SELF-PRESERVING ROUND BUOYANT TURBULENT PLUMES: IMPLICATIONS FOR TURBULENCE MODELS

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Introduction. Turbulence models are often used to analyze practical fires due to the computational intractability of fully resolved three-dimensional time-dependent simulations of practical buoyant turbulent flows. Developing reliable turbulence models, however, has been inhibited due to the absence of measurements; therefore, the objective of the present investigation is to complete measurements within round buoyant turbulent plumes, emphasizing self-preserving conditions far from the source. Present considerations include classical similarity concepts [1] and turbulence models of varying complexity [2,3]. Detailed discussion of the investigation can be found in [4-6].

Experimental Methods. Dense gas sources (carbon dioxide and sulfur hexafluoride) in still air were used to generate the test plumes. Mixture fraction and velocity statistics were measured using laser-induced iodine fluorescence (LIF) and laser velocimetry (LV), respectively.

Results and Discussion. The most significant finding has been that earlier plume measurements failed to reach self-preserving conditions [4-6]. This difficulty was not recognized in the past, causing controversy and impeding the development of turbulence models. The problem is illustrated in Fig. 1, where a similarity variable for mean mixture fraction, F, is plotted as a function of the radial plume similarity variable. The plots include turbulence model calculations and earlier measurements summarized in [2], as well as the present measurements. In order to match predictions and earlier measurements, the model constant, C_μ, was increased from 0.09, its well-established value, to 0.15-0.18 [2]. In contrast, present measurements of truly self-preserving plumes indicate a narrower flow and agree with predictions using the standard value of C_μ; consideration of velocities yielded similar results.

Quantities like the rms mixture fraction and streamwise velocity fluctuations, $\bar{f}'$ and $\bar{u}'$, must be known in order to treat developing flows but finding $\bar{f}'$ is problematical for buoyant flows. This difficulty is illustrated in Figs. 2 and 3 where $\bar{u}'$, and $\bar{f}'$ are plotted for self-preserving conditions [4-6]. The behavior of $\bar{u}'$, (Fig. 2) is similar to nonbuoyant flows [3] and is given reasonably well by the models used in [2]; however, $\bar{f}'$ (Fig. 3) has large values near the axis due to buoyancy-turbulence interactions not treated in [2]. The difficulty is caused by the large streamwise gradient of mean mixture fraction which contributes a production term for $\bar{f}'$ that normally is ignored using the conventional boundary-layer approximations.

Temporal power spectra are another interesting feature of buoyant turbulent flows. Examples of temporal spectra of $\bar{u}'$ in the self-preserving region are illustrated in Fig. 4 but results for $\bar{f}'$ are similar [4-6]. The spectra initially decay according to the -5/3 power of frequency similar to the inertial-convection region of conventional nonbuoyant turbulence, but then exhibit a -3 power decay rate within an inertial-diffusive subrange that only is observed for buoyant turbulent flows [4-6].

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References

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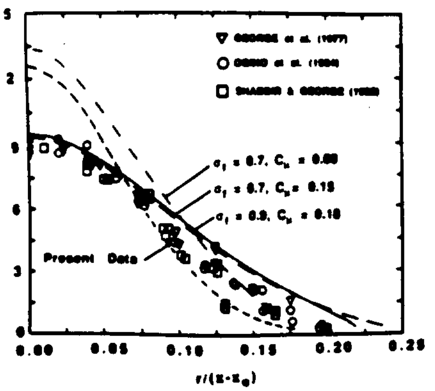

Fig. 1 Predicted and measured mixture fractions.

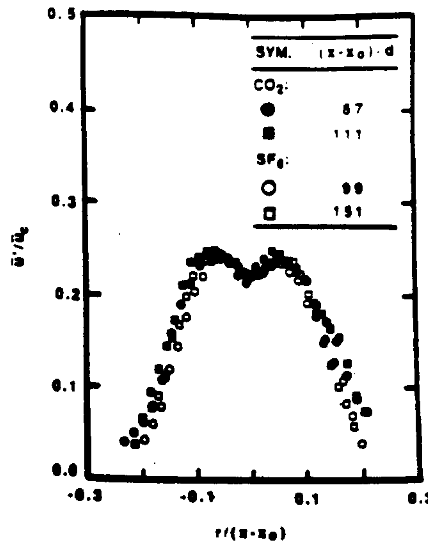

Fig. 2 Radial profiles of streamwise velocity fluctuations

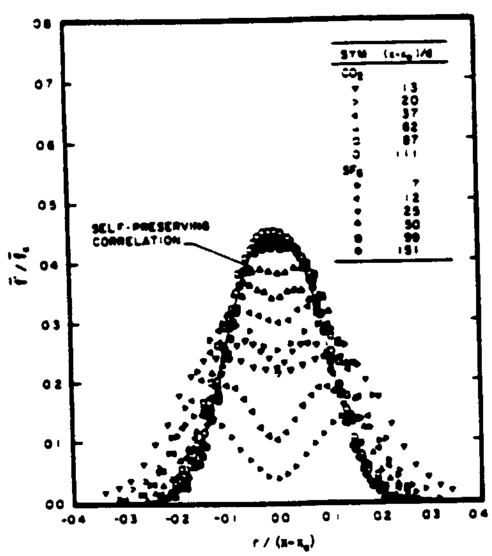

Fig. 3 Radial profiles of mixture fraction fluctuations.

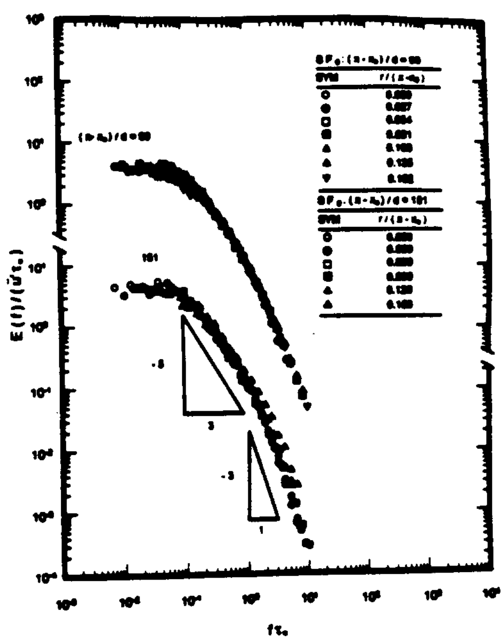

Fig. 4 Temporal power spectra of streamwise velocity fluctuations.