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AUTOMATIC STEERING ALGORITHMS OF THE AIRPLANE SHORT–CUT TOUCHDOWN

Introduction

Condition and trends of modern aviation development cause necessity of researches for a direction of algorithmic ensuring perfecting of automatic landing systems. The last years flight incidents statistics testifies to constant urgency of a problem of the completing flight stage safety raise [1]. Creating the aircraft rescue systems in case of sudden death or consciousness loss of the pilot emergency automatic touchdown also should be provided. And, at last, for an unmanned aviation, landing organization quality is one of major factors of its application effectiveness [2].

In the majority of the publications devoted to airplane landing control, problems of apparatus security [3, 4], navigation and attitude methods [2, 5, 6], the analysis and synthesis of stabilization laws [2, 6], reliability [4], psychological singularities [1] are considered. Selection of a flare path and a mode of its shaping concern to the most important and insufficiently covered aspects of the automatic landing organization problem.

Statement of problem

Let's consider a problem of flare path geometrical and kinematic parameters definition, a mode of its upsetting and stabilization laws, permitting to implement the short touchdown in conditions of the operational disturbances.

Flareout path

Laws of trajectory control at a stage of touchdown should meet the requirements [7]: 1) in tangency point preset values of vertical velocity, pitch angle, ground speed, a place of tangency point on a runway band should be received; 2) the angle of attack, a velocity, controls displacements, vertical overload at motion on the picked line should be of permissible limits; 3) the curve should be the smooth, monotonic, smoothly integrated with a glide path.

Complexity of automation of the airplane classical touchdown all stages (planing, flare, holding, parachuting), and also essential shortages, such as significant spread of touchdown place, low–steering vertical velocity at "caving", causes the other schemes using. The autoflare begins after planing and it is expedient for finishing a tangency of runway.

Trajectory of touchdown is possible to set "rigid", beforehand appointing its each point the certain position concerning tangency point of runway, or "flexible", beforehand appointing only airplane motion parameters in tangency point and a place of a tangency, calculating during flight the law of motion depending on its flowing situation. These two methods at the corresponding supply of information allow to land with pinpoint accuracy runway tangency place arrangement. Thus, there are highly probable excess of legitimate values of angular rates and overloads, and also a tangency vertical velocity. The third, most spread mode, on the contrary, allows to provide the indicated parameters of flight in a time of touchdown and in tangency point at essential spread of a place. In this case, the vertical velocity $\dot{H}_3$ is set proportionally to a present height H:

$$\dot{H}_3 = -\frac{H + H_{ac}}{T_э}. \tag{1}$$

Then at nonperturbed motion a programm flying height

$$H_3 = (H_0 + H_{ac})e^{-\frac{t}{T_э}} - H_{ac}, \tag{2}$$

Where H_0 – a flareout beginning height; H_{ac} – a depth of an exponent asymptote occurence; $T_э$ – time constant of an exponent; t – a time last from a commencement of the flareout.

From expression (2) estimated time of a runway tangency is gained at $H_3 = 0$:

$$t_k = -T_э \ln\left(\frac{H_{ac}}{H_0 + H_{ac}}\right). \tag{3}$$

Proceeding from the above–stated demands to a path of touchdown, it is definable its parameters H_0, H_{ac}, $T_э$. For this purpose at first we shall record a program vertical velocity of an airplane as a time function, having substituted (2) in (1):

$$\dot{H}_3 = -\frac{H_0 + H_{ac}}{T_э} e^{-\frac{t}{T_э}}. \tag{4}$$

For smooth mating the flare exponent to a glide path the program vertical velocity of the flareout commencement $\dot{H}_3(0)$ should be equal to a vertical velocity of gliding:

$$\dot{H}_3(0) = -\frac{H_0 + H_{ac}}{T_э} = \dot{H}_0 = V_0 \sin(\theta_0), \tag{5}$$

whence $T_э = -\frac{H_0 + H_{ac}}{V_0 \sin\theta_0}$, where V_0, θ_0 – a velocity and a slope of a glide path.

From formulas (1) or (3), (4) vertical velocity of runway tangency will be

$\dot{H}_к = \dot{H}(t_k) = -\frac{H_{ac}}{T_э}$, and a depth of exponent asymptote occurrence

$$H_{ac} = -\dot{H}_к T_э . \tag{6}$$

After substitution of last relation in (5) we have a resultant expression for a determination of exponent time constant at a preset tangency vertical velocity, known values of an altitude and a vertical velocity of the flareout commencement:

$$T_э = \frac{H_0}{\dot{H}_к - V_0 \sin\theta_0} . \tag{7}$$

Time constant $T_э$ introduces the defining contribution to value of flare steepness, because a trajectory slope

$$\theta_З = -\arcsin\frac{\dot{H}_З}{V} = \arcsin\left(\frac{H_0 + H_{ac}}{VT_э} e^{-\frac{t}{T_э}}\right), \tag{8}$$

Where the velocity of an airplane V can vary in narrow limits from gliding speed down to a stall velocity. Thus, steepness of a flare path, and, hence, length of an air part of the landing distance is determined by three values: H_0, $\dot{H}_0$, $\dot{H}_к$.

The vertical velocity of gliding on airfield radio aids can vary insignificantly. The vertical velocity of tangency can be set in very narrow limits from null (lack of tangency) up to the maximum value expelling destruction of a landing gear or a fault of freight (passengers). This implies, that minimization of an air–slaked part of the landing distance in case of shaping an exponential path under rules (1) and (2) is possible only by selection the flareout beginning altitude.

Projection of the flare path exponent to runway (flareout distance) we shall discover, having integrated expression for a level speed of flight in a runway center line direction $\dot{X}_g$. With the account (8) we have

$$\dot{X}_g = V\cos(\theta) = V\sqrt{1 - \left(\frac{H_0 + H_{ac}}{T_э V}\right)^2 e^{-\frac{2t}{T_э}}} .$$

Then a projection of flare exponent to runway

$$X_g = \int_0^t \dot{X}_g dt = \int_0^t \sqrt{V^2 - \left(\frac{H_0 + H_{ac}}{T_э}\right)^2 e^{-\frac{2t}{T_э}}} dt .$$

If a modification of velocity during flare is neglected:

$$X_g = V\int_0^t \sqrt{1 - \left(\frac{H_0 + H_{ac}}{VT_э}\right)^2 e^{-\frac{2t}{T_э}}} dt .$$

Last expression by replacement $u = \left(\frac{H_0 + H_{ac}}{VT_э} \right)^2 e^{-\frac{2t}{T_э}}$ is reduced to an integral of a differential binominal with the exponents permitting according to the Chebyshev theorem to transform integrand to a rational function. After two indicated changes of variables, integrations and substitutions of limits we have:

$$X_g(t) = \sqrt{V^2 T_э^2 - \left(H_0 + H_{ac}\right)^2} - \sqrt{V^2 T_э^2 - \left(H_0 + H_{ac}\right)^2 e^{-\frac{2t}{T_э}}} +$$
$$+ VT_э \ln \left(\frac{VT_э e^{\frac{t}{T_э}} + \sqrt{V^2 T_э^2 e^{\frac{2t}{T_э}} - \left(H_0 + H_{ac}\right)^2}}{VT_э + \sqrt{V^2 T_э^2 - \left(H_0 + H_{ac}\right)^2}} \right).$$

Substitution in the last formula the tangency time (3) gives expression for flareout distance:

$$x_k = X_g(t_k) = \sqrt{V^2 T_э^2 - \left(H_0 + H_{ac}\right)^2} - \sqrt{V^2 T_э^2 - H_{ac}{}^2} +$$
$$+ VT_э \ln \left(\frac{H_0 + H_{ac}}{H_{ac}} \cdot \frac{VT_э + \sqrt{V^2 T_э^2 - H_{ac}{}^2}}{VT_э + \sqrt{V^2 T_э^2 - \left(H_0 + H_{ac}\right)^2}} \right).$$

After simple transformations, using (6), (7), we shall exclude from here dependent values H_{ac} and H_0, and we shall receive flareout distance as a function of exponent time constant $T_э$:

$$x_k = T_э \left(\sqrt{V^2 - \dot{H}_0{}^2} - \sqrt{V^2 - \dot{H}_k{}^2} + V \ln \left(\frac{\dot{H}_0}{\dot{H}_k} \cdot \frac{V + \sqrt{V^2 - \dot{H}_k{}^2}}{V + \sqrt{V^2 - \dot{H}_0{}^2}} \right) \right), \tag{9}$$

or, again using (7), as a function of an initial altitude H_0:

$$x_k = \frac{H_0}{\dot{H}_к - \dot{H}_0} \left(\sqrt{V^2 - \dot{H}_0{}^2} - \sqrt{V^2 - \dot{H}_k{}^2} + V \ln \left(\frac{\dot{H}_0}{\dot{H}_k} \cdot \frac{V + \sqrt{V^2 - \dot{H}_k{}^2}}{V + \sqrt{V^2 - \dot{H}_0{}^2}} \right) \right). \tag{10}$$

From (9), (10) it is visible, that the function of flareout distance will increase monotonically and proportionally $T_э$ and H_0. Thus, minimum flareout distance on an exponential path (1), (2) and, hence, minimum length of all landing distance air–slaked part corresponds to minimum flareout commencement height.

Using expressions (9) and (10), it is possible to show an ineffectiveness of a landing distance decreasing by a modification of the flareout commencement vertical velocity $\dot{H}_0$ or a vertical velocity of a tangency $\dot{H}_k$. At a modification of the indicated values the flareout distance varies very slowly (fig. 1). In formulas (9) and (10) they stand under radicals and logarithms, and $T_э$ and H_0 – in the first extent. Besides limits of a possible modification initial and final vertical velocities are very small. The vertical velocity of a tangency for the majority of airplanes is limited by –1,5 *m/s*, while the flareout height can vary within wide range of limits.

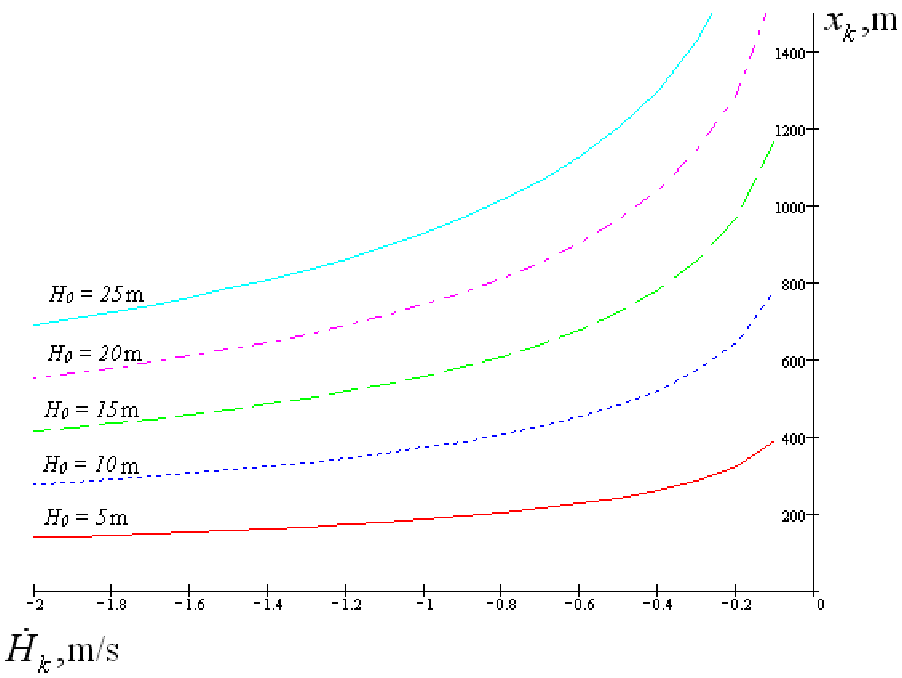

Fig. 1. Flareout distance depending on a vertical velocity of runway tangency for different initial altitudes

The curves represented on fig. 1 are designed for gliding speed $V = 72{,}2\, m/s$ and vertical velocity $\dot{H}_0 = -3{,}35\, m/s$. These values and close to them are typical for the majority of state–of–the–art trunk–route aeroplanes.

From below the flareout initial height is limited by possible overload and effectiveness of control bodies. The highest flareout commencement altitude from two, determined by these limitations, will be optimum in sense of a minimum of the landing distance air–slaked part.

Shaping of master controls and laws of stabilization

Synthesis of airplane stabilization laws on a flare path can be executed by one of the optimum control state–of–the–art theory methods.

Computational means declinations of exponential paths (1) for possible values of a full velocity, initial and final vertical velocities of airplanes do not exceed 1,5°. Attitude angles thus is less 10°. Therefore, in this case then a control object at synthesis of the regulator is admissible to use linearized model of an airplane motion:

$$\dot{X} = AX + BU + WF, \tag{11}$$

where X – the state vector, containing n components – deviations from program values of flight parameters; U – a vector of the controls, containing m components; F – a vector of the disturbances, containing l components; A, B, W – matrixes of model coefficients.

For multivariate linearized plant (11) one of the most convenient and effective methods of regulators synthesis is the method of analytical disign. According to the theory of optimum regulators analytical disign [8], for plant (11) optimum in sense of a minimum of Letov functional

$$I = \int_0^\infty X^T Q X dt + \int_0^\infty U^T R U dt \tag{12}$$

controls $U = -R^{-1}B^T SX$ are, where S – the solution of algebraic equation Riccati

$$SA + A^T S - SBR^{-1}B^T S = -Q.$$

Here Q, R – square matrixes of coefficients, which are set, proceeding from demands to transients quality and to controls values.

The state vector X among other components contains five key parameters of an airplane longitudinal motion: deviations from programm values of a velocity, a path slope angle, pitch angle, pitch angular rate and a flying height. Program values of the indicated parameters should be formed in each instant of touchdown according to the designed trajectory.

Flareout on “free” paths (1) at an operation of significant disturbances can over by a tangency with the big overflies of a computational place on a runway. To reduce this shortage it is represented expediently by the upsetting of program values of some longitudinal motion parameters by a time functions (“rigidly”), and other part – by functions of a present height (“freely”). The contribution of a “rigid” and “free” path component is determined by selection of matrix Q coefficients of a quality functional (12).

Touchdown control of a medium–range airplane

This approach has been used for a control system synthesis of medium–range airplane landing. Programm values of a velocity, pitch angle, pitch angular rate and an altitude were formed by time functions, and a programm path slope angle – by a function of a present height and a programm velocity. For flare control in the longitudinal channel one body (an elevator) was used.

The flareout initial altitude pick equals 10 *m*, a tangency vertical velocity – 0,5 *m/s*. The computational flareout distance is 481,67 *m*, a time of a tangency – 6,67 *s*.

Modelling of touchdown is executed with the help of Matlab tools: Control Toolbox and Simulink. Agency of possible force disturbances is investigated in view of random noises of measuring devices at an operation of random and constant wind (fig. 2).

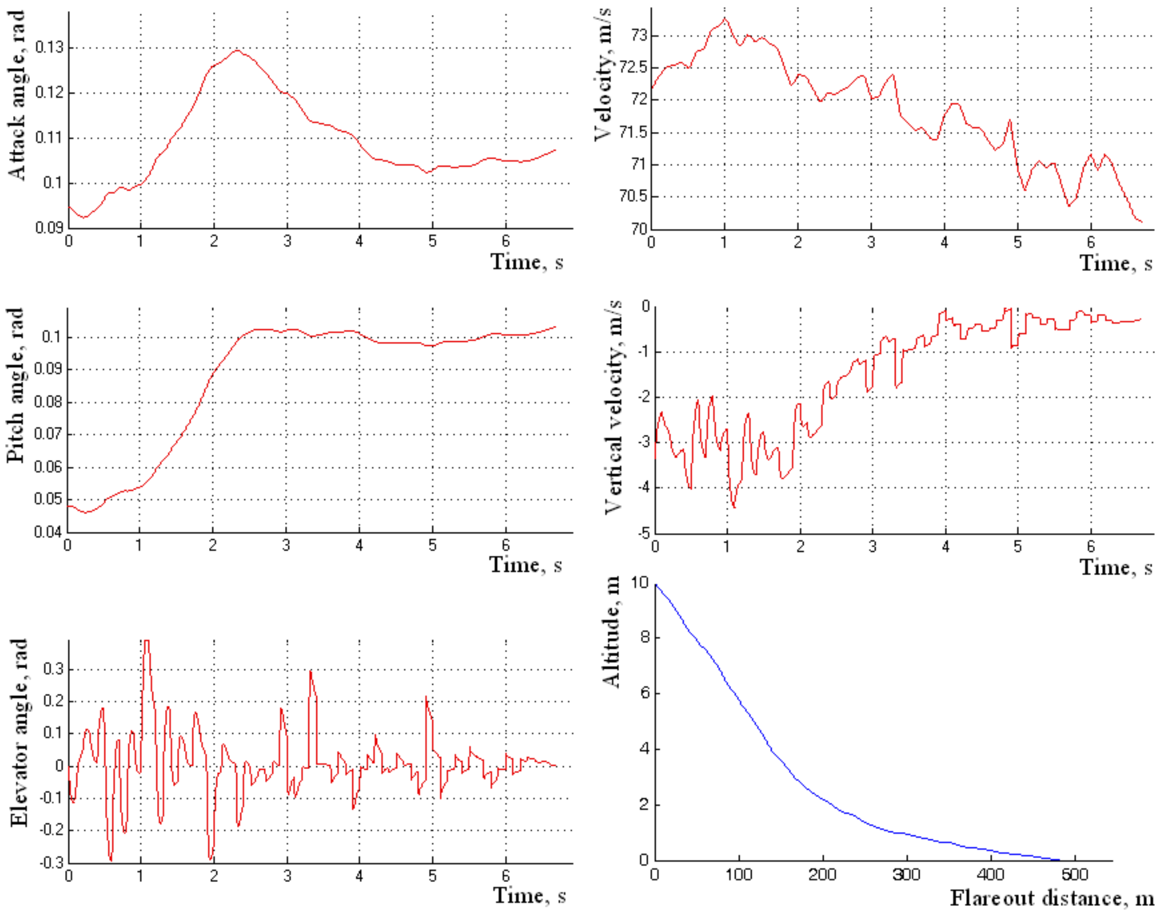

Fig. 2. Flareout of Ty154 in conditions of atmospheric turbulence

The airplane was described by nonlinear differential equations system, aerodynamic characteristics for which are taken for Ty154 from [9]. In the capacity of the atmospheric turbulence model Dryden forming filters with root–mean–square deviation of a vertical wind velocity of 2 *m/s*, contrary – 1,72 *m/s* were used.

Real parameters of touchdown path in conditions of turbulence appeared close to computational and quite comprehensible. The flareout distance is 482 *m*, a vertical velocity of a tangency of –0,35 *m/s*. Modelling has confirmed preferability of a described mode of trajectory shaping in comparison with "rigid" and "free", and also a regularity of flareout initial height selection.

Conclusions

In order to prevent spread runway tangency place position and coarse landings the autoflare should finish by a tangency. For an exponential path the desirable place of a tangency is determined by selection of a flareout initial altitude. Thus, to the optimum landing distance there corresponds minimum possible flareout commencement height in view of admissible overload and effectiveness of controls.

For effective automatic steering of airplane touchdown the part of parameters of longitudinal motion should be set by beforehand certain functions of a time, and other part – by functions of a present height of flight. It proves to be true by modelling of landing medium–range airplane at an operation of wind perturbations, noises of measuring devices and the generalized force disturbances.

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