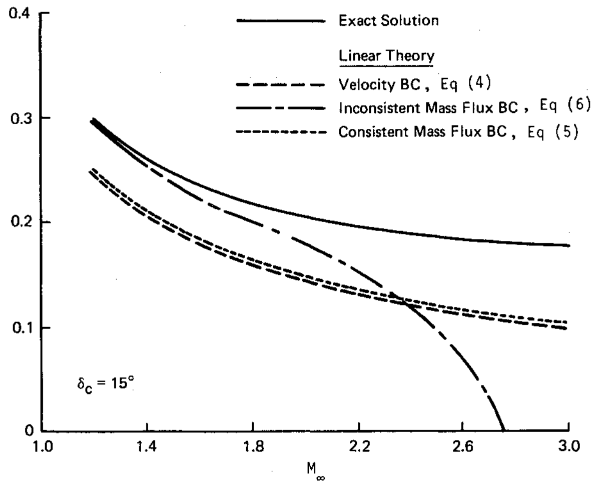

Fig. 1 Comparison of surface pressures on a cone for the various boundary condition relations.

results that are nearly identical to those obtained with the exact velocity boundary condition [Eq. (4)]. The difference in agreement with changing Mach number for the inconsistent mass flux BC is typical of results obtained using equations that have been derived without insuring a uniform order of magnitude of all terms. It also demonstrates vividly the M_∞^2 dependence of the heretofore neglected term.

The difference between the exact solution and the linearized solutions using consistent boundary conditions [i.e., either Eq. (5) or (6)] is clearly due to approximations in the differential equation and the formula used for the pressure coefficient. The close agreement achieved with the inconsistent boundary condition at low Mach numbers is spurious and cannot be relied on as an argument in favor of the inconsistent mass flux boundary condition.

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Application of Photon Correlation to Turbulent Fluid Mechanics

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Introduction

WITHIN the past few years, the commercial availability of fast digital correlators has led to new techniques of measurement based upon the quantum resolved properties of low-light levels. The photon correlation processing technique used in laser velocimetry applications has remarkable power in that it covers a wide dynamic range, is sensitive to extremely low scattered light intensities, and does not require a continuous signal. The low-light level requirements permit the use of relatively small lasers and naturally occurring contaminants as the scattering centers. However, there are drawbacks to the photon resolved technique, such as sensitivity to background ambient light and flare, photon pileup, modest control over the size distribution of the scattering centers, and the facts that, only ensemble-averaged data are retrievable, and mean velocity and turbulent intensity information alone are calculable from the correlation function.

Experimental Design

In order to establish the credibility of the photon correlation technique, a series of different fluid flow configurations is devised and documented. The first segment of the experimental investigation focuses on the measurement of a rectangular nozzle turbulent jet.[1] Considerable data obtained via hot wire anemometry exist for the downstream flow. In addition, the exit plane mean velocity can be varied up to a maximum speed of 260 m/s, which is in the compressible regime. The naturally occurring contaminant present in the laboratory-compressed air supply is used as the source of marking particles.

The naturally "seeded" atmosphere furnished sufficient scattering centers to also allow the photon correlation scheme to be employed in the experimental investigation of the inlet duct flow occurring prior to the combustion chamber of a jet engine.[2] The engine inlet is placed outside the walls of the laboratory. Mean velocities and turbulent intensities are obtained at three different locations, namely: 1) immediately downstream of the leading edge of the bypass contraction; 2) immediately downstream of the venturi section throat; and 3) immediately downstream of the exit from the bypass diffuser. Two different throttle settings (i.e., 50 and 70%) are used.

Difficulties in using a scattering based laser velocimeter led to the next portion of the investigation – the measurement of the velocity field behind a stationary flat disk immersed in and normal to the direction of a subsonic turbulent jet.[3] Once again mean and fluctuating information is sought.

A quanititative analysis of the sensitivity of the photon correlation scheme to incident laser intensity is the next goal of this research. The approach taken is to vary the actual size of the laser beam by means of beam expander/aperture arrangement. The $1/e^2$ beam diameter is varied with the resultant different sized control volumes located in flowfield of the turbulent jet described previously.

With the application of the photon technique to an investigation of a flowfield located in the test section of a wind tunnel, the presence of optical plates and confining walls and their resultant effects on signal quality is noted. Problems associated with flare and/or background light are found to exist, and create uncertainty with respect to both mean and turbulent velocity data. The flowfield chosen for this portion of the project is a two-dimensional wake.[4]

A flapping (oscillating) jet allowed the sensitivity of the photon correlation scheme to an unsteady flowfield to be documented. The nozzle design employed consists of a modified fluidic element with a feedback mechanism.[5] A centrifugal blower with naturally occurring contaminant serving as scatters is used.

Experimental Results and Discussion

Rectangular Nozzle Jet

Mean velocity profiles taken by the photon correlation technique and hot wire anemometry are shown in Fig. 1. Here, the nondimensionalized velocity ratio, U_{CEN}/U_{CORE}, is plotted vs downstream distance, X, from the exit plane. The quantity U_{CORE} is the exit plane mean velocity. Three dif-

Received July 8, 1983; revision received Feb. 6, 1984.

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ferent exit Mach numbers are selected, and excellent agreement exists between the data. Although not shown, agreement for profiles at various downstream locations is also favorable. Unfortunately, a comparison of turbulent intensity profiles, i.e., U_{rms}/U_{LOCAL} vs Y/YD, shown in Fig. 2, demonstrates one drawback of the 5 MHz correlator. An experimentalist is forced to choose between measuring mean velocities or turbulent intensities for fairly high subsonic flows. The centerline mean velocity at this location is approximately 130 m/s. Using the present correlator it is not possible to determine the turbulent intensities near the center of the profile.

Jet Engine Inlet Duct

Mean velocity and turbulent intensity profiles are obtained at the three downstream locations discussed previously. In Fig. 3, the mean velocity ratio, U_{LOCAL}/U_{MAX}, is plotted vs radial position, r/r_0, where r_0 is the radius of the duct and U_{MAX} the velocity at the flow centerline. At first glance, the comparison looks reasonable although the profiles via laser velocimetry are slightly wider. This is because limited access to the duct flow required back scattering with the collector mounted in the plane of the intersecting beams. Unfortunately, the two sets of data differ by approximately 10% in absolute values. Significantly, the laser velocimeter measured mean velocities are lower than the hot wire data near the zero bypass contraction, lower at the outset of the venturi throat, and greater immediately downstream of the expansion section. The turbulent intensity data points to another shortcoming of the photon technique, as shown in Fig. 4. Intensities close to zero are difficult to determine without any ambiguity.

Flow Behind a Disk

A 5-cm-diam ($R = 5$ cm) disk is placed perpendicular to a subsonic jet with an exit plane velocity equal to 130 m/s. Mean velocities, U, are plotted vs nondimensionalized radial displacement in Fig. 5. Note that it is clearly possible to obtain mean velocity information. In Fig. 6, local turbulent intensities are plotted again vs radial displacement. Clearly, the turbulent intensities are, in fact, not constant across the large shear layers. Thus, although the mean velocity data seem reasonable, the turbulence date are not.

Effect of Beam Size/Intensity

The unfocused beam diameter of the 15 MW helium-neon laser is 1.1 mm. Through a series of lenses/aperture, the beam diameter is varied from 0.5 to 10 mm. The varying sized control volume at the intersection of the beams is then placed in the flowfield of the rectangular nozzle jet. It is found that for beam diameters up to 5.0 mm, the variance between the data and the results obtained for a 1.1-mm beam is less than 5% for the mean velocities and less than 10% for the mixing widths. However, for beam diameters greater than 5.0 mm, the apparent errors increase dramatically.

Two-Dimensional Wake Flow

Mean velocities and turbulent intensities are measured in the turbulent wake behind a cylinder. The cylinder is mounted in the test section of a flow visualization type tunnel with optically flat glass used as side plates. The freestream velocity is a 6 m/s, resulting in a Reynolds number equal to 48,000 based on the cylinder diameter. Typical results are shown. The nondimensionalized mean velocity, $(U_{FS} - U)/U_{FS}$, is plotted vs lateral displacement in Fig. 7. Note that there is no similarity in the profiles. The parameter w is the cylinder rotation speed. The turbulent intensities are considerably more open to interpretation, see Fig. 8. The presence of the side optical plates poses a problem for the photon correlation

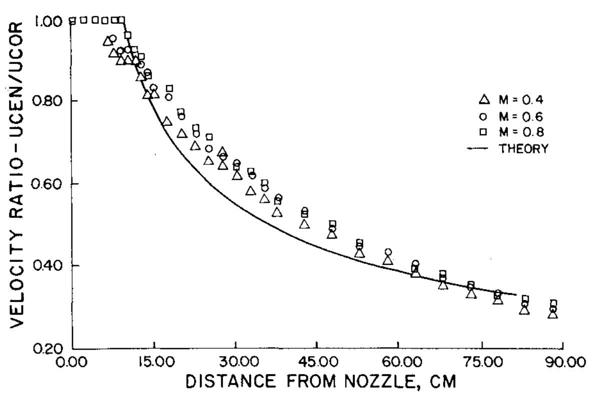

Fig. 1 LV axial velocity profile.

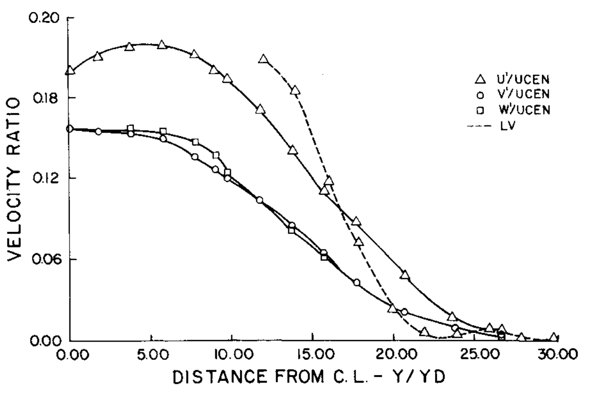

Fig. 2 Hot wire and turbulence intensity at $M = 0.4$ and 50 cm.

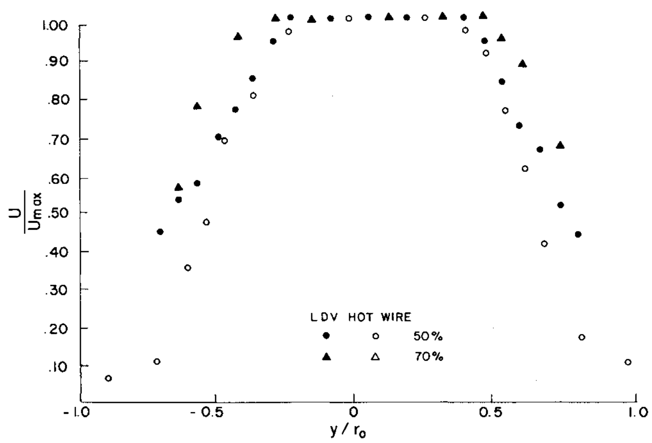

Fig. 3 Mean velocity profile comparison (position II).

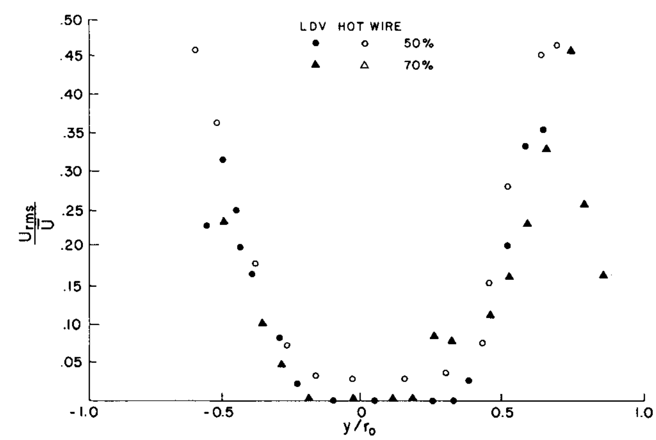

Fig. 4 Turbulent intensity profiles comparison (position II).

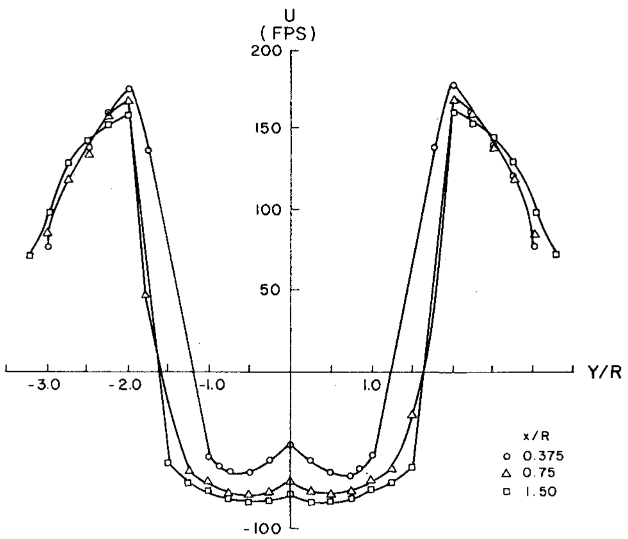

Fig. 5 Mean velocity profiles, 2-in.-diam disk.

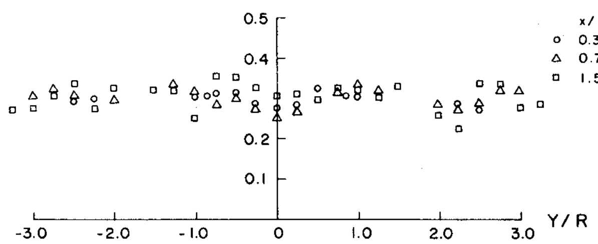

Fig. 6 Turbulent intensity profile summary, 2-in.-diam disk.

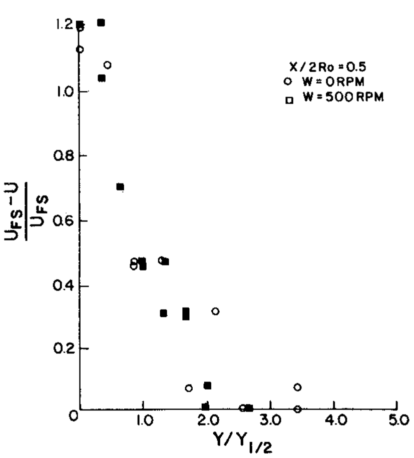

Fig. 7 Wake velocity defect profile, $X/2R_0 = 0.5$.

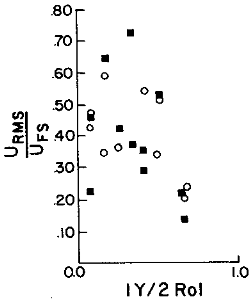

Fig. 8 Turbulent intensity profile, $X/2R_0 = 0.5$.

scheme due to its extreme sensitivity to scattered light. The background flare light and resultant photon pileup cause a skewed and/or distorted photon correlation curve. In an attempt to alleviate this source of error, a data algorithm is proposed and evaluated.

Unsteady (Flapping) Jet

Although the data is not shown in this report, a nozzle fitted with a fluidic feedback loop is oscillated from 4 to 18 Hz. The resultant mean velocities are measured both at the centerline of the flowfield ($Y/D = 0$) and outside the lip of the nozzle ($Y/D = 1.5$) for various downstream locations ($X/D = 1$ to 5). The photon scheme is sensitive to the relatively low frequency oscillations. One interesting observation is that at $Y/D = 0$, the mean velocity is actually the largest in the magnitude at $X/D = 5$.

Summary

The photon correlation technique is used for several different turbulent fluid investigations. The different results point to significant advantages and disadvantages for the photon resolved processor. The main advantages are:

1) Using only naturally occurring contaminant, credible mean velocity measurements can be made in flow configurations which would be inaccessible using the counter and/or tracker techniques.

2) Mean velocity information is not strongly dependent on incident laser intensity, while turbulent intensities are significantly affected.

The main disadvantages are:

1) There is no control over particle size distribution of light scatters.

2) Actual experimental time required for photon resolved autocorrelation curve may be considerable.

3) Time-dependent velocity information is not available.

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Calculation of Turbulent Diffusion Flame Using the Coherent Flame Sheet Model

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Introduction

ONE of the difficulties in the computation of combustion flowfields is the modeling of the chemical reaction terms.

Received Sept. 9, 1983; revision received Jan. 16, 1984.

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