give information on the distribution of pressure and shear stress on the surface of the body. However, it is better to have a physically reliable value of the drag coefficient of the body and to not know the pressure distribution on it than to have the pressure distribution but to know that it is conditional in character.

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REYNOLDS STRESS DISTRIBUTION DURING LONGITUDINAL FLOW AROUND A DIHEDRAL ANGLE

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Study of the structure of so-called complex turbulent flows that cannot be computed sufficiently accurately by methods of the classical theory of a thin shear layer continues to evoke great interest in hydro-aeromechanics. A typical example of shear flows of this kind is the three-dimensional flow along a line of intersection of two surfaces forming a dihedral angle. It is known that similar flows are encountered in different engineering applications, for instance, in the area of wing juncture with the fuselage or other flying vehicle elements, in turbines, and also in prismatic channels.

A whole series of theoretical and experimental researches is devoted to the study of the structure of turbulent flows in angular configurations, in particular, features of the development and interaction of boundary layers [1, 2], the extent of the spatial domain in the transverse direction [2, 3], the secondary flow structure [4], and the influence of different factors on the nature of these complex flows [3, 5]. However, complete information on not only the role of the average velocities but also on the distribution of all the Reynolds stress tensor components is necessary for a correct description of the fundamental physical phenomena in such flows. Similar information is also necessary for further perfection and development of the computation methods, and in particular, for the development of a model of turbulence.

A wide variety of techniques exists for measuring the Reynolds stress component by the hot wire sensor of a thermoanemometer [6]. Analysis of these methods in application to the flow in a dihedral angle shows that the measurement method by a thermoanemometer sensor with a single oblique filament rotating around the housing axis [7] has a number of irrefutable advantages. In particular, it does not require the introduction of any assumptions about the effective velocity in the modified King law, nor also preliminary information about the direction of the stream velocity vector and is released from the necessity to use multichannel apparatus.

Earlier the authors found approval for the mentioned method for the case when the axis of sensor rotation made a right angle with the free stream velocity vector. The maximal error of the Reynolds stress here is on the order of 25-30% of the upper measured value of the appropriate component. It turns out that the fundamental source of errors is due to conditions of aerodynamic sensor interaction with the stream.

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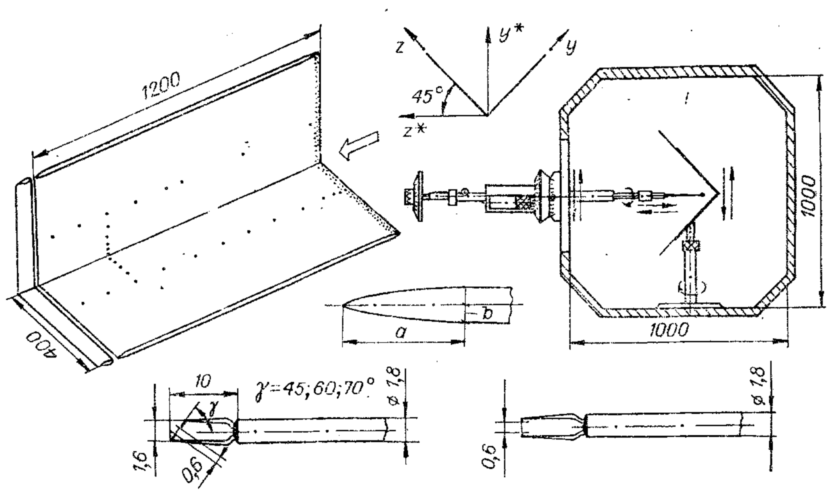

Fig. 1

The purpose of the present paper is to obtain refined data about the Reynolds stress distribution in a three-dimensional incompressible turbulent flow in a dihedral angle on the basis of a perfected experiment methodology.

The tests were conducted in the low-turbulence ITPM wind tunnel of the Siberian Branch of the USSR Academy of Sciences [8] at a 30 m/sec unperturbed stream velocity which corresponds to a Reynolds number of $Re_x = 1.8 \cdot 10^6$ (x = 910 mm) in the transverse section. A sketch of the dihedral angle model is represented in Fig. 1. The model of the angle consists of two plane ground faces mounted at a 90° angle. The nose and tail parts of the plate were fabricated in the shape of a semiellipse with a semi-axis ratio of $b:a = 1:12$ (b = 8 mm). Here, with the exception of the domain in the direct neighborhood of the leading edge, a gradient-free nature of the flow is realized on the model surface. A group of pressure detectors of 0.5 mm diameter was on each face of the angle. A completely developed turbulent boundary layer was achieved by using an artificial turbulizer, which was a strip of 0.8 mm thick emery paper glued along the span of the dihedral angle at a 10 mm distance from the leading edge.

A set of thermoanemometric apparatus 55M of the firm DISA was used to measure the boundary layer parameters and turbulence characteristics. A single-wire miniature thermoanemometer sensor with a Wollaston oblique wire [9] with 3 μm and 0.6 mm working section and length, respectively, was used as primary transducer. The angle γ between the filament and axis of the sensor here varied from 45° to 70°. A number of experiments was executed by a boundary layer type sensor with a normally arranged filament (Fig. 1).

The necessary initial information to determine the mean velocity vector and Reynolds stress components is obtained by rotating the thermoanemometer sensor with the single oblique wire around the housing axis in the stream point under investigation. Special attention is paid to the fact that the middle of the wire remained superposed with the center of rotation during rotation of the sensor. During the experiment the sensor housing could be oriented at an arbitrary angle to the stream velocity vector, which would permit determination of the rational sensor position in the stream to assure a reduced level of artificial perturbations during its streamlining. Depending on the discrete angle of sensor rotation α_m at the desired point in space at the end of the measuring procedure, dependences $\bar{E}(\alpha_m)$ and $\sqrt{\overline{e'^2}}(\alpha_m)$ are obtained, where $\bar{E}$ and $\sqrt{\overline{e'^2}}$ are the mean and rms voltage at the anemometer output. In the presence of appropriate data on the calibrations of the sensors being utilized [10], which had been executed in a sufficiently broad range of variation of the flow conditions, in principle this information is sufficient for determination of the mean stream velocity and Reynolds stress.

Figure 2 shows dimensionless profiles of the normal and tangential stresses (normalized relative to the velocity u_e on the outer boundary layer boundary) measured at the distance $z \approx 10\delta_2$ from the angular line where the nature of the flow is analogous to the flat plate case. The points 1-6 correspond to the Reynolds stress components $\sqrt{\overline{u'^2}}/u_e$, $\sqrt{\overline{v'^2}}/u_e$, $\sqrt{\overline{w'^2}}/u_e$, $\overline{u'v'}/u_e^2$, $\overline{u'w'}/u_e^2$, $\overline{v'w'}/u_e^2$. Presented for comparison is also the fluctuation profile (the darkened circles) which can be considered tests in a definite sense since it is measured by the sensor whose housing and current leads were oriented almost parallel to the stream, while the Wollaston wire was located along the normal to the velocity vector. Results of measurements executed by monotypical sensors in order to confirm reproducibility of the results are shown by points while the lines are averaged

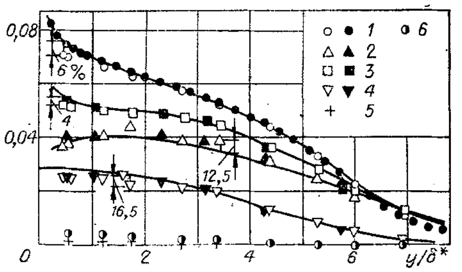

Fig. 2

Klebanoff data [11] for a fully developed boundary layer on a flat plate for $Re_x \approx 4.1 \cdot 10^6$. The good quantitative and qualitative agreement between the normal stress profiles being compared can be seen.

The maximal deviation of the measured values of the longitudinal velocity fluctuation component $\sqrt{\overline{u'^2}}/u_e$, due to the random spread of the experimental values $\sqrt{\overline{u'^2}}/u_e$, from the results obtained by a sensor with a normal filament as well as from data in [11] does not exceed 6%, and the components $\sqrt{\overline{v'^2}}/u_e$ and $\sqrt{\overline{w'^2}}/u_e$ have the maximal deviation 12.5 and 4%, respectively. Attention is turned to the reduced level of the component $\overline{u'v'}/u_e^2$ in the near-wall part of the boundary layer in consideration of the tangential stresses. The deviation of the experimental values of $\overline{u'v'}/u_e^2$ reaches 16.5%. Moreover, it is well known that the components $\overline{u'w'}/u_e^2$ and $\overline{v'w'}/u_e^2$ should be identically zero in the two-dimensional flow case. It is impossible to assert that they are exactly zero in this case but they are at least close to zero.

Therefore, judging by the result of measurements in the flow domain with well-studied properties, utilization of a perfected experimental procedure permits substantial diminution of the error in determining the majority of Reynolds stress components.

Typical distributions of different Reynolds stress components in the transverse section under investigation are shown in Fig. 3 in the form of equivalent lines of these quantities, where a–e correspond to $\left(\sqrt{\overline{u'^2}}/u_e\right)\cdot 10^2 = \text{const}$, $\left(\sqrt{\overline{v'^2}}/u_e\right)\cdot 10^2 = \text{const}$, $\left(\sqrt{\overline{w'^2}}/u_e\right)\cdot 10^2 = \text{const}$, $(\overline{u'v'}/u_e^2)\cdot 10^4 = \text{const}$, $(\overline{u'w'}/u_e^2)\cdot 10^4 = \text{const}$, $(\overline{v'w'}/u_e^2)\cdot 10^4 = \text{const}$. The values of the constants are shown at the lines. The distribution of the line $\sqrt{\overline{u'^2}}/u_e = \text{const}$ is obtained on the basis of measurements by a sensor with the normally disposed Wollaston wire, whose housing and current leads were oriented parallel to the stream while the distribution of the remaining lines is from a sensor with an oblique wire whose axis of rotation was at a 45° angle to the stream velocity vector.

The results of the experiments permit a number of characteristic properties and features of the turbulent flow structure to be noted in the cross section under investigation:

The contour of all the lines represented is distorted substantially by secondary flows which, as is known [1, 5], are developed in the form of vortex pairs in the three-dimensional corner flow domain. In other words, the turbulence field of such a flow is determined to a considerable extent by the magnitude and direction of the secondary flows being developed. However, the interrelation between the Reynolds stress and the secondary flows is probably more complicated, namely: the transverse gradients of these stresses induce secondary flows, and these latter, in turn, redistribute the Reynolds stresses in the transverse section of the corner;

a clearly defined asymptotic transition of the turbulence characteristic in the spatial domain of the corner to certain values characteristic for two-dimensional flow is observed analogously to the averaged flow parameters [3]. The extent of this transition domain in the z (or y) axis direction is a quantity on the order of 3-4 thicknesses of the two-dimensional layer;

there is nothing unusual in the fact that the distribution of the lines $\sqrt{\overline{u'^2}}/u_e = \text{const}$ and $\overline{v'w'}/u_e^2 = \text{const}$ is symmetric in nature relative to the bisectrix plane of the corner while the distribution of the remaining lines is substantially nonsymmetric. It is clear that the damping properties of the walls (the faces of the corner) are identical to the left and right relative to the component $\sqrt{\overline{u'^2}}/u_e$, consequently, the distribution of this component is symmetric in nature. On the other hand, it is also seen that the level of the component $\sqrt{\overline{w'^2}}$, say, on the face z of the corner is noticeably higher than for the component $\sqrt{\overline{v'^2}}$, and its distribution on this face within the limits of experiment error is the same in nature as the distribution of $\sqrt{\overline{v'^2}}$ on the face y of the corner.

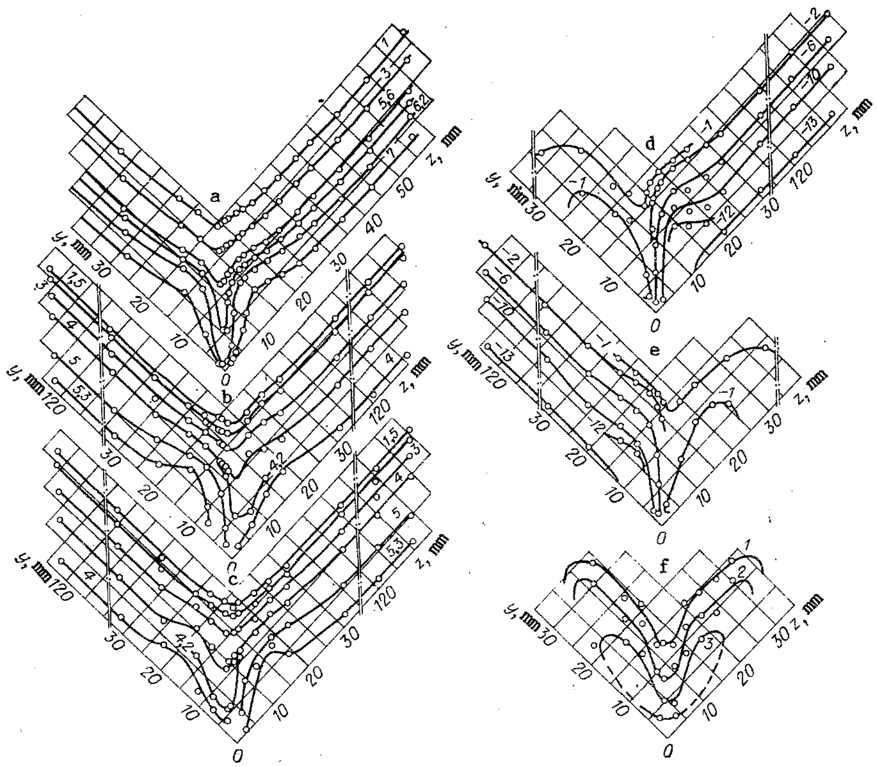

Fig. 3

An analogous feature is also inherent to the stresses $\overline{u'v'}$ and $\overline{u'w'}$ with the sole difference that during passage from the face z to the face y and back a more substantial change in these components is observed up to a probable change in sign in the near-wall flow domain. All this is explained by the different damping properties of the corner faces in the stress components mentioned;

it is clear from physical considerations that individual Reynolds stress components, $\overline{w'^2}$ and $\overline{u'v'}$, e.g., on the face z should equal the components $\overline{v'^2}$ and $\overline{u'w'}$ on the y face, respectively, at similar points. The results obtained show that this requirement is actually conserved with an error no worse than 5-7%. Moreover, from the simple condition of symmetry in the bissectrix plane of the corner the components $\overline{v'^2}$ and $\overline{w'^2}$, as well as $\overline{u'v'}$ and $\overline{u'w'}$ should be identical. Such a requirement is also conserved with an error no worse than 10%. All this is additional proof of the reliability and equal likelihood of the results obtained.

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EFFECTIVE DIFFUSION OF A DYNAMICALLY PASSIVE IMPURITY IN NARROW CHANNELS

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The diffusion equation is rarely solved successfully by analytical means when it contains a convective term in which the velocity components are complex functions of the space coordinates. In the case of diffusion in channels, the author of [1] proposed a method of reducing the basic equation to a simpler form containing an effective diffusion (dispersion) coefficient. This approach was later followed intensively (see [2-4], for example, where other approaches to the problem were also proposed). Here, we obtain a similar equation of effective diffusion in narrow channels under the condition that the stream function in the channel used to express the dispersion factor is known. Calculation of the stream function is an independent problem. We subsequently use the relations obtained to solve the problem of extracting a substance from narrow trenches (slits) when the channel has a boundary through which exchange of the substance with the main flow is possible.

As is known, the flow scheme of Lavrent'ev [5] agrees better with experimental results than does other models for the flow of a low-viscosity fluid in a trench. The flow model is based on the theorem [6, 7] of constancy of vorticity in closed regions. However, vorticity may not be constant when the viscosity coefficient μ is variable [8]. Assuming that the vorticity distribution was known, we obtained a general expression for the stream function in a narrow cavity bounded by the coordinate lines of an orthogonal coordinate system. As an example, we examined the case of extraction of a substance from a deep slit.

We propose an integral transformation which can be used to solve a certain range of problems of the dispersion of a substance in channels.

1. Derivation of Equation of Effective Diffusion and Initial Condition. We will assume that the length of the channel in the X_1 direction is much greater than the length in the X_2 direction. The boundaries of the channel are assumed to coincide with the coordinate lines of the plane X_1, X_2. We will limit ourselves to the two-dimensional problem. Let the stream function Ψ in the channel be known, and let its values at the boundaries of the channel be equal to zero. Then the components of the velocity of the fluid in the channel are determined by the formulas

$$v_1 = H_2^{-1}\partial\Psi/\partial X_2,\ v_2 = -H_1^{-1}\partial\Psi/\partial X_1, \tag{1.1}$$

where $H_{1,2}(X_1, X_2)$ are the Lamé constants. The equation of diffusion of the impurity in the channel has the form

$$\varepsilon^2 H_1 H_2 \frac{\partial c}{\partial t} + \varepsilon W(\psi, c) = \frac{\partial}{\partial x_2}\left(\frac{H_1}{H_2}\frac{\partial c}{\partial x_2}\right) + \varepsilon^2 n \frac{\partial}{\partial x_1}\left(\frac{H_2}{H_1}\frac{\partial c}{\partial x_1}\right),$$
$$W(\psi, c) = \frac{\partial\psi}{\partial x_2}\frac{\partial c}{\partial x_1} - \frac{\partial\psi}{\partial x_1}\frac{\partial c}{\partial x_2}, \tag{1.2}$$

while the dimensionless parameters and coordinates are connected to the dimensional parameters and coordinates by the relations

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