

**MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY**

Department of Avionics

ADMIT TO THE DEFENSE

Head of the department

Professor Pavlova S.V.

" _ " _____ 2022 p.

**DIPLOMA WORK
(EXPLANATORY NOTE)
GRADUATE OF THE EDUCATIONAL
DEGREE "MASTER"**

**Topic: Automated system of flight trajectory formation and
aircraft stabilization**

I did it: _____ Kostin Vladislav Vadimovich

Head of: _____ Романенко Віктор Григорович

Consultants from the sections:

Occupational health and safety

**Protection of the environment
environment**

Normocontroller _____ Левківський Василь Васильович

Kyiv 2022

INTRODUCTION

Nowadays the term "landing" includes the following flight phases: aircraft departure to the aerodrome area and prelanding maneuvering, landing approach and landing itself (leveling, landing, run).

This stage is the most responsible and intense part of the flight. It is here, according to the world statistics, where more than one third of all flight accidents occur. Proximity of the ground and contact with the runway surface requires high accuracy of control of angular and trajectory parameters of the flight, and the load of the pilot and crew members with additional functions (communication with ground services; release - retraction of landing gear and flaps, change of engine operation modes; control of space behind the cabin and others) significantly complicates manual control especially at the landing stage. Therefore, automation of these modes significantly increases flight safety and reduces the load on the crew members.

Due to increase of air traffic density, as well as decrease of meteorological conditions of flight and landing (modern aircrafts have to perform approach and landing even in zero visibility) requirements to information support of so called marginal areas of flight have increased.

Completeness, reliability and high accuracy of information at control at the edge of flight modes and in conditions of reduced vertical and horizontal echelon norms is achieved by integration of piloting and navigation sensors into the unified information system.

The integration of navigation systems and automation of the main processes of information acquisition, processing and use allowed to integrate on the basis of a mainframe computer and specialized calculators heterogeneous navigation equipment into a single navigation complex, which, together with automatic flight control systems, creates NCP. In terms of complexity and multifunctionality, NSPs of modern FPU's can be classified as large information and control systems.

Even the simplest NCP includes more than ten functionally related systems.

The qualitative features of NSP are as follows:

the bundling of on-board navigation systems and facilities, which is carried out with the help of BCOM;

expansion of the range of tasks to be solved by the aircraft;

possibility of using more complicated algorithms for navigation tasks in order to provide higher precision and reliability of navigation;

widespread duplication of systems, tools and methods for determining basic piloting and navigational parameters.

Navigational support of prelanding maneuvering and approach provides high-precision definition of aircraft flight parameters in coordinate system characteristic for corresponding sensor of initial navigation information, realization of coordinate transformations, execution of complex processing of navigation information.

This work is devoted to the problem of solving these problems.

SECTION 1.

TRAJECTORIES OF AN AUTOMATED AIRCRAFT EXIT TO A

PROGRAMMED AERODROME

1.1 TRAJECTORIES OF AIRCRAFT FLIGHT IN THE HORIZONTAL PLANE

The goal of the prelanding maneuvering stage is to bring the aircraft to a point in the airspace relative to the landing airfield so that the aircraft is on the continuation of the runway axis at the set altitude and range. In flight practice there is a concept of "landing calculation", i.e. the pilot or crew calculates the sequence of certain trajectory maneuvers performed by the aircraft. It is this calculation that is automated when the NCP is on board the aircraft.

NCP functioning at this stage of flight consists of formation of a flight trajectory and stabilization of the aircraft on this trajectory. Usually, the trajectory of the entire flight route is programmed so as to include the stage of exit to the landing airfield, i.e. the route is laid out taking into account the air routes and corridors of the airfield area. It is in the air corridor that planes descend or gain altitude. Characteristic points of air routes and corridors are marked with separate drive radio stations, which are used to lay out the route. In addition, take-off and landing zones, lap zones, and waiting areas are arranged around the airfield.

The method of landing airfield approach trajectory creation, which is similar to the method of separate orthodromes creation during aircraft flight, is widely spread for heavy aircraft of civil aviation

along a programmed route. The peculiarity of such algorithm The main feature of the prelanding maneuver trajectory is that the aircraft is taken from the end point to the point of the fourth turn, followed by an exit to the runway axis in the instrumental landing zone. Fig.1.1 shows one example of a trajectory предпосадочной of the aircraft maneuvering

When reaching the Linear U-turn Warning Point (LUR), which in this case is the point of the fourth turn, the aircraft begins to turn and exit to the runway axis beyond the arc of radius R_p .

In case of emergency change of landing airfield, e.g. due to weather conditions, departure to the area of alternate airfield can be performed outside the air routes with the implementation of course or route method of flight along the route.

Let's consider the solution of the problem of aircraft departure to an alternate landing airfield in the horizontal plane by information from the navigation system of short-range navigation and landing of the RSBN type.

1.2 Block diagram of the complex navigation system.

The origin of the coordinate system coincides with the runway center, the OS axis coincides with the runway axis and is directed towards the landing course, and the OZ axis is directed perpendicular to the landing approach. On this axis there is a ground beacon of the WRS system at a distance z_0 from the runway axis.

The trajectory to the landing aerodrome in the general case includes three stages.

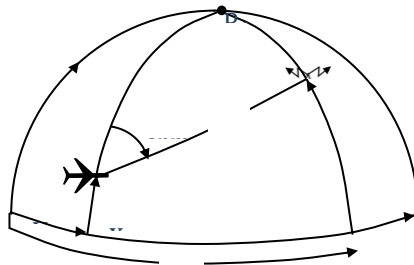
At the first stage the aircraft enters the area of the aerodrome at the boundary, which is determined by the range $D_r = 200...250$ km to the aerodrome's radio beacon. Aircraft control is performed in the same way as for en-route flight, with a programmed aerodrome's DSS beacon being taken as the target navigation point to be flown to. Coordinates of the aircraft at this stage are determined by orthodromic coordinate system, and the control of the aircraft is carried out by course method. To implement this method of control, the landing calculator unit (BOP) of the VLSN system (see Fig. 1.2.) calculates

the specified orthodromic course and distance to the ground radio beacon (Fig. 1.4.):

$$\psi_3^{\text{opt}} = \text{arctg} \frac{(y_M - y_{\text{Лa}}) \cos \frac{x_M}{R_3}}{x_M - x_{\text{Лa}}};$$

$$D = \sqrt{(x_M - x_{\text{Лa}})^2 + (y_M - y_{\text{Лa}})^2 \cos^2 \frac{x_M}{R_3}}$$

where x_M, y_M – orthodromic coordinates of the programmed landing airfield RSSC beacon; $x_{\text{Лa}}, y_{\text{Лa}}$ – current coordinates of the position of the aircraft coming (see Fig. 1.2) from the navigation calculator unit (BON); R_3 – the radius of the Earth.



The set course is fed to the ACS for automatic or semiautomatic control and to the PUP, the range to the beacon on the instrument type PAP. The peculiarity of this stage of prelanding maneuvering is such that parameters of departure to the set point are determined irrespective of whether measurements of azimuth and range to the beacon are carried out or not.

The second stage begins when the aircraft enters the zone of the RSBN beacon at a range of 200...250 km from the runway. Switching on takes place automatically in the presence of signals of operability of the onboard and ground equipment of the SSR system.

The aircraft trajectory is determined by the guidance points A_1 and A_2 (Points for the third U-turn) and point A_0 (point of the fourth reversal), which are arranged accordingly:

point A_0 ($S_3 = 21$ км, $z_3 = 0$) используется to guide the aircraft if the flight direction to the aerodrome does not differ in absolute value from the landing direction by an angle of more than 90° . In other cases, the LA is brought to the point of A_1 , ($S_3=21$ км, $z_3 = 8$ км) or point A_2 ($S_3 = 21$ км, $z_3 = -8$ км) (wt. paint. 1.3).

To derive these conditional points from the measured azimuth A and slant range D to the radio beacon, the current position of the aircraft in the rectangular airfield coordinate system OSZ is determined in the BOP unit of the RSBN system

$$\begin{aligned} s &= D \cos(A - \psi_{\text{БПП}}); \\ z &= z_0 + D \sin(A - \psi_{\text{БПП}}), \end{aligned} \quad (1.1)$$

where $\psi_{\text{БПП}}$ – the true course of the runway of the given aerodrome is programmed.

The aircraft coordinates calculated by formula (1.1) are used to determine the set course of the aircraft and the range to the guidance point:

$$\begin{aligned} \psi_3 &= \psi_{\text{БПП}} + \Delta\psi; \\ \Delta\psi &= \arctg \frac{z - z_3}{s - s_3}; \\ D &= \sqrt{(z - z_3)^2 + (s - s_3)^2}. \end{aligned}$$

The set true course is fed to the ACS for control, and the range D is used in the algorithms for building the trajectory of the maneuver in the vertical plane.

If the aircraft was guided to the point A_1 (A_2), then at a range of 4 км up to it, (at a range equal to the radius of turn of the aircraft) the point of aiming is changed to A_0 , this provides a more intense turn of the aircraft on the landing course. This ends the second stage of the prelanding maneuver and begins the third. When the aircraft enters the corridor ± 5.5 км relative to the runway axis, a new guidance point is formed in the calculator, which starts moving along the runway axis with the speed of the aircraft and has the coordinates $S_3 = S - 2,5$ км, $z_3 = 0$. At the same time, the aircraft will approach the runway axis along the "chase curve". When the lateral deviation from the runway axis reaches ± 1.5 км, the third stage of prelanding maneuvering ends and the switch to approach mode takes place.

1.3 TRAJECTORY OF THE AIRCRAFT FLIGHT IN THE HORIZONTAL PLANE AT THE STAGE OF PRELANDING MANEUVERING WITH THE USE OF THE

MANEUVER "BOX" MANEUVER.

All prelanding maneuvering trajectories formed in the navigation system calculators bring the aircraft from the end point of the route directly to the runway axis for the implementation of the so-called "straight approach" landing approach. But in case of "straight ahead" landing approach the pilot may not be psychologically prepared for landing, moreover, landing approach

"from a straight line" requires too precise piloting with calculation of landing gear release time and landing mechanization of the wing. Therefore, an additional stage of prelanding maneuvering "box" becomes the most common, especially for heavy aircraft. When performing "box", the pilot has an opportunity to make a correct landing calculation and prepare for landing in the best possible way.

Box flight is performed as follows (Fig. 1.5, trajectory 1). After flying over the far-haul radio station (FDRS), the aircraft continues to fly for 90 seconds with the runway course, and then performs the first turn (1p) by 90 to the right or left side (right or left "box"). The next 90° turns are performed at points 2p, 3p, 4p at angles of heading CPSS equal to 240, 240 and 285. After the fourth U-turn, the aircraft enters the landing course in the instrumental landing zone and further control is carried out according to the signals of this system. Automation of control when flying "by the box" is carried out by the heading method, with commands to change the set course are received from the lamellar devices of the course angle tracking system of the radio station of the flight navigator of the PNP type.

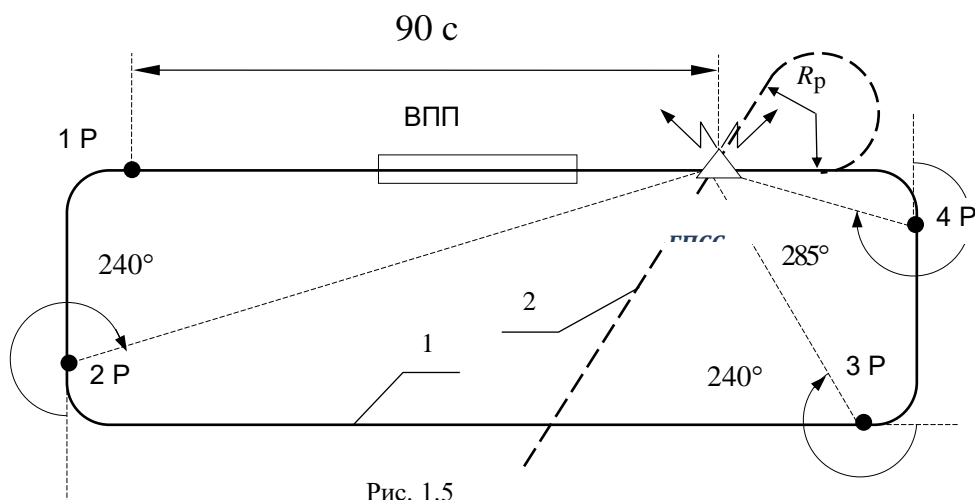


Рис. 1.5

In the modes of semi-automatic or hand wheel exit into the circle zone there is a possibility to adjust to the trajectory of the "box" from any side (to fit into the trajectory) with the subsequent exit to the runway axis.

A backup prelanding maneuver is the so-called "circle over radio station" maneuver performed by signals from a far-drive radio station. A typical landing approach trajectory using CPSS (trajectory 2) is shown in Fig. 1.5.

Such a trajectory is implemented, for example, in semi-automatic approach systems such as "Privod" and "Path-4".

After entering the GPSS, the aircraft continues to fly on the calculated course, which is calculated using information about the runway course. After a certain estimated time the turn with radius RR is performed, as a result of which the aircraft enters the runway axis. Further on, in order to correct the parameters of aircraft movement, a prelanding maneuver "box" may be performed.

At a stage of prelanding maneuvering automatic or director (semiautomatic) control of the aircraft is realized through the roll contour by directional method according to the control laws, which were considered in clause 7.1. The preset roll is formed as:

$$\gamma_3 = \frac{F_{\Gamma P}}{K_{\gamma}} K_{\psi} (\psi - \psi_3)$$

where ψ_3 – a given course formed by the NCP and depends on the method and stage of the prelanding maneuver.

1.4 Trajectories of aircraft flight in the vertical plane.

In the vertical plane, the prelanding maneuver trajectories (descent trajectories) depend on the aircraft type. This is due to the different permissible slope angles of the trajectory of light and heavy aircraft. The basic trajectory of a prelanding maneuver in the vertical plane for civil aviation aircraft is ensured by programming the flight profile in the NCP in the same way as it is done for en-route flight in the horizontal plane.

In this case, a trajectory with a constant descent angle is taken as a given trajectory θ_{ch} . The angle of descent is calculated at the moment the aircraft passes the final point of the route according to the formula:

$$\theta_{ch} = \frac{\text{arctg}(H - h)}{S_{ch}},$$

where H - current altitude of the aircraft; h – target altitude at the end of the descent; S_{ch} – total length of prelanding maneuvering to the end of descent.

The formation of the control signal for the ACS is carried out according to the ratio:

$$\Delta H^{in\delta} = H - h - S_{in\delta} \text{tg} \theta_{in\delta},$$

where S_{ch} – the remaining distance to the point of the fourth U-turn.

The H control signal provides automatic stabilization of the aircraft on the descent trajectory.

Construction of a prelanding maneuver in the vertical plane in the VLSN system occurs according to a different algorithm. The complex system solves the problem of automation of a prelanding maneuver in the vertical plane from an altitude of $NKR = 10000\text{m} \pm 500\text{m}$. If the actual altitude at the moment of switching on the mode of exit to the landing airfield is more than H_{KP} , then the pilot is obliged to descend to an altitude lower or equal to the MIR, using the helm controls. In the RSBN calculates the range to the end point of descent $D_{p.ch}$ (1.3). Value $D_{p.ch}$ is calculated depending on the choice of the set points of the third (A_1, A_2) or a fourth U-turn (A_0).

For points A_1 and A_2 :

$$D_{p.ch} = 8\text{KM} + (H - h) \text{ctg} \theta_{ch},$$

and for the point A_0 :

$$D_{p.ch} = 16\text{KM} + (H - h) \text{ctg} \theta_{ch}$$

where h – the height of the circle is set to 630m; θ_{3H} – the angle of inclination of the descent trajectory; H – current altitude of the aircraft.

At a range greater than $D_{p.3H}$.The flight is performed in the barometric altitude stabilization mode. When reaching $D_{p.ch}$ the plane begins its descent with a constant trajectory slope angle θ_{ch} . The landing calculator unit continuously calculates the current value of the target altitude H_3 , which is used to control the aircraft on the descent with a constant trajectory angle

$$H_3 = h + D \text{tg} \theta_{ch} . \quad \text{(the formula 1.2)}$$

This ensures that the aircraft reaches the end of its descent at an altitude of h (рис.1.6).

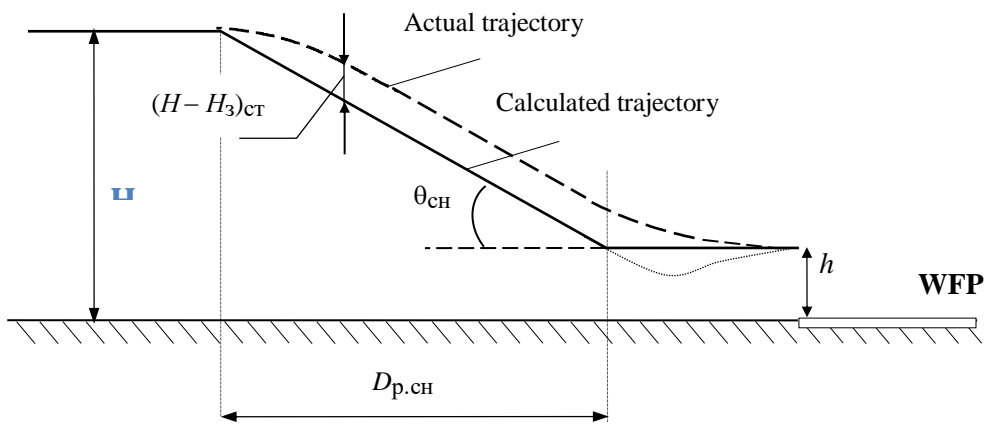


Fig.1.6

When the mode of exit to the landing aerodrome is activated at a range shorter than $D_{p.ch}$, the SSR calculates the desired angle of inclination of the trajectory θ_{ch}^* , which ensures that the airplane is lowered to circle altitude at a given cutoff point:

$$\theta_{ch}^* = \text{arctg} \frac{H - h}{D - D_{p.ch}} .$$

In the case of θ_{ch}^* exceeds the maximum allowable value of the trajectory slope angle for this type of aircraft, the points are moved A (A_1 i A_2) from the runway to a distance that ensures the aircraft's descent with a permissible trajectory slope angle and the aircraft's exit to the landing straight.

In order to automatically implement such a profile of prelanding maneuver the ACS uses the mode of stabilization of the preset barometric flight altitude. During the descent along the program trajectory, the set altitude value is calculated by the formula (1.2).

Certain problems arise when implementing such a descent trajectory due to aircraft drawdown at the leveling stage when reaching circle altitude. In order to eliminate the drawdown, it is advisable to reduce the aircraft along a trajectory that lies above the calculated one (see Fig. 1.6) by creating an error in stabilizing the target altitude. If the target altitude control is implemented through a pitch loop, for example, with isodromic feedback to the servos, you can turn this loop into a static loop by removing the isodromic link from the pitch signal circle with simultaneous connection to the target pitch formation circle ϑ_3 pitch angle signal of horizontal flight $\vartheta_{г.н} = 4 \pm 2^\circ$

$$\frac{T_i p}{T_i p + 1} \delta_b = K_\vartheta (\vartheta - \vartheta_3) + K_{\omega_z} \omega_z,$$

где $\vartheta_3 = \vartheta_{г.н} - \frac{K_H}{K_\vartheta} (H - H_3)$.

A positive debugging error has become $(H - H_3)_{CT}$ is created by the signal $\vartheta_{г.н}$, which is trying to bring the plane into a horizontal flight. At $\vartheta_{г.н} = (3 \dots 4)^\circ$ The average excess of the target altitude is about 100150 m, so at the stage of reaching circle altitude the aircraft smoothly without overshooting switches to horizontal flight.

SECTION 2.

BASIC REQUIREMENTS FOR THE NCP DURING THE RETURN AND LANDING APPROACH PHASES

2.1 Accuracy of NCP requirements

Vector of pilot-navigational parameters, determined by the NCP – $X_{ПНК}$, includes the values characterizing the position and motion of the center of mass of the aircraft, as well as its position and motion relative to the center of mass.

NSP accuracy is characterized by the deviation of current values of pilot-navigational parameters from their set values. Quantitative characteristic of these deviations is $\Delta X_{ПНК}$ – error vector equal to

$$\Delta X_{\text{ПНК}} = X_{\text{ПНК}} - X_{\text{ПНК}}^{\text{зад}}$$

where $X_{\text{ПНК}}^{\text{зад}}$ – a vector of given values of pilot-navigational parameters of aircraft flight.

Permissible values of the error vector components are set in the UTM in the form of RMS, doubled RMS or maximum permissible errors. The latter are usually taken as tripled mean-square errors.

The dimensionality of the NCP error vector is largely determined by the type and purpose of the aircraft on which it is installed. Below are the requirements to the main components of this vector, taking into account the possibility of successful solution of navigation and piloting tasks by the aircraft complex.

The main task of navigation is to determine the horizontal coordinates of the location of the aircraft. In this case, the main method of determining them is path calculation in inertial, inertial-doppler,

Inertial-Doppler or directional-aerometric modes with correction in separate sections of the route. In the path counting mode, errors increase with time. And although the laws of growth of mean square errors in these four modes are diverse, for all path-counting modes set the requirements in the form of $\sigma_{\Delta Z} (\sigma_{\Delta \chi})$ for a certain time interval.

An example of navigation accuracy requirements in different path calculation modes is shown in Table 1.1.

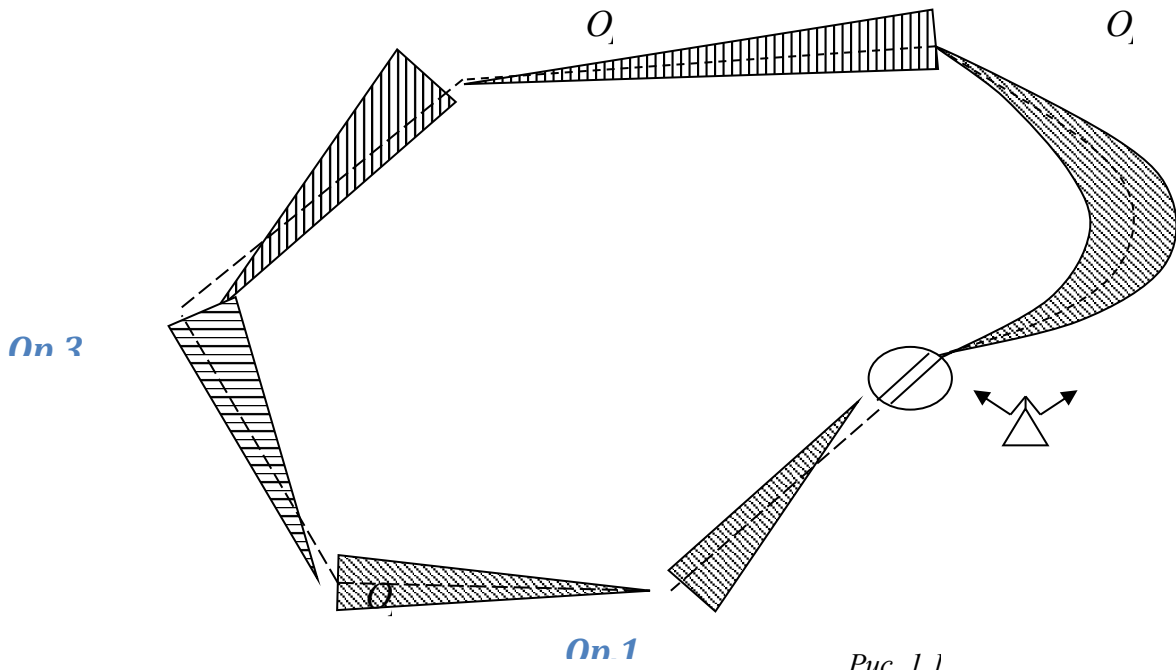


Рис. 1.1

Таблица 1.1

Waypoint counting mode	Precision requirements
Inertial	$\sigma_{\Delta Z} \leq 5$ км за 1 hour
Inertial-Doppler	$\sigma_{\Delta Z} \leq 3$ км за 1 hour
Course-Doppler	$\sigma_{\Delta Z} \leq 3$ км за 20 min
Cursoerometric	$\sigma_{\Delta Z} \leq 10$ км за 20 min

The errors accumulated during the path counting time in the correction interval are written off to the level due to the accuracy of the correction. The latter depends on from the system, algorithm, and correction time, from the operating mode of the correction means and other factors. Examples of requirements for the correction accuracy are given in Table 1.2.

The requirements in Table 1.2 are accompanied by the indication of the correction time. This is due to the fact that under the optimal correction algorithms, the correction accuracy significantly depends on time, since the accumulation of information and averaging of alternating errors increases with increasing correction time. The nature of changes in navigation errors during path calculation and episodic correction is explained in Fig. 1.1.

The errors are written off at the correction intervals with the accuracy determined by the correction means and conditions of its operation and grow smoothly between these intervals. Fig. 1.1 shows these errors as shaded sectors. Correction intervals are selected during navigational training for a flight, taking into account many factors, such as the availability of radio navigation fields, the possibility of radio interference with radio and radar correction aids, the nature of geographic navigation fields for correlation-extreme navigation systems, and the availability of reference points for sighting and radar correction aids. The correction interval depends on the required accuracy of navigation at each successive stage of flight.

Obviously, the higher the accuracy of route calculation, the less frequent the correction, the higher the navigation reliability, the easier the navigational preparation of the flight. From similar considerations and taking into account technical capabilities, tactical and technical requirements for accuracy of coordinate calculation in autonomous mode, such as those specified in Table 1.1. of the flight are formed. Standardized indicators of accuracy of keeping a given trajectory for two-dimensional and three-dimensional navigation are horizontal echelon and keeping an altitude of a given echelon.

Таблица 1.2

Corrective system	Correction conditions	Correction time	Correction accuracy
РСБН	Direct visibility	Almost instantly	$\leq 0.2 \text{ км}$
		100 с	$\leq 0,1 \text{ км}$
РСДН	The coverage area of ground radio beacons	Almost instantly	$\leq 2...3 \text{ км}$
		100 с	$\leq 1...2 \text{ км}$
Optical, electro-	Distance to a	Almost	$\leq 0.2 \text{ км}$

optical viewfinders	landmark 10 km	instantly	
		^{10 c}	$\leq 0,15 \text{ км}$
PJIC	Distance to a landmark 50 km	Almost instantly	$\leq 1 \text{ км}$
		^{30 c}	$\leq 0,5 \text{ км}$
КЭHC (across the field relief)	Medium rugged (hilly terrain)	100 c	$\leq 0,15 \text{ км}$
КЭHC (on the Earth's anomalous field)	Height of the pole 15 km	300 c	$\leq 0,1 \text{ км}$
Satellite navigation systems	No restrictions in the long run		$\leq 0,1 \text{ км}$

In addition to determining the coordinates of the location of the aircraft, the task of NSP is to ensure accurate piloting and, in particular, keeping the aircraft on the specified trajectory.

There are two types of horizontal echelon: longitudinal and lateral. Longitudinal echelon is performed so that the distance between the aircraft along the track line or time interval of overflight points of obligatory notification at one echelon were never less than the approved values. Longitudinal echelon is provided by maintaining the flight speed or compliance with the crews of the dispatcher requirements to fly over the designated point of obligatory communication at a given time.

With the radar control the norms of the longitudinal separation are 30 km on the tracks, 20 km in the aerodrome area. In the absence of radar control, the standard longitudinal echelon, measured in time, set at routes of 10 min when flying the same route.

The lateral deviation of the shortest distance of the point which corresponds to the position of the aircraft's center of mass to a given line of travel is set for aircraft of all

departments at 10 km (5 km in each direction from the axis of the air route). This is also taken into account in determining the precise requirements for autonomous navigation aids and correction methods. Errors from altitude in en-route flights determine (Taking into account additional factors, in particular piloting errors) echelons of altitude. Vertical echelons are distributed depending on geographical direction of flight (from magnetic heading (MC)) $MC = 0...179$ i $MC = 180...359$. The echelon scheme is shown in Fig. 1.2. The echelon scheme is shown in Fig. 1.2. The altitude intervals between oncoming routes at low and medium altitudes (up to 6000 m) are 300 m, and between oncoming routes 600 m. At altitudes up to 12000 m these intervals are doubled. At altitudes higher than 12000 m intervals are 1000 m between oncoming routes and 2000 m between passing routes.

Echelons are counted from a reference level corresponding to the average statistical level of the Baltic Sea. The altitude of a given echelon

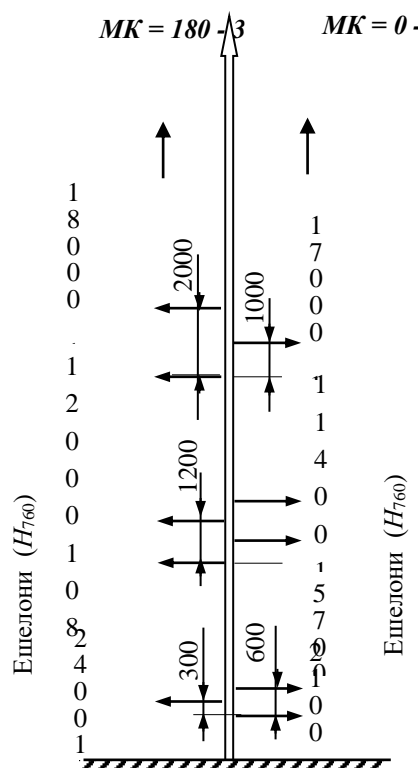


Рис. 1.2

is measured as the barometric altitude. The barometric altitude meter scale zero is set to a pressure of 760 mm Hg.

When determining the minimum echelon altitude, the terrain relief must be taken into account. The safe true altitude is established based on experience of flying in different conditions and depends on the terrain.

The lower safe altitude is determined by rounding the safe true flight altitude to the nearest upper altitude. The band taking into account terrain overruns and artificial obstacles when calculating the lower echelon and safe altitude is taken within the width of the air route. Selecting the minimum true flight altitude $H_{\text{H min}}$ depending on the height of the terrain H_{p} is explained in Fig. 1.3

2.2 Reliability and safety requirements.

Going beyond the designated corridor or flight echelon is a navigational event, which is associated with a dramatic increase in the possibility of accident or disaster. Reliability of navigation depends not only on onboard equipment, but also on ground equipment and air traffic control system. However, the onboard equipment plays a decisive role.

Reliability of navigation is determined by the accuracy and reliability of the NCP. In this case, accuracy requirements are set such that the possibility of navigational events *zavdyahkih natural vikidivnyh* random processes would be minimal. However, failure of even the most accurate NCP can lead to a navigational accident. Therefore, higher requirements are imposed on its reliability.

High reliability of reliable aeronautical-navigation information acquisition is provided by functional redundancy and developed NAV control, so in modern aeronautical-navigation complexes, operability in path counting mode is usually saved at least in two failures.

All this is taken into account in the specifications for reliability and safety of navigation. It is also taken into account the presence of such a control system, which provides reliable identification of a faulty subsystem and automatically turn it off or signal a failure.

2.3 Ergonomic requirements.

One of the main ergonomic requirements to NSP is the ease of control of all its operating modes, combined with the convenience of displaying pilot-navigational

information. These issues will be discussed in detail when teaching the principles of information display systems.

Ergonomic requirements provide for an optimal combination of automatic, director and manual control of the aircraft. When developing such requirements for NSP, it is advisable to proceed from the maximum degree of automation, keeping the upper control level behind a human, using manual control as a backup, if possible, excluding situations when a pilot plays the role of a passive observer.

2.4 Requirements for the operational manufacturability of NCP.

Most of the systems and devices, which are part of NSP, to achieve their maximum possible accuracy require calibration work, alignment, exhibition, metrological support, associated with significant time costs. Meanwhile, the efficiency of NSP can be talked about only in case of ensuring a short duration of all kinds of preparations, fulfillment of conditions of convenient use of NSP in flight, as well as at a sufficiently high operational manufacturability. One of the important operational requirements for NSP is the convenience and relatively short duration of the exhibition of inertial systems. In the future, the azimuth display of ANS can be made both by gyrocompassing, and by landmarks (including during the stages of return to the programmed aerodrome and landing approach).

CHAPTER 3.

GROUND SUPPORT FOR STDC REGIMES DURING THE PRE-LANDING MANEUVERING

3.1 Radio technology systems for short-range navigation

Radio-based close-range navigation systems are combined angle measuring and ranging systems consisting of ground and airborne subsystems. They provide simultaneous measurement of bearing

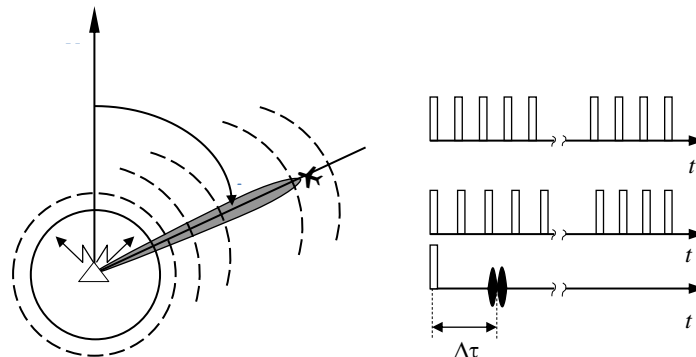


Рис. 3.1

(azimuth) and slant range of the aircraft relative to the radio-navigation point. This makes it possible to simultaneously obtain two position lines - a line of equal bearing of the aircraft and a line of equal distances to the radio-navigational point and thus to determine the position of the aircraft in the polar coordinate system.

The SSRs consist of a ground-based angle measuring and ranging radio beacon and onboard equipment and provide direct measurement on board the aircraft of the bearing and slant range of the aircraft

in relation to the location of the radio beacon. In accordance with ICAO recommendations in areas of high airspace density The standard is to have an omnidirectional ultrashort-wave (VHF) beacon supplemented by a radio beacon and a radio locator,

The standard is to have an omnidirectional ultrashort-wave (VHF) radio beacon supplemented by a radio locator. Such a combination of an omnidirectional beacon and a radio beacon is the basis of most short-range radio navigation systems, both in the CIS and abroad: these are the domestic system of the RSBN type and foreign *VOR/DME* и *TAKAN*. System *VOR/DME* is formed from two radio beacons of the angular *VOR* and rangefinder *DME*, which can also be operated as independent navigation aids.

The polar coordinates measured with the SSBN are displayed on digital or arrow-numeric displays.

The slant range is measured according to the "request-response" principle. The range is determined by the total time of the request signal from the aircraft to the ground and the corresponding signal from the ground to the aircraft. The measured time interval is converted either into information of devices like PPD, which show the range to the radio beacon, or is used in algorithms of correction of the calculated coordinates of the position of the aircraft.

The range request pulse is generated on board the aircraft with a frequency of 30 Hz, which determines the discreteness of range information acquisition with a period of $\tau \cong 0,03$ c. The corresponding pulse is formed by the range channel of the radio beacon, which can simultaneously operate with 100 aircraft.

The aircraft's azimuth is determined by measuring the time delay between the reference pulse and the azimuth reference pulse, which is formed by the beacon and received on board the aircraft. The radio beacon has two antenna systems, one of which provides a circular (omnidirectional) radiation pattern (Fig. 3.1), and the other (azimuthal) generates a narrow, bipedal beam that rotates along the azimuth with a fixed speed $n = 100$ rpm .

On the axis of the azimuthal antenna there are magnetoelectric sensors of reference signals, which form pulses every 10° i 10.25° of rotation of the antenna (respectively 36 and 35 pulses per one revolution). These pulses are emitted by the omnidirectional antenna of the beacon and received by the onboard receiver. The coincidence of pulses "35" i "36" occurs only once per complete revolution of the antenna at the moment when the measuring axis of the rotating radio beam is directed exactly to the north. At this moment a pulse of the beginning of azimuth reference is formed on board the aircraft (reference pulse 1 in Fig. 3.1).

In time after formation of the reference pulse a signal from the rotating azimuth antenna arrives at the input of the aircraft receiver and thus an azimuth reference pulse is formed. The time interval between the reference pulse and the azimuth reference pulse characterizes the aircraft azimuth. Its direct measurement by the onboard circuitry is

performed by counting the number of "36" pulses per period and measuring the time between the last of these pulses and the azimuth reference pulse. The period of discreteness of obtaining information is $n = 0.6$ s. Information is verified at time intervals between the last of pulse "35" and the azimuth reference pulse.

The operating principle of the VOR radio beacon is based on the phase method of azimuth measurement. The rotating antenna of the beacon radiates a transmitter signal with a cardioid beam into space. At the receiving point, this signal is modulated in amplitude by a sinusoidal law with a frequency of 30 Hz because of the rotation of the antenna. The second part of the transmitter signal is amplitude modulated by the signal from the opto-mechanical sensor of the rotating antenna at a frequency of 9960 Hz and is radiated into space by the stationary antenna.

The reference and azimuth signals are phased in such a way that the phase difference is equal to zero if the aircraft is exactly on the north direction. In other directions the azimuth of the beacon is determined by the phase difference.

A wide range of navigational tasks are solved with the help of the SSR. The measured azimuth of the aircraft and the range to the radio beacon make it possible to determine the coordinates of the aircraft location. Knowing current coordinates of the aircraft allows controlling the path, correcting calculated coordinates, performing a flight along a given route, taking the aircraft to a given point, determining a number of navigational elements of the flight, etc. In some cases each of the measured navigation parameters can be used independently.

All angle-measuring and distance-measuring systems operate in the VHF band, and therefore the range of operation cannot exceed the range of radio visibility D_{pb} , although in their energy potential some of them are capable of providing ranges far in excess of D_{pb} . To increase the range of SSRs, it is necessary to increase the altitude of the aircraft.

Note that an important characteristic of an SSR next to range and accuracy is the capacity. Since the range channel of the SSR works on "request-response" principle, the capacity of the SSR is always limited and for the existing systems is 30 ... 100 aircraft. The azimuthal channel of the SSR has no limitations.

As noted above, radio systems for short-range navigation consist of ground and airborne subsystems. The ground-based radio systems consist of:

ground-based SSBN equipment, which is an omnidirectional azimuthal-distance radio beacon with a control point;

mobile radio beacon group comprising a homing beacon, a glide beacon and a landing range repeater.

The aircraft part of the SSR consists of three functionally independent subsystems: azimuth and range measurement channels;

Analog computing device containing Navigation Calculation Block (NCB) and Landing Calculation Block (LCB);

measuring channels of deviation from course zone and glide path of landing;

The RSBN system can be adjusted both for the navigation mode and for the landing mode by means of special programs corresponding to the particular flight task. But in civil aviation of Ukraine and CIS countries the main landing systems are landing systems of meter range, which apply the principles implemented in the international landing system ILS.

3.2 Radio landing systems

At present, the main landing systems (SP) in the civil aviation of Ukraine are SP-50, SP-70 and SP-75 type landing systems.

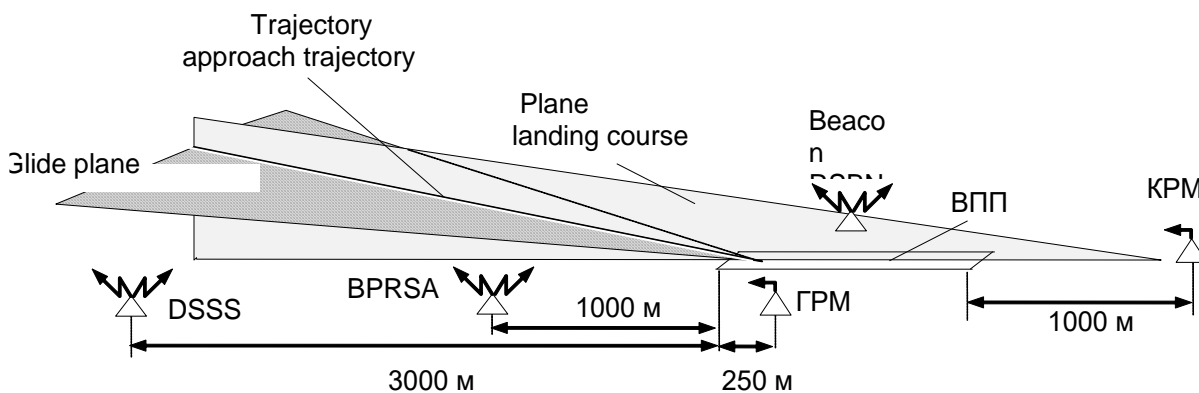


Fig.3.2

The JV includes course, glide path and marker beacons. The approach trajectory is formed by the equal-signal zones of the course beacon (CRM) and the glide path beacon (GMB), the cross section of which becomes the approach trajectory. Fig. 3.2 shows the location of the radio beacons relative to the runway and the principle of formation of the approach trajectory.

The antenna of the course radio beacon, which consists of a carrier frequency generator, 90 and 150 Hz modulators, distributor and phasing device, forms a two-blade pattern that intersects in the plane of the landing course (Fig. 3.2) a vertical plane coinciding with the beginning of the runway axis. In one lobe, the carrier frequency is modulated at 150 Hz and in the other at 90 Hz. In the plane of the landing course (the equal-signal area of the course radio beacon), the modulation depth of both lobes is the same, and when deviating from the course line (runway axis) one or another frequency prevails depending on the direction of deviation of the aircraft. The aircraft's on-board cue radio detects modulation frequencies of 90 Hz and 150 Hz and compares the modulation depth of both signals. The difference in modulation depth carries information about the magnitude of ε_k – the deviation of the aircraft from the equinoctial zone of the course beacon.

The antenna of the glide beacon also forms a two-blade pattern. The upper lobe is dominated by 90 Hz modulation and the lower lobe by 150 Hz modulation. At the equal-signal direction, which forms the glide plane of the aircraft planning, the depth of modulation of both signals is the same. The plane of the glide path is perpendicular to the plane of the landing course and inclined to the horizon by an angle of $\Theta_r = 2^\circ 40' \dots 3^\circ$.

A peculiarity of control loops is that angular rather than linear deviations from the trajectory are used for control (ε_r – is the angular deviation of the aircraft's center of mass from the plane of the glide path, ε_k – angular deviation of the aircraft's center of mass from the plane of the landing course). Naturally, the antenna of the glide radar has narrower lobes of the directional diagrams and, accordingly, a narrower equipotential zone.

The long-range drive radio station (DDRS) and the short-range drive radio station (LDRS) emit special coded signals. From these signals the pilot determines the distance to the runway and, using an altimeter, once again makes sure that the aircraft is moving correctly on the glide path.

Meter range landing systems have a number of significant disadvantages. In particular, the course and glide line are strongly influenced by the terrain and surrounding local objects, are very sensitive to hardware adjustment and require periodic flight tests. In addition, they cannot be used to provide optimal landing trajectories for different types of aircraft. Therefore, MLS microwave landing systems, for which ICAO recommends using 5 GHz frequency band, are intensively introduced in civil aviation practice. There are two principles of MLS operation: directional scanning and Doppler frequency shift.

The principle of MLS with directional scanning is illustrated in Fig. 3.3, a.

The MLS antenna array has a narrow beam that scans within a given sector θ at a strictly defined speed. The angular deviation of the aircraft center of mass from the plane of landing course is calculated by the formula

$$\varepsilon_k = k(t - T_0),$$

where k – coefficient ($k = \theta/T_{ck}$, here T_{ck} – scanning time); t – time between irradiation of the aircraft at the moments of forward and backward stroke of the beam; T_0 – reference time, defining the position of the plane of the landing course ($T_0 = 0,5 T_{ck}$).

The Doppler MLS uses linear antenna arrays with radiation sources switched due to which the motion of the source along the aperture is simulated (Fig. 3.3 b). The dependence of the Doppler frequency shift on the direction to the aircraft k is

determined by the formula

$$f = \frac{V}{\lambda} \sin \varepsilon_k$$

where V – Transmitter speed, λ – is the wavelength of the emitted signal.

The Doppler MLS allows to practically exclude the influence of local objects and over-radiation from the Earth.

Microwave landing systems have improved accuracy and are compatible with other systems, allowing the formation of approach trajectories that are optimal for different types of aircraft.