PULSATIONS IN BOUNDARY PRESSURE IN THE FLOW OF A PLANE TURBULENT JET ONTO A SURFACE

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Results are presented on an experimental study of root-mean-square values of pulsations in boundary pressure when a plane turbulent jet flows onto a plane surface in the ranges of Reynolds numbers Re_n of $0.7 \cdot 10^5$–$2.1 \cdot 10^5$, distances x/d of 19–43, and angles of impingement of 0–90°.

§ 1. The problem of the determination of the pulsation action of a turbulent stream on the surface over which it flows excites interest both in connection with concrete applications and owing to the possibility of using the results in a study of boundary turbulence. The main information on pulsations in boundary pressure has been obtained up to now for flow in a turbulent boundary layer [1], whereas considerably less attention has been paid to jet flows in this field. Below we present the results* of measurements of one of the principal characteristics of a turbulent load — the root-mean-square value of the pulsations in boundary pressure p obtained in the flow of a turbulent jet onto a plane surface.

§ 2. The experiment was carried out on an installation whose main element was a massive tilting slab with a smooth plane working surface. As the detectors of pressure pulsations we used units of the type [2] containing piezoceramic transducers with a sensing surface 1.3 mm in diameter and a sensitivity of about 4 μV/Pa. The detector units were set flush with the working surface in the region of action of the jet. The discharge took place from a slot nozzle with a width d = 15 mm at velocities V_n of 75 to 220 m/sec. The

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*D. E. Leibin and E. B. Solov'ev participated in the work.

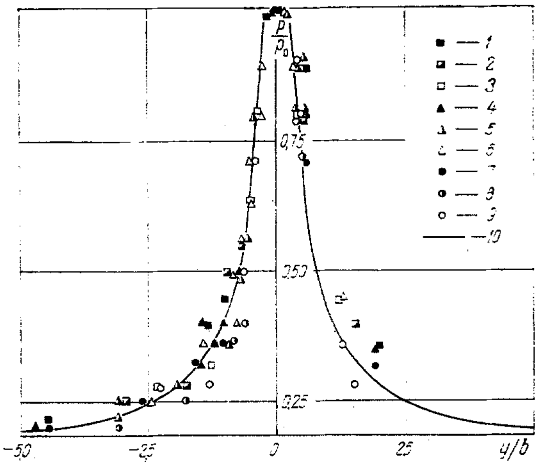

Fig. 1. Distribution of intensity of pressure pulsations along the surface with normal impingement of the jet: 1-3) $Re_n = 0.72 \cdot 10^5$; 4-6) $1.12 \cdot 10^5$; 7-9) $2.08 \cdot 10^5$ with x/d equal to 24, 33, 43, 24, 33, 43, 24, 33, and 43, respectively; 10) function (2).

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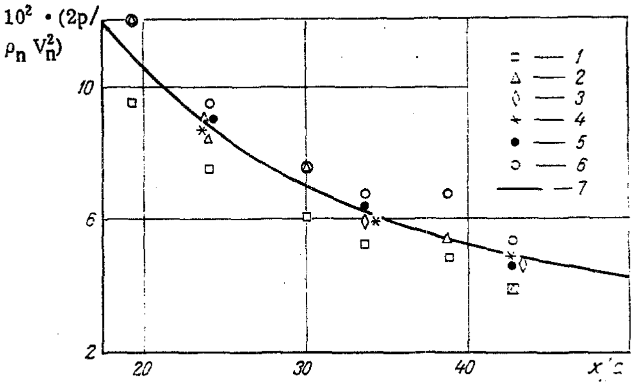

Fig. 2

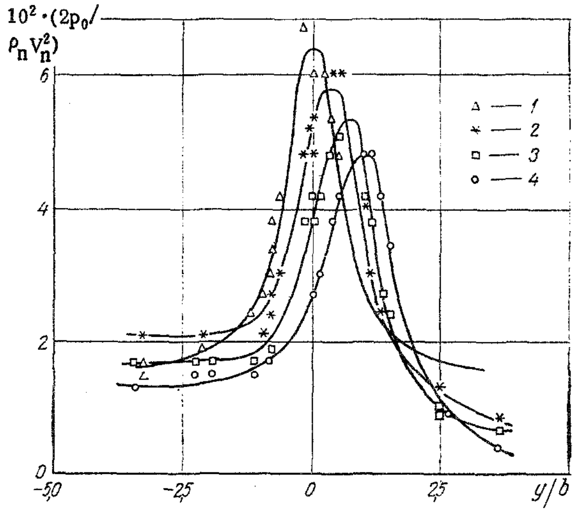

Fig. 3

Fig. 2. Dependence of intensity of boundary pressure pulsations at jet axis on the distance x/d with normal impingement: 1) $Re_n = 0.72 \cdot 10^5$; 2) $1.12 \cdot 10^5$; 3) $1.4 \cdot 10^5$; 4) $1.7 \cdot 10^5$; 5) $1.9 \cdot 10^5$; 6) $2.08 \cdot 10^5$; 7) Eq. (3).

Fig. 3. Effect of angle of impingement on the distribution of intensity of pressure pulsations over the surface ($Re_n = 1.12 \cdot 10^5$, $x/d = 33$); 1) 90°; 2) 60°; 3) 45°; 4) 30°.

corresponding range of Reynolds numbers Re_n is $0.7\text{-}2.1 \cdot 10^5$ and of Mach numbers M_n, 0.2-0.64. The distance x from the nozzle cut to the surface along the jet axis varied from 285 to 640 mm.

The signals sent from the detectors of pressure pulsations were received in the frequency range of 50-10,000 Hz and recorded with an SI-1 instrument. The instrumental measurement error was about ± 10%.

Special tests showed that under the experimental conditions the intensity of the acoustic radiation of the jet was considerably below (by 10^2-10^3 times) the level of the quantities being studied. In this case the noise level of the jet was estimated from measurements of an acoustical apparatus of the Brüell and Kjaer Co. with a 4133 microphone mounted near the jet a few centimeters from its boundary. To monitor the vibrational interference the sensitivity of the detectors to vibrations (on the order of $35\,\mu V \cdot sec^2/m$) was determined and the vibrations were determined at one to three points of the surface of the slab in the course of the tests. The measurements were made with a D-28 accelerometer, included in the outfit of the SI-1 instrument, mounted on the back side of the slab. The order of magnitude of the "vibrational signal" from a detector was estimated from the size of the vibrations. As a result, it was determined that the effect of vibrations on the measured signals is slight.

§ 3. The studies conducted made it possible to establish that with impingement of the jet normal to the surface the distribution of intensity of the boundary pulsations, normalized to the maximum pressure p_0, has an approximately universal dependence on the relative distance y/b along the working surface (Fig. 1), where b is the half-width of the equivalent free jet at a distance x from the nozzle cut, obtained by calculation from the equation [3]

$$b = 0.22x. \tag{1}$$

In this case the function $p/p_0\,(y/b)$ has a maximum in the stagnation region of the jet and is well described by the relation

$$\frac{p}{p_0} = 0.83\,\frac{\ln\left[1 + 6.4\left(\frac{y}{b}\right)^2\right]}{6.4\left(\frac{y}{b}\right)^2} + 0.17. \tag{2}$$

In the represented range of variation of the characteristic parameters the dependence between the intensity of pulsations in the pressure p_0 at the jet axis and the velocity head $\rho_n V_n^2/2$ at the nozzle cut is close to linear, and the quantity $2p_0/\rho_n V_n^2$ proves to be approximately inversely proportional to the distance from the nozzle cut (Fig. 2):

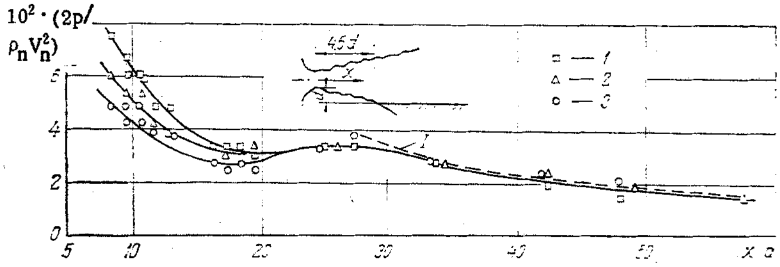

Fig. 4. Pulsations of boundary pressure in a semibounded jet: 1) $Re_n = 0.72 \cdot 10^5$; 2) $1.12 \cdot 10^5$; 3) $2.08 \cdot 10^5$; I) $p = 0.09 \cdot (\rho V_m^2/2)$

$$\frac{p_0}{\frac{\rho_n V_n^2}{2}} \approx 2.1 \frac{d}{x}. \tag{3}$$

A study of the effect of the angle of impingement on the distribution of pulsations over the surface (Fig. 3) showed that when the angle changes from 90° the intensity maximum of the pulsations moves along with the stagnation point of the stream while its magnitude decreases slightly.

In the case of a boundary jet (a diagram of the impingement and the results are presented in Fig. 4) the coefficient $2p/\rho_n V_n^2$ proves to be a universal function of x/d only for large enough values of the argument $x/d \geqslant 25$. In this flow it is natural to distinguish two sections of the jet with fundamentally different natures of the variation of the pulsations as a function of the distance to the nozzle cut. In the first section a rapid decrease in the level of the boundary pressures takes place first owing to the decrease in the intensity of free turbulence of the initial section of the jet. Simultaneously, turbulence is produced directly in the boundary shear. This leads to a certain increase in the overall level of pulsations in the region of x/d = 25–30. Then a second self-similar section of the jet begins in which the intensity of the pulsations comprises about 0.09 of the maximum local velocity head

$$p(x) = 0.09 \frac{\rho V_m^2}{2}, \tag{4}$$

where $V_m(x)$ is the maximum velocity of the boundary jet, calculated from [3].

In conclusion, it should be emphasized that in view of the close connection between the turbulent pressure pulsations and the velocity the data obtained can serve as a source of information on the structure of turbulent processes when a jet flows onto a surface.

NOTATION

p, root-mean-square value of pulsations in boundary pressure; d, width of nozzle exit cross section; V, velocity; Re, Reynolds number; M, Mach number; x, distance along jet axis from nozzle cut to surface; y, coordinate along surface; b, half-width of free jet at a distance x from nozzle; ρ, density. Indices: n, cross section at nozzle cut; 0, cross section at jet axis; m, maximum value.

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