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CORRELATION SPECTROSCOPY METHODS FOR STUDY OF VELOCITY PROFILES IN THIN FLOWS

V. V. Blazhenkov, V. V. Vlasenko,
F. M. Pen'kov, and S. I. Shcheglov

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The study of velocity profiles of laminar and turbulent flows by correlation spectroscopy methods has demonstrated the broad possibilities of that approach [1-3], both as regards the accuracy of resolution over coordinates (of the order of hundreds of μm) and with respect to the time required to gather data and the range of velocities studiable (from μm/sec to hundreds of m/sec).

The recent development of new processes based on use of materials in the monodispersed phase [4] has stimulated study of the mechanism underlying forced capillary decay of liquid jets — a phenomenon upon which creation of monodispersed microparticles is based, i.e., particles having small scattering of parameters and dimensions in the range 10-1000 μm [5].

In studying monodispersed decay of a jet, questions arise regarding relaxation of the velocity field and increase in perturbation within the flow. To study these effects we will use correlation spectroscopy methods. The experimental technique is then quite simple, consisting of measurement of the correlation function (CF) of coherent light scattered on the flow (for example, helium laser light).

The goal of the present study is to briefly analyze the possibilities of correlation spectroscopy for the study of velocity distribution profiles in thin jets.

The correlation function of the scattered light is defined by the expression [1]

$$G^{(1)}(\tau) = \langle \varepsilon^*(0)\varepsilon(\tau)\rangle,$$

where $\varepsilon(\tau)$ is the electric field intensity at time τ, and the angular brackets denote averaging over the ensemble or over time. In our case the scattered light has Gaussian statistics*, i.e., the Siegert relationship

$$g^{(2)} = 1 + |g^{(1)}|^2.$$

*In principle the effects of non-Gaussianness of the scattered light can produce additional information on nonsteady-state flows.

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is valid. Here $g^{(1)}$ and $g^{(2)}$ are normalized first and second order correlation functions. For the ensemble of scattered particles

$$g^{(1)} = e^{-i\omega_0 \tau} \langle e^{i\mathbf{qv}\tau} \rangle_s$$

where v is the velocity of the scatterer, q is the scattering vector, equal to the difference between the vectors K_i and K_s of the incident and scattered radiation, and ω_0 is the circular frequency of the initial beam. The correlation function of the light scattered on the flow has the form

$$g^{(1)} = e^{-i\omega_0 \tau} \int \int e^{i\mathbf{qv}\tau} P(\mathbf{r}, \mathbf{v})\, d^3r d^3v \tag{1}$$

[where P(r, v) is a function of the scatterer distribution over coordinates and velocities]. In the case of equiprobable scatterer source distribution over volume P(r, v) can be written as

$$P(\mathbf{r}, \mathbf{v}) = \frac{1}{V} \delta(\mathbf{v} - \mathbf{v}(\mathbf{r})) \tag{2}$$

(where V is the volume of the scattering region). Substituting Eq. (2) in Eq. (1), we obtain

$$g^{(1)} = \frac{1}{V} e^{-i\omega_0 \tau} \int_V e^{i\mathbf{qv}(\mathbf{r})\tau} d^3r. \tag{3}$$

To study velocity profiles in the regions of interest to us, two experimental configurations are possible. In the first case we locate the scattering vector q parallel to the flow and use a low observation angle (which is reasonable at high velocities) in the plane of stream exhaust. Directing the z-coordinate of a cylindrical coordinate system (z, ρ, φ) along the direction of the flow and considering that for real flows the change in velocity along z in the region surveyed is insignificant, we rewrite Eq. (3) in the form

$$g^{(1)} = \frac{2}{R^2} e^{-i\omega_0 \tau} \int_0^R e^{iq_z v_z(\rho)\tau} \rho\, d\rho$$

(where R is the radius of the flow). Using the Wiener–Hinchin relationship we can make use of Eq. (3) to determine the spectral density of the signal power and then find the characteristics of the velocity profile $v_z(\rho)$ from the frequency dependence. Such an analysis is beyond the scope of the present study, therefore we will rely on a model velocity profile

$$v_z(\rho) = v_0(1 - \alpha x^2).$$

Here $x = \rho/R$; v_0 is the velocity of the center of the flow, α is a parameter which varies from 0 (velocity constant over section) to 1 (for a laminar velocity profile in a capillary). Then

$$g^{(1)} = \frac{2 \sin\left\{\frac{q_z v_0 \alpha \tau}{2}\right\} e^{i\tau q_z v_0 \left(1 - \frac{\alpha}{2}\right) - i\omega_0 \tau}}{q_z v_0 \alpha \tau}. \tag{4}$$

We will consider two experimental situations – natural beating of the scattered light intensity and optical heterodyning. In the first case we observe $|g^{(1)}|$. Therefore, at $\alpha = 0$ there is no additional information except the fact that the velocity is equal over the section. For $\alpha \neq 0$ it is simple to find the velocity of the stream boundary $qv_0(1 - \alpha)$. In the heterodyning regime from experiment we have Re $(e^{i\omega_0 \tau_0} g^{(1)})$, i.e., the sum of two harmonics, one at the frequency qv_0, the second at $qv_0(1 - \alpha)$, which permits determination of the velocity of both the center of the blow and its boundary.

To determine velocities perpendicular to the flow it is convenient to observe light scattering in the plane perpendicular to the flow. For this case from Eq. (2) we have

$$g^{(1)} \sim e^{-i\omega_0 \tau} \int_0^R J_0(q_\rho v_\rho(\rho) \tau) \rho\, d\rho$$

(where J_0 is a zeroeth order Bessel function). Since $e^{i\omega_0 \tau} g^{(1)}$ is a real function, the intensity fluctuation and optical heterodyning methods produce identical information.

Thus, by using various experimental configurations parameters of velocity distributions parallel or normal to the flow axis may be analyzed. It follows from analysis of Eqs. (3), (4) that the velocities of the flow core and edge can differ, with it being better to perform observations by the optical heterodyning method.

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EFFECT OF PULSE LENGTH ON EFFICIENCY OF CO_2 LASER INTERACTION WITH A TARGET IN AIR

A. M. Orishich, A. G. Ponomarenko, and V. G. Posukh

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In the majority of experiments of action of radiation at a wavelength $\lambda = 10.6\ \mu$ on solid targets in air, lasers with a particular pulse output form have been used — namely a powerful leading peak 0.1 μsec in duration followed by a less intense but longer (~1.0 μsec) quasisteady state radiation mode [1, 2].

This study will offer the first detailed investigation of the effect of pulse form and duration $\tau_r \simeq 10^{-7}$-10^{-6} sec upon intensity of gas-dynamic perturbations and the amount of momentum transferred to the target.

The basic energy parameters of the plasma layer and shock wave were defined by the method of [3], based on measurement of characteristics of the shock wave which develops in the cold gas around the target.

The radiation source used was an "LUI-2" high power CO_2 amplifier system with energy of ~1 kJ [4]. Using a wedge-shaped plate 250 mm in diameter made of NaCl, which served as the amplifier output window, multiple reflections from the plate surfaces caused a portion of the radiation to be directed by a spherical mirror and separator plate from a KRS-5 unit to sensors for recording of the pulse energy and form, consisting of a TPI-2-5 impulse calorimeter and a germanium detector [5] with time resolution of ~1 nsec.

Typical oscillograms corresponding to various regimes of amplifier operation are shown in Fig. 1. Pulse 1 is close to a typical CO_2 laser pulse. Pulses 2 and 3 have an identical bell-shaped form and durations differing by a factor of ~10.

The experiments were performed in air at a pressure of 10^5 Pa. The fundamental beam was compressed by a long-focus (F = 250 cm) lens to a section $S_r \simeq 6 \times 7.5$ cm on the surface of the target, formed by a graphite plate with dimensions $0.5 \times 14 \times 18$ cm. In control experiments the value of S_r was varied over the range 4-46 cm^2. The section was decreased by diaphragming the beam for a fixed energy of $q_r \simeq 15$ J/cm^2 and constant target dimensions. A ballistic pendulum, the inclination of which was recorded by a video tape recorder, was used to measure the mechanical impulse I_m conveyed to the target. The uncertainty in measurement

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