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POWER INTERACTION BETWEEN VISCOUS FLOW AND SOME PROFILES WITH FORWARD SHARP EDGE

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ВЗАИМОДЕЙСТВИЕ ПОТОКА ВЯЗКОЙ ЖИДКОСТИ С ПЕРЕДНЕЙ ОСТРОЙ КРОМКОЙ ПРОФИЛЯ

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ABSTRACT: This report deals with the contraction/expansion phenomenon in viscous flow under streamlining of bodies. Using simple hydraulic methods and early proposals [1-4] lets to decompose the problem.

KEY WORDS: viscous flow, lifting force, attack angle, contraction degree, influence radius.

АННОТАЦИЯ: В этом сообщении рассмотрено явление сжатия/расширения потока вязкой жидкости при обтекании тел. Использование простых гидравлических методов позволили упростить решение внешней задачи гидродинамики.

КЛЮЧЕВЫЕ СЛОВА: поток вязкой жидкости, подъемная сила, угол атаки, радиус влияния.

Outline of the problem. It is widely accepted that the external streamlining problem may be solved with the analytic functions, ideal fluid and viscous boundary layer theories as well as the virtual mass and bound vortex models. At the same time, the bound vortex model (Kutta-Joukowski) supposes that a finite velocity exists at back sharp edge but forward edge must be smooth for passing boundary streams from the lower side of wing profile to the more convex upper side according to the Magnus' phenomenon. Fixation of the separation point at the back sharp edge by the Joukowski-Chaplygin condition lets to find the circulation value.

Analysis of recent research and publications. In case of a forward sharp edge there is blocking the bound wortex but nevertheless we shall receive a lifting force more than Newton's impulse component correlated to $\sin^2\alpha\cos\alpha$ function of attack angle. For example, lifting force coefficient C_y and drag resistance coefficient C_x are presented as the sum in accordance with Betz and Fedyaewski works [1-4]:

$$C_y = \frac{dC_y}{d\alpha}\sin\alpha + 2\sin^2\alpha\cos\alpha \quad (1)$$

$$C_x = K\sin^2\alpha + 2\sin^3\alpha \quad (2)$$

where α = attack angle; $\frac{dC_y}{d\alpha}$ = differential of lifting force coefficient; K = constant of drag resistance coefficient considered for this approach [4].

At the present time we have only limited evidence of development of these early proposals regarding power interaction.

Impulse (newton's) component of interaction. Having received numerous experimental correlations of power interaction of non-circulation separated flow under great angles of attack we can see prevailing share of impulse (Newton's) component into drag resistance and lifting force [1-8]. So, drag resistance of struts, wires and building long-ware inclined to the wind direction depends on the $\sin^3\alpha$ function [7,8]. Yet Eiffel's experiments with plates in air flow stated that the share of impulse component of lifting force increases under lengthening plate along the wind direction (fig.1). Perhaps, such approach of the experimental curves to the theoretical function can be explained by decreasing influence of the unequal conditions of streamlining and local attack angles of the boundary streams.

Moreover, for finding out a "pure relationship" it was suggested to equip testing plates with the stream-forming longitudinal stabilizers and the upper stream-separating edge (fig.2). By means of equal influence of local attack angles and equal area of separation at such condition we could show the better correspondence with theoretical $\sin^2\alpha\cos\alpha$ function. On the other hand, the lifting force of the plane long wing equipped only with the upper stream-separating edge for the constant area of separation under great angles of attack corresponds with this function too. We have shown the confirmative results also in the previous paper [2]. To analyze the components of aero-hydrodynamic forces it seems like a reasonable way to find out the pure relationships without any shares of the accompanying factors or to take them into account and to level their influence.

Calculation of profile influence. To evaluate a possibility and origin of lifting force for an endless segmentary wing profile under attack angle $0 < \alpha_0 < \beta_0$ we consider a typical scheme (fig. 3). In this case the forward sharp edge divides the running flow into two parts: upper and lower. Obviously, the upper part of flow undergoes more intensive contraction by more convex side of the profile. The maximum degree of contraction is observed near the maximum deviation of boundary streams $\bar{y}_{max}$ but after this we can see an expansion of flow and some zone of separation. Contraction of the lower part of flow is less intensive and the maximum comes at the back sharp edge with the deviation y_{max}.

It is necessary to note the connection between the internal streamlining and external one is established with the influence radius. In fact, experimental data indicate that we have the immutable flow at some midship diameter distance from profile's surface. There are immutable aero-hydrodynamic parameters (pressure, velocity) out of the influence radiuses. Like the peculiar ring contraction considered before in [2.10] also the 2D flow around profile can be imaged as two 2D contraction between the influence radiuses (R_1 for lower side, R_2 for upper side) and the head surface of the profile. By this mean the external aero-hydrodynamics problem transforms into the internal problem. Then solving can be found with simple hydraulic methods.

After determination of the maximum contraction degree s_m it is possible to find the specific lifting force per unit length by integrating the difference of pressures on the lower and upper sides:

$$F_y = \frac{\rho V_0^2}{2}\int_0^{x_b}\left(\bar{s}^2 - s^2\right)dx + \frac{\rho V_0^2}{2}\int_0^{x_b}\left[\int_1^{s_m}\sin^2\alpha d\left(s^2\right)+\sin^2\alpha_0\right]dx - \\ - \frac{\rho V_0^2}{2}\int_0^{x_p}\left[\int_1^{s_p}\sin^2\alpha d\left(\bar{s}^2\right)+\sin^2\left(\beta_0-\alpha_0\right)\right]dx \tag{3}$$

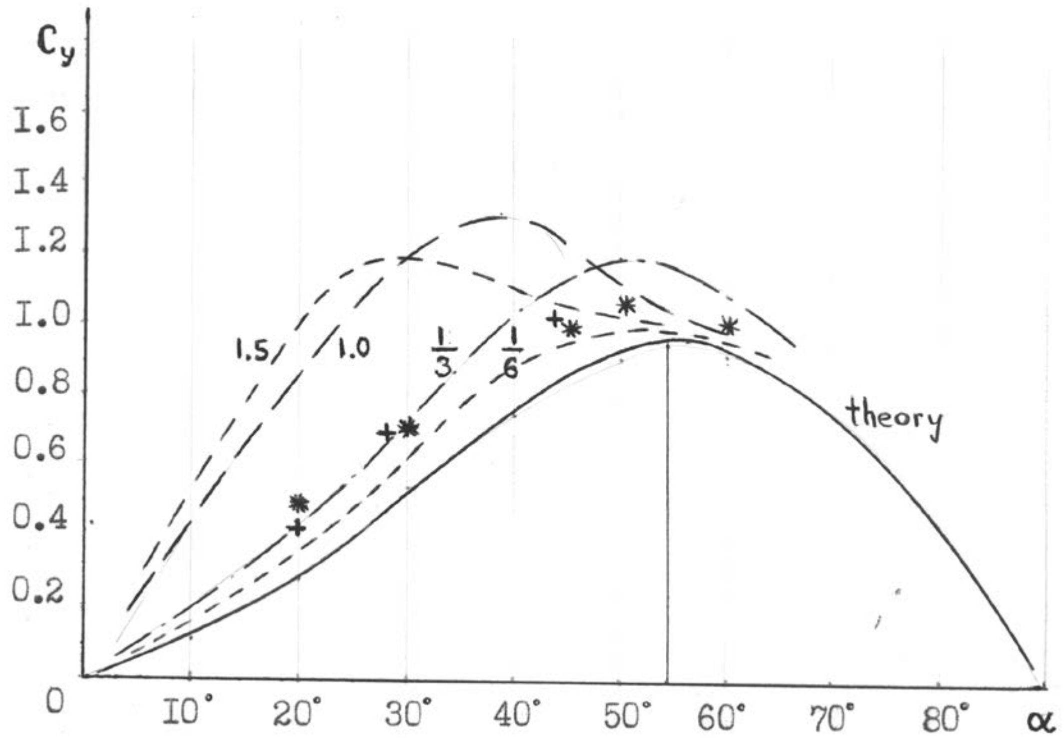
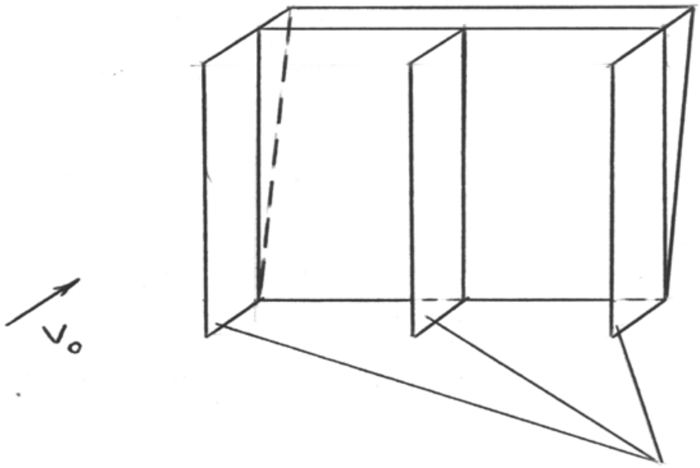


Fig.1 Approach of the lifting force coefficients to the theoretical function:
---- curves 1.5 ; 1 ; 1/3; 1/6; - Eiffel's experiments for different lengthening;
*** square plate with the stream-forming equipment;
+++ plane wing with the stream-separating edge.



stream-forming

Fig 2. Square plate with the stream-forming equipment.

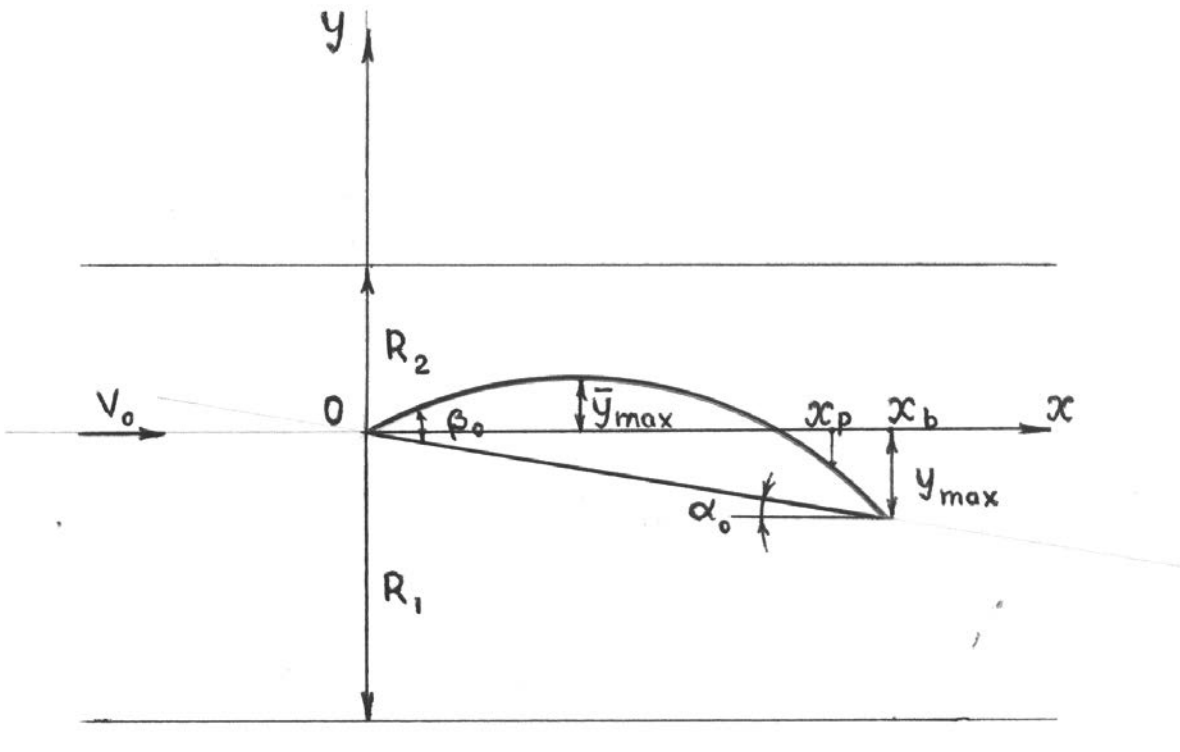


Fig.3 Scheme of profile influence.

where $s = \dfrac{R_1}{R_1 - y}$ = current contraction degree on the lower side;

$\bar{s} = \dfrac{R_2}{R_2 - \bar{y}}$ = current contraction degree on the upper side;

$s_m = \dfrac{R_1}{R_1 - y_{max}} = \dfrac{R_2}{R_2 - \bar{y}_{max}}$ = maximum contraction degree;

s_p = contraction degree at the separation point;

α = current attack (contraction/expansion) angle;

$\beta_0 > \alpha_0$ = contraction condition.

According to the presented model with the fixed maximum contraction degree, the influence radiuses are the constants definited by the maximum deviations of the boundary streams. The experimental data provide the reasons to suppose s_m = 1.43 [2]. Consequently, the influence radiuses will exceed the maximum deviations by 3.33 times:

$$R_1 = \frac{s_m}{s_m - 1} y_{\max} = 3.33 y_{\max} \tag{4}$$

$$R_2 = \frac{s_m}{s_m - 1} \bar{y}_{\max} = 3.33 \bar{y}_{\max} \tag{5}$$

A position of the separation point on the upper side may be found by analysis of the energy balance of boundary streams under the energy accumulation when $d(\bar{s}^2) > 0$ and the energy deliverance when $d(\bar{s}^2) < 0$. But this supposition needs to be accompanied with representative experimental data. At the same time, the excess energy balance of the boundary streams is confirmed by the experimental data of drag resistance coefficient for the axially symmetric bodies like submarine (see also: G. Fuhrmann "Jahrbuch der Motorluftschitt-Studiengesselschaft", Bd. 5).

According to the experimental results the drag resistance of the body with sharp conical head is essentially more than the resistance of the analogous one with the convex paraboloid head under the fully identical lengthening stern (1.13 to 1). Evidently, it is caused by the more energy of the boundary streams in the second case and a displacement of the separation point along the flow to the stern tail point.

Conclusions.

- Asymmetric contraction/expansion phenomenon under asymmetric streamlining of bodies with forward sharp edge results in generation of the profile components of lifting force and drag resistance;
- The better agreement between the experimental data and the theoretical lifting force curve for impulse Newton's component has been obtained with the auxiliary stream-forming equipment of the testing plate;
- In order to provide adequate experimental relations for influence of general attack angle, profile shape and contraction degree it is necessary to take into account the local changes of boundary streams trajectories and their local power interactions with flow.

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