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A COMPARISON OF TURBULENCE MEASUREMENT METHODS

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Laser doppler anemometers are by now widely used to measure the turbulence properties of moving fluids. Their nonintrusive nature makes their use very attractive. By the nature of the measurement process, the turbulence parameters such as turbulence intensity and turbulence scale are based strictly on velocity measurements. However, if one is interested in convective heat transfer and if the gas stream has appreciable density fluctuations (which are equivalent to temperature fluctuations if the static pressure is constant), the turbulence should probably be based on the density-velocity product. Hot-wire anemometers, for instance, give results based on the product of density and velocity, and the operation of a hot-wire anemometer depends on the flow of heat away from the wire. Hot-wire anemometry, though, is not practical in high-temperature or high velocity flows.

In the experiment described herein, temperature (density) and velocity are measured separately but simultaneously as functions of time so that it is possible to determine the relationships among velocity, density, and the product of density and velocity.

DESCRIPTION OF EXPERIMENT

An atmospheric burner rig was used to provide the flow for this experiment. Data were taken at various flow conditions, at mean temperatures ranging from 850 to 1598 °F, at Mach numbers from 0.19 to 0.22, and at values of Reynolds number divided by characteristic length in the range 25 000 to 51 000 in.$^{-1}$. Probe location was varied from 2 to 4 in. from the burner outlet and up to 1/2 in. from the centerline. Temperature fluctuations as great as ±500 °F were measured in a similar burner, so compensated temperature fluctuations are expected to be in this range. This level of temperature fluctuation implies a density fluctuation of approximately 17 percent; previous measurements of velocity fluctuation in this rig were in the range of 5 to 10 percent.

Temperatures were measured with a dual-wire thermocouple probe (fig. 1) which is part of the dynamic gas temperature measurement system (refs. 1 and 2). The probe consists of two platinum-rhodium thermocouples located in close proximity to each other. The wires are of different diameters, 3 and 10 mils, respectively, in this case. By comparing the signals from the two thermocouples at different frequencies, it is possible to generate a compensation spectrum and thus to determine temperature fluctuations at frequencies up to 1 kHz.

Velocity data were supplied by a fringe laser-doppler anemometer (ref. 3) with sampling volume location varied from 0.2 to 2.5 mm upstream of the thermocouples. Data rates varied from 6.2 kHz farther from the burner outlet to 45.2 kHz closer to the burner outlet.

Figure 2 shows the setup of the probe in the flow stream of the burner and the crossing laser beams which form the sampling volume just in front of the probe.

The signals from the thermocouples and the laser were recorded on FM magnetic tape for later processing. The quantities stores are the ac-coupled voltage from both thermocouples, which permits frequency compensation of the temperature data, the dc-coupled signal from the large thermocouple, which provides the mean temperature, and the laser doppler signal, from which both mean and instantaneous velocity can be extracted.

PRELIMINARY RESULTS

For turbulence measurements, the quantities of interest are $V_{rms}/\bar{V}$, $(\rho V)rms/(\overline{\rho V})$, and their autocorrelations, which provide a measure of turbulence intensity and turbulence scale. The cross correlations are also of interest; they will answer questions such as whether the velocity peaks are related to the hotter combustion products or to the cooler, denser filaments of dilution air. Figure 3 is the cross correlation of the velocity and compensated temperature signal from the 3-mil thermocouple. The probe was located on the burner axis 4 in. from the burner face. The flow conditions were $M = 0.325$, $Re/L = 41\ 000\ in.^{-1}$, and $T = 1436$ °F. The sharp, central peak indicates either very high correlation between the temperature and velocity fluctuations or a noise problem. This is under investigation.

FUTURE EFFORTS

Future efforts will proceed in several areas. One will be a closer investigation of the cross correlation for smaller time delays. Cross correlations calculated using uncompensated temperature signals showed peaks for time delays of a few milliseconds (ref. 4). Data from the other probe locations will also be reduced, as the degree of correlation can be expected to decline as more room air is entrained in the flow. The density-velocity product as a function of time must also be generated; it will then be possible to compare turbulence intensity based on velocity with that based on the density-velocity product.

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DUAL WIRE THERMOCOUPLE PROBE

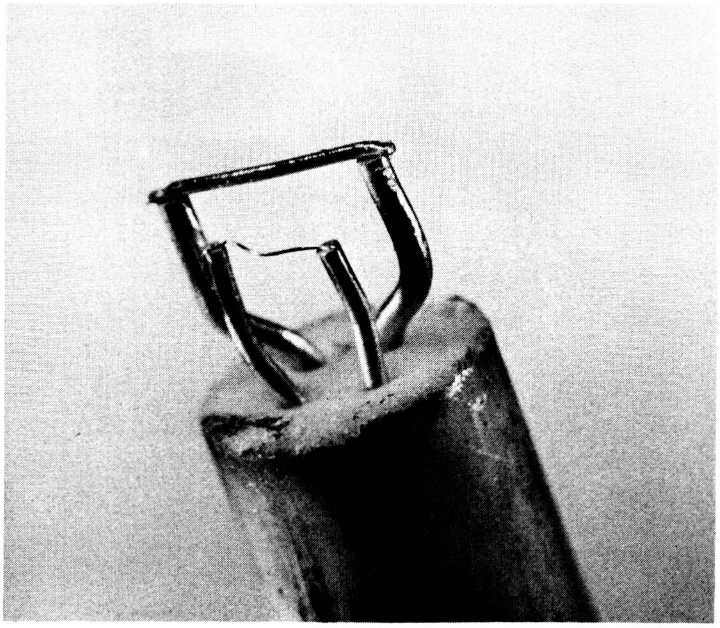

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Figure 1

DUAL WIRE THERMOCOUPLE AND LDA SAMPLING VOLUME IN EXHAUST OF ATMOSPHERIC BURNER

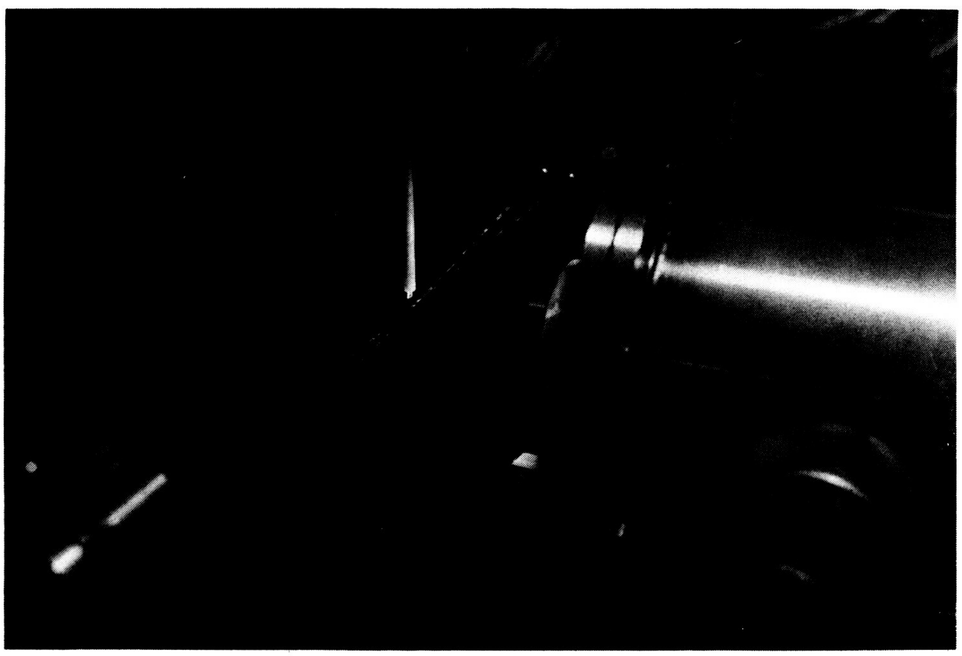

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Figure 2

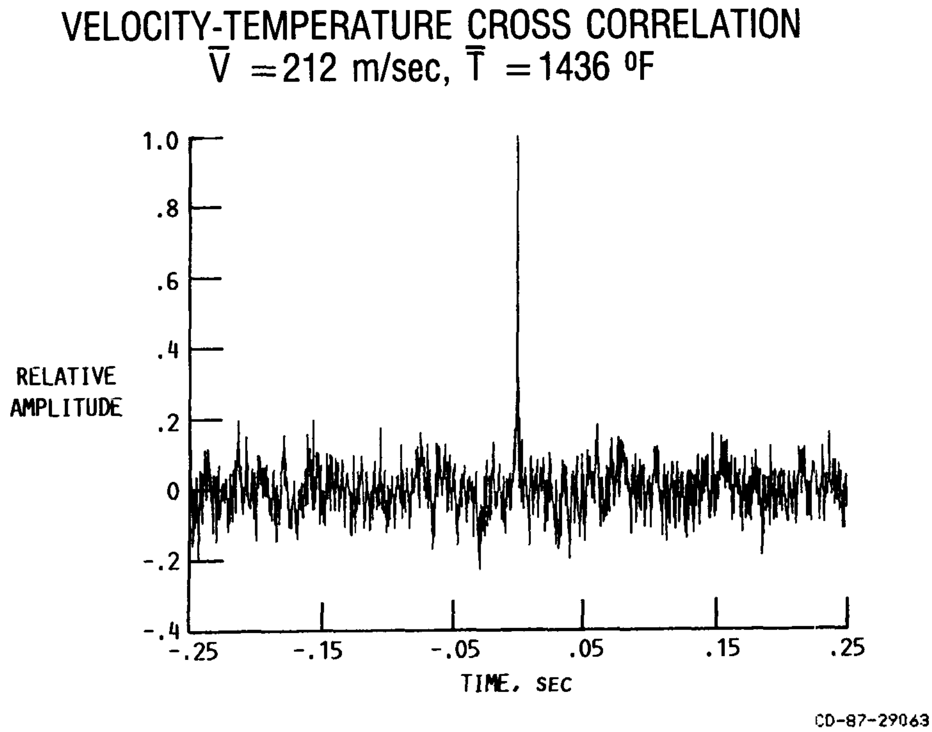
VELOCITY-TEMPERATURE CROSS CORRELATION
$\bar{V}$ = 212 m/sec, $\bar{T}$ = 1436 °F
1.0
.8
.6
.4
RELATIVE
AMPLITUDE
.2
0
-.2
-.4
-.25
-.15
-.05
.05
.15
.25
TIME, SEC
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Figure 3