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UTILIZATION OF THE AIRCRAFT FLIGHT DATA FOR ASSESSMENT OF THE AVIATION WHEEL BRAKES ENERGY STRENGTH

The utilization of flight data for assessing of the energy loading of aviation wheel brakes is proposed. The operational ranges of the main characteristics of the aircraft, which affect the load capacity of the wheel brakes, namely, landing speed, landing mass of the different aircraft using the flight data on-board means of objective control and registration (FDR), are studied.

Key words: *aviation brakes, friction brake elements, flight data.*

Introduction.

The operational resource of the frictional unit of the aviation wheel brake is determined by the intensity of wear of its friction elements (disks). This intensity depends on the level of kinetic energy that the aviation brakes absorb during every aircraft landing.

Method of analysis of loading friction units of aviation brakes.

Under the load of the friction unit, the aviation brake means the portion of the energy of the forward movement of the aircraft on the runway after touchpoint, which is absorbed and dissipated by one brake device.

The aircraft, at the stage of the after-touch run, forms a so-called closed system with a runway.

The change in the kinetic energy of a system from any of its displacement is equal to the sum of the work of the external and internal forces active to this displacement [1].

$$dT = \sum_{i=1}^{n} dA_i ;$$

where A_i – the work of an i-th active force.

It is common knowledge that aerodynamic forces operate during an airplane run F_1, propeller reverse thrust or reverse thrust F_2 engines, braking force, which arises at the expense of the work of the frictional unit F_3, rolling force friction F_4, gravity G and lift force Y.

Thus, the change in the kinetic energy at the elementary displacement due to the actions of these forces is determined as:

$$dT = \left[F_1\left(\cos\left(\hat{F_1,x}\right)\right) + F_2\left(\cos\left(\hat{F_2,x}\right)\right) + F_3\left(\cos\left(\hat{F_3,x}\right)\right) + F_4\left(\cos\left(\hat{F_4,x}\right)\right) + \right.$$

$$\left. + G\left(\cos\left(\hat{G,x}\right)\right) + Y\left(\cos\left(\hat{Y,x}\right)\right)\right].$$

Taking into account that

$$\cos\left(\hat{G,x}\right) \cong \cos\left(\hat{Y,x}\right) \cong 0, \qquad \cos\left(\hat{F_i,x}\right) \cong 1;$$

write down

$$dT = (F_1 + F_2 + F_3 + F_4)dx.$$

The complete change in the kinetic energy of the translational motion will be equal:

$$T_1 - T_2 = \int_{x_1}^{x_2} (F_1 + F_2 + F_3 + F_4)dx = A_{aer} + A_{rev} + A_r + A_T;$$

where A_{aer} – work of aerodynamic forces; A_{rev} – reverse thrust screw or reverse thrust turbofan engine (TFE); A_T – the work of braking force, which arises at the expense of the functioning of the frictional unit; A_r – work of tires friction rolling force.

The purpose of load analysis is to determine the value A_T:

$$A_T = (T_1 - T_2) - (A_{aer} + A_{rev} + A_r);$$

where T_1 – kinetic energy of the aircraft at the moment of inhibition; T_2 – kinetic energy of an aircraft at the calculated moment of time.

Thus, for a frictional node one brake can be written down

$$A_T \cong \frac{1}{n}\left(\frac{M_{AiC}\left(V_{s.b.}^2 - V_v^2\right)}{2} - A_{aer} - A_{rev} - A_r\right);$$

where n – number of braking devices installed on an aircraft; M_{AiC} – mass of the aircraft at the moment of landing; $V_{s.b.}$ – braking start speed; V_v – velocity of the aircraft; A_{aer} – work of aerodynamic forces; A_{rev} – the work of the reverse force of the propeller or reverse thrust TFE; A_r – the work of the forces of gripping pneumatics with the runway surface.

In order to determine the load of the brake, it is necessary to have data from: the landing mass of the aircraft, the speed of the start of braking $V_{s.b.}$ and steering V_v, work of reverse and work of aerodynamic forces. These data can be obtained on the basis of the analysis of flight data, as well as characteristics of engines operating in reverse mode.

The method of determining the work of aerodynamic drag forces is to calculate the strength of the aerodynamic drag and to determine the length of the run at $V_{s.b.}$ to V_v.

The aerodynamic drag at the stage of the run is determined by the known formula:

$$F_1 = C_{xnp}\frac{\rho V^2}{2}S;$$

where C_{xnp} – coefficient of aerodynamic drag at the aircraft landing configuration; ρ – air density; V – airplane speed; S – wing square.

The value C_{xnp} during landing depends on the characteristics and configuration of the aircraft, that is, on the angle of deflection of the flaps, the stabilizer, the angle of deflection of the spoilers. The work of aerodynamic drag could be defined as follows:

$$A_{aer} = \frac{C_{xnp}\rho S}{2}\int_0^l V^2 dl.$$

In this case, we accept that C_x, ρ, S are constant values.

Four types of aircraft were selected for the respective analysis:

AICR1 – medium-range aircraft (maximum take-off mass (MTOW) – 98-102 tons) with three turbofan engines (TFE);

AICR2 – medium-range aircraft (MTOW – 47-49 tons) with two TFE;

AICR3 – short-haul plane (MTOW – 21-21,5 tons) with two turboprop engines (TPE);

AICR4 – short-haul plane (MTOW – 17-17,2 tons) with three TFE.

According to [2-5] coefficients C_{xnp} corresponding to the regular landing configuration are:
for AICR1 – $C_{xnp1} = 0{,}188$, for AICR2 – $C_{xnp2} = 0{,}145$, for AICR3 – $C_{xnp3} = 0{,}166$,
for AICR4 – $C_{xnp4} = 0{,}172$.

On the basis of the foregoing, it follows that the proportion of kinetic energy after the landing, which is absorbed by the forces of aerodynamic resistance, is for AICR1 – 16%, AICR2 – 10%, AICR3 – 21%, AICR4 – 12%.

To determine the operation of the engines reverse device on the stage of the run the formula [1] could be used:

$$A_{rev} = \int_0^l F_2 \cos\left(F_2 \overset{\wedge}{,} x\right) dl \cong F_2 \frac{V_{tron} + V_{troff}}{2} \cdot t_{rev};$$

where l – a path that corresponds to the working time of the engines reverse device; $\cos\left(F_2 \overset{\wedge}{,} x\right)$ – cosine of the angle between the direction of the action of the force and the longitudinal axes; F_2 – traction power of all engines in the reverse mode, taking into account the speed characteristics of the engines; V_{tron} – the speed of the aircraft, which corresponds to the moment of the reverse "on"; V_{troff} – the speed of the aircraft, which corresponds to the moment of the reverse "off"; t_{rev} – active reverse time.

Under the definition of the level of energy load of the brakes, it was assumed that the share of energy absorbed by the friction force of the pneumatics is 3% of the total landing power of the aircraft.

Necessary data obtained as a result of the processing of oscillograms of flight data records with using of FDR (so-called "Black Boxes") according to the Flight Data Monitoring Program (FDMP) to be implemented in accordance with Annex 19 to the Chicago Convention [6-8].

This method of determining the level of energy load of the braking devices is one of the components of the simulation model of the formation of the flow of breakage of aviation brakes in flight operation [9].

Results of analysis of operational loading of friction units of aviation disk brakes. The purpose of the analysis of energy load of the brake equipment of the aircraft of civil aviation was to clarify the operating spectrum of load of friction elements for further use in the simulation model of the formation of the flow of breakage of brake devices [10-12].

According to the developed methodology of carrying out research, the volume of data collection of objective flight information made up 150-200 decoding of landing stages and after landing run for each chosen aircraft type.

The method of post-flight run analysis, which was developed on the basis of [2-5], allowed some assumptions to be made. In particular, an analysis of the crew's actions has shown that intense braking is carried out at the speed of the aircraft, which is 40-60 km / h. Therefore, the calculations did not take into account the share of energy absorbed by the braking devices due to the slow motion of the aircraft to the apron.

The speed of the aircraft when brakes are on is taken as

$$V_{s.b.} = V_l - 15;$$

where V_l – landing speed at the point of contact with the runway, km / h.

The level of energy absorbed by the friction unit depends to a large extent on the landing mass and the landing speed of the aircraft. It is established that the distribution of these quantities (Fig. 1, Fig. 2) is well suited to the normal law.

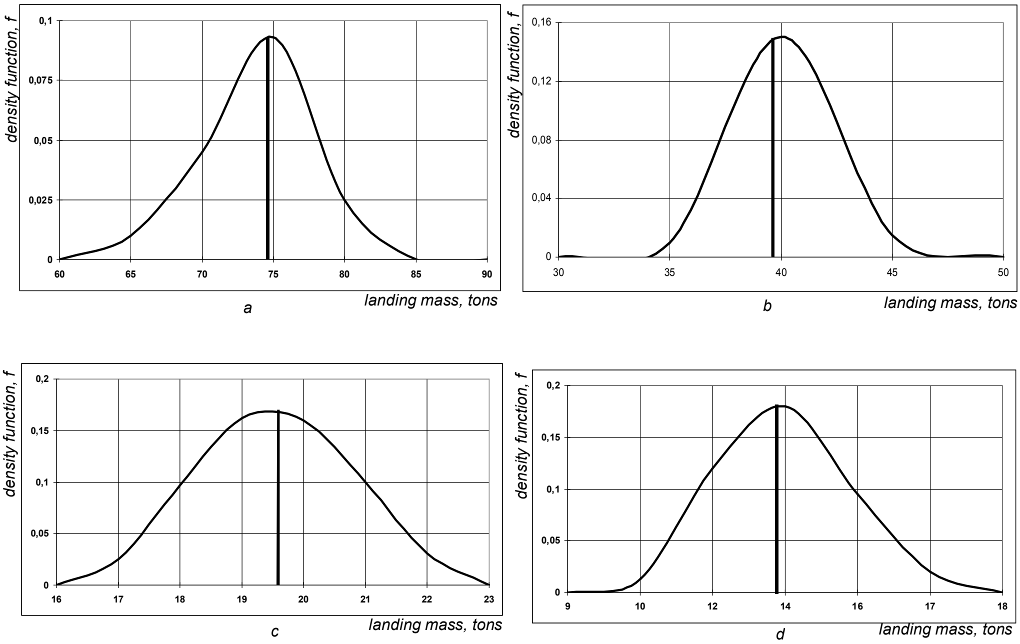

Fig. 1. Distribution of landing masses of some types of civil aviation aircraft: AICR1 – $\bar{x} = 74$, $\bar{\sigma} = 2.6$, $\beta = 0.99$; AICR2 – $\bar{x} = 38.5$, $\bar{\sigma} = 1.4$, $\beta = 0.99$; AICR3 – $\bar{x} = 19.6$, $\bar{\sigma} = 1.0$, $\beta = 0.99$; AICR4 – $\bar{x} = 13.6$, $\bar{\sigma} = 1.1$, $\beta = 0.99$.

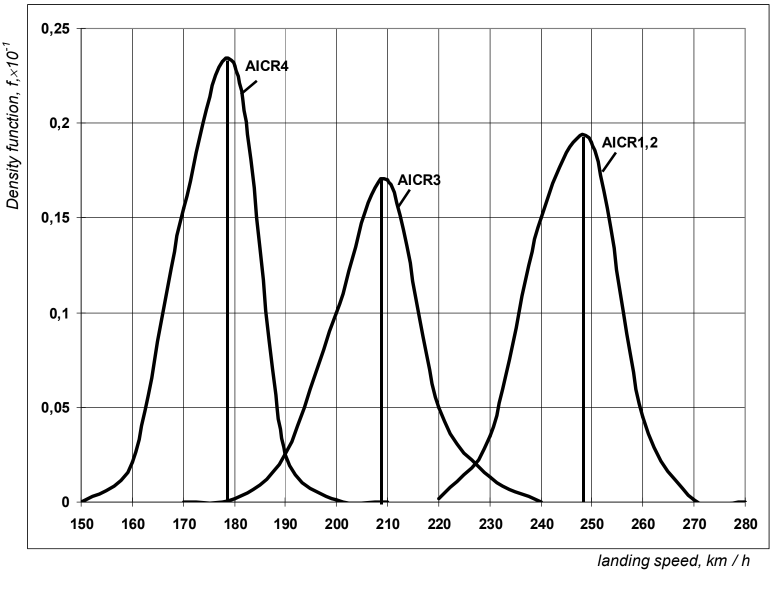

Рис. 2. Distribution of landing speeds of some types of civil aviation aircraft: AICR1 – $\bar{x} = 246$, $\bar{\sigma} = 10$, $\beta = 0.99$; AICR2 – $\bar{x} = 245$, $\bar{\sigma} = 10$, $\beta = 0.99$; AICR3 – $\bar{x} = 208$, $\bar{\sigma} = 12$, $\beta = 0.99$; AICR4 – $\bar{x} = 176$, $\bar{\sigma} = 8$, $\beta = 0.99$.

In fig. 1 the parameters of the laws of distribution of landing mass and velocities are given ($\bar{x},\bar{\sigma}$), as well as confidence probabilityβ.

For AICR1 these values are on average, respectively 74 tones and 246 km / h, for AICR2 – 39,5 tones and 245 km / h, for AICR3 – 19,6 tones and 208 km / h, AICR4 – 13,6 tons and 176 km / h.

The obtained results allowed determining the complete kinetic energy of aircraft at the landing stage, considering it as a stochastic magnificent (Fig. 3). for AICR1 this value is $18{,}2\cdot10^7$ J, which is about 2 times the kinetic energy AICR2 obtained, which is $9{,}7\cdot10^7$ J.

From Fig. 3 it is seen that the total kinetic energy of AICR3 is 6 times smaller than AICR4. Accordingly, the indicated value, as indicated in the table in Fig. 3, for the aircraft AICR4 differs from the AICR1 by more than 10 times ($1{,}7\cdot10^7$ J in comparison with $18{,}2\cdot10^7$ J). Relatively low values of mean-square deviations ($2{,}2\cdot10^7$ J – for AICR1; $1{,}0\cdot10^7$ J – for AICR2; $0{,}48\cdot10^7$ J – for AICR3; $0{,}54\cdot10^7$ J – for AICR4) due to the narrowness of the ranges of permissible velocities and masses relative to the mean values of the indicated quantities.

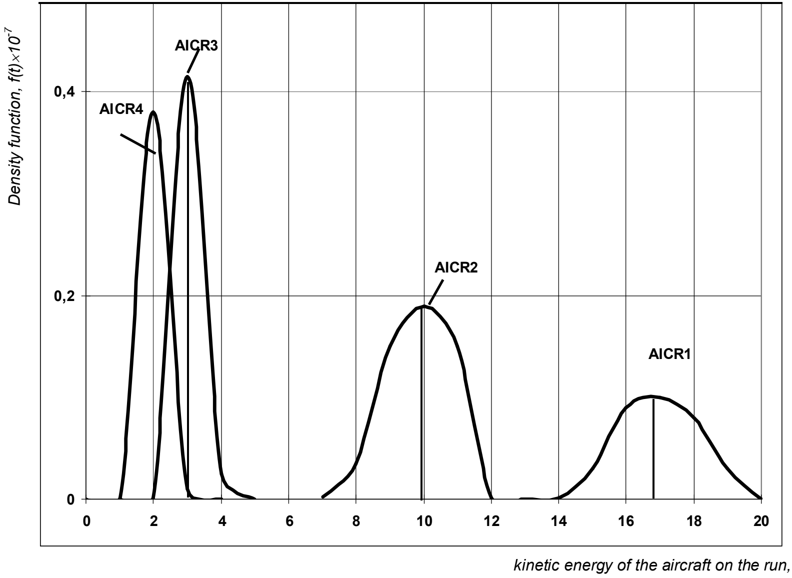

Fig. 3. Distribution of complete kinetic energy of some types of civil aviation aircraft: AICR1 – $\bar{x} = 18.2$, $\bar{\sigma} = 2.2$, $\beta = 0.99$; AICR2 – $\bar{x} = 9.7$, $\bar{\sigma} = 1.0$, $\beta = 0.99$; AICR3 – $\bar{x} = 3.0$, $\bar{\sigma} = 0.48$, $\beta = 0.99$; AICR4 – $\bar{x} = 1.7$, $\bar{\sigma} = 0.54$, $\beta = 0.99$.

The equipment of the aircraft with different types of brake, aerodynamic or reversible devices, as well as the intensity of their application for the absorption of kinetic energy of the translational motion, have a significant effect on the level of operational loading of the frictional knobs of the wheel brakes. Taking into account the before mentioned, the distribution of the average working time of the reversing device or the reciprocating action was determined. For example, (Fig. 4) for an aircraft AICR1, the mathematical expectation of this value is 14 seconds, respectively for AICR2 – 12 seconds, AICR3 – 28 seconds, AICR4 – 18 seconds.

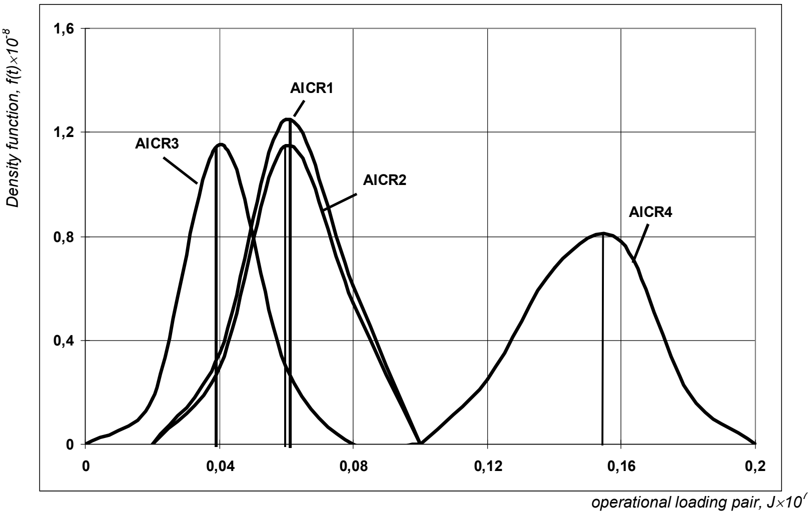

Fig. 4. The distribution of the duration of operation of the of the reversing device (reverse thrust propellers) of some types of civil aviation aircraft: AICR1 – $\bar{x} = 0.064$, $\bar{\sigma} = 0.016$, $\beta = 0.99$; AICR2 – $\bar{x} = 0.063$, $\bar{\sigma} = 0.017$, $\beta = 0.99$; AICR3 – $\bar{x} = 0.039$, $\bar{\sigma} = 0.017$, $\beta = 0.99$; AICR4 – $\bar{x} = 0.148$, $\bar{\sigma} = 0.024$, $\beta = 0.99$.

The difference in average reverse time (reciprocating action) is due to the operating limit on the speed of the aircraft, at which the crew is obliged to turn off the reversing device. For aircrafts AICR1 and AICR2 this speed is within range 105…115 km / h, which explains the comparatively low value of the mathematical expectation of the specified value for these types of aircraft (12 ... 14 sec.).

The specificity of the reciprocal arrangement of the AICR4 aircraft prevents it from being switched on until the touch of the runway, and the pick-up - at a lower speed of the aircraft on the run. This explains the longer work of the reverse on this type of aircraft.

For aircraft AICR3 equipped TPE, this restriction is not available. Because of this, the time of reciprocating thrust is not at the stage of its run quite significant (28 s).

As a result of studies on the intensity of the use of reverse AICR1 and AICR2 devices, the share of the transmitted airborne actuator energy absorbed by them is 7% smaller than the share of AICR3 and is 28% of the value of their total kinetic energy at the start of the run. This is due to the presence of a limit on the speed of the aircraft, on which it is necessary to turn off the reverse device in order to prevent the entry of foreign objects into the gas engine airway.

Conclusions.

Determination of the total kinetic energy of the forward movement of the aircraft at the stage after the landing run, as well as the share of energy absorbed by the aerodynamic means of braking and the reversing device (the effect of reverse thrust) allowed, taking into account assumptions, to determine the load of the friction unit of the disc brakes in the real conditions of operation of air of the vessel. These data can be applied in the future to determine the technical and economic efficiency of the braking devices by means of the imitation simulation.

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ВИКОРИСТАННЯ ПОЛЬОТНОЇ ІНФОРМАЦІЇ ПРИ ОЦІНЦІ НАВАНТАЖЕННЯ ФРИКЦІЙНИХ ВУЗЛІВ АВІАЦІЙНИХ ГАЛЬМ

В статті запропоновано використання польотної інформації для оцінки енергонавантаженості авіаційних колісних гальм. Метою проведення такого аналізу енергонавантаженості гальмівних пристроїв повітряного судна (ПС) було уточнення експлуатаційного спектру навантаженості фрикційних елементів для подальшого використання в імітаційній моделі формування потоку зйомів гальмівних пристроїв

Відомо, що експлуатаційний ресурс фрикційного вузла авіаційного колісного гальма визначається інтенсивністю зношування його фрикційних елементів (дисків) й ця інтенсивність залежить від рівня кінетичної енергії, яку гальмо поглинає при посадці повітряного судна.

Навантаженість фрикційного вузла авіаційного гальма це частка енергії поступального руху ПС на етапі післяпосадкового пробігу, яка поглинається та розсіюється одним гальмівним пристроєм. Під час пробігу на повітряне судно діють сили аеродинамічного опору, зворотна тяга гвинтів або реверсна тяга двигунів, гальмівна сила, яка виникає за рахунок роботи фрикційного вузла, сила тертя кочення, сила ваги повітряного судна та підйомна сила.

Для визначення навантаженості гальма з об’єктивної польотної інформації було визначено посадкову масу повітряних суден, швидкості початку гальмування та рулювання, роботу реверсу й аеродинамічних сил.

Для дослідження було обрано чотири типи повітряних суден із різною максимальною злітною масою, різної конфігурації та різними типами і кількістю двигунів. Застосовуючи певні математичні залежності було проведено розрахунки й доведено, що частка енергії, яка поглинається силою тертя кочення пневматиків складає 3% від повної посадкової енергії повітряного судна. Також, було визначено розподіл середнього часу роботи пристрою реверсу або дії зворотної тяги.

Оснащеність ПС різними типами гальмівних, аеродинамічних або реверсивних пристроїв, а також інтенсивність їхнього застосування для поглинання кінетичної енергії поступального руху мають значний вплив на рівень експлуатаційної навантаженості фрикційних вузлів колісних гальм.

Визначення повної кінетичної енергії поступального руху повітряного судна на етапі після посадкового пробігу, а також частка енергії, яка поглинається аеродинамічними засобами гальмування і пристрою реверсу (дією зворотної тяги) дозволило, з урахуванням прийняти допущень, визначити навантаженість фрикційного вузла дискового гальма в реальних умовах експлуатації повітряного судна. Отримані дані можуть бути застосовані в подальшому для розрахунку показників техніко-економічної ефективності гальмівних пристроїв за допомогою імітаційного моделювання.

Ключові слова: авіаційне гальмо, фрикційні елементи гальм, польотна інформація.

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