MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
FACULTY OF AIR NAVIGATION, ELECTRONICS, AND TELECOMMUNICATIONS

DEPARTMENT OF AVIONICS

APPROVED
Head of department
________S.V. Pavlova
'___'___________2022

GRADUATION WORK

(EXPLANATORY NOTES)

FOR THE DEGREE OF BACHELOR
SPECIALTY 173 'AVIONICS'

Theme: <u>'Research of risk reduction methods of aircraft near-miss cases'</u>

Done by: ___________ V.V.Popenko
(signature)

Supervisor: ___________ L.M. Sutnynskih
(signature)

Standard controller: ___________ V.V. Levkivskyi
(signature)

Kyiv 2022

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
ФАКУЛЬТЕТ АЕРОНАВІГАЦІЇ, ЕЛЕКТРОНІКИ ТА ТЕЛЕКОМУНІКАЦІЙ
КАФЕДРА АВІОНІКИ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач випускової кафедри
_________С.В. Павлова
«___»___________2022

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ
БАКАЛАВР ЗА СПЕЦІАЛЬНІСТЮ 173
«АВІОНІКА»

Тема: «Дослідження методів зниження ризику небезпечних зближень літаків в повітрі»

Виконавець:	__________ (підпис)	Попенко В.В.
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Нормоконтролер:	__________ (підпис)	Левківський В.В.

Київ 2022

NATIONAL AVIATION UNIVERSITY
Faculty of Air Navigation, Electronics and Telecommunications
Department of avionics
Specialty 173 ‘Avionics’

APPROVED
Head of department
_________S.V. Pavlova
‘___’___________2022

TASK for execution graduation work

V.V.Popenko

1. Theme: ‘Research of risk reduction methods of aircraft near-miss cases’, approved by order №352/ст of the Rector of the National Aviation University of 04 April 2022. Duration of which is from 16.05.2022 to 16.06.2022.

3. Input data of graduation work: Methods of resolving potentially conflict situations and development of a universal solution algorithm.

4. Content of explanatory notes: Section 1: Theoretical foundations of conflict situations in air traffic control; Section 2: TCAS as a way to resolve air conflicts. History of creation and improvement. Practical application in aviation; Section 3: Research of methods for resolving potentially conflict situations and development of a universal algorithm;

5. The list of mandatory graphic material: figures, charts, graphs.

6. Planned schedule

№	Task	Duration	Signature of supervisor
1.	Validate the rationale of graduation work theme	16.05-20.05	
2.	Carry out a literature review	20.05- 24.05	
3.	Develop the first chapter of diploma	24.05-30.05	
4.	Develop the second chapter of diploma	30.05-07.06	
5.	Develop the third chapter of diploma	07.06-12.06	
6.	Tested for anti-plagiarism and obtaining a review of the diploma	12.06-16.06	

7. Date of assignment: May 16 2022 year

Supervisor ________________ L.M. Sutnynskih

(signature) (surname, name, patronymic)

The task took to perform ________________ V.V. Popenko (signature) (surname, name, patronymic)

ABSTRACT

The explanatory notes to the graduate work ‘Research of risk reduction methods of aircraft near-miss cases’ contained 62 pages, 45 figures, 19 reference books

Keywords: AIR TRAFFIC CONTROL, AIR DEPARTMENT, CONFLICT SITUATION, POTENTIALLY CONFLICTING SITUATION, COLLISION PREVENTION SYSTEM, CONFLICT RESOLUTION

The object of the research: collision prevention process, air conflict management and security process.

The subject of the research: collision avoidance system in ATC.

The purpose of the graduate work: Investigate the nature of conflict situations in civil aviation. To determine that the prevention of aircraft collisions is to identify and eliminate potential conflict situations (PCS).

Research methods: theoretical and analytical with the search of literature, analysis and generalization of the information obtained for the thesis with further classification and explanatio

Thesis plan

On the topic: “Research of risk reduction methods of aircraft near-miss cases”

Introduction

Abbreviation

ATC - Air traffic control

ATS - air traffic services

AC - aircraft crew

ATM - air traffic management

PCS - potential conflict situation

OCAS - onboard collision avoidance system

ORS - onboard radar station

SSR - secondary survey radar

CCS - Cartesian coordinate system

DAS - dynamic air situation

FOM - Flight Operations Manual

RP - reference point

FC - flight characteristics

MPA- magnetic path angle

ATS - air traffic services

RVF - rules of visual flights

PSR - primary survey radar

GCAS - ground collision avoidance system

DCC - district control center

RC - radar control

Introduction

Relevance of the graduate work: The problem of air traffic safety worries almost everyone, because now the plane is a fast and convenient means of transporting a large number of people at the same time, both over long distances and within the country. Unfortunately, the flight does not always end as planned. This happens for various reasons, the most terrible of which is the plane crash, which kills people.

Ensuring flight safety is largely related to solving the problem of preventing aircraft collisions in the air. At present, the air traffic control system is in charge of this task.

The object of the research: there is a process of separation in air traffic control, detection and prevention of potential conflict situations and the process of collision prevention.

The subject of the research: collision avoidance system in ATC

The purpose of the graduate work: Investigate the nature of conflict situations in civil aviation. Determine what air collision prevention is aircraft is to identify and eliminate potential conflict situations.

CHAPTER 1

THEORETICAL FUNDAMENTALS OF CONFLICT SITUATIONS IN AIR TRAFFIC MANAGEMENT

1.1 Air Traffic Control (ATC). The main tasks and dangers

Air traffic control (ATC) is an integral part of air traffic services (ATS), which is a direct interaction between the air traffic control controller and the aircraft crew (AC), as well as other services (meteorological, technical and aerodrome).

The main tasks of the ATC

• prevention of collisions of aircraft with each other in the air, on the platform and on the runway, as well as prevention of collisions of aircraft with obstacles;

• accelerating and maintaining an orderly flow of air traffic;

• providing the necessary information and assistance to EPS in emergency situations;

• issuance of other necessary information (meteorological, radio engineering, etc.)

The very first task carries the greatest danger. After all, uncoordinated actions of all components of aircraft management, including electronics and misunderstanding of technology, cause plane crashes that cause a large number of victims and cause irreparable damage to the environment. When a plane crash happens, it doesn't go unnoticed.

Air traffic controllers, using air surveillance equipment, radio equipment (radio stations, direction finders, etc.) continuously monitor the air situation and identify potentially conflict situations (situations where there is a threat of ascent of the aircraft in one place, at the same flight level, at the same time).

Potentially conflict situations are resolved by dispatchers by certain methods:

• issuing a command to change the altitude (flight level);

• issuing a command to change the course and route of the flight;

• issuing a command to change the flight speed;

• other methods.

Radio communication between aircraft crews, ATS units and relevant ground services on the territory of Ukraine, in the airspace of Ukraine and in the airspace over the high seas, where the responsibility for ATS is assigned to Ukraine, is carried out in English or Russian, above 275 flight level in English only. in Russian).

The need for research conducted in this work is confirmed by the fact that the current state of the world air transport system is characterized by a steady increase in air traffic, which already leads to the system reaching its maximum capacity. Further increase in air traffic inevitably leads to reduced flight safety, increased aircraft delays both on the ground and in the air, increased fuel consumption and reduced flight efficiency, as well as an irreversible increase in negative environmental impact. Increasing the intensity of traffic in the European network of air routes directly affects the increase in the number of potential conflict situations, according to statistics. As a result, ground control centers experience significant congestion in regulating air traffic flows.

Aircraft collisions with each other cause a large number of accidents, so quantifying flight safety by the allowable risk of aircraft collisions is very important. However, even with the help of highly efficient and highly reliable ATC systems, it is not possible to ensure the necessary flight safety. The fact is that part of the earth's surface is still not covered by ATS systems, and in addition, existing ATS systems do not allow reliable control of flights at low altitudes and in regions of the globe that are difficult to observe.

One of the most important reasons for dangerous collisions with aircraft is that the dispatcher decides to predict and determine conflicts based on incomplete information in a limited time.

The expected result of this work is the creation of a new universal aircraft conflict management system, built on network-oriented technologies and the principles of the theory of constancy, which will meet modern requirements of air traffic management (ATM) to ensure a guaranteed level of flight safety.

Attempts to classify modern methods and algorithms for resolving conflict situations between aircraft can be found in. The generalized form of this classification has a very branched and distributed structure and allows us to draw several important conclusions:

Much of the methods and algorithms are designed for conflict situations involving only two aircraft, and for more complex cases, pairwise enumeration is used, without taking into account the possible impact of one conflict on other conflicts that are relatively close in time and distance;

the greatest effectiveness of conflict resolution is achieved by using distributed terrestrial on-board systems, which are not yet fully implemented.

1.2 Classification of conflict situations in the air

Over the years of monitoring all aviation accidents, it has become clear that they occur due to so-called air traffic control (ATC) problems. In other words, most of the trouble that happens in the air is due to conflict situations between aircraft, which due to the coincidence of various circumstances and minor errors fall into a situation dangerous to many lives.

And now let's take a more specific look at what a conflict situation is, a potential conflict situation (PCS), what is the difference between these two terms, let's define how the PCS search is performed and what the dispatcher has to do with it.

As you know, air traffic controller is one of the main professions that provides air safety. The air traffic controller controls and regulates the separation of aircraft, coordinates, detects and resolves inter-aircraft conflicts in the air. As this is a very responsible, stressful profession, great demands are placed on candidates. Therefore, the main task of the dispatcher is to control the distance between the aircraft, preventing them from approaching, and if such a situation may occur to prevent and coordinate their differences with the happiest end without loss. And since such work cannot be done alone, you need, in addition to all other mental skills, the ability to work in a team, be able to trust and listen to others.

The work of the dispatcher is mental and requires operational thinking to solve operational problems, which is a conflict situation. The process of mental thinking begins with a push, with a problematic situation which in turn has a set of quantitative and qualitative constituent elements with their value and spatial location.

In order to better understand the classification of MCS, it is necessary to understand what it is, how it occurs and how to avoid it.

When we talk about aircraft, we mean such a special location between aircraft (aircraft) in which no intervention of the controller will lead to convergence and possible disaster.

Thus, the conflict situation is an already predicted rapprochement between the aircraft with some violation of separation, which is why it became possible.

Search for conflict situations is a preliminary calculation, monitoring of comparative trajectories of aircraft in a certain place where a conflict situation is possible.

Conflict resolution is the determination of all possible trajectories of divergence of conflicting aircraft, and the choice of all possible options, one of the best and fastest options.

As already mentioned, the main job of all air traffic controllers (ATC) is to detect and eliminate aircraft in a certain area of responsibility. The experience and competence of controllers provides support to understand that the PCS is a spatial perception and modeling of the air situation. During the long years of monitoring, we were offered possible options for the relative position of the aircraft relative to each other. The so-called CS classification covers the mutual location, flight profile and course of the conflicting aircraft.

Among all possible types of conflicts, we can highlight the main ones:

1. Objects move parallel to each other. Collisions may occur if they are at the same level of flight and the distance between them is less than the established separation standards. This conflict situation of parallel objects is called dogon (Fig. 1.1).

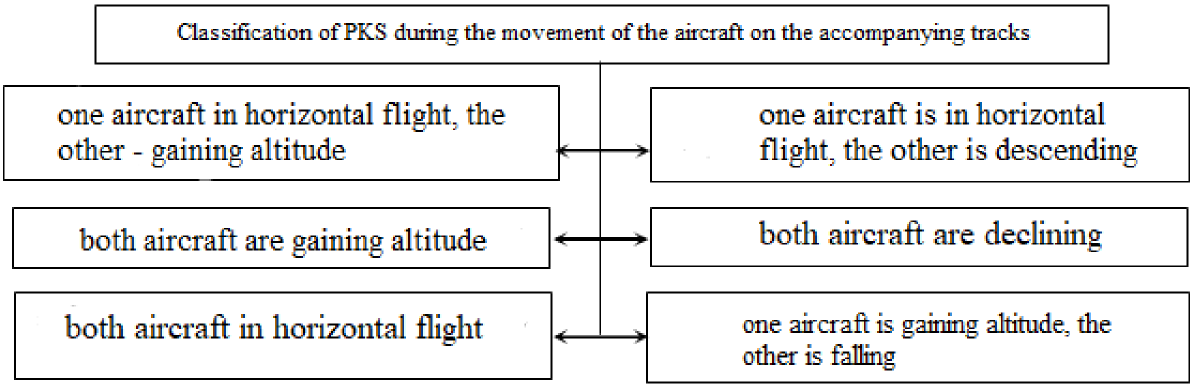

Fig. 1.1. Potentially conflicting situation during the movement of the aircraft on the accompanying tracks

2. Objects move towards each other along one route. This is the situation of oncoming objects (Fig. 1.2).

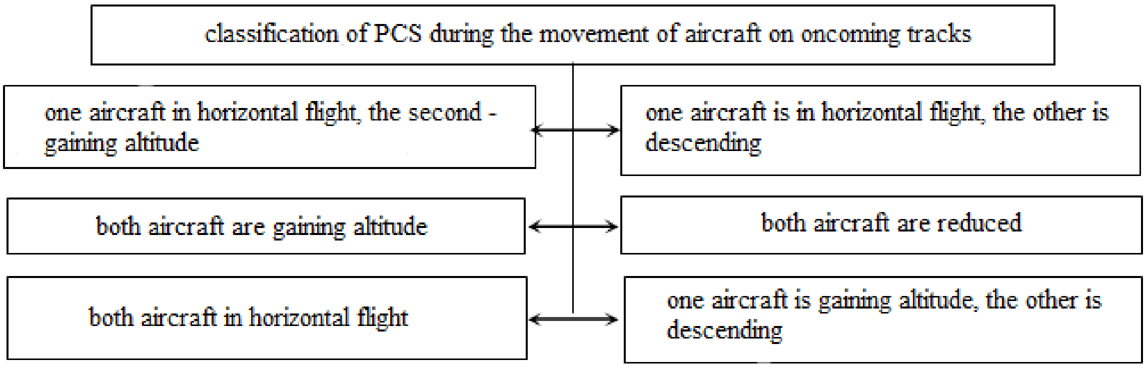

Fig. 1.2. Potentially conflicting situation during the movement of the aircraft on oncoming tracks

The first, fourth and last situations most often occur in the practice of ATC. All others happen occasionally, but the dispatcher must know in any case how to determine how much this situation is conflicting and requires immediate intervention and be able to disperse aircraft.

3. Objects move along intersecting routes, a situation arises in which the aircraft may cross at one of the elevation points. This is the situation of intersecting objects (Fig. 1.3).

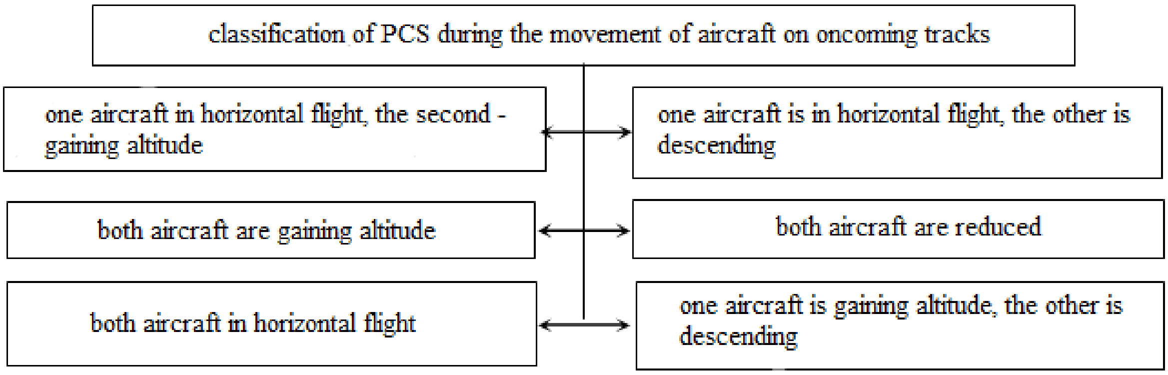

Fig. 1.3. Potentially conflicting situation while driving on intersecting tracks

All six situations occur at the intersections of routes and are of practical importance for the work of the dispatcher.

4. Generalized situation in which more than two objects are involved.

All the types that have been given require the unmistakable intervention of the dispatcher, and the immediate calculation of options for divergence and avoidance of collision. Possible consequences of incorrect, untimely or erroneous work of one of the links in the ATP leads to large losses. Including the tragedies mentioned above.

1.3. The reasons that were the impetus for improving the system

The problem of aircraft collisions in the air is the same age as the aircraft itself. Despite the supposed infinity of the air ocean, planes have always been crowded in the air. This closeness became especially noticeable with the beginning of the rapid development of jet aviation, when the civil air fleet began to develop at an accelerated pace.

Even now, in a time of high technology and innovative progress, many parts of the world's airspace are simply a mess. It is clear that the greater the number of participants in the movement, the probability of their unpleasant meeting at a certain, equally unpleasant moment of time increases.

The problem of aircraft collisions in the air became apparent in the 50's. When the mass casualties began, ICAO (International Civil Aviation Organization) took a close look at the issue. The concept and then the international standards of the Airborne Collision Avoidance System (ACAS) were developed.

Here are some of the tragic examples of plane crashes that prompted the development and improvement of the collision avoidance system, as these crashes occurred due to misunderstandings between pilots and their air traffic controllers on the ground. These examples also show us how much people's lives depend on the professionalism and competence of workers in their field and the reliability of devices.

Due to the mistakes of pilots, according to experts, most of all aviation events occurred. A Boeing study found that 65% of all jet crashes in 1959-1986 were caused by the mistakes of aircraft crew members.

The cause of Northwest Airlines' MD-80 crash in August 1987, which killed 156 people, was that both pilots forgot to release the dampers and dampers. But this operation is an integral part of flight control!

Another example. On the night of 1972 in the area of Florida - Everglades (USA) crashed a wide-body fuselage L-1011 of eastern airlines, killing 100 people. The reason was that the indicator indicating the position of the chassis was not lit, and all crew members were reluctant to solve this problem.

The accident investigation showed that the light bulb had just burned out. A tape recording of the pilots' conversation, which was kept in a black box, shows that none of them noticed that the autopilot turned off, the plane began to descend gradually and eventually crashed into the ground.

It is not always the pilot's fault that he is to blame. Improper actions can be caused by many factors - from the inconvenient location of the cockpit to erroneous instructions from controllers.

Here are just some of the plane crashes caused by air traffic controllers: August 11, 1979 - a collision at an altitude of 8400 m of two Tu-134, which operated regular flights in the Dneprodzerzhinsk region. All passengers and crews (178 people) died.

October 18, 1981 - a Mi-8 helicopter and a Yak-40 flight collided near Zheleznogorsk airfield. All passengers and crews died.

October 11, 1984 - at the Omsk airport after landing Tu-154 collided with two gas stations. 170 people died. The crew survived by accident - jammed the door to the cabin.

Accidental causes also add their tragic share to the list of plane crashes. On July 2, 1991, a helicopter crashed near Tuva (USSR), the engine of which failed due to a thunderstorm, killing 13 people.

And now let's take a closer look at some of the most tragic plane crashes and possible causes of a collision. Here are the investigations that were conducted to shed light on the tragedy.

1.3.1. Examples of catastrophes and their investigations are presented in detail

1. Collision over the Grand Canyon.

The big plane crash that happened on Saturday, June 30, 1956. United Air Lines (UAL) Douglas DC-7 (flight UA718 Los Angeles-Chicago) and Lockheed L-1049-54-80 Super Constellation of Trans World Airlines (TWA) collided over the Grand Canyon (Arizona, USA) TWA002 Los Angeles Kansas City). All who were on both planes killed 128 people, 58 on the DC-7 (53 passengers and 5 crew members) and 70 on the L-1049 (64 passengers and 6 crew members).

It was the first plane crash in the history of civil aviation, killing more than 100 people. The crash received a wide resonance, as a result of which serious changes were made in the organization of air traffic control in the country.

2. Clash over New York

Collision over New York A major plane crash that occurred on the morning of Friday, December 16, 1960 in New York. Two United Air Lines Douglas DC-8-11 and Lockheed L-1049-54 Super Constellation Super World Airlines passengers landed in New York City, each at its own airport, when it collided in the air on intersecting routes and then crashed. on the city located below them. A total of 134 people became victims of the tragedy, including 6 on earth. At the time of the events, it was the largest aviation disaster in the world. This is the first event in the history of the Douglas DC-8.

In the media, the event is also known as the "Park Slope Plane Crash" due to the crash site of United.

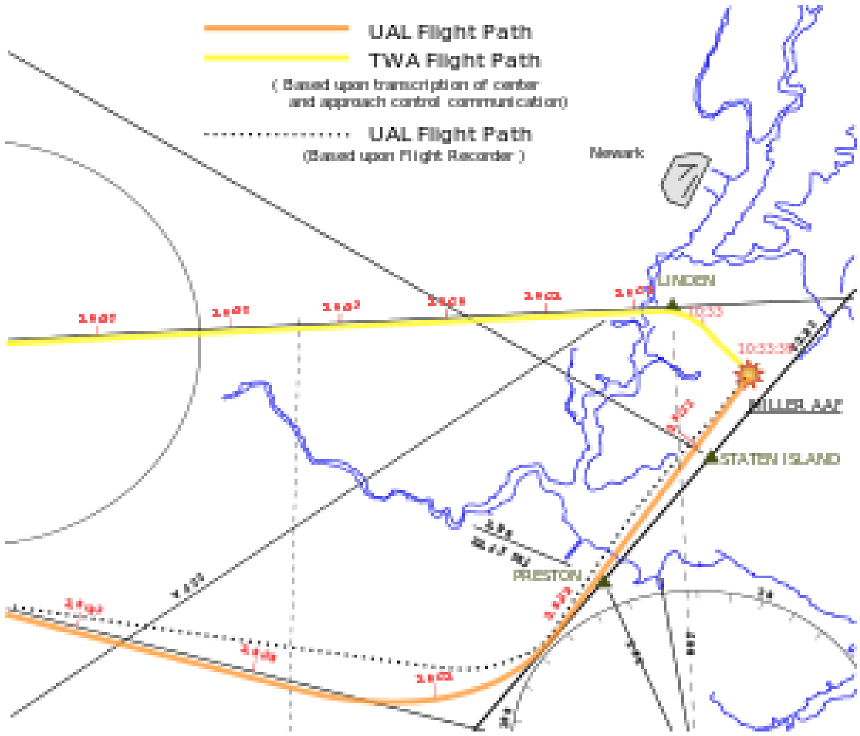

Fig. 1.4. Flight trajectories of UAL (orange) and TWA (yellow) aircraft. The dotted line shows the estimated actual trajectory of DC-8.

Thus, the total number of victims was 134, which made the plane crash over New York at the time the largest not only in the country, surpassing the event four years before the collision over the Grand Canyon, but also in the world, bypassing the crash of US military C-124 in Tatikawa (Japan). It is noteworthy that the crash over the Grand Canyon in 1956 had a number of tragic coincidences with the crash over New York: in a cloud "Douglas" (DC-7) of United Air Lines crashed into the "Super Constellation" of Trans World Airlines. The number of deaths directly on both aircraft in these two crashes is the same 128. Also at that time it was the biggest plane crash.

3. Collision over Lake Constance

The collision over Lake Constance was a major plane crash that occurred on Monday, July 1, 2002. In the skies over Germany near Uberlingen and Lake Constance, a passenger airliner Tu-154M of Bashkir Airlines (BAL) (flight BTC 2937 Moscow-Barcelona) and a cargo plane Boeing 757-200PF of DHL (flight DHX 611 Mukharru-Berga) collided. . All those who were on both planes killed 71 people 2 on a Boeing

757 (both pilots) and 69 on a Tu-154 (9 crew members and 60 passengers, including 52 children).

Flight BTC 2937 departed from Moscow at 18:48.

Flight DHX 611 departed from Bergamo at 21:06.

Despite the fact that both aircraft were over the territory of Germany, air traffic control in this place was carried out by a private Swiss company "Skyguide". Only two air traffic controllers worked night shifts at the control center in Zurich. Shortly before the collision, one of the dispatchers took a break; Only 34-year-old air traffic controller Peter Nielsen, who was forced to work at two terminals at the same time, and an assistant remained on duty.

Part of the control room equipment (including telephone communication) was disconnected, and Nielsen noticed too late that flights BTC 2937 and DHX 611, which were on the same echelon FL360 (10,950 meters), are dangerously close. Less than a minute before their courses had to cross, he tried to rectify the situation and gave the crew of Flight 2937 the command to descend.

The Tu-154 pilots had not yet seen the Boeing 757 approaching from the left, but were prepared to have to maneuver to disagree with it. Therefore, they began to decline immediately after receiving the dispatcher's command (in fact, even before it was completed). However, immediately after that, the airborne collision warning system (TCAS) signaled the need to gain altitude. At the same time, the pilots of flight 611 received a reduction signal from the same system.

One of the crew members of flight 2937 (co-pilot Itkul) drew the attention of others to the TCAS signal, but he was told that the dispatcher gave the command to go down. Because of this, no one confirmed the receipt of the command (although the plane was already down). Seconds later, Nielsen repeated the command, and this time it was immediately confirmed, but Nielsen erroneously reported the incorrect location of another aircraft, saying that he was to the right of the Tu-154. As the transcript of the flight recorders later showed, some of the pilots of Flight 2937 were misled by this message and may have decided that there was another plane invisible on the TCAS screen. Flight 2937 continued to descend following the instructions of the dispatcher, not TCAS. None of the pilots informed the dispatcher about the contradiction in the received teams.

At the same time, flight 611 was reduced by following the TCAS instructions. The pilots of Flight 611 informed Nielsen as soon as possible, but he did not hear these words because he was working at the second terminal, where another landing plane got in touch.

In the last seconds, the pilots of both planes saw each other and tried to prevent the collision, completely rejecting the rudders, but it did not help. At 21:35:32 BTC 2937 and DHX 611 collided almost at right angles at an altitude of 10,634 meters (echelon FL350). The vertical tail stabilizer Boeing 757 hit the fuselage of the Tu-154, cut it in two; falling, the Tu-154 crashed in the air into four pieces that fell to the ground near Uberlingen. The Boeing 757 lost its stabilizer due to the impact, due to which it completely lost control and at 21:37 also fell to the ground 7 kilometers from the Tu-154, losing both engines during the fall. All 71 people on board both planes (69 on flight 2937 and 2 on flight 611) died. Despite the fact that some wreckage of both liners fell into the yards of residential buildings, no one was killed or injured on the ground.

Deciphering the negotiations

21:34:42 TCAS TRAFFIC, TRAFFIC.

21:34:47 BTC 2937 dispatcher ... descends, flight echelon ... 350, hurry up, my board is crossing.

21:34:52 BTC 2937 We are declining.

21:34:54 DHX 611 (TCAS) DESCEND, DESCEND.

21:34:57 BTC 2937 (TCAS) CLIMB, CLIMB!

21:34:58 BTC 2937 Clyme, talk!

21:35:00 BTC 2937 He lowers us.

21:35:02 BTC 2937 dispatcher, descending, flight echelon 350, accelerated descent.

21:35:07 BTC 2937 Accelerate the decline to the echelon 350, BTC 2937.

21:35:12 Dispatcher Yes, we have a board, you two hours, now 360.

21:35:13 DHX 611 (TCAS) DESCEND, DESCEND.

21: 35: 19,3 DHX 611 611, TCAS-descend.

21:35:21 BTC 2937 (abuse), where is he?

21: 35: 23,5 BTC 2937 (TCAS) INCREASE CLIMB, INCREASE CLIMB!

21: 35: 27,3 BTC 2937 Clyme, he speaks!

21: 35: 29,8 DHX 611 (abuse).

21: 35: 31,8 BTC 2937 (abuse).

21:35:32 whack

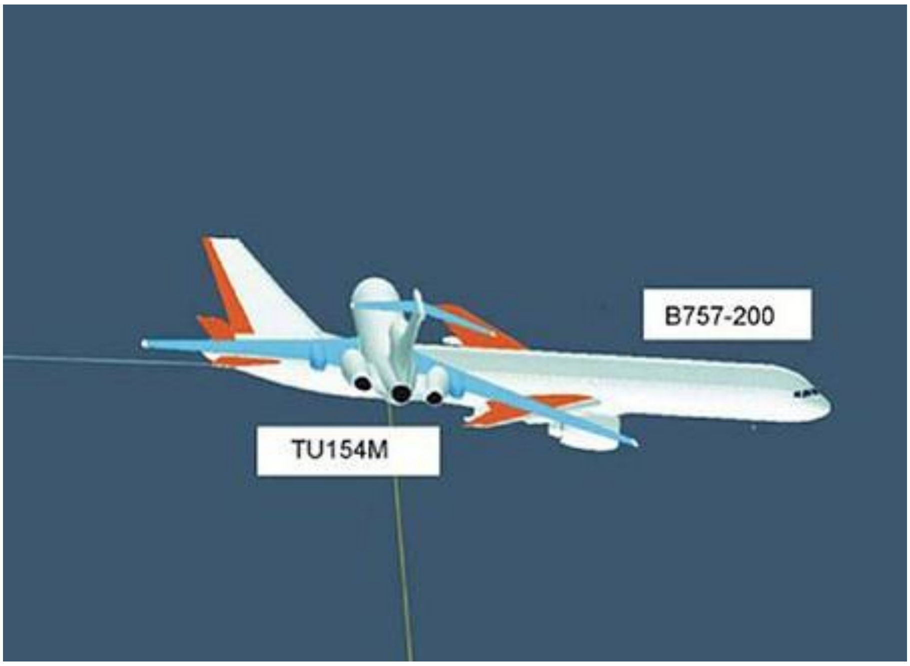

Fig. 1.5. Computer model of collision.

According to the report, the immediate causes of the collision were:

The air traffic controller could not ensure safe separation between the planes, the instruction to descend the crew of the Tu-154 was passed too late.

The Tu-154 crew, in accordance with the instructions of the air traffic control center, performed the descent and continued it, despite the TCAS instruction to gain altitude; a maneuver contrary to the TCAS-RA requirement was performed.

4. Disagreement over Suruga

Disagreement over Suruga Aviation incident involving two Japan Airlines planes that occurred on January 31, 2001 in the sky over the coast of Suruga Bay in Shizuoka Prefecture (Japan). The planes almost collided on ordinary courses.

Chronology of events

At 15:36 local time, B747-446D with registration number JA8904, which was performing domestic flight JAL 907 and flew to Nahu, took off from Tokyo International Airport. There were 16 crew members on board, led by 40-year-old Captain Makoto Watanabe and 411 passengers. Soon the plane took echelon 390 (39,000 feet or 11,700 meters). Meanwhile, DC-10-40D with registration number JA8546, flying international flight JAL 958 from South Korea's Kimhe Airport (Busan) to Narita, Japan, was flying at 370 (37,000 feet or 11,100 meters). On board were 13 crew members, led by Captain Tatsuyuki Akadzawa and 237 passengers.

The planes had to disperse at a safe interval of 2,000 feet (600 meters). Hideki Hatitani, a 26-year-old intern who has worked with a dozen other flights and seen the intersections of flights 907 and 958 on screen, commanded Flight 958 (DC-10) at the Tokyo Flight Control Center in Tokyozawa at 3:54 p.m. to descend to the echelon 350 (35,000 feet or 10,500 meters). However, confused, he called the wrong number 907 (B747). A little later, noticing that the 958 continues to fly at the same altitude, the intern gave the command to this flight on the right turn. But on board the 958th this command was not heard. The head of the intern, Yasuko Momii, realizing the danger of the situation, aired the command "957, start the rise", although no flight 957 at this time was not on the radar. Meanwhile, the TCAS system on board the B747 (flight 907) began to command the climb, while giving the command to the DC-10 pilots (flight 958) to descend. However, the Watanabe pilot ignored the TCAS commands and continued to follow the dispatcher's command to the descent. The Akadzawa pilot, acting on the command of the system, also began the descent. Thus, both planes now flew opposite each other at the same altitudes.

At 15:55:02, the crew of Flight 907, which was at an altitude of 36,200 feet (10,860 meters) at the time, was finally on the air. seconds he saw him flying across flight 958 and completely gave up the helm, directing the 747th sharply down and forcing him to prop up under the DC-10. The planes parted at a distance of less than 100 meters. Watanabe himself stated that the difference in height was only 35 feet (11 meters).

None of those on either plane were killed.

1.4. Conflict detection and resolution processes

Methods for maintaining demarcation between aircraft in the existing airspace system are based on improved routes and procedures for detecting crew warning of possible approach.

1.4.1. Automated air conflict detection

To begin with, you need to clearly define the conflict. Conflict is a situation between two or more aircraft that violates the minimum separation. In other words, the distance between the aircraft violates certain rules, which is considered undesirable. An example of such a criterion is the minimum horizontal distance - 10 km or at least 300 m of vertical distance. The result is a protected area or airspace where each aircraft is located, where other aircraft cannot fly. The protected area can be defined as a much smaller area (for example, a ball with a diameter of 100 m). In any case, the main functions of the conflict prevention system are similar, although the models and scope of prevention are different.

Ways to automate the detection and resolution of conflicts in the air are:

- information on the location of the aircraft;

- dynamic distribution model;

- restrictions on conflict detection;

- conflict resolution;

- Features of maneuvering and managing many conflicts (double and global).

Automated systems are used both in aircraft offices and on the ground to support decision-making, and as an airborne emergency conflict warning system. These systems use confidential information to prevent aircraft conflicts and warn pilots of the possibility of conflict and can provide commands and instructions for resolving conflicts. Relatively simple collision predictions have been and remain part of ATC automation for many years, and the BSPZ installed in the aircraft warns the crew of the risk of a collision (Figure 1.6).

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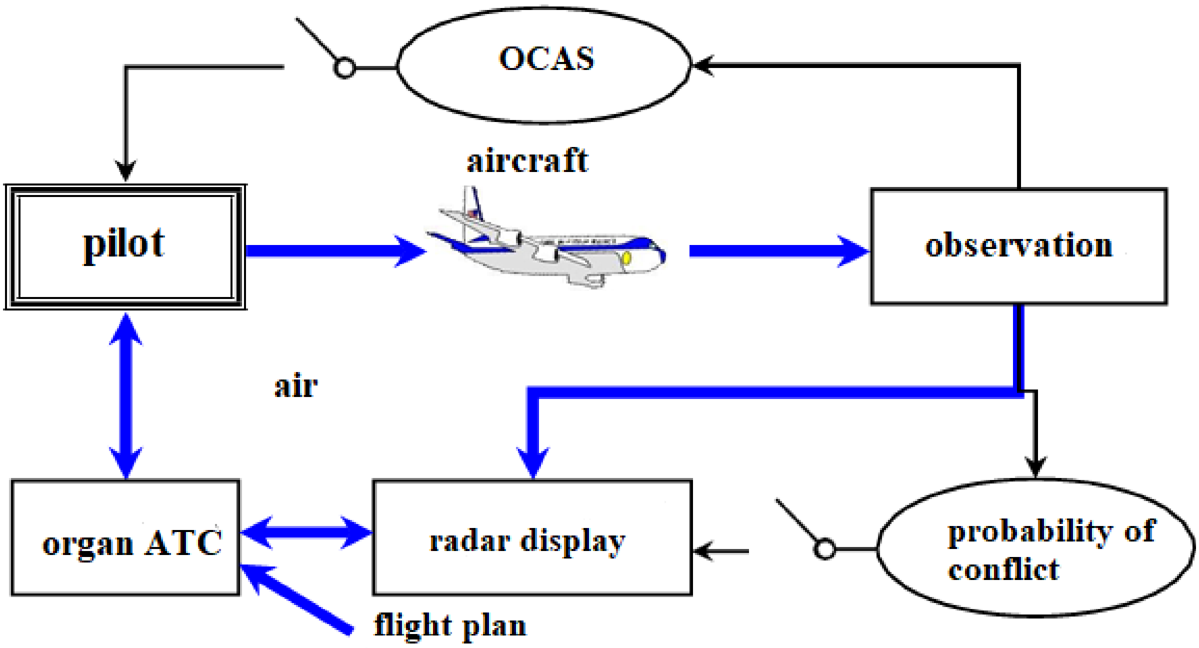


Fig. 1.6. Air and ground components of conflict detection and resolution (bold lines show nominal control directions, thin lines - automated control)

There is a growing interest in developing better automation and conflict resolution tools. These tools can be used in future technologies such as communication channels for current flight plan information, increased safety and the creation of new rules to improve airflow efficiency.

Improved systems and on-board conflict resolution are considered more of a strategic alternative. With increasing airspace occupancy, these types of devices need to be implemented to help operators with higher traffic volumes and increase flow efficiency.

1.4.2. Identification of potentially conflict situations

The purpose of a conflict detection and prevention system is to anticipate that a conflict may occur in the future, to alert the operator to a potential conflict, and in some cases to help resolve it. These three main processes can be organized in several stages or elements, as shown in Fig.1.7. Such systems also include systems to prevent approach to the ground.

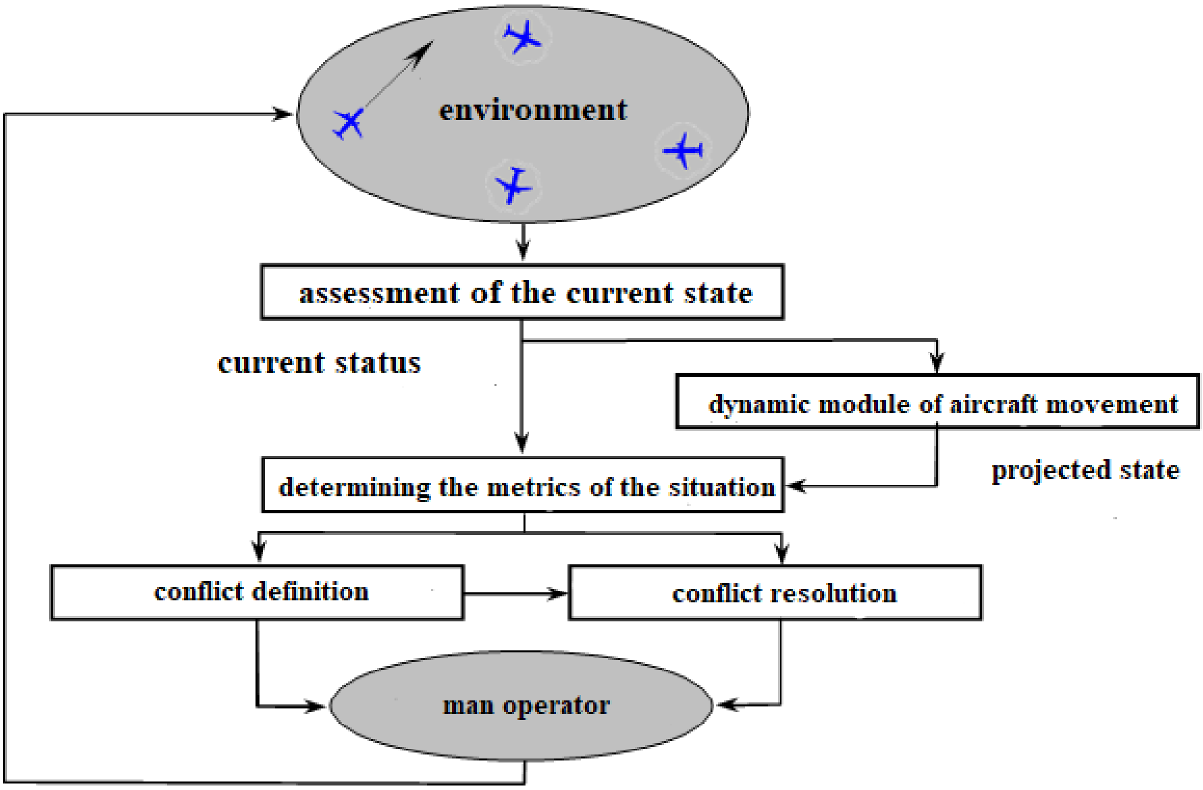


Fig. 1.7. Conflict detection and resolution processes

According to fig. 1.7. First of all, it is necessary to test the transport environment and collect and disseminate relevant information through sensors and communication equipment. These information states are an assessment of the current situation (eg location and speed of the aircraft). The dynamic trajectory model is designed to predict events in order to predict conflict. This design can be based solely on the current state of the data (eg, rectangular extrapolation of the current velocity vector) or on additional procedural information (flight plan). As in the current data, there is some uncertainty for calculating the future trajectory.

Current and forecast conditions data can be combined to provide initial values for air traffic management solutions. In some cases, the initial values include the minimum separation or the estimated time to the nearest point. Given that current and projected provisions can be calculated separately for each aircraft, the initial values for conflict detection require a certain combination between different aircraft.

Given the initial scale of the conflict, a separate solution is used to determine whether the situation is potentially conflicting or whether certain steps need to be taken to maintain separation. Not all planned conflicts require concrete action. For example, a conflict can be foreseen, but in the distant future it is unlikely, so it makes no sense to warn the air force and take any measures to resolve such a conflict.

The stage of solving the MSS is shown in Fig.1.7. as a separate unit requires specific calculations, flight route decision-making models and resolution criteria, which may differ from the features of MSS detection.

Each stage of conflict detection and resolution can be automated or processed using certain procedures. For example, visual flight rules place the responsibility for preventing a collision on the pilot, who must analyze the environment (detect conflict) and, if threatened, take action to resolve the conflict. According to the flight regulations on the devices, air traffic controllers perform the separation between aircraft using radar control (RLU).

If conflicts are not resolved directly by the supervisor or pilot, conflict resolution information is automatically provided by the Collision Warning and Prevention System (TCAS).

Determining the MSS can be seen as the process of determining the time to perform an action and deciding how the MSS should be performed. However, it is not always clear how the definition of MSS differs from its decision.

1.4.3. Classification of approaches to conflict detection

All models for conflict detection and resolution can be systematized using the six basic design parameters described in more detail below, although there are other differences between the models (not listed here). However, keep in mind that a template that seems simple according to the proposed classification scheme can be much more complex than all the obviously more complex models.

Simply put, these two models can be identical to the six features in question, and at the same time completely different in use and improvement.

Reproduction of location. Conflict detection and resolution can be as reliable as the future location of the aircraft. There are three main methods of extrapolation:

- nominal (Fig. 1.8, a) ;.

- the worst case (Fig. 1.8, b);

- probabilities (Fig. 1.8, c).

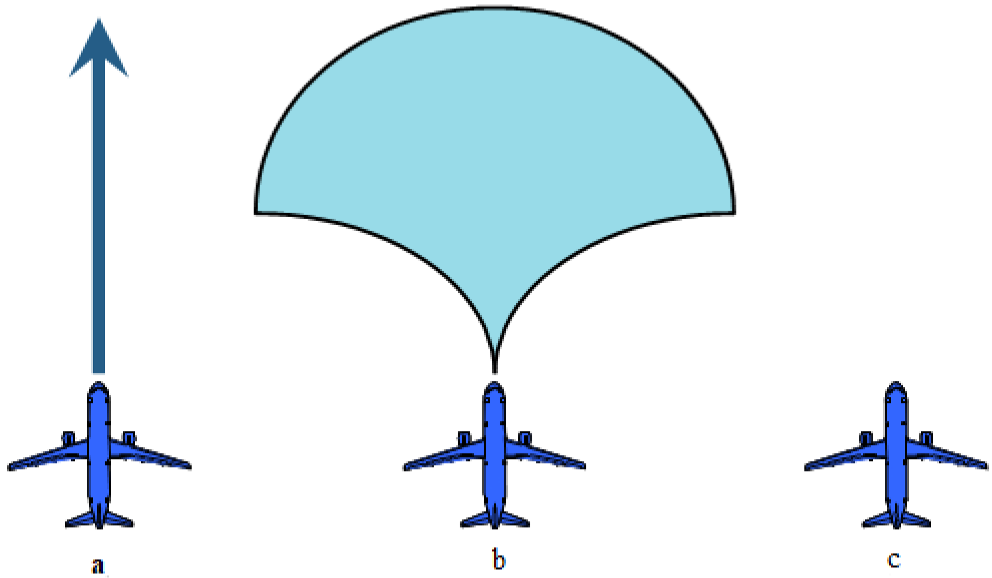


Fig. 1.8. Extrapolation methods:

a - nominal; b - the worst case; c - probability

In the nominal method, the current location is taken in one trajectory without uncertainty analysis. An example of this is the extrapolation of the location of the aircraft with its current vector. The method of nominal design is simple and it is better to place the aircraft later, based on current location information. In cases where it is very easy to predict the trajectory of the aircraft, the nominal trajectory model can be absolutely accurate. The nominal projection does not take into account situations where the aircraft may not behave properly - a factor that is particularly important for the detection of long-term conflicts. Typically, this uncertainty is regulated by entering a security buffer, a minimum distance or time to the point of convergence from which the conflict is determined.

The worst case scenario means that the aircraft can perform various maneuvers. If one of these operations causes a conflict, that conflict can be foreseen. The worst case scenario is conservative, as conflict is evident in every unlikely event.

According to the probability method, variables are modeled to describe possible options for the future trajectory of the aircraft.

The potential approach allows to find a balance between the application of a single trajectory model and the range of maneuvers in the worst case. The advantage of the probability method is that the decision can be made based on the main probability of conflict. At the same time, you can assess the safety and the level of false alarms. This is also the most likely method in the ATS.

The nominal model and the worst model are subgroups of probability trajectories. The nominal trajectory corresponds to the case where the aircraft follows the given trajectory (possibly) with probability 1. The worst case model corresponds to the case when the aircraft will fly on any trajectory with the same probability.

1.4.4. Stages of conflict resolution

Planes of location. Indicate whether the position information used in the model includes only the horizontal or vertical plane, or both. Most models cover three-dimensional space or a horizontal plane. Some models can be easily expanded to cover the extra space.

Conflict detection. Some models do not clearly distinguish between perceived conflicts and non-conflict situations. Non-conflict detection models can be largely based on conflict resolution methods. Conflict detection models can use very simple criteria to determine the existence of a conflict (regardless of whether there is a conflict or not), or may require complex logical steps (whether there is a conflict or not, the distance between the aircraft during the conflict).

Conflict resolution. Shows the method by which the conflict can be resolved. It is advisable to use the recommended maneuvers, which allow the dispatcher / crew to train to perform them automatically. This can reduce the response time when a conflict arises. Although installed maneuvers are less effective than maneuvers that are installed in real time. In many conflicts, it is necessary to adapt maneuvers to avoid conflict situations to take into account unexpected phenomena in the environment. To reduce the sharpness of the maneuver, the conflict should be resolved as simply as possible.

The following maneuvers are possible to avoid conflict situations:

- turn;

- vertical maneuvers;

- change of speed.

In some cases, maneuvers can be combined. In general, providing more maneuvering measurements allows you to resolve conflict more successfully. However, performing such a maneuver puts a strain on the aircraft crew and requires more control by the dispatcher, which increases the workload.

Multiplicative conflict. The multiplicative conflict shows how the model works in a situation with more than two aircraft. The problem can be solved in two ways: pairwise, in which multiple potential conflicts are resolved sequentially in pairs, and global, in which the full situation is checked simultaneously.

In real air traffic, it is necessary for the air traffic controller to detect and resolve conflicts involving more than two aircraft. In pairs, if one solution to a conflict causes a new conflict, the first solution may change until the conflict is resolved. More than one FP is considering a global solution. For example, consider the situation shown in Fig. 1.9.

According to fig. 1.9, and the aircraft on the left identifies the threat at some pre-set time before the collision and tries to gain height or fall. No decision is permissible as it leads to a conflict with another aircraft. According to fig. 1.9, in order to safely resolve the conflict, the Global Resolution considers all three aircraft threats simultaneously and determines that the ascent or descent maneuver must begin earlier than the baseline threshold time.

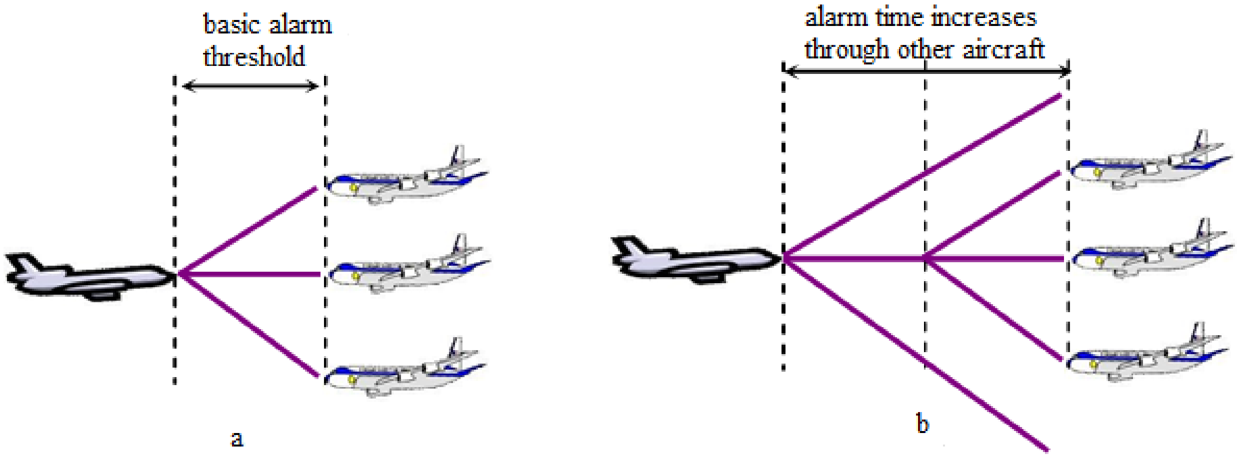


Fig. 1.9. Conflict detection and resolution of a large number of aircraft:

a - method of solving in pairs; b - global solution

It is important to analyze the regulations used in the conflict detection and resolution system, as these norms show the means of monitoring the environment. Some methods of conflict detection and resolution use simplified provisions that reduce the need for a sensor but increase the confidence in resolving the conflict. Information related to the aircraft, in addition to the current position and speed vector (for example, the planned flight plan), will be valuable for identifying strategic conflicts. This information can be used to better design the future trajectory of the aircraft and, therefore, to make better decisions.

Coordinating the resolution of conflicts between aircraft has two benefits. First, the required amount of maneuver for a particular aircraft can be reduced when two aircraft maneuver together, compared to the case where only one aircraft maneuvers.

Second, coordination helps to ensure that the aircraft is not moving in a direction that may continue or exacerbate the problem.

CONCLUSIONS TO SECTION 1

The characteristics of modern aircraft have a fairly wide range, ie speeds range from supersonic to almost zero in helicopters, the speed of descent and ascent ranges from several meters to several tens of meters per minute, flights range from weather-independent to those that can only perform visually. With the increase in the number of users of a certain airspace, the organization of air traffic becomes more complicated.

The increase in catastrophes and deaths in recent years has been caused by a sharp increase in air traffic around the world. Here is another paradox of technological progress: flights are becoming safer, but in absolute numbers the death toll is rising.

Despite the fact that one of the tasks of air traffic control is to prevent air incidents, the most dangerous approaches are the fault of the traffic police.

One of the most important reasons for this convergence is that the air traffic controller makes responsible decisions to predict and determine conflicts between aircraft on the basis of incomplete information. This is complicated by the fact that the decision is made in a short time. At the same time, mistakes are possible.

In the practice of air traffic control in accordance with the standards and recommendations of the International Civil Aviation Organization, the procedure of issuing control permits is used, which consists in performing various calculations to determine the conflict-free trajectory of aircraft. in the traffic control zone.

Therefore, when dealing with technological air traffic control operations, the issues of resolving potential conflict situations should be carefully considered. Thus, it is necessary to determine: types of potentially conflict situations; conflict situation and method of resolving potentially conflict situations, as well as consideration of problems of aircraft collision prevention on average in terms of automation of collision prevention processes in air traffic services.

It cannot be said that an inexperienced or more experienced dispatcher is the most likely participant in a flight separation violation.

The novice dispatcher is not careful enough in a difficult situation. However, the experience of a dispatcher who has not experienced potentially conflict situations for many hours of monotonous work may become complacent and not perform radar control properly.

One of the most important specific functions of the dispatcher is to forecast the air situation. To predict the development of the air situation, it is first necessary to classify the situation in the air situation and potentially conflict situations during air traffic control.

CHAPTER 2

TCAS AS A WAY TO RESOLVE AIR CONFLICTS. HISTORY OF CREATION AND IMPROVEMENT. PRACTICAL APPLICATION IN AVIATION

2.1 Collision avoidance system

After many years of detailed analysis, development and assessment of flights, the Federal Aviation Administration (FAA), other civil aviation authorities (CAA) and the aviation industry have developed the Collision Prevention and Control System (TCAS) to reduce the risk of aircraft collisions. In the international arena, this system is known as the Air Collision Avoidance System or ACAS.

TCAS is a family of on-board devices that operate independently of the ground-based air traffic control (GCM) system and provide collision avoidance protection for a wide range of aircraft types. All TCAS systems provide some degree of collision warning and reflection. TCAS I and II differ primarily in their ability to warn.

TCAS I provides air traffic (PR) guidelines to assist the pilot in the visual acquisition of intruder aircraft. TCAS I is intended for use in the United States for turbine-powered aircraft, passenger aircraft with more than 10 and less than 31 seats. TCAS I is also installed on a number of aircraft and helicopters of general aviation with fixed wings.

TCAS II provides PR and permit recommendations (RA), ie recommended evacuation maneuvers, in the vertical dimension to either increase or maintain the existing vertical separation between aircraft. TCAS II is authorized by the United States for commercial aircraft, including regional airlines with more than 30 seats or a maximum takeoff weight of more than 33,000 pounds. Although not mandatory for general aviation, many turbine-powered general aviation aircraft and some helicopters are also equipped with TCAS II.

The TCAS concept uses the same radar beacon transponders installed on aircraft to operate ATC ground radars. The level of protection provided by TCAS equipment depends on the type of transponder carrying the target aircraft. It should be noted that TCAS does not provide protection against aircraft that do not have a valid transponder.

2.1.1. History of the system

The collision of two airliners over the Grand Canyon in 1956 prompted both airlines and aviation authorities to begin developing an effective collision avoidance system that could act as a last resort in the event of a failure of the ATC's branch services. In the late 1950s and early 1960s, collision avoidance efforts focused on passive and non-cooperating systems. These concepts proved impractical. One of the main operational challenges that could not be overcome with these designs was the need for non-conflict, additional avoidance maneuvers that require high communication integrity between the aircraft involved in the conflict.

One of the most important collision avoidance concepts attributed to Dr. John C. Morrell of Bendix was the use of TAU, which is the range of inclination between aircraft divided by closing speed or flight speed. This concept is based on time, not distance, to the nearest approach point during the meeting.

In the late 1960s and early 1970s, several manufacturers developed aircraft collision avoidance systems based on interrogator / transponder and time / frequency methods. Although these systems functioned properly during the phased testing of aircraft, the FAA and the airline jointly concluded that during normal airline operations, they would generate high levels of unnecessary alarms in tight terminals. This problem would undermine the confidence in the system by flight crews. In addition, each target aircraft had to be equipped with the same equipment to protect the equipped aircraft.

The Lighthouse Collision Prevention System (BCAS) was developed in the mid-1970s. BCAS used response data from air traffic control radar transponders (RSUPRs) to determine the range and altitude of the attacker. At that time, RSUP transponders were installed on all aircraft and military aircraft and in a large number of general aviation aircraft. Thus, any aircraft equipped with BCAS could detect and protect against most other aircraft in the air without imposing additional equipment requirements on those other aircraft. In addition, the discrete address communication methods used in the Mode S transponders then being developed allowed the two conflicting BCAS aircraft to perform coordinated evacuation maneuvers with a high degree of reliability. In 1978, a light aircraft collision with an airliner over San Diego intensified the FAA's efforts to complete the development of an effective collision avoidance system.

2.1.2. Development of TCAS II

In 1981, the FAA decided to develop and implement TCAS, using the basic design of BCAS for interrogation and tracking with some additional features. Like BCAS, TCAS is designed to operate independently of aircraft navigation equipment and ground systems used to provide air traffic control (ATS) services. TCAS interviews ICAO-compliant transponders of all nearby aircraft and, based on the responses received, monitors the range of inclination, altitude (when included in the response) and the relative direction of the movement. From several consecutive responses, TCAS calculates the time to reach the NTN (nearest approach point) with the offender by dividing the range by the closing speed. This time value is the main parameter for sending alerts. If transponder responses from a neighboring aircraft include their altitude, TCAS also calculates the time to reach the total altitude. TCAS can issue two types of warnings:

• Air Traffic (PR) consultations to assist the pilot in visually searching for an intruder aircraft and to prepare the pilot for a potential RA;

• Resolution Consultations (RR) to recommend maneuvers that will either increase or maintain the existing vertical separation from the attack aircraft. When a malicious aircraft is also equipped with TCAS II, both TCASs coordinate their RAs via the Mode S data link to ensure the selection of additional RAs.

TCAS II was designed to operate at a density of up to 0.3 aircraft per square nautical mile (nmi), ie 24 aircraft within a radius of 5 nm, which was the highest traffic density predicted for the next 20 years.

The development of TCAS II collision avoidance algorithms has included the completion of millions of computer simulations to optimize the protection provided by the system while minimizing the frequency of unacceptable or unpleasant recommendations. In addition to these computer simulations, early versions of collision avoidance algorithms were evaluated using pilot simulations in cyclic simulations and during the operation of prototype equipment in FAA aircraft across the NAS.

Extensive safety studies have also been conducted to assess the safety improvements that could be expected with the commissioning of TCAS. These safety studies are constantly updated as collision avoidance algorithms improve. Safety studies have shown that TCAS II will solve almost all critical collisions near the middle of the air involving aircraft equipped with TCAS. However, TCAS cannot handle all situations. In particular, it depends on the accuracy of the reported altitude of the endangered aircraft and on the expectation that the endangered aircraft will not maneuver in such a way as to defeat TCAS RA. Achieving adequate separation also depends on the pilot's response, as expected by CAS logic. A safety study has also shown that TCAS II will cause some critical mid-air collisions, but overall the number of mid-air collisions with TCAS is less than ten percent of what could have occurred without TCAS.

Extensive research has also been conducted to assess the interaction between TCAS and ATS. Analysis of PBX radar data showed that in 90% of cases, the vertical shift required to resolve RA was less than 300 feet. Based on these studies, it was concluded that the ability to respond to TCAS RA, as a result of which the aircraft violates the protected airspace for another aircraft, is remote.

Initial assessments during operation

To ensure that TCAS operates properly in the planned work environment, several operational evaluations of the system have been conducted. These assessments have enabled TCAS pilots and controllers responsible for providing separation services for TCAS-equipped aircraft to have a direct impact on the final design of the system and performance requirements.

2.1.3. Initial operational assessment of TCAS

was conducted by Piedmont in 1982. Using a prototype TCAS II division developed by Dalmo Victor, Piedmont flew approximately 900 hours in scheduled revenue service mode, recording TCAS performance data. These recorded data were analyzed to assess the frequency and suitability of PR and RA. During this assessment, TCAS displays were not visible to pilots, and aviation observers flew with the aircraft to monitor the system and provide technical and operational comments on its design.

In 1987, Piedmont flew about 1,200 hours on an upgraded version of Dalmo Victor equipment. During this assessment, pilots could see TCAS displays, and pilots were allowed to use the information provided to maneuver the aircraft in response to RA. This setup included a dedicated TCAS data logger to quantify TCAS performance. In addition, pilots and observers filled out questionnaires after each PR and RA so that the usefulness of the system for flight crews could be assessed.

This assessment also provided the basis for the development of avionics certification criteria for production equipment, approved pilot training guidelines, provided a rationale for improving TCAS algorithms and displays, and approved pilot equipment use procedures.

Following the successful completion of the second evaluation in Piedmont, the FAA initiated the Restricted Establishment Program (LIP). According to LIP, Bendix-King and Honeywell have built and tested commercial high-quality pre-production equipment for TCAS II that meets the TCAS II Minimum Performance Standards (MOPS). Engineering flight tests of this equipment were performed on both aircraft and FAA aircraft. Using data collected during these flight tests, along with data collected during factory and ground tests, equipment from both manufacturers was certified with a limited supplemental type-certificate (STC) for use in the commercial revenue service.

Bendix-King was operated by United Airlines on B737-200 and DC8-73 aircraft. Northwestern Airlines operated Honeywell equipment on two MD-80 aircraft. More than 2,000 hours of operational experience have been gained with United aircraft and approximately 2,500 hours of experience with northwestern installations.

The experience gained from these operational assessments has led to further improvements in TCAS II logic, improved testing procedures and refined production equipment certification procedures. The most important information obtained from the operational assessments was the almost unanimous conclusion that TCAS II is safe, operational and ready for wider implementation.

2.1.4. Implementation of version 6.0 / 6.04a

In 1986, a DC-9 collision with a private jet over Serritos, California, led to a congressional mandate (Public Law 100-223) to equip certain categories of American and foreign TCAS II aircraft for flight operations in U.S. airspace. . Under Public Law 100-223, the FAA issued a rule in 1989 requiring all passenger aircraft carrying more than 30 seats in US airspace to be equipped with TCAS II by the end of 1991. This law was later amended by Public Law 101 -236 to extend the period of full equipment until the end of 1993. Based on the successful results of the ongoing assessments, RTCA published TCAS II MOPS version 6.0 (DO-185) in September 1989 and version 6.0 units. in the US Revenue Service since June 1990.

As part of the assigned implementation, a broad operational assessment of TCAS, known as the TCAS Transition Program (TTP), was launched in late 1991. Together with TTP in the United States, EUROCONTROL conducted an extensive evaluation of TCAS's activities in Europe and the Japan Civil Aviation Bureau (JCAB) conducted similar evaluations of the effectiveness of TCAS II in Japan and the surrounding airspace. Other countries also conducted operational assessments as TCAS use began to increase.

The proposed improvements to the TCAS II system led to the development and release of TCAS II MOPS version 6.04a (DO-185), published by the RTCA in May 1993. The main purpose of this modification was to reduce troubles. alerts that occurred at low altitudes and during level maneuvers, and corrected problems in the logic of height intersection.

2.1.5. Implementation of version 7.0

The results of the TTP evaluation of version 6.04a showed that the actual vertical shift caused by the RA reaction often exceeded 300 feet, and TCAS had an adverse effect on the controllers and the ATC system. This has led to the development of version 7.0 and numerous changes and improvements in collision avoidance algorithms, audio messages, RA displays and pilot training programs to: (1) reduce the number of issued RA, and (2) minimize height offsets in response to RA. Also included are horizontal distance filtering to reduce unnecessary RA, more sophisticated multi-threat logic, changes to reduce annoying recurring PR on RVSM routes in slow-closing situations, changes to improve surveillance logic, and reversal of TCAS-TCAS meetings.

The MOPS for version 7.0 (DO-185A) was approved in December 1997, and version 7.0 units began to be installed in the United States on a voluntary basis in late 1999.

2.1.6. Implementation of version 7.1

Based on a detailed analysis of TCAS II version 7.0 since 2000, conducted mainly in Europe, additional changes have been identified to improve the RA logic. In response to the almost broadcast that took place in Japan in 2001, and the broadcast that took place in Uberlingen, Germany, near the Swiss border in July 2002, changes were made to further shift the RA in order to address certain vertical pursue geometry. It should be noted that in each of these cases, the pilots maneuvered in front of the reflected RA. Apart from accidents in Japan and Uberlingen, a review of other operational experience has shown that pilots occasionally maneuver in the opposite direction to that specified in the "Vertical Speed Adjustment, Adjustment" (AVSA) RA. To reduce the risk of pilots increasing their vertical speed in response to RA AVSA, all RA AVSAs were replaced by RA Level Off, Level Off (LOLO) RA.

Extensive confirmation of these changes was carried out by Europeans and the United States, which resulted in the publication of version 7.1 of the MOPS (DO-185B) in June 2008. Units 7.1 are expected to be operational by 2010-2011. It should be noted that versions 6.04a and 7.0 are expected to work in the near future where permitted.

2.2. Basic equipment and operating modes of TCAS

2.2.1. TCAS equipment complete set

Computer unit that calculates the development options and determines the issued commands, two transceivers installed above and below the fuselage (one of them directed (top), the other omnidirectional), separate antennas for S-transponders) and a display indicator in the cab.

This display indicator provides information about the movement of nearby aircraft, as well as visual commands to prevent collisions (RA).

There are several types of indicators and options for its installation. It is often combined with existing displays (eg on-board locator, vertical speed indicator) or installed separately if the cab has previously been equipped with mechanical pointers.

The TCAS II display essentially combines three devices: a vertical speed indicator, an air surveillance device (aircraft tracking labels) and a command device that issues recommendation commands for action.

However, TCAS does not have its own receiver and the system uses the so-called receivers of the air traffic control system (ATC), in English. PBX (Air Traffic Control) or transponders.

A transponder is a transceiver that sends its radio signal in response to a received one. In English it will be transponder (from transmitter-responder - transmitter-responder). That is, these devices use the principle of secondary radar.

The essence of this principle is that in contrast to the primary radar, where the locator determines only the azimuth and range to the irradiated object, the secondary locator in the corresponding signal also receives identification data and parameters of the object in space, as well as some other additional information.

The following receivers are installed on all civil aircraft. With their help, the dispatcher identifies the aircraft and has the ability to monitor its movement.

2.2.2. Transponder operating modes

Depending on their design capabilities and conditions of use, transponders can operate in different modes, and according to the mode in the signal they emit, may contain different information.

The first and simplest - mode A. Each aircraft Traffic Control Service (simply the dispatcher) is assigned its four-digit digital identification code (squawk code), in the vernacular "squawk". If the code is not issued by the dispatcher, one of the existing standard ones is used, for example 1200 - US flight code or 7000 - European flight code.

The pilot enters this code into the system via the transponder control panel in his cockpit. There are, by the way, so-called special codes. For example, 7500 - hijacking, 7700 - Emergency on board. When such codes are displayed on the dispatcher's radar screen, alerts for dispatchers are automatically triggered.

So in mode A in the corresponding signal of the transponder is encoded only squeak. That is, the aircraft is identified, there is a mark on the locator screen, but no other data (including flight altitude).

The minimum information is not good, so to correct the situation, mode C was developed. Here, along with the code in the signal there is information about the altitude. Transponders using A + C mode are called RBS or ATC RBS. Such receivers in the United States, for example, are mandatory for flights above 3,000 m (10,000 feet) and within a radius of 30 miles around major airport hubs (airports).

The next mode, the most advanced (also called intelligent), is the mode S (selekt). A transponder operating in this mode responds selectively when asked for it, while those operating in A / C mode respond to any locator radiation signal. This allows you to reduce the overall clutter of the air with transponder responses (there are many of them in space, the interactive map shows this well).

In addition, the S-mode response contains additional information such as speed, altitude, board number (call sign) and may also have GPS coordinates.

In Europe, S-mode transponders are of two types: ELS (Elementary Surveillance) and EHS (Enhanced Surveillance). They differ in the amount of information published. EHS is much more informative.

Thus, the transponder is like a "window to the world" for the TCAS system. However, this window must be opened accordingly. That is, in order for TCAS to properly assess the situation and make the necessary recommendations, it must receive sufficient information about the approach of aircraft. This means that they must be equipped with transponders with at least C mode (preferably S). Moreover, TCAS does not conduct requests in mode A and therefore it does not see aircraft equipped with transponders only with mode A.

2.2.3. The basic principle of operation

TCAS can monitor aircraft in both transponder mode C and mode S. S-mode receivers emit self-generating signals, so-called squitters, every second. This signal contains the sender's address. According to him, TKAS addresses the request and determines the range, course angle (azimuth) and altitude of the controlled aircraft.

The data obtained is sent to a computing unit (computer), which, combining information about all aircraft, calculates the degree of danger of each controlled aircraft in relation to the board on which the TCAS system is installed. It is formed as if a virtual three-dimensional map, which is protected, around our aircraft.

A third-party aircraft that enters a protected area is called an intruder or conflicting aircraft.

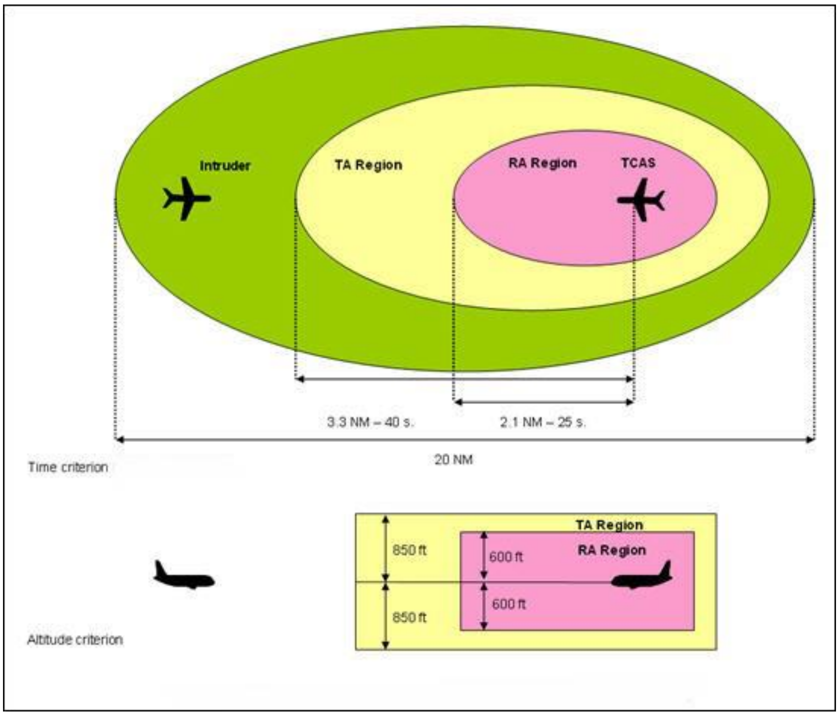


Fig. 2.4. Protected areas in distance, height and time. Time in seconds, distance in nautical miles.

TCAS can detect aircraft up to 40 miles away.

Unlike TCAS I, TCAS II provides not only passive information about the air situation, but also direct recommendations for resolving conflicts. The system can simultaneously monitor up to 30 aircraft and issue conflict resolution commands for three at a time.

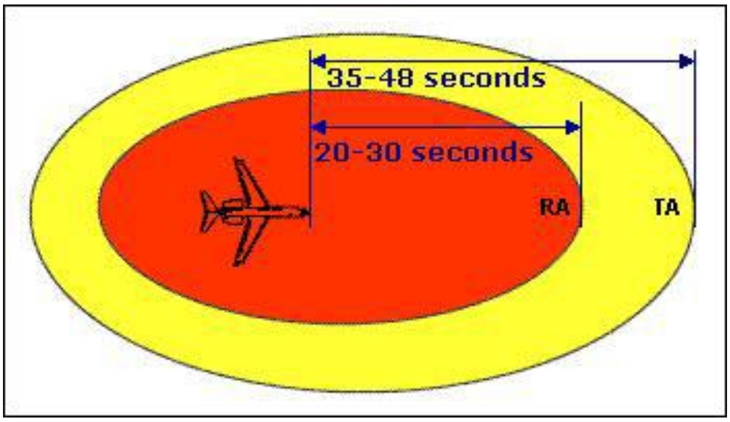
Information from the TCAS II system is displayed visually on the indicator display in the cockpit, as well as in the audio version through the speaker and headphones SPU (aircraft intercom).

Issued commands can be divided into advisory, designated TA (Traffic Advisory) and commands for immediate immediate action to prevent a collision RA (Resolution Advisory). YES is a warning signal. It means that the offending aircraft has entered the protected area, it is necessary to increase attention and caution and be ready to issue an RA command. No active action on the TA team is expected.

If the computer of the system, analyzing the situation, detects the possibility of a dangerous approach or collision, it, in accordance with its program, determines the necessary maneuver to ensure safe vertical separation of aircraft. Simply put, to ensure their safe divergence in height.

Moreover, when choosing a maneuver, it is possible to take into account the characteristics of aircraft (their speed, in particular) and their proximity to the ground.

Fig. 2.5. Time to reach the CPA point.



The TCAS II system determines the actions of the aircraft to prevent a collision only in the vertical plane.

To solve the problem of collision avoidance, the concept of the Closest Point of Approach (CPA) was introduced. So automation in developing a recommended algorithm for the crew takes into account not the distance to the CPA, and the time to achieve it.

It usually remains constant. For zone TA - 35-48 sec., For zone RA - 20-30 sec. That is, the crew, regardless of the speed of approach to the offending aircraft always has some time to perform the necessary actions.

CONCLUSION TO SECTION 2

The problem of aircraft collisions in the air became apparent in the 50's. When the mass casualties began, ICAO (International Civil Aviation Organization) took a close look at the issue. The concept and then the international standards of the Airborne Collision Avoidance System (ACAS) were developed.

Of all the developments according to this concept, the most widespread is the TCAS (Traffic alert and Collision Avoidance System). Literary translation from English reads as follows: Airborne collision warning system (in English transcription the abbreviation is pronounced "tikas").

This system (in its latest versions and modifications) inspects the airspace around the aircraft, detects other aircraft, analyzes the information received, gives it to the crew, and in case of collision, warns pilots and gives the necessary recommendations for immediate action.

Currently, the latest version of the system is TCAS II. Previously, there was a so-called passive surveillance system, which did not actively survey the airspace, but used signals from other aircraft, issued on request from the ground or from other aircraft systems.

Then came the TCAS I system, which analyzed the air situation within a radius of 30 miles and gave the crew approximate information about the movement of other aircraft (altitude and direction of flight). This system could issue signal TA (Traffic Advisory), ie a warning of the imminent passage of another aircraft.

However, only TCAS II is currently fully compliant with ACAS standards. It is currently installed on most commercial aircraft. It is run by Rockwell Collins, Honeywell and ACSS.

The TCAS II system itself currently has three modifications: the first - 6.0.4; the second 7.0 and the third 7.1. The first modification became inconvenient to use after the introduction in European airspace (since January 2002, and in Russia since November 2011) of the reduced minimum vertical separation of aircraft (RVSM).

It has been reduced from 600 m to 300 m and TCAS version 2-6.0.4 has potential problems due to the fact that the flight of aircraft relative to each other with a minimum separation interval can cause a large number of unwanted, long-term and non-carrier correct information of commands, both tA and RA. This takes the crew's attention and complicates piloting.

Version 7.0 is devoid of this and issues in a similar situation 40-50 times fewer TA commands and half as many RA commands. This version currently fully complies with ACAS standards.

However, there is the next version - 7.1. It eliminates some significant shortcomings of the previous version 7.0. The so-called command reversal logic has been changed. The urgency of this change became quite apparent after the famous catastrophe over Lake Constance on July 1, 2002, when the TU-154M (Bashkir Airlines) and the Boeing-757 (DHL) collided.

CHAPTER 3

RESEARCH OF METHODS FOR RESOLVING POTENTIALLY CONFLICT SITUATIONS AND DEVELOPMENT OF A UNIVERSAL ALGORITHM

3.1. Methods of resolving potentially conflict situations

3.1.1. Intersection of level on accompanying tracks

One PC travels in horizontal flight, and the other PC - with a variable profile Give a command to reduce (gain height) to the near adjacent level in the opposite direction and at the time of his occupation:

1. A safe transverse interval at the time of crossing the occupied level is provided, there is no PKS, then allow further reduction (gaining height) (Fig. 3.1).

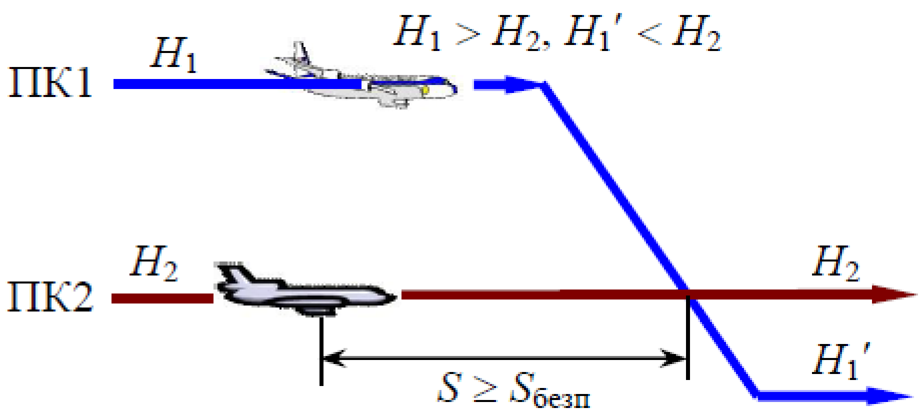


Fig. 3.1. Safe interval provided at the time of crossing

2. Safe transverse interval at the time of crossing the occupied level is not provided (Fig. 3.2), then in the process of reduction (gaining height) requires:

- turn the slower PC to the right (left) and after ensuring a safe side interval give the command to further reduce (gain height) to a faster PC.

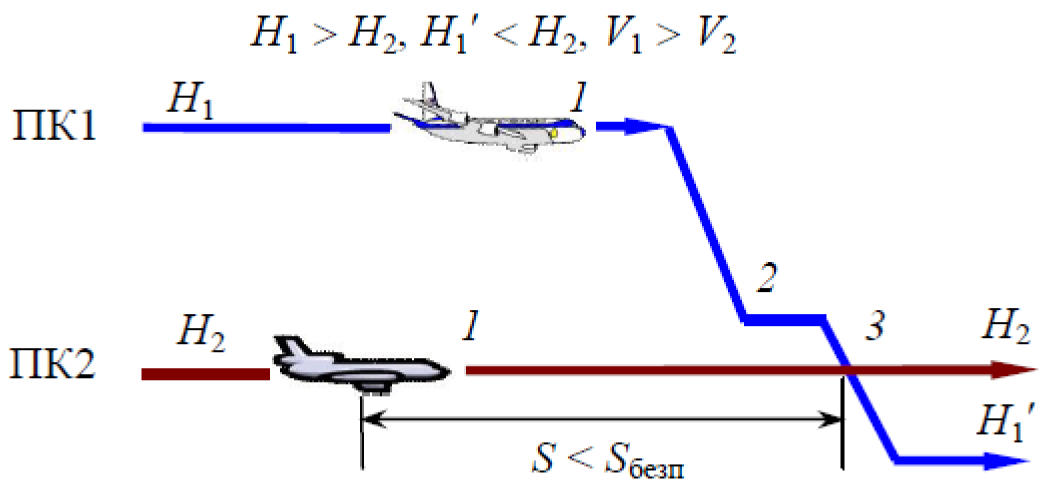


Fig. 3.2. Safe interval not provided at the time of crossing

After the PC differs in height, bring the PC at a lower speed to the line of the specified path (LSH) (Fig. 3.3);

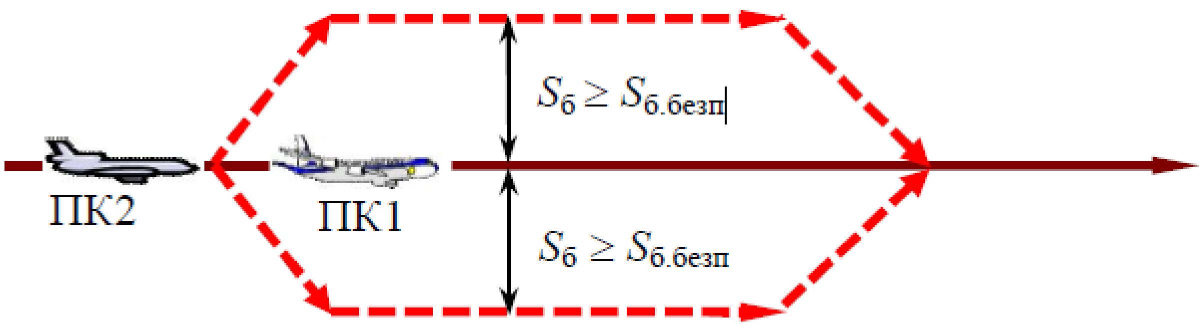


Fig. 3.3. Creating a side interval

- increase the speed of one PC and decrease the speed of the other, if permitted by the Flight Manual (FLE), to create a safe transverse interval. After providing the interval, give the command for further reduction (gaining height) (Fig. 3.4).

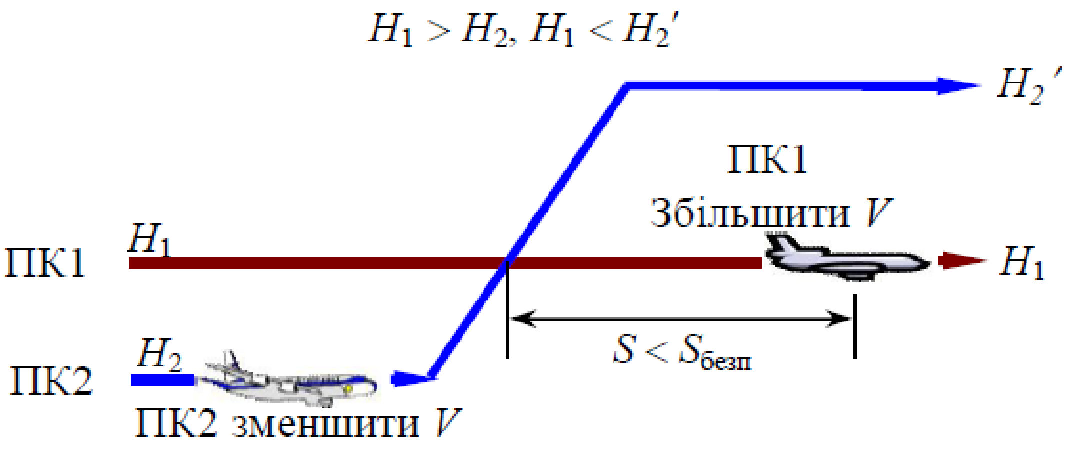


Fig. 3.4. Change PC speeds

3.1.2. Two PCs go in the same direction in the mode of gaining height

1. The cruising level and vertical speed of the first PC is greater than the second PC; in this case PKS does not arise (fig. 3.5).

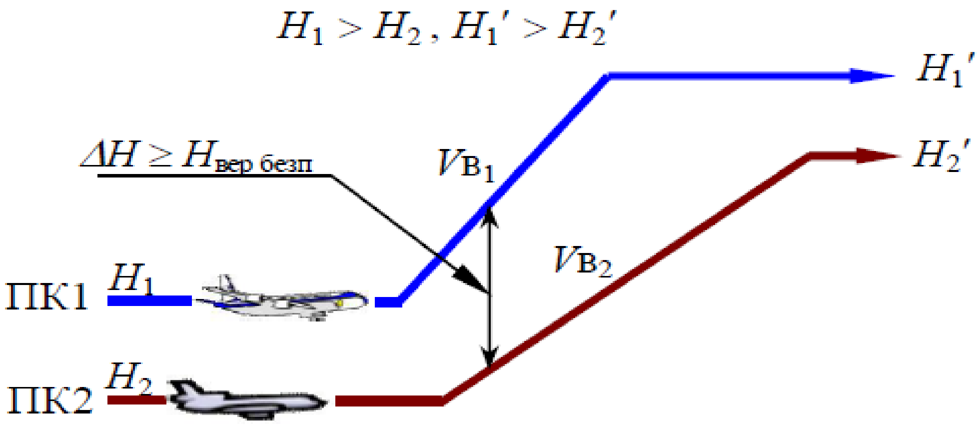


Fig. 3.5. Safe interval provided at the time of crossing

2. The cruising level of the first PC is higher, but the vertical speed is lower than the second PC. In this case, it is possible for the second PC to catch up with the first PC in height, if:

- the transverse interval at the time of crossing the occupied level is provided - there is no PKS (Fig. 3.6);

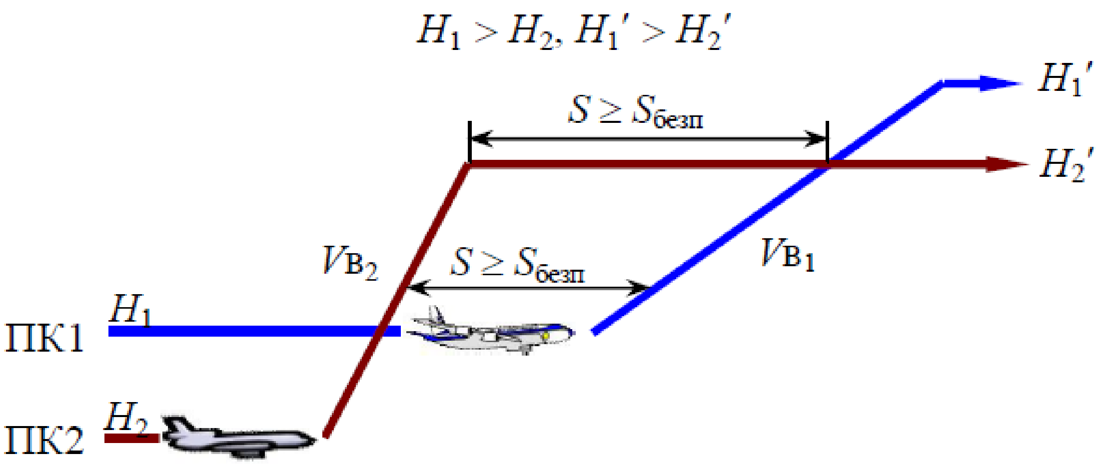


Fig. 3.6. Safe interval provided at the time of crossing

- the transverse interval at the time of crossing the occupied level is not provided. In this case, you need to limit the vertical speed of the second PC so that it is equal to or less than the first PC (Fig. 3.7).

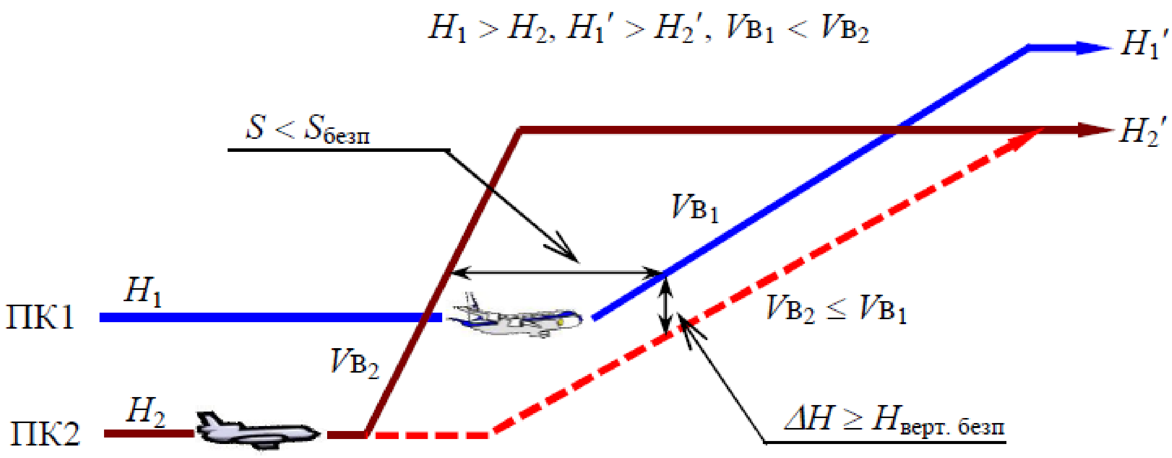


Fig. 3.7. Vertical speed adjustment

3. The cruising level and vertical speed of the second PC is greater than the first PC, then:

a) in the case of providing a transverse interval at the time of crossing the occupied level of flight PKS does not occur (Fig. 3.8);

$$H_1 > H_2,\ H_1' < H_2',\ V\text{в}_1 < V\text{в}_2$$

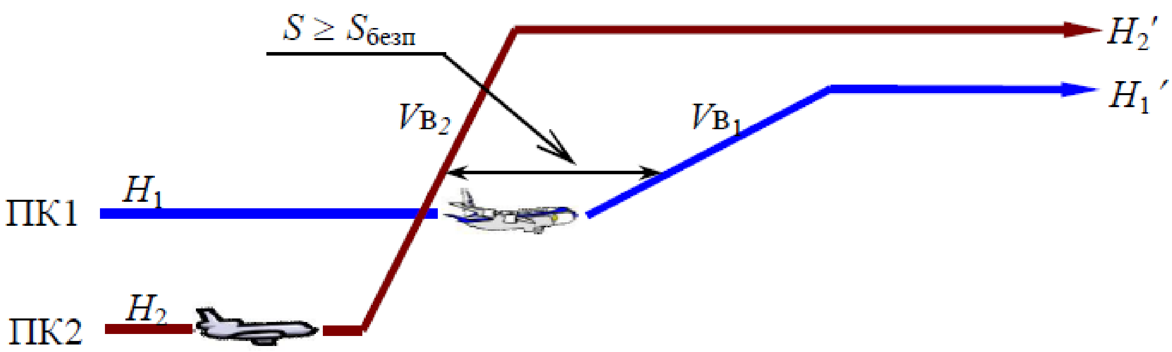


Fig. 3.8. Safe interval provided at the time of crossing

b) in case of failure to provide the transverse interval at the time of crossing the occupied flight level requires:

- allow the second PC to gain a flight level lower than the level set by the first PC, with a vertical speed not greater than the first PC (Fig. 3.9);

$$H_1 > H_2,\ H_1' < H_2',\ V_1 < V_2,\ V\text{в}_1 < V\text{в}_2$$

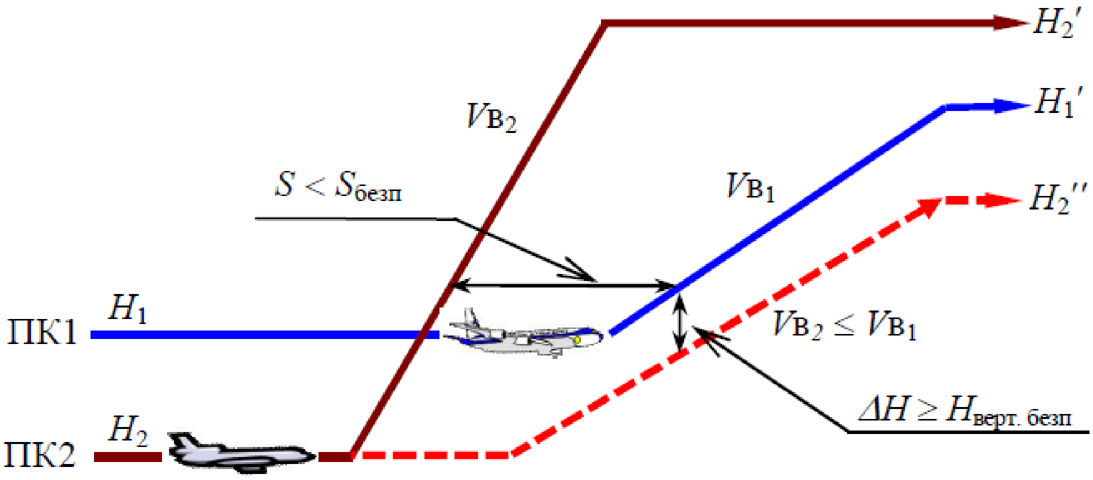


Fig. 3.9. Changing cruise flight levels

- in the process of gaining the specified flight levels, a safe transverse interval was formed. In this case, allow the second PC to continue to gain height;

- in the process of gaining the specified levels did not create a safe transverse interval. In this case, if the CLE allows, increase the speed of the faster PC and reduce the speed of the lower speed PC. When the safe interval between PCs is reached, allow the second PC to gain height;

- if the change of speeds is impossible or does not lead to an increase in the interval between PCs, then in the process of gaining the specified levels you need to create a side interval and allow you to continue to gain height PC. After the difference of the PC in height to bring the PC at a lower speed on the LSH (Fig. 3.9).

4. The cruising levels of the first and second PCs are the same if:

a) the transverse interval at the time of crossing the occupied flight level is provided and the speed of the first PC is greater than or equal to the speed of the second PC; There is no PKS (Fig. 3.10);

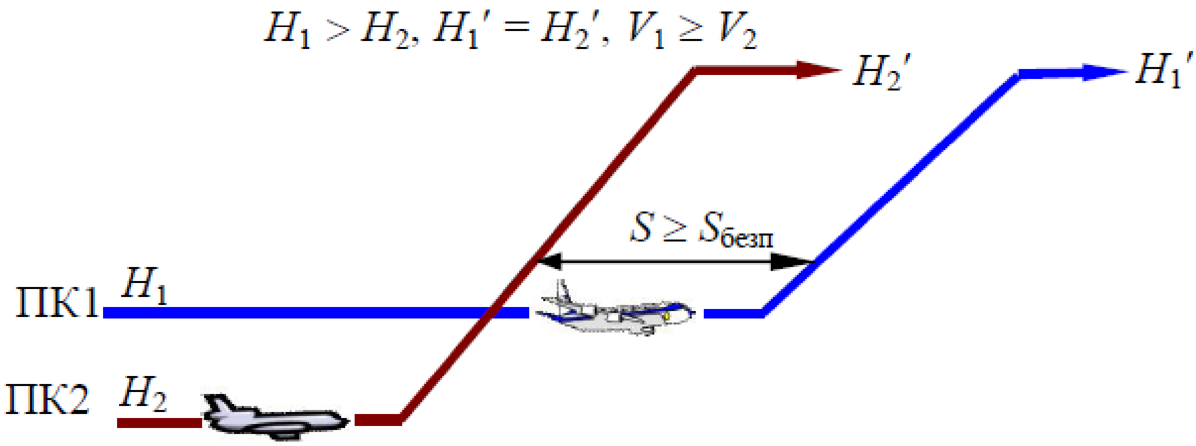


Fig. 3.10. Safe interval provided at the time of crossing

b) the transverse interval at the time of crossing the occupied flight level is provided and the speed of the first PC is less than the speed of the second PC, then it is possible for the second PC to catch up with the first PC. In this case, you can dilute the PC in several ways:

- increase the speed of the first PC and reduce the speed of the second PC, if the CLE allows, and allow both PCs to gain cruising flight levels (Fig. 3.11);

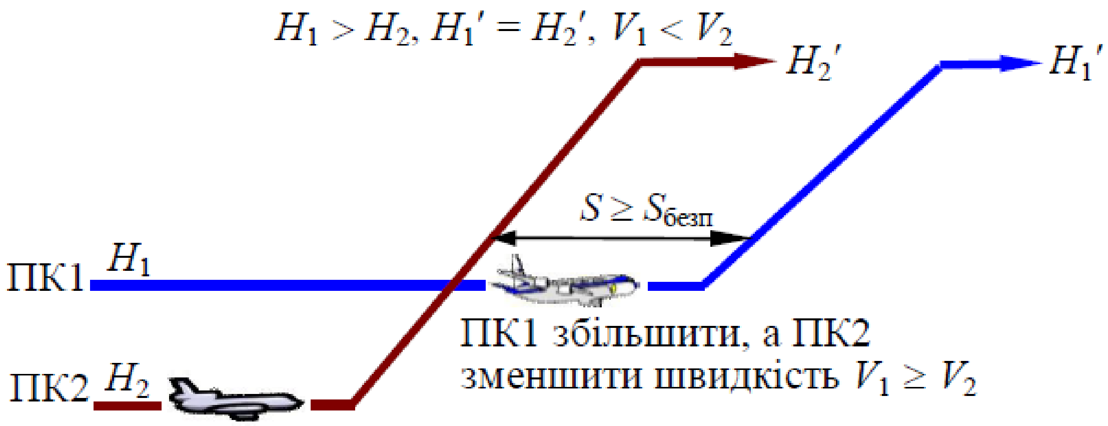


Fig. 3.11. Adjust the horizontal speeds of the PC

- KLE does not allow to change the speed, then one of the PCs will gain a cruising level of flight, and the other PC - the level in the associated direction - lower or higher than the cruising (Fig. 3.12);

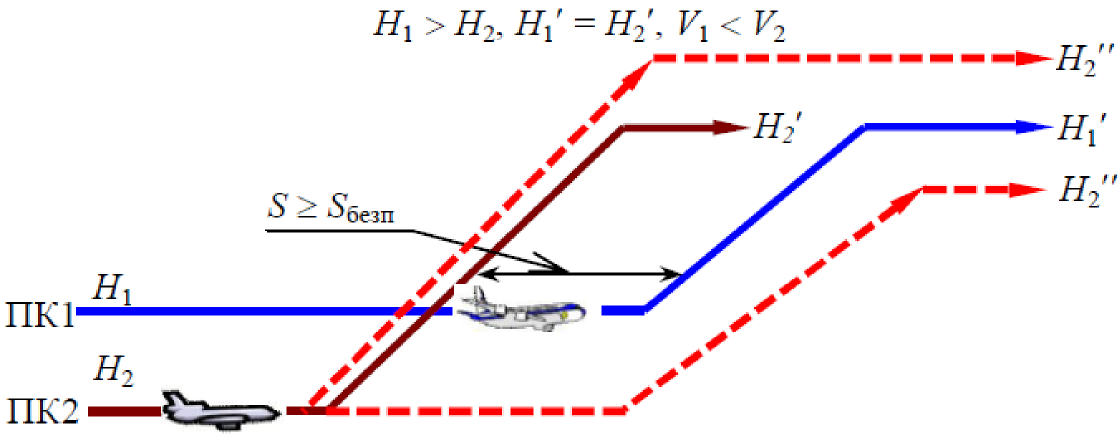


Fig. 3.12. Changing PC cruising levels

c) a safe transverse interval at the time of crossing the occupied flight level is not provided and the speed of the first PC is greater than or equal to the speed of the second PC (Fig. 3.13), then:

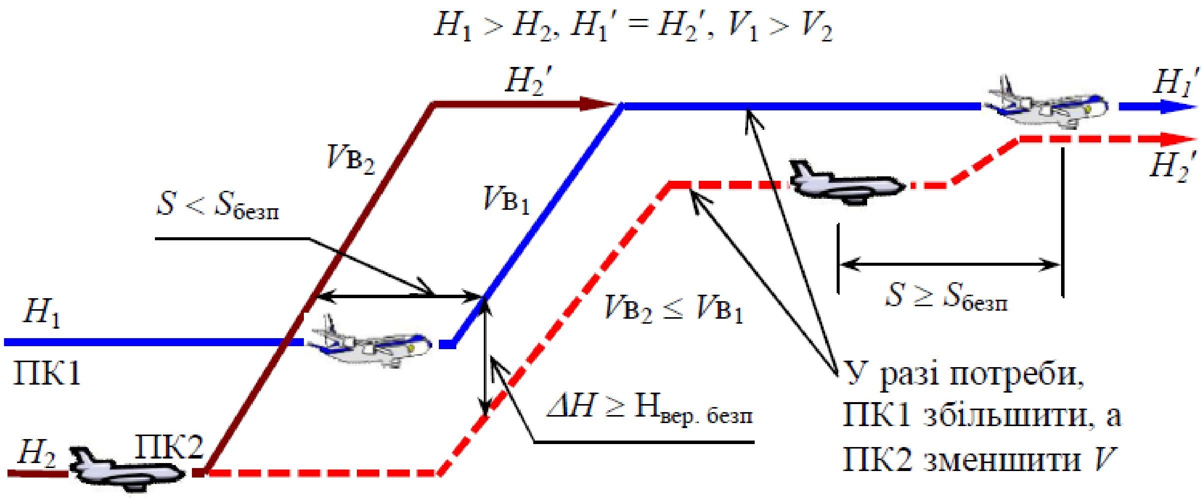


Fig. 3.13. Creating a safe interval

- the first PC is gaining a cruising level, or a level that should be on the verge of ATC transmission, the second PC is gaining a level lower than the specified first PC with a vertical speed not exceeding the speed of the first PC;

- after reaching the set flight levels and creating a safe transverse interval, allow the second PC to continue to gain a cruising level or a level that should be occupied on the border of the transfer of ATC;

- at the moment of ignition of the set levels of flight the safe cross-section interval is not provided, then the first PC increases, and the second PC decreases speed if the CLE allows. After reaching a safe transverse interval between PCs, allow the second PC to gain height;

- change of speeds is impossible or does not lead to an increase in the interval between the PC, then the second PC will go to the adjacent lower level of flight in the same direction;

d) a safe transverse interval at the time of crossing the occupied flight level is not provided and the speed of the first PC is less than the speed of the second PC. Then it is possible for the second PC to catch up with the first PC, in which case you can dilute the PC in several ways:

- the first PC is gaining a cruising level, and the second - a level lower or higher than the cruising level in the associated direction (Fig. 3.14).

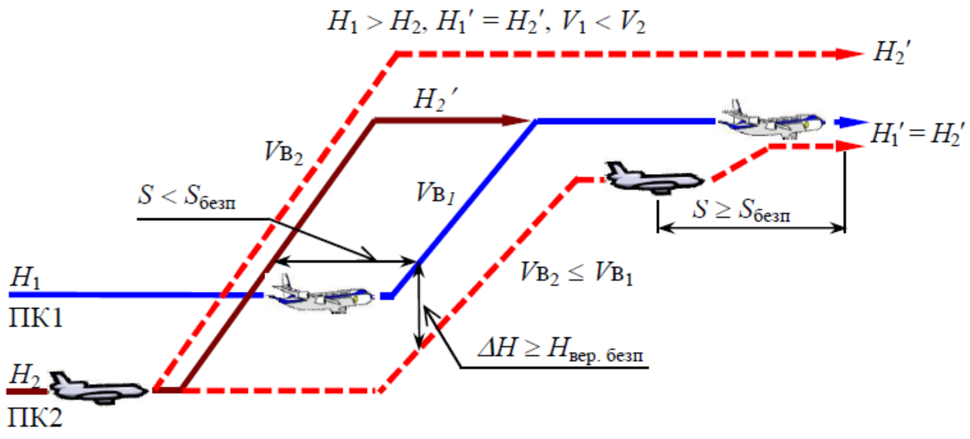


Fig. 3.14. Changing cruise flight levels

If the second commander of the PC decides to gain a level higher than the cruising, you need to create a side interval. After the difference of the PC in height to display the first PC on the LZSH (Fig. 3.3);

- the first PC will gain cruising level, and the second PC will gain and continue to move on the adjacent lower level in the opposite direction until the first PC overtakes and a transverse interval is created. Then the second PC can be allowed to further gain height. If necessary, in the process of gaining height, the first PC to reduce, and the second PC to increase the speed, if allowed by KLE (Fig. 3.14).

3.1.3. Two PCs go in one direction and go down

1. A safe transverse interval at the time of crossing the occupied flight level is provided and the speed of the first PC is greater than or equal to the speed of the second PC, then there is no PKS (Fig. 3.15).

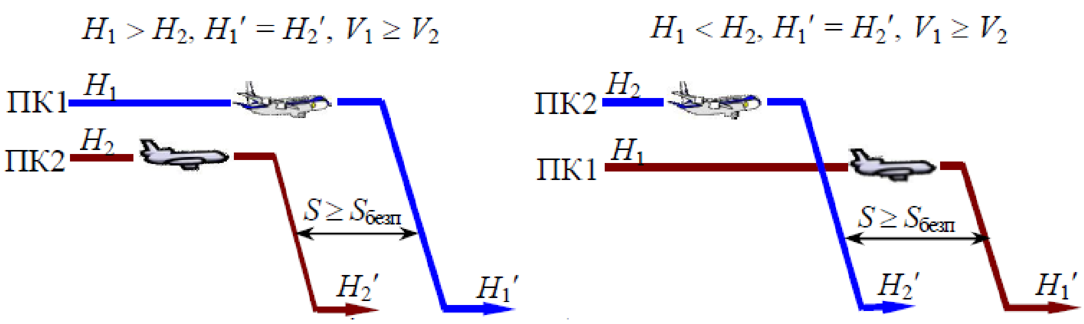


Fig. 3.15. Safe interval provided at the time of crossing

2. A safe transverse interval at the time of crossing the occupied level is provided and the speed of the first PC is less than the speed of the second PC. In this case, it is possible for the second PC to catch up with the first PC, then, without waiting for the reduction of the safe transverse interval:

- give the second PC a command to reduce to a level lower than that which will be given to the first PC (Fig. 3.16);

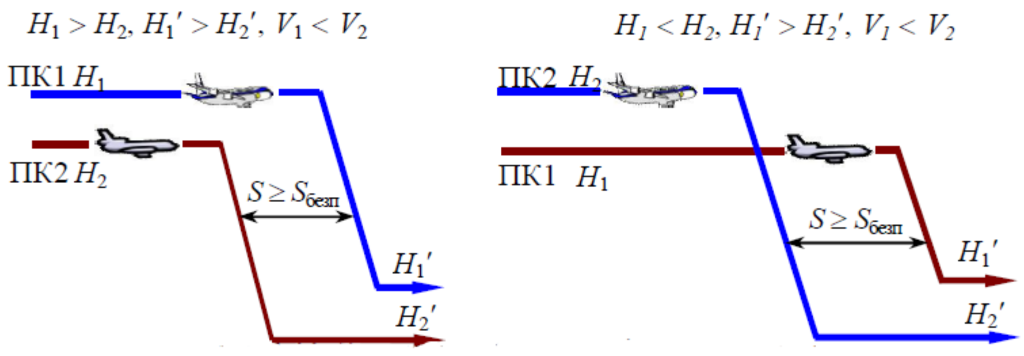


Fig. 3.16. Lower the PC to different levels of flight

- create a safe lateral interval. After the difference of the PC in height to bring the first PC to LZSH (see Fig. 3.3).

3. Safe transverse interval at the time of crossing the occupied level is not provided, then:

- give a command to lower the volume of the PC that moves lower, and the second PC will be reduced to the level of flight in the accompanying direction above. If necessary, you can limit the vertical speed of the second PC (Fig. 3.17);

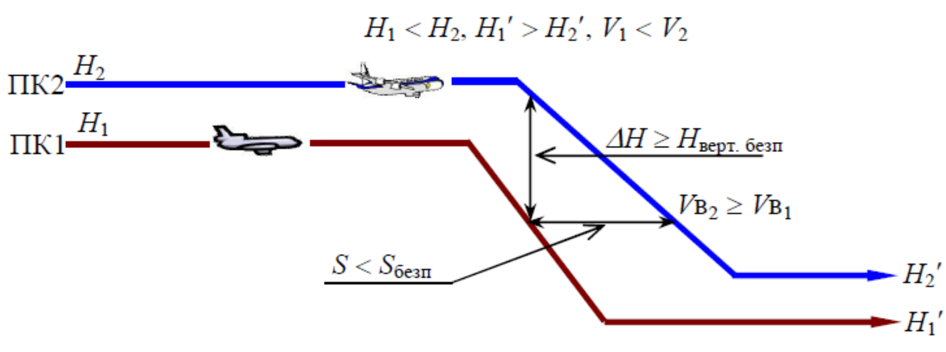


Fig. 3.17. Safe interval not provided at the time of crossing

- create a safe lateral interval (see Fig. 3.3). After its creation, give a command to lower the second PC to a level in the accompanying direction, lower than the level set by the first.

3.1.4. Intersection of the level on oncoming tracks

One PC travels in horizontal flight, and the other PC - with a variable profile

Give a command to decrease (gain height) to the nearest adjacent counter level and after reaching this level:

a) safe intervals (transverse and lateral) at the time of crossing the occupied level are provided, there is no PKS. Allow further reduction (gaining height) (Fig. 3.18);

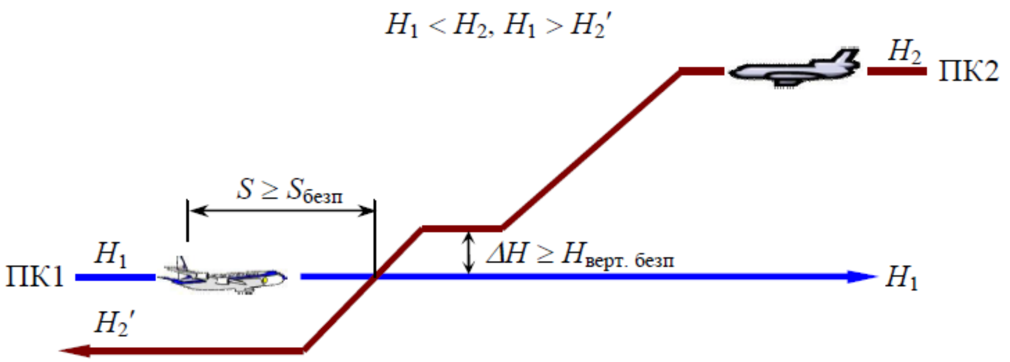


Fig. 3.18. Safe interval provided at the time of crossing

b) safe intervals (transverse and lateral) at the time of crossing the occupied level are not provided, then reduce (gain) height will be allowed in the future after the divergence of the PC (Fig. 3.19).

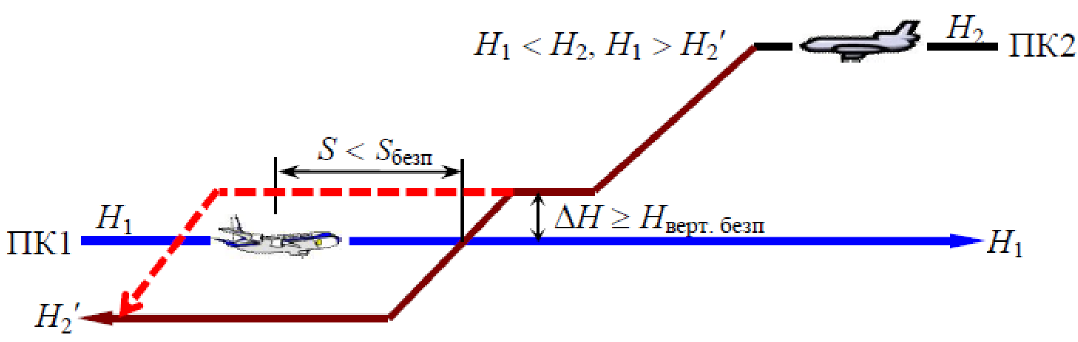


Fig. 3.19. Decrease PC after divergence

The first PC goes down, and the second PC - in the mode of gaining height

Give a command to lower and gain height to the nearest adjacent counter levels and when reaching the specified levels:

a) safe intervals (transverse and lateral) at the time of crossing the occupied level are provided, there is no PKS. Allow to further decrease and gain the height of t the PC (Fig.3.20);

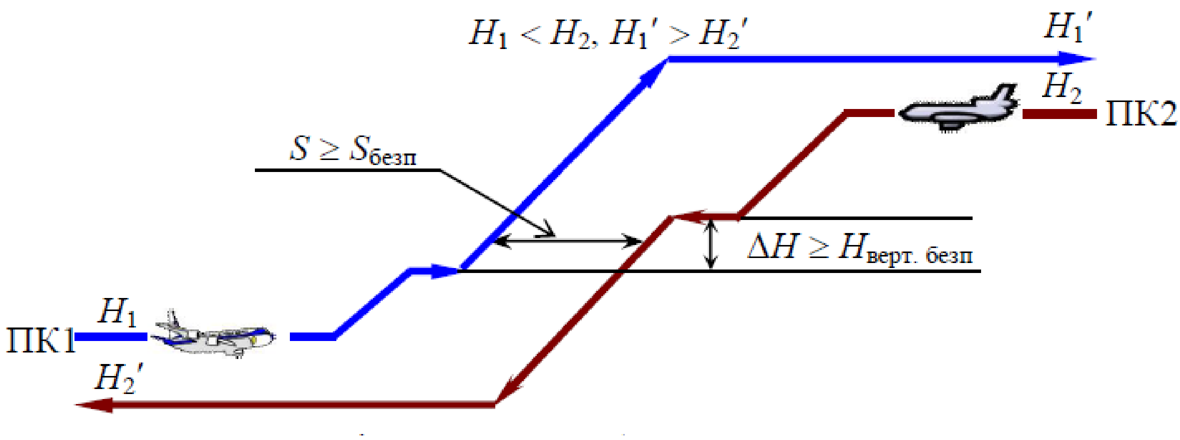


Fig. 3.20. Safe interval provided at the time of crossing

b) safe intervals (transverse and lateral) at the time of crossing the occupied level are not provided, then further reduction and increase in height will be allowed after the divergence of the PC (Fig. 3.21).

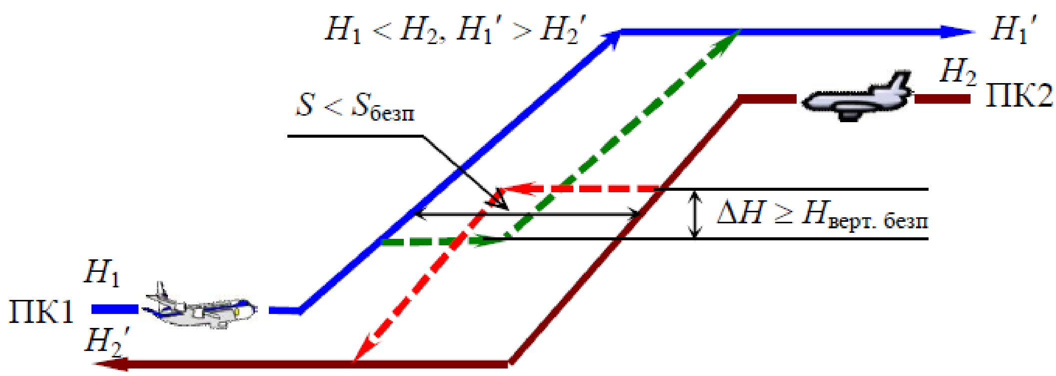


Fig. 3.21. Decrease PC after divergence

3.1.5. Intersection of tracks

1. The transverse interval at the time of crossing the occupied level is provided, there is no PKS (Fig. 3.22).

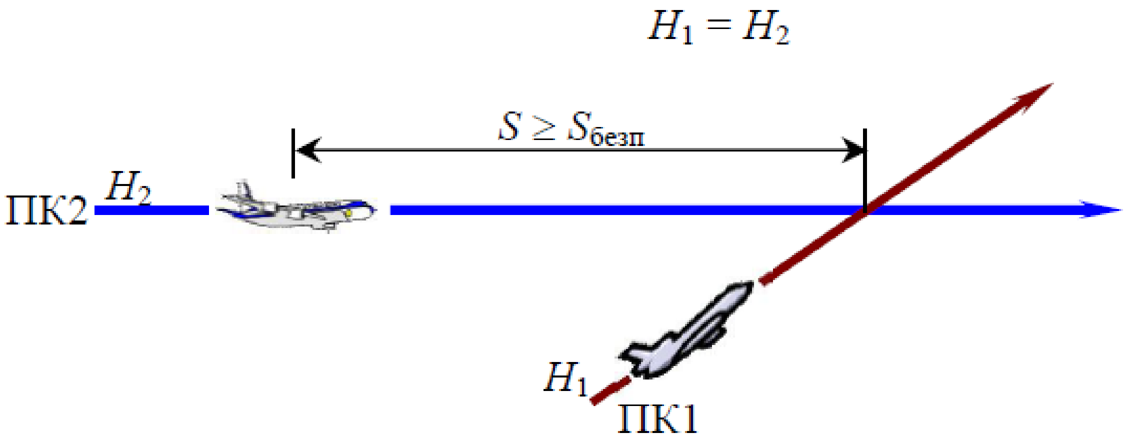


Fig. 3.22. At the moment of crossing the safe interval is provided

2. The transverse interval at the time of crossing the occupied level is not provided, then you can dilute the PC in the following ways:

- change the flight level of one of the PCs (Fig. 3.23);

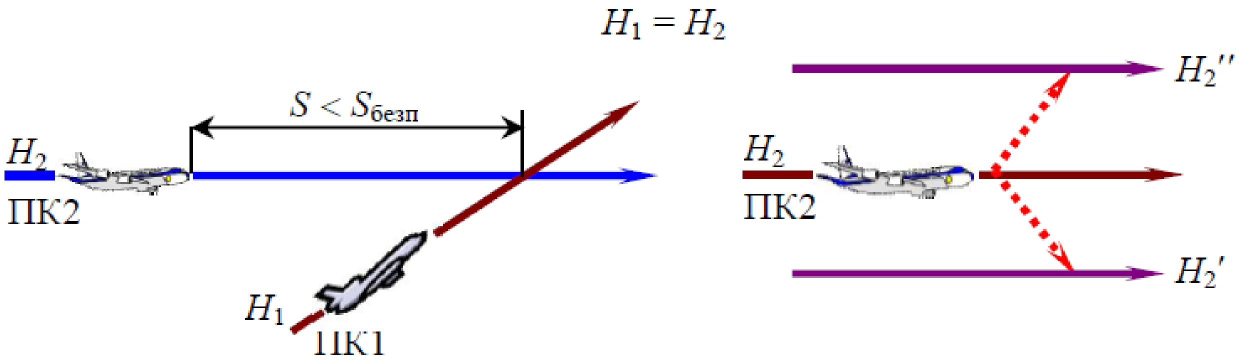


Fig. 3.23. Change PC flight levels

- PC, which is the first to cross the point of intersection of routes, increase the flight speed, and the second PC - to reduce, if allowed by KLE (Fig. 3.24);

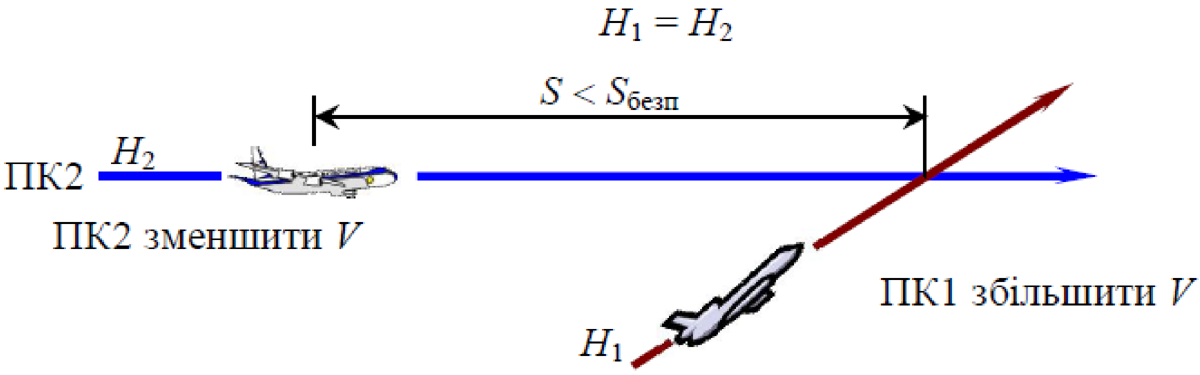


Fig. 3.24. Adjust the horizontal speeds of the PC

- if the interval at the time of crossing the routes is more than half of the minimum safe and it is impossible to change speeds, or their change is not enough, then the slower PC should turn 30º towards the faster PC and bring it to the border. After 1-2 minutes, turn the slower PC 30º towards the route axis (Fig. 3.25).

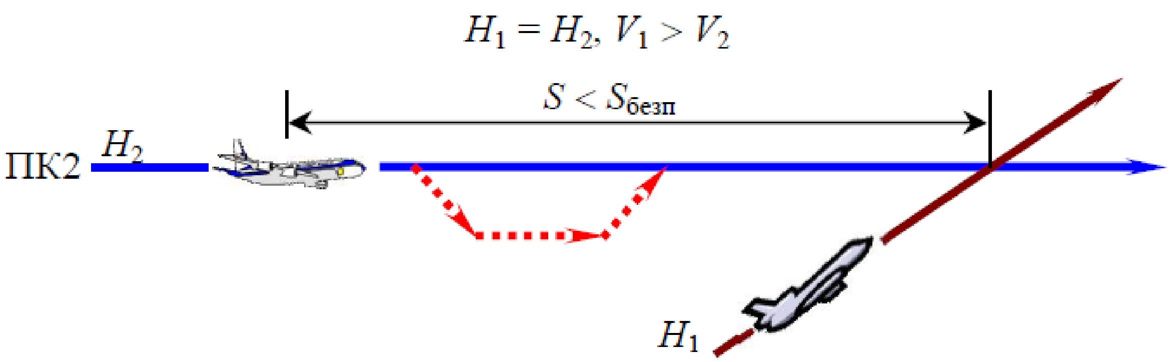


Fig. 3.25. PC distraction

3.1.6. Flight on one level

1. The transverse interval is not provided, then you need to immediately change the flight level of one of the PC (Fig. 3.26);

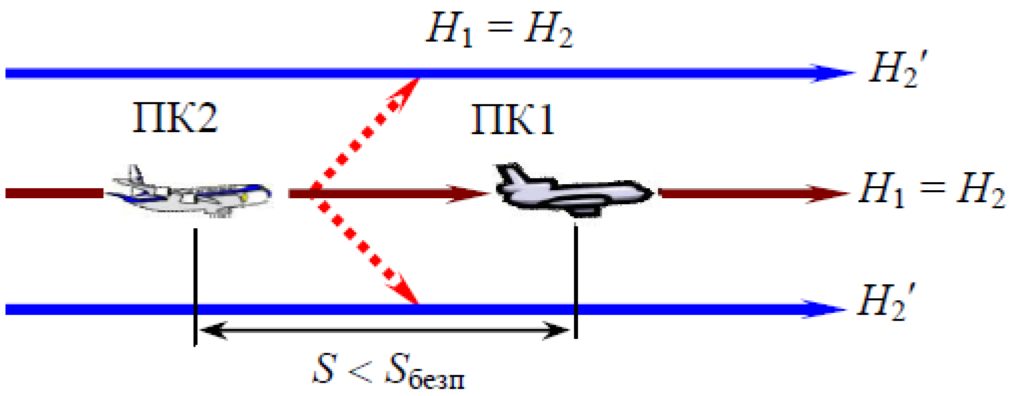


Fig. 3.26. Immediate change of PC flight levels

2. The transverse interval is provided:

a) the speed of the first PC is greater than or equal to the speed of the second PC, PKS

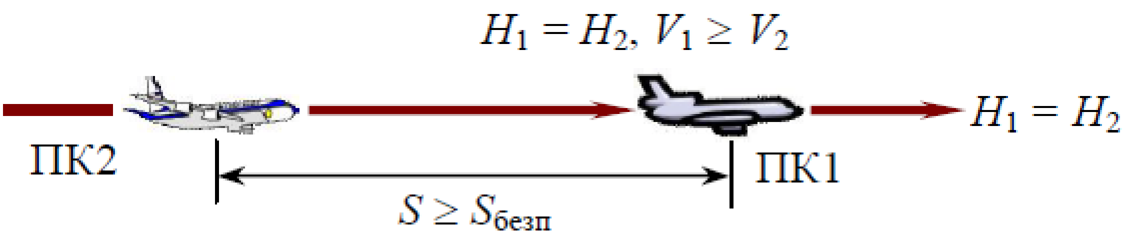


Fig. 3.27. Safe interval provided at the time of crossing

b) the speed of the first PC is less than the speed of the second PC, then the second PC can catch up with the first. In this case, you can dilute the PC in the following ways:

- increase the speed of the first PC, and reduce the speed of the second PC, if the CLE allows (Fig. 3.28);

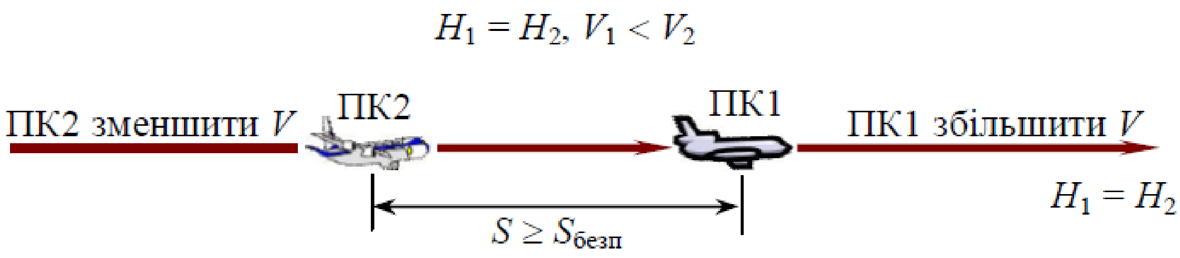


Fig. 3.28. Adjust the horizontal speeds of the PC

- if it is impossible to change the speed, or after their change the interval continues to decrease, you need to change the flight level of one of the PCs (Fig. 3.29).

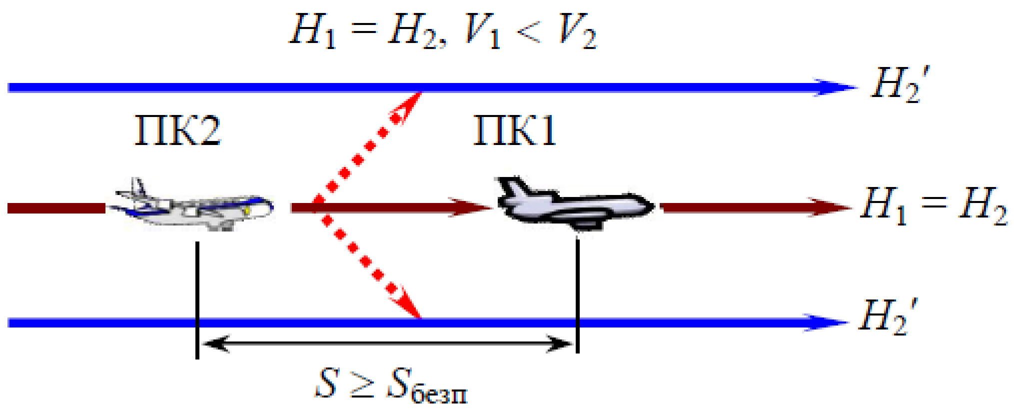


Fig. 3.29. Change PC flight levels

3.2. Development of a universal algorithm for resolving air conflict situations

There are different approaches to solving the problem of conflict prevention, including probabilistic estimates of various flight factors, the use of graph theory, grids and ES-algorithms (Event-step algorithm). This article uses the proposed only approach to the formation of flight paths of dangerous areas, both stationary and moving. In the latter case, it may be moving areas of non-flying weather or areas of dangerous proximity to other aircraft. However, finding the flight paths is performed in the Cartesian system. In this case, for on-board implementation it is necessary to translate all environmental data from the geographical to the Cartesian system, to determine a safe trajectory in it, and then translate the latter into geographical. In addition to a significant increase in computational operations, such translations can lead to significant errors in the results, especially on long distances. A feature of the approach considered in this article is to find the trajectory directly in the geographical coordinate system, ie in the same coordinate system in which the potentially dangerous objects are set.

3.2.1. Formulation of the problem

To solve this problem with on-board aircraft, it is necessary to create effective algorithms that provide resolution of such conflicts in real time during the flight on the route. The algorithm considered in the article is designed to identify and resolve conflict situations for the aircraft on the cruising section of the flight. It is assumed that the AC1 aircraft is moving on a constant specified echelon with a constant speed on each segment between the intermediate points of the route (MPP). Other planes that could potentially have a dangerous approach are flying in the same echelon.

Air traffic information and meteorological information can be obtained from other aircraft and other sources by means of automatic dependent surveillance and from onboard meteorological radars.

Dangerous / restricted areas are set on a grid of 5550 by 3550 points, covering the territory of Europe with a step of 0.01 °. Restrictions on the shape of dangerous / prohibited areas are not imposed, unlike where prohibited areas are set in the form of convex landfills. The grid covers the space between the parallels 35 ° and 65 ° north latitude and the meridians 15 ° west longitude and 40 ° east longitude. In the memory of the calculator, the grid is represented by a two-dimensional array, ie each grid node is determined by two indices of this array. Nodes of the grid that fall into the dangerous / forbidden for flight zones are assigned 1, other nodes - 0. Next, the first of them will be called forbidden areas.

Once the conflict is detected, the options for resolving it are determined and the navigation display shows alternative flight routes in the horizontal plane (without changing the specified flight level).

A feature of the method used in the work is a universal approach to solving the problem. The algorithm of trajectory control, which provides for the resolution of conflict situations, is formed regardless of the physical nature of the conflict: meteorological conditions, administrative flight restrictions, other aircraft. In the latter case, the object moves, so we have to calculate the projected position of the area where potentially dangerous convergence is possible.

The zone of dangerous approach to another aircraft, let's call it AC2, in the horizontal plane is defined by a circle with a radius of 5 nautical miles. The polygon is approximated in the calculations of the boundary of the dangerous convergence zone. Calculations are performed in a geocentric spherical coordinate system with basis $\{\vec{\imath}, \vec{\jmath}, \vec{k}\}$ (Fig. 3.30).

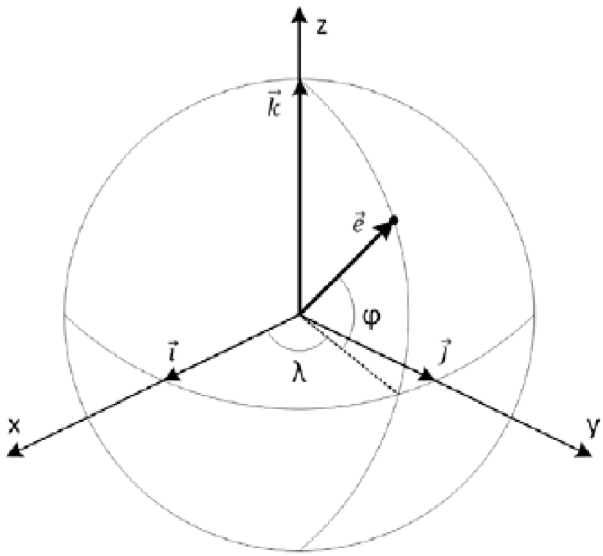


Fig. 3.30 Definition of the unit vector $\vec{e}$

The position of any point in the coordinate system can be determined by the vector (R3 + H) $\vec{e}$, where R3 is the radius of the Earth; H - flight altitude; $\vec{e}$ is a unit vector, which at known values of latitude φ and longitude λ is calculated according to the formula

$$\vec{e} = \{\cos\varphi \cos\lambda\ ; \cos\varphi \sin\lambda\ ; \sin\varphi\}. \qquad (1)$$

Geographical coordinates for a given area of airspace are determined by the components of the vector $\vec{e}$ as follows:

$$\lambda = \tan^{-1}\left(\frac{e_y}{e_x}\right);$$
$$\varphi = \sin^{-1} e_z. \tag{2}$$

3.2.2. Predicting the area of dangerous approach to another aircraft

In this paper, the area of dangerous convergence with other aircraft is approximated by a polygon with 16 vertices. The predicted position of each vertex is determined from the condition that at the predicted movement of aircraft, this vertex and the AC1 aircraft are in this position at the same time.

The motion of each vertex of the polygon is rigidly related to the motion of the AC2 aircraft. If the AC2 aircraft moves in a straight line, then the vertex will be shifted in a straight line, if the AC2 aircraft performs a U-turn, then the entire polygon, ie each of its vertices, will perform a U-turn.

The coordinates of the vertices of the polygon, approximating the area of dangerous convergence, in the current state of the aircraft AC2 can be found by the formulas:

$$\varphi_i = \sin^{-1}\left(\sin\varphi_{AC2}\cos\left(\frac{R_{оп}}{R_з+H}\right) + \cos\varphi_{AC2}\sin\left(\frac{R_{оп}}{R_з+H}\right)\cos\theta_i\right);$$
$$\lambda_i = \lambda_{AC2} + \tan^{-1}\left(\frac{\sin\theta_i \sin\left(\frac{R_{оп}}{R_з + H}\right)\cos\varphi_{AC2}}{\cos\left(\frac{R_{оп}}{R_з + H}\right) - \sin\varphi_{AC2}\sin\varphi_2}\right), \tag{3}$$

where θi is the angle between the direction to the north and the direction to the i-th vertex; φAC2 and λAC2 - latitude and longitude of the aircraft AC2, respectively; Rop is the radius of the area of dangerous convergence.

Here the formation of the zone of dangerous convergence is carried out under the assumption that the AC2 aircraft performs a straight line flight at a constant speed, the value of the AC1 aircraft speed is also constant (Fig. 3.31).

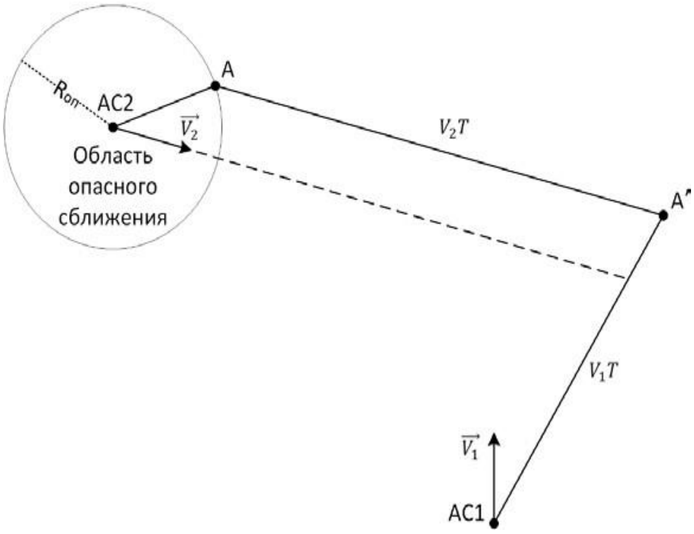


Fig. 3.31. Scheme of possible convergence of aircraft in the horizontal plane

Determination of the geographical coordinates of the point A '(Fig. 3.32) is performed in vector form, there is a single vector $\vec{p}$, the components of which are calculated its geographical coordinates in accordance with formulas (2).

The unit vectors $\vec{e1}$ and $\vec{eA}$, which correspond to the positions of the aircraft AC1 and point A, are calculated by formula (1).

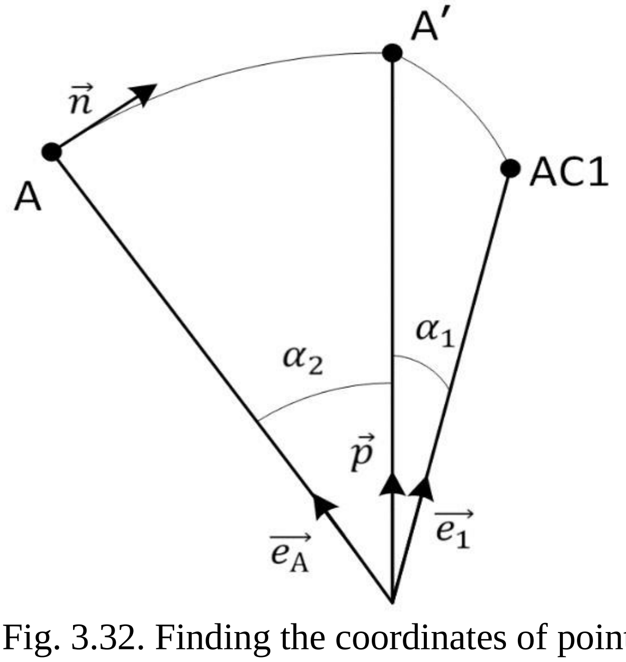


Fig. 3.32. Finding the coordinates of point A '

We assume that the vector $\vec{p}$ is in the orthodorm plane and is equal to

$$\vec{p} = \vec{e_A} \cos \alpha_2 + \vec{n} \sin \alpha_2, \quad (4)$$

where $\vec{n}$ is a single vector lying in the plane of orthodormia;

$$\alpha_2 = \frac{V_2 T}{R_3 + H} \tag{5}$$

-angle at which point A moves in the geocentric coordinate system when forecasting for time T.

During time T, the AC1 plane in the same coordinate system moves at an angle

$$\alpha_1 = \frac{V_1 T}{R_H}. \tag{6}$$

This angle can also be determined from the ratio

$\mathrm{Cos}\,\alpha_1 = (\vec{p}, \vec{e_1})$. (7)

Substituting in this ratio expressions (4), (5), (6), we obtain

$$(\vec{e_1}, \vec{e_2}) \cos\frac{V_2 T}{R_H} + (\vec{e_1}, \vec{n}) \sin\frac{V_2 T}{R_H} = \cos\frac{V_1 T}{R_H}. \tag{8}$$

The angles α1, α2 are small, so the ratio is fair enough

$$(\vec{e_1}, \vec{e_A})\left(1 - \frac{{V_2}^2 T^2}{2{R_H}^2}\right) + (\vec{e_1}, \vec{n})\frac{V_2 T}{R_H} = 1 - \frac{{V_1}^2 T^2}{2{R_H}^2}. \tag{9}$$

After bringing such, we obtain the canonical form of the quadratic equation

$$\frac{{V_1}^2 - {V_2}^2(\vec{e_1}, \vec{e_A})}{{R_H}^2} T^2 + 2(\vec{e_1}, \vec{n})\frac{V_2}{R_H} T + 2\big((\vec{e_1}, \vec{e_A}) - 1\big) = 0. \tag{10}$$

The solution of this equation is the time T corresponding to the simultaneous achievement of point A 'by the aircraft AC1 and point A

$$T = \frac{-(\vec{e_1}, \vec{n})\frac{V_2}{R_H} + \sqrt{\left((\vec{e_1}, \vec{n})\frac{V_2}{R_H}\right)^2 + 2\frac{{V_1}^2 - {V_2}^2(\vec{e_1}, \vec{e_A})}{{R_H}^2}\big(1 - (\vec{e_1}, \vec{e_A})\big)}}{\frac{{V_1}^2 - {V_2}^2(\vec{e_1}, \vec{e_A})}{{R_H}^2}}. \tag{11}$$

Assuming that the AC2 plane moves along the orthodrome, the vector $\vec{n}$ is directed tangent to this orthodrome and is uniquely determined by the angle 2 of the AC2 aircraft relative to the vector $\vec{m}$ lying in the meridional plane and facing north (Fig. 3.33). The unit vector $\vec{m}$ can be determined through the vectors $\vec{k}$ and $\vec{eA}$ by the formula

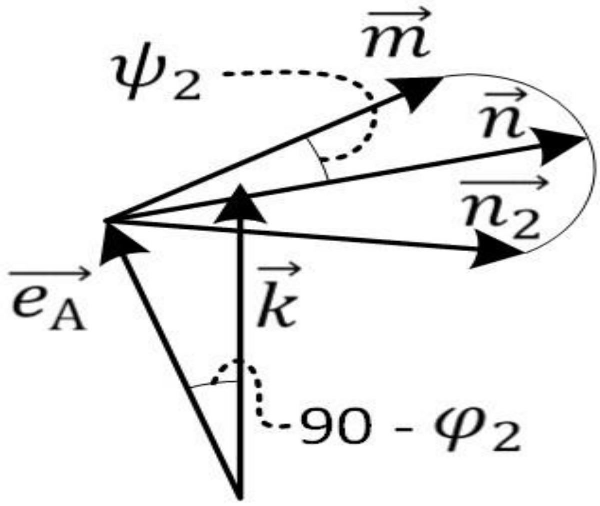


Fig. 3.33 Determination of age $\vec{n}$

$$\vec{m} = \frac{\vec{k} - \vec{e_A}\sin\varphi_2}{\cos\varphi_2}. \quad (12)$$

To find the vector $\vec{n}$ is also used perpendicular to the meridional plane of the vector $\vec{n2}$, equal

$$\vec{n_2} = (-\sin\lambda_2, \cos\lambda_2, 0). \quad (13)$$

The vector $\vec{n}$ is determined by the formula

$$\vec{n} = \vec{m}\cos\psi_2 + \vec{n_2}\sin\psi_2. \quad (14)$$

To find the vector $\vec{p}$ that determines the position of the point A ', we substitute the time T from equation (11) to equation (4). The calculation of the coordinates (latitude and longitude) of this point is performed by equation (3).

As a result of finding the coordinates of all 16 vertices of the polyhedron and their connection by rectilinear segments, we obtain the predicted position of the polyhedron, the interior of which is the predicted region of dangerous convergence.

The results of construction of the forecasted areas of dangerous convergence at different speeds of the AC2 aircraft and the same other initial conditions are obtained. In fig. Figure 3.34 shows the conflict situation in which the planned trajectory of the AC1 aircraft crosses the projected area of dangerous approach to the AC2 aircraft. The situation requires resolving the conflict by changing the flight plan of the AC1 aircraft.

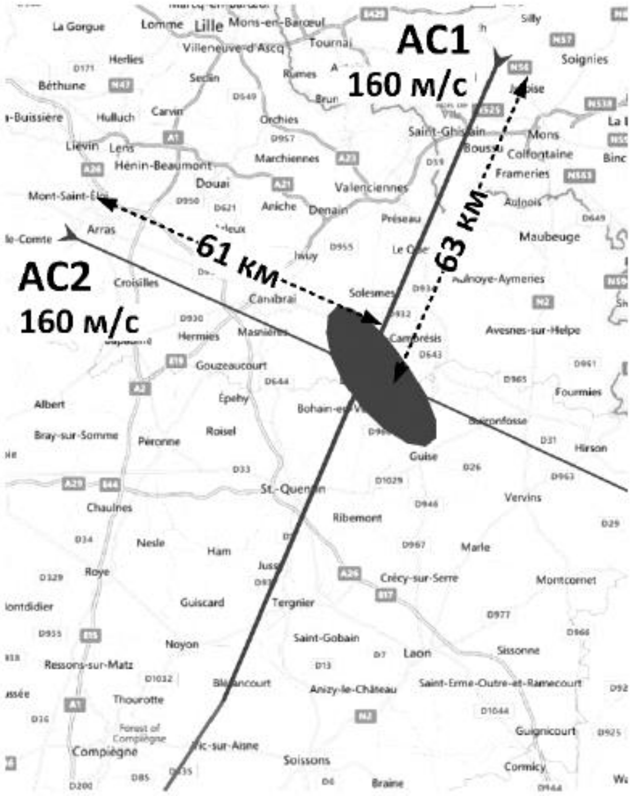


Fig. 3.34. Predicted area of dangerous convergence at **V**2 = **V**1

To identify the predicted areas of dangerous convergence, the nodes of the grid falling into them are marked with the number 1, ie in the same way as for other prohibited areas.

CONCLUSION TO SECTION 3

The constant growth of air traffic requires an increase in airspace capacity, along with the need to ensure an acceptable level of flight safety, which is largely due to the regulation of flights in international and domestic civil aviation. Such requirements necessitate the improvement of on-board aircraft, which on modern aircraft are highly automated integrated hardware and software systems. The software of these complexes is based on algorithmic software, which is subject to optimization in the interests of reducing the need for computing resources and improving the efficiency of solving problems of trajectory control.

Particular attention is paid to identifying and resolving potential conflict situations.

Methods of resolving potentially conflict situations depending on the location of joint aircraft, horizontal and vertical speed and flight profiles, as well as technological procedures and rules of radiotelephone communication in identifying aircraft on radar, transmission of information about mutual location and commands to perform maneuvers to resolve potential conflicts.

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