Assessment of the glide slope entry quality and crew training methodology

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Abstract. The most difficult flight stages for the crew are descent and landing in the directional or manual mode of control, which require increased attention of the pilots to maintain the specified parameters: course, altitude and speed, simultaneously controlling: the systems for increasing of lift wing, extraction of the landing gear, and the thrust of the power plant. Therefore the theoretical and experimental studies presented in the work allow us to give recommendations to the flight crew to improve the quality of the piloting technique before and after entering the glide slope. The possibility of determining the psychophysiological tension of pilots according to the flight parameters is shown. The probabilistic boundaries of the aircraft entering the glide slope are determined. They represent a functional relationship in the form of an ellipsoid. The resulting function makes it possible to estimate the deterioration in the quality of the glide slope entrance, as well as the ability to predict this using autocorrelation functions. It can also be used to assess the quality of crew piloting techniques.

1. Introduction

Among all the stages of the aircraft's flight, the most difficult and stressful the pilots is landing approach. It begins at the entrance of the aircraft to the aerodrome area and pre-landing maneuvers. The main task of pre-landing maneuvering is to bring the aircraft to a given point in the airspace, which is on the imaginary extension of the axis of the runway at a set altitude and range. It is the entry point into the glide slope. According to the practice, one of the factors of successful landing depends on the accuracy of entry to this point. The trajectory of the glide slope is formed by glide slope and localizer beacons. The equal signal zone of the two-petal diagram of the radio signals of the localizer beacon forms the vertical plane of the landing course, and the horizontal plane of the glide slope is formed by the two-petal diagram of the radio signals of the glide slope beacon. The intersection of the above planes forms a line that determines the trajectory of the approach to the landing of the aircraft. The signal of the localizer beacon is received by the course radio installed on board, and the glide slope beacon signal is received by glide slope radio of onboard equipment. The course and glide slope radio generate the corresponding signals of an angular deviation of the aircraft from an equal signal zone of the localizer beacon and glide slope beacon. The angular deviation along the glide slope is directly proportional to the linear deviation in height from the glide slope plane and is inversely proportional to the range of the aircraft to the glide slope beacon. The angular deviation of the course is directly proportional to the linear deviation from the plane of the landing course and inversely proportional to the range of the aircraft to the localizer beacon. The difficulty of piloting the glide slope is a presence of oscillating movements of an aircraft. They interfere with an exact retention of an aircraft on the glide slope. The movement of an aircraft on the glide slope is carried out to the height of the decision to land or depart for the second lap. The height of decision-making according to ICAO depends on an operational category (with a certain horizontal visibility: I category - more than 60 m; II category - from 30 to 60 m; III category - 0 m). Next, the aircraft is leveled, landed.

2. Features of approach in director mode

The main flight stages of a modern aircraft are takeoff, climb, en-route, descent and landing. An analysis of flight accidents over the past decade has shown that the largest number of emergencies occurs at the landing stages. Therefore, consider the process of an aircraft approaching.

There is a visual approach and landing approach using avionics equipment. Instrumentation equipment allows for a precision approach with use of: GLS (GNSS Landing System), ILS (Instrument Landing System), RAPCON (Radar Approach Control System) and non-precision approach with use of: NDB (Non-Directional Beacon) and VOR / DME Beacon and avionics equipment.

The most used today is the Instrument Landing System. This system can be used both in director mode and in automatic landing control mode up to touchdown of a runway. But most airlines require pilots to land in director (manual) mode so that they do not lose control skills.

Modern aircraft make a cruise at altitudes of 30 ... 40 thousand feet, this is the most economical flight mode. During preparation of landing, it is necessary to descend to the "Initial Approach Fix" (IAF) (Figure 1). Before starting the descent, we ask the Al-route Controller for permission to proceed with the descent [1].

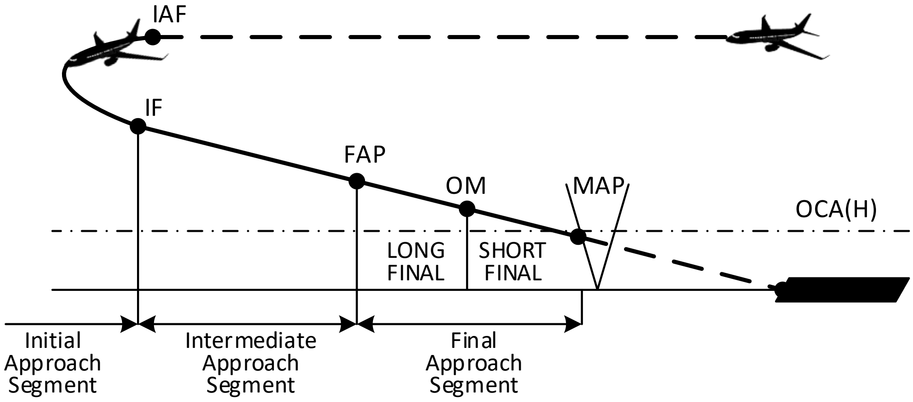

Figure 1. Scheme of the approach. *Source: https://skywaypublic.ru/publ/letnaja_ehkspluatacija/ehtapy_instrumentalnogo_zakhoda_na_posadku/2-1-0-30*

From the IAF point movement begins according to the approach scheme to the aerodrome and approach [2]. Approach according to the scheme implies further descent, passing the trajectory set by a number of control points "Intermediate Approach Fix" (IF) with certain coordinates, often making turns and, finally, entering the runway. At a certain point on the "Final Approach Point" (FAP) at altitudes from 1000 to 3000 feet and from a distance of 5-10 miles from the runway threshold, the aircraft enters the glide slope.

ILS equipment includes ground beacons: localizer, glide slope and marker beacons, as well as the corresponding avionics equipment on the aircraft. The range of the ILS localizer beacon is 20 ... 25 miles, which makes it possible to receive a signal from it at the stage of descent and helps the crew to get on the correct runway course. To receive signals from the ILS system, it is necessary to tune the frequency of the navigation receiver to the frequency of the localizer, and the frequency of the glide slope and DME rangefinder in the runway area will be automatically tuned according to the frequency tables stored in the Flight Management System (FMS) navigation computer. Before entering the glide slope, the ILS should receive a glide slope beacon signal with a maximum range of 10 ... 11 miles. Upon receipt of signals from both radio beacons, two flight directors are visible on the display (PFD), which provide trajectory control along the course and height, while the distance to the runway is determined by the DME.

The antenna system of the localization radio beacon ILS forms a heading line with two lobes of electromagnetic waves, in which the control signals of the envelope frequency have the following values: left - 90 Hz and right - 150 Hz (Figure 2).

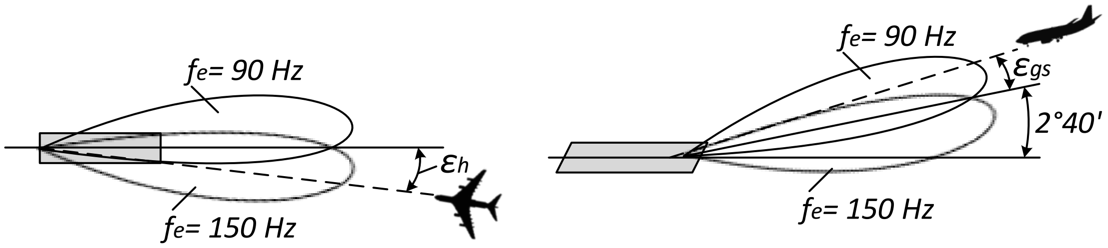

Figure 2. ILS glide slope formation scheme. *Source: https://www.popmech.ru/technologies/7970-vstrecha-s-zemley-posadka-samyy-slozhnyy-etap-poleta/*

The heading line coincides with the equal-signal zone between these lobes, therefore, on the heading line, the difference in the modulation depths of signals with frequencies of 90 and 150 Hz is zero. The radio frequency of the carrier oscillation of the localizer is within 108 - 112 MHz. Each beacon has a separate name and a separate stable carrier frequency, to which the onboard equipment is tuned during landing.

While approaching, the signal with a frequency of 90 Hz predominates to the right of the equisignal zone, and a signal with a frequency of 150 Hz to the left. The greater the deviation from the course line, the greater the difference in the modulation depths of signals with frequencies of 90 and 150 Hz and the magnitude of the deviation signal. The sign of the deviation signal is determined by the direction of the aircraft deviation, therefore, the localizer deviation director signal is displayed on the crew display in proportion to the magnitude and direction of the aircraft deviation from the landing course line.

The radio technical glide slope is created by the antenna system of the ILS glide slope channel also by two lobes of electromagnetic waves, in which the control signals of the envelope frequency have the following values: upper - 90 Hz and lower - 150 Hz. The radio technical glide slope coincides with the equal-signal zone between these lobes, in which the difference in modulation depths of signals with frequencies of 90 and 150 Hz is zero and accordingly a signal with a frequency of 90 Hz prevails above the glide slope, and a signal with a frequency of 150 Hz prevails below the glide slope. The radio frequency of the carrier oscillation of the glide slope beacon is in the range of 332.6 - 335 MHz. The standard slope of the equisignal zone of the glide slope, which means the descent path is 2 ° 40 '.

While following the glide slope, the aircraft reaches the MAP (Missed Approach Point), or missed approach point. This point is passed at the height of decision making (DM).

When landing in automatic mode, it is necessary to select the descent or landing mode on the FCC control panel, select the runway course and descent speed. In addition, there is a choice of ILS or GLS landing systems.

In flight director mode, the crew controls the aircraft manually according to the position of flight directors. In both modes, radio communication with the dispatchers of the areas of responsibility is obligatory: Al-route (Area) Controller, Approach Controller, Tower Controller, Runway Controller and Ground Controller, the passage of marker radio beacons is controlled, and manual control of wing mechanization and landing gear is performed [3].

3. Assessment of the quality of the entrance to the glide slope

The conducted theoretical and experimental studies allow us to give recommendations to the flight crew of airlines to improve the quality of the piloting technique before and after entering the glide slope [4-10]. Let us consider the scheme for obtaining initial data from objective control systems and methods of their processing (Figure 3).

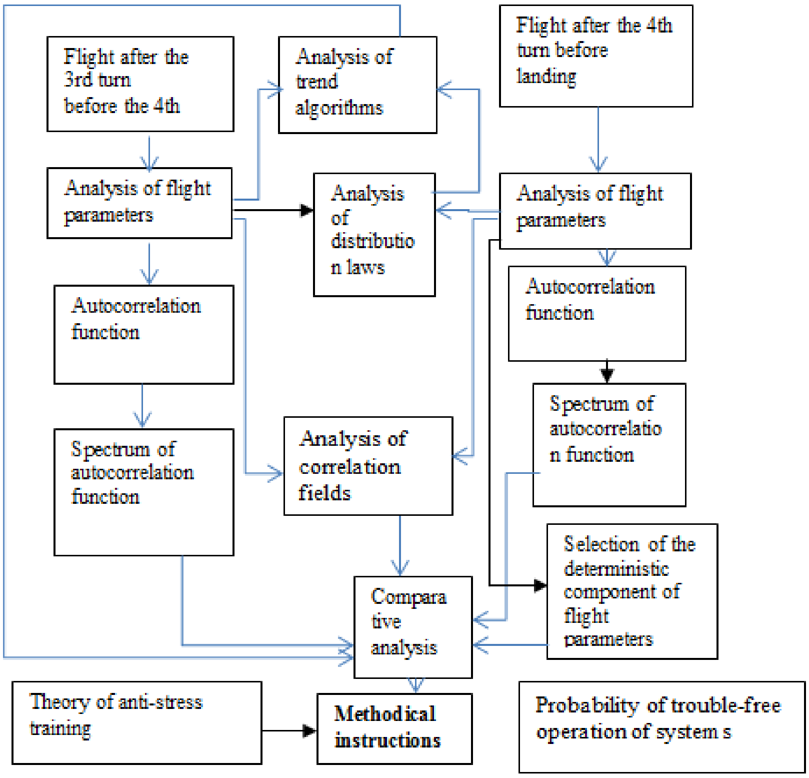

Figure 3. The scheme of obtaining initial data from objective control systems and their provision to the instructor staff.

Earlier, as a result of research work on a complex simulator, the possibility of determining psychophysiological stress according to flight parameters was proved. The research was conducted on complex simulator Tu-154 B2. From the instructor's console the block of failures after the fourth turn before landing was given. They were selected in such a way that they did not affect the aerodynamics of the flight and were duplicate devices. Their simultaneous effect created psychophysiological tension. The quality of piloting equipment for most pilots was deteriorating.

The results of research on the complex simulator Tu-154 B2 were confirmed by the analysis of "flights" on the complex simulator An-148. This aircraft is equipped with modern avionics. In addition, the introduction of more complex failures revealed a deterministic component that can adversely affect the quality of the piloting technique. It was also found that for flights without simultaneously acting failures, the statistical distribution of the roll angle and pitch do not contradict the normal distribution, and for the simultaneous action of more than two failures, the Weibull distribution.

All indicated in figure 1 analysis data should come in the form of tables with coefficients of deterioration of the quality of piloting equipment according to the presented criteria for evaluating the ergatic control system of the aircraft.

The quality of the landing depends on the accuracy of the previous stages of the approach. Of great importance is the accuracy of the entrance to the glide slope. As a result of the analysis of correlation functions, the possibility of estimating the intensity of the pilot at the entrance to the glide slope point on the complex simulator [5-7] was mathematically established. In this regard, the introduction of failures on the complex simulator should be given from the end of the third turn to landing.

As a result of the research, the probabilistic boundaries of the aircraft's entry into the glide slope were determined. They are a functional dependence in the form of an ellipsoid. As experience show the probabilistic boundaries of an aircraft's entry into a glide slope can be useful for assessing the quality of piloting techniques. For this, it is sufficient to have the coordinates of the aircraft that determine its position in three-dimensional space. They can be used to calculate the probability of inaccurate entry into the glide slope.

$$\frac{x^2}{\frac{\Delta}{L}\frac{1}{\frac{1}{3}-\frac{3\chi_1}{L_1}+\frac{2{\chi_1}^2}{{L_1}^2}-\frac{{\chi_1}^3}{3{L_1}^3}}}+\frac{y^2}{\frac{\Delta}{L}\frac{1}{\frac{1}{3}-\frac{3\chi_2}{L_2}+\frac{2{\chi_2}^2}{{L_2}^2}-\frac{{\chi_2}^3}{3{L_2}^3}}}+\frac{z^2}{\frac{\Delta}{L}\frac{1}{\frac{1}{3}-\frac{3\chi_3}{L_3}+\frac{2{\chi_3}^2}{{L_3}^2}-\frac{{\chi_3}^3}{3{L_3}^3}}}=1,$$

where $\frac{\Delta}{L}$ ratio of square of integral difference trajectory of an aircraft's flight Δ to its length L and where each of the semiaxes is determined by the expression:

$$\text{a}=\sqrt{\frac{\Delta}{L}\frac{1}{\frac{1}{3}-\frac{3\chi_1}{L_1}+\frac{2{\chi_1}^2}{{L_1}^2}-\frac{{\chi_1}^3}{3{L_1}^3}}},\quad \text{в}=\sqrt{\frac{\Delta}{L}\frac{1}{\frac{1}{3}-\frac{3\chi_2}{L_2}+\frac{2{\chi_2}^2}{{L_2}^2}-\frac{{\chi_2}^3}{3{L_2}^3}}},\quad \text{c}=\sqrt{\frac{\Delta}{L}\frac{1}{\frac{1}{3}-\frac{3\chi_3}{L_3}+\frac{2{\chi_3}^2}{{L_3}^2}-\frac{{\chi_3}^3}{3{L_3}^3}}}.$$

Thus, the resulting function of the three-axis ellipsoid can be written as

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1$$

A characteristic feature of a three-axis ellipsoid is the formation of ellipses when its surface intersects with planes that are parallel to each of the three coordinate planes (Figure 4).

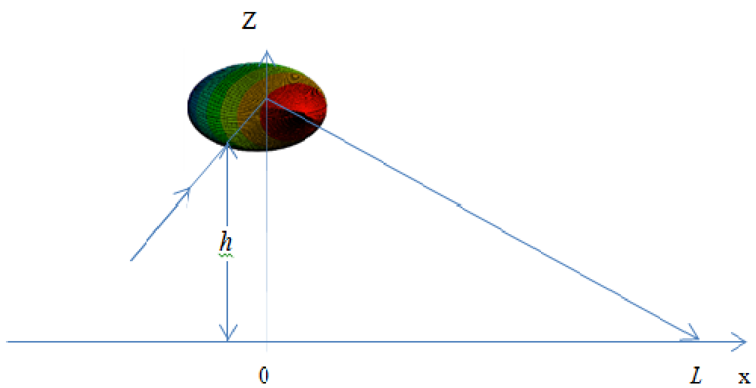

Figure 4. The graph of dependence f (x, y, z) at the entrance to the hisssad after the third turn, where Δ - is the square of the integral difference of flight trajectories (planned and real) in a certain segment, L — is the length of the glide slope, h — is the initial height at the moment of landing.

The obtained results of our research coincide with the data presented in the paper [8]. It addresses the issues of hitting the runway accuracy.

As a result, we can estimate the deterioration of the glide slope entry quality by the deviation from the target boundaries and predict this by the autocorrelation functions.

Conclusions

In the presented work, the probabilistic boundaries of the aircraft entry into the glide slope were determined. They represent a functional relationship in the form of an ellipsoid. As experience shows, the probabilistic boundaries of the aircraft entering the glide slope can be useful for assessing the quality of the piloting technique. To do this, it is enough to have the coordinates of the aircraft that determine its position in three-dimensional space. From them it is possible to calculate the probability of inaccurate entry into the glide slope.

It is proposed to determine the psychophysiological tension of the pilot by the autocorrelation functions of the flight parameters. It is advisable to apply these methods for the automated assessment of the quality of the piloting technique.

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