TRANSFORMATION OF ACOUSTIC DISTORTIONS INTO COHERENT STRUCTURES IN THE TURBULENT WAKE BEHIND A PROFILE

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The article describes the experimental investigation of the effect of acoustic distortions on the mean and pulsating characteristics of flow in the turbulent wake behind a profile. It is demonstrated that acoustic vibrations are intensely transformed into vortex distortions of the flow.

In modern multistage turbines the structure of the turbulent flow between sets of blades is fairly complex but it is indispensable to know it so as to be able to describe correctly the processes occurring there, and to apply the knowledge in the design of new machines. The nature of this turbulent flow is determined, on the one hand, by the viscous flow around the surface of the blades, and on the other hand by the developing turbulence in the wake behind each blade. These wakes behind the blades are exposed to the effect of the turbulence forming the the wakes of the preceding sets of blades, and naturally, the nature of the turbulence of the incoming flow depends on the distance between the guide and rotor blades and on many other factors. At the same time in the flow region there is an acoustic field of high intensity which may exert a considerable influence on the structure of the turbulence as a whole under these conditions, as e.g. it was encountered in investigations of turbulent jet streams [1]. Naturally, if we want to understand the physical mechanisms describing the structure of the flow in installations of this kind, we have to isolate a certain factor and study its influence separately. In this connection the article [2] must be mentioned whose authors studied the behavior of the turbulent wake behind a body with different degrees of turbulence of the incoming stream and showed that turbulization increases the rate of flow equalization in the wake and the rate of spreading of the wake.

The present work also has the task of studying on a model example the effect of an acoustic field on the structure of the turbulent wake behind a profile with sharp rear edge.

The experiment was carried out in a subsonic wind tunnel MT-324 whose test section was 0.2 × 0.2 m in size; the speed of the incoming stream was $U_\infty = 16.5$ m/sec and the degree of turbulence was $u'/U_\infty \sim 0.3\%$. A diagram of the experiment is shown in Fig. 1. The model 1 was a body whose cross section was a symmetrical Zhukovskii profile with a chord 292 mm long and with a sharp rear edge.

To eliminate the laminar section of flow and to attain developed turbulent flow, a turbulizer 2 in the form of a rough patch was glued to the front part of the model. The model was mounted with angles of attack $\alpha = 0$ and $\alpha = 8.5°$. The acoustic distortions were produced by the dynamic loudspeaker 4 using a sound generator GZ-34. The investigations were carried out at the frequency f = 518 Hz of the acoustic distortions. The pulsation characteristics and the parameters of the mean flow in the wake were controlled by the sensor of the hot-wire anemometer 5. The signals were processed by a complex of the hot-wire anemometer apparatus DISA 55D00 and a frequency analyzer FAT-1. The acoustic noise level was checked by a standard noise meter PSI-202. The background noise intensity was equal to 95 dB. Phase measurements were carried out with a double-seam oscillograph and the use of an analyzer in filtering regime with a pass band $\Delta f = 4$ Hz. Synchronization was effected by a reference signal of the sound generator.

Figure 2 shows the profiles of mean speed at the near wake behind the model with angles of attack $\alpha = 0$ and $\alpha = 8.5°$ for two distances from the rear edge. It can be clearly seen that the flow in the wake is characterized by the existence of points of inflection in the

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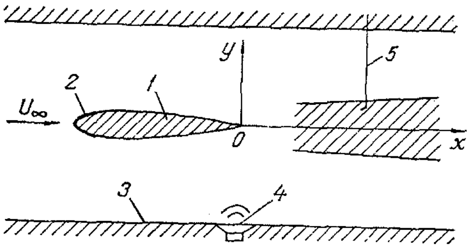

Fig. 1. Diagram of the experiment: 1) model; 2) turbulizer; 3) wall of the test section; 4) loudspeaker; 5) sensor of the hot-wire anemometer.

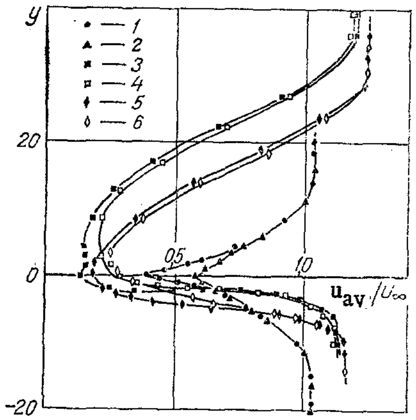

Fig. 2

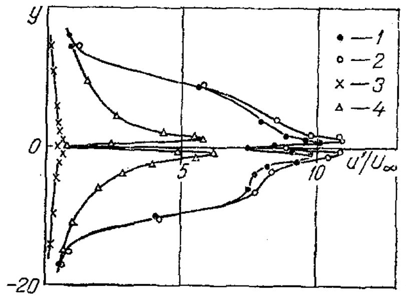

Fig. 3

Fig. 2. Profiles of mean speed in the wake. $\alpha = 0°$: 1) x = 5 mm; 2) 15 mm without acoustic effect; $\alpha = 8.5°$: 3, 4) x = 5 mm; 5, 6) x = 15 mm; dark dots: without acoustic effect, light dots: with acoustic effect. y, mm.

Fig. 3. Profiles of speed pulsations in the wake ($\alpha = 0°$, x = 5 mm): 1, 2) spectrum-integral pulsation intensity without and with acoustic effect; 3, 4) cut out in the 4 Hz band without and with acoustic effect. y, mm; u'/U_∞, %.

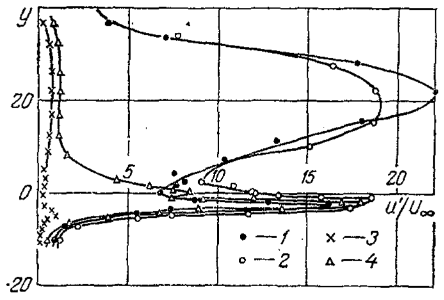

Fig. 4. Profiles of speed pulsations in the wake ($\alpha = 8.5°$, x = 5 mm): 1, 3) spectrum-integral intensity of pulsations and cut out in the 4-Hz band — without acoustic action; 2, 4) spectrum-integral intensity of pulsations and cut out in the 4-Hz band — with acoustic action; y, mm; u'/U_∞, %.

profiles of mean speed, and in addition, the mean flow with $\alpha = 8.5°$ is considerably asymmetrical. When an acoustic field with an intensity of 112 dB is applied, the mean speed is greatly affected when the angle of attack $\alpha = 8.5°$ whereas with a zero angle of attack this effect is negligible, and these points are therefore not shown in the graph so as to avoid overloading the figure.

When there is an acoustic field, the spectrum of the signal in the wake shows a characteristic peak at the frequency of acoustic excitation set by the generator. Phase measurements show that this signal is due to the apperance of a traveling wave in the investigated region, and this indicates the vortex nature of the distortion thereby created [3]. The phase velocity of these distortions for $\alpha = 0°$ was equal to ~ 0.8 and for $\alpha = 8.5°$ to ~ 0.6 of the speed of the incoming flow, i.e., it differed considerably from the speed of propagation of the sonic oscillations. Outside the turbulent wake, in the spectrum of the signal we also find a peak at this same excitation frequency because the sensor of the hot-wire anemometer also reacts to an acoustic field. However, beyond the wake the amplitude of this signal was small and comparable to the magnitude of the natural turbulent pulsations at that same frequency (in the 4 Hz band), and phase measurements showed that there is no dependence of the phase on the longitudinal coordinate, which testifies to the acoustic nature of these pulsations.

Figure 3 shows for one of the sections the results of measuring the longitudinal pulsation component of the speed u'_f/U_∞ cut out in the band $\Delta f = 4$ Hz, without acoustic effect and with acoustic effect for $\alpha = 0°$. For the sake of comparison the same figure shows the distribution of the spectrum-integral longitudinal component of the speed pulsations u'/U_∞. It can be seen that there is qualitative coincidence between the distribution of the amplitude of the integral intensity along the transverse coordinate y and the structure originating under the effect of the sound field. At the same time the position of the maxima of these distortions coincides approximately with the points of inflection in the profiles of the mean speed (see Fig. 2).

Phase measurements along the transverse coordinate for the zero angle of attack showed that the vortex distortion is practically antisymmetric, in other words, the vortices form alternately from the upper and the lower side of the wake.

The asymmetry of the mean flow in the wake with an angle of attack $\alpha = 8.5°$ led to considerable asymmetry in the distribution of the integral pulsations (Fig. 4). The distribution of the intensity of the originating vortex structure is also asymmetrical, and the maximum values are encountered on the lower side of the profile; this is apparently due to the fact that the greatest nonuniformity of the flow in the wake is found in particular in this region.

For the wake with zero angle of attack of the model, measurements were also carried out on a smooth model with a degree of turbulence of the incoming flow of $\sim 3.0\%$. In this case, and with no rough patch, the flow around the model is turbulent, and the distribution of the mean speed in the turbulent wake coincides qualitatively with the distribution for the wake behind a model with a rough patch. When an acoustic field is applied, the same vortex structure forms in the wake as in the above-described case.

Since these vortex structures are long-lived regular formations (against the background of small-scale turbulence) whose characteristic scales are comparable with the transverse dimensions of the shear layer, we are perfectly justified in calling them coherent structures (see [4]).

Our investigations show that in the turbulent wake behind a body with a sharp rear edge the acoustic oscillations are transformed into coherent distortions which, with sufficient intensity of the sound, may effect, on the one hand, the integral characteristics of the flow, and on the other hand they may lead to a substantial change of heat and mass transfer in the given flow. This influence has to be taken into account in the examination of processes occurring in real turbines.

NOTATION

U_∞, speed of the flow against the model; u', spectrum-integral intensity of the longitudinal component of the speed pulsations; α, angle of attack; f, frequency; Δf, passband of the analyzer; u'_f, cut out intensity of the longitudinal component of the speed pulsations in the 4-Hz band; y, transverse coordinate in the wake; x, longitudinal coordinate in the wake; u_{av}, local mean speed.

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CERTAIN FEATURES OF COHERENT FLOW STRUCTURE DEVELOPMENT IN THE INITIAL SECTION OF THREE-DIMENSIONAL TURBULENT JETS

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Results of an experimental investigation of regular, large-scale, vortex structures in three-dimensional submerged jets are elucidated.

Regularities in the propagation of three-dimensional turbulent submerged jets issuing from nozzles with rectangular output section have attracted the attention of many researchers in recent years. A number of distinctive features inherent to flows of this kind have been revealed as a result of detailed experiments they performed [1-4].

Firstly, it has been shown that three characteristic axial velocity attentuation domains are clearly traced in such jets: an initial section, or a domain of constant axial velocity ($u_c \sim \text{const}$), a transition section where the attenuation law for the axial velocity of plane jets ($u_c^2 \sim x^{-1}$) is valid for sufficiently large aspect ratios of the nozzle output section, and an axisymmetric flow section ($u_c^2 \sim x^{-2}$) far from the nozzle.

Moreover, it has been detected that propagation of a three-dimensional submerged jet is accompanied by unique deformations of its cross section, similar to that also inherent to three-dimensional wakes [5]. A result of this deformation is the "inversion" of the major and minor transverse axes of the jet.

This feature of three-dimensional jet development is associated with the nonuniformity of its expansion in two mutually perpendicular planes of symmetry, which is especially noticeable in the initial and transition flow sections. For larger aspect ratios of the nozzle output section, as well as for jet escape from a slot with sharp edges, even jet contraction in the direction of the major transverse flow axis (along the span of the orifice) is observed in these flow domains. Upon radical contraction of the jet along the major transverse axis, the corresponding mean velocity profiles take on a "saddle" shape.

These features of three-dimensional turbulent jet development are visibly due to large-scale periodic structures that are formed in mixing layers near the nozzle. The transverse flows induced by this ordered system of closed vortex formations are indeed the reason for the observed three-dimensional jet deformations [1, 6, 7].

The large-scale ordered vortex formations inherent to turbulent shear flows are investigated in detail in plane and axisymmetric jets [8], which are substantially the limit cases for a three-dimensional jet. However, the coherent structure of three-dimensional jets when the regularities of their development are determined by spatial effects to a significant extent has not been investigated in practice.

The fundamental parameters of a coherent structure in the initial section of three-dimensional turbulent jets formed under different initial escape conditions are experimentally

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