**doi: 10.32620/oikit.2020.88.01**

UDC 621.735

R. Tsukanov, V. Ryabkov, O. Los

# Center-of-Gravity Variation Influence on Flight Range of Transport Category Airplane

*M. Y. Zhukovsky National Aerospace University KhAI,*
*ANTONOV Company*

The method of transport category airplane flight range estimation taking into account its center-of-gravity position variation in the process of fuel utilization at cruising flight mode is presented. The method structure includes the following models:
– Interinfluence of main parameters on each other in the process of fuel utilization;
– CG position influence on required thrust values in level flight;
– Estimation of CG position influence on lift-to-drag ratio in cruise mode;
– Quantitative estimation of center-of-gravity position variation influence on airplane flight range.
Simulation of the main parameters is based on authoring researches, which established interinfluence among geometrical and aerodynamic parameters of wing, parameters of horizontal tail and center-of-gravity position variation caused by fuel utilization in cruise flight. Such model allows estimating of airplane center-of-gravity influence their values and their relative position.
Aerodynamic parameters variation caused by center-of-gravity shift resulted in necessity to take this influence into account, for required engine thrust variation; that is shown in the publication in the form of dependences P(M, m, $x_{CG}$) allowing to take into account the required thrust variation and their influence to range variation.
On the base of interinfluence model and taking into account required thrust variation (when center-of-gravity position shifts), lift-to-drag variation has been obtained and analyzed in the form of dependences K, KM(M, m, $x_{CG}$) for middle airplane of transport category.
Expression for estimation of airplane flight range under variable values of its mass and center-of-gravity position is obtained on the base of these models; that allows flight range increasing by means of center-of-gravity position dedicated shift.
On the example of mid-range transport airplane, it is shown, that at Mach number M = 0.7 and center-of-gravity shift back from $x_{CG} = 0.20$ to $x_{CG} = 0.35$, the increase of lift-to-drag ratio makes ΔK = 0.43.
On the base of presented models, it is shown, that airplane center-of-gravity position influences lift-to-drag ratio, fuel efficiency and as a result on flight range at cruising flight mode.
Application of aft center-of-gravity position allows decreasing of engine required thrust (decreasing fuel consumption), and increasing of lift-to-drag ratio and airplane flight range.
***Key words:*** airplane center-of-gravity, fuel trim transfer, engine required thrust, lift-to-drag ratio, flight range.

## Introduction

One of the main tasks, which transport category airplane designers face, is increasing of flight productivity ($m_{pl}\mathrm{L}$) including flight range increase ($L$).

There are some ways to increase flight range of transport category airplanes, among which it is necessary to mention the following ones:

– Decrease of fuel flow rate per unit of useful work in cruising flight mode;

– Harmonization of power plant parameters with increase of lift-to-drag ratio.

One of the conditions of this harmonization is necessity to provide cruising flight mode with wing optimum angle-of-attack under variable airplane mass and at its center-of-gravity (CG) position variation.

CG keeping within definite range by means of fuel trim transfer has found application in some foreign transport category airplanes: A-310, A-330, A-340, A-380, B-747.

Airplane CG position estimation method taking into account fuel transfer is proposed in the publications [4-6].

In domestic practice, this problem is understudied. In addition, it is necessary to investigate fuel trim transfer (FTT) influence on wing aerodynamic parameters and engine thrust characteristics, such as: angle-of-attack in cruise mode, required lifting force factors, thrust force and engine throttling coefficient, and also airplane lift-to-drag ratio, in cruising flight mode.

## 1. Statement of Investigation Problem

**The goal** of the publication is modeling and quantitative estimation of transport category airplane flight range variation under conditions of practical variation of its mass, required thrust and its engine throttling characteristics, and also airplane aerodynamic properties under the fuel trim transfer.

Achievement of the declared goal should be provided by the following ways:

– Modeling of main parameters interinfluence under the airplane CG position variation in cruise flight mode;

– Analysis of CG position influence on engine required thrust values;

– Estimation of CG position influence on airplane aerodynamic parameters variation in cruise flight mode,

– Quantitative estimation of airplane flight range in conditions of CG position variation.

## 2. Modeling of Main Parameters Inter influence Under the Airplane CG Position Variation at Cruise Flight Mode

In work of authorship [6], expressions to determine engine required thrust taking into account airplane CG variation are obtained:

$$P_{req} = 0.7 p_H M^2 S C_{xa_0} + \frac{(mg)^2}{0.7 p_H M^2 S} A,$$

$$A(x_{CG}) = A_{WHT} \left( \frac{\Delta L + x_{pHT} - x_{CG}}{\Delta L + x_{pHT} - x_{pWHT}} \right)^2 + A_{HT} \frac{S}{S_{HT}} \left( \frac{x_{pWHT} - x_{CG}}{\Delta L + x_{pHT} - x_{pWHT}} \right)^2 =$$
$$= A_1(x_{CG}) + A_2(x_{CG}), \quad (1)$$

where $p_H$ — is atmospheric pressure at the flight altitude; $M$ — is flight Mach number; $S$ and $S_{HT}$ — is area of wing and horizontal tail (HT), correspondingly; $C_{x0}$ — is the airplane drag factor under zero lift; $m$ — is the current flight mass; $A_{WHT}$ and $A_{HT}$ — are drag-due-to-lift factors of airplane without HT and separate HT; $x_{CG}$ — is airplane CG relative to mean aerodynamic chord (MAC) leading edge; $x_{pWHT}$ — is center-of-pressure (CP) of airplane without HT relative to wing MAC leading edge; $x_{pHT}$ — is CP of separate HT relative to HT MAC leading edge; $\Delta L$ — is distance between MAC leading edges of wing and HT; $A_1(x_{CG})$ — characterizes impact of airplane WHT into the drag-due-to-lift factor; $A_2(x_{CG})$ — characterizes impact of HT into the drag-due-to-lift factor.

CG position is a known function of the current flight mass and pitch angle $\upsilon$ [5] (which is equal to airplane angle-of-attack $\alpha$ in cruise flight mode)

$$x_{CG} = f(m, \upsilon). \quad (2)$$

Airplane aerodynamic characteristics $C_{x0}$, $A_{WHT}$ and $A_{HT}$ are defined by airplane geometry and its flight mode (altitude and Mach number) and, consequently, do not depend on airplane CG variation.

CP position of airplane without HT and of separate HT are determined by airplane geometry, flight mode and angle-of-attack:

$$x_{pWHT} = \mathrm{b_{MAC}}\left[\bar{x}_{FaWHT} + \frac{m_{z0WHT}}{\mathrm{C^{\alpha}_{yaWHT}}(\alpha - \alpha_{0WHT})}\right], \quad (3)$$

$$x_{pHT} = \mathrm{b_{MACHT}}\left[\bar{x}_{FaHT} + \frac{m_{z0HT}}{\mathrm{C^{\alpha}_{yaHT}}(\alpha - \alpha_{0HT})}\right], \quad (4)$$

where $b_{MAC}$, $b_{MAX\,HT}$ — are the MAC of wing and HT, correspondingly, $\bar{x}_{FaWHT}$, $\bar{x}_{FaHT}$ — are the CP positions of airplane without HT and of separated HT, correspondingly, $m_{z0WHT}$, $m_{z0HT}$ — are the pitching moment factors at zero lift of airplane without HT and separate HT, correspondingly, $C^{\alpha}_{yaWHT}$, $C^{\alpha}_{yaHT}$ — are the derivatives of lift coefficients with angle-of-attack of airplane without HT and separate HT, correspondingly, $\alpha_{0WHT}$, $\alpha_{0\mathrm{HT}}$ — are the angles-of-attack under zero lift of airplane without HT and separate HT, correspondingly.

Thus, to calculate required thrust, it is necessary to determine airplane angle-of-attack under current flight mass and CG position. Formulas for required lifting force coefficients of airplane without HT and separate HT, correspondingly, have been obtained in publication [6]

$$C_{yaWHT} = \frac{mg}{0.7 p_H M^2 S}\left(\frac{\Delta L + x_{pHT} - x_{CG}}{\Delta L + x_{pHT} - x_{pWHT}}\right). \quad (5)$$

$$C_{yaHT} = \frac{mg}{0.7 p_H M^2 S_{HT}}\left(\frac{x_{pWHT} - x_{CG}}{\Delta L + x_{pHT} - x_{pWHT}}\right). \quad (6)$$

In the same time, lifting force coefficient is related to the angle-of-attack by known formula

$$C_{yaWHT} = C^{\alpha}_{yaWHT}(\alpha - \alpha_{0WHT}), \quad (7)$$

whence, the cruising flight angle-of-attack can be determined

$$\alpha(m, M, x_{CG}) = \alpha_{0\mathrm{WHT}} + \frac{mg}{0{,}7 p_H M^2 S C^{\alpha}_{ya\mathrm{WHT}}}\left[\frac{\Delta L + x_{pHT} - x_{CG}}{\Delta L + x_{pHT} - \mathrm{x_{pWHT}}}\right]. \quad (8)$$

As the right part of the formula (8) includes airplane CG and CP positions, depending on its angle-of-attack, then the angle-of-attack computation is provided by step by step method together with CG position updating by the formula (2) and CP position by the formulas (3) and (4) for each current flight mass value. After CG and CP position calculation, their values are substituted into formulas (5) and (6) to determine the required lifting force coefficients and into formula (1) to calculate the required engine thrust. Dividing the required thrust by available one ($P_{av}$), we get the engine throttling coefficient

$$\xi_{th}(m, M, x_{CG}) = \frac{P_{req}(m, M, x_{CG})}{P_{av}(M)}. \tag{9}$$

### 3. CG Position Influence on Engine Required Thrust Values

Fig. 1 shows level flight required thrust dependence of mid-range transport airplane (at altitude of $H = 11$ km) vs. Mach number for initial ($m_1 = 140$ t), mean ($m_3 = 125$ t) and final ($m_5 = 110$ t) flight masses, and also for the forward ($x_{CG} = 0.20$) and aft ($x_{CG} = 0.35$) CG positions drawn by formulas (1).

Tangent lines to the required thrust curves for the initial and final masses, drawn from the origin, are also shown here. Vertical lines denote Mach numbers in the tangent points (which correspond to the biggest flight range modes). Sharp increase of the required thrust corresponds to compressibility stall propagation both at low Mach numbers (due to approaching to the critical angle-of-attacks), and at big Mach numbers (when reaching the critical Mach numbers).

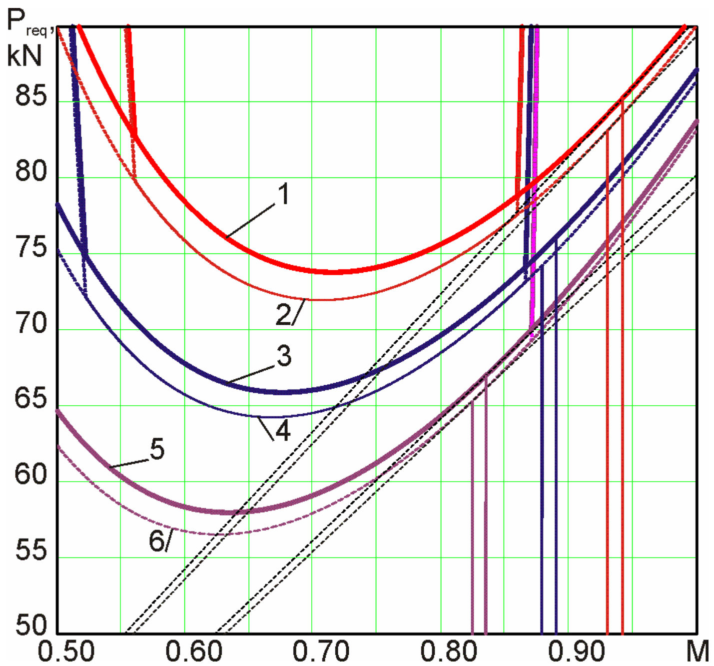


Fig. 1. Required thrust vs. Mach number for different flight masses and CG positions: 1 — Initial mass, forward CG; 2 — Initial mass, aft CG; 3 — Mean mass, forward CG; 4 — Mean mass, aft CG; 5 — Final mass, forward CG; 6 — Final mass, aft CG

From the data shown in Fig. 1, it is followed that at cruising Mach number $M = 0.7$, flight mode is rather far from optimal one to reach the maximum flight range (which is reached at Mach numbers $M > 0.8$).

## 4. CG Position Influence on Aerodynamic Parameters Variation in Cruising Flight

CG position variation in cruising flight results not only in engine required thrust variation, but also in variation of its main aerodynamic characteristic — polar diagram.

Drag-due-to-lift coefficient and its components vs. CG position is shown in Fig. 2.

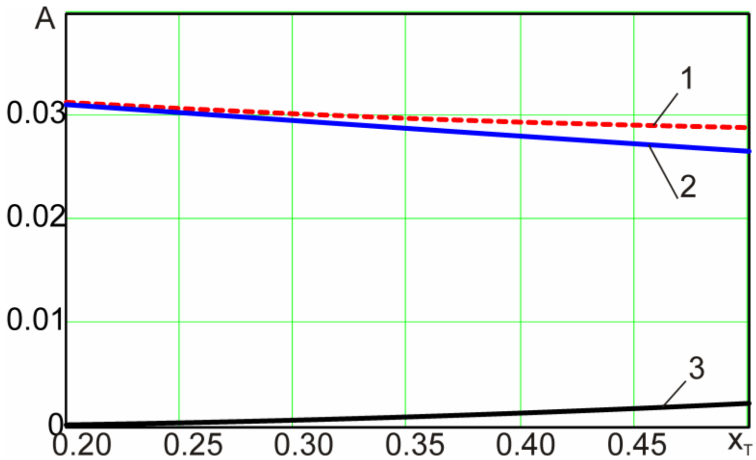


Fig. 2. Drag-due-to-lift coefficient vs. airplane CG:
1 — $A(x_{CG})$; 2 — $A_1(x_{CG})$; 3 — $A_2(x_{CG})$

When calculating the airplane drag coefficient at zero lift, the value $C_{x0} = 0.038$ had been found, that considerably exceeds actual values of the coefficient for the airplanes Ил-76 ($C_{x0} = 0.023$ [7]) and Ан-124 ($C_{x0} = 0.022$ [8]), which are very close to the considered airplane by aerodynamic layout, thus the value $C_{x0} = 0.023$ was assumed for the following calculation.

From the data, shown in Fig. 2, it follows that CG shift back leads to decrease of drag-due-to-lift coefficient of airplane without HT $A_1(x_{CG})$ and to increase of drag-due-to-lift coefficient of HT $A_2(x_{CG})$. In view of that wing area is considerably (2.6 times) exceeds HT area, the drag-due-to-lift coefficient of the airplane decreases.

Taking into account this factor, the airplane lift-to-drag ratio under conditions of steady level flight should be determined as a ratio of airplane current weight to the engine required thrust

$$K(m, M, x_{CG}) = \frac{mg}{P_{req}(M, x_{CG})}. \quad (10)$$

Fig. 3 shows values of lift-to-drag ratio for the same parameters of the mid-range transport airplane.

From the data, shown in Fig. 3, a, follows that CG shift back from $x_{CG} = 0.20$ to $x_{CG} = 0.35$ leads to increase of maximal lift-to-drag ratio on $\Delta K \approx 0.5$ units; but at cruising Mach number $M = 0.7$, lift-to-drag ratio increase makes $\Delta K = 0.37 \ldots 0.49$.

However from data, shown in Fig. 3, b, follows that the biggest flight range could be reached at $M = 0.82...0.86$, if the airplane had been flown with such speed. At Mach number $M = 0.7$ and CG shift back from $x_{CG} = 0.20$ to $x_{CG} = 0.35$, the increase of the product makes $MK_m = 0.26...0.34$.

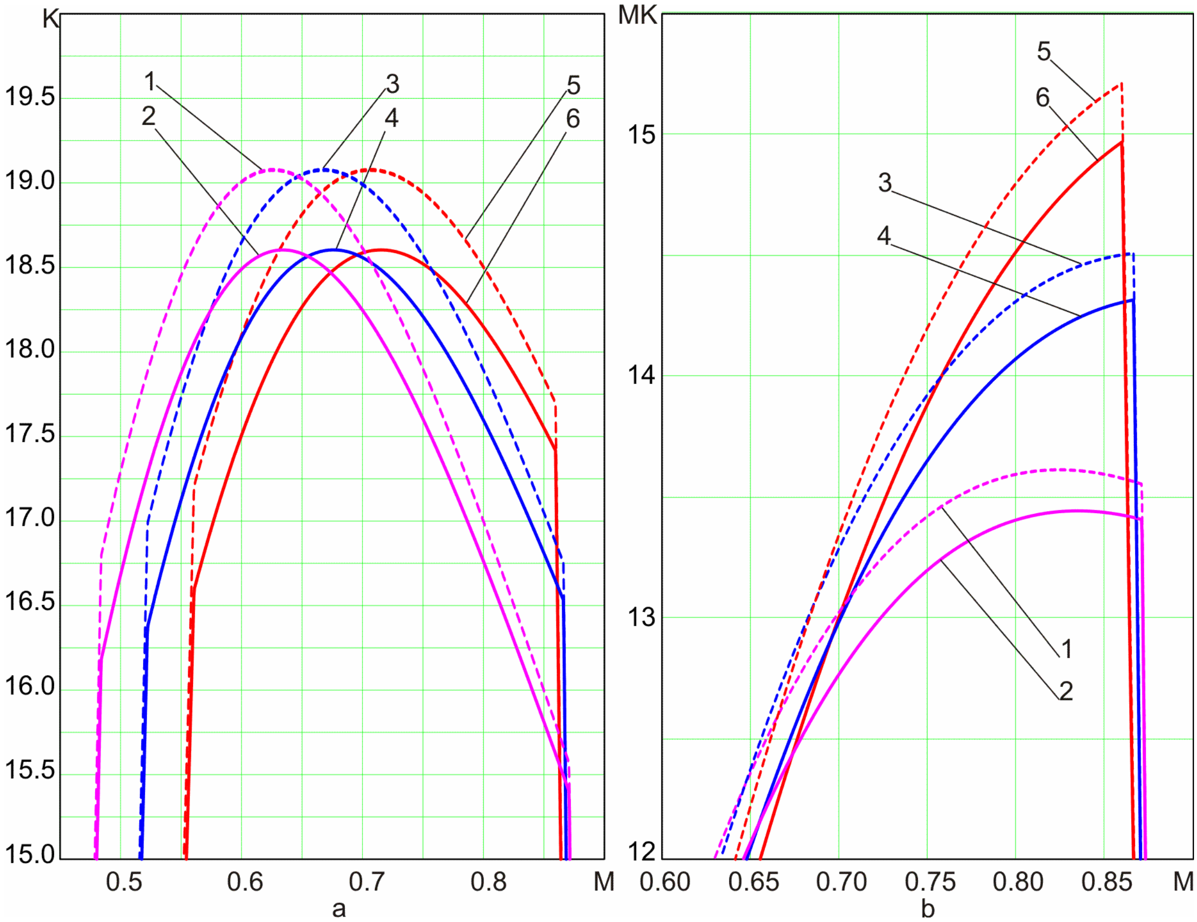


Fig. 3. Aerodynamic parameters $K$ and $KM$ vs. cruising Mach number $M$:
a — Lift-to-drag ratio vs. Mach number for different flight masses and CG positions;
b — Product of Mach number by lift-to-drag ratio vs. Mach number for different flight masses and CG positions: 1 — Final mass, forward CG; 2 — Final mass, aft CG; 3 — Mean mass, forward CG; 4 — Mean mass, aft CG; 5 — Initial mass, forward CG; 6 — Initial mass, aft CG

## 5. Range Variation Estimation Under CG Position Change at Cruising Flight Mode

Application of the models for $MK(M)$ estimation (Fig. 3, b) allows to estimate the flight range variation taking into account CG variation and lift-to-drag coefficient on the base of known expression [12] (Fig. 4)

$$L = 3.6 \frac{a_H MK_m}{C_P g} \ln\left(\frac{m_1}{m_5}\right), \quad (11)$$

where $a_H$ — is the sonic speed at altitude $H$, $K_m$ — is the mean lift-to-drag ratio as for flight masses, $C_p$ — is the specific fuel consumption.

From the shown data, it follows, that at Mach number $M = 0.7$ and CG shift back from $x_{CG} = 0.20$ to $x_{CG} = 0.35$, the increase of lift-to-drag ratio makes $\Delta K = 0.43$, but the increase of flight range makes $\Delta L \approx 110$ km.

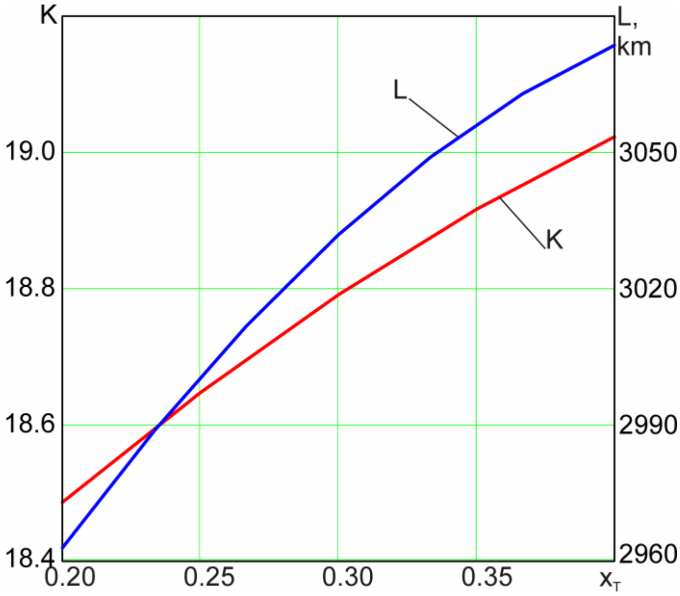


Fig. 4. Lift-to-drag ratio and flight range vs. airplane CG position at M=0.7

## Conclusion

The models to estimate transport category airplane center-of-gravity position influence, caused by fuel usage in cruising flight, on airplane flight range variation have been developed and presented in the publication.

The models are:

– Modeling of main parameters interinfluence under the airplane center-of-gravity position variation in cruise flight mode;

– Analysis of center-of-gravity position influence on engine required thrust values;

– Estimation of center-of-gravity position influence on airplane aerodynamic parameters variation in cruise flight mode,

– Quantitative estimation of airplane flight range under the variable engine required thrust and airplane aerodynamic parameters in cruise flight mode.

On the base of presented models, it is shown, that airplane center-of-gravity position influences lift-to-drag ratio, fuel efficiency and as a result on flight range at cruising flight mode.

Application of aft center-of-gravity position allows decreasing of engine required thrust (decreasing fuel consumption), and increasing of lift-to-drag ratio and airplane flight range. However, for more exact estimation of CG position influence on flight range, the model of airplane polar taking into account wing angle-of-attack variation under CG shift should be improved.

## Reference List

1. Electronic Code of Federal Regulations. Part 25 — Airworthiness Standards: Transport Category Airplanes [Electronic Code]. — URb: http://www.ecfr.gov/cgi-bin/. — 27.04.2015.

2. Electronic Code of Federal Regulations. Part 33 — Airworthiness Standards: Aircraft Engines [Electronic Code]. — URb: http://www.ecfr.gov/cgi-bin/. — 27.04.2015.

3. Концепция создания современных реактивных региональныз пассажирских самолётов [Текст] : монография / П. В. Балабуев, В. А. Богуслаев, А. Д. Донец и др. — Харьков : Нац. аэрокосм. ун-т им. Н. Е. Жуковского «Харьк. авиац. ин-т», 2020. — 271 с.

4. Tsukanov, R. U. Mathematical Simulation of Fuel Burn Schedule Effect on Airplane Center-of-Gravity Position [Text] / R. U. Tsukanov // Авиационно-космическая техника и технология: сб. науч. тр. Нац. аэрокосм. ун-та им. Н. Е. Жуковского «Харьк. авиац. ин-т». — Вып. 1/128. — Харьков, 2016. — С. 18-29.

5. Tsukanov, R. U. Transport Category Airplane Center-Of-Gravity Shift Mathematical Simulation Accounting Fuel Trim Transfer [Text] / R. U. Tsukanov // Вопросы проектирования и производства конструкций летательных аппаратов: сб. науч. тр. Нац. аэрокосм. ун-та им. Н. Е. Жуковского «ХАИ». — Вып. 3 (87). — Харьков, 2016. — С. 41-53.

6. Tsukanov, R. U. Selection of Optimal Center-of-Gravity of Transport Category Airplane from Minimum Required Thrust Condition [Текст] / R. U. Tsukanov // Открытые информационные и компьютерные интегрированные технологии : сб. науч. тр. Нац. аэрокосм. ун-та им. Н. Е. Жуковского «Харьк. авиац. ин-т». — Вып. 76. — Харьков, 2017. — С. 23-30.

7. Бехтир, П. Т. Практическая аэродинамика самолёта Ил-76Т [Текст] / П. Т. Бехтир, В. П. Бехтир. — М. : Машиностроение, 1979. — 155 с.

8. Практическая аэродинамика самолёта Ан-124-100 [Текст] / В. П. Бехтир, В. М. Ржевский, Е. Н. Коврижных, В. Х. Копысов. — Ульяновск. : УВАУ ГА, 2005. — 207 с.

9. Югов, О. К. Согласования характеристик самолёта и двигателя [Текст] / О. К. Югов, О. Д. Селиванов // М. : Машиностроение, 1975. — 204 с.; 2-е изд., 1980. — 200 с.

10. Лось, А. В. Ан-188 Средний военно-транспортный самолёт укороченного взлёта и посадки [Текст] / Киев : ДП «Антонов», 2018. — 118 с.

11. 747-400 Freighter Main deck cargo arrangements. — Boeing, 2010. — 10 p. [Electronic resource]. — Access mode: http://www.boeing.com.

12. Егер, С. М. Проектирование самолётов [Текст] / С. М. Егер, В. Ф. Мишин, Н. К. Лисейцев, А. А. Бадягин, В. Е. Ротин, Ф. И. Склянский, Н. А. Кондрашов, В. А. Киселёв, Н. А. Фомин. — М. :Машиностроение, 1983 г. — 616 с.

## References

1. Electronic Code of Federal Regulations. Part 25 — Airworthiness Standards: Transport Category Airplanes [Electronic Code]. — URb: http://www.ecfr.gov/cgi-bin/. — 27.04.2015.

2. Electronic Code of Federal Regulations. Part 33 — Airworthiness Standards: Aircraft Engines [Electronic Code]. — URb: http://www.ecfr.gov/cgi-bin/. — 27.04.2015.

3. *Koncepcija sozdanija sovremennyh reaktivnyh regional'nyz passazhir-skih samoljotov.* Monografija P. V. Balabuev, V. A. Boguslaev, A. D. Donec i dr. — Har'kov : Nac. ajerokosm. univ. im. N. E. Zhukovskogo «Har'k. aviac. int.» Publ., 2020. 271 p. (In Russian).

4. Tsukanov, R. U. Mathematical Simulation of Fuel Burn Schedule Effect on Airplane Center-of-Gravity Position. R. U. Tsukanov. Aviacionno-kosmicheskaja tehnika i tehnologija: sb. nauch. tr. Nac. ajerokosm. univ. im. N. E. Zhukovskogo «Har'k. aviac. int.» Publ., Vyp. 1/128. Har'kov, 2016. pp. 18-29.

5. Tsukanov, R. U. Transport Category Airplane Center-Of-Gravity Shift Mathematical Simulation Accounting Fuel Trim Transfer. R. U. Tsukanov. Voprosy proektirovanija i proizvodstva konstrukcij letatel'nyh apparatov: sb. nauch. tr. Nac. ajerokosm. univ. im. N. E. Zhukovskogo «Har'k. aviac. int.». Publ., Vyp. 3 (87). — Har'kov, 2016. pp. 41-53.

6. Tsukanov, R. U. Selection of Optimal Center-of-Gravity of Transport Category Airplane from Minimum Required Thrust Condition. R. U. Tsukanov. Otkrytye informacionnye i komp'juternye integrirovannye tehnologii : sb. nauch. tr. Nac. ajerokosm. univ. im. N. E. Zhukovskogo «Har'k. aviac. int.». Vyp. 76. — Har'kov, 2017. pp. 23-30.

7. Behtir, P. T. *Prakticheskaja ajerodinamika samoljota Il-76T*. P. T. Behtir, V. P. Behtir. Moskva, Mashinostroenie, 1979. 155 p. (In Russian).

8. Behtir, V. P. *Prakticheskaja ajerodinamika samoljota An-124-100.* V. P. Behtir, V. M. Rzhevskij, E. N. Kovrizhnyh, V. H. Kopysov. — Ul'janovsk. : UVAU GA, 2005. 207 p. (In Russian).

9. Jugov, O. K. *Soglasovanija harakteristik samoljota i dvigatelja*. O. K. Jugov, O. D. Selivanov. Moskva, Mashinostroenie, 1975. 204 p.; 2-e izd., 1980. 200 p. (In Russian).

10. Los', A. V. An-188 *Srednij voenno-transportnyj samoljot ukorochennogo vzljota i posadki.* Kiev, Oficial'noe izdanie DP «Antonov», 2018. — 118 p.

11. 747-400 Freighter Main deck cargo arrangements. — Boeing, 2010. — 10 p. [Electronic resource]. — Access mode: http://www.boeing.com.

12. Eger, S. M. Proektirovanie samoljotov S. M. Eger, V. F. Mishin, N. K. Lisejcev, A. A. Badjagin, V. E. Rotin, F. I. Skljanskij, N. A. Kondrashov, V. A. Kiseljov, N. A. Fomin. Moskva. Mashinostroenie, 1983. — 616 p.

Поступила в редакцию 30.06.2020, рассмотрена на редколлегии 02.07.2020

## Вплив зміни центрування на дальність польоту літака транспортної категорії

Наведений метод оцінювання дальності польоту літака транспортної категорії з урахуванням зміни положення його центра мас у міру вироблення палива на крейсерському режимі польоту. Структуру методу складають моделі:

– взаємовпливу основних параметрів один на одного у міру вироблення палива;

– впливу положення ЦМ на значення параметрів потрібних тяг у горизонтальному польоті;

– оцінювання впливу положення ЦМ на аеродинамічну якість у крейсерському режимі;

– кількісної оцінки впливу зміни центрування на дальність польоту літака.

Моделювання основних параметрів базується на проведених авторських дослідженнях, що встановлюють взаємозв'язок геометричних та аеродинамічних параметрів крила, параметрів горизонтального оперення та зміни положення центру мас, що обумовлена виробленням палива у крейсерському польоті. Така модель дозволяє оцінити вплив центру мас літака на їх значення та їх взаємположення.

Зміна аеродинамічних параметрів, що спричинена переміщенням центру мас, привела до необхідності врахування такого впливу на зміну потрібних тяг двигунів, що у статті наведено у вигляді залежностей $P(M,m,x_T)$, що дозволяють врахувати зміну потрібних тяг та їх вплив на зміну дальності.

На основі моделі взаємовпливу та з урахуванням зміни потрібних тяг (під час зміни положення центру мас) отримані та проаналізовані зміни аеродинамічної якості у вигляді залежностей $K$, $KM(M,m,x_T)$ для середнього літака транспортної категорії.

На основі таких моделей отримано вираз для оцінки дальності польоту літака зі змінним значенням його маси та положення центру мас, що дозволяє збільшити дальність польоту шляхом цілеспрямованої зміни положення центру мас.

На прикладі середньомагістрального транспортного літака показано, що при числі $M = 0{,}7$ та при зміщенні центру мас назад з $x_T = 0{,}20$ на $x_T = 0{,}35$ зростання аеродинамічної якості становить $\Delta K = 0{,}43$.

На основі запропонованих моделей показано, що положення центру мас літака спричиняє вплив на аеродинамічну якість, на паливну ефективність та як наслідок – на дальність польоту на крейсерському режимі.

Використання задніх центрівок дозволяє зменшити потрібну тягу двигунів (знижуючи витрату палива), збільшити аеродинамічну якість та дальність польоту літака.

***Ключові слова:*** центр мас літака, балансувальне перекачування палива, потрібна тяга двигунів, аеродинамічна якість, дальність польоту.

**About the Authors:**

**Ruslan U. Tsukanov** – senior lecturer of Airplane and helicopter design department (103), National Aerospace University named by M. E. Zhukovsky «Kharkov Aviation Institute», Ukraine.

**Victor I. Ryabkov** – professor of Airplane and helicopter design department (103), National Aerospace University named by M. E. Zhukovsky «Kharkov Aviation Institute», Ukraine.

**Olexandr V. Los** – Vice President — Head of design organization of ANTONOV Company, Ukraine.

**Сведения об авторах:**

**Цуканов Руслан Юрійович** – старший викладач кафедри 103 «Проектування літаків та вертольотів», Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Україна.

**Рябков Віктор Іванович** – професор кафедри 103 «Проектування літаків та вертольотів», Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Україна.

**Лось Олександр Васильович** – віце-президент (з проектування) Державного підприємства «Антонов», Україна.