INTERMITTENCE AND STRUCTURE OF THE TRANSITIONAL BOUNDARY LAYER AT A PLATE USING A LASER ANEMOMETER

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The procedure for investigating the intermittence in a transitional boundary layer using a laser anemometer is described. The distribution of the coefficient of intermittence over the thickness of the boundary layer as a function of the velocity of the oncoming stream is presented.

The coefficient of intermittence γ is an important characteristic of the flow structure in a boundary layer. Usually γ is understood as the ratio of the time of existence of the turbulent regime to the entire time of occurrence of the process, $\gamma = T_t/T_0$. Various empirical theories are constructed with the help of γ which permit a quantitative description of the kinematic and dynamic aspect of phenomena taking place in the transitional region of a boundary layer from the instant of the appearance of turbulent patches [1, 2].

The experimental measurement of γ has been carried out in [3-5] and other reports. In [3] the measurements were made over the length of the plate at a constant distance from the surface, whereas distributions of γ over both x and y were obtained in [4]. To determine γ one usually uses the output signal of a thermoanemometer which is either recorded on the tape of a light-beam oscillograph with subsequent interpretation [3] or is fed to a special instrument [5].

To determine the coefficient γ from data obtained with a laser Doppler anemometer (LDA) we recorded the output signal, corresponding to the "instantaneous" velocity, on the tape of a light-beam oscillograph. Control recordings of laminar, transitional, and turbulent modes of flow were made preliminarily. For a fuller description of the phenomenon of intermittence, it evidently makes sense to introduce two coefficients γ^* and γ. We define the first of these (γ^*) as the ratio of the sum of the times of existence of turbulent and transitional modes to the total time of recording of the process, $(T_t + T_{tr})/T_0$, while γ is T_t/T_0, as usual. A similar procedure for analyzing oscillograms obtained from a thermoanemometer is described in [6], in which only the coefficient γ is analyzed. The measurements were made on a low-turbulence hydrodynamic stand described in detail in [7]. The working section of the stand is built in the form of a rectangular channel with a ratio of height to width and length of $y:z:x = 1:3:33$ (the length of the working section is $\sim$3 m). In the removable bottom there is a rectangular window along the entire width of the working section in which an insert is mounted flush with the outer surface. The insert is built in the form of a composite structure permitting different kinds of surfaces to be mounted on it. The side walls of the working section are made of high-grade glass, which permits the use of different optical research methods, particularly LDA.

The placement of the LDA units in the low-turbulence hydrodynamic stand is described in [8]. Their construction permits a transition from one test cross section to another, as well as movement of the measurement volume in the plane of the required cross section without readjusting the LDA. A system for discrete frequency determination, carried out on a two-level scheme of analysis with a unit for extracting the analog signal of "instantaneous" velocity, was used as the electronic apparatus. The coefficients γ and γ^* were measured over the thickness of the boundary layer in two cross sections of the working section: 1) at distances of 650 mm and 2) 2360 mm from its start at different velocities U_∞. Moreover, measurements with different z were made in a second cross section, on the insert.

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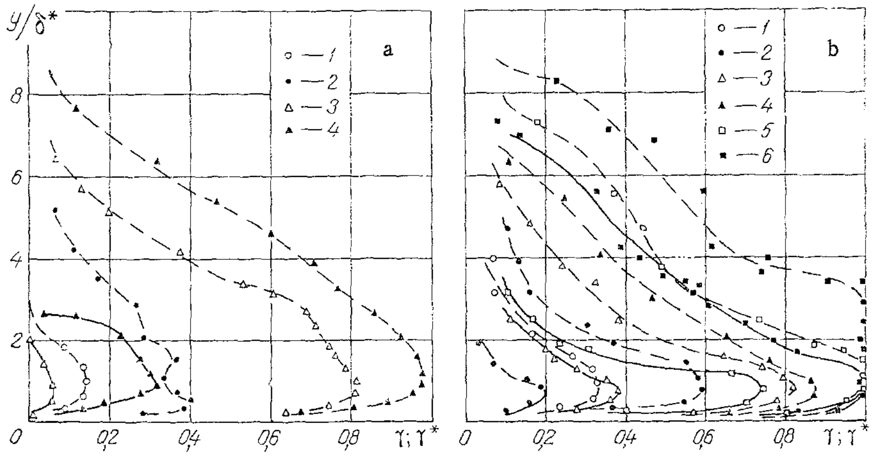

Fig. 1. Distribution of the coefficients γ^* and γ over the thickness of the boundary layer in the first (a) and second (b) cross sections: a) 1) $U_\infty = 0.1$ m/sec; 2) 0.24 m/sec; 3) 0.4 m/sec; 4) 0.6 m/sec; b) 1) $U_\infty = 0.13$ m/sec; 2) 0.15 m/sec; 3) 0.18 m/sec; 4) 0.21 m/sec; 5) 0.27 m/sec; 6) 0.6 m/sec. Solid line) γ; dashed line) γ^*.

The results obtained in the first cross section are presented in Fig. 1. It is seen from Fig. 1a that as the Reynolds number Re (the stream velocity U_∞) increases, the turbulization of the boundary layer grows. This appears first at $U_\infty = 0.18$ m/sec in a rather narrow zone of the boundary layer ($y/\delta^* \approx 0.4$–2.2) and consists in an increase in the coefficient γ^*, although γ still remains equal to zero.

The leading increase of γ^* in this zone is subsequently retained up to $\gamma^* = 1$, which is accompanied by an increase in γ^* over the entire thickness of the boundary layer. Starting with $U_\infty = 0.36$–0.4 m/sec, the coefficient γ in the same region of the boundary layer becomes different from zero and increases to $\gamma = 0.32$ at $U_\infty = 0.6$ m/sec. The region of the maximum coefficients γ^* and γ at low velocities ($U_\infty = 0.15$–0.3 m/sec) coincides with the region of maximum velocity pulsations, while they lie somewhat higher than the latter at higher velocities. The character of the distribution of γ and γ^* over the thickness of the boundary layer is similar to that obtained in [4]. In that report it was also shown that the maximum values of the coefficient of intermittence lie in the zone of the maximum velocity pulsations, which confirms the data presented in Fig. 1b.

The distribution of γ and γ^* over the thickness of the boundary layer in the second cross section at different velocities U_∞ is presented in Fig. 1b. From these functions it is seen that turbulization of the boundary layer proceeds somewhat faster in this cross section than at the start of the working section. For example, the continuous curve (3) in Fig. 1b corresponds to $Re = 0.4 \cdot 10^6$. The maximum value of $\gamma = 0.38$ is reached at $y/\delta^* \approx 0.75$. At the same Reynolds number $\gamma = 0.3$ at the start of the working section. The character of the increase in γ and γ^* with an increase in the Reynolds number remains the same as in Fig. 1a. This permits us to conclude that in the boundary layer at a plate the distributions of γ and γ^* have a clearly expressed maximum at $y/\delta^* \approx 0.4$–3.2, in the region of which the pulsation level is highest and the initial appearance of turbulent patches occurs.

The dependence of γ and γ^* on the Reynolds number, obtained at $y = 3$ mm in these two cross sections, is shown in Fig. 2. The results presented for cross section 1 were found for small values of x and Re in the region of the start of nonlinear deformations of plane disturbances in the boundary layer. As one would expect, only individual zones of turbulent pulsations appear in these stages of the generation of turbulence (see the dashed curve 2 in Fig. 2). The coefficient γ grows more smoothly than γ^* with an increase in the Reynolds number. This permits the conclusion that in this apparatus at $Re = (0.3$–$0.6) \cdot 10^6$ the first stages of the transitional process are more contracted in time, more transient, than subsequent stages, in which the direct generation and development of turbulent patches already occurs.

We also measured the coefficients γ and γ^* in the second cross section at two different values of $z = 10$ and 20 mm and two velocities $U_\infty = 0.18$ and 0.27 m/sec (Fig. 3). The results

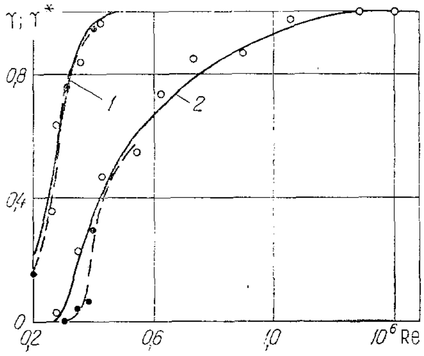

Fig. 2

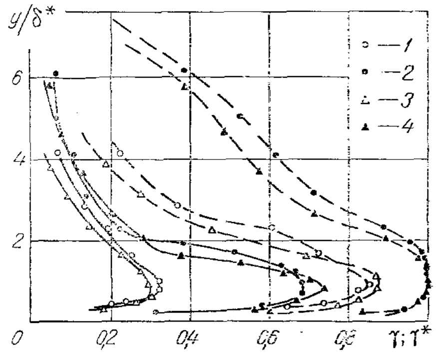

Fig. 3

Fig. 2. Dependence of γ^* (1) and γ (2) on the Reynolds number in cross section 1 (dashed line) and in cross section 2 (solid line).

Fig. 3. Variation of the distributions of the coefficients γ^* and γ over the thickness of the boundary layer for different z and U_∞ in the second cross section at a distance of 2360 mm from the start of the working section: 1) $U_\infty = 0.18$ m/sec, z = 10 mm; 2) 0.27 m/sec and 10 mm; 3) 0.18 m/sec and 20 mm; 4) 0.27 m/sec and 20 mm.

of the measurements confirm the presence of a transverse structure in the transitional boundary layer, although this phenomenon is less clearly traced than for pulsation functions. The character of the variation of γ and γ^* over the thickness of the boundary layer is analogous to the functions presented in Fig. 1b. At $U_\infty = 0.18$ m/sec small differences are observed in the zone of maximum values of γ^*, where this maximum is smaller at z = 10 and 20 mm than at z = 0. The values of γ at the same velocity were increased somewhat compared with z = 0. At $U_\infty = 0.27$ m/sec the maximum of the γ^* curve is considerably wider at z = 20 mm and still wider at z = 10 mm than at z = 0. The same thing can be said about the coefficient γ. From the results of these measurements we can conclude that a transverse structure exists in the boundary layer, connected with stable vortex formations, in the concluding stages of the transitional process. This conclusion is in agreement with [7], where such a transverse structure of a boundary layer was investigated using visualization methods.

The coefficient of intermittence, being an important characteristic of a boundary layer, supplements our concepts about the flow structure and transitional processes, so that the employment of laser Doppler velocity meters for its measurement can be considered as promising and challenging.

NOTATION

x, y, z, coordinate axes; t, time; T, duration of process; γ, γ^*, coefficients of intermittence; U, longitudinal component of averaged velocity; δ, thickness of boundary layer; δ^*, displacement thickness; Re, Reynolds number; U_∞, velocity of oncoming stream.

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THE "SLIP" COEFFICIENT IN TWO-PHASE LIQUID—GAS FLOWS

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We present experimental data on the variation of the "slip" coefficient in two-phase liquid—gas flows.

The simultaneous flow of gas and liquid phases in pipelines takes place with a relative velocity, and is characterized by a multiplicity of structural forms, depending on the flow-rate gas content in the mixture $\beta(0 < \beta < 1.0)$. The relative velocity is the difference between the velocities of the gas U'' and liquid U' phases averaged over the cross section of the channel. In general, the relative velocity can be positive ($U'' > U'$) or negative ($U'' < U'$). In the analysis of such flows, the "slip" is more conveniently characterized by the ratio U''/U' which is called the "slip" coefficient. For a positive "slip," $U''/U' = S > 1.0$, and for negative "slip" $S < 1.0$. In the absence of "slip," $S = 1.0$.

In addition to β, the main parameter is the true gas content of the mixture α, which is the average fraction of the cross section area occupied by the gas phase, $\alpha = F''/F'$. This relationship can be seen most clearly in the expression for the "slip" coefficient S, which can be written in the form

$$S = (1 - \alpha)/(\alpha/\beta - \alpha). \tag{1}$$

The ratio α/β in (1) contains the physical essence of the flow. The deviation of this ratio from unity to either side indicates a two-channel character of the flow. For example, the value $\alpha/\beta < 1.0$ shows that the gas phase is concentrated in the region of large velocities, in comparison with the liquid phase. The relationship between α/β and the quantities which determine the two-phase flow is therefore of a considerable interest.

Experimental investigations have made it possible to establish a direct relationship between the total drop in pressure in such flows ΔP_{2ph} and S, and they show that S depends both on β as well as on the physical properties of the transported media [1]. In particular, it was shown in [1] that a definite value of S corresponds to a definite value of ΔP_{2ph}, independendently of how the change of S occurs: In one case, the change of S is due to a

TABLE 1. The relationship between μ', the velocity characteristics of phases of the mixture, and the pressure drop ΔP_{2ph}

Transported media	Vol. flow-rate $\cdot 10^3$, m/sec		$\mu \cdot 10^3$ nsec/m^2	$\Delta P_{2ph} \cdot 10^6$ N/m^2	Velocities, m/sec				W_{cm}/U''	S
	Q'	Q''			U'	U''	v	W_{cm}		
Water–air	2,08	3,86	1,01	0,123	1,84	2,61	0,77	2,17	0,83	1,42
Oil–petroleum gas	2,11	3,75	32,10	0,177	1,55	2,70	1,17	1,89	0,70	1,76
Oil–air	2,11	3,75	47,91	0,213	1,49	2,80	1,31	1,87	0,667	1,88
Oil–air	2,11	3,86	69,16	0,237	1,47	2,86	1,39	1,85	0,646	1,95

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