UDC 629.735.33.085/.087 **doi: 10.32620/aktt.2021.4.02**

A. DVEIRIN[1], V. RYABKOV[2], L. KAPITANOVA[2], M. KYRYLENKO[2]

[1] ***Antonov Company, Kyiv, Ukraine***
[2] ***National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine***

FORMATION OF BASIC PARAMETERS AREAS OF TRANSPORT AIRCRAFT MODIFICATIONS UNDER CONDITIONS OF ITS BASING

Along with the unique flight performance indicators and economic indicators that characterize heavy transport aircraft, the priority is also to ensure the basing for their heavier modifications at the airfields declared for the base aircraft. This problem arises at the very early stage of the modification creation, when its main parameters such as the gross mass at takeoff $\left(m_0^m\right)$ *and thrust-to-weight ratio* $\left(t_0^m\right)$ *are formed. This is due to the very essence of creating a modification - increasing its carrying capacity (which leads to increase in the gross mass at takeoff* m_0^m *and flight range* $\left(L^m\right)$*) with an increased payload* $\left(m_{cl}^m\right)$ *by increasing the mass of fuel on board. Ensuring growth of flight* $\left(m_{pl}^m L^m\right)$ *and hour* $\left(m_0^m V_{cr}\right)$*, performance underlies the creation of all modifications of transport category aircraft. For heavier modifications than their base aircraft, it is further complicated by the fact that the base models are based on the runways of the second and first class airfields, which creates an insurmountable limitation on the available runway length. The second limitation is the value of the decision-making speed* $\left(V_1\right)$ *during takeoff, in case of failure of the critical engine during the takeoff run, which predetermines the required length of the runway. Since the takeoff masses of aircraft modifications of this type continue to increase, the problem of their basing on the runways of existing airfields arises by forming the takeoff weight relationship* $\left(m_0^m\right)$ *– decision-making speed in case of a critical engine failure* $\left(V_1^m\right)$ *- thrust-to-weight ratio* $\left(t_0^m\right)$*, providing the basing of a heavier modification at the airfield declared for the base aircraft* $\left(L_{RWY}^m = L_{RWY}^b\right)$*. To implement this condition, a model for determining the speed* $\left(V_1^m\right)$*, in which a safe termination of the takeoff run is possible in the event of a critical engine failure. The resulting model allows to take into account a number of restrictions due to the properties of heavy aircraft, such as the minimum and maximum thrust of the cruise engines, which makes it possible to make reasonable recommendations in the operating rules for aircraft of this type. Taking into account the expressions obtained to determine* $\left(V_1^m\right)$*, a model has been formed to determine and assess the required thrust-to-weight ratio of a heavier modification* $\left(t_0^m, \left(m_0^m, V_1^m\right)\right)$ *by condition* $\left(L_{RWY}^m = L_{RWY}^b\right)$ *for modifications with a takeoff weight of more than 300 tons. It has been established that the required relative thrust-to-weight ratio should be within* $\left(0 < \bar{t}_0 \le 1.26\right)$*. Defining parameters such as* m_0^m*,* V_1^m *and* t_0^{-m} *is the basis for the implementation of other modification changes in the heavy transport aircraft.*

Keywords: *heavy transport aircraft; modifications; decision-making speed; thrust-to-weight ratio; basing conditions; landing performance.*

Introduction

The basing condition of a heavy transport aircraft is understood as the required length of the runway, on which modifications of this type of aircraft can be regularly operated in terms of takeoff run length, landing run length and under conditions of aborted takeoff in the event of a critical engine failure [1, 2].

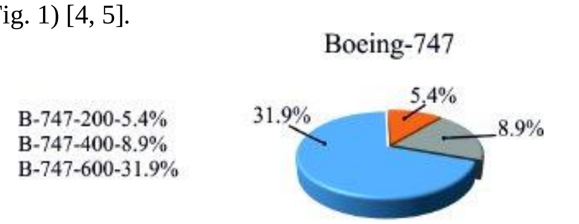
When creating a modification heavier than the base aircraft, to ensure acceptable takeoff and landing characteristics is a priority.

In paper [3], the influence of the takeoff distances $\left(L_{tor}\right)$ during takeoff on selection of the main parameters of the modification during their design $\left(\bar{m}_0^m, t_0^{-m} = f\left(L_{tor}\right)\right)$ has been studied.

But in addition to the takeoff and landing run lengths, the LTC (landing and takeoff characteristics)

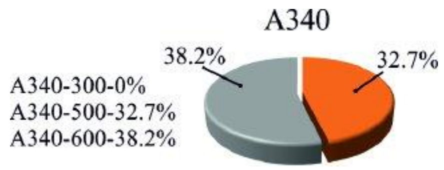
ISSN 1727-7337 (print)
ISSN 2663-2217 (online)

concept also includes the rejected takeoff distance, i.e. the required runway length required to ensure the safe termination of takeoff in the event of a critical engine failure (Fig. 1) [4, 5].



B-747-200 – aircraft mass has been increased by 5.4 % relative to base model
B-747-400 – aircraft mass has been increased by 8.9 % relative to base model
B-747-600 – aircraft mass has been increased by 31.9 % relative to base model

a



A340-300 – aircraft mass has not been changed relative to base model
A340-500 – aircraft mass has been increased by 32.7 % relative to base model
A340-600 – aircraft mass has been increased by 38.2 % relative to base model

b

Fig. 1. Modification mass increase relative to base model: a – Boeing-747; b – A340

Since heavy transport aircraft are already based on class B airfields, for heavier modifications ensuring their basing on existing airfields becomes even more urgent and pushes for a decision.

Research problem statement

Since the required length of the runway for transport category aircraft is predetermined by the conditions of rejected takeoff, the task of this study is to develop models for the formation of areas of required values of the gross mass at takeoff (m_0) and thrust-to-weight ratio (t_0) of modifications of a heavy transport aircraft according to available runway lengths (L_{RWY}) of home airfield.

Evaluation of Decision-Making Speed Variation in Rejected Takeoff Conditions

An important parameter of the rejected takeoff is the value (V_1), i. e, the speed of decision to reject the takeoff run (Fig. 2).

The decision-making speed is set in the Flight Manual (FM) [6, 7] and must be greater than or equal to the minimum involutive takeoff speed $(V_{\min oto})$, at which, in the event of critical engine failure, aircraft is controlled with the help of aerodynamic controls to maintain rectilinear motion, and is also less than or equal to the rotating speed of the nose landing gear, which is also due to the requirements of the Airplane Flight Manual $(V_1 \geq V_{nlg})$.

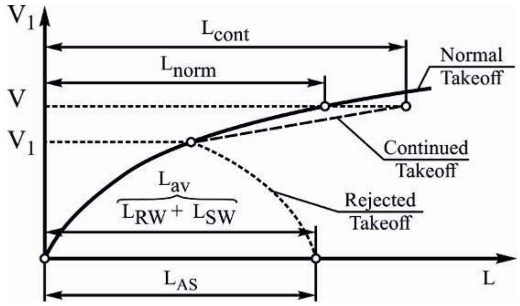


Fig. 2. Decision-Making Speed (V_1) in Case of Failure of Critical Engine during Takeoff

$$L_{RTOD} = L_{0\to V_f} + L_{V_f \to V_1} + L_{V_1 \to 0}, \qquad (1)$$

$$L_{RCTOD} = L_{0\to V_f} + L_{V_f \to V_1} + L_{V_1 \to V_f}, \qquad (2)$$

where $L_{0\to V_f}$ – the length of the takeoff run with all engines running from start to the moment of critical engine failure at speed V_f;

$L_{V_f \to V_1}$ – the length of the acceleration portion with one inoperative engine and, during normal operation of the rest ones, to the decision-making speed;

$L_{V_1 \to 0}$ – the length of the braking portion with one engine inoperative (from speed to complete stop);

$L_{V_1 \to V_{1o}}$ – the length of the acceleration portion with one inoperative engine and during normal operation of the rest ones from speed V_1 up to liftoff speed V_{1o}.

To determine V_1 the available rejected takeoff distance (L_{ARTOD}) (1) reduced by the length of runway-end safety area (L_{RSA}) should be equated to the required distance of the completed takeoff run (L_{RTOD}) (2).

As a result of this operation, we get

$$L_{V_1 \to V_f} = L_{V_1 \to 0} - L_{RSA}. \qquad (3)$$

Using the integral equation to determine the takeoff run

$$L_{tor} = \frac{1}{2g} \int_0^{V_{1o}^2} \frac{dV^2}{t_0 - f_r - \frac{\rho_0 S_w V^2}{2m_0}\left(C_{xtor} - f_r C_{ytor}\right)}, \quad (4)$$

where $V_{1o} = \sqrt{\dfrac{2m_0}{\rho_0 C_{ytor} S_w}}$,

we transform condition (3) to the following form:

$$\frac{V_{1o}^2 - V_1^2}{2g\left[K_1\left(1-\frac{1}{n_e}\right)t_0 - f_r - \frac{\rho_0 C_{xtor} S_w}{6m_0}\left(\frac{V_{1o}^3 - V_1^3}{V_{1o}-V_1}\right)\right]} = \frac{K_2 V_1^2}{2g\left[K_1\left(1-\frac{1}{n_e}\right)r_{rev}t_0 - f_{red} - \frac{\rho_0 C_{x\,r} S_w}{6m_0}V_1^2\right]} - L_{RSA}, \tag{5}$$

where n_e – number of engines;

C_{xtor} – drag coefficient during takeoff run;

K_2 – coefficient taking into account the time for the pilot to make a decision and the time of engaging the aircraft braking devices;

r_{rev} – coefficient of engine reverse thrust-to-forward thrust ratio;

f_r – reduced coefficient of friction of wheels during mileage (mean value),

$$f_{red} = \chi \cdot \left[\frac{\bar{l}_{n\,lg} \cdot f_f + \bar{l}_{m\,lg} \cdot f_r}{1+\bar{h}_{lg}\left(f_f - f_r\right)}\right], \tag{6}$$

where $\chi = 0.75...0...0.95$ - coefficient depending on the quality (in particular on the inertia) of the anti-skid automatic braking machine for the main wheels of landing gear; with brake nose wheels $f_{red} = \chi \cdot f_f$.

f_f – coefficient of friction of main landing gear braked wheels;

$\bar{l}_{n\,lg} = l_{n\,lg}/l_{lg}$, $\bar{l}_{m\,lg} = l_{m\,lg}/l_{lg}$, $\bar{h}_{lg} = h_{lg}/l_{lg}$, – the linear dimensions of nose $l_{n\,lg}$ and main $l_{m\,lg}$ landing gear struts offset from the aircraft center of mass relative to the wheelbase $\left(l_{lg}\right)$,

h_{lg} - the linear dimension from the aircraft center of mass to the runway surface.

To study the modifications, we introduce into consideration the relative values:

$$\bar{t}_0 = t_0/t_0^b,\ \bar{V}_{1o}^2 = V_{1o}^2/\left(V_{1o}^b\right)^2,$$
$$\bar{m}_0 = m_0/m_0^b,\ \bar{V}_1 = V_1/V_1^b,$$

in which index "b" indicates the parameters of the base aircraft.

Using these dimensionless parameters, we simplify expression (5). Expression (7) makes it possible to establish the dependence of the growth of the relative mass $\bar{m}_0^m$ and relative thrust-to-weight ratio $\bar{t}_0^m$ on the value of relative decision-making speed $\bar{V}_0^m$ when developing aircraft modifications (Fig. 3).

$$\frac{\left(V_{1o}^b\right)^2 \bar{m}_0 - \left(V_1^b\right)^2 \bar{V}_1^2}{K_1\left(1-\frac{1}{n_e}\right)t_0^b\bar{t}_0 - f_r - \frac{\rho_0 C_{xtor} S_w}{6m_0\bar{m}_0}\left(\left(V_{1o}^b\right)^2 \bar{m}_0 + V_1^b V_{1o}^b \bar{V}_1\sqrt{\bar{m}_0} + \left(V^b\right)^2 \bar{V}_1^2\right)} = \frac{K_2\left(V_1^b\right)^2 \bar{V}_1^2}{K_1\left(1-\frac{1}{n_e}\right)r_{rev}t_0^b\bar{t}_0 + f_{red} - \frac{\rho_0 C_{x.tor} S_w}{6m_0\bar{m}_0}\left(V_1^b\right)^2 \bar{V}_1^2} - 2qL_{RSA}. \tag{7}$$

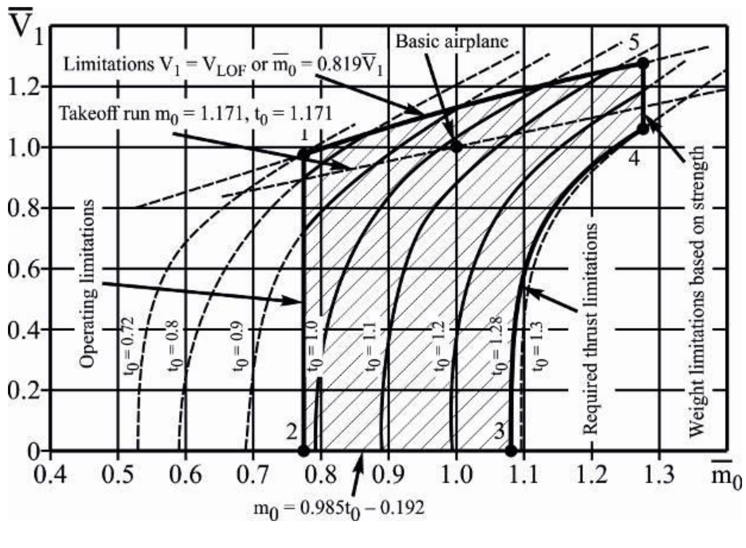


Fig. 3. Influence of relative variation in the takeoff weight of modification on relative value of speed V_1

ISSN 1727-7337 (print)
ISSN 2663-2217 (online)

Determination of Required Thrust-to-Weight Ratio of Heavy Aircraft Modifications

Considering the limitation on the minimum (1), (2) and maximum (4), (5) takeoff weight; by takeoff parameters (1) - (5), as well as by the required thrust of the power plant (3), (4), we obtain the range of acceptable values $\bar{m}_0^m$, $\bar{t}_0^m$ and $\bar{V}_0^m$, in which the existence of aircraft modifications is possible.

A rejected takeoff is considered as normal until the critical engine or aircraft systems that affect takeoff performance fail. After the pilot has made a decision (i.e. V_1) the rejection of takeoff with braking to a complete stop begins.

It is known [5] that for the parameters of base aircraft $m_0^b = 300$ t; $t_0^b = 0.3$; $C_{xtor} = 0.08$; $C_{ylo} = 1.7$ a sufficiently accurate analytical expression for determining the rejected takeoff distance has the form:

$$L_{rto} = \frac{V_1^2}{2q}\left[\frac{1}{K_1 t_0 - f_r - \frac{\rho_0 C_{xtor} S_w}{6m_0} V_1} + \frac{K_2}{K_1\left(1-\frac{1}{n_e}\right) r_{rev} t_0 + f_{red} + \frac{\rho_0 C_{x\,tor} S_w}{6m_0} V_1^2}\right]. \quad (8)$$

One of the determining factors in the selection of main parameters of modifications is the condition of equality required distances of rejected takeoff of base aircraft (b) and its modifications.

$$\frac{L_{rto}^m}{L_{rto}^b} = \bar{L}_{rto}^m = 1.0 \quad (9)$$

Taking this condition, as well as using the relative values $\bar{m}_0^m$, $\bar{t}_0^m$ and $\bar{V}_0^m$, we transform (8) to the form:

$$L_{rto} = \frac{\left(\bar{V}_1^b\right)^2 \bar{V}_1^2}{2q}\left[\begin{array}{l}\dfrac{1}{K_1 t_0^b \bar{t}_0 - f_r - \dfrac{\rho_0 C_{xtor} S_w}{6m_0 \bar{m}_0}\left(V_1^b\right)^2 \bar{V}_1^2} + \\ + \dfrac{K_2}{K_1\left(1-\dfrac{1}{n_e}\right) r_{rev} t_0^b \bar{t}_0 + f_{red} + \dfrac{\rho_0 C_{x\,tor} S_w}{6m_0 \bar{m}_0}\left(V_1^b\right)^2 \bar{V}_1^2}\end{array}\right]. \quad (10)$$

Replacing the second term in (10) from (7), we obtain the relationship of three relative values

$$L_{rto}^b = \left[\begin{array}{l}\dfrac{\left(V_{1o}^b\right)^2 \bar{m}_0 - \left(V_1^b\right)^2 \bar{V}_1^2}{K_1\left(1-\dfrac{1}{n_e}\right) t_0^b \bar{t}_0 - f_r - \dfrac{\rho_0 C_{xtor} S_w}{6m_0 \bar{m}_0}\left(V_{1o}^b\right)^2 \bar{m}_0 + V_1^b V_{1o}^b \bar{V}_1 \sqrt{\bar{m}_0} + \left(V_1^b\right)^2 \bar{V}_1^2} + \\ + \dfrac{\left(V_1^b\right)^2 \cdot \bar{V}_1^2}{K_1 t_0^b \bar{t}_0 + f_{r.} + \dfrac{\rho_0 C_{x\,tor} S_w}{6m_0 \bar{m}_0}\left(V_1^b\right)^2 \bar{V}_1^2} + 2qL_{RSA}\end{array}\right]. \quad (11)$$

From relation (11), it is easy to obtain the desired dependence $\bar{t}_0 = f\left(\bar{m}_0, \bar{V}_1\right)$ by introducing the references:

$$a_1 = f_r + \frac{1}{3}\frac{C_{x\,tor}\left(V_1^b\right)^2}{C_{y1o}\left(V_{1o}^b\right)^2}\frac{\bar{V}_1}{\bar{m}_0}; \quad (12)$$

$$a_2 = a_1 + \frac{1}{3}\frac{C_{x\,tor}}{C_{y1o}}\left(1 + \frac{V_1^b}{V_{1o}^b}\frac{\bar{V}_1}{\sqrt{\bar{m}_0}}\right). \quad (13)$$

They can be substituted in (11) with the subsequent transformation of this expression with respect to $\bar{t}_0$

$$2q\left(L_{rto}^b - L_{RSA}\right) = \frac{V_1^b \bar{V}_1^2}{K_1 t_0^b \bar{t}_0 - a_1} + \frac{\left(V_{1o}^b\right)^2 \bar{m}_0 - \left(V_1^b\right)^2 V_1^2}{K_1\left(1-\dfrac{1}{n_e}\right) t_0^b \bar{t}_0 - a_2} \quad (14)$$

$$\bar{t}_0^2 - \frac{2q\left(L_{rto}^b - L_{RSA}\right)\left(a_1 - \frac{a_1}{n_e} + a_2\right) - \frac{\left(V_1^b\right)^2 \bar{V}_1^2}{n_e} + \left(V_{1o}^b\right)^2 \bar{m}_0}{2q\left(L_{rto}^b - L_{RSA}\right)K_1\left(1 - \frac{1}{n_e}\right)t_0^b}\bar{t}_0 + \frac{2q\left(L_{rto}^b - L_{RSA}\right)a_1 a_2 + \left(V_1^b\right)^2\left(a_2 - a_1\right)\bar{V}_1^2 + \left(V_{1o}^b\right)^2 a_1 \bar{m}_0}{2q\left(L_{rto}^b - L_{RSA}\right)K_1^2\left(1 - \frac{1}{n_e}\right)\left(t_0^b\right)^2} = 0. \qquad (15)$$

It is obvious that formula (15) includes the parameters of both the base aircraft (index "b") and modified aircraft. If we substitute the basic parameters of base aircraft into it $L_r^b = 1716$ m, $L_{RSA} = 300$ m, $V_1^b = 65$ m/s and $V_{tor}^b = 71.828$ m/s, then it is:

$$\bar{t}_0^2 - \left(0.277 + 0.077\frac{\bar{V}_1}{\sqrt{\bar{m}_0}} + 0.123\frac{\bar{V}_1^2}{\bar{m}_0} - 0.208\bar{V}_1^2 + 1.015\bar{m}_0\right)\bar{t}_0 + 0.016 + 0.006\frac{\bar{V}_1}{\sqrt{\bar{m}_0}} + 0.016\frac{\bar{V}_1^2}{\bar{m}_0} +$$
$$+0.006\frac{\bar{V}_1}{\sqrt{\bar{m}_0}} + 0.016\frac{\bar{V}_1^2}{\bar{m}_0} + 0.004\frac{\bar{V}_1^3}{\bar{m}_0\sqrt{\bar{m}_0}} + 0.004\frac{\bar{V}_1^4}{\bar{m}_0^2} + 0.107\bar{V}_1^2 + 0.048\frac{\bar{V}_1^3}{\bar{m}_0} + 0.083\bar{m}_0 = 0. \qquad (16)$$

Parametric variation of $\bar{V}_1$ and $\bar{m}_0$ allows to obtain a numerical interpretation of expression (16) presented in Table 1.

Table 1

Numerical values of dependence $\bar{t}_0 = f\left(\bar{m}_0,\ \bar{V}_1\right)$ when modifying the base aircraft with the parameters shown in Fig. 3, at $\bar{L}_{rto} = 1.0$

$\bar{m}_0$	$\bar{V}_1$							
	0	0.5	0.8	0.9	1.0	1.1	1.2	1.3
0.4	0.601	0.582						
0.5	0.703	0.689						
0.6	0.804	0.789	0.64					
0.7	0.906	0.891	0.779	0.684				
0.8	1.007	0.993	0.893	0.828	0.722			
0.9	1.109	1.092	1.005	0.950	0.875	0.756		
1.0	1.210	1.193	1.110	1.062	1.000	0.914	0.759	
1.1	1.312	1.294	1.214	1.171	1.117	1.045	0.943	0.774
1.2	1.413	1.395	1.317	1.275	1.226	1.163	1.080	0.960
1.3	1.515	1.495	1.421	1.382	1.335	1.276	1.201	1.107
1.4	1.616	1.595	1.521	1.483	1.439	1.384	1.316	1.236

The same data is shown in Fig. 4. In addition, zone (1–2–3–4–5–1) of the dependence $\bar{t}_0 = f\left(\bar{m}_0,\ \bar{V}_1\right)$ at $\bar{L}_{rto} = 1.0$ formed by the following constraints (boundary conditions) is as follows:

Line 1-2 - limitations on the conditions of possible aircraft operation (for example, decrease in the takeoff weight of base aircraft when it is not fully loaded with fuel or payload). In this case, the restriction $\bar{m}_{0\min} = 0.78$, that is 234 tons instead of $m_0 = 300$ t has been taken.

1. Line 2-3 - limitation $\bar{V}_1 = 0$. Under this condition, Eq. (16) turns into the dependence $\bar{m}_0 = 0.985\bar{t}_0 - 0.192$, which can be considered as a completed takeoff run with one critical engine failure at the time of aircraft takeoff.

This example requires the distance of the completed takeoff run.

$L_{rctod} = L_{rto} - L_{RSA} = 1716 - 300 = 1416$ m

both for the base aircraft and for all its modifications.

2. Line 3-4 - limitations on the available opportunities to increase the required thrust of the power plant,

 ISSN 1727-7337 (print)
ISSN 2663-2217 (online)

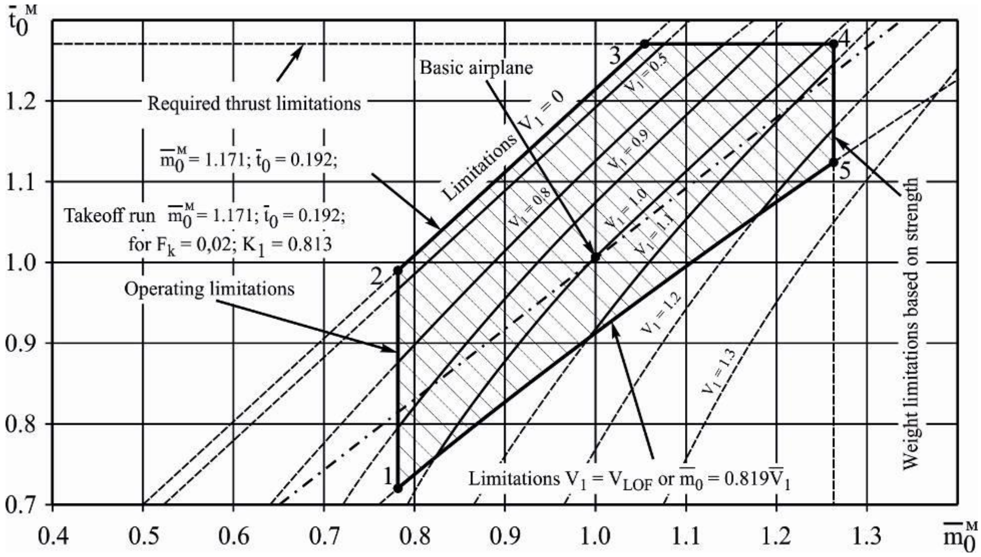


Fig. 4. Dependency $\bar{t}_0^m = f\left(\bar{m}_0^m;\ \bar{V}_1^m\right)$ when Designing Modifications by Condition $\bar{L}_{rto} = 1.0$

and, consequently, the power-to-weight ratio of the aircraft $\bar{t}_{0\max} = 1.28$.

Increase in the required thrust of the aircraft power plant within the considered relative limits $1.0 < \bar{t}_0 \le 1.28$ can be provided both by automatic activation of forced operation mode, and by the possibility of installation of powerful engines on modifications.

3. Line 4-5 - limitations on aircraft mass based on strength conditions are determined by the most severe cases of loading of various aircraft components (wing, empennage, landing gear, etc.) by operating modes. In this case, it is accepted $\bar{m}_{0\max} = 1.26$.

4. Line 5-1 - limitation $V_1 = V_{1o}$. This limitation gives the dependence:

$$V_1^b \bar{V}_1 = V_{1o}^b \bar{V}_{1o} = V_{1o}^b \bar{m}_0;$$

$$\bar{m}_0 = \frac{\left(V_1^b\right)^2}{\left(V_{1o}^b\right)^2} \bar{V}_1^2$$

or $\bar{m}_0 = 0.819\bar{V}_1^2$, which should be considered as a completed takeoff run with one critical engine inoperative at the moment of aircraft liftoff.

Shown in Fig. 3 data combined with dependencies $\bar{V}_1 = f\left(\bar{m}_0,\ \bar{t}_0\right)$ shown in Fig. 2, give the designer a complete idea of the available takeoff weight $\bar{m}_0^b$ variation of modified aircraft, its thrust-to-weight ratio and speed $\bar{V}_1$ while maintaining one of the main parameters – the rejected takeoff distance, which has a decisive influence on the determination of the modification base aerodromes.

Conclusions

1. Along with the flight performance and economic indicators of heavy transport aircraft, the priority is given to the conditions of basing at class A and B airfields, which have the longest available runways.

2. Since the takeoff masses of this type of aircraft modification continue to increase, the problem arises to ensure their basing on the runways of existing airfields by forming at the design stage the relationship takeoff mass m_0^m – decision-making speed, V_1^m, - thrust-to-weight ratio t_0, providing the basing of a heavier modification at the declared airfield for the base aircraft $L_{RWY}^m = L_{RWY}^b$.

3. To implement this condition, a model has been developed for determining the speed V_1^m at which it is possible to safely terminate the takeoff run in the event of a critical engine failure. The resulting model allows to take into account a number of limitations due to the properties of a heavy aircraft, such as minimum and maximum takeoff masses, in terms of takeoff parameters and thrust of cruise engines, which makes it possible to make reasonable recommendations in the rules of flight operation of this type aircraft.

4. Taking into account the expressions obtained for the evaluation of V_1^m a model for determining and quantifying the required thrust-to-weight ratio has been formed $\left(\bar{t}_0\left(m_0^m,\ V_1^m\right)\right)$ by condition $L_{RWY}^m = L_{RWY}^b$ for modification with takeoff weight of more than 300 tons. It was found that the value of the mass should be within the limits $1.0 < \bar{t}_0 \le 1.26$ as m_0^m, V_1^m, t_0^m is

the basis for the formation of other most important parameters of heavy aircraft modifications at the stage of their design.

References (GOST 7.1:2006)

1. Electronic Code of Federal Regulations. Part 25 – Airworthiness. Standards Transport Category Airplanes [Electronic resource]. – Access mode: https://www.ecfr.gov/cgi-bin/text-idx?SID= 014274dd0db07b340da3eda13ac8f6cd&mc= true&node=pt14.1.25&rgn=div5 – 27.04.2015.

2. Electronic Code of Federal Regulations. Part 33 – Enforcement of nondiscrimination on the basis of handicap in programs or activities conducted by the department of labor [Electronic resource]. – Access mode: https://ecfr.federalregister.gov/current/title-29/subtitle-A/part-33. – 27.04.2015.

3. Капитанова, Л. В. Метод определения взлетных масс модификаций самолетов транспортной категории по условиям взлета и посадки [Текст] / Л. В. Капитанова // Вісник двигунобудування – 2015. – № 2. – С. 15-19.

4. IATA. Airline Industry Financial Forecast. [Electronic resource]. – Access mode: https://www.iata.org/en/iata-repository/publications/ economic-reports/airline-industry-economic-performance---april-2021---report/. – 11.05.2021.

5. Офіційний портал ICAO. ICAO DATA+ Pricing Grid [Электронный ресурс]. – Режим доступа: https://data.icao.int/newDataPlus/Home/Pricing. – 11.03.2019.

6. Егер, С.М. Проектирование самолетов [Текст] / С. М. Егер, В. Ф. Мишин, Н. К. Лисейцев. – М. : Машиностроение. – 1983. – 616 с.

7. Андриенко, Ю. Г. Метод формирования совокупности технико-экономических характеристик в процедуре выбора проектных решений при разработке транспортных самолетов [Текст] / Ю. Г. Андриенко // Открытые информационные и компьютерные технологии. – 2002. – Вып. 12. – С. 125-138.

References (BSI)

1. *Electronic Code of Federal Regulations. Part 25 – Airworthiness. Standards Transport Category Airplanes.* Available at: https://www.ecfr.gov/cgi-bin/text-idx?SID=014274dd0db07b340da3eda13ac8f6cd&mc=true&node=pt14.1.25&rgn=div. (accessed 27.04.2015).

2. *Electronic Code of Federal Regulations. Part 33 – Enforcement of nondiscrimination on the basis of handicap in programs or activities conducted by the department of labor*. Available at: https://ecfr.federalregister.gov/current/title-29/subtitle-A/part-33. (accessed 27.04.2015).

3. Kapitanova, L. V. Metod opredeleniya vzletnykh mass modifikatsii samoletov transportnoi kategorii po usloviyam vzleta i posadki [Method for determination of takeoff masses of transport category aircraft modifications according to take-off and landing conditions]. *Visny`k dvy`gunobuduvannya – Herald of Aeroenginebuilding*, 2015, no. 2, pp. 15-19.

4. *IATA. Airline Industry Financial Forecast.* Available at: https://www.iata.org/en/iata-repository/ publications/economic-reports/airline-industry-economic-performance---april-2021---report/. (accessed 11.05.2021).

5. Web-portal ICAO. ICAO DATA+ Pricing Grid. Available at: https://data.icao.int/newDataPlus/ Home/Pricing. (accessed 11.03.2019).

6. Eger, S. M., Mishin, V. F., Liseitsev, N. K. *Proektirovanie samoletov* [Airplane designing]. Moscow, Mashinostroenie Publ., 1983. 616 p.

7. Andrienko, Yu. G. Metod formirovaniya sovokupnosti tekhniko-ekonomicheskikh kharakteristik v protsedure vybora proektnykh reshenii pri razrabotke transportnykh samoletov [The method of forming a set of technical and economic characteristics in the procedure for choosing design solutions in the development of transport aircraft]. *Otkrytye informatsionnye i komp'yuternye tekhnologii – Open Information and Computer Integrated Technologies*, Khar'kov, 2002, vol. 12, pp. 125-138.

Поступила в редакцию 01.06.2021, рассмотрена на редколлегии 09.08.2021

ФОРМУВАННЯ ОБЛАСТЕЙ ОСНОВНИХ ПАРАМЕТРІВ МОДИФІКАЦІЙ ТРАНСПОРТНОГО ЛІТАКА ЗА УМОВАМИ ЙОГО БАЗУВАННЯ

А. З. Двейрін, В. І. Рябков, Л. В. Капітанова, М. В. Кириленко

Поряд з унікальними льотно-технічними та економічними показниками, що характеризують важкі транспортні літаки, пріоритетним є також забезпечення базування для їх більш важких модифікацій на аеродромах, що заявлені для базового літака. Ця проблема виникає на самому ранньому етапі створення модифікації, коли формуються основні її параметри, такі як стартова маса ($m_0^м$) і тягооснащеність ($t_0^м$). Пов'язано це з самою суттю створення модифікації - підвищення її вантажопідйомності (що призводить до зростання

ISSN 1727-7337 (print)
ISSN 2663-2217 (online)

стартової маси $m_o^м$ і дальності польоту ($L^м$) зі збільшеним корисним навантаженням ($m_{к.н}^м$) шляхом збільшення маси палива на борту. Забезпечення зростання рейсової ($m_{пн}^м L^м$) і часової ($m_o^м V_{крейс}$) продуктивності лежить в основі створення всіх модифікацій літаків транспортної категорії. Для більш важких модифікацій, ніж їх базовий літак, ускладнюється ще й тим, що самі базові моделі базуються на злітно-посадкові смуги аеродромів другого і першого класу, що створює непереборне обмеження за існуючою довжиною злітно-посадкової смуги. Другим обмеженням виступає величина швидкості прийняття рішення (V_1) при розбігу, при відмові критичного двигуна на розбігу при зльоті, яка і визначає потрібну довжину злітно-посадкової смуги. Оскільки злітні маси модифікацій літаків цього типу продовжують зростати, то виникає проблема їх базування на злітно-посадкових смугах існуючих аеродромів шляхом формування на етапі проектування взаємозв'язку «злітна маса» ($m_o^м$) - швидкість прийняття рішення при відмові критичного двигуна ($V_1^м$) - тягоозброєність ($t_o^м$), що забезпечує базування важчій модифікації на аеродромі, заявленому для базового літака ($L_{ВПП}^м = L_{ВПП}^б$). Для реалізації такої умови розроблена модель визначення швидкості ($V_1^м$), при якій можливо безпечне припинення розбігу при відмові критичного двигуна. Отримана модель дозволяє врахувати ряд обмежень, зумовлених властивостями важкого літака, таким як мінімальна і максимальна величина тяги маршових двигунів, що дозволяє внести обґрунтовані рекомендації до правил експлуатації літаків цього типу. З урахуванням виразів, отриманих для визначення ($V_1^м$), сформована модель визначення та оцінки потрібної тягоозброєності важчої модифікації ($t_o^м$, $(m_o^м$, $V_1^м$) за умовою ($L_{ВПП}^м = L_{ВПП}^б$) для модифікацій зі злітною масою понад 300 т. Встановлено, що потрібна відносна величина тягоозброєності повинна знаходитися в межах ($0 < \bar{t}_o \leq 1{,}26$). Визначення таких параметрів, як $m_o^м$, $V_1^м$ і $\bar{t}_o^м$ є основою для реалізації інших модифікаційних змін в важкому транспортному літаку.

Ключові слова: важкий транспортний літак; модифікації; швидкість прийняття рішення; тягоозброєність; умови базування; посадкові характеристики.

ФОРМИРОВАНИЕ ОБЛАСТЕЙ ОСНОВНЫХ ПАРАМЕТРОВ МОДИФИКАЦИЙ ТРАНСПОРТНОГО САМОЛЕТА ПО УСЛОВИЯМ ЕГО БАЗИРОВАНИЯ

А. З. Двейрин, В. И. Рябков, Л. В. Капитанова, М. В. Кириленко

Наряду с уникальными летно-техническими и экономическими показателями, характеризующими тяжелые транспортные самолеты, приоритетным является также обеспечение базирования для их более тяжелых модификаций на аэродромах, заявленных для базового самолета. Эта проблема возникает на самом раннем этапе создания модификации, когда формируются основные её параметр. такие как стартовая масса ($m_o^м$) и тяговооруженность ($t_o^м$). Связано это с самой сутью создания модификации – повышения её грузоподъемности (что приводит к росту стартовой массы $m_o^м$ и дальности полета ($L^м$) с увеличенной полезной нагрузкой ($m_{к.н}^м$) путем увеличения массы топлива на борту. Обеспечение роста рейсовой ($m_{пн}^м L^м$) и часовой ($m_o^м V_{крейс}$), производительности лежит в основе создания всех модификаций самолетов транспортной категории. Для более тяжелых модификаций, чем их базовый самолет, осложняется еще и тем, что сами базовые модели базируются на взлетно-посадочные полосы аэродромов второго и первого класса, что создает непреодолимое ограничение по располагаемой длине взлетно-посадочной полосы. Вторым ограничением выступает величина скорости принятия решения (V_1) при разбеге, при отказе критического двигателя на разбеге при взлете, которая и предопределяет потребную длину взлетно-посадочной полосы. Поскольку взлетные массы модификаций самолетов этого типа продолжают возрастать, то возникает проблема их базирования на взлетно-посадочных полосах существующих аэродромов путем формирования на этапе проектирования взаимосвязи «взлетная масса» ($m_o^м$) – скорость принятия решения при отказе критического двигателя ($V_1^м$) – тяговооруженность ($t_o^м$), обеспечивающей базирование более тяжелой модификации на аэродроме, заявленном для базового самолета ($L_{ВПП}^м = L_{ВПП}^б$). Для реализации такого условия разработана модель определения скорости ($V_1^м$), при которой возможно безопасное прекращение разбега при отказе критического двигателя. Полученная модель позволяет учесть ряд ограничений, обусловленных свойствами тяжелого самолета, таким и как минимальная и максимальная величина тяги маршевых двигателей, что позволяет внести обоснованные рекомендации в правила эксплуатации самолетов этого типа. С учетом выра-

жений, полученных для определения ($V_1^{\text{м}}$), сформирована модель определения и оценки потребной тяговооруженности более тяжелой модификации ($t_o^{\text{м}}$, $(m_o^{\text{м}}, V_1^{\text{м}}$) по условию ($L_{\text{ВПП}}^{\text{м}} = L_{\text{ВПП}}^{\text{б}}$) для модификаций со взлетной массой более 300 т. Установлено, что потребная относительная величина тяговооруженности должна находиться в пределах ($0 < \bar{t}_o \le 1,26$). Определение таких параметров, как $m_o^{\text{м}}$, $V_1^{\text{м}}$ и $\bar{t}_o^{\text{м}}$ является основой для реализации других модификационных изменений в тяжелом транспортном самолете.

Ключевые слова: тяжелый транспортный самолет; модификации; скорость принятия решения; тяговооруженность; условия базирования; посадочные характеристики.

Двейрін Олександр Захарович - канд. техн. наук, заступник Генерального директора з проєктування ДП «Антонов», Київ, Україна.

Рябков Віктор Іванович – д-р техн. наук, професор, професор кафедри Проектування літаків і вертольотів, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Капітанова Людмила Валеріївна – д-р техн. наук, доцент, доцент кафедри Проектування літаків і вертольотів, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Кириленко Марина Володимирівна - зав. лабораторією Інженерної лінгвістики навчального центру CAD\CAM\CAE, ст. викладач кафедри Прикладної лінгвістики № 703, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Oleksandr Dveirin – PhD in Technical Sciences, Deputy General Director for Designing of the Antonov Company, Kyiv, Ukraine,
e-mail: dveirin@antonov.com, ORCID: 0000-0003-3726-4838.

Victor Riabkov – Doctor in Technical Sciences, Professor of Airplanes and Helicopters Designing Department, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine,
e-mail: v.riabkov@khai.edu, ORCID: 0000-0001-6512-052X.

Liudmyla Kapitanova – Doctor in Technical Sciences, Assistant Professor, Airplanes and Helicopters Designing Department, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine,
e-mail: l.kapitanova@khai.edu, ORCID: 0000-0003-3878-6734.

Maryna Kyrylenko – Head of Linguistics Laboratory of Educational Center CAD\CAM\CAE, senior lecturer of Applied Linguistics Department 703, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine,
e-mail: m.kyrylenko@khai.edu, ORCID: 0000-0002-3258-7251.