UDC 629.735.05

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Speed control when landing on a short runway

Methods of automatic speed control at the stages of alignment and run along a short runway are analyzed. The synthesis of the contours of the coordinated control of the flight speed and the pitch angle at the stage of the flight along the glide path is presented.

Analysis of European airfields in small towns shows that today airfields with "short runways" are the largest group, and in the future their number will only increase due to: the desire to bring airfields to densely populated areas, as well as due to low, compared with the "elite" airfields, construction costs.

The minimum runway length required for landing is the sum of the length of the airborne phase of landing, the landing distance, and the size of the touchdown zone.

The length of the air section of the landing distance may be reducing by increasing the angle of inclination of the glide path. Herewith increasing the angle of inclination of the glide path when landing along an exponential trajectory (without leveling and maintaining) allows reducing not only the length of the air section of the landing distance, but also the required length of the runway. An approach with a steeper glide path is also preferable from the point of view of reducing the noise level of engines on the terrain in the airfield area. However, on the way of increasing the steepness of the landing glide path, there are limitations on the vertical landing speed associated with the strength of the landing gear, as well as issues of balancing and acceptable characteristics of stability and controllability of the aircraft when descending along a steep glide path.

The landing distance (landing run) depends primarily on the landing speed, as well as on the braking means used and the condition of the runway. On a wet runway, the landing distance increases by more than 10%, and if there is a water layer on the runway of more than 2–3 mm, the effect of hydrodynamic planing may occur, and then the landing distance increases by 50–70%.

An equally important factor is to reduce the size of the landing zone, i.e. improving landing accuracy so that after touchdown, leave as little part of the runway as possible behind the aircraft. The size of the landing zone is determined by the piloting accuracy (the accuracy of the automatic control system at the landing stage), as well as the accuracy of the information and measurement systems.

The trend of the short runways using is accompanied by the emergence of short take-off and landing aircraft SR.

To date, in the practice of world aircraft construction, various energy systems for increasing the lift of STL aircraft have been tested. For passenger and transport aircraft, it is of interest to use as an energy system the system of the blowing of the wing and multi-link flaps deflected at large angles by jet jets of engines, which makes it possible to increase the lift coefficient by 1.8 ... 2 times.

But the analysis of materials published in recent years shows that at present the interests of design bureaus involved in the development of KVP aircraft have shifted from the issues of aerodynamics of aircraft to the issues of the implementation in the aircraft's automated control systems the modern technologys of landing on "short runways".

Based on the analysis of the experience of developing such ACS, the following requirements for onboard short-landing systems can be determined:

1. The high-precision automated control of the landing using the steep glide path with a point of contact located at the beginning of the runway;

2. Direct control of the thrust of the power plant with the optimal combination of the action of the chassis brakes and reverse thrust at the stage of the mileage of the aircraft on the runway.

The first requirement is implemented through the channel of elevator, and the second is based on the computational traction control system (CTCS) of the power plant of aircraft and the chassis braking system.

In the CTCS, during the air phase of landing, it is proposed to implement coordinated control of airspeed and pitch angle.

The mutual influence of the velocity and pitch stabilization contours is determined by the system of equations:

$$\begin{aligned} \dot{V} &= -a_x^V V - a_x^{\theta}\vartheta - (a_x^{\alpha} - a_x^{\theta})\alpha + a_x^{\delta_{tr}}\delta_{tr} - \dot{W}_{x_g}; \\ \dot{\omega}_z &= -a_{m_z}^V - a_{m_z}^{\alpha}\alpha - a_{m_z}^{\omega_z}\omega_z + a_{m_z}^{\delta_{el}}\delta_{el}; \\ \dot{\alpha} &= a_y^V V + a_y^{\alpha}\alpha + \omega_z; \\ \dot{\vartheta} &= \omega_z. \end{aligned} \tag{1}$$

Where $V, \vartheta, ...\alpha, \omega_z$ – parameters characterizing the longitudinal motion of the aircraft, $a_x^V, a_x^{\theta}, ...a_y^{\alpha}, a_{mz}^{\delta в}$ – coefficients of the linearized mathematical model of the longitudinal motion of the aircraft, δ_{el}, δ_{tr} – control actions (deflection of the elevator and change of engine thrust)

We write the system of equations (1) in the matrix form

$$\dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{M\Delta} + \mathbf{f}\ , \tag{2}$$

Where $\mathbf{x} = (V \quad \omega_z \quad \alpha \quad \vartheta)^T$; $\mathbf{\Delta} = (\delta_{tr} \quad \delta_{el})^T$; $\mathbf{f} = (\dot{W}_{x_g} \quad 0 \quad 0 \quad 0)^T$;

$$M = \begin{pmatrix} a_x^{\delta_{tr}} & 0 & 0 & 0 \\ 0 & a_{m_z}^{\delta_{el}} & 0 & 0 \end{pmatrix}^T; \qquad A = \begin{pmatrix} -a_x^V & 0 & -(a_x^{\alpha} - a_x^{\theta}) & -a_x^{\theta} \\ -a_{m_z}^V & -a_{m_z}^{\omega_z} & -a_{m_z}^{\alpha} & 0 \\ a_y^V & 1 & a_y^{\alpha} & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}.$$

It is necessary to synthesize a control such that the closed-loop system is described by the equation

$$\dot{\mathbf{x}} = \mathbf{Bx} + \mathbf{Nu} + \mathbf{f}\ , \tag{3}$$

Where

$$\mathbf{B}=\begin{pmatrix}-b_{11} & 0 & 0 & 0\\ 0 & -b_{22} & 0 & 0\\ a_y^V & 1 & a_y^{\alpha} & 0\\ 0 & 1 & 0 & 0\end{pmatrix};\quad \mathbf{N}=\begin{pmatrix}b_{11} & 0 & 0 & 0\\ 0 & b_{22} & 0 & 0\end{pmatrix}^{\mathrm{T}};\quad \mathbf{u}=(V_з,\omega_{zз})^{\mathrm{T}}.$$

In matrices **B** and **N**, the elements b_{11}, b_{22} are quantities that are inversely proportional to the time constants of the autonomous aperiodic processes of the control loops of the flight speed and pitch speed, respectively. These coefficients can be selected from conditions $t_{pV}=3/b_{11}$; $t_{p\omega_z}=3/b_{22}$, where $t_{pV}\approx 15\ldots 30\,\text{sec}$ is the regulation time in the flight speed control loop; $t_{p\omega_z}\approx 3\ldots 6\,\text{sec}$ - control time in the pitch speed control loop.

Equating the right-hand sides of equations (2), (3), we obtain the relation

$$\mathbf{Ax}+\mathbf{M\Delta}=\mathbf{Bx}+\mathbf{Nu} \tag{4}$$

Matrix equation (4) has a solution

$$\mathbf{\Delta}=\mathbf{M}^{+}\left[(\mathbf{B}-\mathbf{A})\mathbf{x}+\mathbf{Nu}\right] \tag{5}$$

Here $\mathbf{M}^{+}=\left(\mathbf{M}^{\mathrm{T}}\mathbf{M}\right)^{-1}\mathbf{M}^{\mathrm{T}}$ - (6)

is a pseudo-inverse matrix.

Let's calculate this matrix:

$$\mathbf{M}^{\mathrm{T}}\mathbf{M}=\begin{pmatrix}a_x^{\mathrm{tr}} & 0 & 0 & 0\\ 0 & a_{m_z}^{\delta_{\mathrm{el}}} & 0 & 0\end{pmatrix}\begin{pmatrix}a_x^{\mathrm{tr}} & 0\\ 0 & a_{m_z}^{\delta_{\mathrm{el}}}\\ 0 & 0\\ 0 & 0\end{pmatrix}=\begin{pmatrix}\left(a_x^{\mathrm{tr}}\right)^2 & 0\\ 0 & \left(a_{m_z}^{\delta_{\mathrm{el}}}\right)^2\end{pmatrix} \tag{7}$$

$$\left(\mathbf{M}^{\mathrm{T}}\mathbf{M}\right)^{-1}=\begin{pmatrix}\dfrac{1}{\left(a_x^{\mathrm{tr}}\right)^2} & 0\\ 0 & \dfrac{1}{\left(a_{m_z}^{\delta_{\mathrm{el}}}\right)^2}\end{pmatrix}\quad \mathbf{M}^{+}=\left(\mathbf{M}^{\mathrm{T}}\mathbf{M}\right)^{-1}\mathbf{M}^{\mathrm{T}}=\begin{pmatrix}\dfrac{1}{a_x^{\mathrm{tr}}} & 0 & 0 & 0\\ 0 & \dfrac{1}{a_{m_z}^{\delta_{\mathrm{el}}}} & 0 & 0\end{pmatrix}$$

Since the influence of speed on aerodynamic forces and moments is very insignificant, there is no need to implement speed cross-coupling from autothrottle into the autopilot. Therefore substituting into solution (5) the corresponding values from relations (2), (3), (7) and performing the necessary operations on the matrices, we get only the control laws of autothrottle

$$\delta_{\mathrm{tr}}=\frac{1}{a_x^{\delta_{\mathrm{tr}}}}\left[\left(a_x^V-b_{11}\right)V+\left(a_x^{\alpha}-a_x^{\theta}\right)\alpha+a_x^{\theta}\vartheta+b_{11}V_{\mathrm{set}}\right] \tag{8}$$

A closed-loop coordinated speed control system is described by equation (2). The block diagram of the closed loop is shown in Fig. 1.

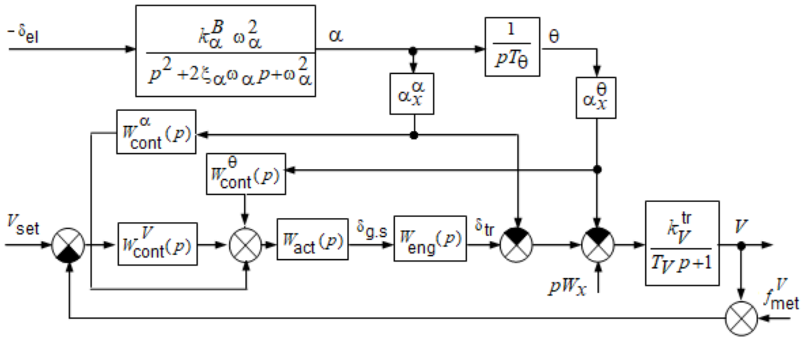

Fig.1. The block diagram of the closed loop coordinated speed control system

To compensate for the inertia of the transfer function $W_{\text{eng}}(p)$, describing the aircraft engine, the transfer functions $W_{\text{cont}}^{\alpha}(p)$ and $W_{\text{cont}}^{\theta}(p)$ must include forcing links:

$$W_{\text{cont}}^{\alpha}(p) = \frac{a_x^{\alpha}\left(T_{\text{eng}}p+1\right)}{k_{\text{eng}}}; \quad W_{\text{cont}}^{\theta}(p) = \frac{a_x^{\theta}\left(T_{\text{eng}}p+1\right)}{k_{\text{eng}}}$$

Summing up the synthesis, as well as preventing the passage of high-frequency oscillations from the elevator channel to the autothrottle channel and taking into account the expediency of compensating for the disturbances arising when the flaps and landing gear are extended we obtain the following form of the control law of the autothrottle with continuous feedback in the servo-actuator:

$$\delta_{\text{g.s}} = \left(K_V + \frac{K_{\tilde{V}}}{p}\right)\left(V_{\text{set}} - V\right) + K_{n_x} n_x + \frac{(K_\alpha \alpha + K_\theta \theta)(T_{\text{eng}}p+1)}{T_f p + 1} + F_{\delta_{\text{flap}}}\delta_{\text{flap}} + F_{\delta_{\text{gear}}}\delta_{\text{gear}}$$

Here $F_{\delta_{\text{flap}}}\delta_{\text{flap}}$, $F_{\delta_{\text{gear}}}\delta_{\text{gear}}$ components compensate for the increase in drag when the flaps and landing gear are extended; $1/(T_f p+1)$ filter of high-frequency components of the angle of attack and the angle of inclination of the trajectory. In order to increase the accuracy of maintaining the trajectory of the aircraft during landing, a correction of the thrust control program is proposed through the use PID-regulator. At that the information about the longitudinal overload of the aircraft n_x plays the role of a derivative of the main control signal.

The coordinated flight speed control system will allow combining the maximum possible speed with the autonomy of the pitch control processes and stabilization of the given approach speed at the stages of entering the glide path.

In this case, the CTCS actuator moves the traction control handle to the "Low throttle" position, and the calculator switches to the mode of formation of the landing speed stabilization law, which should not exceed the stall speed by more than 30%. Thrust increment, which calculated in CTCS according to the stabilization law of contact velocity V_{cont}

$$\Delta P = \left(K_V + \frac{K_{\tilde{V}}}{p} \right) \left(V_{\text{cont}} - V \right) + K_{n_x} n_x$$

transmitted to the electronic-digital control system of the engine, which provides support for optimal engine performance.

In the area of tangency CTCS generates a signal "Permission to reverse thrust" according to the usual logic of checking the specified conditions: the position of the aircraft relative to the runway, the value of the flight speed and altitude, the position of the flaps, landing gear, throttle sectors and the engine rotor speed.

At the stage of the run of the aircraft on the runway, algorithms for complex braking by reverse thrust and wheel brakes are proposed, taking into account the operation of anti-skidding automation.

Integrated traction reversing braking and wheel brakes can be represented as follows:

$$-\frac{G}{g}\frac{dV}{dt} = c_x S \rho \frac{V_a^2}{2} - \left(R_\Sigma^+ - R_\Sigma^- \right) - \left[\left(f_{\text{roll-fric}} + f_{\text{drag}} \right) \left(G - c_y S \rho \frac{V_a^2}{2} \right) \right]$$

where R_Σ is the total reverse thrust of the engines; G is the aircraft weight; $f_{\text{roll-fric}}$ is the rolling friction coefficient; f_{drag} is the drag coefficient.

If the landing is carried out on a wet or snowy runway, then during braking, the aircraft may slip in the lateral plane, in which lateral overload occurs. An easy way to combat this phenomenon is to release the brake of wheels to a level where the lateral gload is zero.

The law of braking by wheel brakes taking into account work of anti-skiding automatic equipment at $V \le 50\ldots90$ km/h can be presented in the following look:

$$f_{\text{drag}} = K_{\text{drag}} P_{\text{drag}};$$

$$P_{\text{drag}} = \frac{K_{\text{wh.br}}}{T_{\text{wh.br}} p + 1} \left(\delta_{\text{drag}} - K_{n_z} n_z \right),$$

where Kn_z is the gear ratio in the lateral overload channel; δ_{drag} is the moving of the brake control; $K_{\text{wh.br}}$ is the gear ratio in the channel of wheel brakes; $T_{\text{wh.br}}$ is the time constant in the channel of wheel brakes; P_{drag} is the braking force.

References

1. Rogozhin V.A., Sineglazov V.M., Filyashkin N.. Automated aircraft control systems: K .: NAU, 2003. - 502 p.

2. Inozemtsev A. A., Konyaev E. A., Medvedev V. V. and et al. Aircraft engine PS-90A M .: FIZMATLIT, 2007 .- 320 p.

3. Kulikov G.G., Kotenko P.S., Fatikov U.S., Ishchuk V.P. Providing of required characteristics of short take off and landing of aircraft with turbopropfan. // Aerospace engineering and technology. 2008. -№ 4(51). - PP. 29-33/