Journal of Engineering Physics and Thermophysics, Vol. 66, No. 3, 1994

SPECIFIC FEATURES OF WAKE FLOW BEHIND A TWO-DIMENSIONAL BODY WITH A CAVITY ON ITS REAR EDGE

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UDC 532.543.6

We present experimental results on the effect exerted by the width of a cavity made at the rear edge of a two-dimensional model on the magnitude of the bottom pressure, the Strouhal number, and the turbulent characteristics of a wake.

Introduction. The shape of the rear edge of a model plays a decisive role in the formation of the pattern of the flow immediately adjacent to the model. In turn, there is a direct relationship between the structure of the wake near the model bottom and the magnitude of the pressure at its rear edge. Behind bodies having a blunt rear edge, separation of boundary layers leads to the formation of a rarefaction, which is responsible for the high resistance at the bottom. Investigations [1, 2] have shown that without changing the height of the rear edge, it is possible to substantially decrease the bottom resistance, i.e., to increase the pressure at the model bottom, by creating a certain geometry of that edge. One of the efficient solutions allowing a decrease in the bottom resistance of the model is the provision of a cavity on the rear edge. For the case where the width of the cavity amounted to $\simeq$ 90% of the rear edge height, the pressure at the model bottom increased by 20-25%. The effect of a cavity was also noted when studying the influence of a jet blown from the rear edge of a model into the attached wake region [3], but again at commensurable dimensions of its width and the height of the model bottom. It is of interest to determine the extent to which the influence of a cavity on the pressure changes with reduction in the dimensions of the cavity. It is advisable to supplement these investigations with measurements of the frequency with which the vortical system behind the body forms and of the turbulent characteristics of the wake flow. This will make up to some extent for the absence of such interrelated data in the literature.

Experimental Setup. Experiments were conducted in an open-type wind tunnel [4]. The test section of a rectangular 280×1400 mm channel had a length of 1300 mm. The air flow velocity was held constant at $U_0 = 14$ m/sec. The level of the background turbulence in the channel was equal to 0.1%. The model was a rectangular plane body with a semicircular leading edge and a blunt rear edge [5], which, together with upper and lower plates, bound an internal cavity. The rear edge is formed by two identical rectangular blocks fixed on the upper and lower plates in such a way that a slit is formed along the symmetry axis of the model bottom. This slit connected the internal cavity of the model with the surrounding medium. We could vary the width of the slit both by changing the position of the blocks and by replacing them with new ones. We investigated eight models differing only by the ratio of the width of the slit h to the height of the rear edge H: $h/H = 0.02$ (model 1); 0.05 (model 2); 0.7 (model 3); 0.1 (model 4); 0.18 (model 5); 0.26 (model 6); 0.4 (model 7); 0.75 (model 8). The maximum opening of the internal cavity was attained by removing both blocks (model 8). The pressure distribution along and across the slit was determined using a system of holes made symmetrically in each of the blocks. The value of the pressure coefficient $(C_p)_b = (p_b - p_0)/(1/2\rho U_0^2)$ was calculated from the arithmetic mean value of p_b found by measurements in the central cross section of the model. For model 8 the pressure in the plane of the bottom was measured by a Pitot-Prandtl tube. Similar measurements were also made for model 7. They showed that the values of $(C_p)_b$ based on the pressure p_b measured with the help of the system of holes and with the aid of the Pitot-Prandtl tube differed

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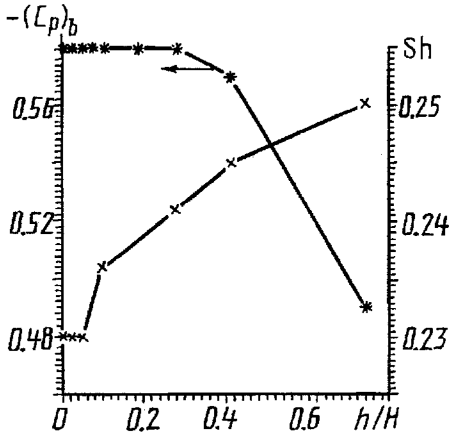

Fig. 1. Change in the pressure on the bottom of a model and the Strouhal number in the wake behind the model as a function of the slit width.

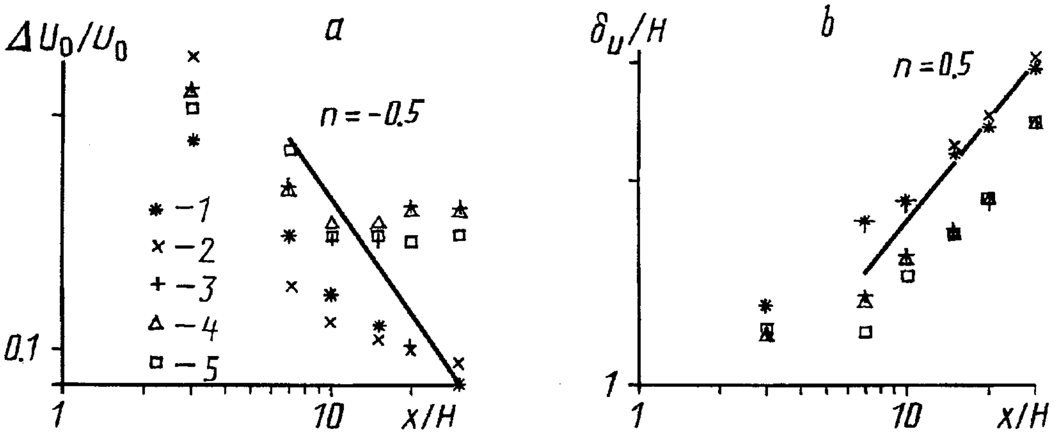

Fig. 2. Degeneration of the mean velocity defect (a) on the wake axis and growth of the wake width (b). (1) $h/H = 0$; (2) 0.1; (3) 0.26; (4) 0.4; (5) 0.75.

by no more than 3%. The model was installed on the symmetry axis of the channel at the beginning of the test section with a zero angle of attack. All of the investigations were made at a Reynolds number of $\mathrm{Re} = 3.7 \cdot 10^4$, based on the height of the rear edge of the model.

The frequency of the formation of vortices behind the model was measured by a single-wire probe placed in the external region of the wake and was recorded by a Nicolet 660 frequency spectrum analyzer. The profiles of the mean velocity and the longitudinal and transverse fluctuations of the wake flow were measured simultaneously by an X-shaped probe connected with Dantec thermoanemometric equipment. Turbulent characteristics were measured in six cross sections behind the model: $x/H = 3$, 7, 10, 15, 20, and 30.

Results and Discussion. The investigations showed that the influence of the internal cavity of the model on the magnitude of the pressure coefficient was observed only when $h/H > 0.26$ (Fig. 1). For models 1-6 the pressure on the real edge practically did not differ from the pressure in the absence of a slit. The increase in pressure under the influence of the internal cavity acquired practical significance starting from the value $h/H > 0.5$.

The Strouhal number (Sh) is subjected more to the effect of the parameter h/H. Starting with model 4, the characteristic frequency of the formation of a vortical system behind the body had a stable tendency to grow with increase in the slit width (Fig. 1). However, the maximum change of $\simeq 9\%$ in the Strouhal number for model 8 is much smaller than the maximal increase of $\simeq 16\%$ in the pressure coefficient, i.e., small changes in the frequency of the formation of a vortical system behind the model were responsible for a much larger decrease in the bottom resistance.

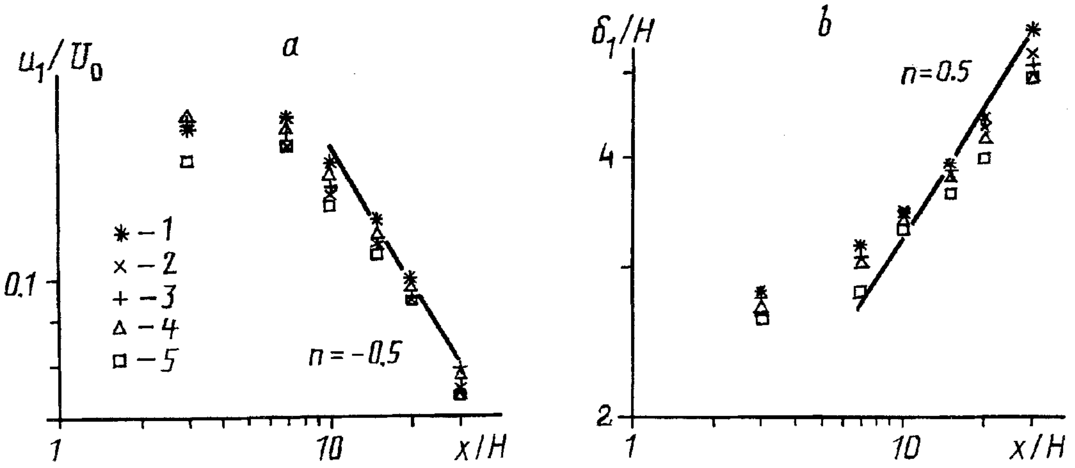

Fig. 3. Degeneration of longitudinal velocity fluctuations (a) on the wake axis and growth of the wake width (b) (the coordinates of the point of intersection of the axes are (1, 2)). Notation is the same as in Fig. 2.

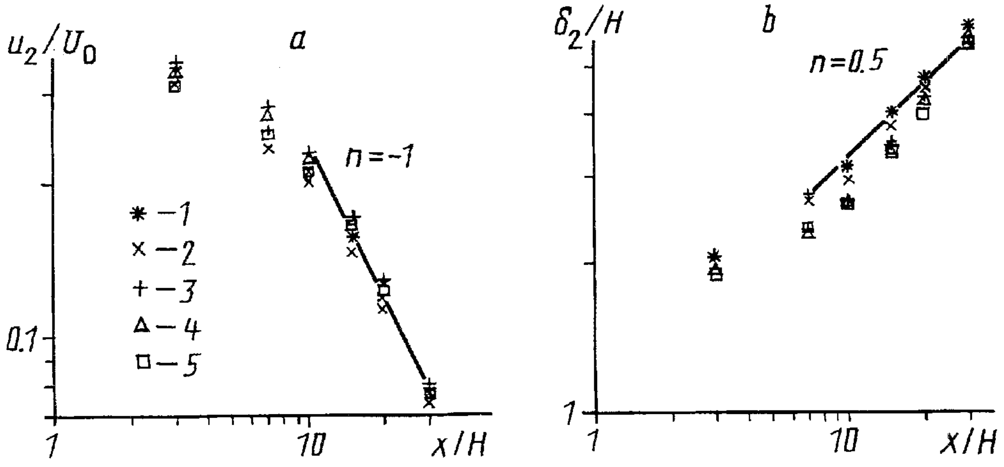

Fig. 4. Degeneration of transverse velocity fluctuations (a) on the wake axis and growth of the wake width (b). Notation is the same as in Fig. 2.

The wake flow structure underwent appreciable changes compared to the corresponding characteristics behind a model without a slit on the rear edge when $h/H > 0.1$. The mean velocity defect on the axis behind models 6-8 grew and starting from the cross section $x/H = 10$ appeared to be "frozen" (Fig. 2). The mean velocities on the axis behind models 1-4 differed only slightly in magnitude and character of the degeneration. This is also true for the wake width behind the indicated models (Fig. 2). The wake width behind models 6-8 decreased noticeably but, in contrast to the velocity defect, its change corresponded to the power law $\delta_u \simeq (x)^{0.5}$ for all the models when $x/H > 10$. As is known, this law is valid in the self-similar region of wake flow.

Longitudinal and transverse velocity fluctuations in a wake decreased with opening of the slit with a simultaneous decrease in the wake width (Figs. 3 and 4). The degenerations of the fluctuations on the wake axis did not undergo appreciable changes and were described by the laws $u_1 \simeq (x)^{-0.5}$ and $u_2 \simeq (x)^{-1}$ when $x/H >$ 10. The wake width determined for both components of velocity fluctuations increased in accordance with the law $\delta_1 = \delta_2 \simeq (x)^{0.5}$ at the same distance from the models. It should be noted that the turbulent characteristics of the wakes behind models 1-4 differed little [6] and therefore they are represented by the data pertaining to model 4. The present investigations demonstrated that the influence of the internal cavity of the model on the fluctuational characteristics manifested itself most clearly in the change in the wake width and exhibited a very insignificant effect on velocity fluctuations.

Conclusions

1. The change in the pressure on the model bottom under the influence of its internal cavity, which exceeds the measurement error, manifested itself when the width of the slit made on the rear edge was more than twice the height of this edge, i.e., $h/H > 0.5$. Thus, this value of the parameter h/H may be considered to be the limiting one below which the influence of the cavity on the change in the resistance of the body is negligible.

2. The growth in the Strouhal number with the ratio h/H indicates a change in the formation of the vortical system behind the body under the influence of the internal cavity. Of interest is the established interrelation between the increase in the pressure on the model bottom and the growth in the characteristic frequency of the vortical system.

3. The effect of the internal cavity on the turbulent characteristics of the wake flow manifested itself in an increase in the mean velocity defect, a decrease in velocity fluctuations, and a decrease in the wake width. The mean velocity defect on the wake axis ($x/H > 10$) and the wake width were subjected to the greatest changes.

NOTATION

U_0, potential flow velocity in the channel, m/sec; p_b, static pressure on the model bottom, Pa; p_0, static pressure in the potential flow, Pa; ρ, air density, kg/m^3; u_1, longitudinal velocity fluctuations, m/sec; u_2, transverse velocity fluctuations, m/sec; δ_U, wake halfwidth based on the mean velocity profile, m; δ_1, δ_2, wake halfwidths based on the profiles of the longitudinal and transverse fluctuations, respectively, m.

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