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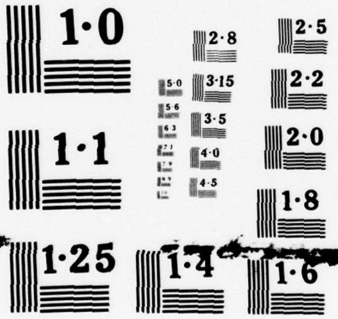
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FOREIGN TECHNOLOGY DIVISION

PROBLEM OF INVESTIGATING TAKEOFF-LANDING CHARACTERISTICS OF JET AIRCRAFT WITH SHORT TAKEOFF AND LANDING RUN

by

V. I. Surus

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EDITED TRANSLATION

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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

PROBLEM OF INVESTIGATING TAKEOFF-LANDING CHARACTERISTICS OF JET AIRCRAFT WITH SHORT TAKEOFF AND LANDING RUN

V. I. Surus

In examining the aerodynamic and takeoff and landing characteristics of jet aircraft with a short takeoff and landing run (STOL) [СУВП] and vertical takeoff and landing (VTOL) [СВВП] [1-6] the negative effect of secondary forces induced by the jet stream of the engine as a result of its ejection properties is not considered. This can be so substantial that for some STOL systems (Fig. 1) airplanes equipped with boundary-layer control [УПС] may be preferable.

Here we encounter the question of justifying the development of certain types of aircraft or, in any case, determining the limit of their feasible use. For this we need an exhaustive comparative analysis of these types of aircraft. This would include analysis from the standpoint of the takeoff and landing and flight characteristics and from the standpoint of safety and economy.

In this article we examine one aspect of the indicated problem: Taking into consideration the secondary forces which are characteristic of certain STOL systems, we compare (Figs. 2 and 3) the distances of the takeoff run and takeoff of the following hypothetical jet destroyer-type aircraft.

1. Standard aircraft used as original with typical wing geometry: swept or triangular in plan, low aspect ratio and great taper, supersonic profile.

2. STOL with one lifting engine with thrust $P_{\text{п}}$ and sustainer engine with thrust $P_{\text{м}}$, located on the fuselage (scheme 1, Fig. 1).

3. STOL with a single lift-sustainer engine of thrust $P_{\text{п.м}}$ in the fuselage (scheme 2, Fig. 1).

4. An aircraft with a standard boundary layer blow-off system

(BLB) through a slot on the upper surface of the deflected flap. This system is found on series-produced aircraft with turbojet engines. Based on statistical data, the coefficient of lifting force C_y of such aircraft with the wing geometry described in paragraph 1 increases by approximately 0.25 for a $10^{0}/_{0}$ air bleed from the engine compressor, while thrust drops by $15^{0}/_{0}$.

5. Aircraft with effective boundary-layer control systems, for example, combination, which combines preceeding boundary-layer blow-off system with air suction through slots along leading edge of wing. This system can provide effective laminarization of the flow past the entire wing and increase C_y by $\Delta C_y = 0{,}65$ for a $20^{0}/_{0}$ bleed of air from the engine and a $20^{0}/_{0}$ reduction in its thrust.

Let us make the following assumptions.

1. The thrust of the engines of the studied aircraft changes with respect to takeoff velocity according to the law

$$P = P_0 - \frac{dP}{dV}V,$$

where P_0 is static thrust; $dP/dV = const = 0.1$.

2. The quantities which depend on the speed of the takeoff run, including secondary forces, are averaged and are considered constant

in the process of the takeoff and lift, which gives us an error of about 20°/₀ and is considered permissible in a rough estimate of the secondary forces.

3. For aircraft 2 and 3 the thrust losses which are caused by air which is contaminated by dust and heated by the jet stream being drawn into the air intake [7] as well as by the secondary jet stream [2, 7] constitute 8°/₀.

4. The thrust vectors of the lift and lift-sustainer engines of STOL deflected from the vertical by angles of $\varphi_{п}$ and $\varphi_{п.м}$, respectively, (Fig. 1) are constant during takeoff (in gaining altitude angle $\varphi_{п.м}$ of aircraft 3 equals 90°). Angle $\varphi_{п}$ is selected from the statistics and is equal to 12° [8], while $\varphi_{п.м}$ is calculated [4] by formula

$$\cos\varphi_{п.м}=\frac{P_{п.м}}{G}.$$

5. The direction of the thrust vectors of aircraft 1, 4, and 5 and of the thrust of the sustainer engine $P_{м}$ of aircraft 2 coincide with the direction of motion.

6. For aircraft 4 and 5 coefficient C_{x} during takeoff are assumed to be the same as for the original aircraft 1, because the boundary-layer blow-off system increases inductive resistance by

decreasing profile resistance.

7. The height of the barrier during takeoff is considered to be 15 m.

8. The aerodynamic characteristics of the airframes of the compared aircraft and the thrust characteristics of the engines are identical.

The secondary forces during the takeoff of a STOL (just as in gaining altitude) can be considered as follows:

$$C_{y_p} = C'_{y_p} - \Delta C_{y_p}; \quad C_{x_p} = C'_{x_p} + \Delta C_{x_p},$$

where C_{y_p} and C'_{x_p} represent the coefficient of lift and drag, respectively, during takeoff without secondary forces considered.

The coefficients of decrease in lift ΔC_{y_p} and increase in drag ΔC_{x_p} due to secondary forces must be determined experimentally in view of the complexity of their mathematical interpretation. However, bearing in mind assumption 2, in the case of rough calculations these coefficients can be considered from the following approximate dependences, which were obtained on the basis of processing theoretical and experimental studies [2, 5, 9, 10] and are in satisfactory agreement with experimental data:

$$\Delta C_{y_п} \approx k_1 \left(\frac{\bar{q}}{\bar{h}}\right)^2 \bar{S}; \quad \Delta C_{x_п} \approx k_2 \frac{\bar{q}}{\bar{h}} \bar{S}.$$

where $\bar{h} = \frac{H}{d}$ is the ratio of the distance from earth to the fuselage (Fig. 1) to the diameter of the jet stream;

$\bar{q} = \frac{W}{V_{ср}}$ - ratio of discharge velocity of the jet stream to the average speed of the takeoff run;

$\bar{S} = \frac{S_{стр}}{S_{кр}}$ - ratio of area of the cross section of the stream to the wing area;

k_1, k_2 - correction coefficients, which are functions of the discharge angle of the jet $\varphi_п (\varphi_{п.м})$, the angle of attack of the wing α, the angle of deflection of the flaps $\delta_з$, the angle of deflection of the elevator $\delta_{р.в}$ and other parameters.

These dependences also apply to investigated STOL which have a rectangular wing in plan form and $\overline{h}$ ~~ 0.9-1.2.

The takeoff distance is calculated by formula

$$l_{\text{взл}} = l_{\text{р}} + l_{\text{в}}.$$

The length of the takeoff run $l_{\text{р}}$ was determined by formula

$$l_{\text{р}} \approx -\frac{1}{2A} \ln \frac{B - V^2_{\text{отр}} - БV_{\text{отр}}}{B},$$

which is approximate, with an error of less than 2°/₀, by solving an integral in the form of

$$l_{\text{р}} = -\frac{1}{A} \int\limits_0^{V_{\text{отр}}} \frac{V}{V^2 + БV - B}\, dV.$$

obtained from the general expression for the distance of the takeoff of the run

$$l_{\text{р}} = \int\limits_0^{t_{\text{отр}}} V dt = \int\limits_0^{V_{\text{отр}}} \frac{V}{\dot{V}} dV.$$

From the equation of motion during the takeoff run

$$\sum P_{i,x} = 0$$

we can determine the value of acceleration

$$\dot{V} = A(C - V^2),$$

where

$$A = \frac{1}{2p} \rho g (C_{x_{\text{р}}} - fC_{y_{\text{р}}});$$
$$C = B - БV.$$

For aircraft 2

$$B = 2\frac{P_{\text{оп}}(\sin\varphi_{\text{п}} + f\cos\varphi_{\text{п}}) + P_{\text{ом}} - fG}{\rho S(C_{x_{\text{р}}} - fC_{y_{\text{р}}})}; \qquad (1)$$

$$Б = 2\frac{0{,}1\,(1 + \sin\varphi_{п} + f\cos\varphi_{п})}{\rho S\,(C_{x_{р}} - fC_{y_{р}})}. \qquad (2)$$

For aircraft 3

$$Б = 2\frac{0{,}1\,(\sin\varphi_{п.м} + f\cos\varphi_{п.м})}{\rho S\,(C_{x_{р}} - fC_{y_{р}})}, \qquad (3)$$

while in expression (1) we must replace thrust $P_{оп}$ by $P_{оп.м}$, angle $\varphi_{п}$ and $\varphi_{п.м}$, and make thrust $P_{ом}$ equal to zero.

For aircraft 1, 4, and 5 in expression (1) and (3) $\varphi_{п} = \varphi_{п.м} = 90°$, while thrust $P_{оп}$ is assumed equal to zero, and thrust $P_{ом}$ is replaced by the thrust of the corresponding aircraft.

The distance of lift and takeoff run with an obstacle 15 m high is calculated by the known formula

$$l_{п} = \frac{1}{\frac{P_{ср}}{G} - \frac{1}{K_{ср}}}\left[\frac{V_{п}^2 - V_{отр}^2}{2g} + 15\right].$$

As an example let us calculate the takeoff characteristics of the hypothetical aircraft indicated above with the following data: weight of aircraft G = 9600 kg, specific load on wing $\overline{p} = G/S = 400$ kg/m^2; gravitational acceleration $g = 10$ m/s^2; air density $\rho = 0.125$ $kg\ s^2/m^4$; coefficient of friction force f = 0.03 (dry concrete runway); thrust-to-weight ratio values of aircraft $\bar{t}$ = 0.6, 0.7, 0.8, 0.9; $\alpha_p = 2°$; $\alpha_{отр} = 10°$; $\delta_з = 45°$, for aircraft 2 k_1 ~~ k_2 ~~ k ~~ 0.906; for aircraft 3 the value of k changes over a range of 0.25-0.68, $\bar{h}$ = 1.06, $\bar{q}$ = 4, $\bar{S}$ = 0.0236; the values for the aerodynamic coefficients for the original aircraft 1:

$$C_{y_p} = 0{,}55;\quad C_{x_p} = 0{,}1;\quad C_{y_{отр}} = 0{,}95;\quad C_{y_п} = 0{,}67;\quad C_{x_п} = 0{,}2.$$

The results of calculating the dependences of the takeoff run l_p and takeoff $l_{вз}$ distances of the studied aircraft on thrust-to-weight ratio $\bar{t}$ = P/G are shown in Figs. 2 and 3. They can be used as the basis for the following deductions.

1. Of the studied airplanes, number 2 apparently has significantly greater takeoff run and takeoff distances. This can be explained by the negative effect of the jet stream, which as a result of drawing in (ejecting) the atmospheric air surrounding the aircraft creates a force which is opposite the listing force (secondary force).

2. If special measures are not taken, then the effect of the secondary forces may prove to be so great that aircraft 2 may even be inferior in its takeoff characteristics to the original standard aircraft 1, not to mention aircraft 5, which is equipped with an effective boundary layer control system.

3. In studying the takeoff and landing characteristics of jet short takeoff and landing aircraft of various systems we must consider the effect of secondary forces, which, as indicated at the beginning of this article, are ignored in many studies. ¶ 4. On the basis of certain select criteria we must conduct an exhaustive comparative analysis of STOL and aircraft with promising modern boundary-layer control system in order to determine the boundary, which indicates when we must give preference to a certain type of aircraft.

5. It may happen that development of individual STOL systems, which at first glance appeared promising from the standpoint of takeoff and landing characteristics, will turn out to be entirely inadvisable because of the advantages of aircraft with boundary-layer control systems.

6. Aircraft 3 occupies an intermediate position between compared aircraft. Up to the value of $\bar{t} \approx 0.7$ it is only slightly inferior to the original aircraft, at $\bar{t} \approx 0.7$ it is equal to it, at $\bar{t} > 0.7$ it significantly surpasses aircraft 1, and when $\bar{t} > 0.8$ it is even preferable to aircraft 4.

7. The problem of secondary forces is one of the many problems encountered in creating short takeoff and landing and vertical takeoff and landing aircraft. It is rather complex, especially its theoretical side. To resolve this problem deep theoretical and experimental studies must be conducted

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Fig. 1. Schemes of studied STOL.

Fig. 2. Takeoff run distance $l_р$ as function of thrust-to-weight ratio of aircraft: 1, 2, 3, 4, 5 - airplanes compared.

Fig. 3. Takeoff distance $l_{взл}$ as a function of weight-to-thrust ratio of aircraft: 1, 2, 3, 4, 5 - airplanes compared.

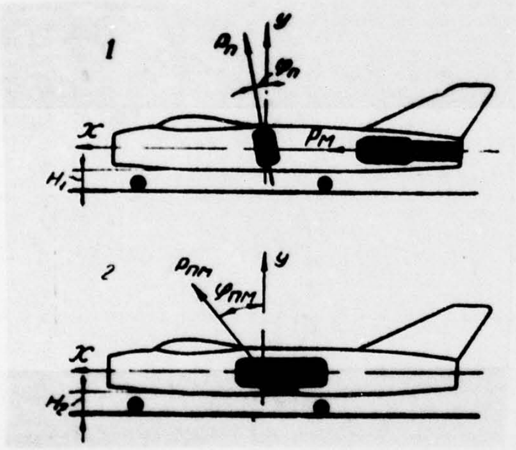

Fig. 1.

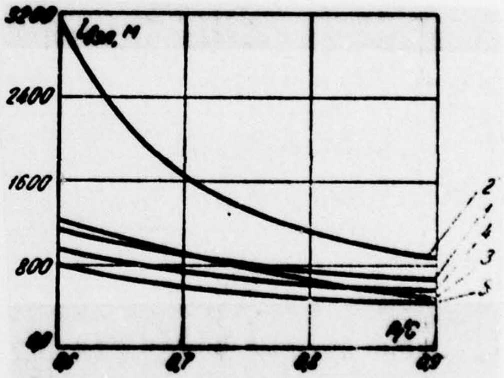

Fig. 2.

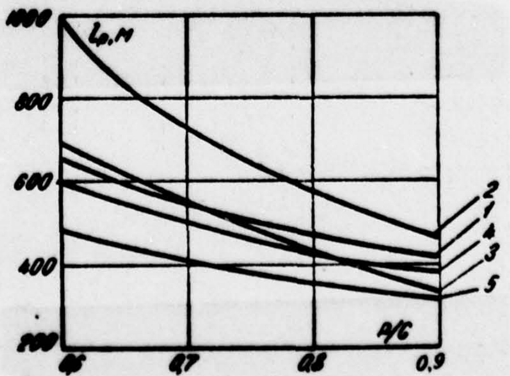

Fig. 3.

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