Dynamic methods for controlling the weight of the aircraft and helicopter

A V Egorov1, A V Lysyannikov2, Yu F Kaizer2, S V Dorohin3, A V Kuznetsov4, A M Kaidakov1, E N Bogdanov1 and N N Lysyannikova2

1 Volga State University of Technology, 424000, Yoshkar–Ola, 3, Lenin Square, Russia
2 Siberian Federal University, 660041, Krasnoyarsk, 82/6, Svobodny Avenu, Russia
3 Voronezh State University of Forestry and Technologies Named after G.F. Morozov, 394087, Voronezh, 8, Timiryazeva str., Russia
4 Krasnoyarsk State Agrarian University, 660074, Krasnoyarsk, 2, Kirenskogo, Russia

E–mail: kaiser171074@mail.ru

Abstract. Despite the achieved level of development of methods and means of controlling the weight of aircraft, the number of emergencies associated with exceeding the allowable take-off weight of aircraft remains significant. Therefore, the question of the development of new methods for controlling the weight of aircraft, either immediately before take-off in the course of movement along the runway or immediately after take-off at the minimum flight height, remains relevant. This paper presents a scientific and technical substantiation of dynamic methods for controlling the mass of aircraft taking off and helicopters, based on introducing into the flight test program measurements of horizontal (for airplanes) and vertical (for helicopters) aircraft accelerations before take-off (for airplanes) and during take-off (aircraft) with a maximum take-off weight, and their comparison with horizontal (for airplanes) and vertical (for helicopters) aircraft accelerations measured during operation takeoff (for airplanes) and during takeoff (for helicopters) with an unknown weight, respectively.

1. Introduction
The current level of development of methods and means of controlling the weight of the aircraft is determined on the basis of data on the flight dynamics in take-off, climb, or all flight segments [1-6]. However, despite the successes achieved, the number of aviation accidents in the world related to overloading or incorrect positioning of cargo on board aircraft remains significant.

Therefore, the task of developing new and developing existing methods and means of controlling the weight of aircraft, including on the basis of assessing the dynamics of their movement, remains one of the priority tasks on the path of increasing safety.

From the point of view of minimizing the consequences that may arise during the flight of an overloaded aircraft or helicopter, is the control of the weight of the aircraft accelerating along the runway and the control of the weight of the cargo directly detached from the supporting surface of the helicopter or attached to the helicopter.

2. Development of a dynamic method for controlling aircraft weight during takeoff
Consider the scheme of action of forces on a aircraft taking off (figure 1).
Figure 1. The scheme of action of forces on the aircraft taking off.

Engines give aircraft some acceleration when taking off. Denote the weight of the aircraft \( m \) known weight placed on its board (for example, the passport value of the maximum take-off weight), and by \( m_u \) we denote the unknown weight of the aircraft preparing for takeoff. The engine traction force at a specific speed of the takeoff run of the aircraft is denoted by \( F(V) \).

Let on a specific engine mode at a particular position of controls and specific parameters of the external environment (thermodynamic parameters of air, condition of the runway, wind direction and speed) an aircraft of weight \( m \) undergoes horizontal acceleration during acceleration to take-off on the runway \( a(V) \). And when accelerating to take-off along the runway, an aircraft of weight \( m_u \) at the same specific mode of operation of the engines, at the same specific position of the governing bodies and the same specific parameters of the external environment, gets horizontal acceleration \( a_1(V) \).

On a specific mode of operation of the engines at a specific position of the aircraft's controls, specific parameters of the external environment, assuming that the values of the moments of rolling resistance of the landing gear wheels are equal, we write down the projections on the \( Ox \) forces acting on the aircraft of weight \( m \) and \( m_u \) during takeoff:

\[
F(V) = ma(V),
\]
\[
F(V) = m_u a_1(V).
\]

Since during acceleration to take-off, the position of the aircraft's controls, the operating modes of the engines, the parameters of the environment were the same, and, accordingly, the traction force of the engines \( F(V) \) at a the specific speed of the aircraft developed each time the same.

Equating (1) to (2) we determine the unknown weight \( m_u \):

\[
m_u = m \frac{a(V)}{a_1(V)}.
\]

Controlling the take-off weight \( m_u \) of the aircraft is possible on the basis of measuring the linear acceleration of the aircraft during its takeoff on the runway \( a(V) \) and comparing this value with the linear acceleration of the aircraft along the runway \( a_1(V) \) with the maximum take-off weight \( m \).

An application for the invention of the Russian Federation has been submitted for a dynamic method for controlling the weight of an aircraft taking off [7].

3. Development of a dynamic method for controlling the weight of a helicopter

Consider the scheme of forces acting on a helicopter taking off (figure 2).

The motor-screw complex reports some acceleration when lifting a helicopter in a vertical plane in a given altitude range.

We denote the weight of the helicopter \( m \) with the known weight placed on its board (for example, the maximum take-off weight), and we denote by \( m_u \) some unknown weight of the helicopter taking off. The traction force of a motor-screw complex in a given altitude range at a specific lifting speed is denoted by \( F(V) \).
Let with specific parameters of the environment in a specific mode of operation of a helicopter motor-screw complex of weight $m$ with a vertical take-off in a given altitude interval, the vertical acceleration $a(V)$ is experienced. And with a vertical take-off helicopter of unknown weight $m_u$ with the same specific parameters of the external environment, the same specific mode of operation of the motor-screw complex in the same predetermined altitude range the undergoes vertical acceleration $a_1(V)$.

With a vertical take-off of a helicopter in a given altitude range on a specific mode of operation of a motor-screw complex, the equations of motion of a helicopter of weight $m$ and $m_u$ are based on the projection of acting forces on the axis $Oy$:

$$F(V) = m(a(V) + g), \quad (4)$$

$$F(V) = m_u(a_1(V) + g), \quad (5)$$

where $g$ - acceleration of gravity.

Since during a vertical take-off in the specified altitude range, the parameters of the external environment and the operating modes of the motor screw complex were the same, and, accordingly, the traction force of the motor screw complex $F(V)$ developed to the same.

Equating (4) to (5), we determine the unknown mass $m_u$:

$$m_u = m \frac{(a(V) + g)}{(a_1(V) + g)} \quad (6)$$

The proposed dynamic method of controlling the weight of the helicopter will allow signaling that the permissible take-off weight is exceeded immediately at the beginning of the climb of the helicopter.

An application for the invention of the Russian Federation has been filed for a dynamic method for controlling the weight of a helicopter taking off [8].

### 4. Conclusion

Thus, knowing the parameters of the movement of the aircraft during takeoff with the maximum take-off weight and controlling the parameters of the movement of the aircraft during takeoff with an unknown weight, it is possible to control this unknown weight.

By introducing into the flight test program of an aircraft, measuring the linear acceleration of an aircraft during a takeoff just before takeoff with a maximum take-off weight for specific external and internal parameters and monitoring the aircraft’s linear acceleration during a takeoff just before takeoff with an unknown weight cargo during the same specific external and internal parameters, you can control the current weight of the aircraft just before takeoff and cancel the takeoff at the very last moment before being taken off the runway.
By introducing into the flight test program of helicopters, measure the vertical acceleration of a helicopter during takeoff directly after separation from the reference surface with a maximum takeoff weight with specific external and internal parameters and controlling the vertical acceleration of the helicopter during operation during takeoff directly after separation from the supporting surface with an unknown weight with the same specific external and internal parameters, it is possible to control the current weight of the helicopter directly at the beginning as and when required rejected take-off at minimum altitude dialed.

References
[1] Sun J, Ellerbroek J and Hoekstra J M 2018 Aircraft initial mass estimation using Bayesian inference method *Transportation Research Part C: Emerging Technologies* 90 59–73
[2] Alligier R, Gianazza D and Durand N 2013 Learning the aircraft mass and thrust to improve the ground-based trajectory prediction of climbing flights *Transportation Research Part C: Emerging Technologies* 36 45–60
[3] Alligier R, Gianazza D and Durand N 2015 Machine Learning and Mass Estimation Methods for Ground-Based Aircraft Climb Prediction *IEEE Transactions on Intelligent Transportation Systems* 16 3138–49
[4] He F, Li L, Zhao W and Xiao G 2018 Aircraft mass estimation using quick access recorder data *AIAA/IEEE Digital Avionics Systems Conference – Proceedings*
[5] Lee H-T and Chatterji G B 2010 Closed-form takeoff weight estimation model for air transportation simulation *10th AIAA Aviation Technology, Integration and Operations Conference* 2
[6] Brindisi A, Ameduri S, Concilio A, Ciminello M, Leone M, Iele A, Consales M and Cusano A 2019A multi-scaled demonstrator for aircraft weight and balance measurements based on FBG sensors: Design rationale and experimental characterization *Measurement: Journal of the International Measurement Confederation* 141 113-23
[7] Egorov A V 2018 Dynamic method of controlling the weight of an aircraft taking off *Application for the invention of the Russian Federation № 2014139170 / 20 (065031)*
[8] Egorov A V 2018 Dynamic method of controlling the weight of the helicopter *Application for the invention of the Russian Federation № 2018139226 / 20 (065095)*