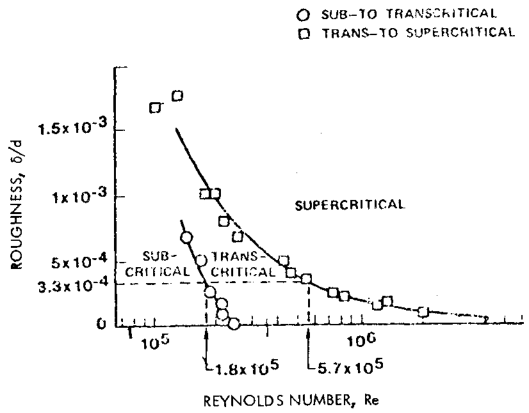

Fig. 4 Limits of flow regimes for different relative roughness sizes (Ref. 14).

over four cylinder diameters before von Kármán-type vortex shedding is established.

In summary, then, it appears that a necessary condition for the establishment of vortex periodicity in cylinder wakes is the existence of a well-defined, two-dimensional separated flow region. Consequently, one would expect that the periodic vortex shedding with the associated problems of self-excited oscillations could be eliminated by introducing three-dimensional flow disturbances that prevent the formation of a well-defined, two-dimensional flow separation geometry.

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On-Axis Velocity Component Measurement with Laser Velocimeters

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Introduction

MEASUREMENT of fluid velocities with Doppler-shifted laser light was demonstrated almost two decades ago; since then, laser velocimetry has developed into a powerful method for measuring fluid and other velocities. While it has been relatively easy to measure the two velocity components normal to the optical axis of the system, measuring the on-axis velocity component has not been as simple. Methods used for measuring the on-axis component include both reference-beam (local oscillator) and dual-beam (fringe mode) techniques. Some of the methods used in the past are discussed herein.

Fridman et al.,[1] Bossel et al.,[2] and Dubnistchev and Vasilenko[3] used three-component, reference-beam systems with forward scattering. In these geometries, the point of measurement is illuminated by focused laser light of single color, and the light scattered by the particles in the fluid is detected by three photodetectors. The position of the photodetectors determines the velocity components measured, which are not necessarily the preferred components. The three measured velocity components are then resolved to yield the Cartesian velocity components of interest.

Fridman et al.[1] installed their detectors in front of the laser and the test section. In their system, unscattered light was focused to and heterodyned on the detectors to sense the Doppler shift. The scheme proposed by Bossel et al.[2] used Wollaston prisms to combine and heterodyne forward scattered light from two different directions on the photodetector. By properly choosing polarizations and Wollaston prism orientations, they devised a scheme for measuring three arbitrary velocity components. The heterodyning of light in the system of Dubnistchev and Vasilenko[3] was achieved with the use of light reflected from a reflector in front of the system.

Orloff and Logan[4] devised an optical geometry to measure a velocity component close to the on-axis component. Their arrangement uses backscattered light from one of the beams of a dual-beam velocimeter with a crossing angle of θ. The reference beam is obtained as a spurious reflection from a splitter cube and aligned with scattered radiation onto the photomultiplier tube. The measured velocity component is $\theta/4$ off the axis of the velocimeter, and for small θ, this is close to the desired on-axis component. Farmer et al.[5] also used a similar system to measure the on-axis component in addition to two normal components. The reference-beam backscatter method generally yields large values of Doppler shifts, and thus may not be suitable for many applications.

The direct measurement of the on-axis component is also difficult with dual-beam (fringe mode) methods. One of the schemes for such a direct measurement involves crossing the forward and backward (reflected) beams, thus forming fringes perpendicular to the optical axis of the velocimeter. Because of physical and geometrical constraints, the angle between the crossing beams and hence the Doppler shift in this

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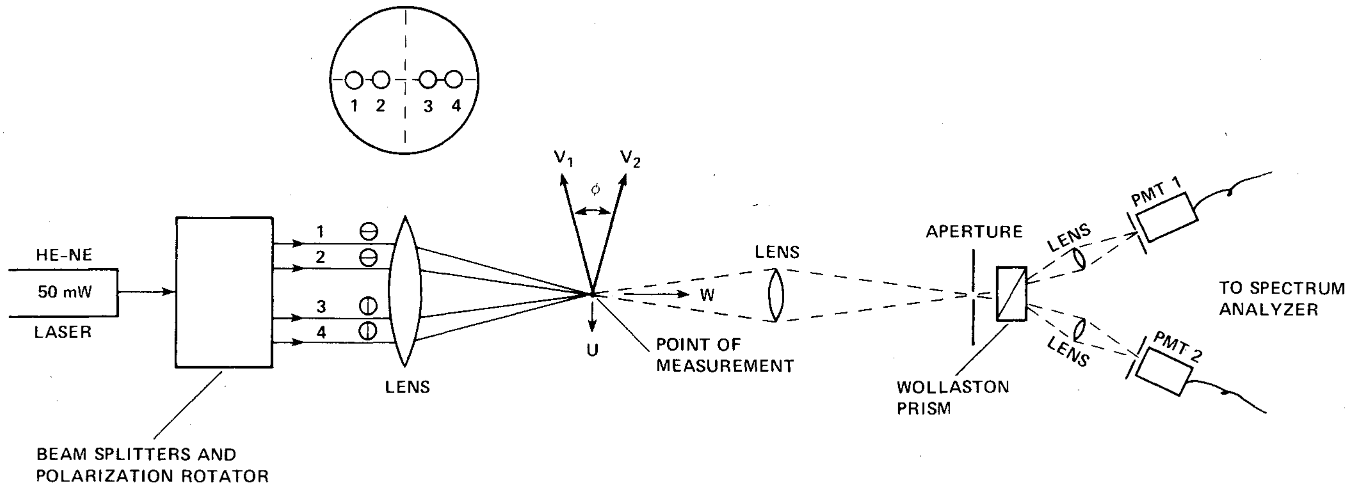

Fig. 1 Beam geometry and experimental setup used in the present work.

scheme tends to be too large. Farmer[6] proposed a method for indirectly measuring the third orthogonal velocity component by use of two rotationally displaced laser velocimeters, but this scheme remains to be tested.

A method proposed by Hallermeier[7] involves the use of three focused and frequency-shifted beams crossing at a point, and a single detector. The position of the detectors in the fringe velocimeter does not affect the velocity component measured. The outputs corresponding to the three velocities to be measured are separated by appropriate electronic filtering of the signal. Ohtsuka[8,9] rejected this scheme and proposed a similar system with four frequency-shifted beams. The optical geometry proposed by Johansson et al.[10] also falls into this category. It utilizes four incoming beams which are all frequency shifted. Three of these propagate in a plane and are used to measure two independent velocity components in this plane. The fourth beam, which is off this plane, together with one of the three beams mentioned above, form a velocimeter that measures the other component of velocity. Thus, three independent velocity components are measured to provide both on- and off-axis velocity sensing. This system is also expected to make simultaneous multipoint measurements with the help of beam splitters.

Kulybin[11] has also used a fringe-type laser velocimeter with three focused beams. Scattered light is detected by a single photodetector. The additional component required is measured by shifting the three beams to a different orientation, to an off-axis angle. Details about this technique are not complete, and Kulybin presents only some preliminary results obtained with a spectrum analyzer.

Dual-beam, multicomponent velocimeters seem the best prospects for on-axis measurements. This is especially true in sparsely seeded flows because of the better signal-to-noise ratios feasible with dual-beam geometries. The window area available for access to the test section is limited in most applications. In such cases, the on-axis component can be deduced from two slightly off-axis velocity components with either forward or backscatter. A geometry capable of measuring the on-axis component in this manner was used in the present work to verify its feasibility at small off-axis angles.

Experimental Setup

The beam geometry used here is shown in Fig. 1. The measurement point is illuminated with two pairs of equal-intensity beams of orthogonal linear polarization. All four beams are in one plane (the horizontal plane). The beams are all focused by a single lens to cross at the measurement point. Each pair of beams forms a traditional one-dimensional, dual-beam fringe system that measures a slightly off-axis velocity component, V_1 or V_2. The on-axis component W can be determined once V_1 and V_2 are known by using the equation

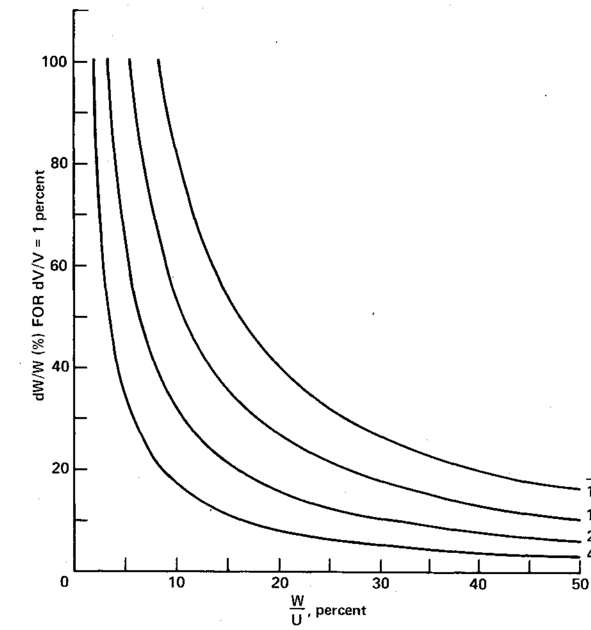

Fig. 2 Calculated error in the on-axis velocity component.

$$W = (V_1 - V_2)/2\sin(\phi/2) \tag{1}$$

where ϕ is the angle between V_1 and V_2. The angle ϕ is limited by the size of the wind-tunnel window available. The individual beams in each pair cross at an angle θ, and θ is limited by the maximum Doppler shift frequency that can be handled by the receiving electronics.

The accuracy achievable in the measurement of the on-axis component with this configuration is a function of the angle ϕ between the measured velocities, the accuracies in the measured velocities V_1 and V_2, and the ratio of the on-axis to normal velocity components. The fractional error in the on-axis velocity W can be written as

$$dW/W = (1/\sqrt{2})(dV/V)[(W/U)\tan(\phi/2)]^{-1} \times [1 + (W/U)^2\tan^2(\phi/2)]^{1/2} \tag{2}$$

where dV/V is the fractional uncertainty in the measured components (assumed to be the same for both components),

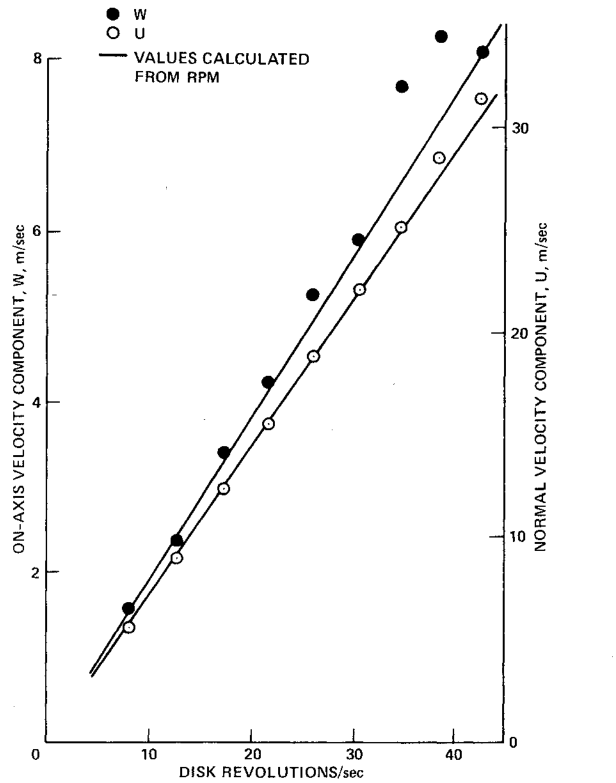

Fig. 3 Measured and calculated values of on-axis and normal velocity components using a rotating disk.

and U is the velocity component normal to the optical axis. If $(W/U)^2 \tan^2(\phi/2) \ll 1$, this equation reduces to

$$\mathrm{d}W/W \approx (1/\sqrt{2})(\mathrm{d}V/V)[(W/U)\tan(\phi/2)]^{-1} \qquad (3)$$

Figure 2 shows the error in W using Eq. (3) plotted as a function of W/U for various values of ϕ, assuming a 1% accuracy in measuring V_1 and V_2.

Simulated velocity measurements with a rotating Plexiglas disk were made using the configuration just described. A beam from a 50-mW He-Ne laser was passed through a set of beam splitters to produce four beams, as shown in Fig. 1. A polarization rotator was used to make the polarization of the two pairs of beams orthogonal. The beams were focused to a point with an f/2.5 lens with a focal length of 305 mm. The light scattered by the rotating disk was collected in forward scatter by another lens, focused through an aperture, and passed through a Wollaston prism to separate the scattered light into two beams of orthogonal linear polarization. The light corresponding to the components V_1 and V_2 was detected by two photomultiplier tubes. The outputs of the photomultiplier tubes were analyzed using a spectrum analyzer to obtain the components V_1 and V_2.

Results

The values obtained for the normal and on-axis components U and W are plotted in Fig. 3. In this measurement, the angle between components ϕ was 15 deg and θ was 3.5 deg. The disk was at an angle of 75.25 deg to the optical axis, giving a W/U ratio equal to 26%. The measured velocities are in good agreement with the velocities calculated from the rpm of the disk. The largest errors in W are less than 19%, and the mean error is less than 6%. From Fig. 2, the maximum uncertainty expected for the preceding values of ϕ and W/U, with a 1% accuracy in determing V_1 and V_2, is about 21%. Thus, the measured values are seen to be well within the expected limits.

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Coupled Thermomechanical Effects in High Solids Propellant

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I. Introduction

It has been suggested that the master relaxation modulus together with the time temperature shift factor characterized under isothermal conditions might be used to predict the transient response, i.e., stretching while cooling (or heating), for thermorheologically simple viscoelastic materials.[1] Observations have shown that the extension of linear viscoelastic theory for thermorheologically simple materials will predict a transient stress response which is much lower than that obtained experimentally in modern high solids propellant.[2]

The permanent memory constitutive relation developed from mechanical and thermodynamic theory[3] provides the

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