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THE METHOD FOR PRELIMINARY DEVELOPMENT OF MAIN PARAMETERS FOR DEEP VARIATION IN VARIANTS OF TRANSPORT CATEGORY AIRCRAFT

The method of a preliminary development of main performances during deep variation in variants of a transport category aircraft, that is, when changing a wing area and a powerplant output, has been proposed. The main performance of any aircraft on the stage of its modifying is takeoff mass to, its value depends on structural members' masses, in which modifications changes are present. The method is based on the comparative evaluation of take-off mass increments of a basic aircraft and it's variant. That allows qualitatively and quantitatively to evaluate the specific value of the take-off mass increment of an airplane variant depending on engineering and economical requirements changes. Also, it is obvious that changes in the combination of performances their changes in the process of an aircraft variant creation, move the solution of an existence equation at new point, which corresponds to a new takeoff mass. The analysis of the method was implemented on the example of the regional passenger aircraft variant with two turboprop engines. The method of a preliminary development of main performances of a transport category aircraft subject to deep modification, i.e. when changing a wing area or a powerplant output, is proposed. The mathematical model for the estimation of the takeoff mass increment, depending on requirement groups realized in modifications, is developed by using the models of calculation of required mass (due to change of modification) and available mass (constant for a base variant). Statistical equations for the preliminary estimation of a takeoff mass increment, that create the relationship between the constituent masses and the takeoff mass for a regional aircraft, are used. For middle-range and long-range airplanes an adjustment is needed. The proposed method and the mathematical models allow at a preliminary designing stage of an airplane variant not only typical required quantitative change in structure, but the necessary changes of a wing area and a powerplant output to satisfy the required engineering and economical requirements, which aircraft and air-lines' markets dictate.

Keywords: *aircraft variant, take-off mass, mass increment simulation*

Introduction

The world practice shows that modern development of aircraft relates not only to one way: a creation of new aircraft. Also, it is presented (another way) mainly through a development of variants of high efficiency aircraft.

Table 1 shows the aircraft variants of the Antonov, Boeing, Airbus companies as the examples. There are some reasons and ways how they can be developed. They can be divided conditionally into two groups:

– Typical aircraft variants with higher useful load and no changeable wing area and power plant output N;

– Aircraft variants with deep variation in the useful load ($m_{u.l}$), flight range L, new wing area S and available thrust.

The simulation for the determination of masses and other main aircraft performances for typical aircraft modifications has obtained circumstantial justification in general theory developed by the Sheynin M. [3,4].

In modern time, an aircraft variant development is made more often by deep modifying, because this way can provide the maximum possible efficiency of a variant and its competitiveness in a market.

Objective

The method and technique development for an aircraft main performances determination for deep changes in the transport category variants.

Method Development

The main performance of any aircraft on the stage of its modifying is takeoff mass t_o, its value depends on structural members' masses, in which modifications changes are present:

$$m_{t-o} = f\left(\sum m_i, \in P_i\right) \quad (1)$$

where $m_i \to m_{str}, m_{pp}, m_{fuel}, m_{eq}, m_{pl}$ – structural mass,

Table 1

List of airplane`s variants for different companies

«Antonov» State Company	An-24, An-26, An-30, An-32, An-72, An-74, An-74-TK200, An-74-TK300, An-148, An-148-100A, An-148-100B, An-148E, An-124, An-124-100, An-132
Boeing Company	B-737-100, B-737-200A, B-737-200F, B-737-200C, B-737-300, B-737-400, B-737-400H, B-737-500, B-737-600, B-737-700, B-737-800, B-737-900
Airbus Company	A-319, A-319-100, A-319-130, A-320-110, A-320-210, A-320-230, A-330-200, A-330-300, A-340-300E, A-340-500, A-340-600

powerplant mass, fuel mass, equipment mass and payload mass;

P_i – modified performances.

The equation (1) essentially is the mathematical model for masses for a base aircraft and for its variant if P_i is available.

In this mathematical model the takeoff mass is a "link" performance, or a "dimensional" performance, and a complex of other performances P_i , that characterize a project, can be divided into two systems by their physical sense:

$$m_{req} = m_{pl}(m_{t-o};R;L;C;D) + m_{eq1}(m_{t-o};R;L;C;D) \quad (2)$$

$$m_{av} = 1-[\bar{m}_{str}(m_{t-o};R;L;C;D) + \bar{m}_{pp}(m_{t-o};R;L;C;D) + \bar{m}_{fuel}(m_{t-o};R;L;C;D) + \bar{m}_{eq2}(m_{t-o};R;L;C;D)] \quad (3)$$

where m_{req} – conventional required mass with the given requirements for an aircraft variant and a complex of system and equipment functions;

m_{av} – conventional available mass at the modern engineering level with certain complex of performances $P_i(R;L;C;D)$ that describe base aircraft and it`s variant.

Give it in other words, the conventional required mass (m_r) determines the takeoff mass part, which should be constant for the modification task: a payload and necessary equipment that functions are specified in engineering and economical requirements, with a specific complex of project parameters.

The conventional available mass shows the part of takeoff mass, which is possible to be used for the realization of a requirement with the same complex of performances to be changed.

Clear, that to solve an existence equation, i.e., to create an aircraft with the given requirements, the required and available conventional masses should be equal.

Also, it is obvious that changes in the combination of performances R, L, C, i.e. their changes in the process of an aircraft variant creation, move the solution of an existence equation at new point (Fig. 1), which corresponds to a new takeoff mass.

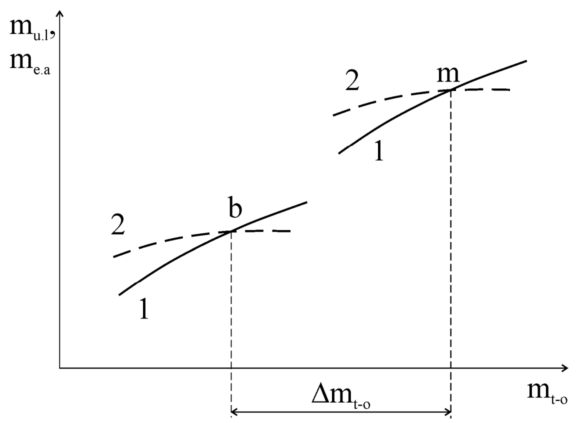

Fig. 1. Increasing of $m_{u.l}$, $m_{e.a}$ and m_{t-o} in a process of an airplane modification creation: b – point for base project; m – point for modification project; 1 – mass of useful load; 2 – mass of empty airplane

The takeoff mass in these cases is calculated by equation:

$$m_{t-o} = \psi \times \frac{m_{p.l} + m_{eq}(n_{pas}, L)}{1-\left[\bar{m}_{str}(m_{t-o}) + \bar{m}_{p.p}(m_{t-o}) + \bar{m}_{fuel}(m_{t-o})\right]}, \quad (4)$$

where Ψ – factor of engines' number and arrangement;

$m_{eq}(n_{pas}, L)$ – mass of fixtures and equipment that depends on the number of a crew, passengers and flight range;

$\bar{m}_{str}(m_{t-o})$, $\bar{m}_{p.p}(m_{t-o})$, $\bar{m}_{fuel}(m_{t-o})$ – specific masses of a structure, powerplant and fuel.

The change of a variant takeoff mass can be determined by the equations:

$$dm_{t-o} = \frac{\sum \frac{\partial m_r}{\partial P_i} dP_i - \sum \frac{\partial m_a}{\partial P_i} dP_i}{\frac{\partial m_a}{\partial m_{t-o}} - \frac{\partial m_r}{\partial m_{t-o}}}$$

or

$$dm_{t-o} = \frac{1-\sum \frac{\partial m_a}{\partial P_i}\cdot\frac{\partial P_i}{\partial m_r}}{\frac{\partial m_a}{\partial m_{t-o}} - \frac{\partial m_a}{\partial P_i}\cdot\frac{\partial m_r}{\partial m_{t-o}}}\cdot dm\,, \qquad (5)$$

where $dm = dm_r - dm_a$.

Under the condition of proposed mathematical models of mass changes' estimation for a real airplane variant, the true statistical data should be used.

The equipment mass $m_{eq}(n_{pas},L)$ is determined by the equation:

$$m_{eq} = 80\times n_{crew} + 95\times n_{pas}\times(5\cdot10^{-5}\times L + 0,66)\,, \qquad (6)$$

where n_{crew} – the number of crew members;

L – a flight range, km.

The change of $\bar{m}_{str}(m_{t-o})$ is determined by the

$$\bar{m}_{str} = k_{n.m}k_{f.d}k_{f.sh}k_{h.l.d}k_{sw.a}\times \times\left(0,5k_{airf.config} - 4,5\cdot10^{-4}\frac{m_{t-o}}{S}\right), \qquad (7)$$

where S – wing area, m^2;

m_{t-o} – takeoff mass of an airplane, kg;

$k_{n.m}$ – coefficient of new structural material used;

$k_{f.d}$ – coefficient of a fuselage diameter;

$k_{f.sh}$ – coefficient of a fuselage cross-section shape;

$k_{h.l.d}$ – coefficient of a high-lift devices type;

$k_{sw.a}$ – coefficient of a wing swept angle;

$k_{airf.config}$ – coefficient of an airframe configuration (arrangement of engines on a wing, on a fuselage, etc.).

Values of these coefficients are present in the book [1, 5 – 8].

In concise form

$$\bar{m}_{str} = \left(0,5 - 4,5\cdot10^{-4}\frac{m_{t-o}}{S}\right). \qquad (8)$$

For the $\bar{m}_{p.p}(m_{t-o})$ determination it will be used the following equation [3,4]:

$$\bar{m}_{p.p} = a_1\left(1+0,11\frac{n_{eng.rev}}{n_{eng}}\right)\gamma_{eng}\frac{n_{eng}\cdot P_{t-o}}{m_{t-o}} + b_1\,. \qquad (9)$$

where a_1, b_1 – statistical coefficients;

$a_1 = 0,95$, $b_1 = 0,0185$ – two engines under wing;

$a_1 = 1,04$, $b_1 = 0,0192$ – four engines under wing;

n_{eng} – total number of engines on an airplane;

$n_{дв.рев}$ – numbers of engines with a thrust reverser;

γ_{eng} – specific weight of engine;

P_{t-o} – engine`s takeoff thrust, daN.

For an airplane with two engines under a wing (both engines with a thrust reverser)

$$\bar{m}_{p.p} = 2,109\gamma_{eng}\frac{P_{t-o}}{m_{t-o}} + 0,0185\,. \qquad (10)$$

The specific fuel mass is a sum

$$\bar{m}_{fuel} = \bar{m}_{fuel.cr} + \bar{m}_{fuel.n.r} + + \bar{m}_{fuel.cl} + \bar{m}_{fuel.ap-land} + \bar{m}_{fuel.n.u}\,, \qquad (11)$$

where $\bar{m}_{fuel.cr}$ – specific fuel mass for a cruise flight mode;

$\bar{m}_{fuel.nav.reserv}$ – specific fuel mass for a fuel reserve;

$\bar{m}_{fuel.climbing}$ – specific fuel mass for a climbing flight mode;

$\bar{m}_{fuel.ap.land}$ – specific fuel mass for approach and landing flight modes;

$\bar{m}_{fuel.notusable}$ – non-usable specific fuel mass;

Components $\bar{m}_{fuel.nav.reserv}$, $\bar{m}_{fuel.climbing}$, $\bar{m}_{fuel.ap.land}$, $\bar{m}_{fuel.non-usable}$ very tentatively can be independent from take-off mass and will be calculated by equation [2]:

$$\sum\bar{m}_{fuel.i} = \bar{m}_{fuel.nav.reserv} + \bar{m}_{fuel.climbing} + +\bar{m}_{fuel.ap.land} + \bar{m}_{fuel.notusable} = const.$$

$$\bar{m}_{fuel.cr} = 1 - \exp\left[-\frac{(L - 40H_{av}\cdot C_{fuel}}{(V_{cr} - W)\cdot K}\right], \qquad (12)$$

where L – cruising flight range, km;

$40H_{av}$ – ground range of climbing and descent H_{av} – average flight altitude for cruise mode, km);

C_{fuel} – specific fuel consumption for cruise flight mode, kg/[daN h];

V_{cr} – cruise flight speed, km/h;

W – front wind speed, km/h.

Lift-to-drag ratio K is possible to be expressed as a function of a take-off mass of aircraft variant:

$$K = \frac{m_{t-o}g}{\frac{\rho V^2}{2} C_D S} = \frac{m_{t-o}g}{qS(C_{D0} + AC_L^2)}, \qquad (13)$$

where q – dynamic pressure, $q = \frac{\rho V^2}{2}$

A_p – deviation of an airplane polar graf, $A_p = \frac{1}{\pi \lambda_{ef}}$;

λ_{ef} – effective aspect-ratio of a wing;

C_{D0} – drag coefficient of an airplane for zero lift;

C_L – an airplane lift force coefficient.

Based on equations (4), (6), (7) it seems possible to quantify the change of main parameters of an airplane variant with a deep change of wing area (S) and powerplant output (N) on the example of a regional passenger aircraft with two turboprop engines (Table 2).

Table 2

Changes of main performances of a regional passenger airplane for it's deep change variant

Numbers of pax	S, м²	56,4	58	60	62	64
	N_{oi}, hp	2500	2600	2700	2800	2900
n = 52	m_{t-o}, kg	19290	19614	19978	20342	20704
n = 56	m_{t-o}, kg	19946	20271	20639	21004	21368
n = 60	m_{t-o}, kg	20589	20917	21287	21654	22020
	L_{rw}, m	1868	1719	1606	1510	1427

As seen from the table, development of an airplane variant with increased powerplant output (with constant wing area and flight range) leads to increased takeoff mass, but also to reduced takeoff distance and required runway length. In some cases the latter factors may be decisive in terms of the final decision.

For development a general view of an airplane variant it is important to estimate a change of a wing area S influence on aircraft main performances. The proposed equations (4), (6), (9) allow to estimate this influence quantitatively (fig. 2).

Figure 2 shows (with powerplant output N_{t-o} = const = 2 500 hp):

1) Graphs of takeoff masses – 1, 2, 3;

2) Graphs of takeoff distances – 4, 5, 6;

3) Graphs of takeoff distances with one failed engine – 7, 8, 9;

4) Point 10 – 52 passengers with wing area 56,4 m^2 and takeoff distance 830 m;

5) Point 11 – 56 passengers with wing area 61,2 m^2 and takeoff distance 830 m;

6) Point 12 – 60 passengers with wing area 65,5 m^2 and takeoff distance 830 m;

7) Point 13 – 52 passengers with area 56,4 m^2 and takeoff distance 1450 m with one failed engine;

8) Point 14 – 56 passengers with wing area 63,7 m^2 and takeoff distance 1450 m with one failed engine;

9) Point 15 – 60 passengers with wing area 70,0 m^2 and takeoff distance 1450 m with one failed engine;

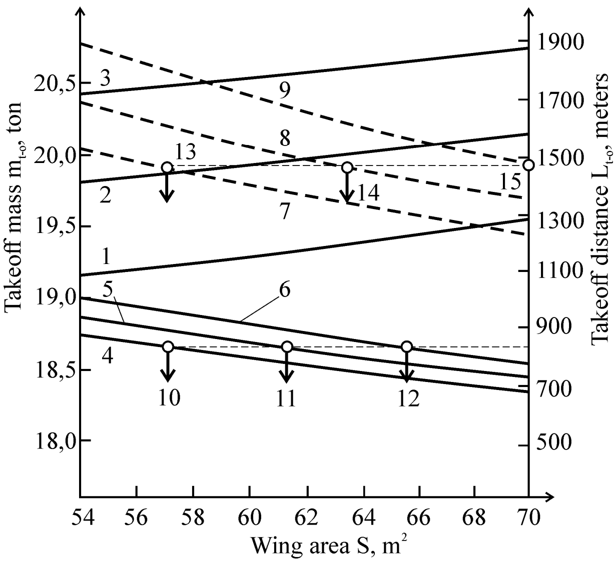

Fig. 2. Changes of the takeoff mass (1, 2, 3), takeoff run length (4, 5, 6) and takeoff distance with one failed engine (7, 8, 9) for airplane`s variants (passengers' number 52, 56, and 60 accordingly) with dependence on a wing area and a powerplant output (at N_{t-o} = const)

As it shown in Figure 2 any changes in the payload and correspondingly in the takeoff mass require increase of the wing area.

Conclusions

1. The method of a preliminary development of main performances of a transport category aircraft subject to deep modification, i.e. when changing a wing area or a powerplant output, is proposed.

2. The mathematical model for the estimation of the takeoff mass increment, depending on requirement groups realized in modifications, is developed by using the models of calculation of required mass (due to change of modification) and available mass (constant for a base variant).

3. Statistical equations for the preliminary estimation of a takeoff mass increment, that create the relationship between the constituent masses m_{eq} (n_{pax}, L), $\bar{m}_{str}(m_{t-o})$, $\bar{m}_{pp}(m_{t-o})$, $\bar{m}_{fuel}(m_{t-o})$ and the takeoff mass for a regional aircraft, are used. For middle-range and long-range airplanes an adjustment is needed.

4. The proposed method and the mathematical models allow at a preliminary designing stage of an airplane variant not only typical required quantitative change in structure, but the necessary changes of a wing area and a powerplant output to satisfy the required en-

gineering and economical requirements, which aircraft and airlines' markets dictate.

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МЕТОД ПОПЕРЕДНЬОГО ФОРМУВАННЯ ОСНОВНИХ ПАРАМЕТРІВ ПІД ЧАС ГЛИБОКИХ МОДІФІКАЦІЙНИХ ЗМІН У ЛІТАКАХ ТРАНСПОРТНОЇ КАТЕГОРІЇ

Д. В. Тіняков, В. І. Рябков

Запропоновано метод попереднього формування основних параметрів під час глибоких модифікаційних змін у літаках транспортної категорії, тобто під час зміні площі крила і потужності силової установки літака. Метод базується на порівняльній оцінці збільшення стартової маси модифікації і базового літака, що дозволяє якісно і кількісно оцінити відносну величину приросту стартової маси модифікації у залежності від зміни техніко-економічних вимог. Тестова реалізація методу і моделей здійснена на прикладі модифікації регіонального пасажирського літака з двома ТГД.

Ключові слова: модифікації літаків, стартова маса, моделювання збільшень маси.

МЕТОД ПРЕДВАРИТЕЛЬНОГО ФОРМИРОВАНИЯ ОСНОВНЫХ ПАРАМЕТРОВ ПРИ ГЛУБОКИХ МОДИФИКАЦИОННЫХ ИЗМЕНЕНИЯХ В САМОЛЕТАХ ТРАНСПОРТНОЙ КАТЕГОРИИ

Д. В. Тиняков, В. И. Рябков

Предложен метод предварительного формирования основных параметров при глубоких модификационных изменениях в самолетах транспортной категории, т. е. при изменении площади крыла и мощности силовой установки самолета. Метод базируется на сравнительной оценке приращения стартовой массы модификации и базового самолета, что позволяет качественно и количественно оценить относительную величину приращения стартовой массы модификации в зависимости от изменения технико-экономических требований. Тестовая реализация метода и моделей осуществлена на примере модификации регионального пассажирского самолета с двумя ТВД.

Ключевые слова: модификации самолетов, стартовая масса, моделирование приращений массы.

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