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JUN 78 V Y IVANOV, V M KOVALENKO

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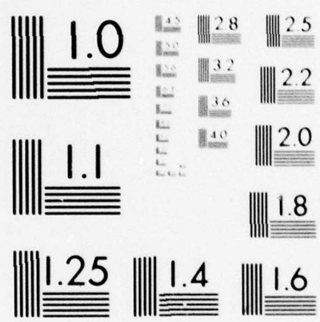

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THE EFFECT OF WEAK VISCOUS INTERACTION ON THE RESISTANCE OF A WING SECTION

By

V. Ya. Ivanov and V. M. Kovalenko

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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

THE EFFECT OF WEAK VISCOUS INTERACTION ON THE RESISTANCE OF A WING SECTION

V. Ya. Ivanov and V. M. Kovalenko

As is known the lines of flow in the boundary layer separate from the streamlined surface as a result of the light braking action on the part of the wall, which leads to a change in pressure distribution along this surface. In other words, the boundary layer governed by the external flow exerts an inverse effect on this flow - what we have is the so-called effect of viscous interaction.

From the practical standpoint the estimation of the effect of the interaction of the boundary layer with the external flow on the actual wing section is of considerable interest. Such an interaction is manifested in the change in the wave drag of the profile and in its friction drag. The actual pressure distribution along the wing section surface with a two-dimensional motion of the viscous gas flow coincides with the pressure distribution during a smooth flow of an ideal gas around a body, formed by the builtup of the displacement thickness, calculated according to the actual pressure distribution [1], of the boundary layer δ_1 on the wing section and on both sides of the zero line of flow in its wake. With this approach the problem of determining the actual pressure distribution is solved using the method of successive approximations. The numerical calculations have shown that even the first approximation enables us to obtain the principal quantitative portion of the correction which takes into account the inverse effect of the boundary layer on the theoretical distribution of pressure.

The effect of viscous interaction at hypersonic speeds has been studied extensively in [2, 3]; less attention has been devoted to the problem dealing with the effect of a weak interaction on the drag of a wing section at moderate supersonic speeds, in particular, with the presence of a mixed boundary layer on such a profile. This question has been formulated most extensively in [4, 5].

We will use the following designations in this work: x, s - coordinates along the chord and along the profile generatrix, respectively, $\bar{x}=x/b$; b - length of the profile chord; c - profile thickness, $\bar{c}=c/b$; $l_{т,п}$ - extent of the transition zone of the boundary layer from the laminar state into turbulent state, $\bar{l}_{т,п}= l_{т,п}/b$; δ_1, δ_2 - displacement thickness and thickness of the impulse loss of the boundary layer; ρ, μ, and T - density, viscosity factor, and gas temperature;

$$Re_\infty = \frac{u_\infty b \rho_\infty}{\mu_\infty}, \; Re_x = \frac{u_\delta x \rho_\delta}{\mu_\delta} -$$

Reynolds numbers,

M - Mach number; $\bar{T}_w = \frac{T_w}{T_e}$ - temperature factor; c_f - local coefficient of friction drag; c_x - coefficient of profile resistance. The subscripts: δ pertains to the parameters on the external line of the boundary layer; w - to the parameters on the wall; e - to the parameters on the heat-insulated wall; ∞ - to the parameters of the incident flow; л, т - laminar and turbulent layers, respectively; and пл. - plate.

In this work we investigate the effect of viscous interaction on a symmetrical parabolic profile (Fig. 1). It is assumed that the shock wave arising on a sharp leading edge of the profile is rectilinear. This fact excludes from the examination the cases of relatively thick profiles at low supersonic speeds. It is also presupposed that, in contrast to works [4, 5], the transition of the boundary layer from laminar to turbulent state occurs not as a shock wave but occupies a certain region. Furthermore, the turbulent boundary layer is calculated by a more perfect method and the estimation of the additional wave drag of the friction was accomplished over a wide range of change in the basic parameters of the incident flow and the geometrical dimensions of the profile.

The distribution of speeds along the initial profile can be written in the form of the functional relationship

$$\bar{u}_{\delta 0} = f[\beta(\bar{x}),\ \beta(0)]. \tag{1}$$

Here $\bar{u}_{\delta 0} = u_{\delta 0}/u_{\infty}$: $u_{\delta 0}$ - speed at the outer limit of the boundary layer without the consideration of the interaction; u_{∞} - velocity of the incident flow; $\beta(\bar{x})$ - angle between the direction of the incident flow and the tangent to the initial contour of the profile at its every point; $\beta(0)$ - initial rotation angle of the flow.

The velocity of the external flow $u_{\delta +}$ disturbed by the boundary layer, in accordence with what was said above, can be written in the form

$$\bar{u}_{\delta +} = f[\beta(\bar{x}) + \Delta\beta,\ \beta(0) + \Delta\beta_0], \tag{2}$$

where due to the smallness of $\Delta\beta$

$$\Delta\beta \approx \operatorname{tg}\Delta\beta = \frac{d\delta_1}{ds}. \tag{3}$$

The assumption regarding the smallness of $\Delta\beta$, which is valid for the points sufficiently removed from the leading edge, is a necessary condition of the weak interaction $\left(M\frac{d\delta_1}{ds} < 1\right)$. However, close to the leading edge the derivative $d\delta_1/ds$ is large and there is strong interaction $\left(M\frac{d\delta_1}{ds} > 1\right)$. But since the area of strong interaction is very small on thin tapered bodies, its contribution to the overall effect is negligible. In view of this fact, when calculating the region close to the leading edge, as was done in [5], we used the condition

$$\left.\frac{d\delta_1}{ds}\right|_{0 \leqslant \bar{x} \leqslant 0.05} = \left.\frac{d\delta_1}{ds}\right|_{\bar{x}=0.05} = \Delta\beta_0, \tag{4}$$

which allows us to calculate this area in the approximation of a weak interaction.

The distribution of the velocities and pressures along the profile contour was calculated according to the A. Ye. Donov's theory of third approximation [6], i. e., it was assumed that

$$\bar{u}_{\delta 0} = 1 + b_1\beta(\bar{x}) + b_2\beta^2(\bar{x}) + b_3'\beta^3(\bar{x}) + (b_3 - b_3')\beta^3(0), \quad (5)$$

$$\bar{p}_{\delta 0} = a_1\beta(\bar{x}) + a_2\beta^2(\bar{x}) + a_3\beta^3(\bar{x}) + a_{1d}\beta^3(0). \quad (6)$$

In a particular case, when $\beta(0) \leqslant 0$, the coefficients $b_3' = b_3$ and $a_{1d} = 0$. In formulas (5) and (6) the pressure coefficient $\bar{p}_{\delta 0} = \frac{p_{\delta 0} - p_\infty}{q_\infty}$, values p_∞ and q_∞ are pressure and velocity head of the incident flow, respectively, b_i and a_i are functions of the M_∞ number [6].

If expand (2) in the Taylor series, using relationships (4) and (5), and keep the terms only to the third degree of smallness inclusively (in this case $\frac{d\delta_1}{ds}$ - value with the second degree of smallness), equation (2) will assume the form

$$\bar{u}_{\delta +} = \bar{u}_{\delta 0} + [b_1 + 2b_2\beta(\bar{x})]\frac{d\delta_1}{ds} + \Delta\bar{u}_\delta, \quad (7)$$

where value $\Delta\bar{u}_\delta$ is determined by the initial (i. e., when $\bar{x}=0$) values of the angles $\beta(0)$ and $\Delta\beta_0$ and is necessary for a correct recalculation of the shock wave with the consideration of the interaction.

The formula for the pressure coefficient $\bar{p}_{\delta +}$ can be obtained in the same way with the consideration of the interaction of the boundary layer with the external flow:

$$\bar{p}_{\delta +} = \bar{p}_{\delta 0} + d\bar{p} + \Delta\bar{p}, \quad (8)$$

where

$$d\bar{p} = [a_1 + 2a_2\beta(\bar{x}) + 3a_3\beta^2(\bar{x})]\frac{d\delta_1}{ds}, \quad (9)$$

$\bar{p}_{\delta o}$ is determined by relationship (6), and $\Delta\bar{p}$ in the same way as the value $\Delta\bar{u}_\delta$ by the values $\beta(0)$ and $\left.\frac{d\delta_1}{ds}\right|_{\bar{x}=0,05}$.

First, formulas (5) and (6) are used to calculate the external flow. The determined distributions of pressure and velocity along the contour allowed us to determine the values of the displacement thickness of the boundary layer in the first approximation. Then, using formulas (7) and (8), the external flow is calculated in the second approximation, taking into account the effect of interaction.

According to the data in [4, 5], the estimation of this effect can be limited by the second approximation.

The calculation of the wave drag c_{x_B} for one side of the profile, and also of the additional resistance Δc_{x_B} caused by the effect of interaction, was accomplished in a rapid coordinate system using the simplified formulas obtained from the exact expressions for the c_{x_B} and Δc_{x_B} [6] with the expansion of the trigonometric functions, which enter into them, in a series of powers of the corresponding angles with an accuracy to the terms which are proportional to the cubes of the angles (which is possible for a slender profile at relatively small angles of attack). These formulas have the form

$$c_{x_B} = \int\limits_0^1 \left(\bar{p} + \frac{p_\infty}{q_\infty}\right) \beta_\delta(\bar{x})\, d\bar{x}, \tag{10}$$

$$\Delta c_{x_B} = \int\limits_0^1 (d\bar{p} + \bar{\Delta p})\, \beta_\delta(\bar{x})\, d\bar{x}, \tag{11}$$

Here

$$\beta_\delta(\bar{x}) = \beta(\bar{x}) \left[1 + \frac{\alpha^2}{2} \pm \alpha\beta(\bar{x})\right] + \frac{1}{3}\beta^3(\bar{x}) \tag{12}$$

($\pm$ for the upper and lower surfaces of the profile, respectively); α - angle of attack.

In a general case the estimation of the effect of viscous interaction was accomplished in the presence of a mixed boundary layer. The characteristics of the laminar layer were calculated according to the method in [7], which is suitable, however, only for the relatively small gradients of pressure. The method in [8] was used to calculate the turbulent boundary layer; this method can be used for a continuous flow around a wing section with attached shock wave. The momentum equation is used to determine the local coefficient of friction drag which can be written in the form

$$c_{f\delta} = \frac{2\mu_w}{u_\delta \rho_\delta} \left\{ \frac{d\,Re_w^{**}}{dc_{f\delta}} \frac{dc_{f\delta}}{ds} + \left[\frac{d\,Re_w^{**}}{dM_\delta} + \frac{Re_w^{**}(H+1)}{M_\delta\left(1 + \frac{\varkappa - 1}{2} M_\delta^2\right)} \right] \frac{dM_\delta}{ds} \right\}, \tag{13}$$

where

$$Re_w^{**} = \frac{u_\delta \rho_\delta \delta_2}{\mu_w} = Re_w^{**}(c_{f\delta}, M_\delta, \bar{T}_w). \tag{14}$$

Thickness of the momentum loss δ_2 is determined using the data for a plate and the form-parameter H is determined according to the formula

$$H = 1.285\,\bar{T}_w + 0.2\,M_\delta^2\,(1 + 1.15\,\bar{T}_w). \quad (15)$$

As the boundary condition we used the condition where in the first calculation point, which is relatively close the leading edge (when $\bar{x}$=0.03),

$$c_{f\delta}|_{\bar{x}=0.03} = c_{f\delta_{пл}}(M_\delta|_{\bar{x}=0.03}, Re_x|_{\bar{x}=0.03}, \bar{T}_w). \quad (16)$$

In the case of a mixed boundary layer the determination of the boundary condition depends on the assumptions regarding the relative length of the transition zone $\bar{l}_{т.п}$. If we assume that the transition occurs instantly (i. e., $\bar{l}_{т.п}$=0), the local coefficient of resistance of the turbulent friction at the point of transition can be determined from the condition of equality of the momentum loss thicknesses of the laminar and turbulent boundary layers. In the case when the length of the transition zone has a finite dimension ($\bar{l}_{т.п}$>0), the boundary condition for equation (13) can be determined by introducing certain assumptions. The displacement thickness of the boundary layer at the end of the transition zone was assumed to be equal to the half-sum of the displacement thicknesses of the laminar and turbulent boundary layers, which were calculated for the point on the profile which is located in the middle of the transition zone; in this case, the thickness $\delta_{1\,т}$ at this point is calculated from the condition $\delta_{2л}=\delta_{2т}$ (see Fig. 2). The measurement results obtained for the displacement thickness on a flat plate in the transition zone can serve as a certain confirmation of this assumption [9].

Equation (13) was solved numerically according to the Runge-Kutta method with a fixed step, which equals to 0.01 of the chord. After the values of the $c_{f\delta}$ were determined, we calculated the local coefficients of the friction drag $c_{f\infty}$, referred to the conditions in an incident flow. In determining the average friction coefficient c_F, i. e., when integrating the values of $c_{f\infty}$ along the profile's contour and projecting the friction force onto the direction of the incident flow, it was assumed that, in the transition zone, the local friction coefficient changes linearly.

Change in the pressure of an inviscid flow, arising due to the effect of the boundary layer, leads to the change in the surface friction determined according to the initial pressure distribution in an inviscid flow, thus

$$\Delta c_F = c_{F+} - c_{F0}, \tag{17}$$

where c_{F+} - average friction drag coefficient determined with the consideration of the interaction; c_{F0} - without the consideration of the interaction.

The total effect derived from the interaction between the boundary layer and the external flow can be expressed by means of the coefficient

$$K_{\delta 1} = \left(1 + \frac{\Delta c_{xB}}{c_{F0}}\right)\left(1 + \frac{\Delta c_F}{c_{F0}}\right) \approx 1 + \frac{\Delta c_x}{c_{F0}}. \tag{18}$$

The calculations were carried out on a computer according to the established procedure over a wide range of change in the basic parameters of the flow $(2 \leqslant M_\infty \leqslant 6,\ 10^7 \leqslant Re_\infty \leqslant 10^9,\ 0{,}6 \leqslant \bar{T}w \leqslant 1)$ and the geometry of the profile $0 \leqslant \bar{c} \leqslant 0{,}06)$. The static parameters of the incident flow $(T_\infty,\ p_\infty,\ \rho_\infty,\ \mu_\infty)$ correspond to the altitude of 20 km. Figures 3 to 7 show some calculation results obtained for the coefficients of additional resistance Δc_{xB} and Δc_F, attributed to the friction resistance of the initial contour. The comparison with the friction drag is made due to the fact that the source of both components of the additional resistance is, ultimately, the viscosity of the flow.

From an analysis of the calculation material we can conlude that the thicker the boundary layer and, consequently, the greater the displacement thickness, i. e., the larger the M_∞ (Fig. 3) and $\bar{T}_W$ (Fig. 5) numbers and the smaller the Re_∞ number (Fig. 4) the greater the additional resistance of the profile. Furthermore, for two profiles which differ in thickness and which are in the same flow, greater additional resistance arises on a thicker profile (Fig. 6). In comparison with the friction drag, for example at the numbers $M_\infty=3$ and $Re_\infty=10^7$, the portion of this resistance comprises from 2 to 3% for the profiles with the relative thickness of 2 to 4% and it rapidly increases with an increase in the M_∞ number.

Of practical interest is the question concerning the influence of the position of the transition zone and its extent on the components of additional resistance of the profile. The calculations have shown that, in the case of a mixed boundary layer, there are ranges of basic parameters of a flow at which the interaction may have no effect on the wave or total resistance of the wing section, while in other cases, it can lead to a decrease in the wave and total resistances. The maximum of this decrease corresponds to the case where the point of transition is close to the middle of the profile; its value depends on the flow parameters (Fig. 7). The extent of the transition region virtually has no effect on the magnitude of the additional wave resistance within the limits of this region and and it is manifested only in the change of the specific contribution to the value $c_{x\text{в}}$ of the purely laminar and purely turbulent areas of the flow.

The calculations show that the additional resistance of the wing section, caused by the effect of viscous interaction, is significant for important cases in practice and it must be taken into account. It is possible to assume that the values of Δc_x, calculated in this manner, remain in force also for the profile which is in the flow at a small angle of attack.

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BIBLIOGRAPHY

1. L. G. Loytsyanskiy. Mechanics of liquid and gas. M., "Nauka", 1970.
2. R. H. Korkegi. Viscous interaction and flight at high Mach numbers, N. Y., AIAA Paper, No. 70-781.
3. U. D. Hays and R. F. Probstin. Theory of hypersonic flows. M., Publishing House of Foreign Lit., 1962.
4. A. D. Young and S. Kirby. ARC Technical Report C. P., No. 451. London, November, 1958.
5. R. E. Luxton and A. D. Young. ARC Reports and Memoranda, 1964, No. 3393.
6. A. Ye. Donov. Reports by the AS USSR, Mathematical series, 1939, No. 6.
7. R. E. Luxton and A. D. Young. ARC Reports and Memoranda, 1962, No. 3233.
8. V. M. Kovalenko. Friction resistance of a profile in a supersonic flow. Technical reports of TsAGI, 1967, issue 308.
9. C. B. Schubauer and P. S. Klebanoff. NACA Rep., 1956, No. 1289.

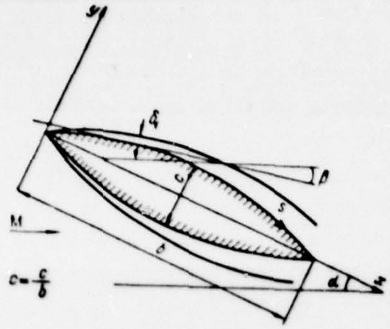
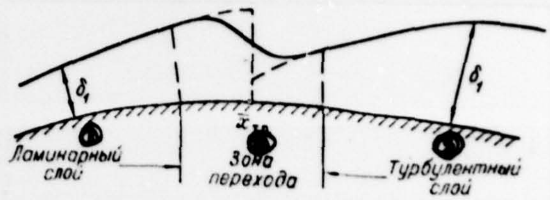


Fig. 1. Parabolic profile at the angle of attack.



KEY: 1) Laminar layer 2) Transition zone 3) Turbulent layer

Fig. 2. Distribution of the displacement thickness in the transition zone [9]

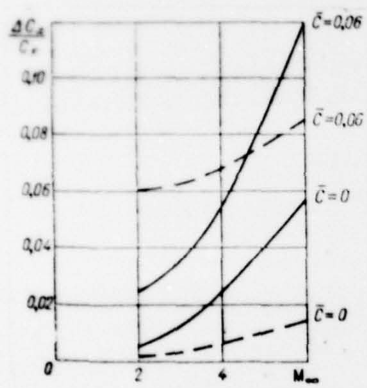


Fig. 3. Additional total drag as a function of the M_∞ number for a plate and a parabolic profile with the thickness $\bar{c}$=0.06. $Re_\infty = 10^7$, $\bar{T}_W$=1.0

______ turbulent layer. --- laminar layer.

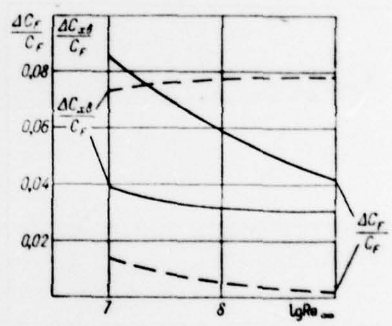


Fig. 4. Additional wave drag and Friction drag as a function of the Re_∞ for a parabolic profile ($\bar{c}$=0.06). M_∞=6, $\bar{T}_W$=1.0.

______ turbulent layer.

--- laminar layer.

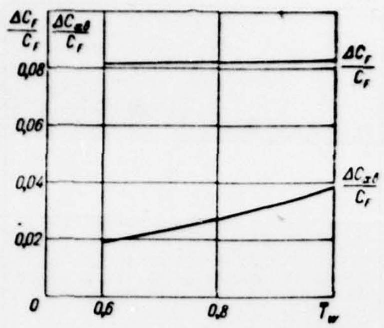


Fig. 5. Effect of the temperature factor on the magnitude of the additional wave drag and friction drag of a parabolic profile ($\bar{c}$=0.06), M_∞=6, Re_∞=10^7, $\bar{x}_T$=0.

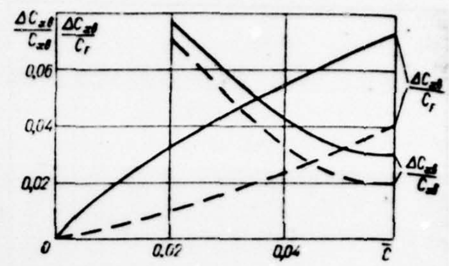


Fig. 6. Effect of the thickness of a parabolic profile on the magnitude of the additional wave drag, M_∞=6, Re_∞=10^7; $\bar{T}_W$=1.0.

____ turbulent layer, --- laminar layer.

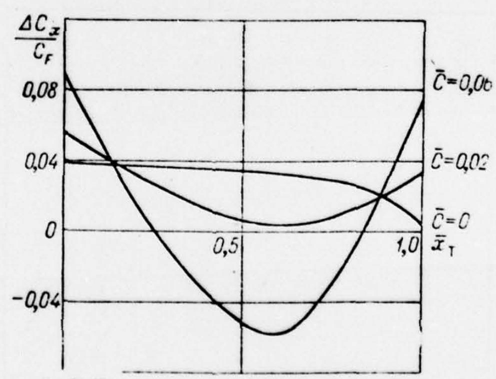


Fig. 7. Additional resistance of a plate and two parabolic profiles ($\bar{c}$=0.02 and 0.06), due to the effect of viscouse interaction, depending on the position of the point of transition.

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