RECENT ADVANCEMENT OF TURBULENT FLOW MEASUREMENT TECHNIQUES*

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In a turbulent flow, pressure, density, temperature, velocity, momentum, and chemical-species-concentration are the fluctuating quantities to be measured. After a search of the current measuring techniques, it is found that piezoelectric pressure probes are well developed; and the hot-wire, the pitot probe, and the laser doppler velocimeter have been developed for velocity measurements to a certain degree of sophistication. The Raman Scattering technique, which had a history in analytic chemistry, is capable of determining the chemical species concentration even in a chemically reacting region. Since these techniques have had some years of development history and many more papers probably will be devoted to some specific advances in their respective methods, they will not be discussed any further.

Instead, attention is paid to recent advancements of the fluctuating density gradient cross beam laser Schlieren technique, the fluctuating line-reversal temperature measurement and the development of the two-dimensional drag-sensing probe to a three-dimensional drag-sensing probe. So the three-dimensionality of the instantaneous momentum vector can shed some light on the nature of turbulence especially with swirling flow. All three measured fluctuating quantities (density, temperature, and momentum) can provide valuable information for theoreticians.

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(1) Cross beam laser Schlieren system

The cross beam laser radiation absorption technique was first developed around 1966, (Ref. 1-3), where the chemical species fluctuations were assumed to be in a one-to-one correspondence with density fluctuations in a flow. Not only was this assumption difficult to verify but also the fluctuating signal had only a small value on top of a large DC signal and the fluctuating signal caused by the index of refraction could not be separated from the absorption signals. The development of the laser Schlieren system (Ref. 4-7), which measures the density gradient fluctuation, became both a logical step and a simple workable system.

Recently, we examined the laser Schlieren from an experimental point of view, concerning the choice of the laser system, the additional information of signal correlation with a rotating knife edge and the effect of the angle of the knife edge relative to the plane of polarization of a linearly polarized laser. Experiments were conducted to determine the correlation length of a small turbulent air jet and the mean rotational velocity in the shear region of the turbulent jet with one circular and one plane polarized laser. On the one hand, the laser beam is bent due to index of refraction changes; on the other hand, the index of refraction is a function of dielectric constant of the fluid. The magnetic permeability is constant for most non-ferro materials. Hence, the light is bent differently in the same fluid depending on the relative vector angle between the E-field in the laser light beam and the gradient of the index of refraction of a fluid. From the measurements, we concluded that the circular polarized laser (inexpensive one) is more suitable than the higher quality linearly polarized laser. We also found that the correlation signal can be 20 percent to 30 percent lower if the plane of polarization is perpendicular to the knife edge. It is also found that from the cross beam laser Schlieren that it is possible to obtain information on mean rotational velocities. This is due to the fact that in correlating the signals of two laser beams with a fixed separating distance, one is trying to identify the same fluctuating component downstream of the flow. Since the Schlieren system only measures the density gradient (a vector quantity) perpendicular to the knife edge, and since the same fluctuating gradient will rotate to a certain angle flowing downstream, then rotation of the knife edge to find the maximum cross-correlation signal will yield the mean rotational speed as well as the correlation distance in a turbulent flow.

(2) Line-reversal temperature fluctuation measurement.

When instantaneous temperature fluctuation data is needed, only the radiation line-reversal or a fast response thermocouple are feasible. The Raman Scattering Method requires a very high repetition rate and high power laser; thus it is not likely to be available for small laboratories. A fast response thermocouple contains velocity signals as well as temperature signals, and therefore is not the best instrument if one has a choice. The radiation line reversal method is an old technique based on the principle that if a background radiation source is focused at a point in a fluid, the chemical species will absorb and re-radiate light at certain discrete radiation lines. When the neighborhood wave length has the same intensity as the discrete line intensity, then the chemical species has absorbed and re-radiated equal amounts of photons at that time and the background radiation source has the same temperature as the fluid. The most commonly used discrete line is the sodium D-line, due to the fact that seeding sodium compounds in a hot fluid can be relatively simple. Recently, the technique has been modified in several ways. Light pipes are used at the exit slit of a monochronometer to direct the sodium-D line and the neighboring line into two PMT's. The PMT outputs contain DC and AC components. The DC signals are used to balance the background radiation source strength, and the fluctuating signal (AC component) of the sodium line is used as a measurement of the fluctuating temperature. The system can be pre-calibrated so

$$\Delta V/V_{DC} \approx 4\frac{\Delta T}{To}$$

In a simple experimental setup, large temperature fluctuations were created by pulsating the pre-mixing chamber of a Mecker burner with a small air jet. Responses and the fluctuating data obtained will be presented. Other lines can also be used for different temperature regimes.

(3) Three-dimensional drag-sensing probe.

Less than two years ago, we demonstrated that a small light sphere mounted on a stereo magnetic phono cartridge could simultaneously monitor u' and v' in a cold small jet (Ref. 8-9). Direct multiplication of the u' and v' signals yielded the instantaneous momentum flux. The DC average of u', v' yielded the Reynolds stress $\overline{\rho u'v'}$. Many advancements of the two-dimensional probe has been made, such as the measurement of Reynolds stress profiles of a turbulent jet. Comparisons of velocity fluctuation profiles with hot-wire measured profiles were also made. The prototype two-dimensional probe had many disadvantages due to the fact that a commercially purchased cartridge was the only source of a magnetic sensor available. Disturbances due to the body of a cartridge and the 90° supporting sting were undesirably present. This problem was compounded by the difficulty in finding the true magnetic axis.

It would be desirable to have a streamline support probe with the supporting sting hiding behind the sphere. A new concept of how to use differential and total magnetic flux to separate three signal channels has been discovered. This makes a three-dimensional drag-sensing probe (Fig. 1) design possible. Preliminary results of the three-dimensional signal will be presented. This enables us to track the rotational velocity fluctuation as well as momentum fluctuation, and in principle the signal can be displayed in any coordinate system of the experimenter's choice. Work is still in progress to adopt the new 3-D probe to boundary layer measurements in a high subsonic wind tunnel.

REFERENCES

1. Fisher, M. J. & Krause, F. R., "The Crossed-beam Correlation Technique", J. Fluid Mechanics (1967), Vol. 28, part 4, pp. 705-717.

2. Krause, F. R. & Wilson, L. N., "Optical Crossed-beam Investigation of Local Sound Generation in Jets", NASA SP-189, 1968.

3. Fisher, M. J. & Damkevala, R. J., "Fundamental Considerations of the Crossed Beam Correlation Technique", NASA CR-61252, Jan. 1969.

4. Funk, B. H., and Cikanek, H. A., Jr., "Optical Probing of Supersonic Aerodynamic Turbulence with Statistical Correlation. Phase I: Feasibility. NASA TM X-53850, June 9, 1969.

5. Funk, B. H., "A Direct Measurement of the Most Probable Preferred Angular Velocity of Turbulent Structures by Optical Correlation of Laser Schlieren Signals", NASA TN D-6029, Oct., 1970.

6. Parthasarathy, S. P., Massier, P. F. & Cuffel, R. F., "Comparison of Results Obtained with Various Sensors Used to Measure Fluctuating Quantities in Jets", AIAA Paper No. 73-1043, Oct. 1973.

7. Massier, P. F., Parthasarathy, S. P., & Cuffel, R. F., "Experimental Evaluation of Fluctuating Density and Radiated Noise from a High-Temperature Jet", AGARD Paper No. 131, 1973.

8. Cheng, D. Y., & Wang, P., "Viscous Force Sensing Fluctuating Probe Technique", AIAA Progress in Astronautics & Aeronautics Series, Vol. 2, MIT Press, 1974. (Presented as Paper 73-1044 at AIAA Aero-Acoustics Conference, Seattle, Wash., Oct. 15-17, 1973.)

9. Cheng, D. Y., & Wang, P., "A Simple Method of Measuring Two Orthogonal Components of Fluid Velocity", accepted for publication by Journal of Fluid Mechanics.