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**Svitlana Pavlova[1],**
**Dmytro Voloshenyuk[2]**

# METHOD OF AIRCRAFT LANDING BY CURVILINEAR GLIDE PATHS WITHIN THE BOUNDARY TRAJECTORIES

National Aviation University
Kosmonavta Komarova Avenue 1, 03680, Kyiv, Ukraine
E-mails: [1]psv@nau.edu.ua; [2]p-h-o-e-n-i-x@ukr.net

**Abstract**

***Purpose:*** *The paper is dedicated to improving of civil aviation flight safety question by the way of new method of aircraft landing by curvilinear glide paths within the boundary trajectories. Proposed method ordered for improving of safety level, sustainability and cost effectiveness of the aircraft landing with own individual, optimal vertical descending profile from flight level to the runway threshold.* ***Methods:*** *Landing method, based on generation (calculation and construction) of virtual curvilinear glide paths of landing within the boundary trajectories with taking into account of "fully controllable state areas" of aircraft has been proposed.* ***Results:*** *New aircraft landing method that has large profit in the reducing of the level of noises, fuel consumption and harmful emissions.* ***Discussion:*** *The essence of the method consists in using of fully controllable state areas that are constructed taking into account on linearity in aircraft flight characteristics, probable changes into environmental state, criterion of landing implementation optimality, all functional and aerodynamic aircraft capabilities for virtual curvilinear glide path construction, meant by some aircraft traffic trajectory for time and distance reducing, that are necessary for stage from start of descending from flight level to runway threshold.*

**Keyword:** aircraft; air traffic; border trajectory; curvilinear glide path; landing method.

## 1. Introduction

Today civil aviation flight quantity is growing constantly, that leads to growing of aviation noises level, atmosphere pollution amount and flight control devices overweighting. Because of strict international legislation regulation of ecological safety rules, some limits of aircraft exploitation in airports have appeared correspondingly.

For these problems solving, the mission of aviation industry system creation correspondingly sets, that would allow:

– elevating of the ecological and economical level of flights quantitatively and qualitatively in aviation in general;

– essential elevation of safety flight level;

– unloading of holding area in the airport area;

– solving of the airport overloading problem, that is appearing afterwards rising of air traffic intensiveness;

– increase the efficiency of using aviation vehicles, etc.

Landing of the aircraft is the most responsible and difficult stage, that characterizes by the changing of flight mode, psycho physiological stresses and impermanence. Successive landing approach problem solving requires: clear crew definition of rules and landing approach accomplishment order; equipment of airfields, landing zones by special technical systems; development of methods, recommendations for the crew about usage of the landing systems and about operations during exceptional or dangerous situations. This is precisely why the new landing method development, which would at least partially solve the issue of air traffic conformity to modern aviation requirements and that would allow to assure ensure the operation of air transport in the conditions of a sharp increase in air traffic - is the actual problem.

## 2. Analysis of recent research and highlighting the unresolved part of the problem

Modern status of research in the area of aircraft safe landing conditions definition characterizes by variety of approaches to improving air traffic control (ATC) procedures and aircraft control by automating the actions of air traffic control specialists and aircraft crews. Scientific problem solving of the development of methods, models and devices of informational decision making support for construction of optimal landing trajectory for further advancement of aviation safety level and improvement of ecological and economical aircraft usage rates is an important problem today.

After analyze of literature sources [1-8] further conclusions could be done - one of the efficiency improvement methods is an aircraft landing by border(free) trajectories. For example, such is the principle of the “flexible” trajectories [4]. Principle of the “flexible” trajectories implements a program strategy of control and it is in realization of “flexible”, updating (frequently recalculating) with prescribed period, programmatic trajectory of aircraft movement, that provides accomplishing of the control during the “real conditions”.

Principle resides in refusal of matching of controlled aircraft movement to preplanned (nominal) trajectory and formation (if necessary) of much more profitable traffic trajectories, correspondingly to current situation, on the assumption of factual conditions of the aircraft movement.

Basic difficulties of solving the problem of control for “flexible” trajectories are stipulated by its double point border character. Quite effective concept of its solving bases on usage of, so called, method of inverse dynamic problems. A characteristic feature of which lies in the fact that, at first, program aircraft movement is designated (that fulfills prescribed border conditions) and then control that realizes this movement is determined. However, such concept is unfit for general class of nonlinear control objects.

## 3. Statement of research problems

In basis of the work, creation problem of a new aircraft landing method has been set. This method would be directed to correspondence to current civil aviation requirements and enhancement of ecological level and flight economical efficiency.

The aim of the work is development of the generation method (calculation and construction) of virtual curvilinear glide paths of landing within the boundary trajectories with support of his own individual, optimal vertical descending profile from flight level to the runway threshold [9].

The aircraft landing by curvilinear glide paths is the procedure, during that an aircraft descends uninterruptedly from the horizontal flight to the landing with minimal thrust use [10-11].

An accomplishment of the assigned problem in the developed method provides that before the start of the aircraft landing maneuver, generation (calculation and construction) of the virtual curvilinear glide paths of landing within the boundary trajectories is carried out, for which in the method:

– data from ground-based dispatch center or from available onboard database about terminal aircraft landing point (her coordinates and characteristics of the runway, location, peculiarities of an airport), aircraft onboard system’s data about current state of an aircraft, flight mode and characteristics and environment conditions, physical and aerodynamic parameters and characteristics of concrete aircraft type are using;

– construction of fully controllable state areas (in consideration of “margin of control”), including “zones of uncertainty” (ability of deviation during the calculation of exact aircraft coordinates, with periodical prediction of terminal state implementation) is providing;

– virtual curvilinear glide paths of landing within the boundary trajectories are being calculated and analyzed on the basis of total received data (trajectories that require the least resources and aircraft capacities, time and distance for the stage from the moment of the start of the flight level to the stop of the aircraft in the runway).

Besides, this method includes calculation algorithms of the landing trajectory performance optimality with maximal usage of the aerodynamic components of the aircraft control system and minimal use of engines trust.

The analyzing and calculating process of virtual curvilinear glide path of landing is taking place in real time scale (with constant recalculation for every moment of time that takes as initial), with taking into account of all possible changes during the flight process [12].

## 4. Method of aircraft landing by curvilinear glide paths within the boundary trajectories

An aircraft landing by curvilinear glide paths is the method that could provide fluent aircraft descending from flight level with constant angle for landing on the runway. It intends for reducing expenditure of fuel and level of noises by the side of other traditional landing methods.

An aircraft landing by curvilinear glide paths within the boundary trajectories begins from the highest point of the descending start, in other words, on the cruise flight altitude and it allows aircraft to support own individual optimal vertical profile until the runway threshold.

The essence of method is in the accounting of fully controllable state areas of aircraft what are constructed with taking into account “uncertainty zones”, nonlinearities in aircraft flight characteristics, possible changes into environmental state, optimality criteria for aircraft landing, all functional and aerodynamic aircraft abilities for virtual curvilinear glide path construction, which means a certain trajectory of the aircraft to reduce the time and distance necessary for the stage from the beginning of the descent from the flight level to the runway threshold. This will allow to assure guaranteed safety level of aircraft landing, to expand the condition field in which the method can function, to rise the aviation vehicle’s use and crew’s effectiveness, as well as to reduce harmful influence to the environment (as a result of emission and engine noises level reducing) and to assure fuel (material resources) economy.

This method is realized in the following way.

On a specific aircraft that is in flight at the level and approaches to the airport, from the moment of landing approach start in real time scale, exact aircraft situation coordinates are constantly determined (with discretization $\Delta t$) and considered possible deviations and uncertainties of its situation, that have been conditioned by current situation estimation errors, inadequateness of mathematical model, environmental influence, navigational deviations, etc. From the earth-based dispatch center an aircraft receives the exact information about the point of landing (information about territory, runway and environment), and from onboard systems it receives exact information about the status, characteristics and parameters of flight, weather conditions, physical and aerodynamic characteristics of concrete aircraft. Assessment and analysis of total received data are made and, correspondingly, fully controllable state areas of aircraft are calculated. These areas characterize an aircraft movement parameters changing capability during the one moment of time and allows characterizing nonlinearity of the aircraft’s behavior and flight process in general. An example of calculated probable aircraft controllability area $Q$ is shown in fig.1. Parameters of the aircraft’s landing would be calculated thereafter, that are:

– coordinates of the initial point of descend;
– aircraft speed, angle of attack and flight-path angle from the initial point of descending to the terminal point with corresponding changes through the trajectory line of descend;
– coordinates of terminal point of the descend;
– necessary time for an aircraft descend;
– working parameters of the engines with taking into account maximal decreasing of its power;
– parameters of using of all aerodynamic components of the aircraft control system (elevator, ailerons, flaps, interceptors, etc).

Reducing of power of the engines allows decreasing of harmful influence on the environment (reducing of the emission, noises, vibrations and harmful atmospheric discharge near the airport), as well as to rise of the economical efficiency by the way of fuel economy and reducing of the engine wear. Using of all aerodynamic components of the aircraft control system will allow rising of the quality of control during the descend stage, regulating of the speed of the aircraft, to assuring of the worthy level of flight safety. Then, on the basis of the defined parameters, virtual curvilinear glide path of the aircraft landing generates (calculates and constructs).

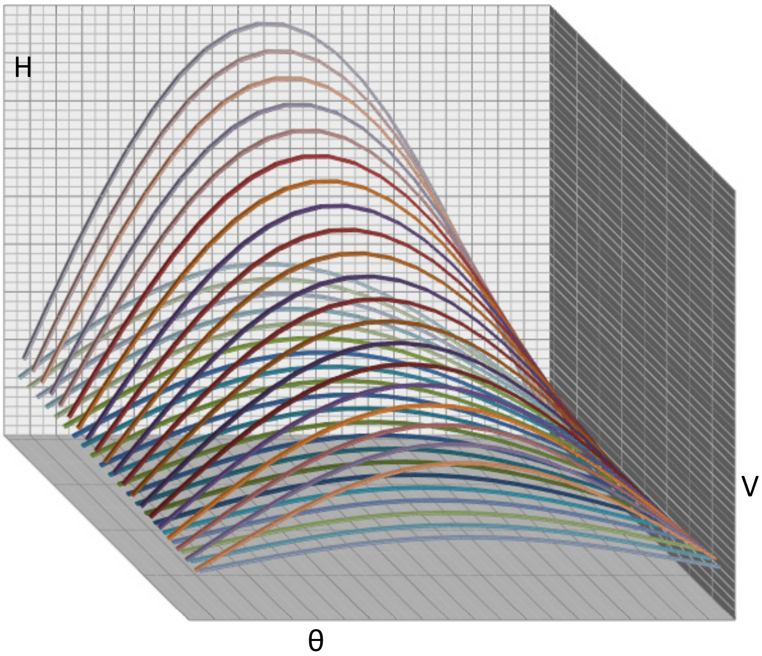


Fig. 1. The example of the projection of the fully controllable state area of aircraft $Q(H, V, L, \theta)$ on parameters $(H, V, \theta)$

The aircraft virtual curvilinear glide path directs to reducing of time and distance, that are necessary for descending of an aircraft, assurance of maximal precision of the descending maneuver accomplishment by the way of virtual curvilinear glide path updating in each moment of time with prescribed discretization (generation of the glide path takes place in the real time scale), accomplishment of each plane individuality, flight conditions and other parameters. Generation of virtual landing curvilinear glide path takes place in following mathematical tool:

$$r_1 = \frac{V_1^2}{2 * g * (\cos(\theta_1) - n_{y1})} + \frac{V_2^2}{2 * g * (\cos(\theta_2) - n_{y1})},$$

$$r_2 = \frac{V_3^2}{2 * g * (n_{y2} - \cos(\theta_3))} + \frac{V_4^2}{2 * g * (n_{y2} - \cos(\theta_4))},$$

$$\Delta h_1 = -r_1 * (\cos(\theta_1) - \cos(\theta_2)),$$

$$\Delta h_2 = r_2 * (\cos(\theta_3) - \cos(\theta_4)),$$

$$\Delta H = -(\Delta h_1 + \Delta h_2),$$

where $r_1$ - radius of the first part of the landing curvilinear trajectory;

$V_1$ – aircraft speed at the beginning of the trail along the first part of trajectory;

$V_2$ – aircraft speed at the end of the trail along the first part of trajectory;

$g$ – acceleration of gravity;

$\theta_1$ – flight-path angle at the beginning of first part of trajectory;

$\theta_2$ – flight-path angle at the end of first part of trajectory;

$n_{y1}$ – overload along the whole trajectory;

$\Delta h_1$ – altitude drop during the descending maneuver at the first part of the trajectory;

$\theta_3$ – flight-path angle at the beginning of the second part of trajectory;

$\theta_4$ – flight-path angle at the end of the second part of trajectory;

$r_2$ – radius of the second part of the landing curvilinear trajectory;

$V_3$ – aircraft speed at the beginning of the trail along the second part of the trajectory;

$V_4$ – aircraft speed at the end of the trail along the second part of the trajectory;

$\Delta h_2$ – altitu dedrop during the descending maneuver at the second part of the trajectory;

$L$ – distance;

$\Delta H$ – common altitude drop of the whole trajectory.

Assurance of the aircraft landing by virtual curvilinear glide path will allow additionally reducing the workload of pilots, air traffic control agencies, to discharge airports and approach of aviation industry to transition from area navigation to free flights.

Moreover, during the generation of aircraft landing virtual curvilinear glide path mathematical probabilities and adaptive optimality criteria's are used. They are directed to assurance of landing border trajectory construction that is necessary for maximal reducing of time and distance essential for landing, assurance of minimal power of engines on the stage of landing. An illustration of construction of the landing virtual curvilinear glide path within the boundary trajectories is shown in fig.2.

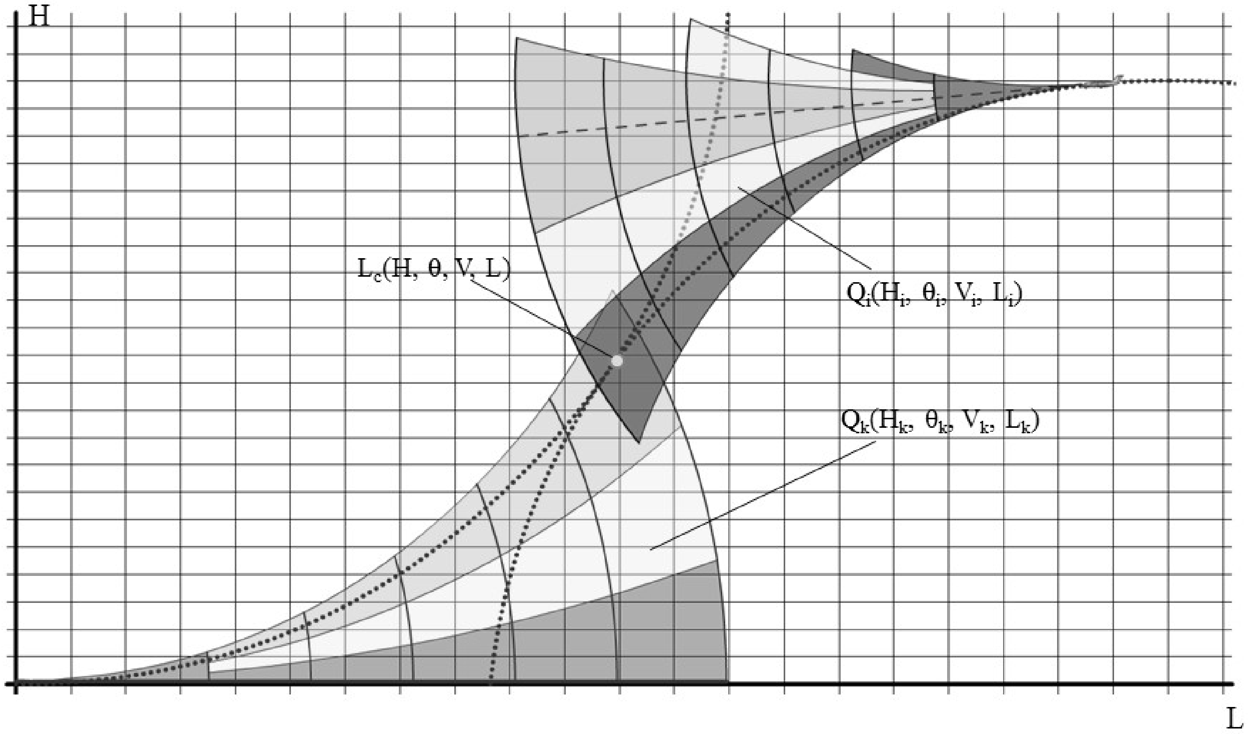


Fig. 2. The illustration of principle of construction of the landing virtual curvilinear glide path within the boundary trajectories ($L_c$ – point of union of two trajectory parts; $Q_i(H_i, V_i, L_i, \theta_i)$ – area of possible aircraft movement trajectories at the first part of landing; $Q_k$ $(H_k, V_k, L_k, \theta_k)$ – area of possible aircraft movement trajectories at the second part of landing)

During the method realization process after construction of landing glide path, test simulation of aircraft trajectory accomplishment takes place for assurance of appropriate safety level. An example of generated virtual landing glide path within the boundary trajectories of the concrete aircraft during the test simulation process is shown on fig.3.

According to the results of test simulation, formation of control commands to the aircraft systems and indication and signalization tools takes place. An example of indication of the probable aircraft movement on the stage of landing by the declared method is shown on fig.4. (square signs - modern standard of an aircraft landing approach by the glide path, round signs - an aircraft landing by curvilinear glide paths).

After the end of implementation of the method (after every landing of the aircraft) recording of all landing parameters and virtual curvilinear glide path to the storage database takes place for the simplification of method realization in case of repetition of flight conditions. Verification to the database takes place at the beginning of every realization of the method.

The method has a cyclic implementation, is performed on each aircraft during the landing procedure in real time.

The aircraft landing by curvilinear glide paths within the boundary trajectories proposes flexible uninterrupted descending flight trajectory during the landing approach, that assures basic ecological and economical profits, including reducing of fuel combustion, gaseous emissions and noise influence without any negative influence on the safety by virtue of:

1) minimal thrust of the engines, that has been set during the descending;

2) minimal atmospheric drag due to active using of aerodynamic components and capabilities of aircraft;

3) enhanced altitude of flight trajectory during the landing approach process.

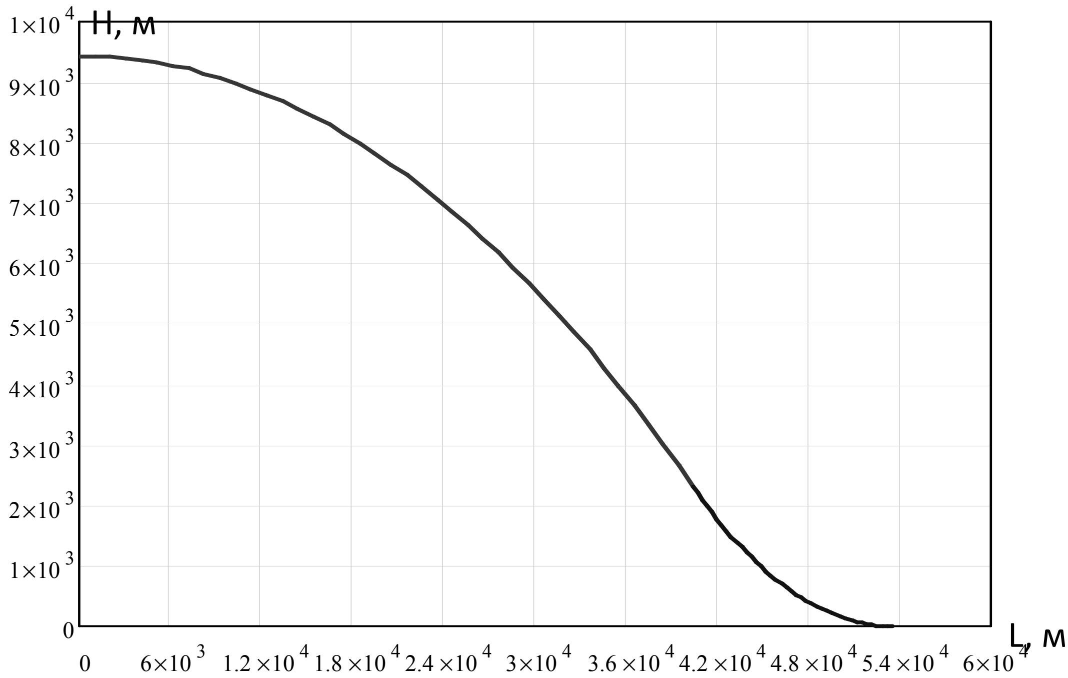


Fig. 3. Example of generated virtual landing glide path within the boundary trajectories of the concrete aircraft

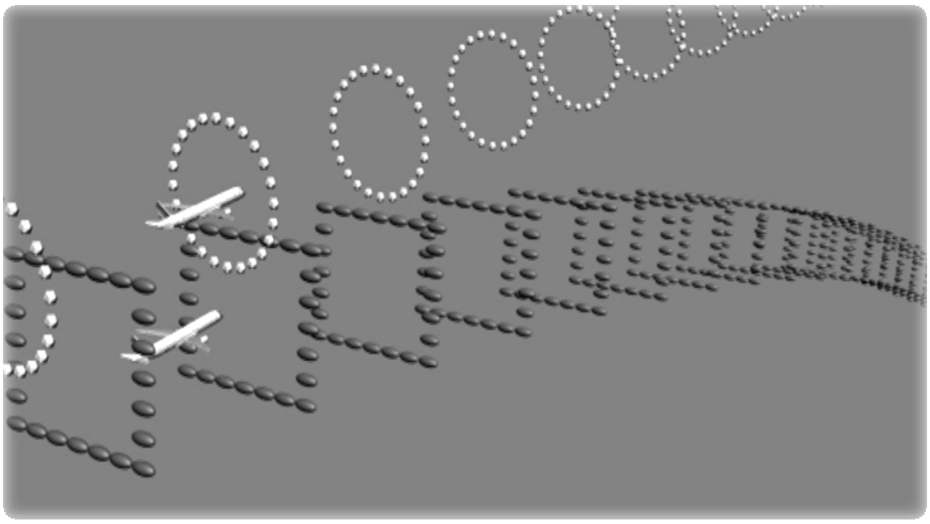

Fig. 4. Indication of probable aircraft movement on the stage of landing

## 5. Conclusions

The aircraft landing by curvilinear glide paths within the boundary trajectories could have essential profits in reducing of the level of noises, fuel consumption and harmful emissions.

The influence on the environment in current time is a serious problem for aviation in complex, so such factor should be considered during the designing of air space and procedures of instrument flights and, also, during the air traffic control.

Method, that has been proposed, is based on using of all aerodynamic and functional aircraft abilities for the control of lift force, speed and drag during the process of descending. Defined, that during the descending all the engines are kept in the mode of "flight-idle". It tends to fuel economy, reducing the level of noises and harmful emissions at the atmosphere. Moreover, construction of the curvilinear glide paths allows reducing of total distance that is an indispensable condition for the aircraft landing from descending from the flight level to the runway threshold from 200 km to around 70 km that reduces time necessary for landing. It would essentially reduce the intensiveness of the air traffic in the airport zones.

It is predicted, that method of the aircraft landing by curvilinear glide paths would allow enhancing of the acceptance rate of the airports by 30-40%.

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**С.В. Павлова[1], Д.О. Волошенюк[2]**

**Метод посадки літаків за криволінійними глісадами в межах граничних траєкторій**

Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mails: [1]psv@nau.edu.ua; [2]p-h-o-e-n-i-x@ukr.net

**Мета:**Робота присвячена питанню підвищення безпеки польотів у цивільній авіації шляхом створення і впровадження нової системи посадки літаків за криволінійними глісадами в межах граничних траєкторій. Запропоновано метод спрямований на підвищення безпеки, екологічності та економічності посадки літаків із підтримуванням свого індивідуального, оптимального, вертикального профілю зниження з ешелону польоту до початку злітно-посадкової смуги. **Методи дослідження:** Пропонується метод посадки, заснований на генерації (розрахунку і побудові) віртуальних криволінійних глісад посадкового зниження, в межах граничних траєкторій, з урахуванням «областей повністю керованого стану» літаків. **Результати:** Новий метод посадки літака, що має значні вигоди в зменшенні рівня шуму, витрат палива і шкідливих викидів. **Обговорення:** Суть методу полягає в розрахунку та використанні областей повністю керованого стану, що враховують нелінійності у характеристиках літака, можливі зміни у стані навколишнього середовища, критерії оптимальності виконання посадкового зниження літака, всі функціональні та аеродинамічні можливості літака, для побудові віртуальної криволінійної глісади, під якою розуміється деяка траєкторія руху літака, що може бути суттєво викривлена на межі його можливостей, для зменшення часу і відстані необхідних для етапу від моменту початку зниження з ешелону польоту до початку злітно-посадкової смуги.

**Ключові слова:** гранична траєкторія; криволінійна глісада; літак; метод посадки; повітряний рух.

**С.В. Павлова[1], Д.А. Волошенюк[2]**

**Метод посадки самолетов по криволинейным глиссадам в пределах граничных траекторий**

Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mails: [1]psv@nau.edu.ua; [2]p-h-o-e-n-i-x@ukr.net

**Цель:** Работа посвящена вопросу повышения безопасности полетов в гражданской авиации путем создания и внедрения новой системы посадки самолетов по криволинейным глиссадам в пределах граничных траекторий. Предложен метод направленный на повышение безопасности, экологичности и экономичности посадки самолетов с поддержанием своего индивидуального, оптимального, вертикального профиля снижения с эшелона полета до начала взлетно-посадочной полосы. **Методы исследования:** Предлагается метод посадки, основанный на генерации (расчет и построение) виртуальных криволинейных глиссад посадочного снижения, в пределах граничных траекторий, с учетом «областей полностью управляемого состояния» самолетов. **Результаты:** Новый метод посадки самолета, который имеет значительные выгоды в уменьшении уровня шума, расхода топлива и вредных выбросов. **Обсуждение:** Суть метода заключается в расчете и использовании областей полностью управляемого состояния самолета, учитывающих нелинейности в характеристиках самолета, возможные изменения в состоянии окружающей среды, критерии оптимальности выполнения посадочного снижения самолета, все функциональные и аэродинамические возможности самолета, для построении виртуальной криволинейной глиссады, под которой понимается некоторая траектория движения самолета, которая может быть существенно искажена на грани его возможностей, для уменьшения времени и расстояния необходимых для этапа с момента начала снижения с эшелона полета до начала взлетно-посадочной полосы.

**Ключевые слова:** воздушное движение; криволинейная глиссада; метод посадки; предельная траектория; самолет.

**Pavlova Svitlana** (1966). Doctor of Engineering. Professor.
Head of the Department of Avionics, National Aviation University.
Education: Kyiv Civil Engineering Institute, Kyiv, Ukraine (1988).
Research area: analysis and synthesis of nonlinear ergatic systems, critical technology, nonlinear dynamics.
Publications: 200
E-mail: psv@nau.edu.ua

**Dmytro Voloshenyuk** (1990). Post-graduate Student.
Lead Engineer, Department of Avionics, National Aviation University.
Education: National Aviation University, Kyiv, Ukraine (2013).
Research area: flight dynamics, intelligent control of dynamic objects.
Publications: 75
E-mail: p-h-o-e-n-i-x@ukr.net