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Development of hydraulic transmission for implementing an active drive of the landing gear wheels of modern transport aircraft

V Brusov[1,2,3], A Menshikov[1,2] and Y Merzlikin[2]

[1]Bauman Moscow State Technical University
[2]The Central AeroHydrodynamic Institute named after Prof. N.E. Zhukovsky

[3]E-mail: vasyab2@rambler.ru

Annotation An active drive of the wheels of the chassis is necessary on the take-off and run with reduced coupling characteristics of the airplane on an unpaved or icy runway in cross-wind conditions to reduce lateral drift from the axis of the strip. The hydraulic transmission has been developed for the active drive of the wheels by aircraft chassis. At using a control system, that regulates the moment wheels characteristics and includes an adaptive circuit with neural network, it is possible to reduce the lateral drift of the aircraft about 30–40 %. The output parameters of the hydraulic motors intended for the landing gear wheels of aircraft weighting 21 tons are determined.

Introduction

With the development of sparsely populated and inaccessible regions of the Russian Federation, including the Arctic zone, the problem of passenger, transport and special tasks arises. This is explained by a number of reasons, among which the low density of aerodrome and road networks, the lack of economic opportunities and practical feasibility of constructing airfields with concrete coverings of runways, and also the climatic features are of decisive importance.

In many ways, the solution to this problem is associated with the development of aviation communications. For these regions, the development of aviation is directly related to the increased cross-country ability of aircraft on elementary prepared unpaved runways with irregularities at the stages of take-off and run. Under the cross-country ability of aircraft refers to the ability of the aircraft to operate safely on this type of runway airfield. Aircraft cross-country ability is limited by three factors: excessive contact loads on the landing gear support elements and flight strips, unacceptable glider overloads and loss of controllability of the aircraft due to the absence of contact connections between the landing gear and the supporting surface on take-off and landing modes [1, 2]. In this regard, the landing gear is a unit that sets the limiting indicators of the cross-country ability of any aircraft.

At the same time, the quality of cross-country ability is closely related to the takeoff and landing capabilities of the aircraft as a whole, due to the perfection of its aerodynamic layout, mass characteristics, the thrust-weight ratio of the power plant, and the effectiveness of aerodynamic controls. A significant effect on the performance of cross-country ability can have the chosen method of piloting the aircraft. It is especially noticeable on low-strength unpaved runways, when complex interaction processes, including slippage and slipping, are manifested in contact between the chassis and the deformable soil medium.

One of the ways to increase aircraft flotation is to use an active wheel drive in conjunction with adaptive landing gear moment control algorithms.

The most optimal option for the implementation of an active drive of the chassis wheels is the use of a hydraulic transmission with proportionally controlled elements that control the flow and pressure in the hydraulic lines. Using these elements, it is possible to control the torque of each wheel of the aircraft chassis [3]–[5].

The torque control algorithm of hydraulic motors is carried out based on the following parameters:

1) Specific power spent on movement;

2) The ratio of the useful work of the traction force on the wheel to the perfect work of the torque supplied to the wheels;

3) Wheel slipping;

4) Specific traction and specific energy losses during rolling of the front and main landing gear wheels.

An active drive of the wheels of the chassis is necessary on the take-off and run with reduced coupling characteristics of the airplane on an unpaved or icy runway in cross-wind conditions to reduce lateral drift from the axis of the strip.

The article discusses the prospect of using a hydraulic drive as a transmission element for aircraft chassis wheels (Fig. 1).

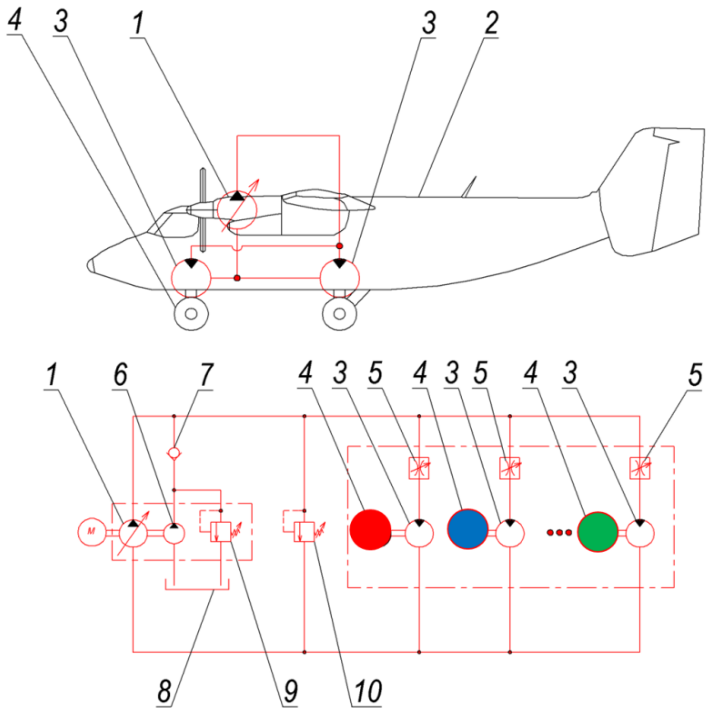

Fig. 1. Variant of adjustable hydraulic transmission of the aircraft for driving of the wheels of the landing gear. Designated: 1 — adjustable pump; 2 — airplane glider; 3 — hydraulic motors; 4 — landing gear wheels; 5 — flow controllers; 6 — make-up pump; 7 — check valve; 8 — tank; 9 — safety valve; 10 — overflow valve.

Using a single hydraulic system to create an effective power transmission of an aircraft provides the ability to control its parameters and characteristics. At the same time, the developers of the hydraulic system are faced with the task of optimal control moving along various types of surfaces with a wide range of speeds.

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In transport equipment with a large number of uncertainties and random disturbances, it is advisable to use control systems with several adaptive circuits operating at different speeds to control the object [6]–[9].

The proposed methods for controlling the moment characteristics of the wheels of the chassis can create a theoretical and methodological basis for a new generation of ground-based transport aircraft with increased cross-country ability.

Methods

The study of controlled aircraft movement is carried out on the basis of a mathematical model that is usually used to assess the characteristics of static stability and controllability of an aircraft with wheeled landing gears during take-off (run) along a horizontal unpaved runway. The equations of the model reflect only three degrees of freedom of movement of the aircraft: movement in the longitudinal and transverse directions and angular motion relative to its vertical axis (Fig. 2). The equations use well-known forms of representing the aerodynamic forces and moments from the airframe of the aircraft.

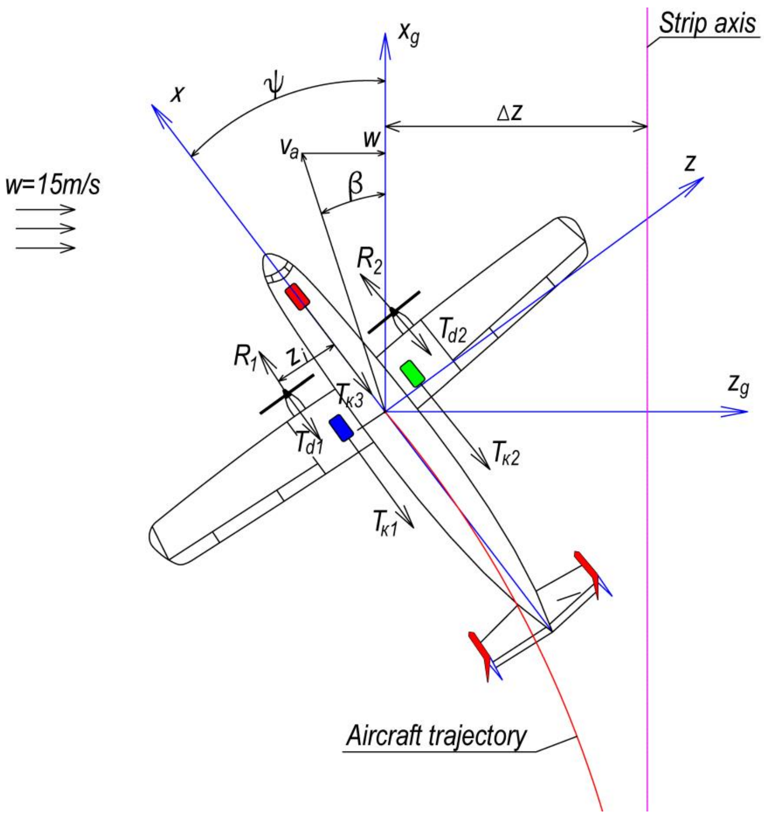

Fig. 2. Diagram of power actions during the take-off of the aircraft in crosswind conditions.

The ability to limit only three degrees of freedom of its movement for describing the lateral movement of an aircraft is due to the fact that in the case of cross-connections introduced into the lateral movement by the aerodynamic rudders and brake elements of the chassis with their real force effects, they lead only to negligible changes in the angle of heel and pitch, not significantly affecting the accuracy of calculations.

The main assumptions and provisions adopted in the construction of the mathematical model:

1) Consider the rectilinear motion of an aircraft on a flat soil base;

2) The relationship of the wheels with the aircraft fuselage in the vertical plane is considered taking into account the elastic and damping properties of the shock absorption system and the longitudinal compliance of the guide elements of the landing gear is taken into account;

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3) The fuselage is undeformable;
4) The friction in the joints, bearings is negligible;
5) The engine torque acts directly on the wheel, the elastic-damping properties of the transmission elements are not taken into account;
6) The magnitude of the torque is determined by the fraction of the change in position of the control;
7) Take into account the possibility of separation of the wheels from the ground.

If you use the trajectory $Ox_k y_k z_k$, associated $Oxyz$ and the normal earth $O_0 x_g y_g z_g$ coordinate systems when compiling the differential equations of lateral motion of the aircraft, the differential equations can be reduced to the following form:

$$\begin{aligned}
\dot{v}_n &= \frac{1}{m}\cdot\left(X_{\sum}\cdot\cos\beta_a + Z_{\sum}\cdot\sin\beta_a\right)\\
\dot{\beta} &= \frac{1}{m\cdot v_a}\cdot\left(Z_{\sum}\cdot\cos\beta - X_{\sum}\cdot\sin\beta\right)+\omega_y\\
\dot{\omega}_y &= \frac{M_{y\sum}}{I_y}\\
\dot{\psi} &= \omega_y\\
\dot{x}_g &= v_n\cdot cos\psi_n\\
\dot{z}_g &= v_n\cdot\sin\psi_n,
\end{aligned}$$

where: v_n — ground speed of the aircraft; v_a — airspeed of the aircraft; β — slip angle; β_a — slip angle in absolute motion; m — mass of the aircraft; I_y — moment of inertia of the aircraft about the axis Oy; ω_y — angular velocity of yaw; ψ — yaw angle; ψ_n — air speed yaw angle.

Between kinematic parameters there are the following relationships:

$$\begin{aligned}
\beta_a &= \psi - \psi_n;\\
v_a &= \sqrt{\dot{x}_g^2 + \left(\dot{z}_g + \omega\right)^2};\\
\psi_n &= \arcsin\left(\frac{\dot{z}_g}{\sqrt{\dot{x}_g^2 - \dot{z}_g^2}}\right).
\end{aligned}$$

In the general case, for an aircraft with N_d marching engines, N_m brake elements (wheeled landing gear), the forces and moments in the equations are presented in the form of the following expressions:

–projection of the resultant force on the axis associated with the aircraft Ox:

$$X_{\sum} = \left(\sum_{i=1}^{N_d} T_{dixg} + \sum_{k=1}^{N_m} T_{mkxg}\right)\cdot\cos\psi - \left(\sum_{i=1}^{N_d} T_{dizg} + \sum_{k=1}^{N_m} T_{mkzg}\right)\cdot\sin\psi;$$

–projection of the resultant force on the axis associated with the aircraft Oz:

$$X_{\sum} = Z + \left(\sum_{i=1}^{N_d} T_{dizg} + \sum_{k=1}^{N_m} T_{mkzg}\right)\cdot\sin\psi + \left(\sum_{i=1}^{N_d} T_{dixg} + \sum_{k=1}^{N_m} T_{mkxg}\right)\cdot\cos\psi;$$

–total moment relative to the vertical axis Oy:

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$$M_{y\sum} = M_m + M_d + M_y.$$

Here: $Z = c_z^{\beta} \cdot \sin\beta \cdot \rho \cdot \frac{v_a^2}{2} \cdot s + c_z^{\delta_н} \cdot \delta_н \cdot \rho \cdot \frac{v_a^2}{2} \cdot s$ — transverse aerodynamic force of the aircraft; $X = c_x \cdot \rho \cdot \frac{v_a^2}{2} \cdot s$ — longitudinal aerodynamic force of the aircraft; T_{mkzg}, T_{mkxg} — projection on the $O_0 z_g$ axis and $O_0 x_g$ axis the friction forces of the brake elements, calculated using the ratios:

$$T_{mkxg} = -T_{mk} \cdot \frac{\dot{x}_{mkg}}{v_{mk}};$$

$$T_{mkzg} = -T_{mk} \cdot \frac{\dot{z}_{mkg}}{v_{mk}};$$

$$v_{mk} = \sqrt{\dot{x}_{mkg}^2 + \dot{z}_{mkg}^2};$$

$$\dot{x}_{mkg} = \dot{x}_g + z_{mkg} \cdot \omega_y;$$

$$\dot{z}_{mkg} = \dot{z}_g - x_{mkg} \cdot \omega_y;$$

$$x_{mkg} = \sqrt{x_{mk}^2 + z_{mk}^2} \cdot \sin(\xi_{mk} + \psi);$$

$$z_{mkg} = \sqrt{x_{mk}^2 + z_{mk}^2} \cdot \cos(\xi_{mk} + \psi);$$

moreover, in the last two formulas — for wheeled landing gear on the left side ($k < \frac{N_т}{2}$): $\xi_{mk} = \pi - \arcsin\left(\frac{x_{mk}}{\sqrt{x_{mk}^2 + z_{mk}^2}}\right)$; and for the landing gear located on the right side($k > \frac{N_т}{2}$): $\xi_{mk} = \arcsin\left(\frac{x_{mk}}{\sqrt{x_{mk}^2 + z_{mk}^2}}\right)$; $T_{mk} = \frac{m \cdot g - Y}{N_m} \cdot f_m$,

where: f_m —coefficient of friction of the wheeled landing gear on the surface of the runway; T_{dizg}, T_{dixg} — projection on the $O_0 z_g$ and $O_0 x_g$ axis the forces of the impulse resistance of the engines.

The moments due to the resistance of the brake elements in contact with the surface of the runway, as well as the moments of the impulse resistance of the engines are:

$$M_m = \sum_{i=1}^{N_m} T_{ixg} \cdot z_{ig} - \sum_{i=1}^{N_m} T_{ixg} \cdot x_{ig}.$$

The aerodynamic moment of the aircraft is determined by the ratio:

$$M_y = m_y \cdot \frac{\rho \cdot v_a^2}{2} \cdot s \cdot l + m_y^{\beta} \cdot \sin\beta \cdot \frac{\rho \cdot v_a^2}{2} \cdot s \cdot l + m_y^{\dot{\beta}} \cdot \dot{\beta} \cdot \rho \cdot v_a \cdot s \cdot \frac{l^2}{4} + m_y^{\omega_y} \cdot \omega_y \cdot \rho \cdot v_a \cdot s \cdot \frac{l^2}{4} + m_y^{\delta_н} \cdot \delta_н \cdot \frac{\rho \cdot v_a^2}{2} \cdot s \cdot l$$

For the appearance of various torques on the wheels of the aircraft landing gear in order to reduce lateral drift during a take-off run with a crosswind, it is necessary to apply a signal to the pressure regulators (item 5, Fig. 1). Then the braking forces can be written in the form of the following relations [10]–[13]:

$$T_{\kappa i} = T_{\kappa 0} + sign(\Delta z)\cdot(z - z_0)\cdot k_{zi}\cdot th\left[\frac{z}{z - z_0}\cdot\frac{t}{t_{\max}}\right] + sign(\Delta\psi)\cdot(\psi - \psi_0)\cdot k_{\psi i}\cdot th\left[\frac{\psi}{\psi - \psi_0}\cdot\frac{t}{t_{\max}}\right],$$

where: k_{zi}, $k_{\psi i}$ — the feedback coefficients adopted in the control of the aircraft during take-off when controlled by a wheeled landing gear.

These coefficients can be varied using the adaptive neural circuit implemented in the control system [14]–[21].

Results

Using the described equations, a mathematical model of the movement of the aircraft on an unpaved runway has been developed. Design studies of the aircraft on take-off in lateral wind conditions were carried out. The lateral drift values of the aircraft were obtained at maximum thrust for different wind speeds (Fig. 3). The studies were conducted for type Il-112 aircraft with a take-off weight of 21 tons.

Using an additional controller with elements of a neural network to control the active drives of the wheels of the landing gears allows to reduce lateral drift of the aircraft from the runway:

–at a cross-wind speed of 5 m / s — an average of about 40%;
–at a crosswind speed of 10 m / s — an average of about 36%;
–at a crosswind speed of 15 m / s — an average of about 30%.

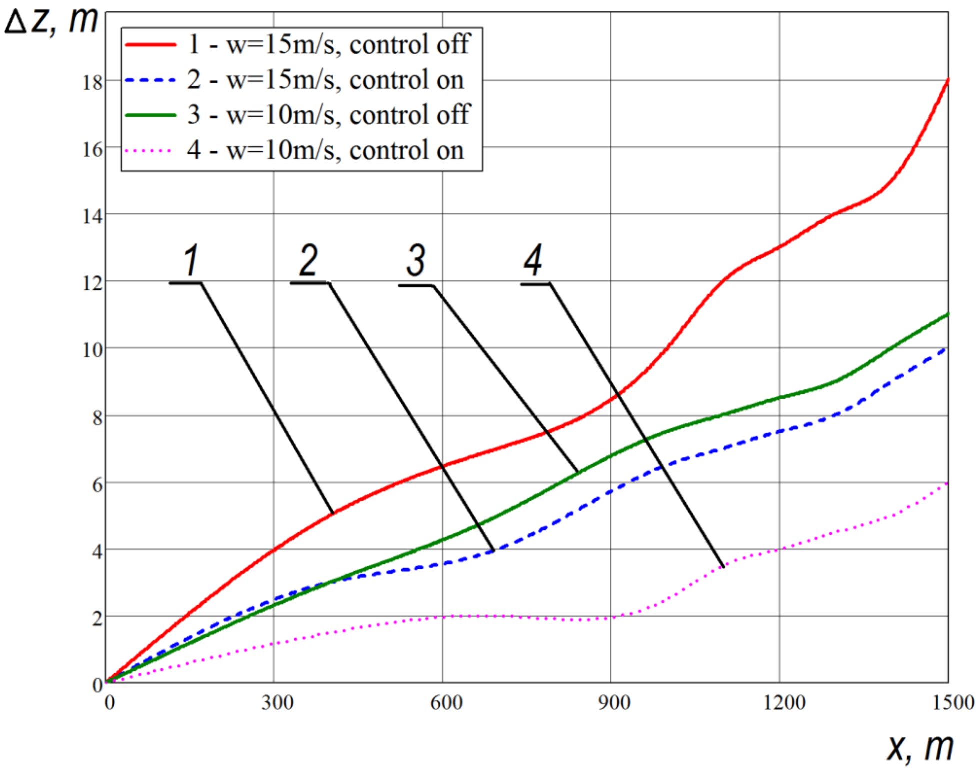

Fig. 3. Computational studies of the takeoff run of an Il-112 type aircraft. Lateral drift at maximum traction for different wind speeds.

Conclusions

The urgent tasks of expanding the conditions for the deployment of promising aircraft, increasing the cross-country ability and safety of the grounding of new aircraft can be successfully solved only on the basis of a sufficiently detailed study of the characteristics of the "elastic aircraft - unprepared runway" system. At the same time, the results of comprehensive studies on the mechanics of loading the chassis on deformable and uneven runways, on the aerodynamics of aircraft in the take-off and landing configuration and the dynamics of their take-off and landing using special cross-country ability criteria should be consistent even at the early stages of aircraft design.

The developed design conditions for the flotation of airplanes, including external ground-based conditions, are subject to standardization and refinement as experience accumulates in the creation and operation of appropriate aircraft.

Mathematical modeling of the movement of an aircraft equipped with active drives of the wheels of the landing gears on an icy and / or snowy runway with randomly changing characteristics in the conditions of side wind at the stages of take-off and run allowed optimization of the developed algorithms to counteract the drift of the aircraft away from the runway axis.

The developed torque control algorithm on hydraulic motors significantly reduced lateral drift of the aircraft from the strip.

The required ranges of changes in the torque of the drive (hydraulic motor) of the landing gear wheel are determined. In particular, for an aircraft of the Il-112 type:

–range of moments - (0 ... 450) Nxm;

– range of rotation frequencies - (100 ... 500) rpm (up to 3000 rpm - on the take-off run to take-off speed).

To increase the safety of take-off and landing of the aircraft on unprepared runways and to further reduce the offset from the axis of the runway in conditions of strong crosswind, especially at high speed (at the end of the take-off phase and at the beginning of the run), it is advisable to introduce a control loop using aerodynamic surfaces of aircraft.

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