Laser Velocimeter Measurements of Turbulence in a High Subsonic Jet

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Theme

UTILIZING an LDV to determine flow velocities has become a widely used technique in laminar and turbulent flow studies.[1-3] However, LDV's have had limited use in obtaining turbulence data, in particular for compressible flows, due to the difficulty of their continuously measuring instantaneous flow velocities. A novel velocity detection scheme that allows continuous and direct measurements of instantaneous flow velocities with an LDV has been developed. The technique, particularly applicable to measurements of high velocities, is based on a static slightly defocussed spherical Fabry-Perot interferometer (DFPS) used in conjunction with a special mask for the detection of instantaneous Doppler frequency shifts generated by the velocity fluctuations. Combining such a detector with an LDV, measurements of turbulence intensity and turbulence scale size were carried out in a high subsonic jet, and the results show good agreement with existing hot wire data.

Contents

The concept of the basic LDV velocity detection scheme is outlined in Fig. 1. A laser beam is incident upon the flow. The radiation scattered from the aerosol-seeded flow is Doppler shifted from the laser frequency by a frequency shift given by

$$f_D(t) = [2U(t)/\lambda_o] \sin(\theta/2) \qquad (1)$$

where $U(t)$ is the time varying flow velocity, λ_o the laser wavelength, and θ the scattering angle. The Doppler frequency shifts are then measured using a spherical Fabry-Perot (F-P) interferometer.

The spherical F-P extensively studied by several authors[4,5] is a high resolution optical spectrum analyzer, consisting of two spherical mirrors spaced at a distance equal to their radius of curvature. When light from a source lying close to the axis is incident on the F-P a multiple circular interference pattern is produced in the vicinity of the central plane of the interferometer. By detuning (defocussing) the optical cavity, Bradley and Mitchell[6] showed that the radii of these fringes becomes linearly proportional to the radiation wavelength introduced into the Fabry-Perot. Using this idea here the Doppler shifted scattered radiation is introduced as a collimated beam into a slightly defocussed Fabry-Perot interferometer yielding a fringe pattern which consists of a single circular fringe (the number of fringes depends on the diameter of the collimated beam introduced into the F-P) which radius is linearly dependent on the Doppler shifted frequency and hence the flow velocity. Any change in velocity, therefore, will result in a proportional change in the fringe radius, and by monitoring these changes through time, direct velocity fluctuations can be measured.

This radial fringe motion is detected here by using a special mask located in front of a photomultiplier on which the fringe pattern is projected. The mask is shaped so that the section of the interference fringe transmitted through it results in a photomultiplier output proportional to the radius. Since at any instant of time the radius is proportional to the Doppler shifted frequency, the photomultiplier output becomes a display of the instantaneous flow velocity. To account for fluctuations in the scattered radiation intensity, the detection system can be modified by introducing a second photomultiplier to sample the total fringe intensity. By dividing the two signals, the fluctuation effect is removed and the divider output becomes the instantaneous velocity display.

The actual LDV system outlined in Fig. 1 and detailed in Ref. 7 employs a single axial mode argon laser (Spectra Physics) to illuminate the flow borne particles. The receiving optics then transmit the radiation scattered by the flowing particles directly into the defocussed Fabry-Perot. These receiving optics consist of an F/50 lens, and an 0.3 spatial filter defining an almost spherical probe volume approximately 0.5 mm diam, and a collimating lens that gives a collimated beam about 3 mm diam. The DFPS used here has a 500 MHz free spectral range and a finesse of 30, yielding in the present system a velocity resolution of about 3 m/sec. The output from the DFPS in the form of a circular fringe is expanded through the output lens. A beam splitter is then used to generate two beams, one of which is

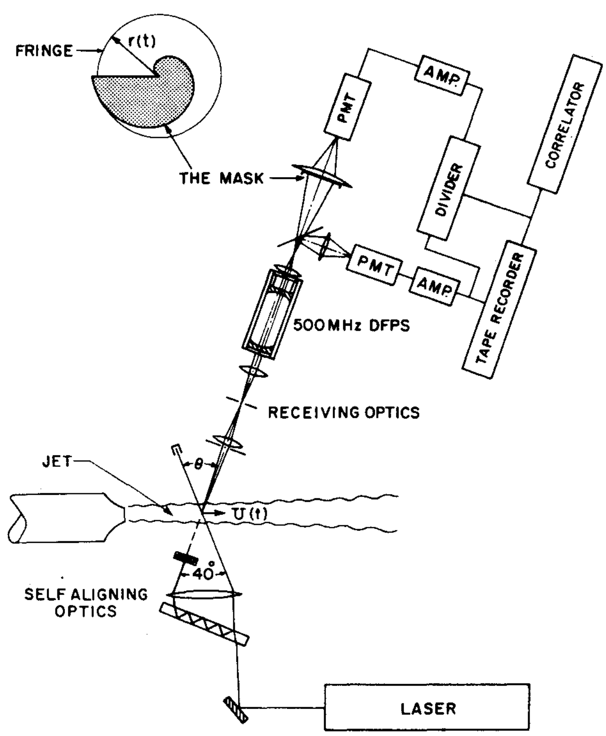

Fig. 1 Schematic of the LDV system.

Received June 14, 1974; presented as Paper 74-579 at the AIAA 7th Fluid and Plasma Dynamics Conference, Palo Alto, California, June 17–19, 1974; synoptic received November 1, 1974; revision received November 22, 1974. Full paper available from AIAA Library, 750 Third Avenue, New York, N.Y. 10017. Price: Microfiche, $1.50; hard copy, $5.00. **Order must be accompanied by remittance.**

Index categories: Research Facilities and Instrumentation; Jets, Wakes and Viscid-Inviscid Flow Interaction.

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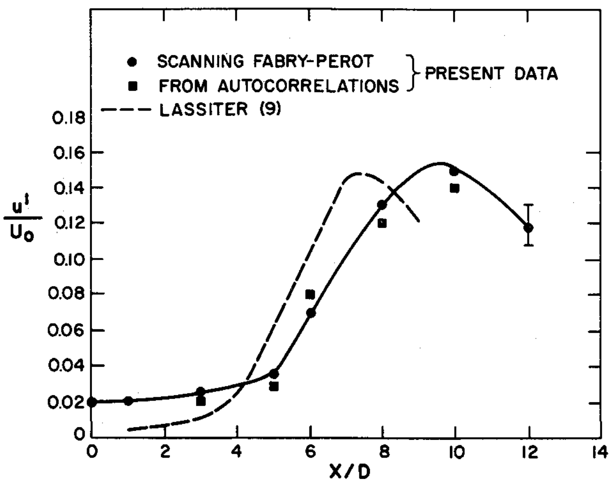

Fig. 2 Axial intensity of u' fluctuations.

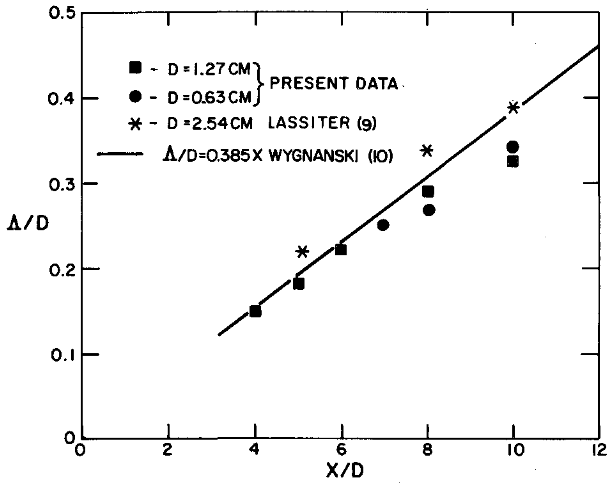

Fig. 3 Axial variation of longitudinal turbulence scale size.

projected through the special mask on the face of one photomultiplier and the other is projected directly on the face of another photomultiplier (both EMI 9789B). The signals from these two PMT's are amplified and then divided by an analog divider, the output of which is then recorded on a high speed tape recorder with a 500 kc frequency response for later data reduction and processing.

Turbulence measurements on a high subsonic jet (exit Mach no. = 0.8) were carried out on a test set up which consisted of a settling chamber to which was fitted a 1/2 in. convergent nozzle. The chamber also served as the aerosol generating chamber, where the particles introduced into the flow to serve as scattering centers were generated using the exploding wire aerosol generator technique described elsewhere.[8]

From the recorded LDV output, longitudinal velocity autocorrelations were generated using an analog correlator (Federal Scientific UC201). From these, the turbulence intensity distribution along the jet axis was determined where the results shown in Fig. 2 show good overall agreement with hot wire data reported by Lassiter[9] and LDV data obtained using a scanning spherical Fabry-Perot interferometer. The difference in the location of the maximum could be attributed to the difference in jet exit velocity and turbulence level at the jet exit. Invoking Taylor's hypothesis of frozen convection the longitudinal integral scale of the velocity was calculated from the autocorrelation data. The present data which include some results using a smaller jet shown in Fig. 3 agree nicely with incompressible jet results.[9,10]

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