter of diploma	10.10-08.11	
6.	Develop the fourth chapter of diploma	09.11-16.11	
7.	Develop the fifth chapter of diploma	17.11-24.11	
8.	Obtaining a review of the diploma	25.11-30.11	

7. Date of assignment: «___ » ____________ 2022

8. Supervisor ______________ Hryshchenko Y.V.

The task took to perform ______________ Lakhtyr D.A.

ABSTRACT

Explanatory notes to master's work "Information technology of intellectual control of conflict situations of dynamic objects at real-time scale": 97 pages, 57 figures, 39 references.

AVIATION, FLIGHT SAFETY, INFORMATION TECHNOLOGIES, CONFLICT SITUATIONS, INTELLECTUAL CONTROL, DYNAMIC OBJECT, COLLISION AVOIDANCE.

Object of the investigation – the process of resolving conflict situations between dynamic objects.

Purpose of the master's work – increasing the safety of flights in aviation by ensuring a guaranteed level of safety during the prevention of collisions of dynamic objects based on the development of a new information technology for solving conflict situations of dynamic objects on a real-time scale.

Method of investigation – conducted research is based on the theory of intelligent control, methods of mathematical analysis, theory of probability, theory of automatic control, statistical and simulation modeling, theory of navigation, theory of optimization of systems and processes, theory of navigation and flight dynamics of aircraft.

Scientific novelty – As a result of the work, an information technology (containing methods, algorithms, system) for managing conflict situations of dynamic objects was developed. The technology is based on network-centric, invariant and adaptive technologies and theories, and is intended for qualitative resolution and prevention of possible conflict situations of dynamic objects. The technology provides determination of the location of dynamic objects, obtaining data on their heading, altitude and speed, assessing the probability of crossing trajectories of movement and in case of threat of a collision, promptly ensures the issuance of corrective signals for the parameters of the movement of dynamic objects. The social-economic significance of the developed informational technology consists in development of modern means of ensuring a guaranteed level of flight safety with the help of created algorithms for the prevention of collisions of dynamic objects.

LIST OF CONTENTS

LIST OF ABBREVIATIONS

ADS-B	Automatic Dependent Surveillance - Broadcast
ATC	Air Traffic Control
CPA	Closest Point of Approach
CS	Conflict Situation
DO	Dynamic Object
ICAO	International Civil Aviation Organization
JSON	JavaScript Object Notation
RA	Resolution Advisory
TA	Traffic Advisory
TCAS	Traffic Collision Avoidance System
XML	eXtensible Markup Language

INTRODUCTION

The current state of the global air transport industry is characterized by a stable increase in the volume of air transport, which is already leading to it reaching its limit. Further growth in the intensity of air traffic inevitably leads to a decrease in the safety and efficiency of flights, an increase in fuel costs and delays of aircraft (DO) both on the ground and in the air, and an unacceptable increase in environmental costs. The high traffic intensity in the European network of air routes directly affects the increase in the number of potential conflict situations. As a result, ground control centers face a significant overload when regulating air traffic flows.

The term "dynamic object" (DO) refers to a manned or unmanned aircraft designed to perform a target flight under specified conditions.

Conflict situations (CS) are events that correspond to an actual or predicted violation of the rules for ensuring the echeloning of aircraft in space and, in the absence of appropriate actions by pilots or air traffic control authorities, can lead to a catastrophic situation - a collision of aircraft. As for the concept of "managing" conflict situations, it also includes the concept of conflict resolution.

Modern air traffic control (ATC) requirements are as follows:

- increasing the capacity of the ATC system;

- flexible use of air space;

- the ability to fly along optimal trajectories;

- dynamic correction of flight plans;

- reduction of flight arrival delays;

- minimization of aircraft deviations from planned trajectories;

- ensuring a high guaranteed level of flight safety, etc.

To implement these requirements, a new concept of air traffic organization "FreeFlight" was developed [1]. Its main task is to increase the efficiency of air traffic in general and optimize the flight performance of an individual airship by giving the crew complete freedom in choosing the trajectory of movement while maintaining a guaranteed level of safety. The main idea of the FreeFlight concept is to give the crew the ability to choose the flight path along the route, speed and instrument flight profile to a greater extent than the visual flight rules allow. But such autonomy must effectively co-exist with the reliability of safe departure of DO by means of on-board equipment.

The gradual transition to flights on arbitrary routes [2], which is expected to be carried out within the next 10-15 years, entails additional difficulties, such as the increase in the number and complexity of potentially conflicting situations that arise between DO. All this affects the decrease in the level of flight safety and, accordingly, this is precisely what determines the relevance of the topic of this study.

The collision of DO in the air causes a large number of disasters, therefore, the quantitative assessment of flight safety by the amount of the permissible risk of collision of aircrafts is very important. However, even with the help of highly efficient and highly reliable ATC systems, it is impossible to ensure the necessary flight safety. This is due to the fact that until now part of the earth's surface is not covered by the range of ATC systems, and in addition, the existing ATC systems do not allow reliable control of flights at low altitudes and in hard-to-observe regions of the earth's surface.

Ensuring the safety of flights is directly related to solving the task of preventing collisions between DO in the air. To maintain the acceptable risk of collisions when the intensity of air traffic increases or to reduce it under conditions of constant intensity of traffic, it is necessary to increase the reliability of navigation and air traffic control systems, primarily by increasing the reliability and quality of the technical means of these systems.

It should be noted that the modern air traffic control system is a controlled dynamic system, information on its status is periodically updated. The trajectory of controlled objects - airplanes is continuous, and is mathematically described by continuous dynamics equations. The analysis of the airspace situation, which is compiled and forecast, as well as decision-making on the prevention of the forecasted conflict, are performed at discrete moments of time. Therefore, the task of conflict prevention has a hybrid structure, in which the discrete-time process of analysis and decision-making is combined with the continuous dynamics of the process of decision implementation. Such a hybrid structure should produce commands that can be implemented by an on-board flight control system based on modern intelligent control technologies.

Today, the solution of this task depends on the dispatching service of the air traffic control system, the aircraft crew and on-board collision avoidance systems. However, as the intensity of air traffic continues to increase, air traffic control services and aircrews are faced with increasing difficulties in preventing dangerous convergence of aircraft in the air. And the technical means and collision prevention systems installed on board aircraft no longer meet modern requirements and do not provide the necessary level of flight safety.

Visual methods used in aircraft control do not ensure the necessary flight safety, since even with very good visibility, pilots in some cases detect an oncoming aircraft when there is not enough time to perform an evasive maneuver. In addition, visual methods are associated with subjective errors in determining the range to the aircraft, its speed and in assessing the degree of danger of collision [3].

Due to the overload of the dispatching staff, the available ATC system, also does not fully ensure the control of compliance with the given navigation parameters by each aircraft performing instrument flight.

Automation of flight control and management processes, implementation of more advanced radar systems, computing complexes, and information display systems is a fairly effective means of increasing the reliability and efficiency of ATC system. It can be said that the automation of ATC systems is the basis of the development of means of ground control over aircraft flights. The introduction of automated systems already significantly increases the efficiency and safety of air traffic, reduces the load on controllers and pilots. At the same time, the automation of flight control processes and the improvement of radar equipment cannot sufficiently ensure the prevention of dangerous approaches on routes with heavy traffic passing through hard-to-reach areas, as well as during intercontinental flights [4].

The creation of a new information technology for resolving conflict situations in real time and the implementation of such technology with appropriate algorithms will ensure effective prevention of dangerous approaches. The development of a technology for solving dangerous approaches will make it possible to ensure the divergence of DO relative to each other at a distance that meets the norms of DO echeloning, at the conditions of complex multiple conflicts involving a large (up to 50) number of DO and in the case of an extremely complex geometry of the conflict (intersection of two dense flows of DO, convergence at one point and at the same time of aircraft flying in different directions, conflict with a combination of intersections and overtaking of several aircraft at one point, etc.).

In conclusion, today, the scientific and practical task of developing a new information technology for resolving conflict situations of DO, which will make it possible, in the presence of detected conflicts, to provide a spatial evasive maneuver with the prevention of a possible dangerous convergence of DO, and after the resolution of the conflict - to ensure return to the planned trajectory. This will make it possible to ensure a guaranteed level of flight safety in conditions of a sharp increase in traffic intensity. The creation of a new information technology for solving conflict situations of dynamic objects on a real-time scale and the implementation of such management with appropriate algorithms ensures effective prevention of dangerous convergence

CHAPTER 1

METHOD OF PLOTTING AREAS OF COMPLETELY CONTROLLED STATE OF A DYNAMIC OBJECT

1.1. Definition of controlled state area

In order to solve the problem of conflict resolution in air navigation space and, especially, polyconflicts, it is important to consider the concept of the area of a fully controlled state, with the help of which it is possible to determine the potential capabilities of control objects (aircrafts) to perform evasive maneuvers that are in a conflict situation in relation to each other. With the help of areas of a fully controlled state, during the resolution of a conflict situation among the DOs, we will determine the priority and sequence of DOs that will perform evasive maneuvers [5-7].

The region of the fully controlled state is determined by the mathematical model of the system and the equations of absolute nonlinear integral invariance [8].

In general, the mathematical model of complex dynamic objects, including an airship, is a multidimensional nonlinear system of differential equations of the type:

$$\frac{dx}{dt} = f(t, x, u, v), \quad (1.1)$$

$$x \in Q_x, u \in U, v \in V, t \in T = [t_0; \infty],$$

Where:

t – time;

x – n-dimensional state vector of the system n≥3;

u – m-dimensional state vector of controlling influences;

v – l-dimensional vector of disturbances acting on the system;

f – n-dimensional nonlinear piecewise continuous vector function;

Q_x – set of vector x states;

U – set of vector u states;

V – set of vector v states;

T – system definition interval;

t_0 – initial time.

In the general statement of the problem of controlling a complex nonlinear system, the initial data for the synthesis of control functions, as a function of the state of the system and environment $u = u(t_0, x_0, x, v) \in U$, are the initial x_0 and final $x_к$ states of the system, and accordingly, the sets X^0 - initial states and X^K - final states of the system. A necessary condition for the synthesis is that all points of the trajectory of the behavior of the system $X(t_0, x_0, x_k, x)$ belong to the region of restrictions $Q^{обм}$ during the controlled transfer of the system from the initial state x_0 to the final state x_k:

$$X(t_0, x_0, x_k, x) \in Q^{обм} \tag{1.2}$$

In terms of (1, 2), we can consider the definition given in [13].

The region of the fully controlled state of the system (1.2) along the x coordinate is called the region $Q_x^{кс.} \leq Q_x$, such that any two points x^1 and x^2 of which are mutually connected by the corresponding constrained control u=$u(t_0, x_0, x, v) \in U$.

In order to construct the areas of a fully controlled state for the DO, which are participants in the conflict situation, we will apply a computer method and a computational procedure, which are based on a model representation of the system in the form (1.1), analytical approaches and methods of Computer Science.

As it was noted earlier, in order to determine the region of the fully controlled state of the system, in addition to its mathematical model, it is necessary to construct the equations of absolute nonlinear integral invariance [10-11, 12].

For systems in the form (1.1), the absolute nonlinear integral invariance equation can be represented in the form:

$$F(t,x,u,v) = p, \quad u \in U, v \in V,$$

where F - the right-hand side of the differential equation (1.1),

p - the right part of the "measurement" system [12].

The domain of the fully controlled state $Q_x^{кс} \in Q_x$is defined as the mapping of the domain of real controls V to the domain of virtual controls P over $x \in Q_x, v \in V$ for each $t : U \xrightarrow{F} P$. Based on the conditions of smoothness in the regions of continuity of the function $F\ (t,x,u,v\ )$ and the conditions for constructing the invariant region Q^{inv}, common to all $v \in V$:

$$P = \bigcap_{\upsilon = V} F(x,u) = F^*(x,u),$$

where $F^*(x,u)$ is the image of the set of controls $u \in U$.

In order to determine the potential opportunities for performing an evasive maneuver of each of DO that are participants in the conflict, it is necessary to analyze their areas of a fully controlled state, which is defined as:

$$Q_x^{\kappa c} = \left(Q_x \times P\right).$$

The aircraft that will be the first to perform an evasive maneuver is selected from the condition:

$$ПК_i\left(Q_x^{\kappa c(i)}\right) = \max_i\left(Q_x^{\kappa c(i)}\right),$$

where $Q_x^{\kappa c(i)}$- the region of the fully controlled state for the *i*- th DO,

x - state parameter of the DO.

Let's consider an example of building the areas of the fully controlled state of a medium mainline aircraft for the selection of a priority aircraft in a conflict situation.

When solving control tasks, it is extremely important to know whether a given system has a non-zero region of the controlled state, and how it is located in the state space of the given system. At the same time, we will be interested in the question of the region of the controlled state not in general, but more specifically - in a detailed plan, from the point of view of researching the regions of the fully controlled state and the regions of the positively semi-controlled state. Let’s give appropriate definitions.

Let the analytical system be given, but with y = 0 and let us be interested in the controllability of the *x coordinate*:

$$\frac{dx}{dt} = \Phi\left(t,x,z,\theta,u\right) \quad u \in И,$$

$$\frac{dz}{dt} = W\left(t,x,z,\theta,u\right) \quad \theta \in V.$$

Then, the region of the fully controlled state of the system by coordinate x we will call such a region $Q_x^{\kappa c}$of space x, any two points of which are mutually connected by means of controls $u \in U$ at arbitrary $\vartheta \in$ V, $z \in Q_z$. Here $Q_z$is some subfield of z.

Furthermore, the region of the positively semi -controlled state of the system along the x -coordinate will be called such a region of $Q_x^{+n\kappa c}$, each point x of which is connected to the region $Q_x^{кс}$ using $u \in U$ at any $\vartheta \in$ V, $z \in Q_z$.

If the system is perturbed, then the limit system that describes the object together with the invariant control device is no longer perturbed along the *x* coordinate that we were interested in. The parameter *p* of the new control specifies a certain set of varieties of the functional behavior of the system ⅀ *(t, p)* in space $Q_x = pr_x\, Q_{xz}$:

$$\frac{dx}{dt} = \Phi_U(t, x, p, \mu),\ \ p \in Q_p \text{ for everyone} (x, z) \in Q_{xz}$$

$$\frac{dz}{dt} = W_U(t, x, z, \theta, p)\ \ \theta \in V.$$

The regions $Q_x^{кс}$and $Q_x^{+пкс}$ are constructed according to the equations for *x*, including from the system:

$$\frac{dx}{dt} = \Phi_U(t, x, p, \mu),\ \ p \in Q_p, x \in Q_x.$$

At the same time, the regions $Q_x^{кс}$and $Q_x^{+пкс}$ are built as regions of a fully or semi-controlled state by the control *p*. The properties of the boundary system depend significantly on the parameter $\mu \in M$, where M is the set of parameter values *p* characterizing various properties of the boundary system of equations. By introducing the set *M*, the set of possible varieties ⅀ *(t, μ, p)*.

The construction of regions $Q_x^{кс}$ and $Q_x^{+пкс}$for the system is at least an order of magnitude simpler than for the original system, firstly, due to its unperturbedness in terms of ϑ and *z* and, secondly, due to the simplicity of the right-hand sides of the boundary equations. So, for example, with $\Phi_u = p$ or $\Phi_u = Ax + p$, where *A* is a matrix with constant parameters, the task of finding regions $Q_x^{кс}$ and $Q_x^{+пкс}$ becomes as easy as possible. The regions $Q_x^{кс}$ and $Q_x^{+пкс}$, found for the limit system at some μ, will be denoted by $Q_{x\mu}^{кс}$, $Q_{x\mu}^{+пкс}$. Then the relationship between the regions $Q_x^{кс}$, ... and $Q_{x\mu}^{кс}$, ... for two types of systems can be characterized by the relation:

$$Q_{x\mu}^{\kappa c} \subseteq Q_x^{\kappa c} \forall \mu \in M \ ,$$

$$Q_{x\mu}^{+n\kappa\kappa} \subseteq Q_x^{+n\kappa\kappa} \forall \mu \in M \ .$$

It follows that the domain $Q_x^{\kappa c}$(and $Q_x^{+n\kappa c}$) represents the coverage of the sum of sets $Q_{x\mu}^{\kappa c}$ (and $Q_{x\mu}^{+n\kappa c}$) on $\mu \in M$.

However, in the applied sense, we will be interested in areas $Q_{x\mu}^{\kappa c}$ and $Q_{x\mu}^{+n\kappa c}$as properties characterizing the "object - control device" system.

Then the construction of the region $Q_x^{\kappa c}$ can be performed as follows: we represent the region Q_x in the form of some sum of intersecting regions Q_x^i, $i \in$ l. Let's match each area with the Q_x^i maximum possible set $Q_p^i \subseteq Q_r$, invariant to x and z.

The set Q_p^i is defined as the common part of all intersections $Q_p^{x\vartheta}$ on ϑ and x:

$$Q_p^i = \bigcap_{\theta \in V} \bigcap_{(x,z) \in Q_{xz}^i} Q_p^{x\theta} \ ,$$

where Q_{xz}^i— a part of the region Q_{xz} that has "width" Q_x^i.

For each constant in magnitude value $p_i \in Q_p^i$ corresponds to its own set of functional behaviors ꭓ (t, p_i, μ) in the space x. Thus, we have in the x-space a collection of sets ꭓ(t, p_i, μ) $\forall$ $p_i \in Q_p^i$, the implementation of which is guaranteed, at least in Q_x^i. In other words, Q_x^i reduces the calculation based on the limit system of sets ꭓ(t, p_i, μ).

Let there be such closed trajectories on the set M {ꭓ(t, p_i, μ)} that any two of its points can be connected. We will call such elements closed in Q_x^i the trajectory of full controllability. Let's denote these elements by $q\ (t, x, p, \mu)$.

Let the domain Q_x^i contains some set M $\{q(t, x, p_i, \mu)\}$ of fully controllable elements.

Two elements q_i and q_j from the set M $\{q\}$ will be considered to have direct contact if there is at least one point that belongs to both elements at the same time. In other words, two elements q_i and q_j are in direct contact if $q_i \cap q_j \neq 0$.

We will also consider the relationship of indirect contact of elements q_i amd q_j: two elements q_i and q_j are in indirect contact if a sequence of pairs of elements (q_α, q_β), (q_β, q_γ), (q_γ, q_n),... with direct contact can be found such that the set of all elements of this sequence q_α, $\alpha \in A_\gamma^{ij}$ contains the given elements q_i and q_j. In other words, the elements $q_i$and $q_j$are in an indirect contact relationship, if q_i,$q_j \in A_\nu^{ij}$, where the set A_ν^{ij}consists of elements:

$$q_\alpha \cap q_\beta \neq 0,$$

$$q_\beta \cap q_\gamma \neq 0,$$

$$\ldots\ldots\ldots\ldots$$

$$A_\nu^{ij} = \{q_\alpha, q_\beta, \ldots\}.$$

It is clear that any two points x from the set A_ν^{ij}can be connected. Let's denote the entire set of points formed by the set of elements A_ν^{ij}, through l_ν^{ij}:

Then, having identified all possible sets of fully controlled states in Q_x^i:

$$I_\gamma^i \forall \gamma \in \Gamma_i,$$

for all Q_x^i at $i = I$ it is possible to find all regions of controlled state $Q_x^{кс}$ with the sane method of indirect contact. Meaning the method of determination of maximum possible set of subregions $l_\gamma^i \forall \gamma \in \Gamma_i$; $i \in I$, which are in relation to each other:

$$Q_{xg}^{кс} \supseteq> \max_{i,\gamma} L_g, \gamma \in \Gamma_i, i \in I,$$

where $L_g = \{l_\alpha^i, l_\beta^j, l_l^\lambda, \ldots\}$, all elements of which satisfy the indirect contact relation ($l_\alpha^i \cap l_\beta^i \neq 0$, $l_\beta^j \cap l_l^\lambda \neq 0$, ……..)

1.2. Calculation of areas of the controlled state of a dynamic object

When determining the necessary maneuvers, it is convenient to use the construction of mathematical controllability functions of each DO in order to determine its control capabilities. The solution to this problem is based on the analysis of the constructed graphs of the dependencies of the control parameters of the DO on each other and obtaining the so-called regions of the controlled state of the DO, which characterize the possibilities of DO with regard to changing the movement parameters at one moment of time.

Let's consider the models of kinematics and dynamics of the motion of the DO taking into account the aerodynamic characteristics of each DO [13]: the equation of motion of the center of mass; kinematic equations of motion; equations of aerodynamic forces and, accordingly, their aerodynamic coefficients of frontal resistance, lifting force and lateral forces; equations describing the performance characteristics of engines; equation of accelerations occurring during flight.

The equation of motion of the center of mass:

$$\dot{V} = \frac{1}{m}(P\cos(\alpha + \varphi_{\partial в})\cos(\beta) - mg\sin(\theta) - X_a),$$

$$\dot{\theta} = \frac{1}{mV}(P\sin(\alpha + \varphi_{\partial в})\cos(\gamma_a) - mg\cos(\theta) + Y_a\cos(\gamma_a) - Z_a\sin(\gamma_a)),$$

$$\dot{\psi} = \frac{1}{mV\cos(\theta)}(P\sin(\alpha + \varphi_{\partial в})\sin(\beta)\cos(\gamma_a) - Y_a\sin(\gamma_a) - Z_a\cos(\gamma_a))$$

Kinematic equations of motion:

$$\dot{L} = V\cos(\theta)\cos(\psi),$$

$$\dot{H} = V\sin(\theta),$$

$$\dot{Z} = -V\cos(\theta)\sin(\psi).$$

The equation of aerodynamic forces and, coefficients of frontal resistance, lifting force and lateral force:

$$X_a = C_x \frac{\rho V^2}{2} S,$$

$$C_x = f(\alpha, \beta, V, H),$$

$$Y_a = C_y \frac{\rho V^2}{2} S,$$

$$C_y = f(\alpha, \beta, V, H),$$

$$Z_a = C_z \frac{\rho V^2}{2} S,$$

$$C_z = f(\alpha, \beta, V, H).$$

The equation describing the characteristics of the engines:

$$P = f(H, M, \delta_{РКД}),$$

$$P = P_{\partial в} \delta_{РКД},$$

$$P_{\partial в} = P_0 (1 - 0.65(\frac{H}{11000}) + 0.35((M - 0.5 + 0.2(\frac{H}{11000}))^2 - 0.25)).$$

In the equations:

m – aircraft weight;

P – aircraft thrust;

$P_{дв}$ – engine thrust;

ρ – air flow density;

α – angle of attack;

$\varphi_{\partial в}$ – engine installation angle;

$\delta_{РКД}$– angle of the engine control knob;

β– sliding angle;

θ – pitch angle;

ψ – yaw angle;

γ_a – roll angle;

X_a – aerodynamic drag force;

Y_a – aerodynamic lifting force;

Z_a – aerodynamic lateral force;

C_x, C_y, C_z– coefficients of frontal resistance, lifting force and lateral force;

M– Mach number;

S– wing area;

H - height;

L – traveled path;

Z – lateral shift.

By substituting the values of the parameters of specific aircraft into the formulas described above and making all the necessary mathematical calculations with modern mathematical modeling tools (such as, "MatLab"), you can build the corresponding areas of the controllable state of the aircraft. In fig. 1.1-1.3 illustrations of such graphs for a virtual dynamic object are shown.

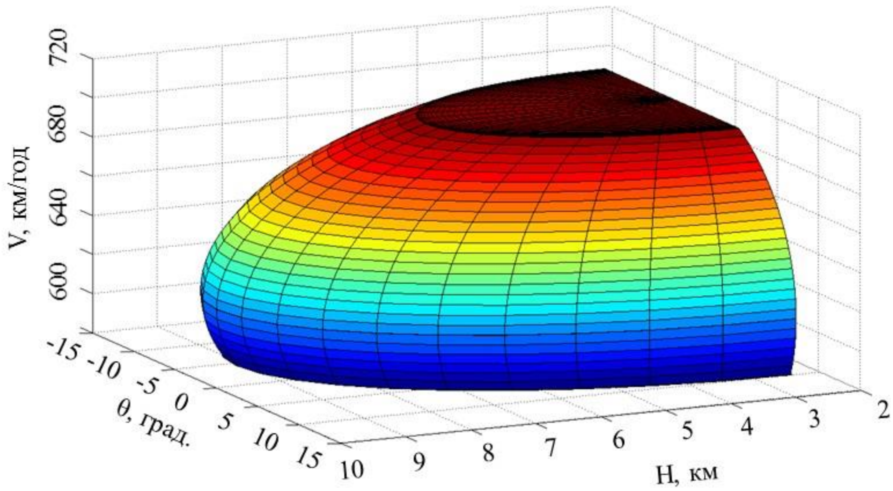

Figure 1.1 – The area of the controllable state of the DO depending on the speed, altitude and pitch angle

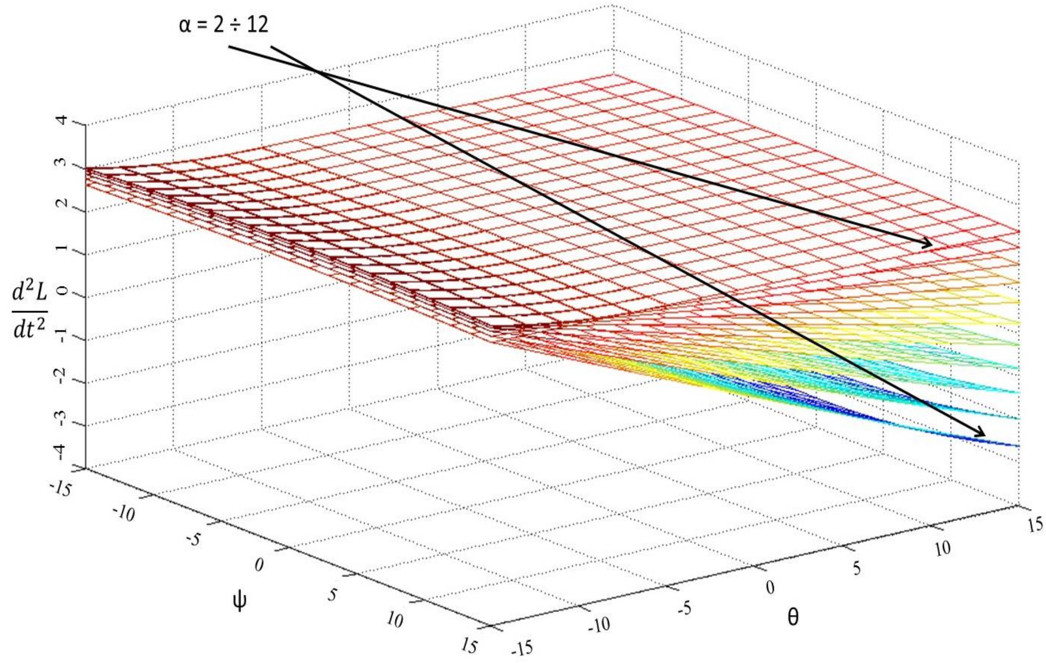

Figure 1.2 – Area of controllable state of DO as a function of yaw and pitch angles and acceleration

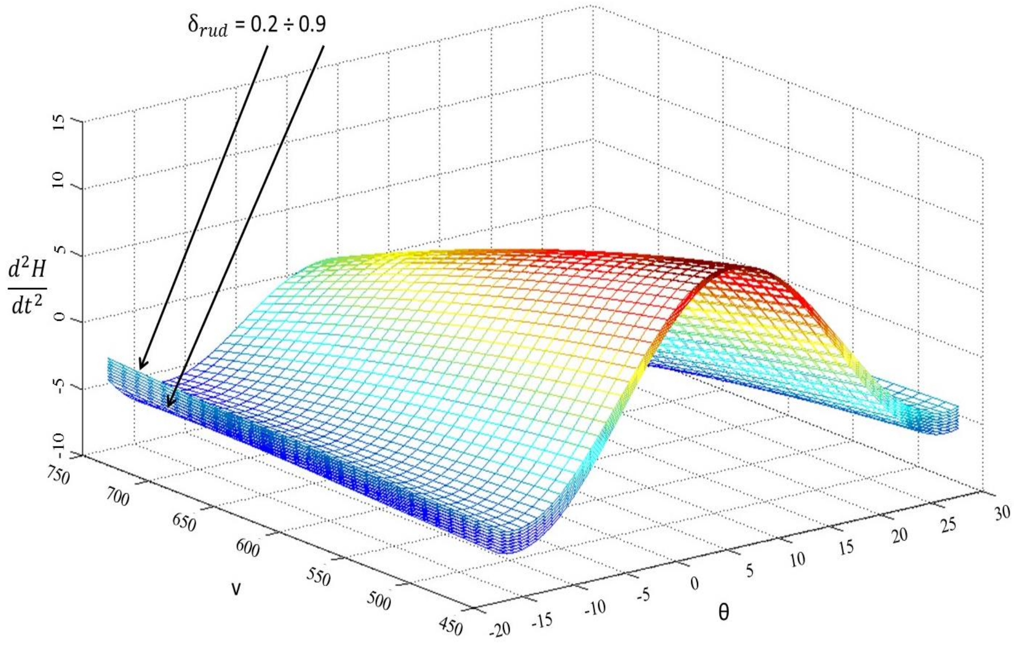

Figure 1.3 – The area of the controllable state of DO depending on the pitch angle , speed and vertical acceleration

Simulation modeling and mathematical models allow to obtain information about the functional and aerodynamic capabilities of each aircraft participating in the conflict by superimposing and comparing these graphs in the " MatLab " environment, as well as to determine which of the aircraft will perform an evasive maneuver according to the rule of priority setting. Namely: the evasive maneuver must be performed by the DO that has a greater margin of maneuverability, however, if the capabilities of one DO are not enough to ensure a guaranteed divergence, the evasive maneuver must also be performed by other DOs in order of priority.

The type of required maneuver, namely: changing the altitude of one or more DO, changing the speed of movement, changing the course or a combination of these maneuvers for one or more DO - is also determined based on the areas of the controlled state according to the following principle: the type of maneuver to avoid one or more DO depends from the areas of the controllable state determined on the basis of the capabilities of these DO to change the parameters of their movement at one specific moment in time (the DO that has a greater reserve of controllability receives a higher priority in performing the maneuver).

For example, by comparing controllable state areas (Fig. 1.4) of two medium-haul aircraft, we can determine that aircraft No.2 has more aerodynamic and functional capabilities for maneuvering in the horizontal plane. Accordingly, it will be identified as a priority aircraft for maneuvering in this possible conflict situation.

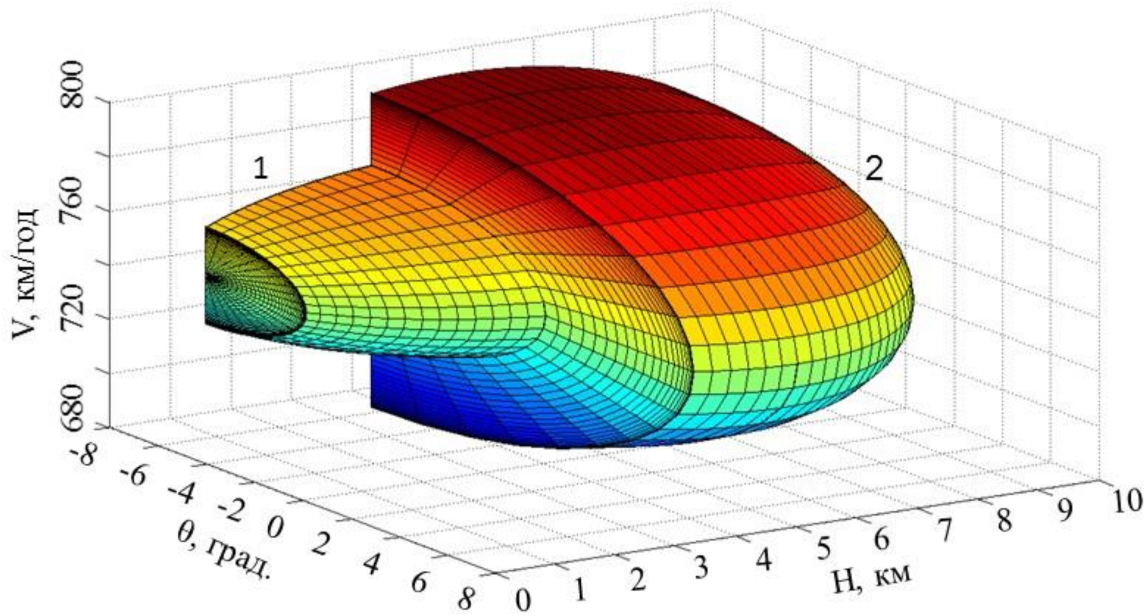

Figure 1.4 – Graphical illustration of the comparison of the areas of the controllable state of the two DOs depending on the speed, altitude and pitch angle

1.3 Determination algorithm of a dynamic object to perform an evasive maneuver, based on the regions of the controlled state

This algorithm (Fig. 1.5) implements the logic of selecting an aircraft that will perform an evasive maneuver to resolve a conflict situation, based on the calculation and comparison of areas of the controlled state (trajectory, kinematic and aerodynamic control) of aircraft. The algorithm is designed to calculate the controlled area of one's own DO and the controlled state of other DO which enter the conflict zone. Sequence of actions of the algorithm:

- the regions of the controlled state of DO are compared according to the parameters θ, ψ, α in the horizontal and vertical planes.

- the regions of the controlled state of DO are compared according to the parameters θ, ψ,$\delta_{РКД}$ in the horizontal and vertical plane.

- the regions of the controlled state of DO are compared according to the parameters θ, ψ, h in the horizontal and vertical planes.

- the regions of the controlled state of DO are compared according to the parameters θ, ψ, v in the horizontal and vertical planes.

- the regions of the controlled state of DO are compared according to the parameters θ, v, α in the horizontal and vertical planes.

- the regions of the controlled state of DO are compared according to the parameters θ, v,$\delta_{РКД}$ in the horizontal and vertical plane.

- the regions of the controlled state of DO are compared according to the parameters θ, v, h in the horizontal and vertical planes.

The notations in the algorithm mean:

θ pitch angle;

ψ – yaw angle;

α – angle of attack;

$\delta_{РКД}$– angle of installation of the engine control handle

h – height;

v – speed.

According to these parameters of the comparison, the DO that will perform the evasive maneuver is determined based on the lowest value of the energy consumption to perform this maneuver.

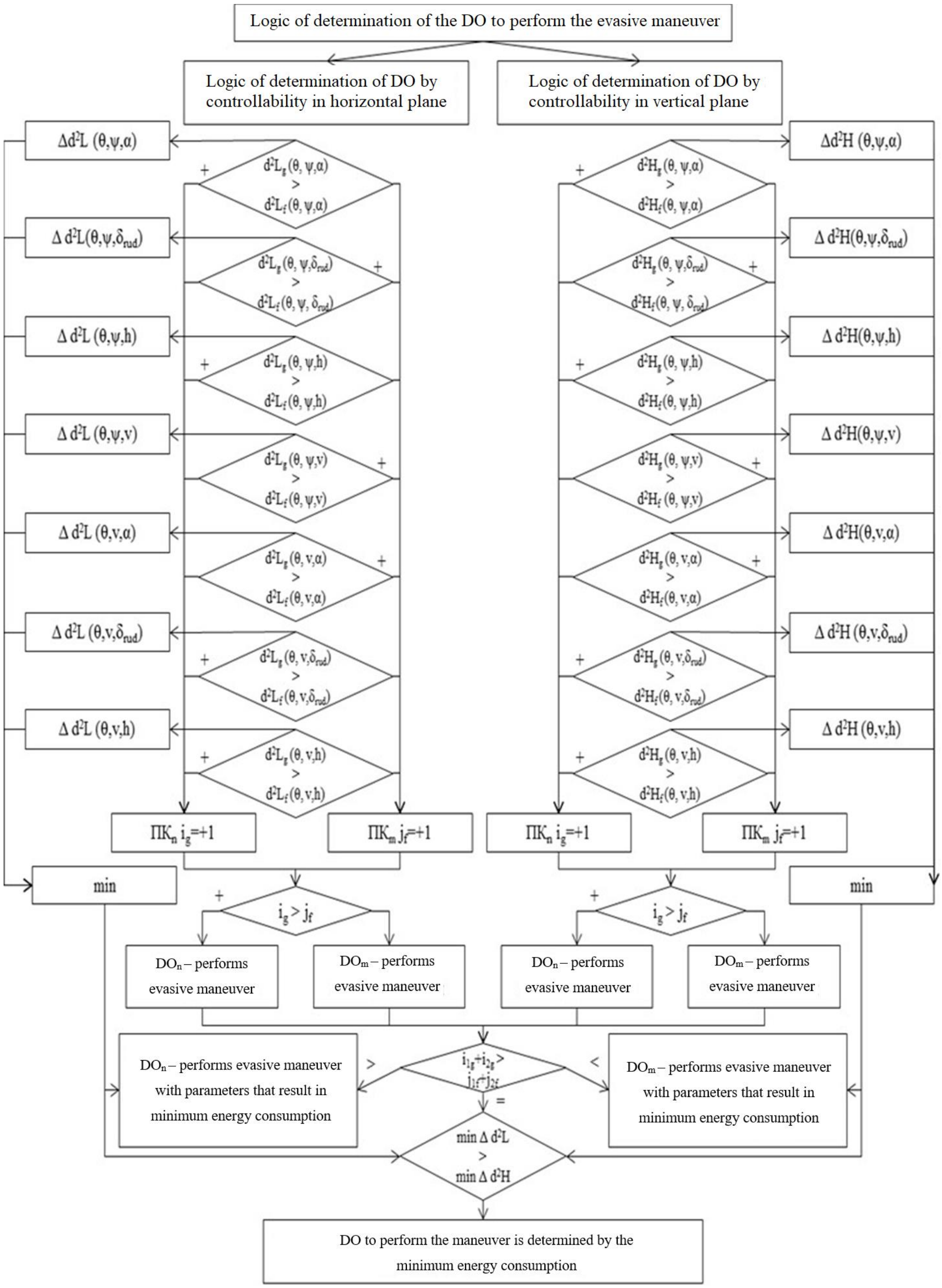

Fig. 1.5. – The algorithm for determining dynamic objects to perform an evasive maneuver based on areas of the controlled state

CHAPTER 2

INFORMATION TECHNOLOGY FOR RESOLVING CONFLICT SITUATIONS OF DYNAMIC OBJECTS ON A REAL-TIME SCALE

2.1. Current dangerous approach warning system of dynamic objects in the air

There are several modern DO collision prevention systems [14]. To reduce the risk of aircraft collisions, the TCAS system is used to prevent dangerous approaches of aircraft in the air. There are different variants of this system. ICAO recommends using the 2003 TCAS II system. TCAS II is a mandatory system in Europe for airplanes with more than 11 passengers or with a maximum take-off weight of more than 5700 kg and in the USA with a total number of passengers more than 30 [15].

The TCAS II system can detect aircraft at distances of up to 40 miles, issue information about the air situation and direct recommendations for eliminating the conflict situation. The system can track up to 30 aircraft at the same time and issue conflict resolution commands for three at the same time.

The system issues two commands:

- TA (Traffic Advisory) – a warning signal, which means that the conflicting aircraft has entered the protective zone and must be ready to be issued the RA command;

- RA (Resolution Advisory) - commands for immediate actions to prevent a collision.

Let's consider in more detail the principle of operation of the TCAS II system (Fig. 2.1-2.2).

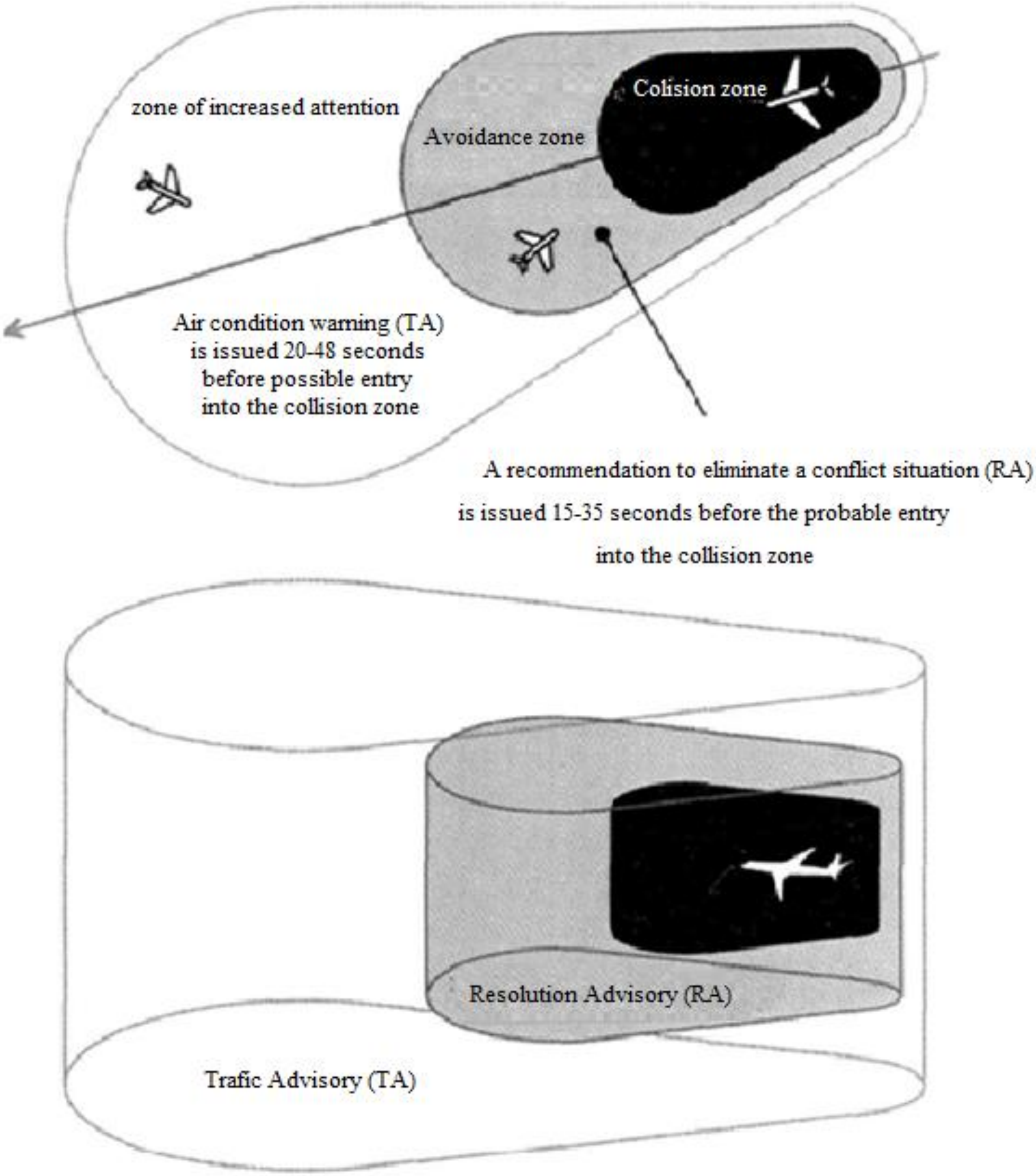

Figure 2.1 – Schematic principle of operation of the TCAS II system

The joint movement of two aircraft was studied, each of which performed its own flight task (movement along a given route with a variable flight profile in height). At the same time, to prevent collisions and dangerous approaches in the air, the operation of the TCAS II system was simulated [16, 17, 18].

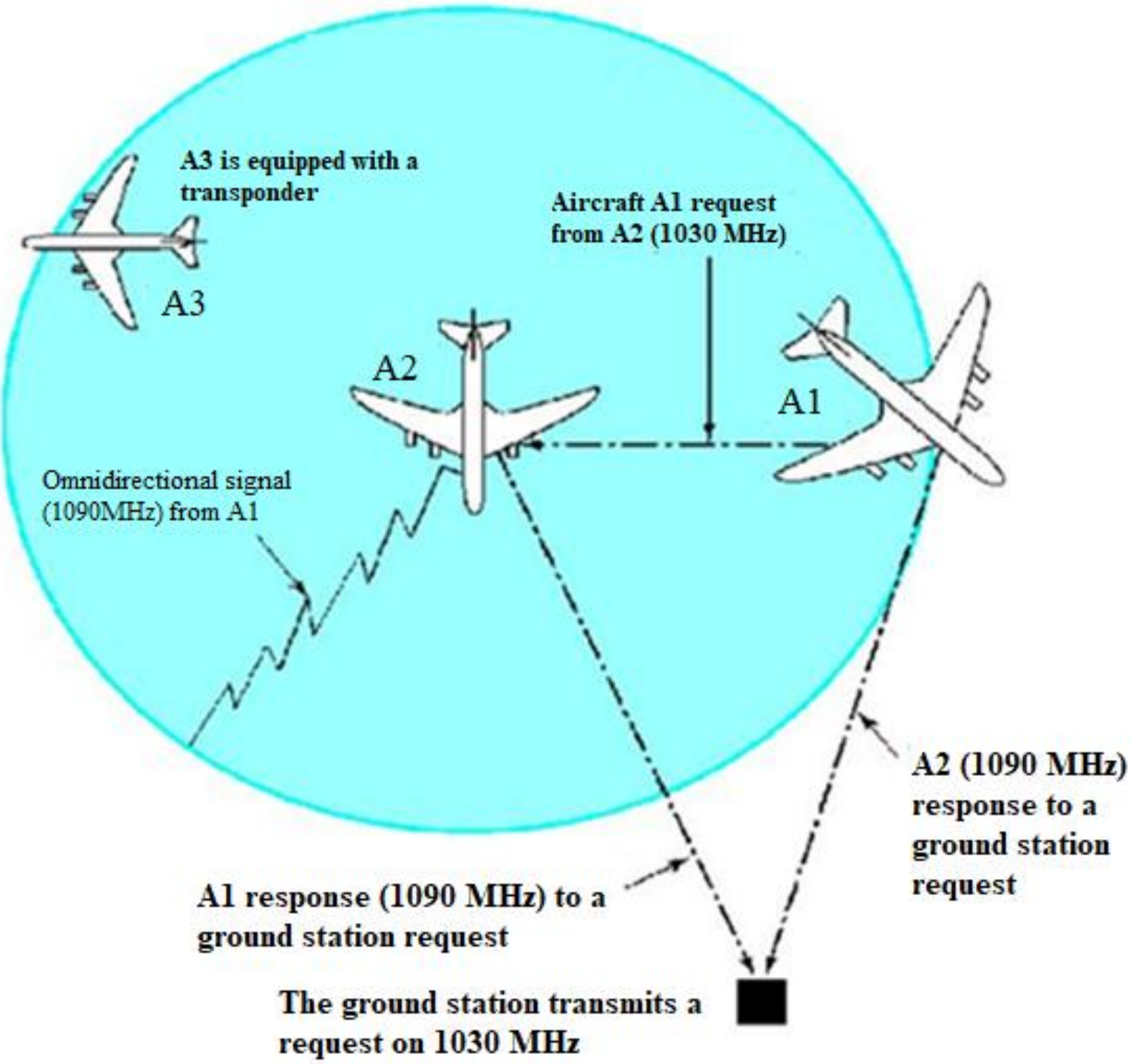

Figure 2.2 – Functional principle of operation of the TCAS II system

The work of TCAS II is based on determining the flight time to the point of closest approach to the CPA (Closest Point of Approach) depending on the altitude ranges (sensitivity level). In the 1-second cycle mode, TCAS II tracks other aircraft by interrogating their transceivers, and when the range check and altitude check are positive, TCAS issues a TA warning (Traffic Advisory) and, if the planes continue to approach, the crew receives a TCAS message about the need to resolve the conflict situation RA (Resolution Advisory) and a command to perform a descent or climb maneuver. If both aircraft are equipped with TCAS systems, they exchange information to prevent the same divergence maneuvers (Fig. 2.3).

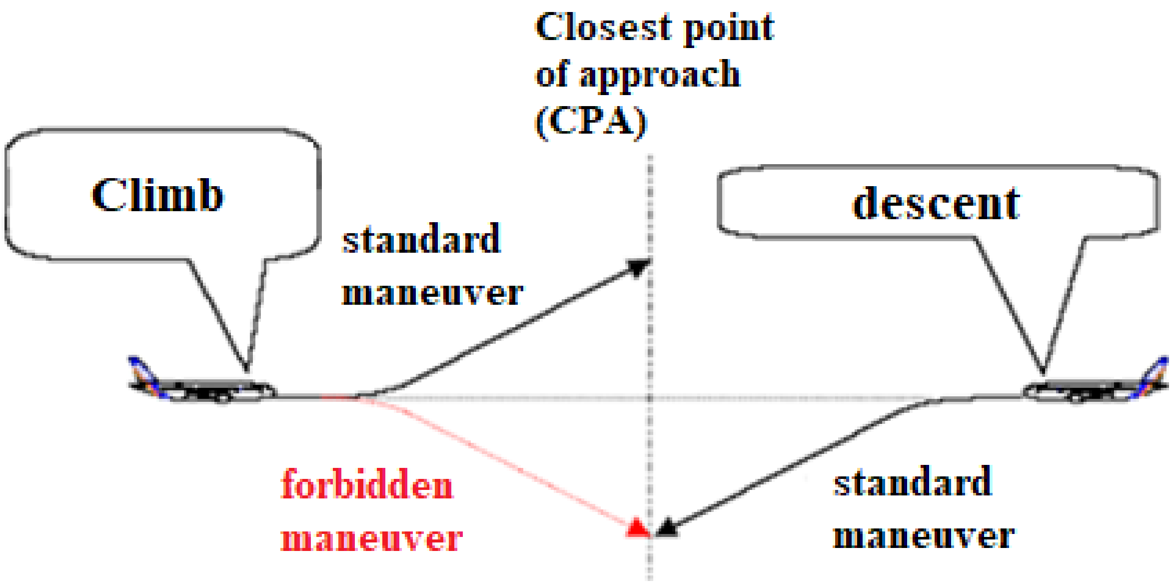

Figure 2.3 – Schematic representation of the operation of the TCAS system in the event of a conflict between two DO

The TCAS II system calculates the flight time to the CPA point based on the approach speed and the distance between the aircraft and if this time is less than the established threshold value (Table 2.1), then TA and RA are issued (Figure 2.4).

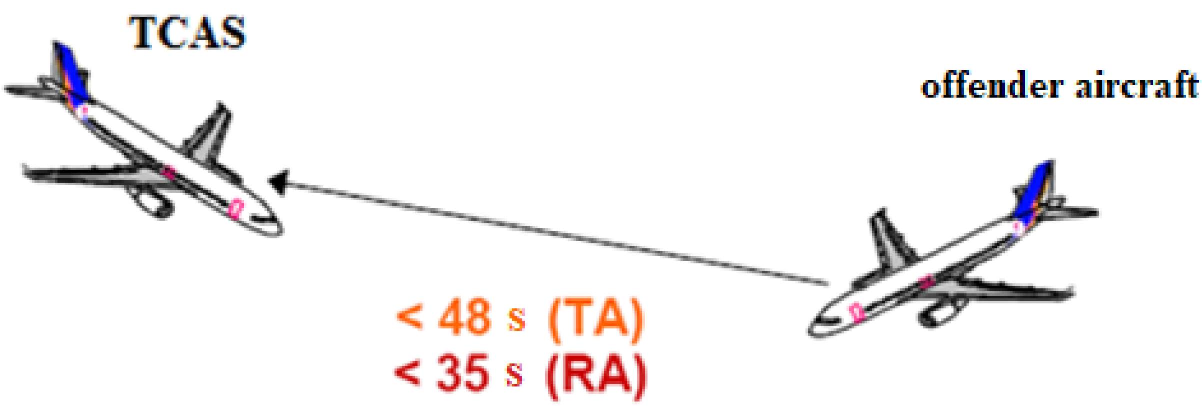

Figure 2.4 – Procedure for issuing TA and RA commands

In the case of a very low speed of approach of airplanes, if the distance between the airplanes is less than the set protective distance D_0, then the TCAS II system issues TA and RA (Fig. 2.5).

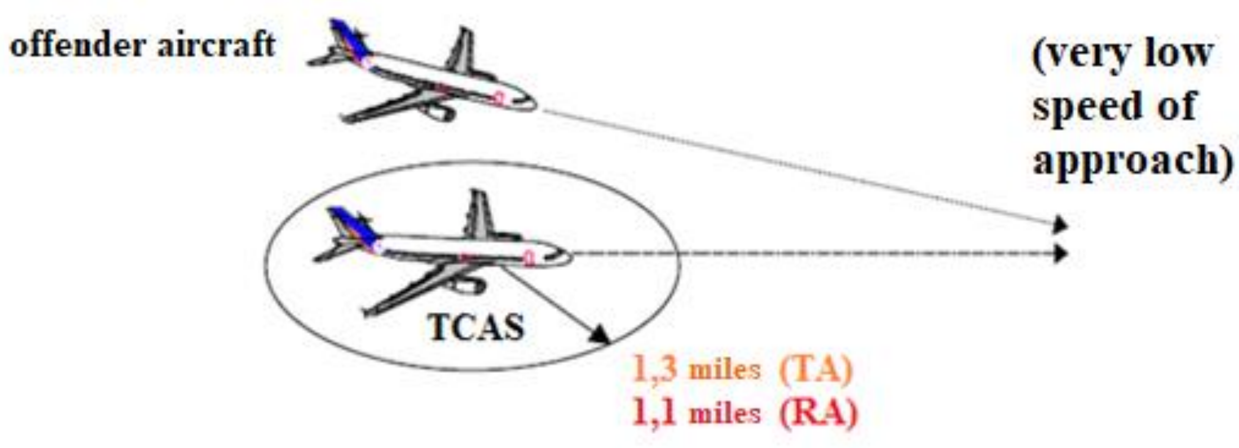

Figure 2.5 – Rules for issuing TA and RA commands

The TCAS II system calculates the flight time until reaching the same altitude based on the relative altitude between the aircraft and the relative vertical speed and, if the current time is less than the set threshold value H_0 (Table 2.1), then TA and RA are issued (Fig. 2.6).

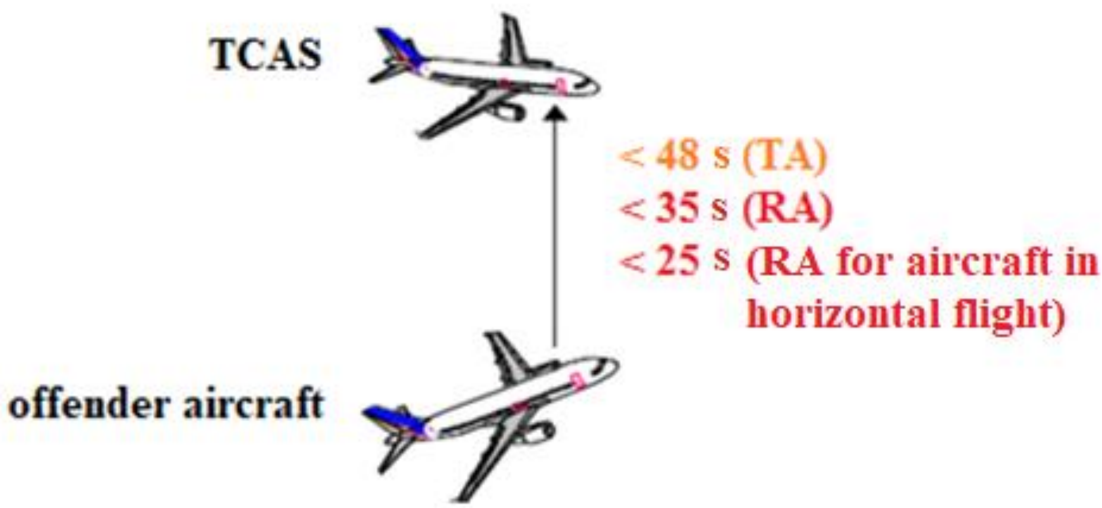

Figure 2.6 – Rules for issuing TA and RA commands

In the case when the aircraft are in horizontal flight and if the relative altitude between the aircraft is less than the set height threshold H_0, the TCAS II system issues TA and RA (Fig. 2.7).

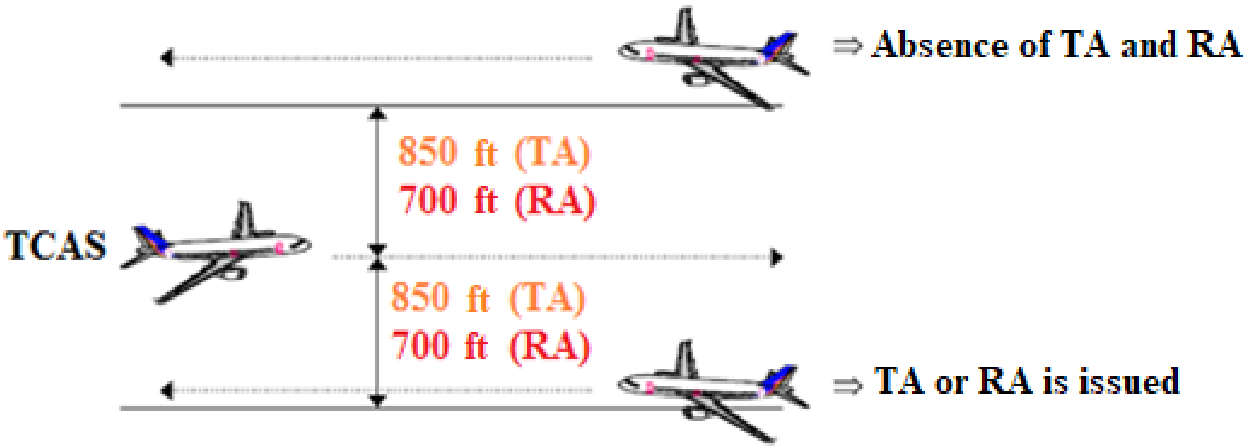

Figure 2.7 – Rules for issuing TA and RA commands

Table 2.1 Threshold values of TCAS commands

Altitude range (ft.)	*CPA* (s)		D_0 (n. miles)		Altitude threshold H_0 (ft.)	
	TA	RA	TA	RA	TA	RA
<1000	20	N/A	0.30	N/A	850	N/A
1000-2350	25	15	0.33	0.20	850	300
2350-5000	30	20	0.48	0.35	850	300
5000-10000	40	25	0.75	0.55	850	350
10000-20000	45	30	1.00	0.80	850	400
20000-42000	48	35	1.30	1.10	850	600
> 42000	48	35	1.30	1.10	1200	700

While the advantage of using TCAS is undeniable, this system has a number of significant limitations:

- the ATC system does not receive instructions issued by TCAS to aircraft, so air traffic controllers may not be aware of such instructions, and may even give contradictory instructions, which is the reason for the hesitation of crews;

- for the effective operation of the TCAS system, it is necessary for all aircraft to be equipped with this system, as the aircraft detect each other by transponders;

- the system cannot detect aircraft not equipped with RBS transponders; if the sensors of the conflicting aircraft for some reason do not provide data about their altitude, then TCAS may not identify them on the display;

- in order to resolve the conflict situation, the system issues commands only in the vertical plane, maneuvers in the horizontal plane are still impossible for it.

2 .2 Development of subsystem for solving conflict of dynamic objects in real time as an addition to the TCAS system

2 .2.1 Structural diagram of the subsystem for solving conflict of dynamic objects on a real-time scale

For the implementation of such information technology, a subsystem is proposed to ensure the guaranteed resolution of defused (with the necessary and sufficient time reserve) conflicts of aircraft on a real-time scale to increase the safety of flights in aviation and the efficiency of the use of aviation equipment [19, 20, 10].

The subsystem is implemented in the form of a separate unified equipment that works with the use of satellite and radio navigation systems, which will allow determining the coordinates of the DO on a real-time scale. It is predicted that the subsystem should be installed on all aircraft and integrated into their on-board network to properly ensure its functionality and interaction with on-board navigation systems (Fig. 2.8).

Figure 2.9 shows the structural and functional diagram of the specified subsystem. As shown, the real-time aircraft conflict resolution subsystem consists of two modules containing blocks and some isolated blocks that perform separate functions.

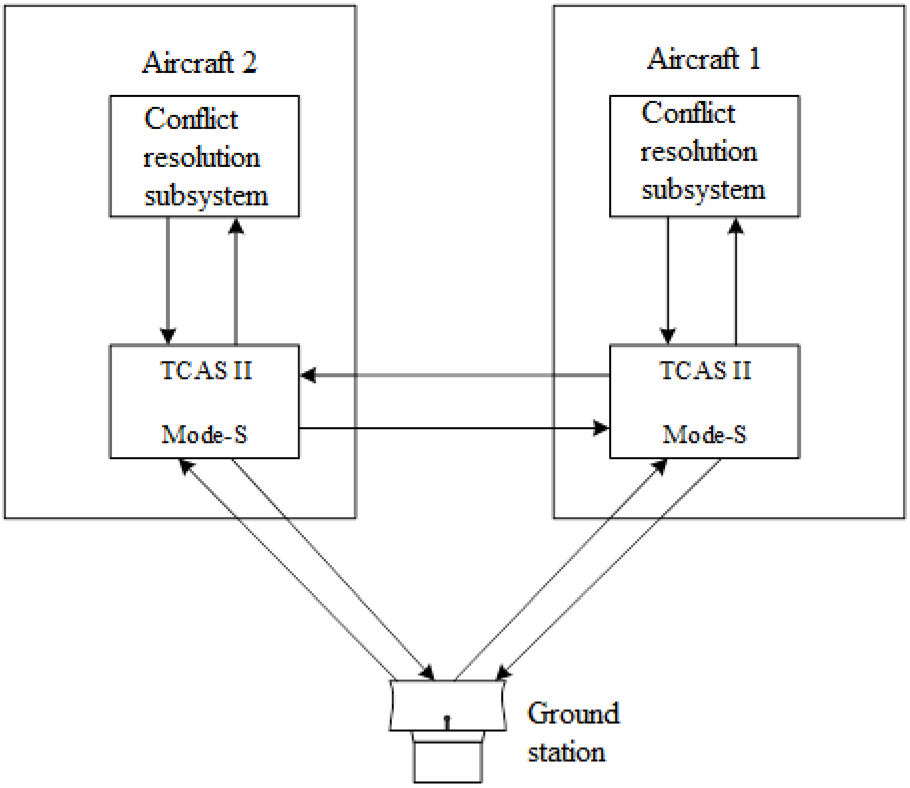

Figure 2.8 – Scheme of interaction of dynamic objects with implemented conflict resolution subsystem

The subsystem contains the following modules:

- collision threat detection module;

- a module for calculating maneuvering parameters.

In turn, the module for determining the threat of collisions consists of: a unit for determining the coordinates of the DO, a unit for calculating the predicted trajectories of the DO, a unit for analyzing data and determining the threat of collisions, and a unit for taking into account uncertainty zones.

The module for calculating the maneuvering parameters consists of: a block for calculating and comparing areas of the controlled state, a block for determining the priority of DO and selecting the type of maneuver, a block for determining the trajectory of the maneuver, a block for determining the trajectory of returning to the initial trajectory, and a block for taking into account the global optimum (namely, estimating temporal and spatial losses to perform a maneuver to resolve a conflict situation).

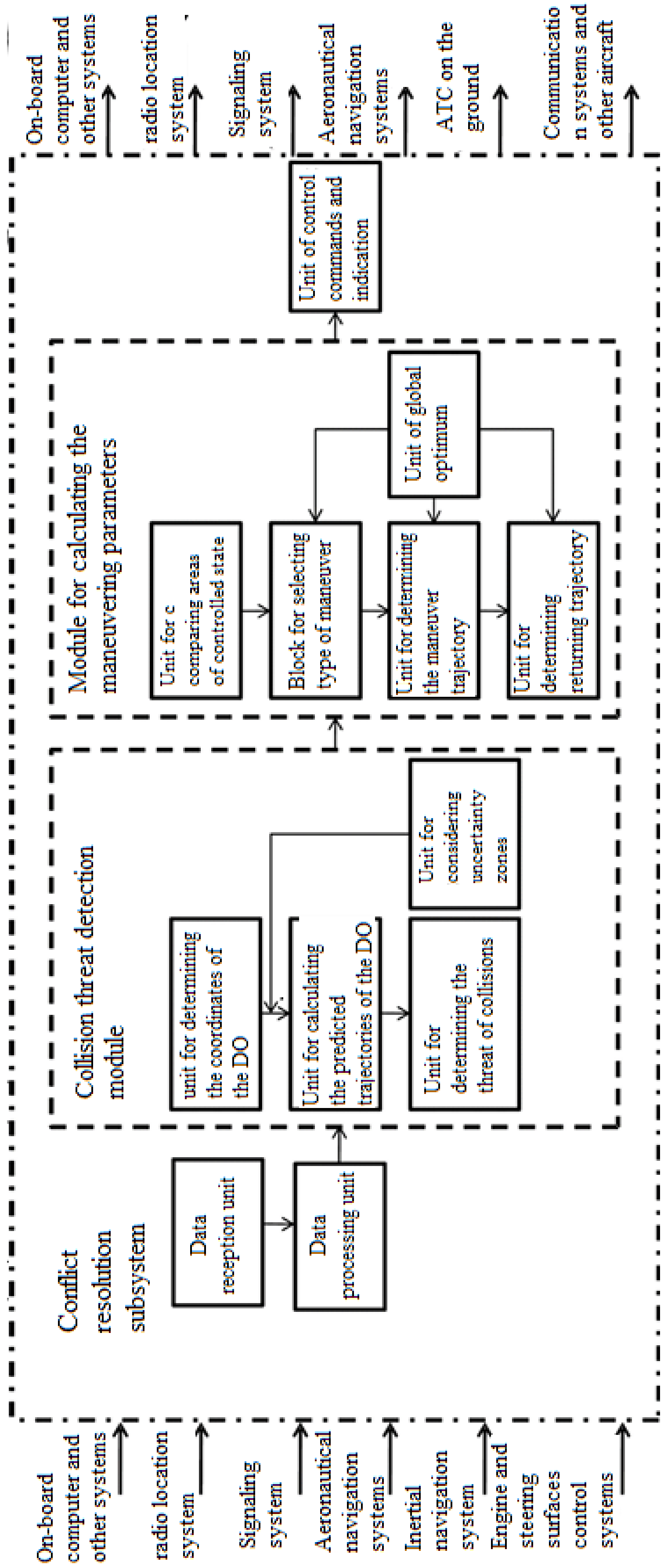

Figure 2.9 – Structural and functional scheme for systems of guaranteed conflict resolution of dynamic objects

In addition, the subsystem contains several separate blocks, namely:

- data reception unit;
- data processing unit;
- unit for issuing control commands, signaling and indication.

2.2.2 The general algorithm of the dynamic object conflict resolution subsystem on a real-time scale

Consider the principle of operation of the developed subsystem, the algorithm of which is shown in Fig. 2.10. The subsystem works cyclically, continuously receiving data from many sources of its aircraft and all other DOs located in a certain given limited part of airspace, transmitting the resulting data to other DOs, systems of its DO, and ground services and systems. Data is constantly received and processed in the respective devices, some of them can be stored for use in subsequent time intervals if necessary.

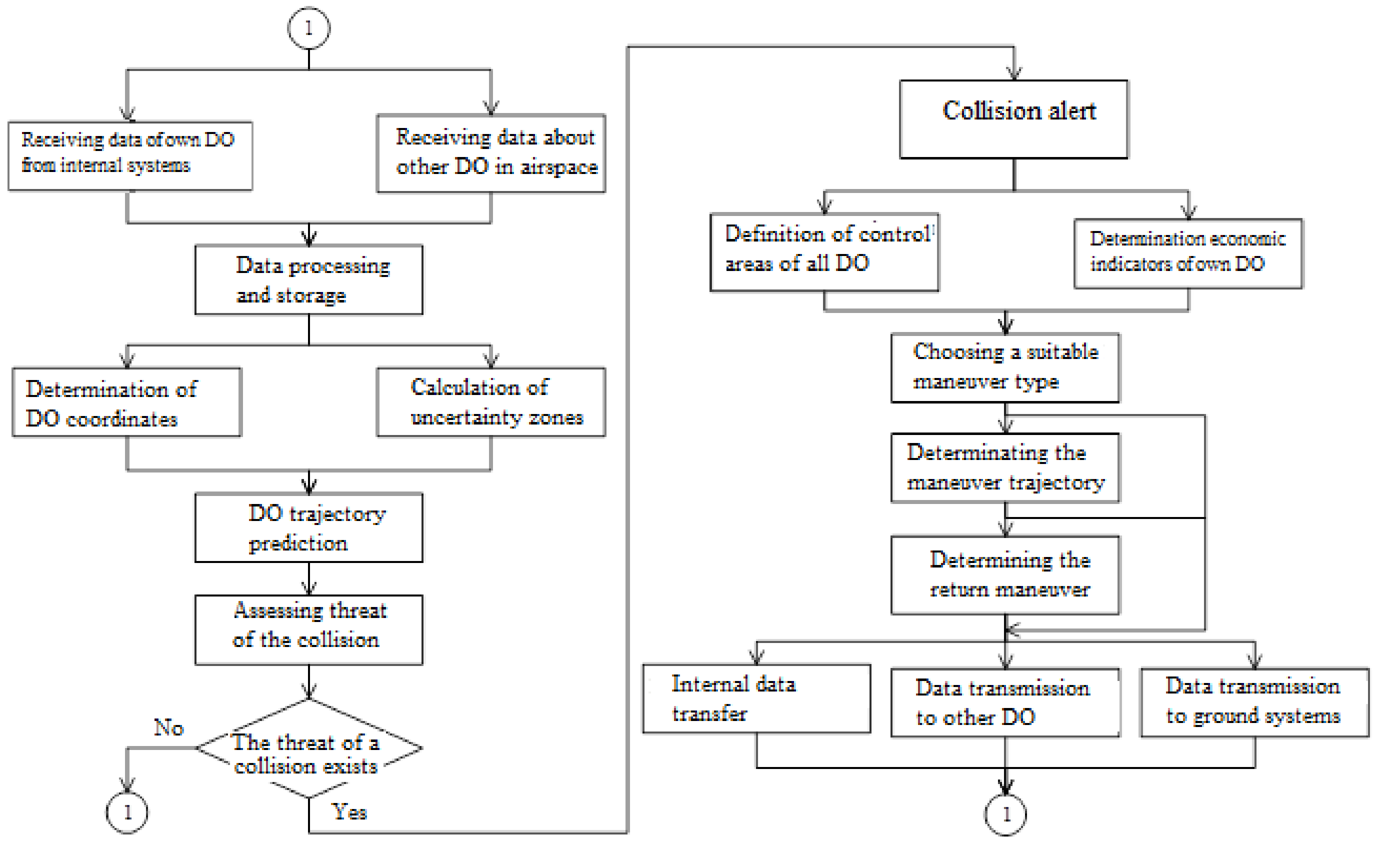

Figure 2.10 – Algorithm of the dynamic object conflict resolution subsystem

After receiving and processing, the data is sent to the physical module for determining the threat of collision. The analysis of the threat of a collision is based on forecasts of the trajectories of DO movement in the given zone, which is based on coordinates, speed, acceleration, course and possible additional parameters of the mathematical models of the movement of DO. In addition, information on the so-called "uncertainty zones" is taken into account to determine the coordinates of all DOs on the space-time coordinate grid. On the basis of the received data and predicted trajectory of the DO, analysis and modeling is carried out to determine the probability of the collision threat of DO in a given area of space. If there is no threat of collision, the subsystem returns to the initial state and cyclically continues the analysis.

In the event of a collision threat, a signal is issued, which is used to alert the pilot and upon receipt of which the physical module for calculating maneuvering parameters is activated, the main task of which is to determine the optimal trajectory of the maneuver to avoid a collision. Aggregated information about the predicted trajectories is used to determine the controllability areas of the DO in the zone of the conflict situation at each moment of time. In addition, the economic indicators of one's own DO are taken into account, namely, the change of the maneuver route in terms of distance and time, fuel economy, the convenience of transporting passengers and luggage, and others. These indicators and criteria will be taken into account in calculations to determine deviation trajectories. On the basis of the combined information from all previous blocks, the type of maneuver is selected, which is most suitable for the given conflict situation, the trajectory of the evasion maneuver and the steps to return to the initial trajectory after evasion are calculated. Each of the obtained results is transferred to the output of the subsystem immediately upon completion of the calculation.

For the formation of control commands and cyclic operation of the subsystem, information is transmitted to the internal systems of the DO, such as the on-board computer, autopilot, display and signaling devices in the crew cabin, communication and data transmission systems, and other systems. With the help of communication and data transmission systems, the developed subsystem transmits information to other DOs in a given part of airspace about their own maneuvers and trajectories, as well as to ground systems, such as control centers, radar systems and navigation complexes.

2.2.3 Description of the hardware part and implementation technology of the dynamic object conflict resolution subsystem on a real-time scale

For the implementation of the proposed information technology, a subsystem of the TCAS system is proposed. This subsystem expands its capabilities and performs safe resolution of DO conflicts in real time, which increases the overall efficiency and safety of flights. The subsystem is a combination of hardware and software developed according to European standards. Fig. 2.11 shows the structural diagram of the components and connections of the subsystem, the main components of which are:

- general memory device;
- collision threat processing unit;
- maneuvering parameters processing module;
- TCAS/Mode-S interface;
- real time clock;
- shared memory device;
- collision warning unit;
- common control and data transmission channel.

The general memory device is the main device for storing information in the subsystem, which, using a common control and data transmission channel, receives information from the internal systems of the DO about the flight parameters and permanent characteristics of its DO. Information from the TCAS system and the Mode-S transponder about all DOs in a certain specified limited part of the airspace is also received through a common channel, which is received in real time through a specialized interface with direct access to the systems.

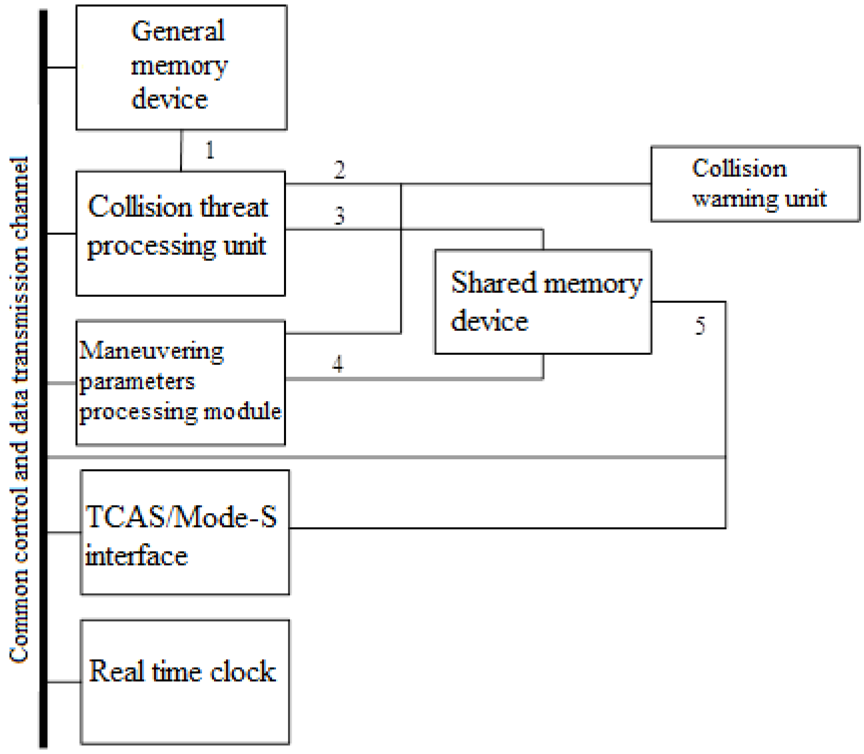

Figure 2.11 – Structural diagram of the components and connections of the dynamic object conflict resolution subsystem

The collision threat processing unit implements the collision threat detection module. The module is connected directly to the general memory device using a separate transmission channel (1), which provides better speed and bandwidth for real-time system operation. The processor element is programmed for cyclic execution of the corresponding part of the algorithm. If during data processing the probability of a collision exceeds a predetermined value, it is considered that a threat of a collision occurs, the processing element issues an interrupt signal to the collision alarm unit and the maneuvering parameters processing unit (transmission channel (2)) and transmits to the shared storage device (transmission channel (3)) summary information - input data on which calculations were performed, and output data after the block's operation. The collision warning unit notifies the pilot of the existing possibility of collision with the help of an indicator. If the threat probability does not exceed a given value, the collision threat processing unit returns the calculation results to the common memory device through the common control and data transmission channel. The transmitted information is stored in the subsystem for several cycles and can be used for further calculations.

The maneuvering parameters processing unit implements the maneuvering parameters calculation module. In passive mode, it receives information from the general memory device about some economic indicators of its own DO, such as fuel level and many others. It operates in idle mode, listening for an interrupt state from the collision threat handler (transmit channel (2)). Upon receiving the interrupt signal, the block reads information from the shared memory device (transmission channel (4)) and starts processing it according to the algorithm. At the completion of each calculation, its result is transmitted through the common channel of control and data transfer to storage to the general memory device and back to the shared memory device using the transmission channel (4) in the reverse direction.

The TCAS/Mode-S interface, as mentioned above, is directly connected to the aircraft critical approach warning system and the Mode-S transponder. Direct access to the systems allows to speed up the acquisition of information about the DO in a given part of the airspace and to return the results of the subsystem to the elements of the systems through which messages are transmitted to other DO and ground services. Inside the subsystem, the interface interacts with general memory device, to which it transfers the information received from the devices, and with the output data of the subsystem, part of which comes through the common control and data transmission channel from the maneuvering parameters processing module, and the other part from the common memory device (transmission channel (5)). The output data is processed to conform to the structure of the TCAS system and transmitted to its elements.

The real-time clock is the main connecting link of subsystem elements, which helps synchronize the interaction of processing units and determine delays and necessary moments for event indications. Integrated circuit of the clock implemented on the basis of a quartz resonator, which provides 2^{15} cycles per second and provides high accuracy for calculations.

The shared memory device is an auxiliary device for storing information, which is used to speed up the transfer of data between processing units of the subsystem, which is provided by using separate special data transmission channels (3, 5) and a solid-state drive. Information in the shared memory device is stored throughout the flight and is transmitted to other systems of the aircraft (transmission channel (5)).

The common control and data transmission channel is connected to the external interfaces of the subsystem, transmits and receives commands and data between the developed subsystem and other systems of DO. The resulting data and control commands in the form of auxiliary information are fed back through a common channel to a general memory device to ensure the cyclical operation of the subsystem and to external systems of the DO to perform maneuvers.

2.2.4. A computer program for modeling the conflict resolution subsystem of dynamic objects on a real-time scale

As an applied development for the proposed subsystem, a computer program for simulating the resolution of the DO conflict on a real-time scale was implemented. The modeling process allows to show the connections and properties of aviation systems, elements and processes, which allows to assess their condition, make a prediction, make a reasoned decision, check the accuracy and correctness of the model, and more. DOs are implemented as static models, each with its own physical characteristics, state and vector of planned movement. The dynamic component of the model is the process of functioning and development of static elements, i.e., characteristics and indicators of flight, trajectories that change over time. Modeling of the developed subsystem requires the creation of DO models in the flight area, the movement of which can cause a conflict situation to arise.

Initial data for modeling:

- The number of DO located in some part of the space;
- The number of ground stations located in some part of the space;
- Initial coordinates of each DO and each ground station;
- Availability of a developed subsystem on each DO;
- Unchangeable physical parameters of each DO (size, weight, priority, etc.);
- Changeable physical indicators of each DO (speed, height, fuel reserve, etc.).

The simulation process is performed with discretization of the movement of the DO with a certain time interval using the system clock, which interacts with the clocks of the DO and ground stations. According to the initial coordinates and the trajectory of movement, DOs move in some defined three-dimensional plane, both within the radius of action of the

TCAS-II system and, possibly, beyond it. Modeling the movement of aircraft outside the zone covered by the TCAS-II system is necessary to take into account the occurrence of conflict situations in the event of a possible change in the trajectories of some DOs. Each DO exchanges information with other vehicles during movement according to the algorithm of the developed information technology, and performs a prediction of the threat of collision in some defined area. In the event of a conflict situation, DOs calculate the maneuvering parameters and return to the previous trajectory after the maneuver.

Own model of the conflict resolution subsystem is created for each DO during generation. The model consists of software abstractions that represent hardware elements of the subsystem. Models of the subsystems of each DO interact with each other, and the functionality of the hardware elements corresponds to the description from the previous sections.

The computer program for modeling was developed using two programming languages - Java and C. The high-level object-oriented Java programming language is used for system modeling and graphical interfaces. Procedural imperative programming language C was used in modeling individual components of the system, such as DO, elements of the subsystem, ground control stations, and others. The combination of these programming languages made it possible to develop a computer simulation program that is most similar to a real aircraft system.

The modeling system was developed according to the principles of object-oriented programming. The presentation layer was written using the Java programming language version 8. The lower layer, which implements the hardware model, was written in the C programming language of the C11 standard. Java was used to run program code written in C through the Java language Native Interface (JNI) – a mechanism for launching code in the C/C++ languages, under the control of the Java virtual machine (JVM).

The structure of the computer program for modeling the subsystem of conflict resolution of aircraft on a real-time scale is shown in fig. 2.12. The four main modules of the program implement separate components of the general model. In addition to them, there are a number of DOs, each of which has its own specific characteristics, system clock and graphical interface.

First of all, a three-dimensional coordinate plane model is created in which the system will be modeled. With the help of manual input, such parameters as the size of the plane, the scale of the radar, the number of DOs and control points are adjusted. An instance of the main plane model class contains the coordinates of the location of each DO after generation and after each cycle of the system.

According to the number of DOs, which was specified when setting up the coordinate plane, instances of DO models are created using the DO generation module. Input data for generation can be both manual inputs using a graphical interface, and files in JSON or XML formats that contain all the necessary parameters. For each DO, the parameters are its changing and unchanging physical parameters, the coordinates of the initial and final points of the flight, and the flight trajectory. Also, each instance contains an internal clock that is synchronized with the common clock, and systems for receiving and transmitting messages. Every clock cycle, the DO model updates its current coordinates on the plane model and transmits them to the DO and ground control centers within range using communication systems.

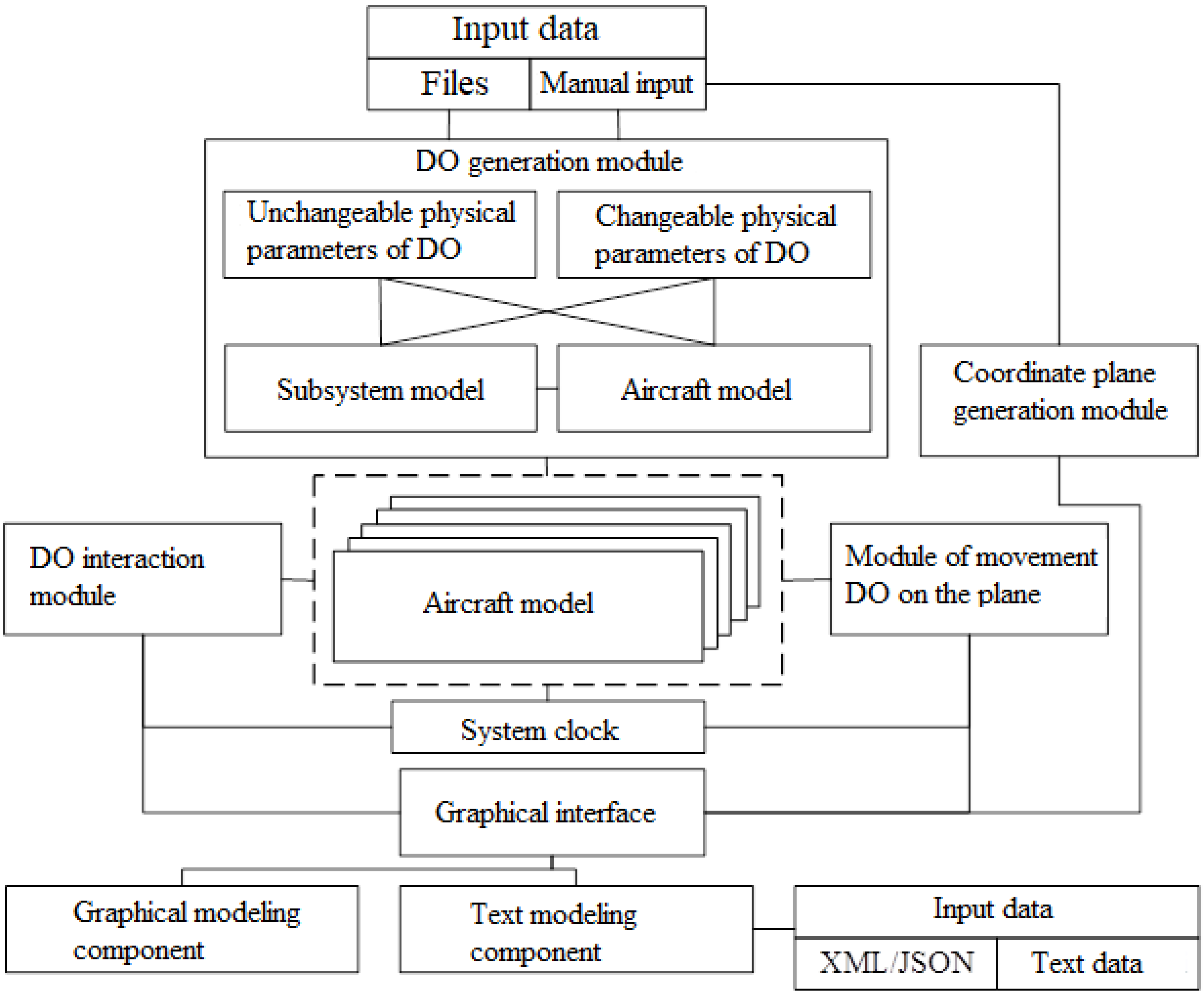

Figure 2.12 – The structure of the computer program for modeling the conflict resolution subsystem

The model of the developed subsystem is implemented for each DO, on which it is installed, in the form of hardware and software elements. The full implementation of the subsystem allows estimating the time and hardware costs during the movement and interaction of aircraft on the plane.

Algorithms for the physical movement of aircrafts are embedded in the movement module. During the simulation, the component parts of the module check the possibility of moving the aircraft according to the given trajectory, interacting with the subsystem model or the TCAS system of each DO. If the systems are notified of a possible conflict situation, the movement module edits the path of the DO based on the information it receives.

The graphical interface of the computer program is written in the Java programming language using the JavaFX and SWT platforms. The interface consists of the main window

(Fig. 2.13-2.14), the settings window (Fig. 2.15), the help window and the window of the graphic editor of DO trajectories (Fig. 2.16). Additionally, system program windows are used to save and open files.

The main program window consists of three zones. At the top there are five buttons for running the simulation, a field for entering numerical values, a "Settings" button and a "Help" button. The left part of the window contains a graphical component representing the simulated space in the form of a radar and the "View" button, which is located in the lower left part of the radar. In the right part, there is a text component - a field for displaying the system log information of the model, a widget for selecting the source of information (a list of all DOs, dispatch centers or the general system log) and buttons to save the current open log and all logs at the same time. Saving is done in XML markup formats or JSON or in text format.

System simulation can be step-by-step or sequential. Step-by-step simulation is performed with the "1 Clock" or "10 Clocks" buttons. A sequential simulation is started by pressing the Start button and paused or completely finished by pressing the Pause and Stop buttons, respectively. The speed of the sequential simulation is adjusted using the numerical value input field for the number of cycles per second, which is located between the start and pause buttons. The "Settings" button opens the simulation complex settings window, which will be described below. The "Help" button displays a help window for using the computer program.

The first way to display the modeling process is the graphic component located in the left part of the main program window. The basic image in the form of a radar DO contains a degree grid and a polar coordinate system. The scale of the area imaged by the radar is set in the settings window. Each DO is a separate graphic element located on the radar as a point, and with the help of the context menu, additional elements that will be displayed can be configured for it (for example, trajectory or uncertainty zones). The movement takes place along the trajectory that was configured in the graphic editor, however, in the process of flight simulation, it may change depending on the selected maneuvers of the DO. However, in any case, the starting and ending points of the flight are unchangeable. The

"View" button, located in the lower left part of the radar, allows you to change the projection between horizontal and vertical (Fig. 2.13-2.14).

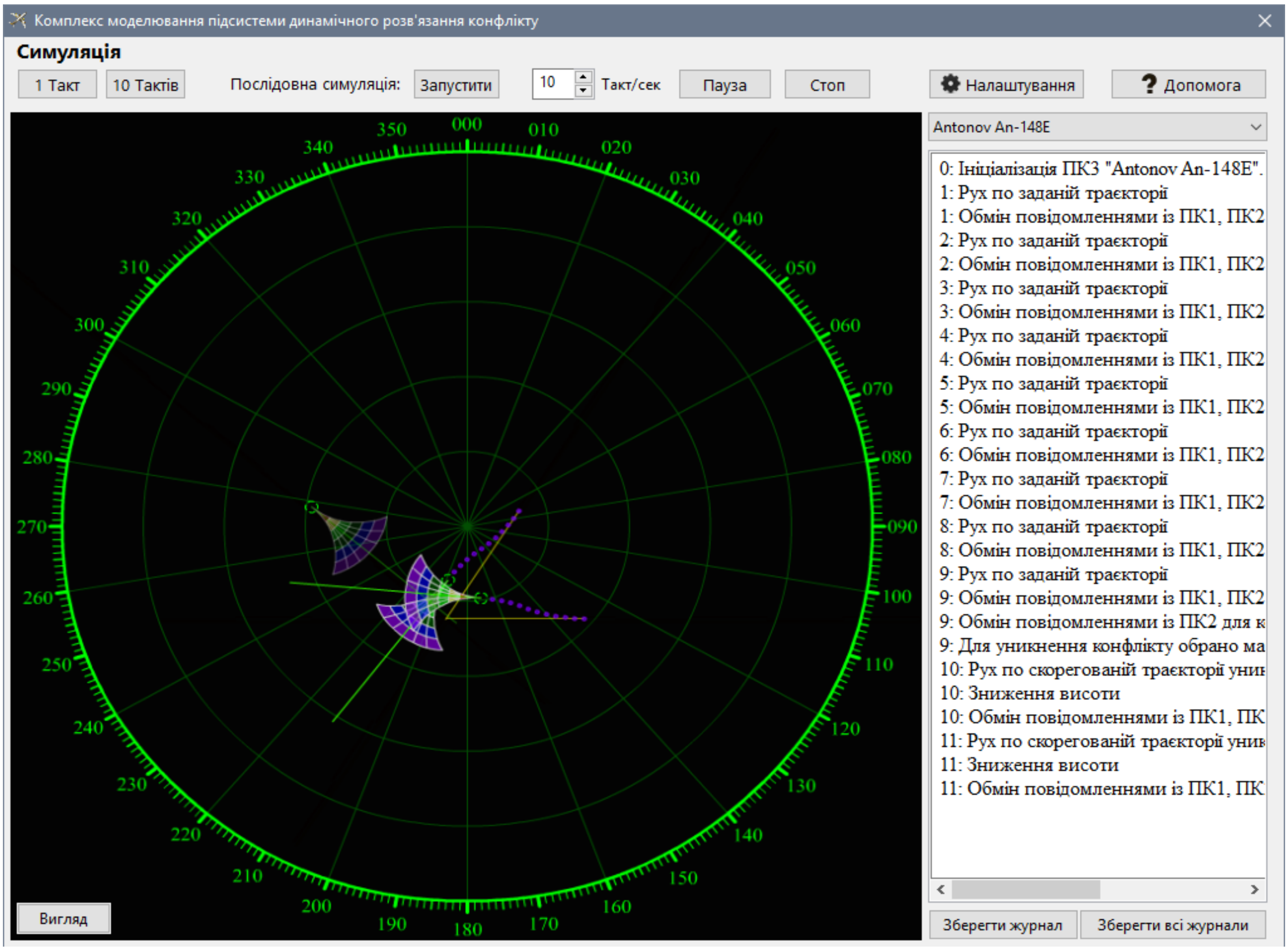

Figure 2.13 – The main window of the computer modeling program (horizontal projection)

The text component of the simulation process display is a widget in the right part of the main program window. There are separate event logs for each element of the system (ground control center, DO, model of the developed subsystem) and for the system as a whole. During each cycle, information about each event that occurred is added to the corresponding log. With the help of the drop-down menu above the widget , a journal is selected, which is displayed in the widget . If necessary, you can change the level of detail of the displayed information using the context menu of the widget. By default, only summary information about the movement and maneuvers of the DO, interaction between the DO and/or ground control centers, and notification of the subsystem when a conflict situation is detected is displayed. In addition, depending on the level of detail, additional data can be displayed, such as: all variable and constant parameters of the DO, each message that is transmitted between two DOs or DOs and the dispatch center, complete information about the operation of the subsystem. In fig. 2.13 shows textual information of medium detail, and in fig. 2.14 - minimal detail.

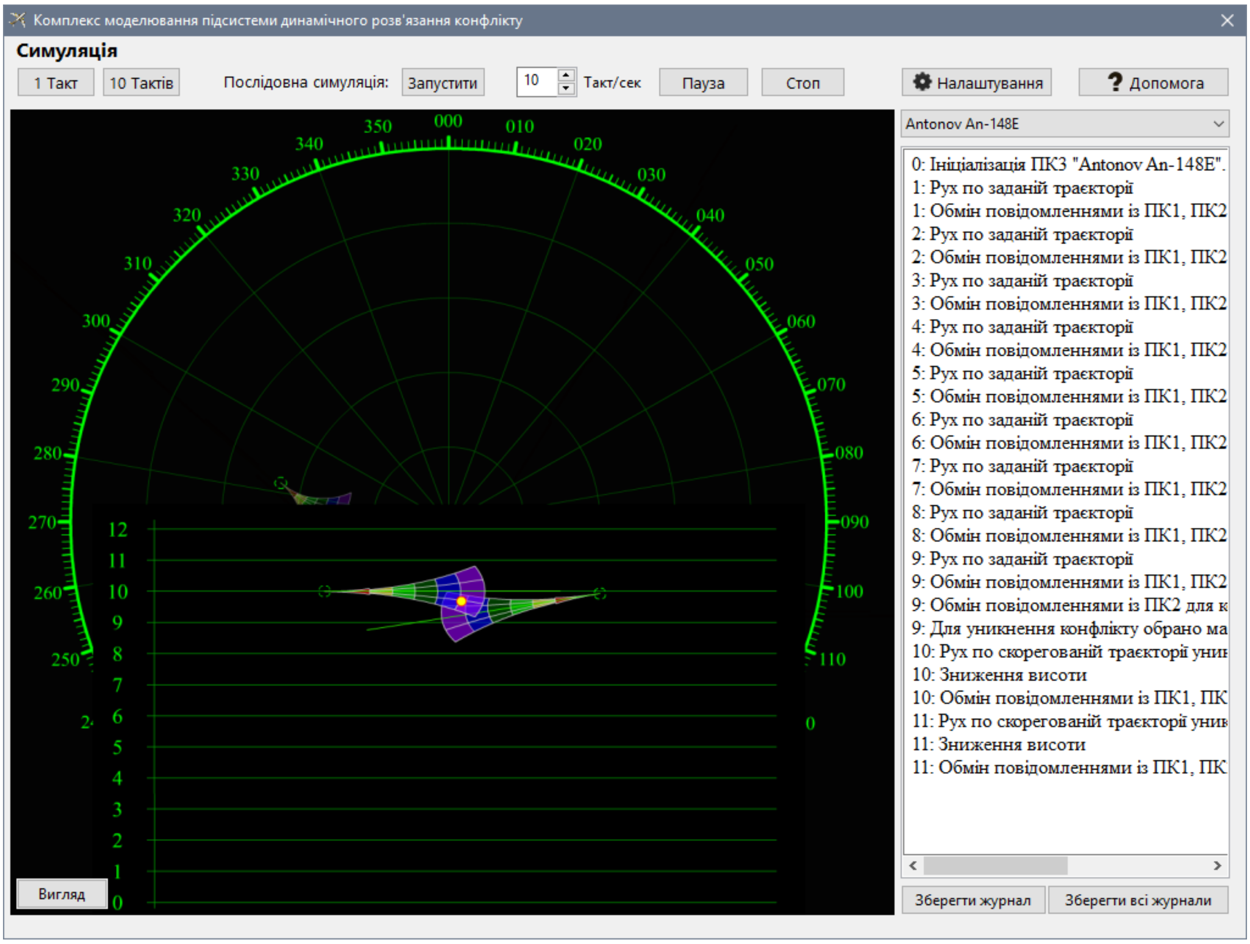

Figure 2.14 – The main window of the computer modeling program (vertical projection)

The settings window of the computer simulation program (Fig. 2.15) contains three zones for configuration of parameters and a zone of buttons. In the upper part of the window there is a zone for setting the modeling space, in the middle part there are DO settings, and in the lower part there is a zone for setting trajectories. At the very bottom of the window there are buttons for saving and resetting settings. In addition, to increase the ease of use for the user, the "Help" button is placed in the upper right corner of the settings window, which opens a window on the help page for configuring the computer program.

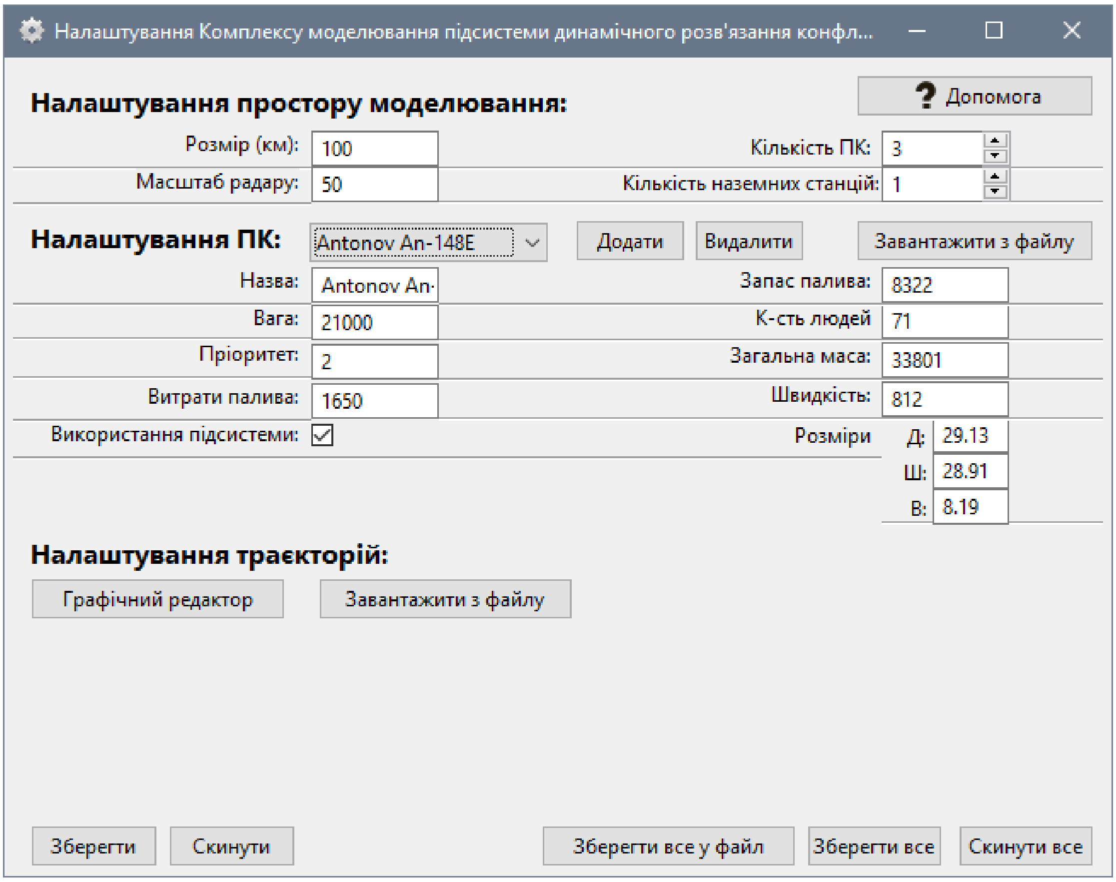

Figure 2.15 – The computer simulation program settings window

Most of the values are set using widgets that allow you to enter data of the appropriate type (integers or real numbers, symbols). When configuring a DO, the "Add" and "Remove" buttons respectively add or remove the DO instance to the list of all DOs in the system. In case of incorrect entry of parameters or other errors, an error message will be displayed and the corresponding widgets will be highlighted in red. It is possible to adjust trajectories in the graphic editor shown in fig. 2.16. To edit trajectories, it is necessary to fill in all other information about the DO and the simulation space. Formation or change of trajectories occurs by setting markers of the beginning and end of the movement and the lines of the desired trajectory.

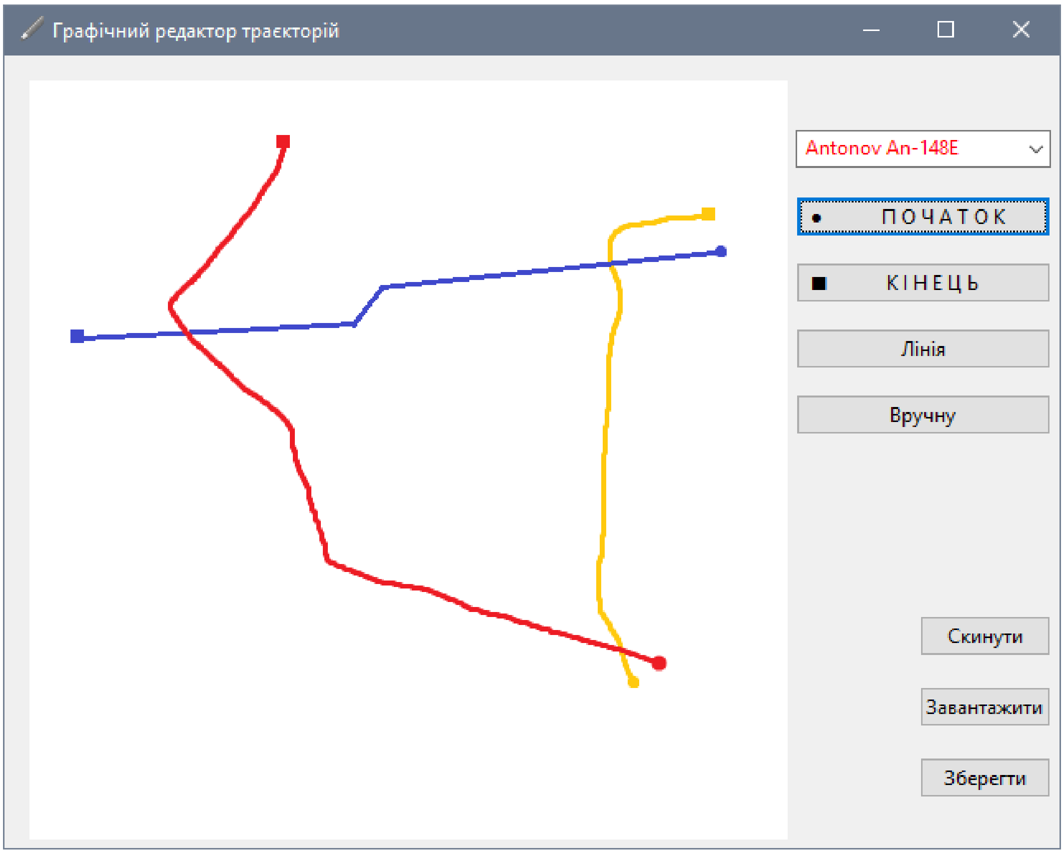

Figure 2.16 – The window of the graphic editor of trajectories

2.3 The base of rules for the divergence of dynamic objects in a conflict situation

A necessary component of the proposed method is the base of rules (knowledge base for the subsystem) of the divergence of the DO in a conflict situation. The rules themselves for clarity were built on the model of Euler-Venn diagrams with the imposition of zones of uncertainty of DO during a conflict situation.

The Euler-Venn diagram is a schematic representation of all possible intersections of several sets. Euler-Venn diagrams depict all 2*n* combinations of *n* properties, that is, a finite Boolean algebra. They are also a geometric representation of sets. The construction of the diagram consists in depicting a large rectangle representing a universal set, and inside it - circles (or some other closed figures) representing sets. The shapes must intersect in the most general case required by the task and must be labeled accordingly. Points lying inside different regions of the diagram can be considered as elements of corresponding sets. With the diagram constructed, certain areas can be shaded to indicate newly created sets. Set operations are used to obtain new sets from existing ones.

In our case, the rectangle is the area of the considered airspace with a size of 50 kilometers. We will depict the protective zones of the DO in the form of sectors, which also take into account the uncertainty zones of the position of the DO. The area of intersection of the protective zones of several DO (a new set) is the zone of a conflict situation (the danger zone of the collision of DO).

The basis of the creation of divergence rules according to Euler-Venn diagrams is the construction and comparison of the regions of the controlled state of DO, and for each individual case of a conflict situation, these rules will have their own characteristic features. However, these rules are also provided for cases when the construction of areas of the controlled state is impossible for any reason, or these areas will be the same for conflicting aircraft.

Fig. 2.17 gives an example of a possible conflict situation between two DOs. In this case, the DOs move on the same echelon, with a corresponding course.

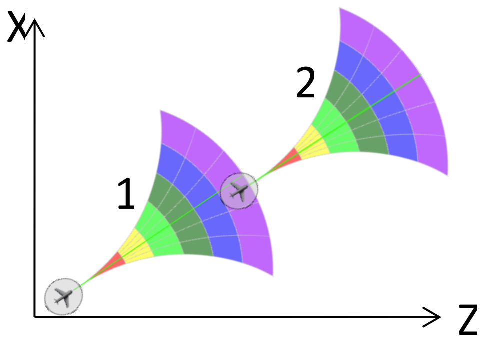

Figure 2.17 – An example of a possible conflict situation between two DOs

According to the developed rules of divergence in this conflict situation (there is a violation of the "protective zones" of the DO) in the case that the areas of the controlled state of the DO are unknown to us or they are the same, or in the case when, for example, based on the analysis of the obtained areas of the controlled state, we determine that the ability of aircraft No.2 to control the speed parameters in the horizontal plane is less, and accordingly aircraft No.1 has priority in performing the maneuver, then the divergence rule will sound like this: the advantage in CS is given to the DO whose speed is lower; in the event that one DO is catching up the other (with an advantage in speed), it is necessary to overtake on the right, having previously gained altitude to avoid wake turbulence. An example of the divergence of TO according to this rule is shown in fig. 2.18.

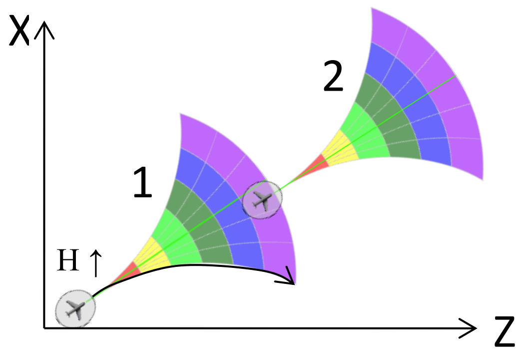

Figure 2.18 – An example of divergence of DO

Mathematically, the process of resolving a conflict situation will be presented in the form of an algebra logic:

if $S_1(x, y, z) = S_2(x, y, z)$,

and $H_1 = H_2$,

and $\psi_1 = \psi_2$,

and $\theta_1 = \theta_2 = 0$,

and $V_1 > V_2$,

then S_1 and S_2 - fly directly on parallel courses and intersect in the coordinates *(x, y, z)* at the same time *t* ,

and then S_1 should change ψ_1 by deviating to the right by previously increasing H_1 .

Symbols here mean:

S_1 and S_2 – plane No.1 and plane No.2;

(x, y, z) – spatial coordinates of the position of the aircraft at time *t* ;

ψ_1 and ψ_2 – course of the first and second aircraft;

V_1 and V_2 – the speed of the first and second aircraft;

θ_1 and θ_2 –the angle of inclination of the trajectory of the first and second aircraft;

H_1 and H_2 – are altitudes of the first and second aircraft.

Let's consider another example of a DO conflict situation and the construction of Euler-Venn diagrams with the derivation of the corresponding divergence rule. Echelons of planes: one is gaining altitude, the other is flying straight, the headingis parallel (Fig. 2.19).

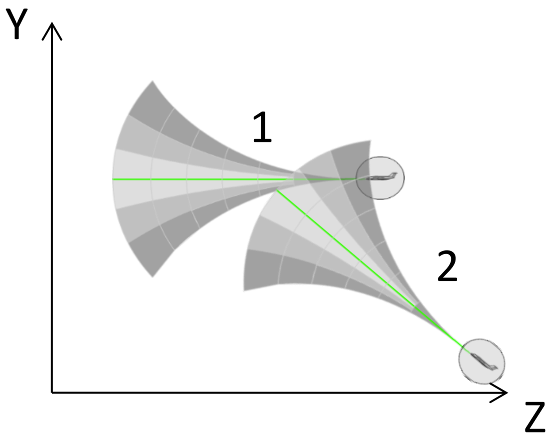

Figure 2.19 – An example of a conflict situation before

Suppose, in the case that we do not know the regions of the controlled state of DOs or they are the same, or in the case when, for example, according to the obtained regions of the controlled state, we determine that the capabilities of aircraft No. 2 to control the speed and altitude parameters in the vertical plane are smaller, and accordingly, aircraft No. 1 has priority in performing the maneuver, then the divergence rule will sound like this: priority is given to the DO that is located below; the plane flying higher must deviate on the course to the left. An example of the divergence of DO according to this rule is shown in fig. 2.20.

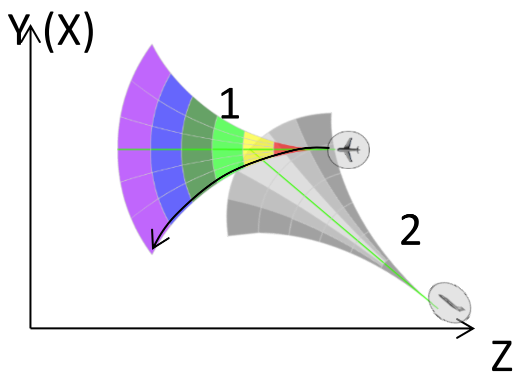

Figure 2.20 – An example of the divergence of DO

Mathematically, the process of resolving a conflict situation will be presented in this case for clarity in a predicative form:

$$S1(H1(t0), \psi 1(t0), \theta 1(t0), V1(t0), pos1(t0))\ ;$$

$$S2(H2(t0), \psi 2(t0), \theta 2(t0), V2(t0), pos2(t0))\ ;$$

$$V1(t0) = V2(t0) = V1(t1) = V2(t1) = const$$

$$\psi 1(t0) = \psi 2(t0) = \psi 1(t1) = \psi 2(t1) = const;$$

$$\theta 1(t0) = \theta 1(t1) = const, (H1(t0) = H1(t1) = const);$$

$$\theta 2(t1) = \theta 2(t0),\ \ H2(t1) > H2(t0))\ ;$$

$$H1(t1) = H2(t1)\ ;$$

$$pos1(t1) + \varepsilon = pos2(t1) + \varepsilon\ ;$$

$$S1(H1 = const, \theta 1 = const, V1 = const);$$

$$S2(H2 \uparrow, \theta 2 > 0,\ V2 = const, \psi 2 = const;$$

$$\psi 1(t1) = \psi 1(t0) - \Delta\psi\ ;$$

$$\psi 1(t1) \neq \psi 2(t1)\ ;$$

$$H1(t1) = H2(t1)\ ;$$

$$pos1(t1) + \varepsilon \neq pos2(t1) + \varepsilon\ .$$

CHAPTER 3

SIMULATION OF INFORMATION TECHNOLOGY FOR RESOLVING CONFLICT SITUATIONS OF DYNAMIC OBJECTS ON A REAL-TIME SCALE

3.1 Modeling the operation of the TCAS II system

To analyze the effectiveness of the existing traffic collision avoidance system and compare it to the proposed technology, we will use a mathematical model. It can allow to reliably simulate situations in which large numbers of dynamic objects are interacting simultaneously. The results of the modeling can be shown graphically on 3-dimensional and 2-dimensional plots, representing trajectories of each dynamic objects. We can also then plot distances between each DO at each point of time. This method can help estimate effectiveness of the technology.

Fig. 3.1 shows an example of the trajectory of five aircraft moving along different routes, at different altitudes and at different speeds - they will all cross at the same point *C* - at the same time *t*. This represents trajectories without using TCAS, and which will result in the collision of the DOs.

The conflict model is built in the MatLab environment. Parameters of Boeing 767 and Airbus A321 aircraft were used to create mathematical and aerodynamic models of aircraft movement [21-22].

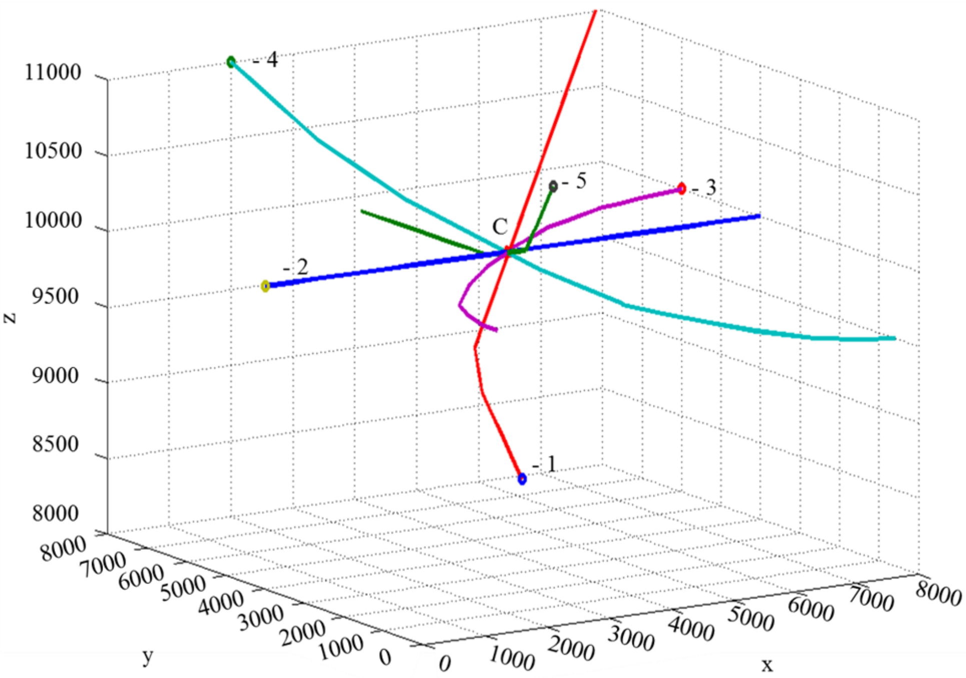

Figure 3.1 – Three-dimensional model of the trajectory of the movement of five identical dynamic objects

Fig. 3.2-3.4 shows two-dimensional projections of the above example of the conflict model for clarity.

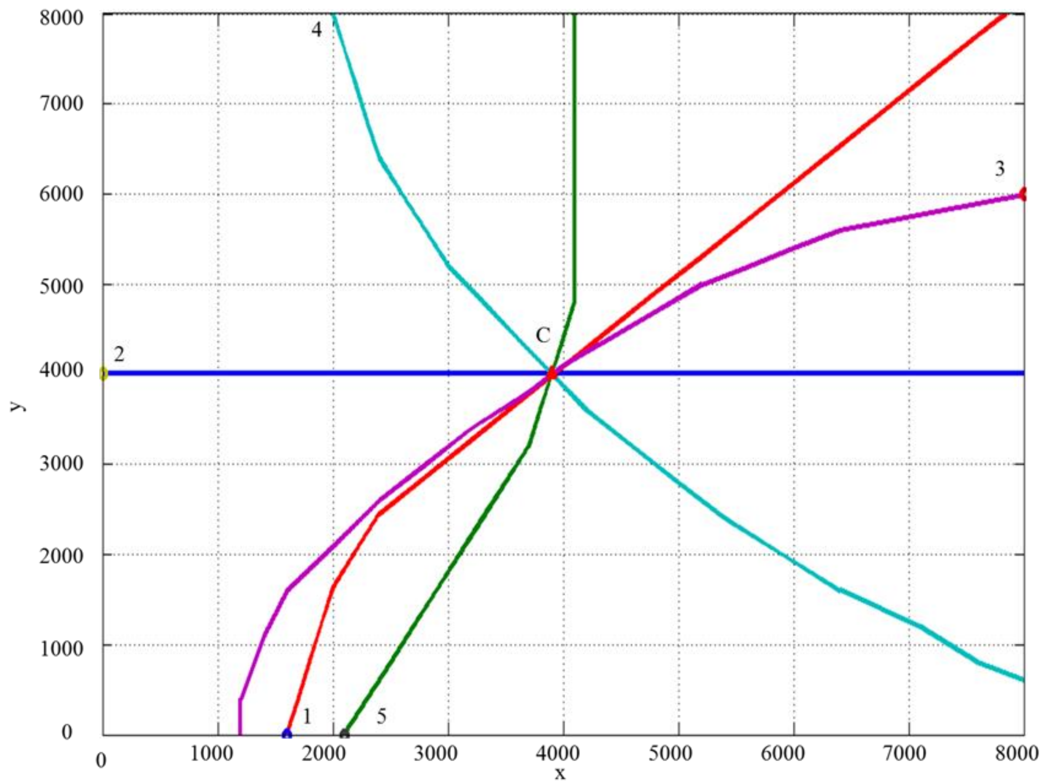

Figure 3.2 – Two-dimensional projection No. 1 of the conflict model

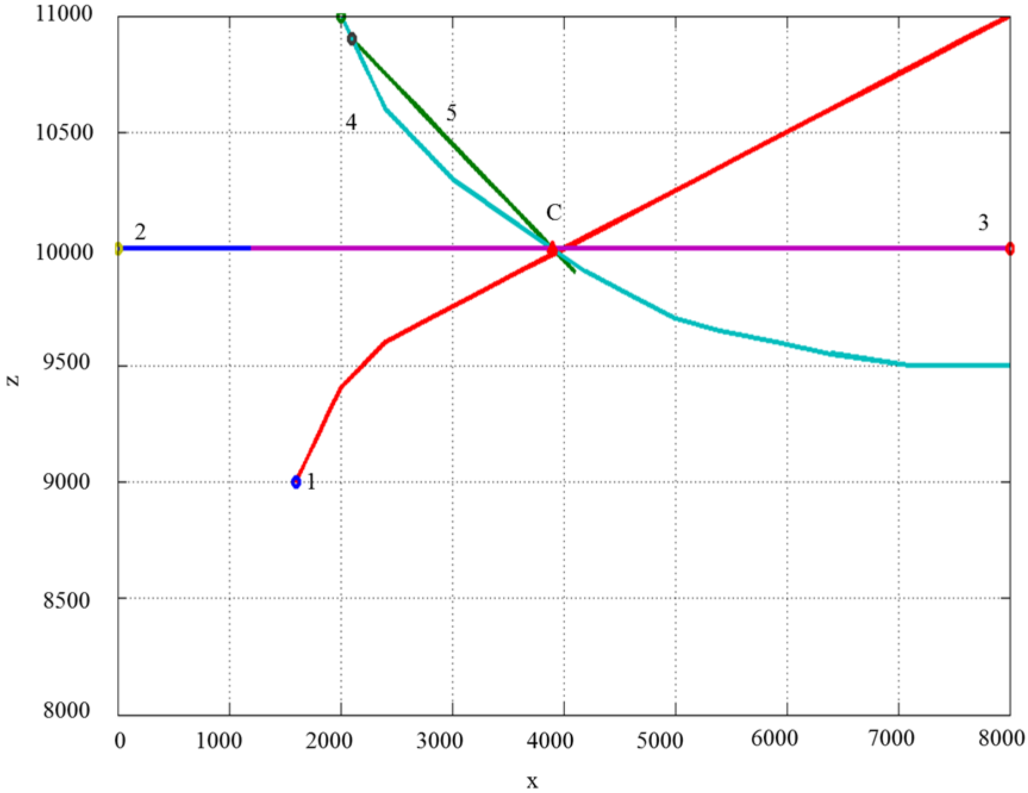

Figure 3.3 – Two-dimensional projection No.2 of the conflict model

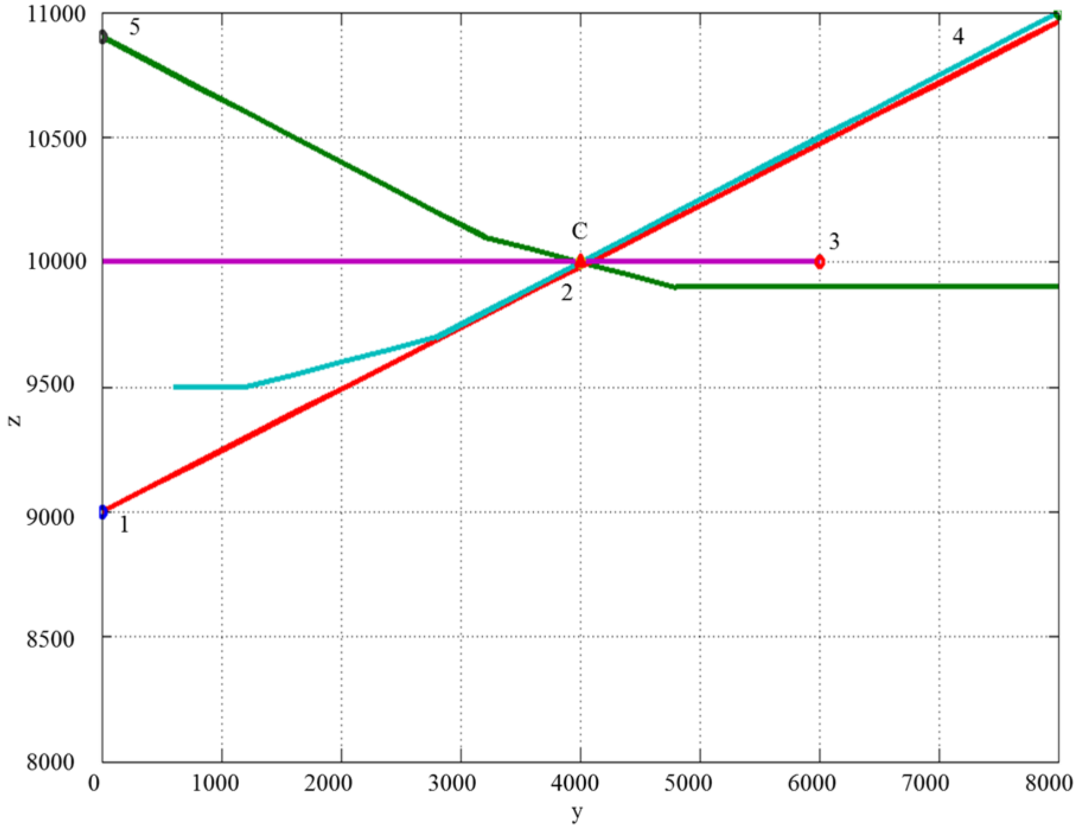

Figure 3.4 – Two-dimensional projection No. 3 of the conflict model

Fig. 3.5 shows an example of solving the above-defined three-dimensional conflict model (polyconflict) of five aircraft using the TCAS II system used in modern aviation. The simulation was carried out in the MatLab environment according to the built-in algorithm of the TCAS II system. Based on the obtained result, it can be noted that the conflict of five planes has been successfully resolved. However, the imperfection of the current TCAS system caused the emergence of new pairs of conflicts during the process of resolving one conflict, which can be seen in points a and c.

Fig. 3.6-3.8 shows for clarity two-dimensional projections of new pairs of conflict situations that arose as a result of the solution of a multi-conflict situation by the TCAS system.

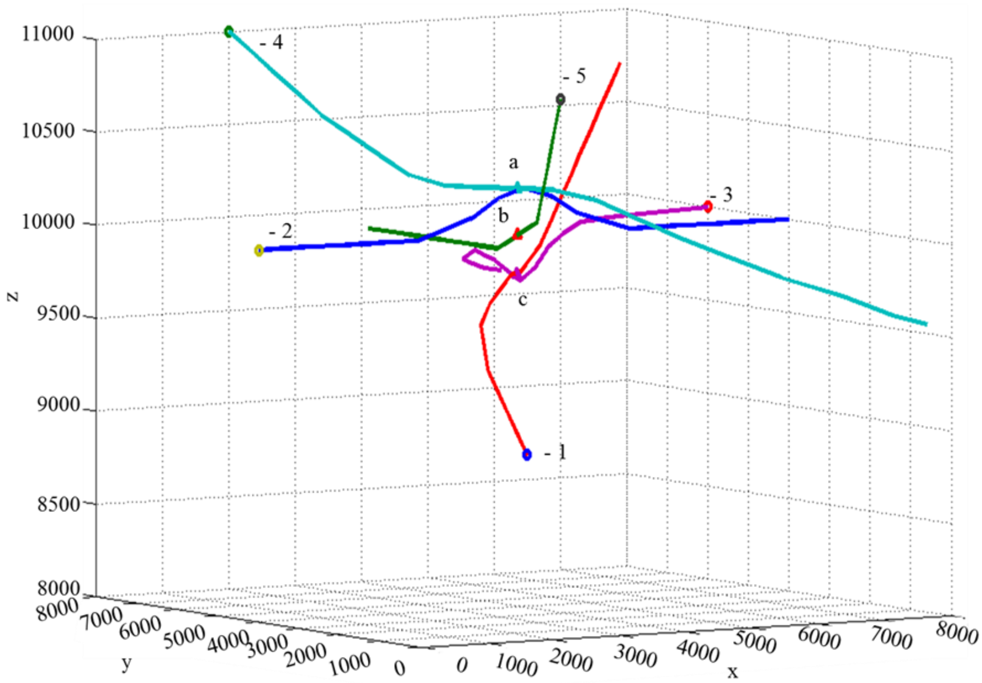

Figure 3.5 – Resolution of the conflict situation of five dynamic objects by the TCAS II system

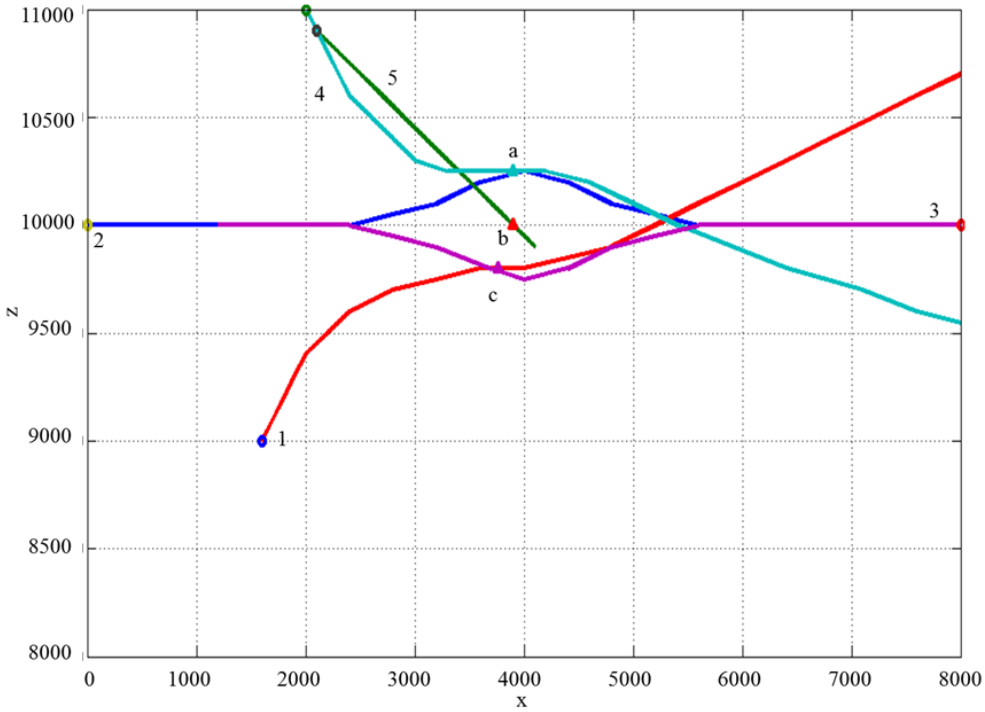

Figure 3.6 – Two-dimensional projection No. 1 of resolving a conflict situation of five dynamic objects by the TCAS system

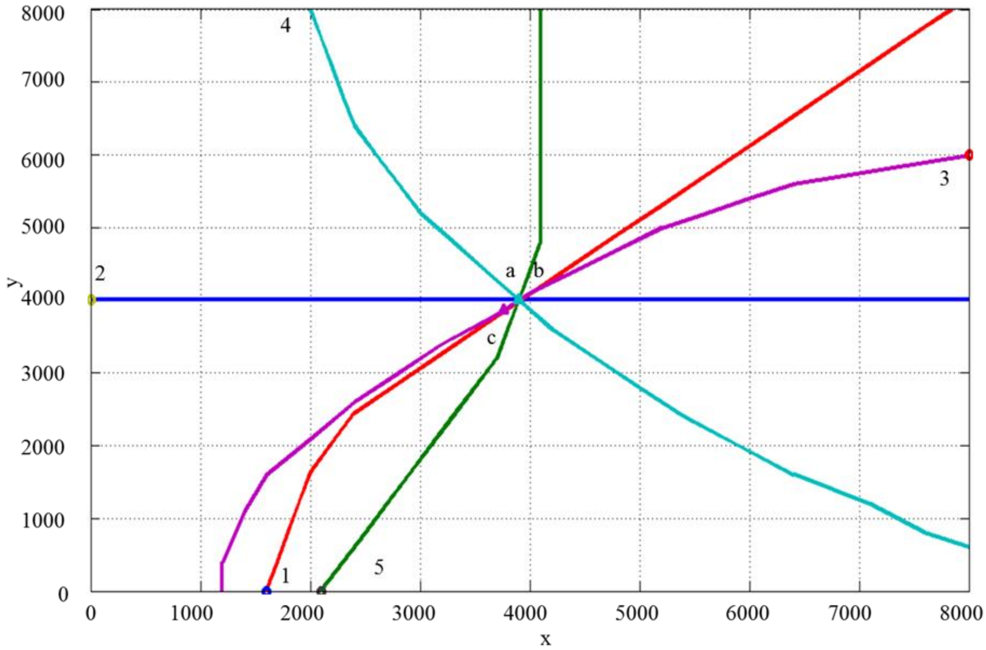

Figure 3.7 – Two-dimensional projection No. 2 of resolving a conflict situation of five dynamic objects by the TCAS system

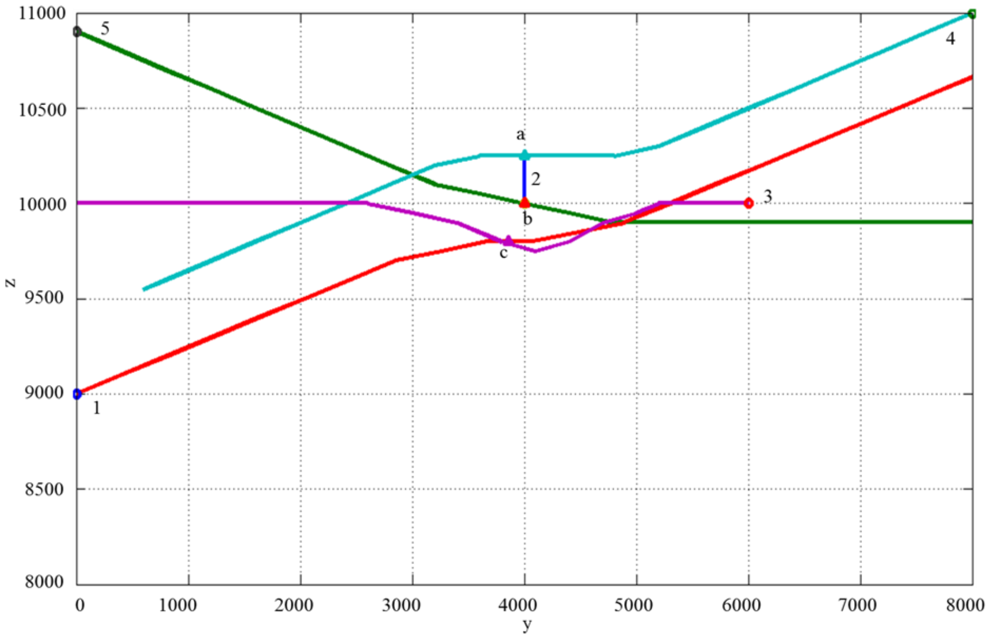

Figure 3.8 – Two-dimensional projection No. 3 of resolving a conflict situation of five dynamic objects by the TCAS system

3.2 Modeling of the information technology of resolving the conflict situation of dynamic objects on a real-time scale

3.2.1 Conflict situation of five dynamic objects

Let us once again consider the three-dimensional model of the polyconflict of five identical aircraft, which, moving along different routes, at different altitudes and speeds, will all cross at the same point *C* at the same time *t* [23, 24, 25].

According to the developed rules for the separation of conflicting aircraft (constructed using Euler-Venn diagrams), in order to eliminate the shortcomings of the current TCAS system, the above example of the conflict situation model of aircraft is proposed to be solved as follows.

1. The aircraft which priority in the conflict will be higher, if any, is determined. In this situation, it is plane No. 1, since the plane flying lower has priority over the planes flying higher. Accordingly, aircraft No.1 must continue the flight without changes (rule No.6, see Appendix B).

2. Next, aircraft No.4 must stop descending, giving way to aircraft No.5, which is lower and has a higher priority (rule No.12).

3. Airplane No. 5 (rule No. 6, taking into account rule No. 1) must stop descending and deviate on a course to the right, giving way to airplane No. 1, without creating a wake for it.

4. Aircraft No.2 (according to rule No.9) must give way to aircraft No.1, however, also in view of its conflict with aircraft No.3, (rule No.9 is changed to rule No.3) aircraft No.2 must divert to the right.

5. Aircraft No.3 to resolve the conflict with aircraft No.1 (according to rule No.8) must deviate to the right.

According to the described sequence of solving the conflict situation of aircraft, the obtained model of divergence of aircraft is given (Fig. 3.9). Based on this model, we see that the conflict was successfully resolved and the resolution of this conflict did not lead to the creation of new conflict situations, which is an important advantage in ensuring the guaranteed divergence of aircraft. Moreover, aircraft can successfully continue their course to the original end point.

In fig. 3.10-3.12 show the two-dimensional projections of the above example of the aircraft separation model for clarity.

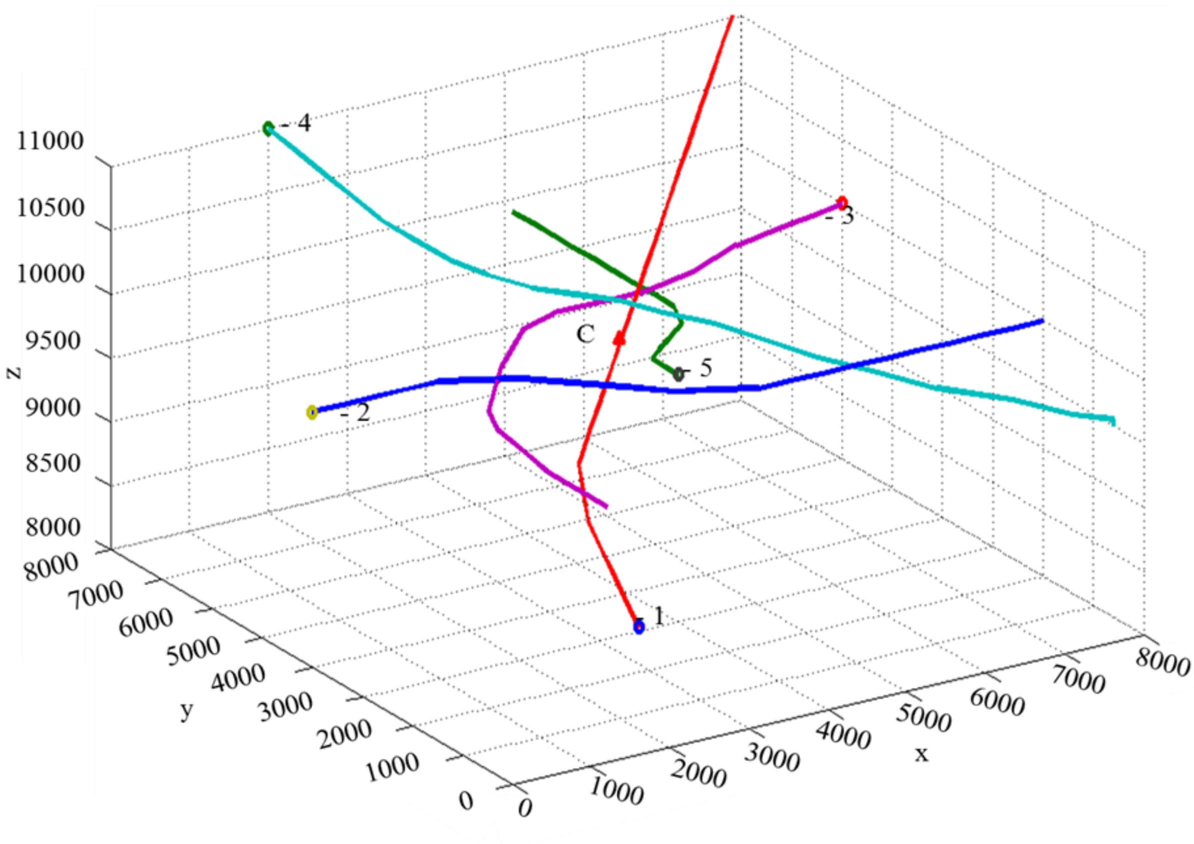

Figure 3.9 – The model of the separation of dynamic objects in a polyconflict situation according to the proposed method

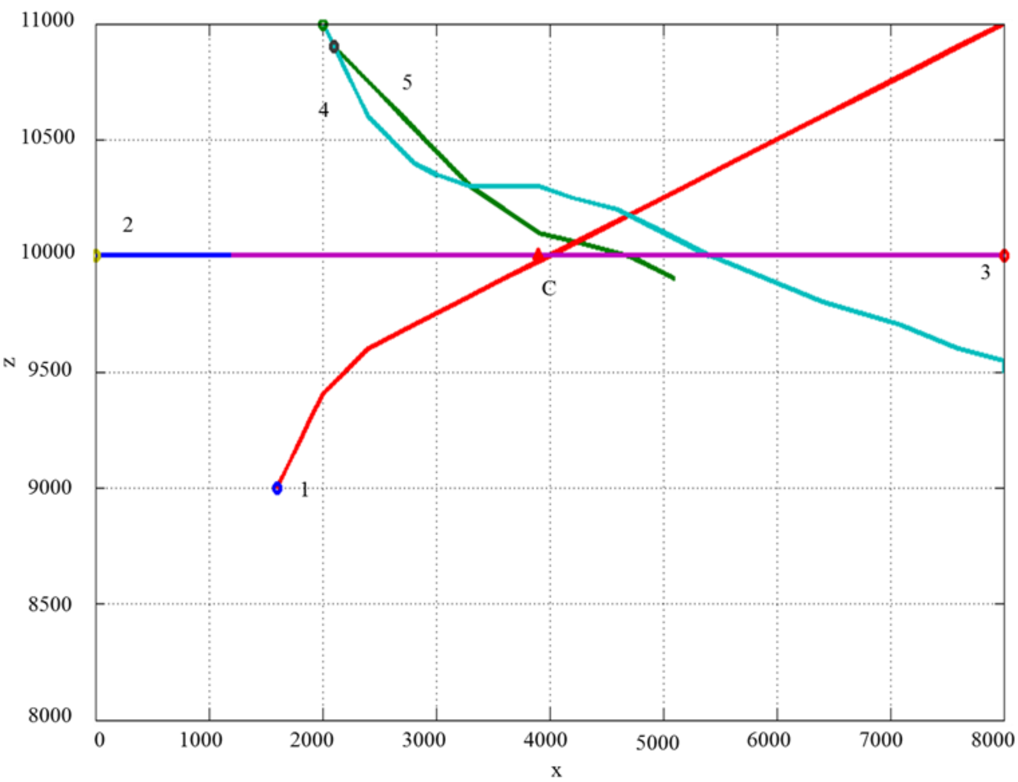

Figure 3.10 – Two-dimensional projection No. 1 of resolving a conflict situation using a new method

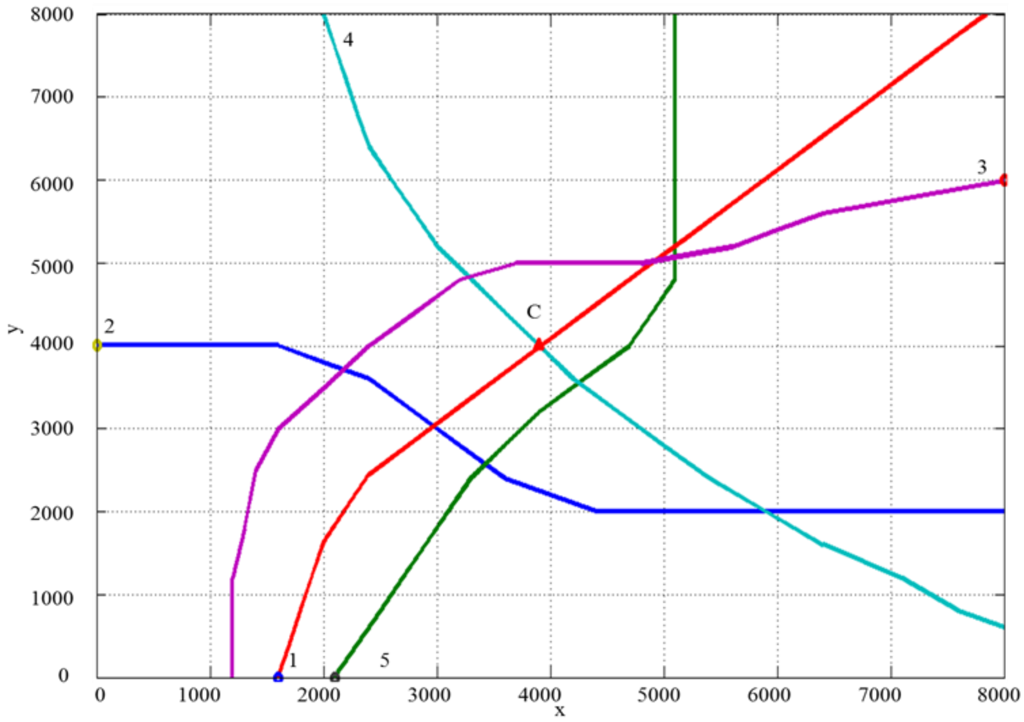

Figure 3.11 – Two-dimensional projection No. 2 of resolving a conflict situation using a new method

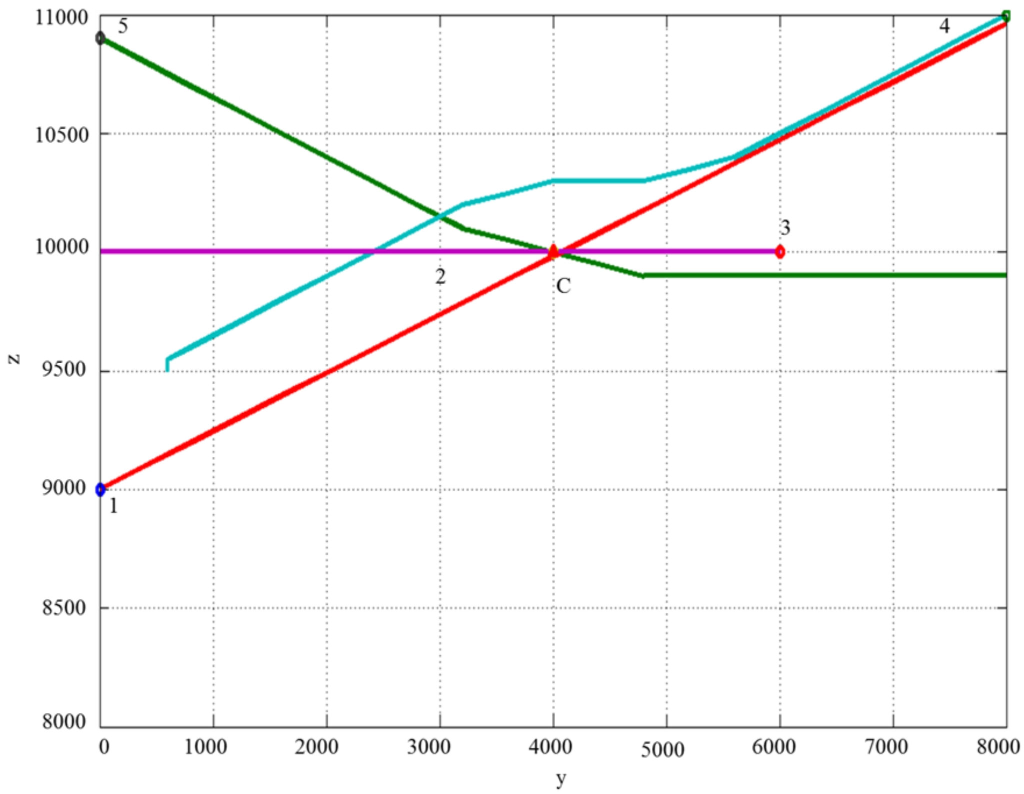

Figure 3.12 – Two-dimensional projection No. 3 of resolving a conflict situation using a new method

We will present the mathematical logic of determining and solving the conflict situation of aircraft according to the given example (the result of the system work):

- block 1 - determination of current flight parameters and aircraft positions;

- block 2 - determination of aircraft movement characteristics (dynamics of their flight);

- block 2.1 - an example of determining the characteristics of aircraft movement (on the example of aircraft No. 5): the speed does not change, the course changes between 1 and 2 time points (deviation along the course to the left) and is constant between 0 and 1 time points (straight flight), angle of inclination of the trajectory is constant between 0 and 1 time points (less than zero) and increases (to zero) between 1 and 2 time points, the altitude decreases between 0 and 1 time points;

- block 3 - determination of the point of intersection of aircraft trajectories;

- block 4 - determination of aircraft flight parameters that must be changed in accordance with the declared rules to resolve the conflict situation;

- block 4.1 - determination of the flight parameters of the aircraft (using the example of aircraft No. 5), which must be changed (in accordance with the stated rule No. 6 and taking into account rule No. 1) to diverge from other conflicting aircraft: it is necessary to stop the descent at time point 1 by increasing the angle of inclination of the trajectory to avoid hitting the altitude at time point 2; speed remains constant; it is necessary to change course by deviating to the left at time point 1 to avoid hitting the wake turbulence at time point 2.

Symbol designation:

S1-S5 – planes No. 1-5;

t0 – time at the starting point of aircraft movement (beginning of simulation);

H1-H5 - aircraft altitude;

V1-V5 – aircraft speed;

t1 – time at the moment of conflict detection;

θ1-θ5 – angle of inclination of the aircraft trajectory;

t2 – the time of the aircraft's being at point C ;

ψ1-ψ5 – aircraft course;

t3 – the time between t1 and t2, the time of the start of maneuvers to prevent conflict;

pos1-pos5 – *x* and *y coordinates of the* planes.

Block 1:

S1: $(H1(t0),\psi1(t0),\theta1(t0),V1(t0), pos1(t0))$;

S2: $(H2(t0),\psi2(t0),\theta2(t0),V2(t0), pos2(t0))$;

S3: $(H3(t0),\psi3(t0),\theta3(t0),V3(t0), pos3(t0))$;

S4: $(H4(t0),\psi4(t0),\theta4(t0),V4(t0), pos4(t0))$;

S5: $(H5(t0),\psi5(t0),\theta5(t0),V5(t0), pos5(t0))$.

Block 2:

$V1(t0)=V1(t1)=V1(t2)= const$,

$\psi1(t0) \neq \psi1(t1) = \psi1(t2)$, $\psi1(t0)+ \Delta\psi = \psi1(t1)$,

$\theta1(t0)=\theta1(t1)=\theta1(t2) >0$,

$H1(t0)<H1(t1)<H1(t2)$;

$V2(t0)=V2(t1)=V2(t2)= const$,

$\psi2(t0)=\psi2(t1) = \psi2(t2)= const$,

$\theta2(t0)=\theta2(t1)=\theta2(t2)= const$,

$H2(t0)=H2(t1)=H2(t2)= const$;

$V3(t0)=V3(t1)=V3(t2)= const$,

$\psi3(t0) \neq \psi3(t1) \neq \psi3(t2)$, $\psi3(t0)- \Delta\psi = \psi3(t1) – \Delta\psi =\psi3(t2)$,

$\theta3(t0)=\theta3(t1)=\theta3(t2)= const$,

$H3(t0)=H3(t1)=H3(t2)= const$;

$V4(t0)=V4(t1)=V4(t2)= const$,

$\psi4(t0) \neq \psi4(t1) \neq \psi4(t2)$, $\psi4(t0)- \Delta\psi = \psi4(t1) – \Delta\psi =\psi4(t2)$,

$\theta4(t0) = \theta4(t1) = \theta4(t2) <0$,

$H4(t0)>H4(t1)>H4(t2)$.

Block 2.1:

$V5(t0)=V5(t1)=V5(t2)= const$,

$\psi5(t0) = \psi5(t1) \neq \psi5(t2)$, $\psi5(t1)- \Delta\psi = \psi5(t2)$,

$\theta5(t0) = \theta5(t1)<0$, $\theta5(t1)+ \Delta \theta= \theta5(t2)=0$,

$H5(t0)>H5(t1)=H5(t2)$.

Block 3:

$H1(t2)=H2(t2)=H3(t2)=H4(t2)=H5(t2)$;

$pos1(t2)+\varepsilon=pos2(t2)+\varepsilon= pos3(t2)+\varepsilon= pos4(t2)+\varepsilon= pos5(t2)+\varepsilon$.

Block 4:

S1: $(H1(t3)>H1(t2),\theta1(t3)=\theta1(t2)>0$,

$V1(t3)=V1(t2)= const$, $\psi1(t3) = \psi1(t2)$;

S2: $(H2(t3)=H2(t2) = const$, $\theta2(t3)=\theta2(t2)= const$,

$V2(t3)=V2(t2)= const$, $\psi2(t3)\neq \psi2(t2)$,

$\psi2(t3)=\psi2(t1)+ \Delta\psi$;

S3: $(H3(t3)=H3(t2) = const$, $\theta3(t3)=\theta3(t2)= const$,

$V3(t3)=V3(t2)= const$, $\psi3(t3)\neq \psi3(t2)$,

$\psi3(t3)= \psi3(t1) + \Delta\psi$;

S4: $(H4(t3) > H4(t2)$,

$V4(t3)=V4(t2)= const$, $\psi4(t3)= \psi4(t2)$,

$\theta4(t3)=\theta4(t1)+\Delta \theta =0$.

Block 4.1:

S5: $(H5(t3)>H5(t2)$, $\theta5(t3)=\theta5(t1) +\Delta \theta =0$,

$V5(t3)=V5(t2)= const$, $\psi5(t3)\neq \psi5(t2)$,

$\psi5(t3)= \psi5(t1) - \Delta\psi$.

In order to obtain a comparative characteristic of the change in the flight route of each of the aircraft during the maneuver, the length of the route along the initial smooth trajectory, the trajectory with the execution of the maneuver according to the proposed method for resolving the conflict situation, and the difference in these routes were determined. The results are given in the table. 3.1.

Table 3.1 – Change in the lengths of routes of dynamic objects from maneuvering in the CS

Airplane No.	Planned route length, m	Changed length of the route after the maneuver, m	Difference, m
1	8000	8680	680
2	8520	9130	610
3	10780	10780	0
4	10030	10840	810
5	9380	9600	300

As an indicator of successful resolution of the multi-conflict situation of five aircraft by the proposed method Fig. 3.13 shows the distances between the aircraft from the moment the dangerous approach began and until its successful resolution. As can be seen on the graph, the shortest distance between the planes was more than 300 meters, which confirms compliance with the established rules of echeloning.

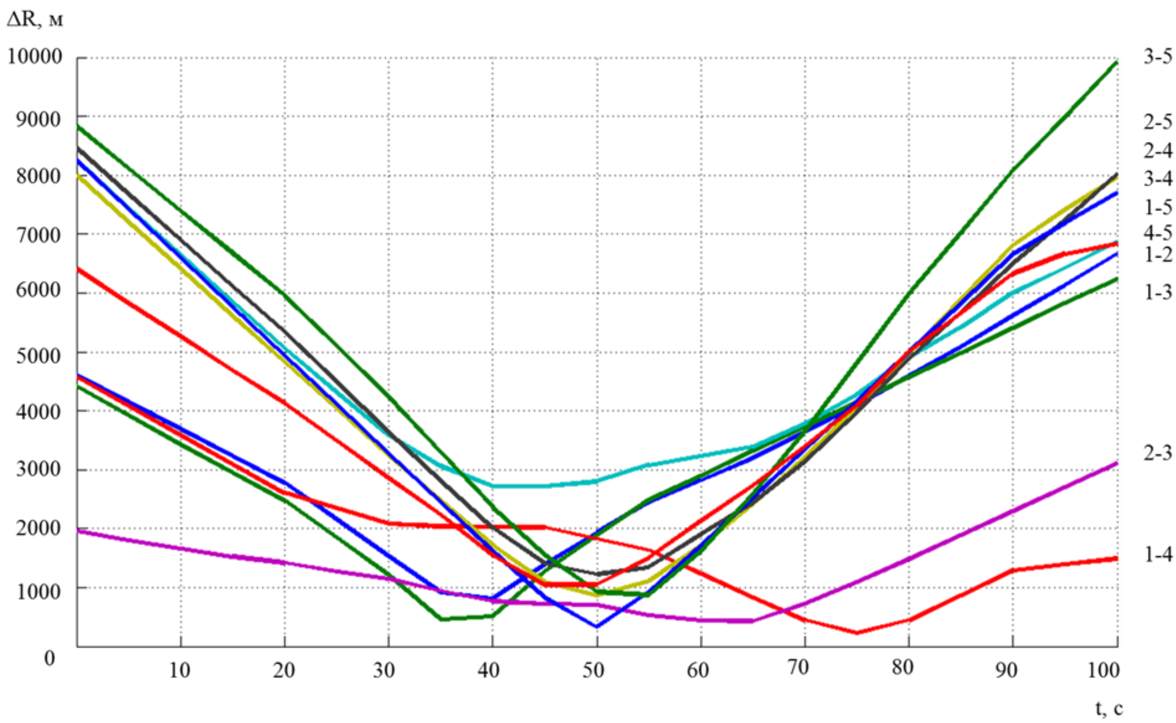

Figure 3.13 – Changes in the distance between DOs during the emergence and resolution of a multi- conflict situation

3.2.2 Conflict situation of four dynamic objects

Resolution of the conflict situation of four aircrafts (Fig. 3.14) by the declared method (rule No. 11: for aircraft 1 and 2, the one flying lower has priority, the plane flying higher must stop descending; rule No. 8 for planes 1, 3 and 4, the one which is lower has the priority; the plane flying higher must deviate on the course to the right) are shown in Fig. 3.15.

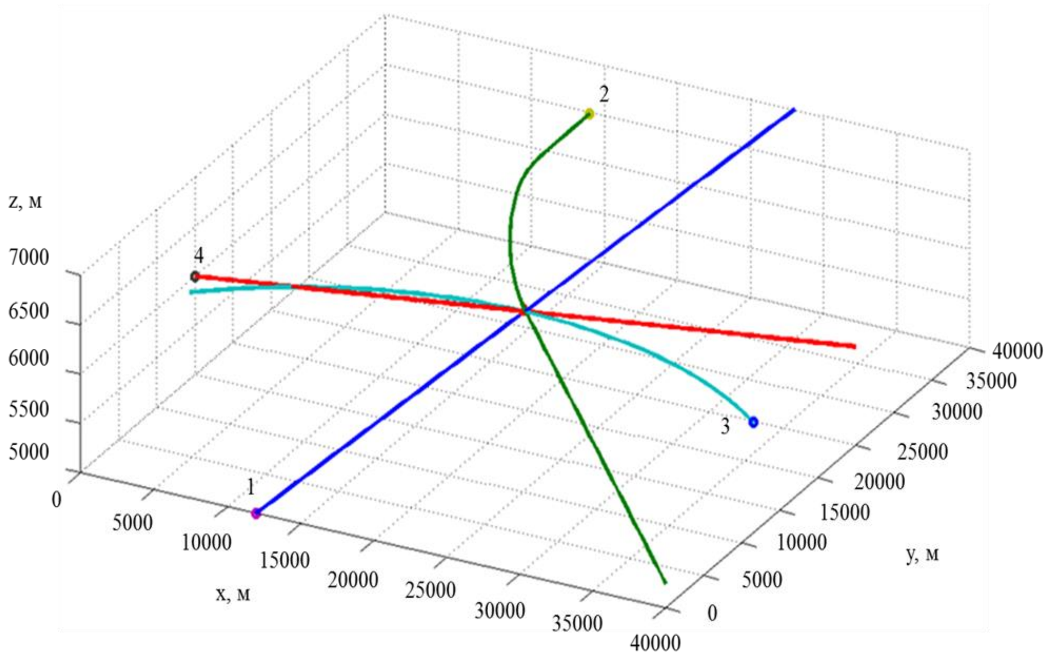

Figure 3.14 – Conflict situation of four dynamic objects

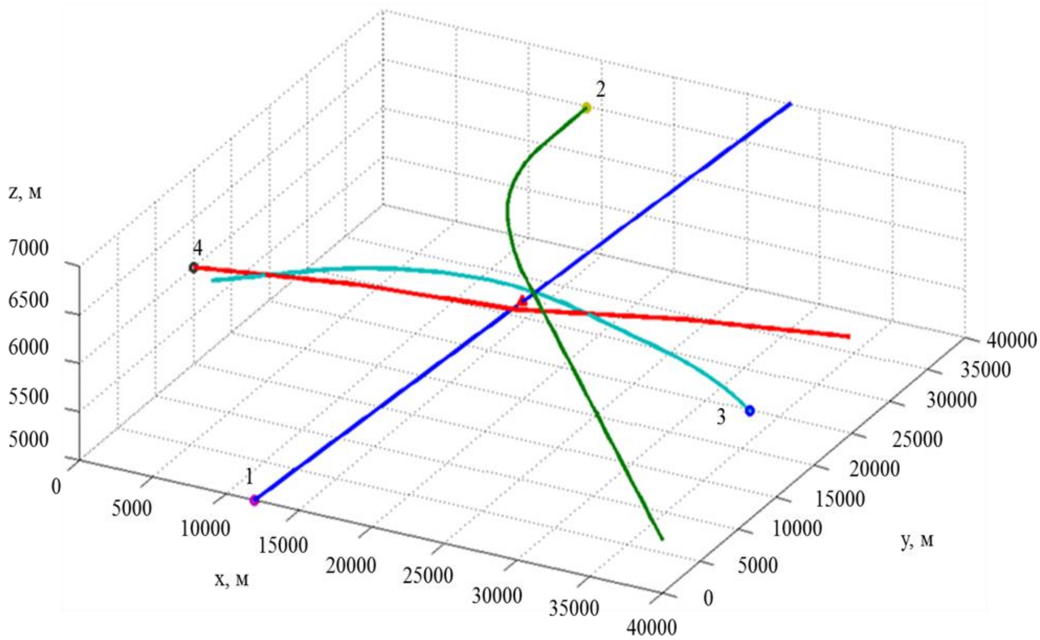

Figure 3.15 – The model of the divergence of three DOs according to the developed method

Two-dimensional projections of the model of the divergence of dynamic objects are shown in Fig. 3.16-3.18.

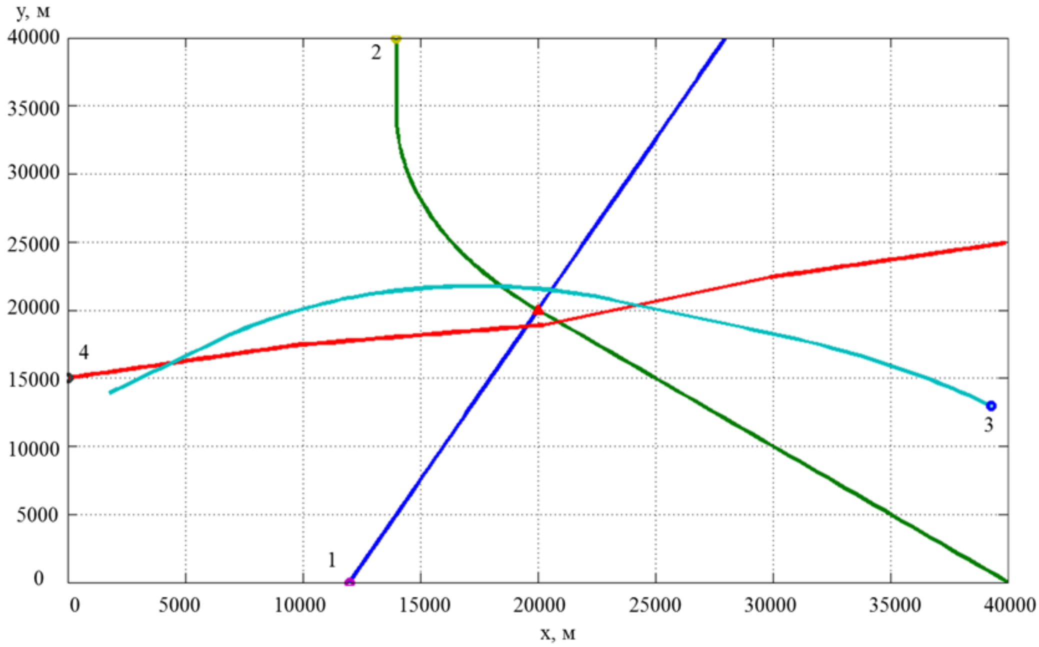

Figure 3.16 – Two-dimensional projection No. 1 of the resolution of the conflict situation of the four DOs by the developed method

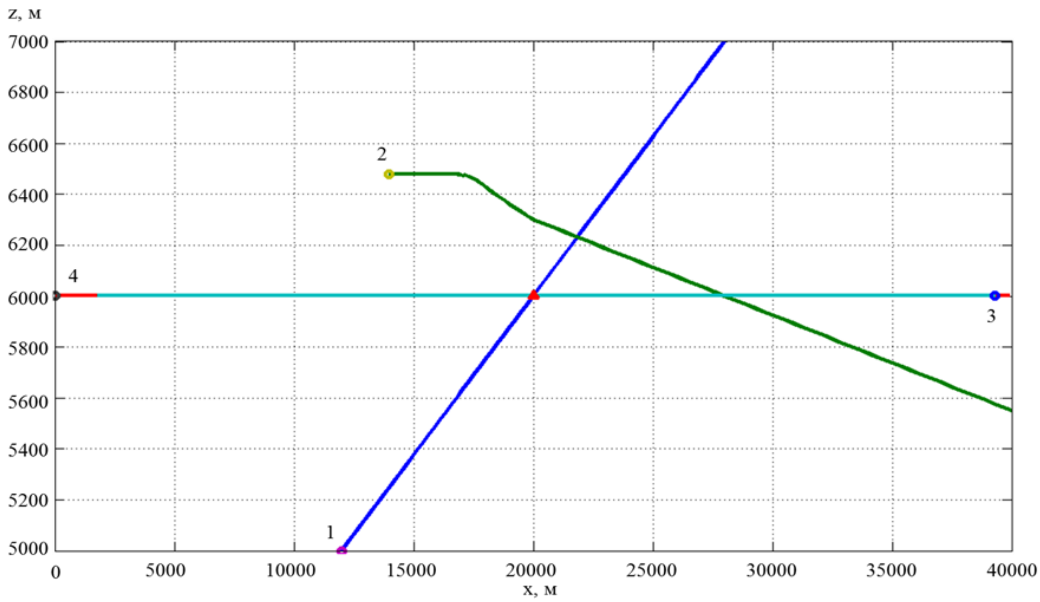

Figure 3.17 – Two-dimensional projection No. 2 of the resolution of the conflict situation of the four DOs by the developed method

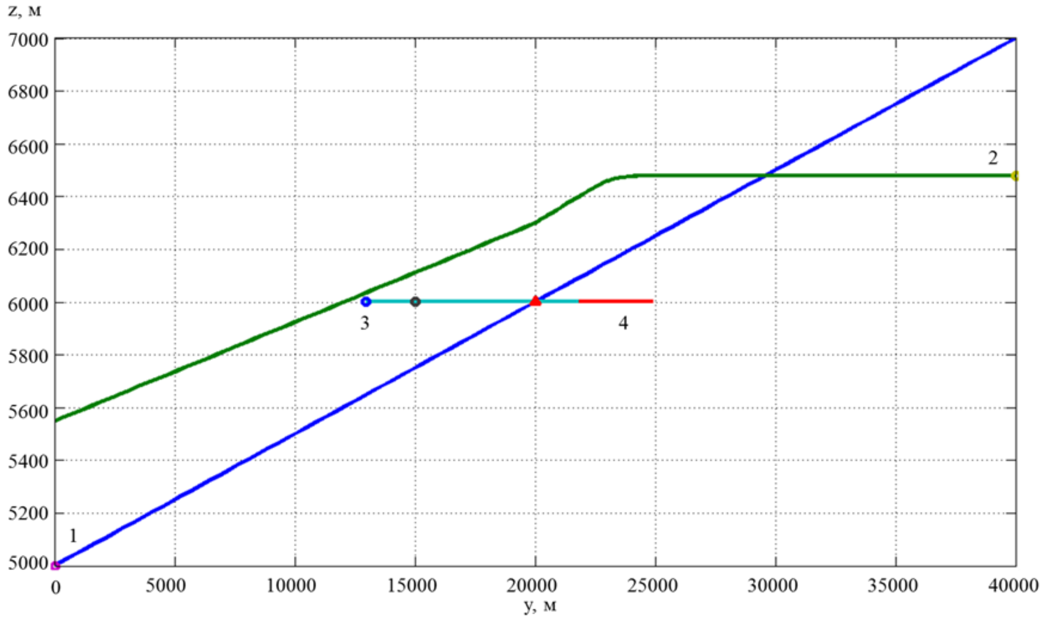

Figure 3.18 – Two-dimensional projection No. 3 of the resolution of the conflict situation of the four DOs by the developed method

The change in the distances between the DOs in the process of the emergence and resolution of a multi-conflict situation (Fig. 3.19):

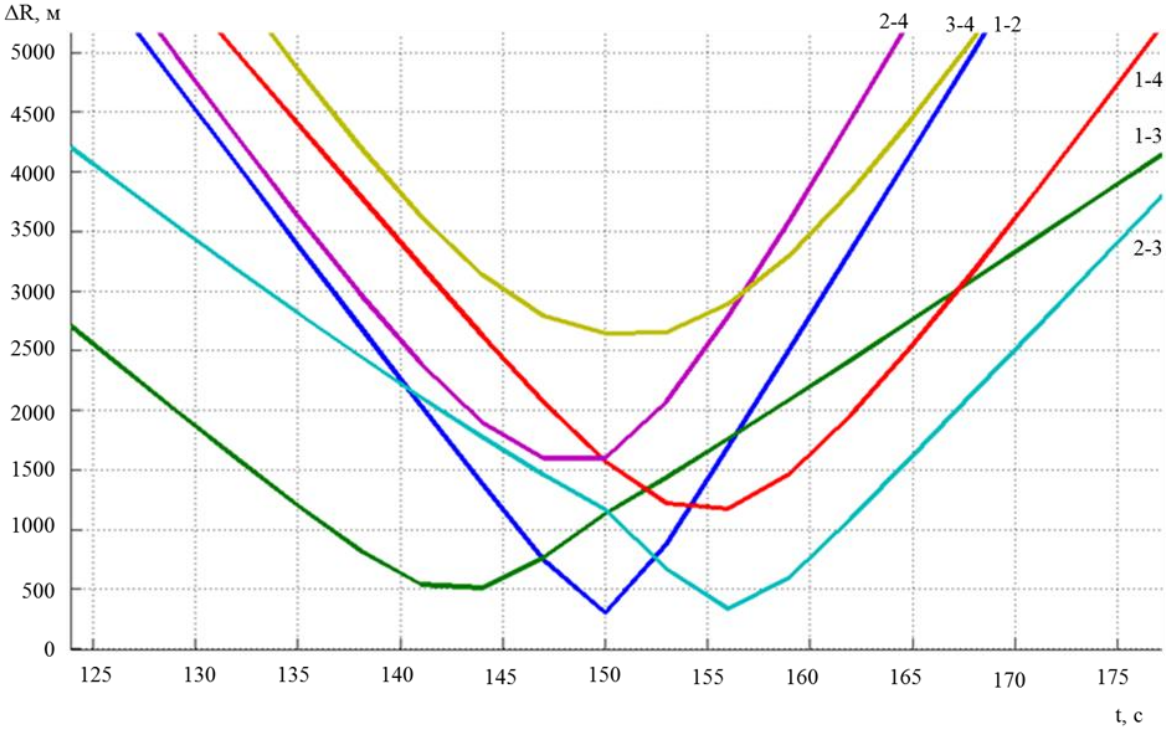

Figure 3.19 – Changes in the distances between DOs during the emergence and resolution of a multi- conflict situation

the table 3.2 shows the length of the route of dynamic objects according to the initial planned trajectory, the trajectory with the execution of the maneuver according to the proposed method for resolving the conflict situation, and the difference in these routes.

Table 3.2 – Change in the lengths of routes of dynamic objects from maneuvering in the CS

Airplane No.	Planned route length, m	Changed length of the route after the maneuver, m	Difference, m
1	43127	43127	0
2	49913	50321	408
3	41231	42093	862
4	41887	43342	1455

3.2.3 Conflict situation of three dynamic objects

The resolution of the conflict situation of three dynamic objects (Fig. 3.20) by the declared method (rule No. 18: for planes 1, 2 and 3, the one which is on the U-turn has the priority, other planes must turn to the right) is shown in Fig. 3.21.

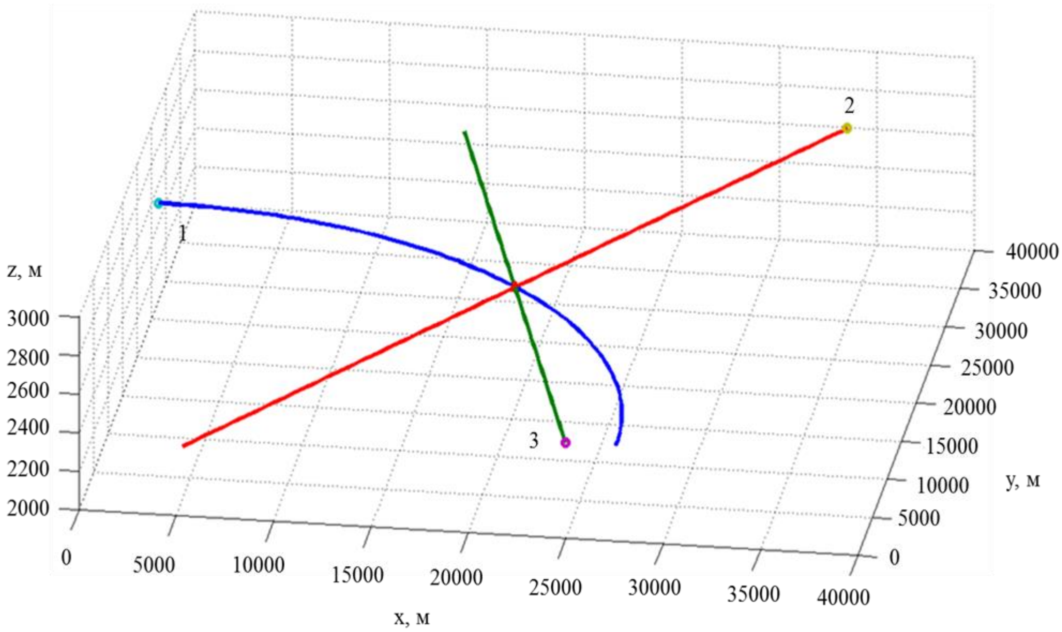

Figure 3.20 – Conflict situation of three dynamic objects

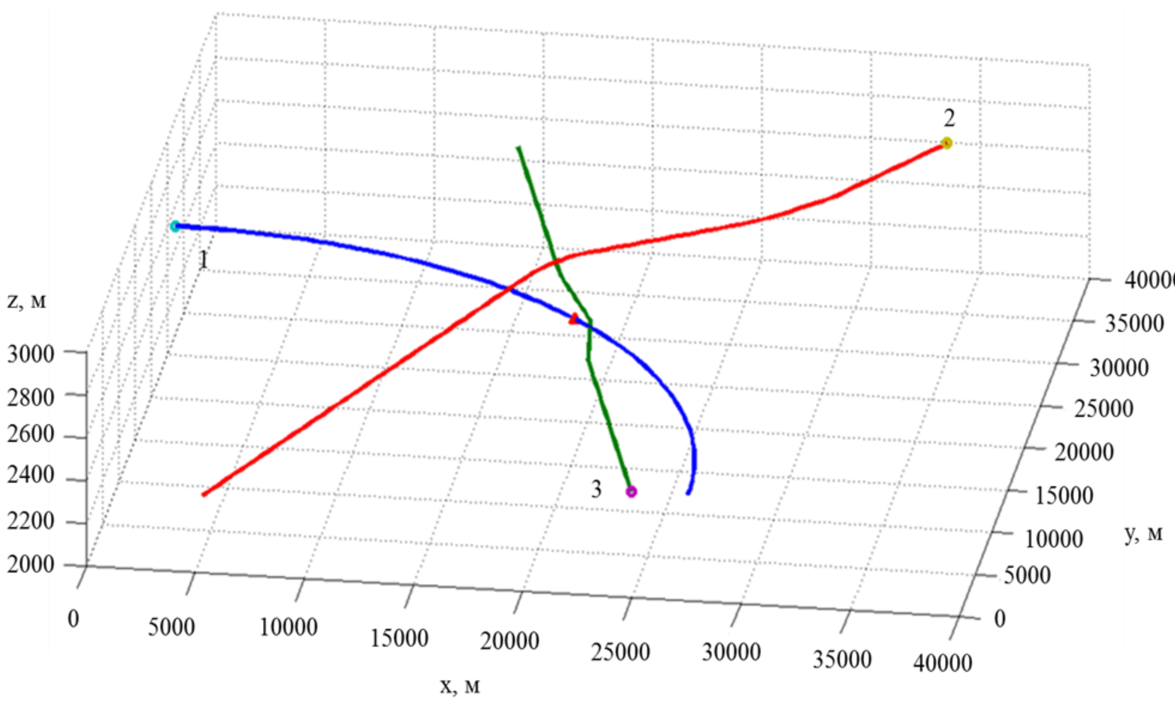

Figure 3.21 – The model of the divergence of three DOs according to the developed method

Two-dimensional projections of the model of the divergence of dynamic objects are shown in fig. 3.22-3.24.

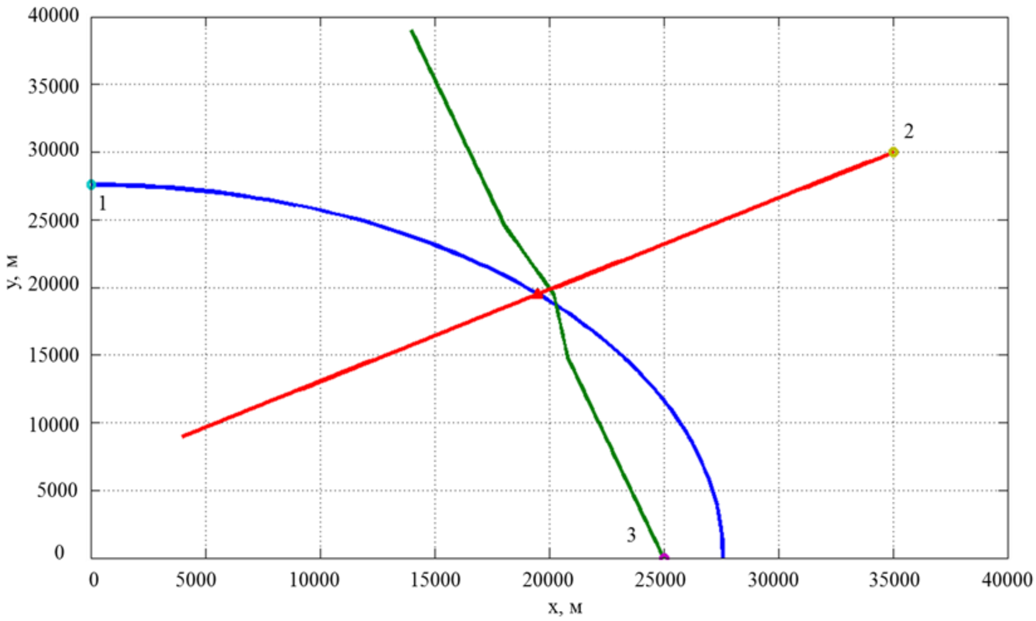

Figure 3.22 - Two-dimensional projection No. 1 of the resolution of the conflict situation of three DOs by the developed method

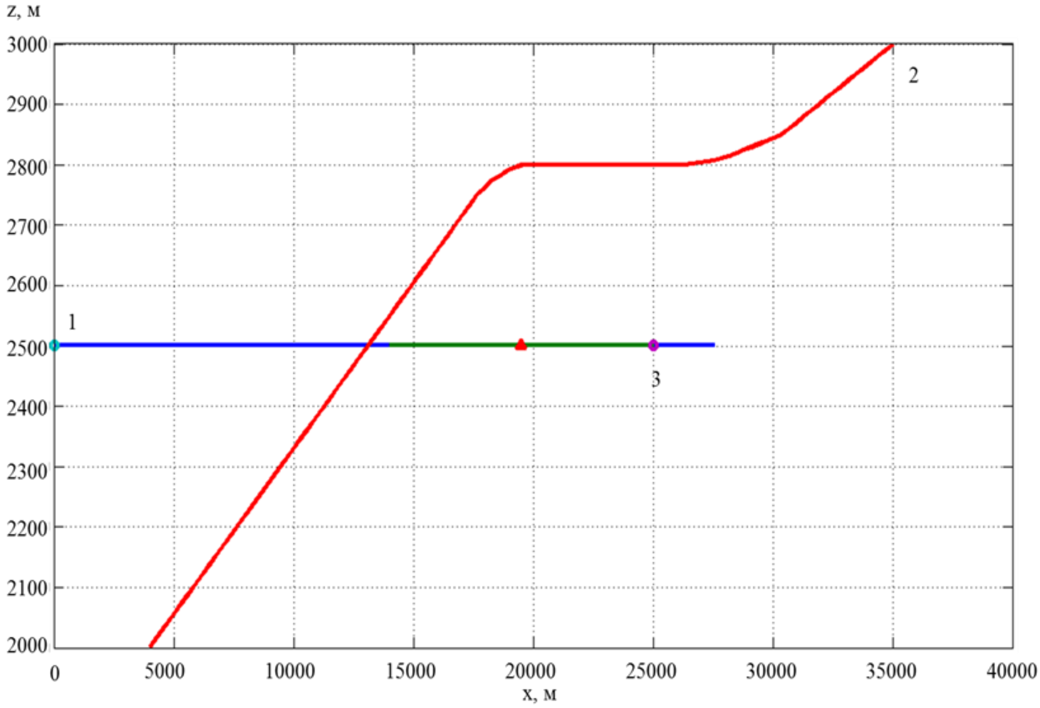

Figure 3.23 – Two-dimensional projection No. 2 of the resolution of the conflict situation of the three DOs by the developed method

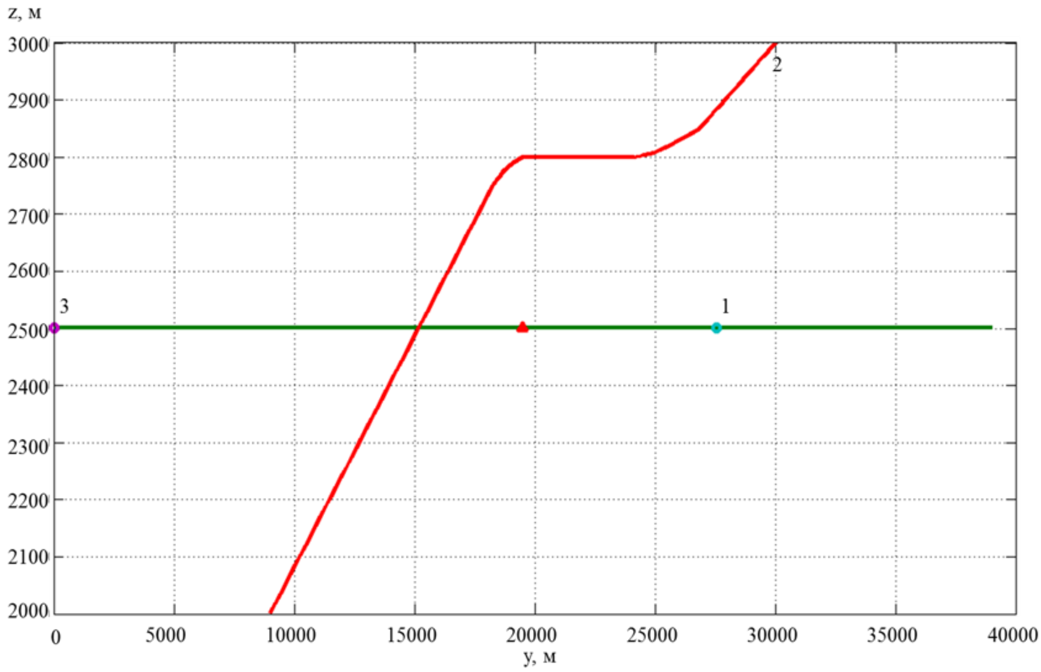

Figure 3.24 - Two-dimensional projection No. 3 of the resolution of the conflict situation of the three DOs by the developed method

The change in the distances between the POs in the process of the emergence and resolution of a multi- conflict situation (Fig. 3.25):

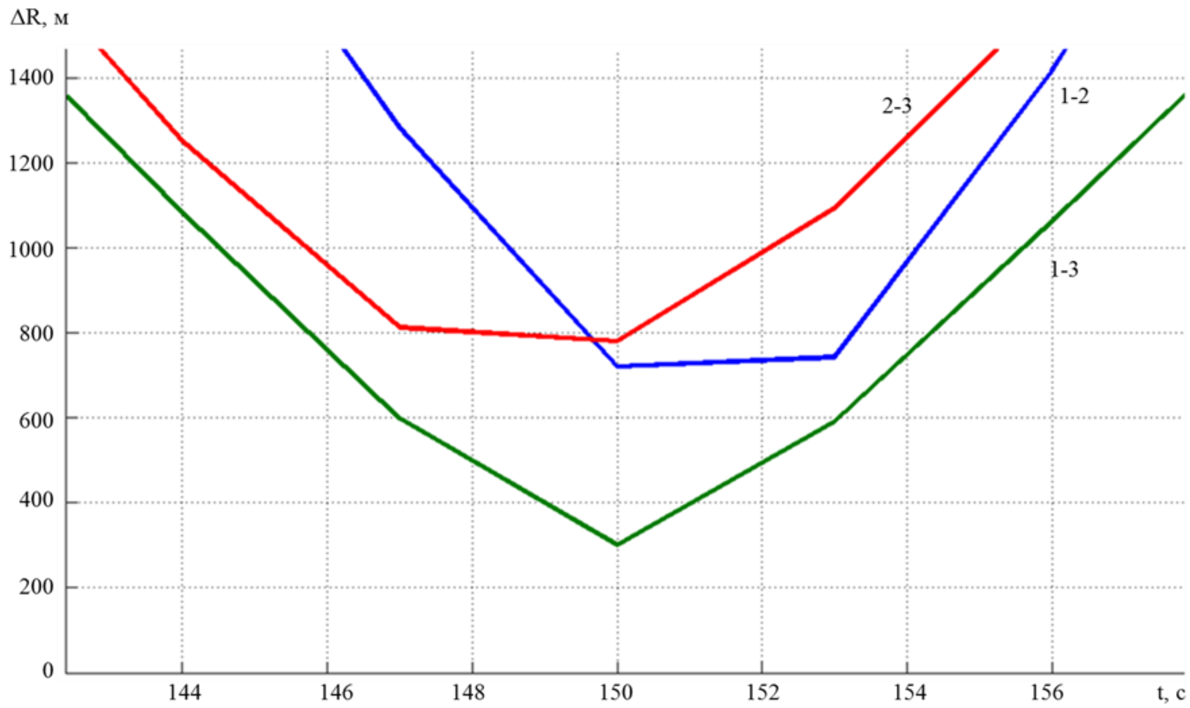

Figure 3.25 – Changes in the distances between DOs during the emergence and resolution of a multi- conflict situation

Table 3.3 shows the length of the route of dynamic objects according to the initial planned trajectory, the trajectory with the execution of the maneuver according to the proposed method for resolving the conflict situation, and the difference in these routes.

Table 3.3 – Change in the lengths of routes of dynamic objects from maneuvering in the CS

Airplane No.	Planned route length, m	Changed length of the route after the maneuver, m	Difference, m
1	43317	43317	0
2	40521	41289	768
3	37456	38197	741

3.2.4 Conflict situation of two dynamic objects

The resolution of the conflict situation between two DO (Fig. 3.26) by the declared method (rule No. 11: the one flying lower has the priority, the plane flying higher must stop descending) is shown in Fig. 3.27.

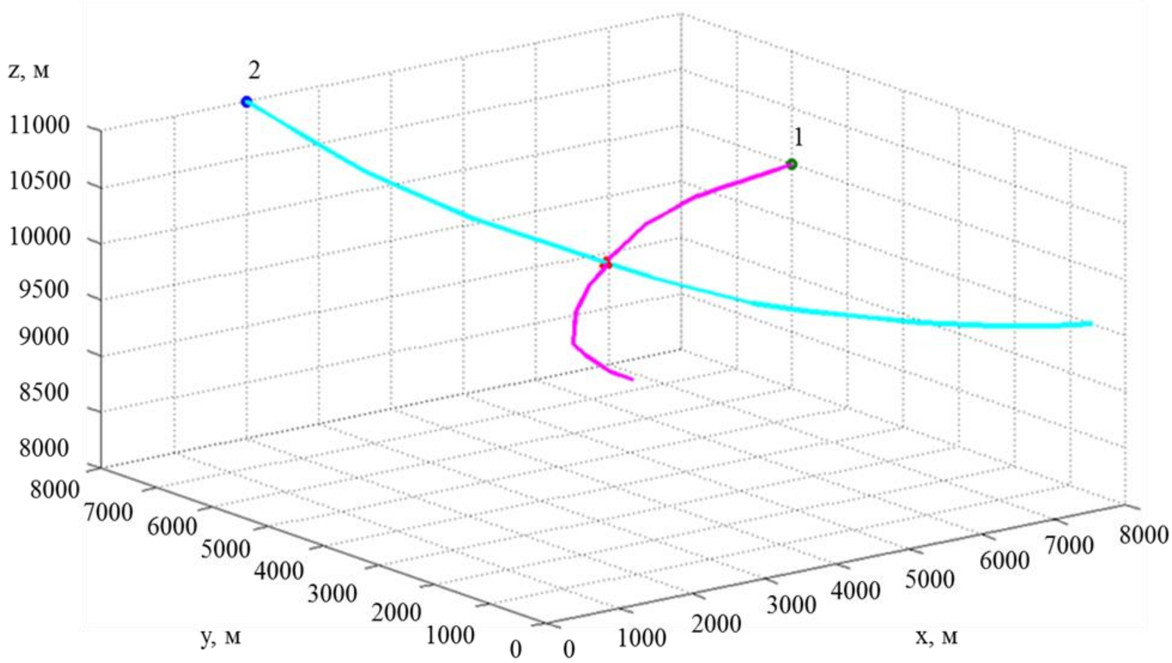

Figure 3.26 – Conflict situation of two dynamic objects

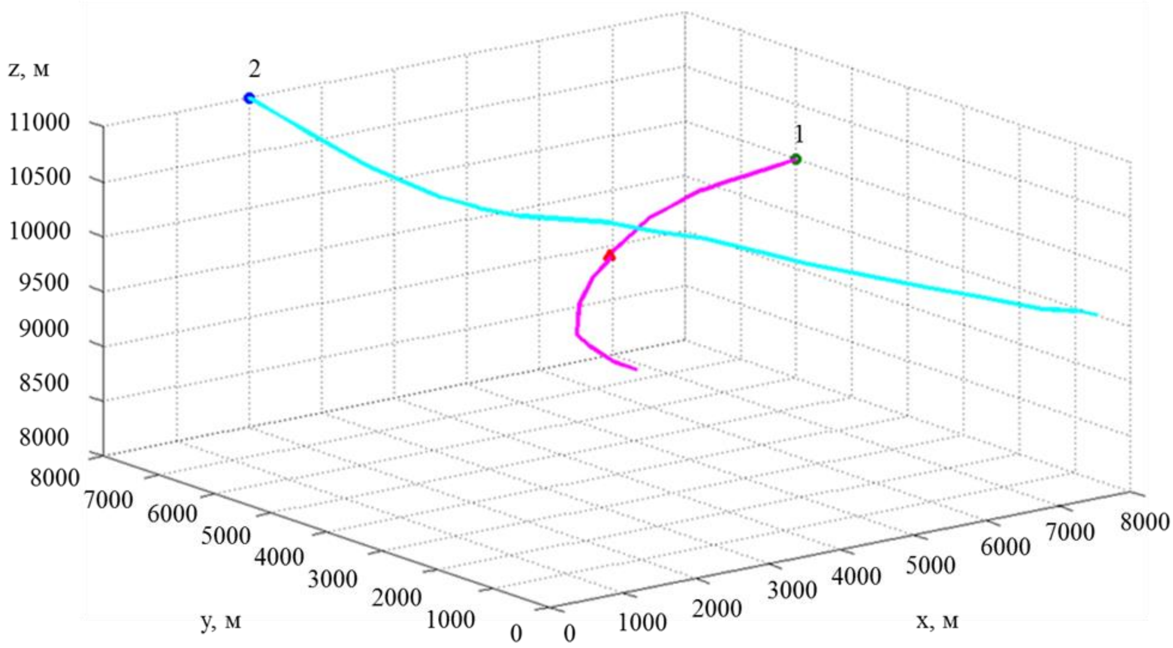

Figure 3.27 – Trajectory of the divergence of two DOs according to the new method

Two-dimensional projections of the model of the divergence of dynamic objects are shown in fig. 3.28-3.30.

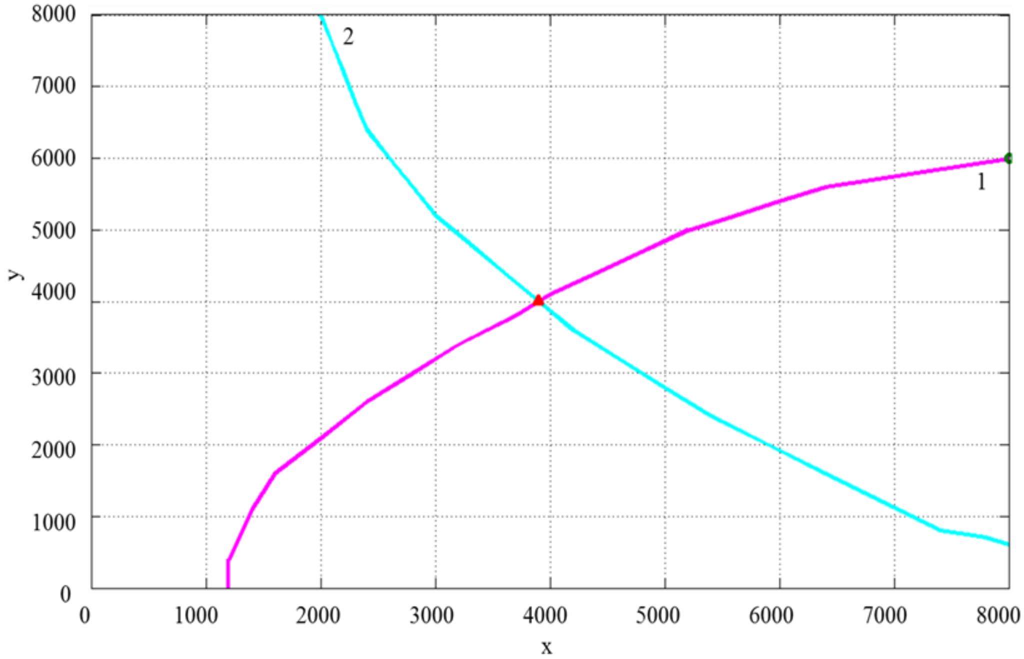

Figure 3.28 – Two-dimensional projection No. 1 of the resolution of the conflict situation of two TOs by the developed method

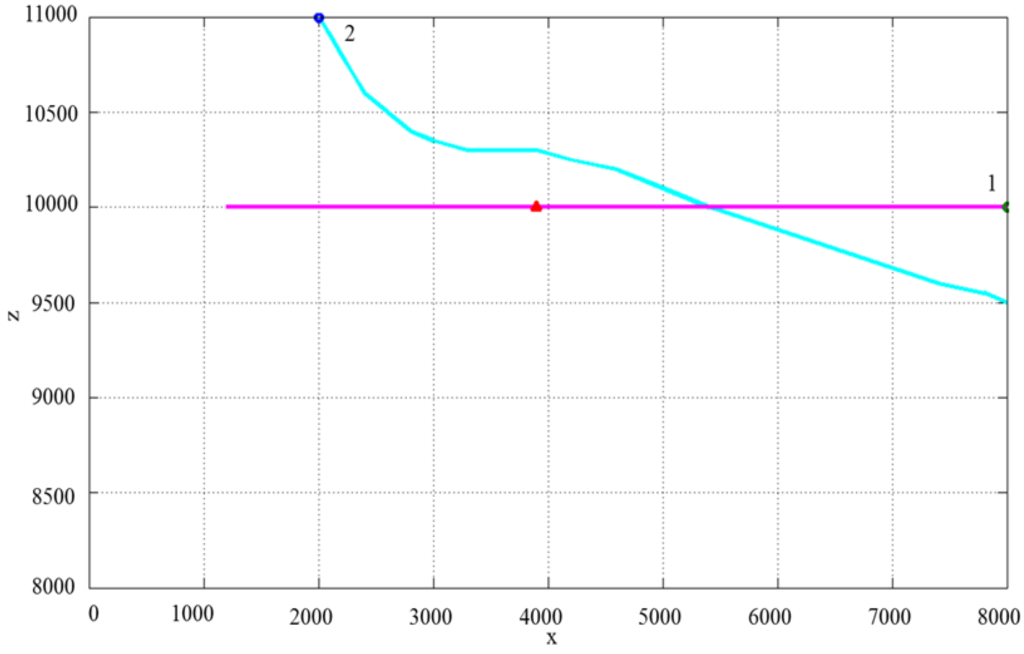

Figure 3.29 - Two-dimensional projection No. 2 of the resolution of the conflict situation of two TOs by the developed method

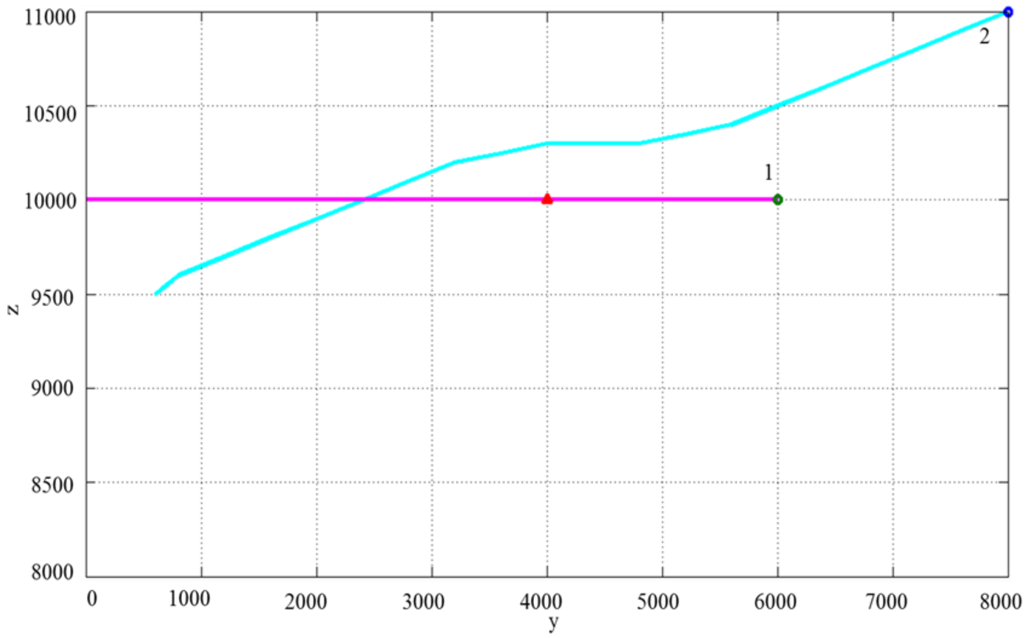

Figure 3.30 - Two-dimensional projection No. 3 of the resolution of the conflict situation of two TOs by the developed method

The change in the distances between the POs in the process of the emergence and resolution of a multi- conflict situation (Fig. 3.31):

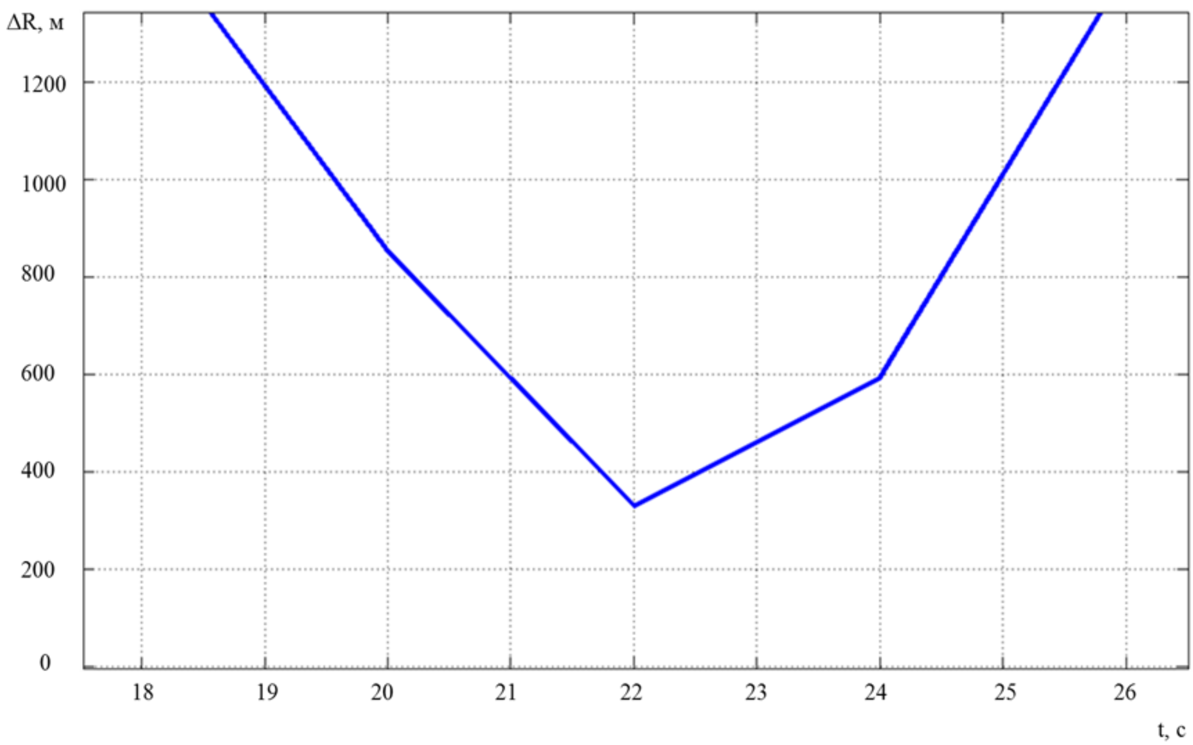

Figure 3.31 – Changes in the distance between POs during the emergence and resolution of a conflict situation

the table 3.4 shows the length of the route of dynamic objects according to the initial planned trajectory, the trajectory with the execution of the maneuver according to the proposed method for resolving the conflict situation, and the difference in these routes.

Table 3.4 – Change in the lengths of routes of dynamic objects from maneuvering in the CS

Airplane No.	Planned route length, m	Changed length of the route after the maneuver, m	Difference, m
1	9375	9375	0
2	10031	10840	810

CHAPTER 4

LABOR PROTECTION

The task of this chapter is to analyze the occupational safety and health measures for protection of engineer on avionics developing the information technology of intellectual control of conflict situations of dynamic objects at real-time scale. The subject of protection is an engineer-developer of the intellectual control technology, who could implement the occupational safety recommendations developed in this chapter. An engineer-developer of an intellectual control technologies mainly works with computer equipment and programs. The most suitable workplace for an employee performing such tasks is an office with organized personal workplace with working table and personal computer.

4.1 Overview of harmful and hazardous factors of the office work environment

General requirements for working conditions at enterprises are established by labor legislation. Working conditions at the workplace, safety of technological processes, equipment and other means of production, the conditions of means of collective and individual protection, which used by the employee, as well as sanitary conditions must meet the requirements of the law [26].

Among environmental factors that may affect safety and health of an office employee, who works with personal computer, we may consider:

- Working room conditions: crowdedness of workplaces; fire safety equipment; availability of natural lighting; air conditioning; floor materials, etc.
- Work place ergonomics: size and height of work table, work chair, it’s construction, comfort; correct placement of computer screens, cabinets, shelves, racks for storing and organizing documents, etc.

- Microclimate: air temperature, humidity, airflow speed.
- Lighting conditions: general level of lighting; direction of natural lighting; level of pulsation of artificial light sources, their placement to avoid reflections on screens, etc.
- Noise pollution: noise pressure level of different frequencies at the workplace.
- Vibration levels: vibrations of different frequencies affecting the employee
- Non-ionizing electromagnetic radiation and electrostatic fields: electric and computer equipment may create static charges and electromagnetic fields affecting the employee
- Electrical safety: correct installation and insulation of electrical equipment, power lines, connectors, lighting; following the safety rules for working with electrical equipment by the employee
- Fire safety: use of fire safe materials, availability of fire protection equipment; following the fire safety rules by the employee

Considering the working environment, occupational hazards of the office workers may include:

- Uneven distribution of brightness in the field of vision, increased brightness resulting in eye fatigue and damage
- Danger of electrocution
- Strain of vision and attention
- Long lasting static loads
- Psychological stresses

Most of the regulations regarding the working conditions of office workers in Ukraine are set at the level of state standards. The main ones are:

- State sanitary norms of industrial noise, ultrasound and infrasound DSN 2.3.6.037-99
- State sanitary norms of industrial general and local vibration DSN 3.3.6.039-99
- State sanitary norms of the microclimate of industrial facilities DSN 3.3.6.042-99
- State sanitary rules and regulations for working with visual display terminals of electronic computing machines DSanPiN 3.3.2.007-98

- Rules of labor protection during the operation of electronic computing machines, approved by the order of Derzhhirpromnahliad No. 65
- General requirements regarding the provision of occupational health and safety by employers, approved by the order of the Ministry of Emergency Situations No. 67

4.2. Analysis of microclimate conditions of a workplace

Under microclimate conditions we consider such factors as air temperature, humidity and airflow speed. According to various studies, microclimate conditions can affect both the health and the productivity of office workers [27]. Maintaining comfortable microclimate reduces discomfort factors for the employee increasing his productivity and attention. On the other hand, increased temperature may cause fatigue and lethargy, increasing chances of incidents and reducing productivity; lower temperatures and increased humidity may increase spread of infections; low humidity can lead to dehydration, etc.

State occupational safety and health legislations provide optimal and acceptable values of microclimate conditions at the workplace [28]:

Table 4.1 – Optimum values of temperature, relative humidity and speed of air movement in the working area of industrial premises (for light work category)

Season	Work category	Air temperature, °C	Relative humidity, %	Airflow speed, m/s
Cold	Light 1a	22-24	40-60	0.1
	Light 1b	21-23	40-60	0.1
Warm	Light 1a	23-25	40-60	0.1
	Light 1b	22-24	40-60	0.2

According to the state building regulations, workplaces for working with personal computers must be equipped with heating, air conditioning, or supply and exhaust ventilation systems. Optimal values of microclimate parameters: temperature, relative humidity and air mobility must be ensured in workplaces in accordance with norms and rules. Additionally, heating and ventilation systems must provide [29]:

- Normative parameters of concentration of harmful substances in the air
- Compliance with normative levels of noise and vibrations during the work of the equipment
- Fire and explosion safety
- Protection of atmospheric air from emissions
- Mechanical and electrical safety
- Efficient use of energy resources
- Reliability and serviceability of the equipment

4.3. Recommendations to improve microclimate conditions

As was mentioned earlier, comfort microclimate can significantly increase worker's productivity, reduce health hazards and risk of incidents. Thus, it is important to maintain the required level of microclimate conditions. To verify the microclimate parameters, measurements are performed. Temperature and humidity are measured by using psychrometer based devices. Airflow speed is measured by anemometers. Measurements of microclimate parameters are performed at the workplaces at the beginning, middle and the end of the work shift. The placement of measuring devices should be at a height of 0.5-1.0 meters from the floor, when working while sitting and 1.5 meters when working while standing. Measurements should be performed at least twice a year, for warm and cold seasons [28]. In the case of detection of deviation of microclimate parameters, measures of microclimate normalization should be done.

The means and measures of microclimate normalization include: construction and planning, organizational and technological measures, as well as means of individual protection of workers. The normative values of microclimate parameters should be maintained, first of all, by the rational planning of the work rooms and optimal placement of the heating, air conditioning and humidifying equipment. In the case of excess internal heat, natural or mechanical ventilation may be used [30].

Additional means of improving microclimate conditions may also be considered. They may include:

- Regular cleaning of working rooms and workplaces, including removal of dust from surfaces of keyboards and computer screens.
- Regular aeration of rooms by opening windows. However, air drafts must be avoided.
- Installation of additional air humidifiers or heaters if required.
- Placing interior plants near the workplaces and in working rooms [27].

4.4. Fire safety measures

Fire safety at work is a set of measures and means aimed at preventing ignition, fires and explosions in the production environment, as well as to reduce the negative effects of hazardous and harmful factors that occur in the event of fire. In office workplace, most of the fire safety concerns are related to electrical equipment and office appliances.

One of the elements of ensuring fire safety in the office is the primary fire extinguishing equipment. The primary means of extinguishing fire include: fire extinguishers, fire blankets (a cover made of non-combustible heat-insulating fabric), sand boxes, barrels of water, fire buckets, rags, crowbars, axes, etc. The most convenient for use in the office are fire extinguishers. In addition of being equipped with any type of fire extinguishing system, fire alarm system or internal fire hydrants, office premises must also be provided with the primary means of fire extinguishing.

Successful extinguishing of a fire depends on the correct choice of the type of fire extinguisher. The selection of the type and the required number of fire extinguishers is carried out in accordance with the Rules of operation and the standards for the conditions of fire extinguishers, approved by the order of the Ministry of Internal Affairs of Ukraine dated January 15, 2018 No. 25

According to the rules, administrative buildings on each floor must have at least two portable (powder, water-foam or water) fire extinguishers with a charge mass of fire-extinguishing substance of 5 kg or more.

In addition, on each of 20m² of floor space in office premises with office equipment, one gas fire extinguisher with a fire extinguishing substance charge of 3 kg or more should be provided. Premises with office equipment should be equipped with portable gas fire extinguishers, not less than one fire extinguisher of the specified types per room. Employees should conduct practical lessons with fire extinguishers at least twice a year, to familiarize themselves with structure, principle of operation and methods of using fire extinguishers [31].

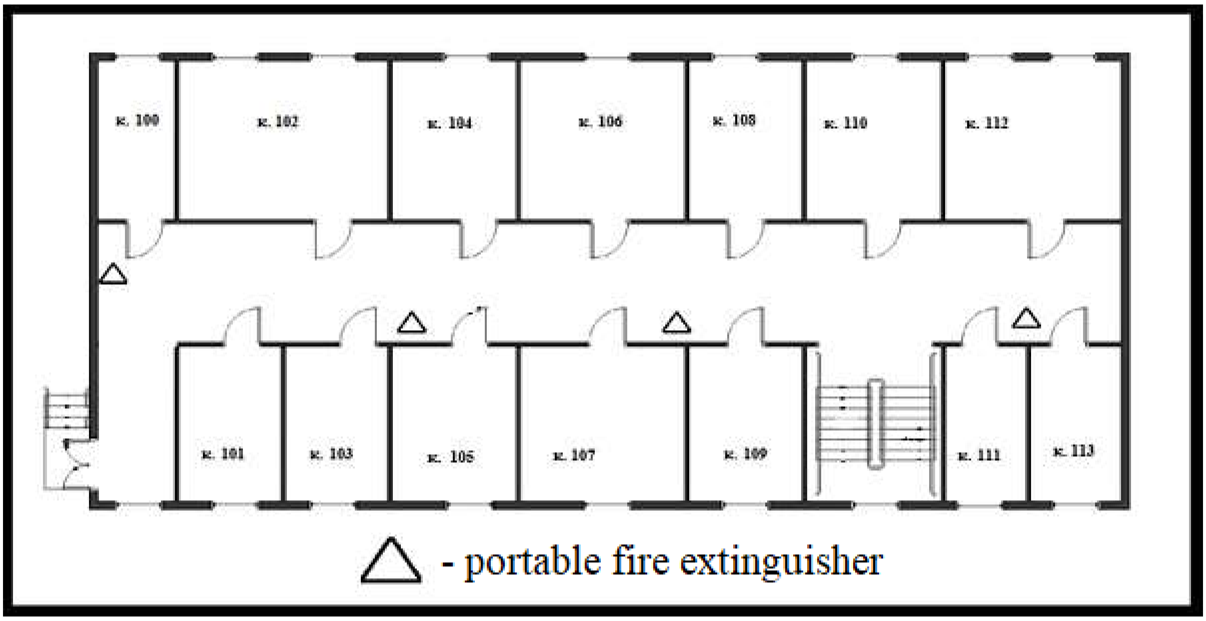

Fig. 4.1. Example of placement of fire extinguishers in the office premise

Given that there is a lot of equipment, devices and documents in office premises, in order to prevent their damage during extinguishing, it is preferred to use gas (carbon dioxide) fire extinguishers. The use of powder fire extinguishers for extinguishing such fires is acceptable only in the absence of gas fire extinguishers.

In addition to providing and maintaining fire safety and primary fire extinguishing equipment, employees must follow basic fire safety and electrical safety rules [32]:

- furniture and equipment must be placed in such a way as to ensure a free evacuation passage to the exit door from the premises (at least 1 m wide). Evacuation routes and exits must be kept free at all times and not obstructed by anything.
- electrical networks, electrical devices and equipment should be operated only in good condition, taking into account the instructions and recommendations of the manufacturing companies. In case of detection of damage to electrical wires,

switches, sockets, etc., they must be immediately turned off. Usage of damaged electrical equipment is forbidden.

- documents, paper and other combustible materials should be stored at a distance of at least 1 m from electrical panels, 0.5 m from electric lamps and 0.6 m from automatic fire alarm detectors.
- all employees must be able to use available fire extinguishers, other primary means of fire extinguishing, and know their location.

Forbidden actions in the office premises:

- arrangement of temporary power grids;
- laying electrical wires directly on the combustible materials;
- smoking, use of flammable liquids;
- carrying out fire, welding and other works without a special permit;
- turning on electric heating devices without non-flammable stands and, in those places, where their use is not allowed.

If the case of fire it is necessary:

- urgently notify the fire department by phone 101, indicating the address, number of floors, place of fire, presence of people;
- organize the evacuation of people and material values;
- notify the administration and duty officer (if available);
- turn off electrical devices and ventilation;
- start extinguishing the fire with available primary fire extinguishing means;
- organize a meeting of fire protection units and provide consulting and other assistance in the process of extinguishing a fire.

CHAPTER 5

ENVIRONMENTAL PROTECTION

5.1 Overview of environmental effects of the implementation of the proposed information technology of resolving conflict situation of dynamic objects

As explained in the previous chapters, the proposed technology of resolving conflict situations of dynamic objects can be implemented as a subsystem of the TCAS II. Thus, the possible effects of such technology on the environment can be analyzed through TCAS performance.

TCAS involves communication between several aircraft using transponders. The communication is performed via 1030/1090 MHz radio frequencies (1030 MHz for interrogation signal; 1090 MHz for the reply signal). The system includes directional and omnidirectional TCAS antennas and two transponder antennas [18].

Considering this, we may analyze the effects of electromagnetic radiation emitted during the work of the TCAS equipment. The work of antennas on specific radio frequencies and radio noise connected with it, may affect human health, impact animals and plants, depending on the power and the proximity of the radio source. The TCAS frequencies lay in the UHF (Ultra High Frequency) band. Frequencies in the UHF band are also widely used in other communication technologies such as Wi-Fi, television broadcasts and cellular networks. Thus, usage of the proposed technology may increase the general level of electromagnetic noise.

The other sources of the effects on the environment may be contributed to the process of production of the components used in the proposed technology and TCAS radio equipment. Such components include printed circuit boards, microprocessors, storage devices, electrical wires etc.

During their production, emissions of greenhouse gasses, connected with high power consumption, as well as direct pollution by toxic materials and gases as by-products may occur. Other concerns may include noise pollution by the production facilities, mining of raw materials and deforestation.

5.2. Environmental impact and hazardous factors connected with implementation of the proposed technology

The UHF electromagnetic radiation is classified as non-ionizing. The biological effect of intense UHF radiation result in heating of tissues, which is hazardous for human health. However, taking into the account principle of operation of TCAS antennas, these effects may be disregarded due to low power of the radio sources and large altitudes of flight. The effects of low power electromagnetic radiation were studied. However, results of these studies show no evidence of any health effects of low power radio frequency exposure [33].

Ground-based radar and communication stations are placed in accordance to regulations to protect residents from harmful effects of high intensity electromagnetic radiation. The placement of ground station must be chosen taking into account the power of the transmitters, the characteristics of the radiation direction, the height of the location and design features of the antennas, the topography of the area and the functional purpose of the adjacent territories so that the electromagnetic field levels in the residential areas do not exceed the maximum allowed norms [34].

Considering the impact on the ecology, there are several studies, shoving presence of hazardous effects of microwave electromagnetic radiation. Hazardous effects on birds, insects and plants were observed. For example, electromagnetic noise may disrupt magnetic compass orientation of birds. This causes disorientation and disruption of migration of some bird species, as they lose the ability to sense the direction of Earth’s magnetic field. Limited studies were conducted on the effects on trees and plants, which indicated different effects, depending on the plant species and their growth stage. It includes changes in biochemistry and stress of plant cells [35]. Increasing levels of electromagnetic radiation contributes to a decline of insect’s populations, including pollinators. Effects include biochemical changes in honey bees, which can change their behavior. Decrease of reproductive capacity was observed in other insects [36].

The electronic components for proposed system contribute to environment pollution during their manufacturing process. In addition to that, many of those components include toxic materials, which will become contaminants themselves, if disposed inappropriately by the end of the service life. The worldwide increase of demand on electronic components, in which components for avionics and aircraft navigation systems are contributing as well, results in increased concerns of environment pollution.

During production of printed circuit boards (PCB), such techniques as etching, drilling, image transfer and electroplating are used, thus generating waste products containing heavy metals, acids, organic polymers. Waste materials often end up polluting soil and water bodies. This mainly effects freshwater and marine ecosystems and can be dangerous to humans as well. Dangerous materials can contaminate food and fresh water sources, leading to negative health effects [37].

The other huge source of pollution is the semiconductor industry. Semiconductors are used in various electronic components, such as surface-mount devices, memory and storage devices, chips, microprocessors, etc. The main environmental concerns of semiconductor chips production include [38]:

- High electricity consumption, which significantly contributes to carbon emissions;
- High consumption of fresh water, contributing in depletion of water resources;
- Raw materials depletion;
- Water contamination – waste water contains toxic substances, mainly acids and metals;
- Eutrophication of water bodies;
- Air pollution, including emissions of greenhouse gases, acidifying gases and formation of smog;
- Large amounts of waste solvents, which is required to be managed and stored;
- Plastic waste;
- Soil contamination;
- Land occupation.

These effects negatively impact various ecosystems, can be dangerous to human health and contribute to the climate change.

The final possible environmental effects are associated with electronic components recycling, When the electronic and radio equipment must be replaced, waste components need to go somewhere. Most electronic components can be recycled or reused. However, if the recycling is done improperly, or is not done at all, toxic materials, which are contained in the components can get into the soil and water, contaminating the environment. Some of the harmful substances may include lead, mercury, arsenic, acids, rubber, etc. Large portion of the electronic waste is processed improperly, ending up in landfills, where it can leak toxic materials into the soil or be burned releasing them into the atmosphere [39].

5.3. Ways of reducing environmental impact

The environmental impact of the proposed technology can be harmful both for the ecosystem and human health. As was discussed above, problems can arise during manufacturing of the required equipment, during the use of the technology and during the recycling of damaged or replaced equipment. Different means and measures can be applied to reduce the hazardous impact at all stages of the technology production and use.

The environmental effects during the process of exploitation of the radio equipment, used in the technology, are least dangerous. The equipment doesn’t produce any harmful substances during its normal work. However, there are still some recommendations, which can be applied, for example:

- Plan aircraft routes away from residential areas and natural habitats, if possible;
- Ground navigation stations must comply with regulations of electromagnetic radiation safety;
- Selection of ground station locations in order to reduce their possible impact on the natural habitats of birds and insects;
- Consider safety measures for maintenance personnel while working with radio equipment.

The largest part of the environmental impact of the proposed technology will be contributed to the process of manufacturing electronic and radio components. At the same time, it is also the hardest to reduce the impact. Significant improvements in this field will require changes in manufacturing processes, use of alternative raw materials, implementation of costly technologies, etc. The recommendations to reduce environmental impact of electronic components and semiconductor industry may include:

- Use of alternative “eco-friendly” materials in production of PCBs;
- Developing of new manufacturing techniques, which reduce or eliminate use of toxic materials;
- Implementation of waste water treatment stations in production plants;
- Developing of more efficient manufacturing processes to reduce use of water, electricity and raw resources;
- Implementation of waste management and recycling during the manufacturing;
- Implementation of air filtering equipment;
- Enforcement of more strict state laws, regulations and standards regarding pollution levels;
- Consider placement of factories in order to reduce possible damage to natural habitats, fresh water resources and residential areas;
- Efficient overall design of the radio and navigation equipment, to reduce demand on materials and components.

There are also some measures, which can be implemented on the stage of recycling of equipment that ended its life cycle. The main aim of such measures is to reduce amount mismanaged waste. It may include:

- Enforcement of state regulations regarding management of dangerous and toxic waste products;
- Proper sorting and disposal of electronic components waste;
- Refurbishing of individual undamaged and serviceable components if possible;
- Installing of air filtering and water treatment equipment at recycling plants.

The combination of several measures during the life cycle of electronic equipment may considerably reduce its carbon footprint and atmosphere and water pollution. In addition to that, in the case of radio equipment, reducing hazardous effects of electromagnetic radiation should also be considered.

Conclusion to the chapter

In this chapter we have discussed potential impact on the environment by the implementation of proposed technology of intellectual control of conflict situations of dynamic objects. We have highlighted areas, where different harmful factors can occur:

- Emissions and pollutions during manufacturing process;
- Electromagnetic radiation during the normal operation of the equipment;
- Recycling of damaged or replaced components.

Each area has different sources of hazardous impact on the environment, thus different measures should be applied. Such measures were advised in this chapter, the main ones are:

- Implementation of new technologies to reduce overall emissions and polluting factors;
- Enforcement of respective regulations in the fields of waste disposal, emission reduction and electromagnetic radiation safety;
- Correct management and disposal of waste products.

CONCLUSIONS

Despite the active search for ways to solve the problem and the development of information technologies, the issue of solving the problem of managing conflict situations of DO is extremely actual. The conducted studies confirmed the insufficient efficiency of the operation of traditional navigation systems and the ATC system.

In order to increase the safety of flights in aviation by ensuring a guaranteed level of safety during the prevention of collisions of dynamic objects, a new information technology was developed for solving conflict situations of dynamic objects on a real-time scale. During the work there was:

- the definition of the concept of conflict situations, the classification of methods of solving conflict and potentially conflict situations of DO, and the advantages and disadvantages of the main methods are highlighted; perspective concepts of changing air traffic control to determine the location of the CS in the future are presented, and norms for echeloning and resolving conflict situations are presented;
- a critical analysis with conclusions of the main modern theoretical and practical technologies, methods and systems for preventing DO collisions is given;
- a mathematical description of the conflict situation of DO was carried out, the task of a possible solution of the CS using the theory of invariance and differential games was set;
- a new method of solving conflict situations of aircraft on a real-time scale has been developed, algorithms for its action have been developed. An algorithm for determining a priority aircraft, the trajectory of which will not change during a critical situation, an algorithm for determining an aircraft that should change its trajectory when a critical situation occurs, is proposed;
- an algorithm for determining the DO priority in the CS was created in order to ensure the operation of the new method of solving the CS;
- a database was developed for the operation of the subsystem for solving conflict situations of the DO, which is based on taking into account the uncertainty zones of the DO and the construction of Euler-Venn diagrams;

- the mathematical logic of the action of the database when solving the CS is given in the predicative form and in the form of the algebraic logic;

- real-time prediction of the state and dynamics of the aircraft flight is ensured (with the provision of system and functional-temporal compatibility) by developing a synthesized model of the DO's dynamic movement and taking into account the distributed control environment;

- verification of the developed information technology was carried out by means of computer simulation; a methodical evaluation of the effectiveness of the proposed algorithms for resolving the conflict situation of DO is given, which was carried out using typical experimental scenarios, ranging from simple conflicts between two DOs to extremely complex ones, with the participation of a significant number of DOs in one conflict;

- a model of the conflict management subsystem of aircraft was synthesized; the subsystem is implemented in the form of a separate unified equipment that works with the use of satellite and radar navigation systems and provides determination of the coordinates of the DO on a real-time scale; it is stipulated that the subsystem must be installed on all airships and integrated into their on-board network to properly ensure its functionality and interaction with on-board navigation systems.

The novelty of the developed method is:

- calculation of predicted trajectories of DO traffic at each moment of time;

- calculation and consideration of "uncertainty zones" and areas of the controlled state of the DO;

- consideration of non-linearity in the behavior of the DO;

- determination of the global optimum by the minimum deviation criterion.

This will provide an opportunity to ensure a guaranteed level of safety during the prevention of collisions of DO in the CS.

The development and implementation of the proposed intelligent information technology will contribute to increasing the reliability and efficiency of ground-based ATC services. Also, the implementation of the development will ensure the automation of flight control and management processes, the introduction of more advanced computing complexes and information display systems. Automation of ATC systems is the basis of the development of means of ground control over the flights of dynamic objects. The introduction of automated systems significantly increases the efficiency and safety of air traffic, reduces the burden on controllers and pilots.

The creation and implementation of a new information technology for solving conflict situations of dynamic objects on a real-time scale and the implementation of such management with appropriate algorithms will ensure effective prevention of dangerous approaches. The development of a technology for solving dangerous approaches will make it possible to ensure the separation of dynamic objects relative to each other at a distance that corresponds to the echelon norms, in the conditions of complex multiple conflicts, which include a large (up to 50) number of dynamic objects and with an extremely complex geometry of the conflict (intersection of two dense streams of dynamic objects, convergence at one point and at the same time of dynamic objects flying in different directions, conflict with a combination of intersections and bypassing of several dynamic objects at one point, etc.).

REFERENCES

1. Eurocontrol. Airspace Strategy for the ECAC States. ISAO: 2001. – 91 p.

2. Kharchenko V.P., Argunov H.F., Zakora S.A. Risks of collision and echeloning of airships: textbook. Kyiv: NAU, 2011. 326 p.

3. Druzhinin V.V., Kontorov D.S. Conflict radilocation: a textbook. Moscow: Radio and Communication, 1982. 124 p.

4. Akhmedov R.M., Bybutov A.A., Vasiliev A.V. Automated air traffic control systems. New information technologies in aviation: textbook. St. Petersburg: Polytechnic, 2004. 446 p.

5. Semko V.V. Concept topological situational analysis and synthesis in "small" object control in the conditions of conflict, uncertainty behavior and variable plural objects observation. *Current problems of state information security provision.* Materials of scientific and technical conference of students, postgraduates, teachers and scientists: December 18, 2014. Kyiv: State university of Telecommunications, 2014. p. 90–91.

6. Semko V.V., Chepizhenko V.I. Construction of control areas of dynamic object. *Telecommunication and information technologies*, 2015. No. 3. p.25–30.

7. Semko V.V. Topological situational analysis and synthesis of control strategies of the object in the conflict conditions, behavior uncertainty and variable plural objects observation. ScienceRise, 2016, No. 9/2(26). p. 62–69.

8. Volkov O.E., Pavlova S.V. Conflicting interaction of airships on the warning of threats collision: article. Kyiv: *Control systems and machines*, 2017. No. 4. P. 83–91.

9. Pavlov V.V. Beginnings of the theory of ergatic systems: monograph. Kyiv: Naukova dumka, 1975. 240 p.

10. Pavlov V.V. Invariance and autonomy of nonlinear control systems: monograph. Kyiv: Naukova dumka, 1971. 271 p.

11. Pavlov V.V. Conflicts in technical systems: monograph. Kyiv: Higher School, 1982. 183 p.

12. Pavlov V.V., Pavlova S.V. Intellectual control of difficult non-linear dynamic systems. Analytics of intelligence: a monograph. Kyiv: Naukova dumka, 2016. 214 p.

13. Bodner V.A. Aircraft control systems: textbook. Moscow: Mashinostroenie, 1973. 501 p.

14. Chepizhenko V.I., Volkogon V.O. The role of modern concepts of transformation of CNS/ATM systems in provision of autonomous flights of aircraft: article. Dnipro: *Current problems of automation and informational technologies,* 2015. No. 19. 112-120 p.

15. Kuchar J. K., Yang L. C. Prototype conflict alerting logic for free flight *Proceedings of 35th AIAA Airspace Science Meeting Exhibit.* 1997. Vol. 20. 4. pp. 768–773.

16. Airworthiness and Operational Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders. US Dept. of Transport. Federal Aviation Administration. June 2002. p. 51.

17. Honeywell Inc. (2000). Collision Avoidance System User's Manual TCAS II/ACAS II. ACS-5059, Revision 5. 02. May. 2000. p. 83.

18. Introduction to TCAS II Version 7. US Dept. of Transport. Federal Aviation Administration. November 2000. p. 45.

19. Volkov O.E., Pavlov V.V. Device for warning collisions of moving objects in dynamic conflict in real time scale: patent on useful model 106766 Ukraine: IPC G05B1/00, G05B15/00, G05B17/00, G06F9/00, G06N7/00, G08G5/00. No. 201510019; stated _ 13.10.2015; published 10.05.2016, Bull. No. 9. 9 p.

20. Volkov O.E., Pavlova S.V. System of guaranteed resolution of dynamic conflicts of aircrafts in real time: article. K.: *PROCEEDINGS OF THE NATIONAL AVIATION UNIVERSITY*: *Scientific journal*. Scientific article, 2017. No. 1. P. 29-35.

21. Volosheniuk D. E., Volkov O.E. Application of computer modeling in development of aviation landing systems and aircraft collision warning: theses. IMT-2014: All-Ukrainian scientific and practical conference “Informatiom and Modeling Technologies” May 29-31, 2014, Cherkasy, 2014. - p. 53.

22. Volosheniuk D.O., Volkov O.E. Modern 3D computer modeling of aircraft for conducting aerodynamic studies: theses. *Problems of information and computer science techniques*: All-Ukrainian scientific and practical conference, May 27-31, 2013. Chernivtsi, 2013. – pp. 53-54.

23. Volosheniuk D.O., Volkov O.E. Computer program "Modeling of aircraft flight on the base of ergatic network-centric control systems”: certificate of registration of copyright No. 56158 Ukraine, publ. 20.08.2014.

24. Volkov O.E., Pavlov V.V. Computer program of collisions warning of moving objects in dynamic conflict in real time scale: certificate of registration copyright No. 61656 Ukraine, publ. 14.09.2015.

25. Volkov O.E., Pavlova S.V. Modeling of the invariant method of resolving dynamic aircraft conflicts: article. Kyiv: *Cybernetics and system analysis*, 2017. No. 53. pp. 105-112.

26. The Law of Ukraine on labor protection, 14.10.92, No. 2694-XII.

27. Kamarulzaman, N., Saleh, A. A., Hashim, S. Z., Hashim, H., & Abdul-Ghani, A. A. (2011). An Overview of the Influence of Physical Office Environments Towards Employee. Procedia Engineering, 20, pp. 262–268.

28. Sanitary norms of the microclimate of industrial facilities DSN 3.3.6.042-99, 01.12.99, No. 42.

29. Heating, ventilation and air conditioning DBN V.2.5-67:2013, 01.25.2013, No. 24.

30. K.N. Tkachuk, M.O. Khalimovskyi, V.V. Zatsarnyi, Basics of labor protection: Textbook. 2nd edition, Osnova, 2006, p. 448.

31. Rules of operation and typical standards of fire extinguishers, NAPB B.01.008-2018, 15.01.2018, No 25.

32. Instructions on fire safety measures in office premises of the Ministry of Strategic Industries of Ukraine, 12.02.2021, No.29.

33. Kundi, M. (2005), Epidemiology of Health Effects of Radiofrequency Exposure, Environmental Health Perspectives, 113(3).

34. State sanitary norms and rules for the protection of the population from the influence of electromagnetic radiation, DSN 239-96, 01.08.1996, No.239.

35. Balmori, A. (2014). Electrosmog and species conservation. Science of The Total Environment, 496, 314–316.

36. Balmori, A. (2021). Electromagnetic radiation as an emerging driver factor for the decline of insects. Science of The Total Environment, 767, 144913.

37. Gerić, M., Gajski, G., Oreščanin, V., Domijan, A.-M., Kollar, R., & Garaj-Vrhovac, V. (2017). Environmental risk assessment of wastewaters from printed circuit board production: A multibiomarker approach using human cells. Chemosphere, 168, 1075–1081.

38. Villard, A., Lelah, A., & Brissaud, D. (2015). Drawing a chip environmental profile: environmental indicators for the semiconductor industry. Journal of Cleaner Production, 86, 98–109.

39. Debnath, B., Roychowdhury, P., & Kundu, R. (2016). Electronic Components (EC) Reuse and Recycling – A New Approach towards WEEE Management. Procedia Environmental Sciences, 35, 656–668.