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SPECTRAL CHARACTERISTICS OF THE PULSATION EFFECT OF A PLANE TURBULENT JET ON A SOLID SURFACE

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INTRODUCTION

Turbulent processes in jets interacting with solid surfaces attract the attention of many researchers at this time [1-4]. Fundamental difficulties in both computational and experimental investigations hence arise in studying turbulence in the most important flow domain directly at the surface. Information about pressure fluctuations at the surface is an additional source of knowledge about the structure of turbulence in this domain. Moreover, data about turbulent near-wall pressures also have a direct applied value, related mainly to problems of computing the vibrations of structure elements [5].

§1. The present experiment was conducted with plane air jets issuing from a slot nozzle of width $d=15$ mm (length 350 mm) at velocities of 75-220 m/sec. The Reynolds numbers hence varied in the range $0.7\cdot10^5$-$2.1\cdot10^5$, and the Mach number, in the range 0.2-0.64. The jet impinged on the flat surface of a massive turntable at distances of 360-640 mm from the nozzle exit. Modules with piezoelectric pressure fluctuation converters, similar to those described in [6], were mounted flush with the working surface of the slab. Spectral analysis of the signals from the converters was accomplished by an SI-1 spectrometer in three-octave frequency bands in the 50-10,000-Hz range. Transducers with a 1.3-mm-diameter detection surface had a practically constant response of about 4μV/Pa with respect to the frequency in this range. In order to check the vibration interference, the vibration response of the transducers was determined and the slab vibrations were measured during the tests.

§2. It was clarified in an analysis of the measurement results that the governing parameters of the fluctuating effect of the jet on the surface perpendicular to the jet at a distance x from the nozzle exit are the mean characteristics (the density ρ, the axial velocity v, and the width 2b) of the equivalent free jet at a distance x. This agrees with the information that the zone of interaction in the case under consideration extends a distance on the order of the nozzle width along the normal to the surface [7, 8]. Therefore, the flow in this domain should be determined by the free jet characteristics at a distance on the order of $x-d$ or, for $x \gg d$, at a distance x from the nozzle exit. It is seen from Fig. 1 that the values of the spectral density of the pressure fluctuations $\Phi/\rho^2 v^3 b$, reduced to dimensionless form, are functions of the reduced frequency $\omega b/v$ and the relative removal y/b from the jet axis in the whole range of velocities and distances x investigated. Three cases with different values of y/b are presented here: a) 0; b) 0.73; c) 2.7. The numbers correspond to the following values of v_0 in m/sec and x/d: 1) 75, 24; 2) 75, 33; 3) 75, 43; 4) 117, 24; 5) 117, 33; 6) 117, 43; 7) 218, 24; 8) 218, 33; 9) 218, 43.

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The values of v and b were hence determined by means of the usual relations [9]

$$v/v_0 = 2.7\sqrt{d/x};\ b = 0.22x,$$

where v_0 is the escape velocity from the nozzle.

The most intensive fluctuations are observed at the stagnation point on the jet axis where their common level

$$\sqrt{\langle p^2 \rangle} = \sqrt{\int \Phi d\omega}$$

is approximately $0.15\rho v^2/2$. In this case the spectral density in the frequency band $0.2 < \omega b/v < 2$ varies slightly, and then decreases, where the law of the decrease is almost a power law in a significant section: $\Phi \sim \omega^{-2.5}$. The change in the spectral density function upon removal to a distance $y \approx b$ from the jet axis is characterized by a noticeable diminution in the values at the low frequencies and by a decrease at mainly the high frequencies when y is increased further, with a gradual formation of a self-similar spectrum of the semiinfinite jet considered below (see Fig. 1, curve c).

The maximum fluctuation intensity shifts together with the stagnation point when the angle of jet impingement is changed. The shape of the spectrum at the stagnation point hence remains practically unchanged (Fig. 2, where values of the spectral density at the stagnation point are presented for v_0 =117 m/sec, x/d =33 at different angles of impingement: 1 – 90; 2 – 60, 3 – 45; 4 – 30°).

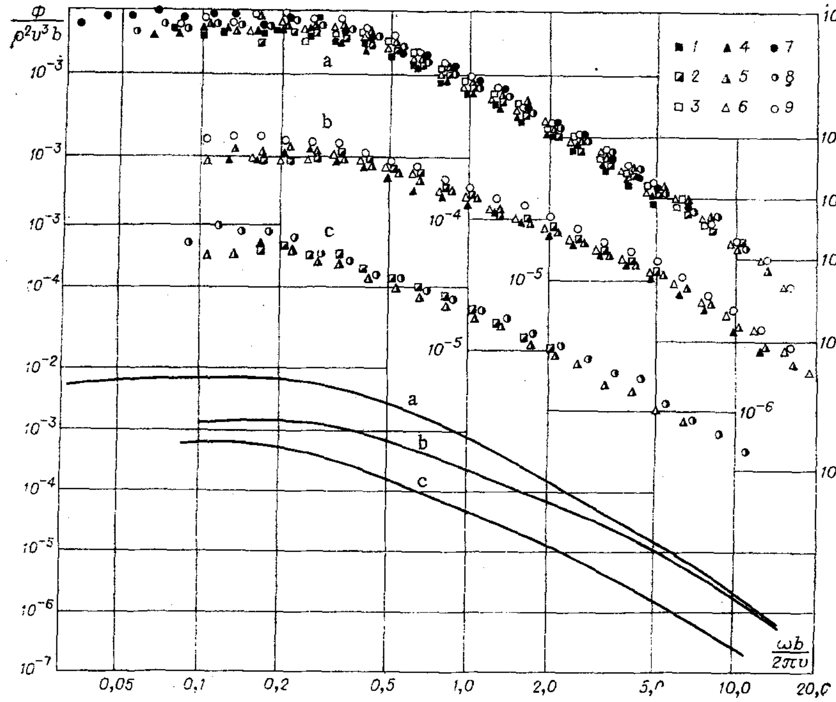

Fig. 1

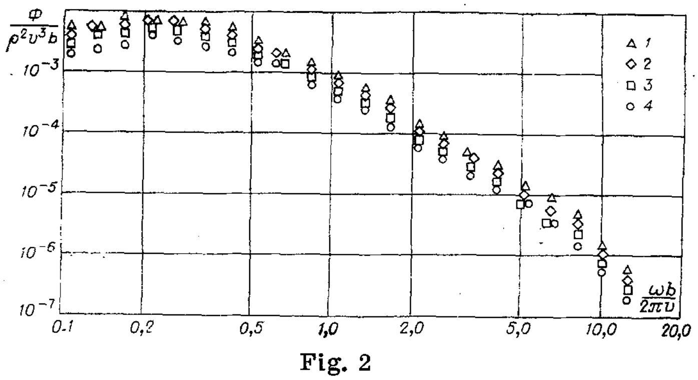

Fig. 2

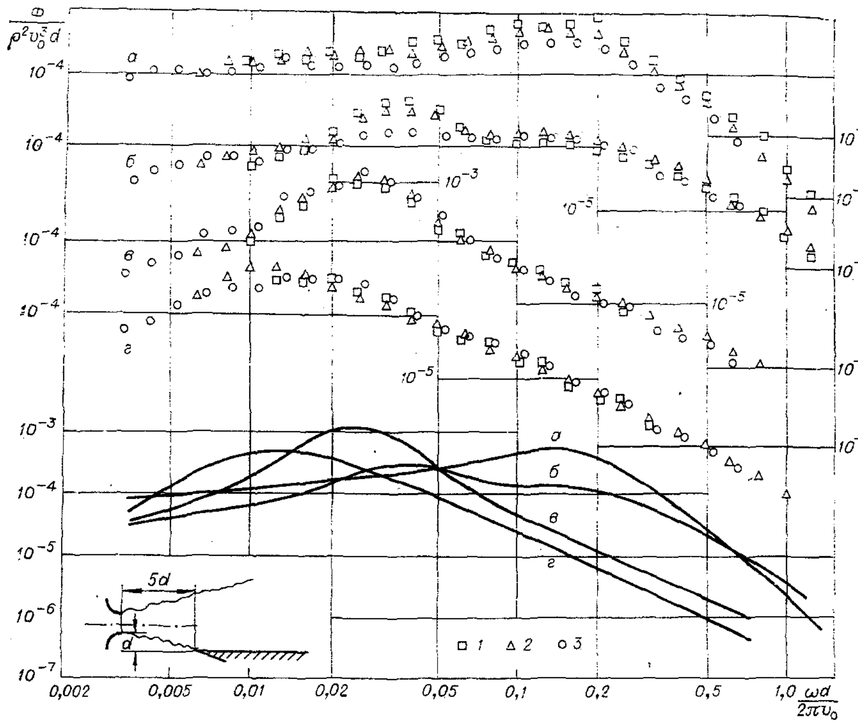

Fig. 3

§3. The experimental apparatus was also used to investigate near-wall pressure fluctuations in semi-infinite jets. The jet escaped parallel to the working surface which was at a distance 1.5d below the axial plane of the nozzle, and the leading edge of the turntable was at a distance 5d from the nozzle exit. As Fig. 3 shows, in this case the character of the dimensionless spectral density function $\Phi/\rho^2 v_0^3 d$ of the reduced frequency $\omega d/v_0$ is determined approximately by the relative distance x/d from the nozzle exit, where the accuracy of the approximation rises with the increase in x/d. Four cases with different values of x/d are presented here: a) 8.4; b) 13; c) 27; d) 42, with three values of the velocity v_0 in each: 1) 75; 2) 117; 3) 218 m/sec.

Curves of the spectral density in the near-wall jet undergo significant changes as the distance from the nozzle increases. For small values of $x/d \leqslant 10$ the spectrum is characterized by elevated values at the high frequencies which are probably associated with the intensive free turbulence of the initial section of the jet. Furthermore, the fluctuation level in this frequency range diminishes with the simultaneous formation of a new maximum generated directly by the near-wall turbulence. Starting with the values x/d = 25-30, the change in the spectrum is almost self-similar in nature and is due just to the diminution in the characteristic velocity and the intensity of the stream turbulence. Here the spectral density functions in the domain of decrease with respect to the frequency are described well by the power law $\Phi \sim \omega^{-2}$.

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