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## Abstract

## Full Text

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*HYDROMECHANICS*

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# MEASUREMENT OF THE TURBULENCE OF GAS FLOWS BY AN OPTICAL METHOD

*(Presented by Academician S. A. Khristianovich on 21 VII 1967)*

In [1] an optical method was described for measuring velocity pulsations in plasma jets, using correlation analysis of signals from two points of the flow. In the present work this method is used to investigate the intensity and frequency spectrum of the longitudinal component of the turbulence of a cold-gas flow.

The arrangement of the apparatus is shown in Fig. 1. A stationary air flow issuing from a profiled nozzle 1 of diameter 25 mm with a turbulizing grid 2, made in the form of a perforated plate

**Fig. 1. Schematic of the apparatus**

with holes of diameter 3.2 mm, was placed in the field of view of a schlieren system.

For the purpose of optically marking the gas in a specified cross section of the flow, a thin heated wire 3 (diameter 0.1 mm) was placed in this cross section upstream of the region under investigation. Owing to the small diameter of wire 3 and its considerable distance from the region under investigation, the gas-dynamic disturbances introduced by it into the flow are small.

The schlieren image of the plume spreading from the heated wire is projected onto a screen 4 having two apertures that select

Fig. 3. Estimate of the cross-correlation function

Figure 3: Fig. 3. Estimate of the cross-correlation function

**Fig. 2. Oscillogram of the signals at the outputs of the photomultipliers**

two points with a distance between them $L = 2.9$ mm. The apertures are connected by light guides to photomultipliers 5 and 6. The signals were recorded by means of an MPO-2 loop oscillograph on vibrators with a natural oscillation frequency of 5 kHz. Recording with a loop oscillograph proved possible because of the low flow velocity and, correspondingly, the low frequency of the turbulent pulsations.

Thus, the passage past the apertures in diaphragm 4 of images of turbulent vortices in the cross section under investigation, made visible as a re-

as a result of optical alignment, cause signals to appear in photomultipliers 5 and 6.

A typical example of an oscillogram of the signals is shown in Fig. 2. The time-marker value is 1 $\mu$sec. It is clear from the oscillogram that the signals from the two points have a similar character and are shifted in time.

The mathematical processing of the obtained signals was carried out with the aid of a digital computer. Fig. 3 gives an estimate of the normalized cross-correlation function $r_{xy}(\tau)$ of the signals from two points of the flow, which was found from formula (1) (2):

$$r_{xy}(\tau) = K_{xy}(\tau)/\sqrt{K_{xx}(0)K_{yy}(0)}, \quad (1)$$

where

$$K_{xy}(\tau) = \frac{1}{T-\tau}\int_0^{T-\tau}[x(t) - m_x][y(t+\tau) - m_y]\,dt,$$

$$K_{xx}(0) = \frac{1}{T}\int_0^{T}[x(t) - m_x]^2\,dt;$$

$K_{xy}(\tau)$ is the cross-correlation function; $K_{xx}(0)$ and $K_{yy}(0)$ are the variances of the random processes $x(t)$ and $y(t)$.

As can be seen from Fig. 3, the cross-correlation function has a sharply pronounced maximum at $\tau = 1.0$ $\mu$sec, which corresponds to an average flow velocity of 2.9 m/sec.

**Fig. 3. Estimate of the cross-correlation function**

Fig. 4. Frequency spectrum

Figure 4: Fig. 4. Frequency spectrum

To determine the velocity pulsations, the spectrum of the cross-correlation function is found. In contrast to the spectrum obtained in [1], in the present case the spectrum is the result of frequency modulation of one random process by another random process (Fig. 4). As can be seen from this graph, the carrier frequency $f_0$, corresponding to the most probable frequency of optical fluctuations, is in this case equal to 3550 Hz. The spectrum carries information both about the amplitudes of the turbulent velocity pulsations and about their frequencies; moreover, the root-mean-square velocity pulsation is deter–

**Fig. 4. Frequency spectrum**

is the effective deviation $\Delta f$:

$$\sqrt{\overline{u'^2}}/\overline{U} = \Delta f / f_0,$$

where $\sqrt{\overline{u'^2}}$ is the root-mean-square fluctuation of the velocity; $\overline{U}$ is the mean flow velocity.

The quantity $\Delta f$ can be calculated from the formula

$$\Delta f = \int_{-\infty}^{\infty} (f - f_0)^2 S(f)\, df \Big/ \int_{-\infty}^{\infty} S(f)\, df, \tag{2}$$

if one assumes that the spectral-density function $S(f)$ follows the probability-density distribution law over frequencies. In the case presented, $\Delta f \approx 200$ Hz, which corresponds to a degree of flow turbulence $\varepsilon \approx 6\%$. This latter value, as well as the value of the mean velocity, agrees with measurements carried out with a constant-temperature hot-wire anemometer within the accuracy of the experiment.

The effective modulation frequency $f_m$ is determined by the most probable frequency of the velocity fluctuations (in our case, 1100 Hz). This value is close to that expected, since the diameter of the cells of the turbulence grid in our case was 3.2 mm.

Although the possibilities for applying this method of flow seeding are limited, the experimental results indicate the promise of using correlation processing of optical signals from two nearby points to obtain turbulence characteristics independently of the method of seeding the flow.

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*Note: Figure translations are in progress. See original paper for figures.*