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Influence of basic energetic parameters of turbofan engine on multipurpose aircraft maneuvers indexes

Abstract: Multipurpose aircraft, during one mission, very often must perform many tasks and at the same time must use the energy sources for the maneuvers. The mathematical model of the chosen tasks of an aircraft has been presented, which due to the energetic and economical requirements do not allow to build the uniform optimization criteria. The models of such flight stages have been presented: take off, climbing with the maximum velocity and the maximum angle of climb, horizontal flight both sub-and supersonic, turn determined. In order to make the considerations easier the engine model was reduced to two parameters: non-dimensional loading coefficient and the coefficient of relative engine measure. During the conducted calculations the values of the non-dimensional coefficients were determined which allow to optimize the tasks performed by the aircraft during the mission. By making comparisons of the determined characteristics there were shown the acceptable values of the non-dimensional engine coefficients and there were presented the assessment criteria of the aircraft manoeuvre properties which are important for the realization of the whole its mission.

Key words*: turbofan engines, multipurpose aircraft, airplane engine integration*

Wpływ podstawowych parametrów energetycznych silnika dwuprzepływowego na wskaźniki manewrowości samolotu wielozadaniowego

Streszczenie: Samolot wielozadaniowy, wykonując cały szereg różnorodnych zadań, niejednokrotnie w czasie jednej misji, musi wykorzystywać zasoby energetyczne dla uzyskanie wymaganej sytuacją manewrowości. Przedstawiono model matematyczny wybranych zadań samolotu, które z racji wymagań energetycznych i ekonomicznych uniemożliwiają zbudowanie jednolitych kryteriów optymalizacji. Przedstawiono modele takich etapów lotu jak : start, wznoszenie z maksymalna prędkością i maksymalnym katem wznoszenia, lot poziomy pod- i naddźwiękowy, zakręt ustalony. Dla uproszczenia rozważań model silnika sprowadzono do dwóch parametrów: bezwymiarowego współczynnika obciążenia (który zawiera w sobie parametry cyklu roboczego silnika jak temperaturę przed turbiną, spręż całkowity silnika) oraz wskaźnik względnego wymiaru silnika. W trakcie przeprowadzonych obliczeń wyznaczono wartości wskaźników bezwymiarowych pozwalających optymalizować poszczególne zadania wykonywane przez samolot w trakcie misji. Dokonując porównania wyznaczonych charakterystyk wskazano dopuszczalne wartości wskaźników bezwymiarowych silnika i wskazano te kryteria oceny własności manewrowych samolotu, które są istotne dla realizacji całej jego misji.

Słowa kluczowe: *turbinowy silnik dwuprzepływowy, samolot wielozadaniowy, integracja samolotu i zespołu napedowego*

1. Introduction and preliminary assumptions

In the process of aircraft designing the right strategy of the aircraft and engine characteristics is of the great importance in order to get the system capable to perform certain air tasks at the smallest energetic expenditure. The energetic possibilities of an aircraft depend on the parameters and characteristics of the power unit. The power unit should ensure required by an aircraft performance properties at all stages of air task i.e. during the take off, climbing, overshoot and during the complex combat manoeuvre (turning, pull up, loop). The energetic requirements of an aircraft are fixed limitations for the engine designer. They determine the range of the possible changes in thermo-gas-dynamical parameters of the engine comparative cycle, its size, mass and the way of control. It is assumed that the characteristics of an aircraft for which the power unit is chosen are known. There are known the following parameters: aircraft aerodynamic characteristics (polar), aircraft mass parameters and performed by an aircraft tasks – determined by the flight parameters such as flight velocity and flight height. The aim is to find the energetic engine parameters which will enable to determine (for the assumed criteria and limitations) the optimum adjustment of engine and aircraft characteristics for the realization of the required air task. For the models building there were used the general non-dimensional parameters [4,5,6,7,8]. The parametrical analysis, conducted on the basis of the non-dimensional parameters, enables to find the main directions of optimum research of an engine and the aircraft as a whole.

2. Mathematical model of aircraft and power unit

The aircraft movement in co-ordinate system connected with aircraft velocity has been presented in [1,2]. The aircraft movement equations introduced there have been written in a form which takes into account the dimensional character of variables. For the needs of the presented article the non-dimensional analysis was presented. The way of movement equations derivation considering the non-dimensional variables has been shown in [4,5]. For further considerations there have been reminded the basic relations (presented in [5,6,7,8]). Non-dimensional coefficient S_{ZN} (called the geometrical parameter of engine adjustment to an aircraft), determining the relative engine dimension:

$$S_{ZN}=\frac{iF_{Sil}}{F_{sk}} \tag{1}$$

where:

F_{Sil} - engine cross- sectional area,
F_{SK} – aircraft wing area,
i – number of engines.

Non-dimensional coefficient of aircraft wings loading:

$$\Psi_S=\frac{m_S g}{p_H F_{SK}} \tag{2}$$

where:

m_s- aircraft mass,
p_H – static pressure

Non-dimensional coefficient of thrust loading:

$$\nu=\frac{K_{sil}S_{ZN}}{\Psi_S} \tag{3}$$

In equations(1-3) the parameters of engine K_{sil} i m_s depend on the engine characteristics.

3. Method of selection of engine and aircraft parameters

While selecting the power unit for the multipurpose aircraft it is necessary to show such parameters and criteria of engine assessment which ensure the realization of air tasks at the required energetic expenditure. The selection of engine parameters should be done on the basis of energetic criteria. The use of non-dimensional parameters, which later will be treated as "adjustment" parameters of engine to an aircraft enable to build the analytical model of the energetic system of the power unit-aircraft-air task. It makes possible further assessment of the influence of the accepted parameters of engine on the indexes of aircraft efficiency assessment. Taking into account the non-dimensional parameters as in (1-3), the equation of the aircraft movement (the way of its derivation) has been shown in detail in w [4,5]) and has the form of:

$$\nu=\frac{a}{g}\frac{dM_a}{dt}+\left(1+\frac{a}{g}M_a^2\frac{da}{dH}\right)\sin\Theta+\frac{1}{2}\frac{kc_x M_a^2}{\Psi_S} \tag{4}$$

It is the formula, which for the assumed parameters of air task (M_a, H, ψ_S), allows to determine indispensable for flight value of ν coefficient. It is then assumed that the ν value determined on the basis of the aircraft flight conditions will be marked by the „N"- ν_N. index. The first term of (4) equation means the value of the thrust loading coefficient for the case of horizontal acceleration, whereas the second one for the climbing with the constant velocity at the angle Θ, and the last term in (4) equation means the value of ν_N coefficient for the horizontal flight with constant velocity.
On the other hand, the ν value can be determined for the power unit. This value, as a disposable value for the engine is marked by "R" index:

$$\nu_R=\frac{K_{sil}S_{ZN}}{\Psi_S} \tag{5}$$

The above dependence enables to determine non-dimensional thrust loading coefficient and the relative fuel usage only when it is known the flight plan; that is the height change H and flight velocity Ma during the mission and there are known the engine characteristics.

4. Criteria of aircraft maneuvering

The significant criterion of maneuvering assessment of multipurpose aircraft is climbing. Following [2] and assuming that the total aerodynamic lift is on the aircraft plane and the vectors of thrust force are directed along the flight path of an aircraft, then the angle of the fastest climbing γ_{PWmax} will be determined from the following formula:

$$\sin\gamma_{PWmax}=\frac{\nu E^2_{PWmax}-\sqrt{1+E^2_{PWmax}\left(1-\nu^2\right)}}{1+E^2_{PWmax}} \tag{6}$$

where:

perfection of the fastest climbing

$$E^2_{PWmax}=\frac{6}{\nu\Gamma\left(1+\frac{36Kc_{D0}}{\nu^2\Gamma^2}\right)}$$

coefficient

$$\Gamma=1+\sqrt{1+\frac{12Kc_{D0}}{\nu^2}}$$

c_{D0} – parasitic drag,
K – coefficient of aircraft polar.

The data for calculating the aircraft polar was taken from [1]. In fig. 1 there has been presented the dependence of the angle γ_{PWmax} from ν coefficient in the borders (ν_{min},ν_{max}).

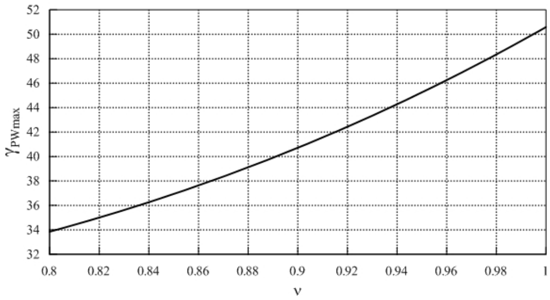

Fig. 1 Dependence of angle of fastest climbing γ_{PWmax} from ν parameter.

The next characteristic flight stage is the right turn of an aircraft (without the sideslip). The right turning can be performed only when the bank angle of an aircraft Φ is bigger than zero [2]. The bank angle is determined by the G-load coefficient *n* :

$$n=\frac{1}{\cos\Theta} \tag{7}$$

Non-dimensional thrust loading coefficient ν for the right turn can be determined from the formula:

$$\nu=\frac{kM_a^2}{2}\left(\frac{c_{D0}}{\Psi_S}+\frac{4\Psi_S Kn^2}{\left(kM_a^2\right)^2}\right) \tag{8}$$

Formula (8) allows to determine the indispensable value of the ν coefficient depending on the *n* G-load coefficient and non-dimensional wing loading coefficient ψ_S, in which is "hidden" the aircraft mass. On the G-load coefficient in turn there are imposed limitations which concern the situation when the aircraft mass is partially decreased by the mass of the used during the flight fuel and armament (so-called combat mass) and it is assumed that the coefficient n=9. On the other hand for the maximum take off mass the assumed value of the n G-load coefficient in turn is smaller and is n=7 [2].
The most important part of the aircraft mission is its take off. In the procedure calculations of aircraft take off it is better to assume the length of the take-off run L_S and determine for it the indispensable value of the thrust loading coefficient at the take off:

$$\nu_S=\mu_S+\frac{\frac{k_S\zeta_S}{c_{Zmax}}}{1-e^{-\tau L_S}} \tag{9}$$

where:

$$k_S=\frac{M_0}{M_S}$$

M_S – stalling speed,

$$\tau=\frac{gk\zeta_S}{a^2\Psi_S}$$

ζ_S - reduced coefficient of aircraft total resistance during takeoff [5,6]
C_{Zmax} – value of coefficient of aerodynamic lift in the conditions of take off.

5. Calculation example, conclusions

To find limitations there have been conducted the calculations for exemplary aircraft data. It was assumed that the take off mass of aircraft m_s=10500 [kg], the atmosphere parameters are according to the standards of International Standard Atmosphere [1]. At this stage of calculations there are not known the characteristics of engine that is why to simplify the considerations the calculations have been conducted for some values of ψ_S coefficient. It was assumed that this coefficient is the function of wing loading coefficient at the start ψ_{S0} according to the formula:

$$\Psi_S=k_m\Psi_{S0} \tag{10}$$

Coefficient k_m determines the change of aircraft mass during the air mission, caused by the fuel usage ad armament (k_m=1 – for takeoff mass, k_m=0.55 – aircraft without fuel and armament).
The change in value of coefficient ψ_S in function of H height has been presented in fig.2.

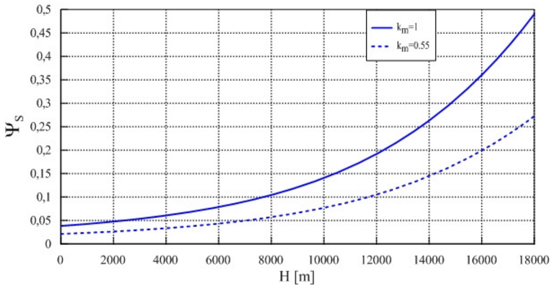

Fig.2 Change of values of non-dimensional wing loading coefficient ψ_S together with the growth of flight height for two values of coefficient k_m. (k_m=1 – for takeoff mass, k_m=0.55 –aircraft without fuel and armament).

The decline in pressure connected with the growth in flight height causes the increase in the value of ψ_S coefficient. The lines which limit the graph show the border of the changes in values of the coefficient ψ_S for an aircraft depending on the flight height. During the take off the value of the coefficient in the accepted example is ψ_{S0}=0.04. In fig. 3 it has been presented the influence of values of ψ_S coefficient and the length of the run on the indispensable value of ν coefficient.

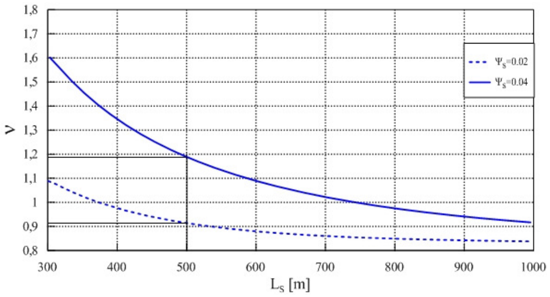

Fig. 3 Influence of run way L_S and ψ_S coefficient on the value during the take off. The calculations for two values $\psi_S=\psi_{S0}$= 0.04 , and ψ_S=0.02 (for k_m=0.55).

Multipurpose aircraft can perform a number of tasks at various subsonic and supersonic velocities. There were conducted the calculations on the influence of the ψ_S coefficient and flight velocity on the ν coefficient during the horizontal flight with constant velocity. The results of the calculations have been presented as graphs in fig. 4.

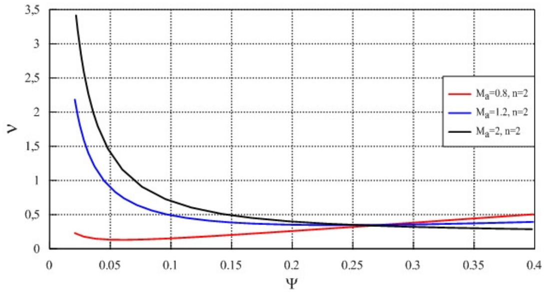

Fig.4 The influence of flight velocity and changes of ψ_S coefficient on the value of indispensable non-dimensional loading thrust coefficient ν during the steady horizontal flight.

The fulfillment of the requirement, obtaining the minimum value of the thrust indispensable during the turn performed at the given value of *n* G-load coefficient is important from the point of view of aircraft maneuvering has been presented in fig.5. From the graph in fig. 6 one can assume that in order to perform the turn with the high values of *n* G-load coefficient the flights with high wing loading (big aircraft mass) require the big values of the indispensable thrust, which exceeds the requirements for the take off.

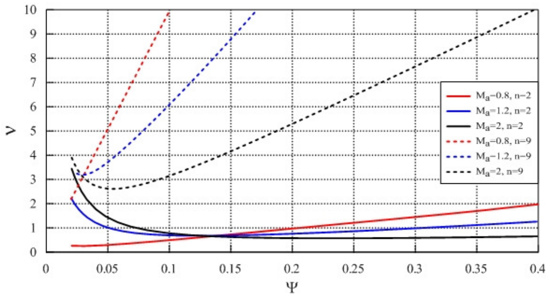

Fig.5 Dependence of ν coefficient from ψ_S during performing the right turn for two values of the *n* G-load coefficient (n=2 – full lines, and n=9 – break lines) and for the chosen velocity values of M_a flight.

In fig. 6 there have been presented the requirements for the ν coefficient, critical with regard to ν stages of flight.

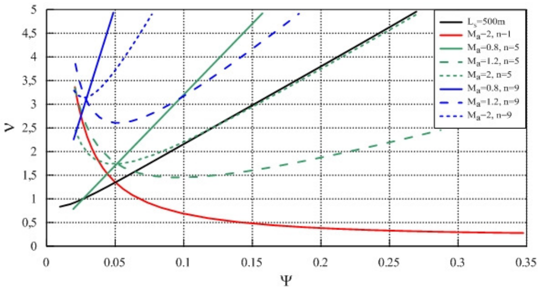

Fig.6 Influence of some chosen aircraft flight conditions and changes of wing loading coefficient ψ_S on indispensable for flying value of wing loading coefficient ν.

Each curve presented in fig. 7 is the borderline value for ν, at the given flight velocity and ψ_S (aircraft mass) The biggest requirements because of the ν value concern the turn (in figures n=1) at small flight velocities as the growth gradient ν together with the growth of the flight height (grows ψ_S) is the biggest among all the presented curves. The requirement of the horizontal flight with the constant supersonic velocity is not a limitation at big heights. The consequence of the maneuver choice which determines the loading ν during the aircraft flight is to determine the values of the indispensable coefficient, non-dimensional thrust loading which must be counterbalanced by the power unit and the thrust depended on the thermo-gas-dynamical parameters.

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