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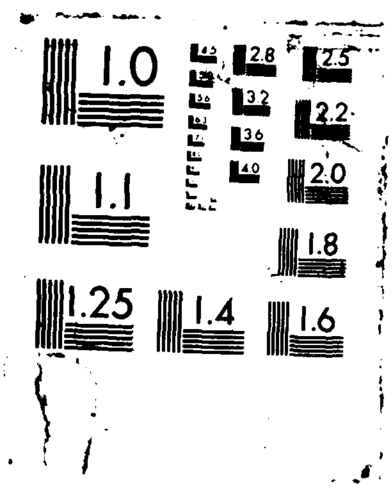
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An experimental investigation of the relationship between flow structure and chemical reaction in turbulent reacting flows is in progress. The principal objective of the research is to examine the spatial structure of the unsteady reaction process as it relates to the unsteady velocity field. The configuration chosen for study is a co-flowing, non-premixed jet flame. A small perturbation in the fuel jet velocity, produced acoustically, is used to create a very periodic and controllable flame, suitable for conditional sampling. Initial measurements of the unsteady velocity field in the flame have been obtained using laser anemometry. In addition, flow visualization experiments have been conducted using direct and schlieren photography and Mie scattering from seed particles introduced into the flow. Planar laser-induced fluorescence images of the OH radical, which provide spatially and temporally resolved information on the instantaneous location of the reaction zone, have been obtained. A particle tracking technique to facilitate acquisition of velocity field data has been developed, and is being used to provide velocity field data to be overlaid on the reaction field data to reveal the flame-flow interaction. KEYWORDS

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AN INVESTIGATION OF FLOW STRUCTURE, MIXING AND CHEMICAL REACTION IN COMBUSTING TURBULENT FLOWS

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SUMMARY

An experimental investigation of the relationship between flow structure and chemical reaction in turbulent reacting flows is in progress. The principal objective of the research is to examine the spatial structure of the unsteady reaction process as it relates to the unsteady velocity field. The configuration chosen for study is a co-flowing, non-premixed jet flame. A small, acoustically produced, perturbation in the fuel jet velocity is used to create a very periodic and controllable flame, suitable for conditional sampling. Initial measurements of the unsteady velocity field in the flame have been obtained using laser anemometry. In addition, flow visualization experiments have been conducted using direct and schlieren photography and Mie scattering from seed particles introduced into the flow. Planar laser-induced fluorescence images of the OH radical, which provide spatially and temporally resolved information on the instantaneous location of the reaction zone, have been obtained. A particle tracking technique to facilitate acquisition of velocity field data has been developed and is presently being used to map planar velocity fields in the flame. This data will be overlaid on the reaction field data to reveal the flame-flow interaction. In an effort to better understand the fluid mechanics of the flame we have initiated an investigation of a co-flowing helium jet which simulates the overall density variation in the flame. Under certain conditions the helium jet exhibits an extraordinarily repeatable fine scale structure. Future work will involve the use of the particle tracking technique to measure velocity fields in the helium jet and the investigation of techniques for controlling the fine structure of the jet.

BACKGROUND AND RESEARCH OBJECTIVES

Recent research in turbulent combustion has focused on establishing appropriate models for the interaction between turbulence structure and flame chemistry. Although our understanding of the physics of mixing and combustion has improved, there are as yet no data which directly reveal the coupling between the unsteady velocity field and the unsteady reaction field in a combusting flow. The objective of the present work is to combine time-resolved field measurements of velocity and of the concentration of short-lived species in a time-dependent hydrocarbon-air flame. Interpretation of the results will employ topological methods which have been used to characterize the structure of non-reacting flows. This methodology provides a unified approach for characterizing various strain and rotation fields which can occur in turbulent flows. The work will lead to an improved understanding of the sequence of flow events involving entrainment, mixing and reaction of free stream reactants in unsteady flames. Information of this type should contribute to improved models of combustion.

STATUS OF RESEARCH

The configuration investigated in this study is a co-flowing, non-premixed jet flame, with methane in the core flow and air in the surrounding flow. The methane passes through a small chamber containing a loudspeaker which can be used to add a velocity perturbation to the core flow at various frequencies and amplitudes. During the third year of the program, progress has been made in the following areas:

1) Use of a particle tracking technique to make instantaneous planar measurements of the velocity vector field in the flame.

Our experience using laser anemometry to measure velocities in the pulsed co-flowing jet flame has led us to consider techniques to measure the velocity field over a plane rather than at a single point. Therefore, in conjunction with this research, we have purchased a copper-vapor laser which we are using to produce a pulsed sheet of light illuminating small particles suspended in the flame. In developing the technique we have investigated particles of titanium dioxide produced by the reaction of water vapor with titanium tetrachloride upstream of the jet exit and aluminum oxide particles from a fluidized bed. Although the titanium dioxide particles are useful for visualizing the colder portions of the flame they tend not to be found in the hotter portions of the flame. We have attributed this partly to thermophoresis and partly to differential diffusion between the gaseous fuel and solid particles. Scanning Electron Microscope pictures together with mass spectrometer data reveal that the titanium dioxide particles, which are typically on the order of a micron in size, contain significant amounts of water and hydrochloric acid. It appears that those particles that do reach the hot combustion zone tend to lose much of their mass through evaporation leaving behind crystalline material which is too small to scatter sufficient light to expose the film. In addition to these problems we have not had good success at getting the titanium dioxide seeding to be repeatable. At the present time aluminum oxide particles seem to be the best choice for our measurements. Further discussion of some of these issues is given in reference 3.

Figure 1 is an image of particle tracks in the pulsed flame at one phase of the excitation cycle. Each track is identifiable as a sequence of three dots forming a straight line. Both the inner and outer flow fields have been seeded with Aluminum oxide particles. Images of this type obtained at various phases of the excitation cycle allow observation of the unsteady development of the flame. The crosses visible in Figure 1 are fiducial marks which are used to accurately align the images at various heights above the jet tube to give an overall view of up to fifteen diameters of the flame at a given phase.

The flame images are digitized using a Princeton scanner with a maximum resolution of 300 dots per inch and software has been developed which converts the image data to velocity vector field information. The algorithm is based on a search technique which first locates the centroids and diameters of all the particles in the field. Once these have been identified an initial particle is chosen and the program proceeds outward on a series of circles of increasing radius until a nearest neighbor is identified. This defines an angular region within which a further search is carried out to identify a third particle which is collinear with the first two. If the second search is successful a velocity vector is formed. All the particles in the image are processed in this fashion with due consideration to particle overlap and possible repeat encounters with the same particle. Processing of a typical image takes approximately one to two minutes depending on the number of particles which have to be processed. Although in a few instances obviously incorrect vectors are generated, preliminary results with this software have been encouraging. We have applied the process to an image of the near field of the jet under steady noncombusting conditions. This image was digitized previously by hand to generate the parabolic profile at the jet exit. With automated processing the scatter about the parabolic profile was reduced by about a factor of two.

2) Planar laser-induced fluorescence of flame radicals.

In order to visualize the unsteady reaction field, instantaneous images of key chemical species are being obtained using laser-induced fluorescence. We are presently using a new high-resolution camera system, to obtain images of the OH radical concentration field at a number of different phases in the excitation cycle. These images show that OH is a reasonably good indicator of flame location in the flow, but that OH images yield flame thicknesses that are too large. To obtain a more accurate measurement of flame thickness, which is useful for interpreting the effects of the strain field on the flame, planar fluorescence imaging of the CH concentration field has been attempted. Since the CH radical is short-lived and exists only in the reaction zone of the flame, it should provide a better measure of flame thickness than the longer lived OH radical. In the initial experiments, low signal-to-noise ratios precluded accurate measurement of the CH radical concentration field in the presence of soot luminosity. Utilization of a more sensitive camera system and a more powerful pump laser, currently available in our laboratory, should allow meaningful CH images to be obtained.

3) Rayleigh Scattering Measurements

In non-premixed jet flames, the scalar concentration field can be used to quantify mixing between the fuel and oxidizer flows. We have initiated a study of Rayleigh scattering as a means of inferring the instantaneous scalar concentration field from measurements of laser light scattering from an inert tracer species, with a large Rayleigh scattering cross-section, which has been added to the fuel jet. Initial concept validation experiments are being conducted in a steady, laminar hydrogen jet flame in which CO_2 or SF_6 is added to the hydrogen flow. For the flame conditions investigated, probe measurements show virtually no reaction of the tracer species.

FUTURE WORK

In the fourth year of this program, the following tasks will be performed:

1) Early in the fourth year we will be completing a series of "for the record" experiments which are presently underway. These will combine high resolution OH and possibly CH images with velocity vector images at a number of phases of the flame excitation cycle. These measurements will finally give us a direct view of the evolution and development of the chemical reaction field and the velocity field in an unsteady diffusion flame. Topological methods will be used to interpret the data.

2) The unusual structure of the helium jet will be investigated using the copper-vapor laser to measure planar velocity fields and to provide sheet illumination of a seed material. for visualizing the three-dimensional structure of the flow.

3) Methods for controlling the fine scale structure of the helium jet will be investigated.

It is expected that the results will lead to new information on the structure of variable density flows, to an identification of methods for controlling such flows and to an improved understanding of some of the mechanisms by which flow control works. With the experimental data becoming available, there is a strong need for a parallel computational effort on the same flow geometry. This effort will be essential for a complete understanding of the fluid mechanics of this flame and for the development of useful models.

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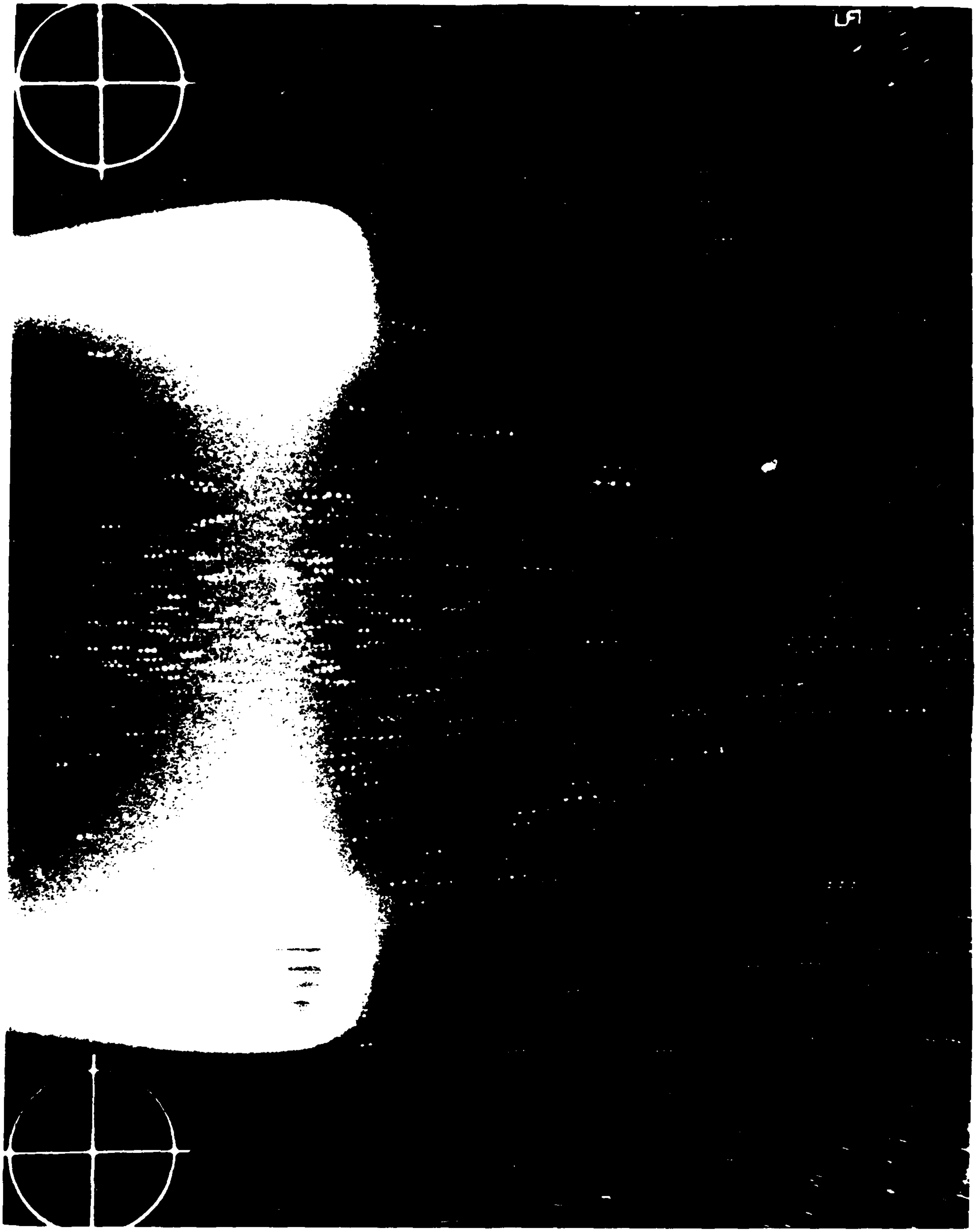

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