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EXPERIMENTAL STUDY OF SPECTRA CORRESPONDING TO SOME TWO-POINT FOURTH-ORDER MOMENTS IN A DEVELOPED TURBULENT FLOW IN A TUBE

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In [1, 2] the results of hot-wire measurements of spectral distributions corresponding to second- and third-order moments were reported. This paper deals with spectral distributions related to some fourth-order moments for pulsatory velocities of a turbulent flow.

The measurements were taken in a developed turbulent flow in a straight tube of diameter $2R_0 = 0.06$ m. The Reynolds number Re calculated from the mean flow velocity and the tube diameter was equal to $3.47 \cdot 10^4$. The axial flow velocity was equal to 10 m/sec, the kinematic viscosity coefficient $\nu = 1.4 \cdot 10^{-5}$ m^2/sec, and the friction velocity $v_* = 0.433$ m/sec. The unit and experimental method employed were described in [1–5].

One of the goals of this study was to verify whether or not an approximate similarity principle existed in the energy range of wavenumbers. This principle would provide a sufficiently universal representation of spectral distributions divided by the magnitudes of corresponding one-point moments by using wavenumbers normalized on an integral correlation scale. As such a scale we chose an "isotropic" longitudinal integral scale Λ_0 calculated from the local values of the energy of fluctuations and the rate of energy dissipation (see [6]).

To evaluate the spectrum, the fast Fourier transform and the procedure described in [7] were used. The flow is described in more detail in [2].

Spectra $E_{xx,rr}(k)$ of differences between the two-point fourth-order moments and the corresponding products of the one-point second-order moments not increasing with the distance between the points have been measured, for example, $\langle u_{xx,rr}\rangle - \langle u_x^2\rangle\langle u_r^2\rangle$ [8, 9]. Velocity fluctuations are as follows: $u_x = u_1$, $u_r = u_2$, $u_\varphi = u_3$. The subscripts 1 and 2 in the spectra correspond to subscripts x and r respectively. Spectra of the moments, in which the two components of velocity fluctuations correspond to one point and the two components of velocity correspond to the other, have been considered. The distance between the points varied along the flow axis. The transition to wavenumbers was done according to Taylor's formula $k = 2\pi f/\langle V_x\rangle$, where $\langle V_x\rangle$ is the local mean value of the longitudinal flow velocity, and f is the frequency, the dependence on which is determined experimentally.

The correspondence of the spectra and moments is given in Table 1. The measured values of the one-point fourth-order moments divided by v_*^4 are shown in Table 2. The data for the second- and third-order moments were reported in [2].

The fourth-order moments have been calculated from the spectral distributions. The values of the one-point moments for the longitudinal velocity fluctuations measured with an x-shaped and a single-wire probes differ by around 6%. A comparison with the results reported in [10, 11] is shown in Table 3 for the excess coefficients $\delta_1 - 3 = \langle u_1^4\rangle/\langle u_1^2\rangle^2 - 3$, $\delta_2 - 3$ and $\delta_3 - 3$. For [10] the superscripts correspond to $\mathrm{Re} = 8 \cdot 10^4$, the subscripts to $4 \cdot 10^4$. The agreement is satisfactory.

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TABLE 1

$E_{11,11}$	$E_{12,12}$	$E_{12,11}$	$E_{11,22}$	$E_{22,22}$	$E_{12,22}$
$\langle u_x^4\rangle - \langle u_x^2\rangle^2$	$\langle u_x^2 u_r^2\rangle - \langle u_x u_r\rangle^2$	$\langle u_x^3 u_r\rangle - \langle u_x^2\rangle\langle u_x u_r\rangle$	$\langle u_x^2 u_r^2\rangle - \langle u_x^2\rangle\langle u_r^2\rangle$	$\langle u_r^4\rangle - \langle u_r^2\rangle^2$	$\langle u_x u_r^3\rangle - \langle u_r^2\rangle\langle u_x u_r\rangle$

TABLE 2

r'	$\langle u_x^4\rangle/v_*^4$	$\langle u_x^2 u_r^2\rangle/v_*^4$	$\langle u_x^3 u_r\rangle/v_*^4$	$\langle u_x u_r^3\rangle/v_*^4$	$\langle u_r^4\rangle/v_*^4$	$\langle u_\varphi^4\rangle/v_*^4$
0	1.46	0.377	−0.01	0	0.70	0.687
0.2	2.78	0.621	0.655	0.336	0.88	1.02
0.4	6.70	1.33	1.77	0.795	1.45	2.08
0.6	9.67	1.82	2.55	1.07	1.82	2.88
0.8	24.0	3.82	6.07	2.14	3.11	6.07

TABLE 3

r'	$\delta_1 - 3$			$\delta_2 - 3$		$\delta_3 - 3$
	This paper	[10]	[11]	This paper	[11]	This paper
0	0.41	0.43 / 0.55	0.60	0.54	0.82	0.50
0.2	0.42	0.40 / 0.48	0.46	0.46	0.68	0.46
0.4	0.12	0.08 / 0.20	0.16	0.30	0.52	0.28
0.6	−0.14	−0.17 / −0.07	−0.10	0.13	0.36	0.15
0.8	−0.26	−0.25 / −0.27	−0.18	0.14	0.29	0.10

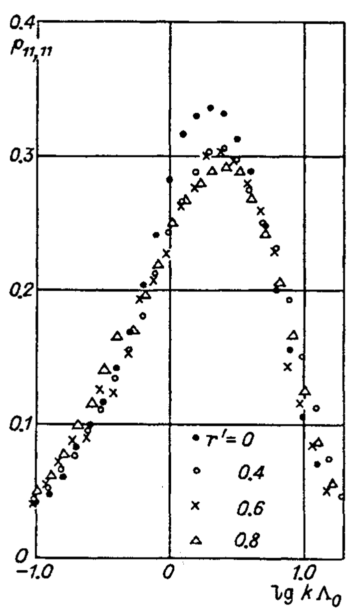

Fig. 1

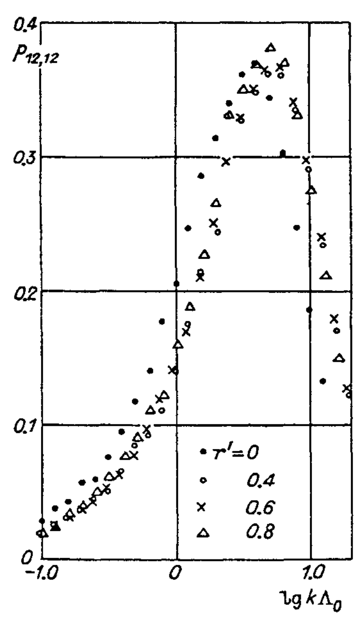

Fig. 2

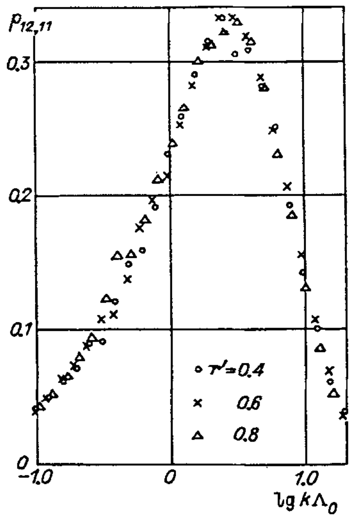

Fig. 3

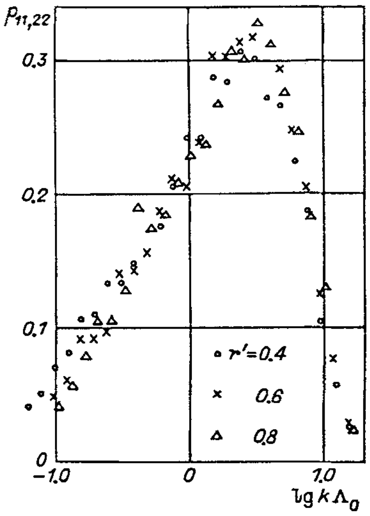

Fig. 4

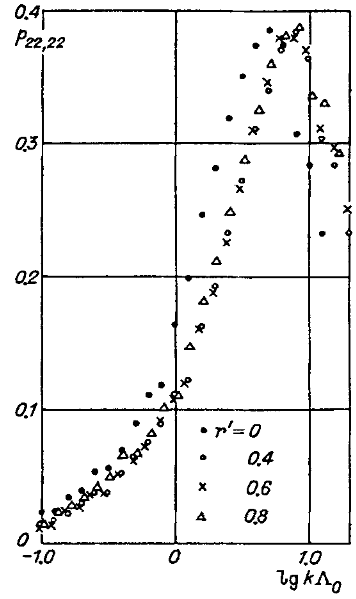

Fig. 5

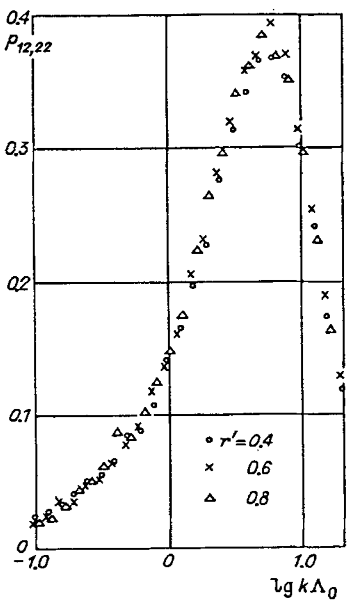

Fig. 6

Figures 1–6 present spectral distributions of the fourth-order moments in terms of normalized variables $p_{\alpha\alpha,\beta\beta} = kE_{\alpha\alpha,\beta\beta}(k)/\int E_{\alpha\alpha,\beta\beta}(k)\,dk$ and $k\Lambda_0$ (no summing over α or β). Here the values of the dimensionless radius are given: $r' = r/R_0 = 0$, 0.4, 0.6, 0.8.

The spectral distributions are concentrated around some universal dependence similar to the case of second- and third-order moments [2]. Distortions in the inhomogeneous flow close to the wall are small. This is probably due to the fact that the spectrum for a fourth-order moment is similar to the convolution of spectra for the second-order moments resulting in wiping out the distortions.

Data on the behavior of the spectra for fourth-order moments are essential for the refinement of the semiempirical theory of turbulent transfer. In particular, this would provide a means for tracing the relationship between the hypothesis that fourth-order cumulants are equal to zero, and the correlation moments of the fourth and second order.

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