N88-11147

CORRELATION OF VELOCITY AND VELOCITY-DENSITY TURBULENCE IN THE EXHAUST OF AN ATMOSPHERIC BURNER

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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 to be 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 740 to 1620 °F, Mach numbers from 0.26 to 0.38, and values of Reynolds number divided by characteristic length in the range 33 000 to 64 000 in^{-1}. Temperature fluctuations as great as $\pm$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 (ref. 1). 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-type laser-doppler anemometer (ref. 2), with sampling volume location varied from 0.2 to 2.5 mm upstream of the thermocouples. Data rates varied from 400 Hz for unseeded flow to 15 kHz for fully seeded flow.

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 stored are the ac-coupled voltages from both thermocouples, which will permit 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 $v_{rms}/\bar{v}$, $(\rho Z)_{rms}/\rho\bar{v}$, and their autocorrelations to 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 the temperature signal from the 3-mil thermocouple; figure 4 is the cross correlation of the same signal from the 10-mil thermocouple. The correlations were calculated at a 5-kHz sampling rate. Both figures relate to the same flow; $M = 0.28$, $Re/L = 32\,000\ in^{-1}$, $T = 1581$ °F. In both cases, the temperature signals were uncompensated for the frequency response of the thermocouples. When the temperature signals are compensated, the shape of the cross correlation curves may change, but it can be seen that the two quantities, velocity, and density are correlated; they show a characteristic cross correlation peak. A distinctive characteristic of the curves is the delay between the velocity and density. This was seen in all the data, for 13 different flow conditions, with seeded or unseeded flow. The delay was consistently greater for the larger thermocouple, but as yet, we are unable to relate the delay to the time constant of the thermocouples.

FUTURE EFFORTS

Future efforts will proceed in several areas. One will be further analysis on the effect of sensor time constant on correlation delay. The above described correlations will also be repeated after the temperature signals are compensated for. The density-velocity product as a function of time must also be generated; it will then be possible to compare turbulence based on velocity with that based on the density-velocity product. Having done that, the experiments will be rerun with heat-flux instrumentation in the flow field. This will permit relating the convective heat-transfer coefficient to both the velocity and velocity-density turbulence.

REFERENCES

1. Elmore, D.L.; Robinson, W.W.; Watkins, W.B.: Dynamic Gas Temperature Measurement System. NASA CR-168267.

2. Seasholtz, R.G.; Oberle, L.G.; Weikle, D.H.: Laser Anemometry for Hot Section Applications Turbine Engine Hot Section Technology-1983. NASA CP-2289, 1983, pp. 57-68.

DUAL WIRE THERMOCOUPLE PROBE

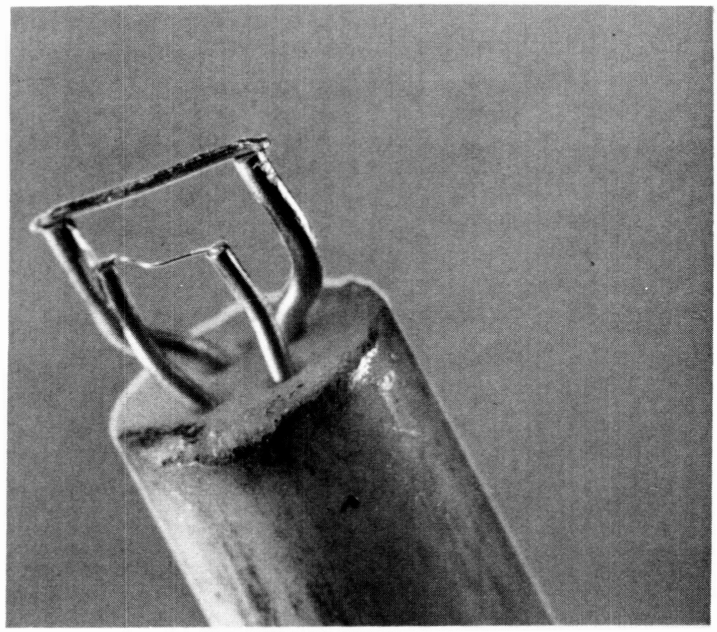

Figure 1

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

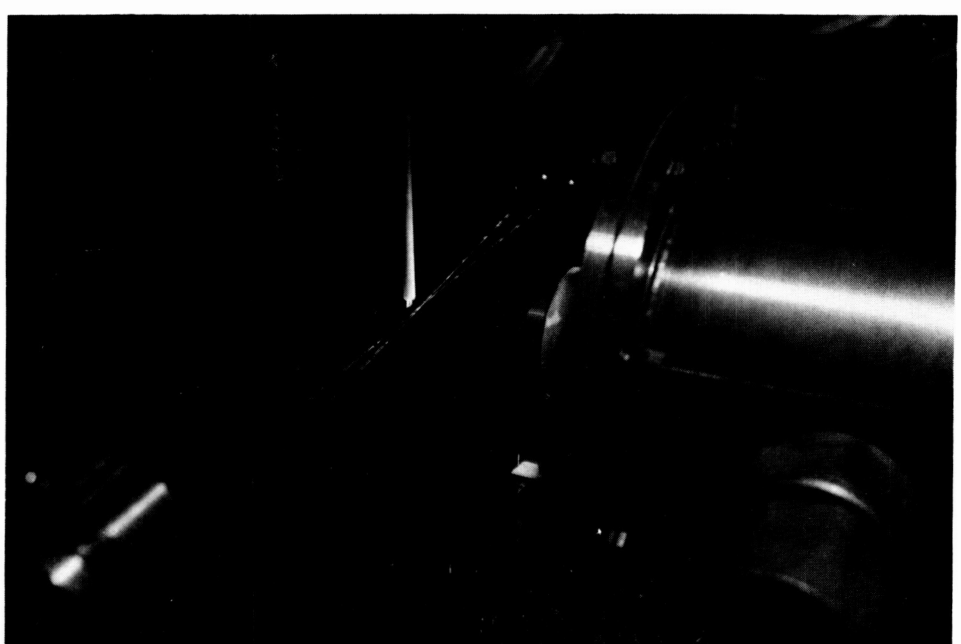

Figure 2

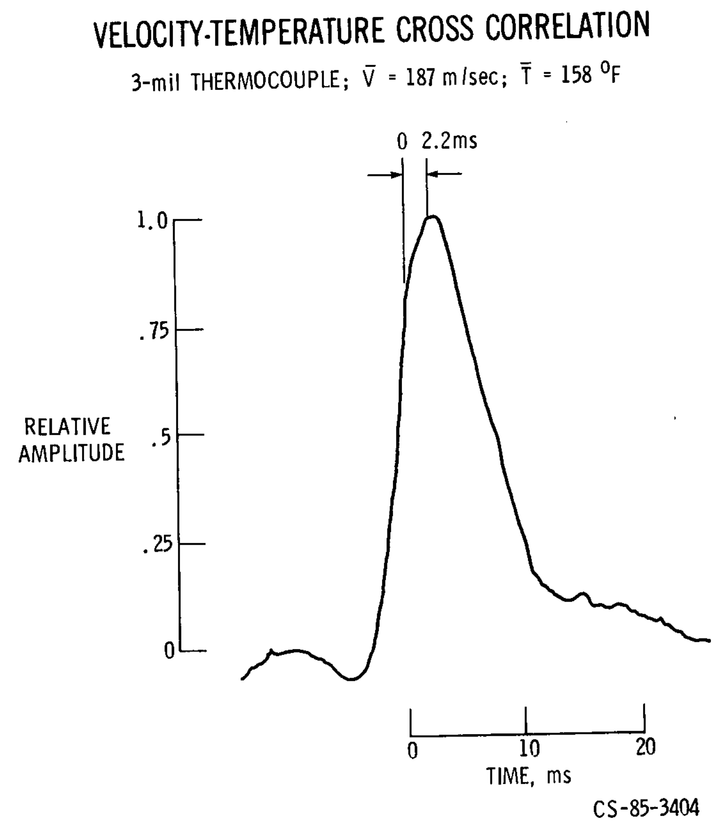

Figure 3

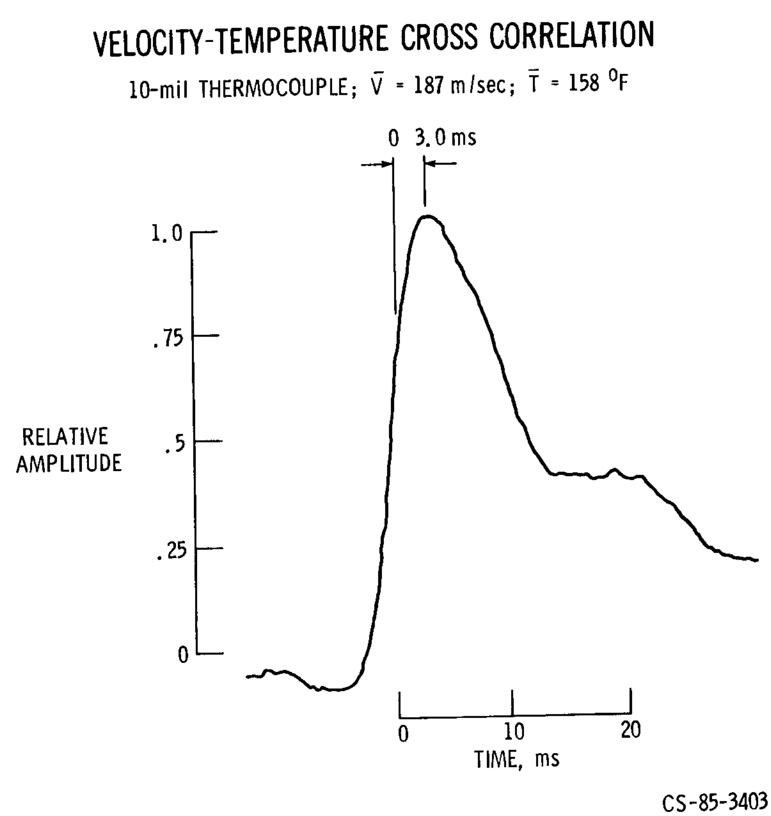

Figure 4