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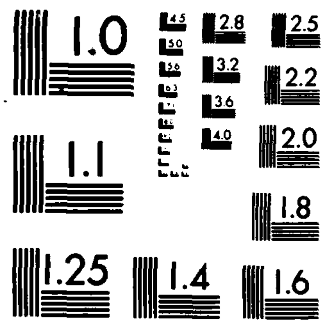

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AD-A174 515

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

Annual Technical Report
September 1, 1985 to August 31, 1986

AFOSR Grant Number 84-0373A

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SUMMARY The principal objective of these

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 studied ~~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 is being developed. Future work will involve overlaying the velocity field and reaction field data to reveal the flame-flow interaction.

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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 is being developed. Future work will involve overlaying the velocity field and reaction field data to reveal the flame-flow interaction.

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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 results from this study can be used to address the following important question: how much detail of the physics of the flame-turbulence interaction is required for the development of models for a given level of prediction?

STATUS OF THE 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 loudspeader which can be used to add a velocity perturbation to the core flow at various frequencies and amplitudes. During the second year of the program, progress has been made in the following areas.

1) <u>Completion of experiments in the variable pressure flow facility to document the structure and controllability of the pulsed flame over a range of flow conditions.</u>

Preliminary results from these experiments were discussed in the First Annual Technical Report. During the past year, single velocity component measurements at several different test section pressures were completed. The LDA measurements of the streamwise velocity were conditioned on the phase of the jet excitation. Aluminum-oxide particles were used to seed the jet fluid and water particles were used to seed the outer fluid. Various schemes were used with both streams seeded simultaneously and then each stream seeded separately to further condition the velocity measurements on the basis of whether the particles marked jet fluid or free stream fluid. The velocity data support earlier flow visualization observations of the flame. In particular, the effect of forcing on the breakup of the flame and the associated reduction of flow acceleration and turbulence levels was confirmed. Complete documentation and discussion of the experiments can be found in References [1] and [2].

2) Development of a particle tracking technique for making instantaneous measurements of the velocity vector field in a plane.

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 ratner 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. The particles are titanium dioxide produced by the reaction of water vapor with titanium tetrachloride upstream of the exit of the jet tube.

Figure 1a is a close-up of particle tracks near the jet exit in a non-combusting flow without pulsing. Each track is identifiable as a sequence of three dots forming a straight line. This print was processed manually to produce the velocity profile in Figure 1b. The agreement with the expected parabolic shape is quite good, and these preliminary results have encouraged us to pursue this technique for making field velocity measurements in the pulsed jet diffusion flame. Currently we are evaluating various means of automatically reading these images and constructing the vector field.

Figure 2 shows a high density of particles in the case where the jet flow is pulsed, but noncombusting. At this seeding density, the individual velocity vectors are not distinguishable, but a general streamline pattern can be discerned. Note that a continuation of the pattern into the unseeded external flow would seem to match with a toroidal eddy surrounding the jet with its center outside the seeded region.

Figure 3 is a composite of particle track photographs taken in the flame at the same phase but at various heights above the jet exit. They form an image of the velocity field in the core of the flame over the first 15 jet diameters of the flow. Each of the blocks in this figure was taken at a different time; the fact that they fit together reasonably well is evidence of the repeatability of the flame.

3) Flowfield visualization using Mie scattering from TiO_2 seed particles.

In order to reveal, qualitatively, the structure of the unsteady reacting flow, a sequence of images of laser light scattering from TiO_2 seed particles were obtained. In these experiments, TiO_2 particles were produced by reacting $TiCl_4$ vapor in a dry fuel jet with water vapor formed in the flame. The light source for the scattering measurements is the pulsed copper vapor laser. The output from the laser is formed into a sheet, which illuminates a diametric plane in the flame. Photographs of the scattering signal were recorded on photographic film. A sequence of these images, taken at eight equally-spaced times in the excitation cycle, is shown in Figure 4a. The images reveal the complex structure of the flow, with key features being vortical structures and an inner stagnation point.

4) Planar laser-induced fluorescence images of the OH radical.

In order to visualize the unsteady reaction field, instantaneous images of key chemical species will be obtained using laser-induced fluorescence. To date, we have obtained images of the OH concentration field. A sequence of these images, at the same points in the excitation cycle as in Figure 4a, are shown in Figure 4b. From the evolution of the species images, it is clear that OH is a good indicator of the zones of chemical reaction in this flame.

FUTURE WORK

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

1) Continue development of the particle tracking technique for making velocity field measurements. This involves developing an improved seeding method, perfecting the particle imaging, adding fiducial marks to the images and developing a technique for digitizing images. In this connection, we have purchased a Macintosh-based optical scanner that enables us to digitize images at a maximum resolution of 300 dots per inch with six bits of gray scale data per dot. We are now experimenting with processed images, with the goal of developing algorithms for image noise reduction and particle track identification.

2) Use the particle tracking technique to obtain planar velocity field measurements at various phases of the flame excitation. The variable pressure flow facility will be used to carry out these measurements in order to allow seeding of both the jet fluid and free-stream fluid.

3) Continue planar laser-induced fluorescence measurements of radical species to obtain the unsteady reaction field at various phases of flame excitation. Additional data on OH distributions will be obtained, and attempts will be made to image the CH radical.

4) Overlay velocity field and reaction field data.

With the experimental data being 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.

PUBLICATIONS

1) Strawa, Anthony W., and Brian J. Cantwell, "Visualization of the Structure of a Pulsed Methane-Air Diffusion Flame," Physics of Fluids 28, 2317, 1985.

2) Vandsburger, U., G. Lewis, J. M. Seitzman, M. G. Allen, C. T. Bowman and R. K. Hanson, "Flame-Flow Structure in an Acoustically Driven Jet Flame," Paper 86-19, presented at the Western States Combustion Institute Meeting, 1986.

PERSONNEL

Dr. C. T. Bowman, Professor

Dr. B. J. Cantwell, Associate Professor

Dr. U. Vandsburger, Research Associate

Mr. A. W. Strawa, Research Assistant

Mr. G. Lewis, Research Assistant

INTERACTIONS

1) Bowman, C. T. and B. J. Cantwell, "Investigations of Flow Structure, Mixing and Chemical Reaction in Reacting Turbulent Flows," presented at the 22nd JANNAF Combustion Meeting, 1985.

2) Vandsburger, U., G. Lewis, J. M. Seitzman, M. G. Allen, C. T. Bowman and R. K. Hanson, "Flame-Flow Structure in an Acoustically Driven Jet Flame," Poster presented at the 21st International Combustion Symposium, 1986.

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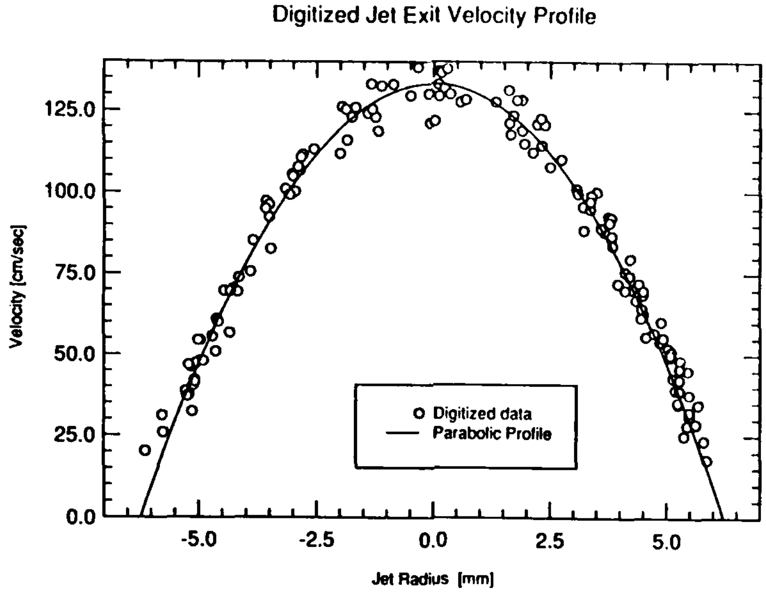
1) Strawa, A. W. and B. J. Cantwell, "The Effect of Pressure Variation on the Structure of a Pulsed Methane-Air Diffusion Flame," Paper WSS/CI 85-25 presented at the Western States Section of the Combustion Institute Fall Meeting, U.C. Davis, October 21-22, 1985.

2) Strawa, A. W., "An Experimental Investigation of the Structure of an Acoustically Excited Diffusion Flame." Stanford University Department of Aeronautics and Astronautics Ph.D. thesis and SUDAAR 558, August 1986.

Figure 1b



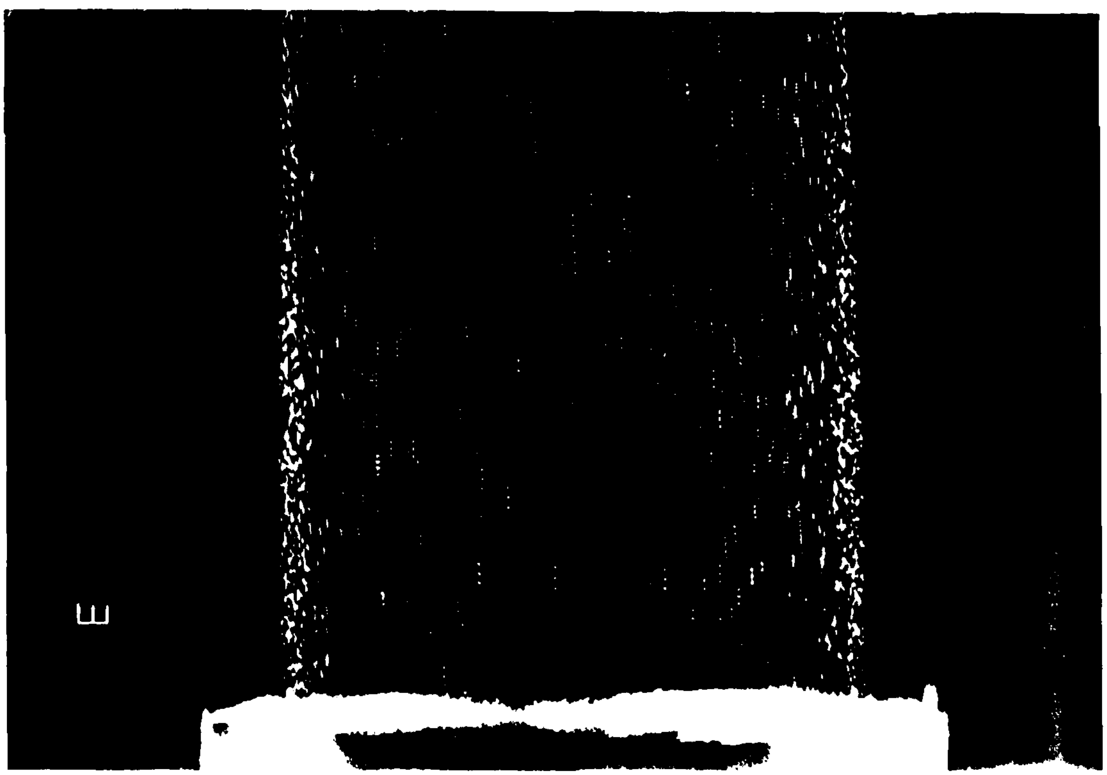


Figure 1a

Figure 2

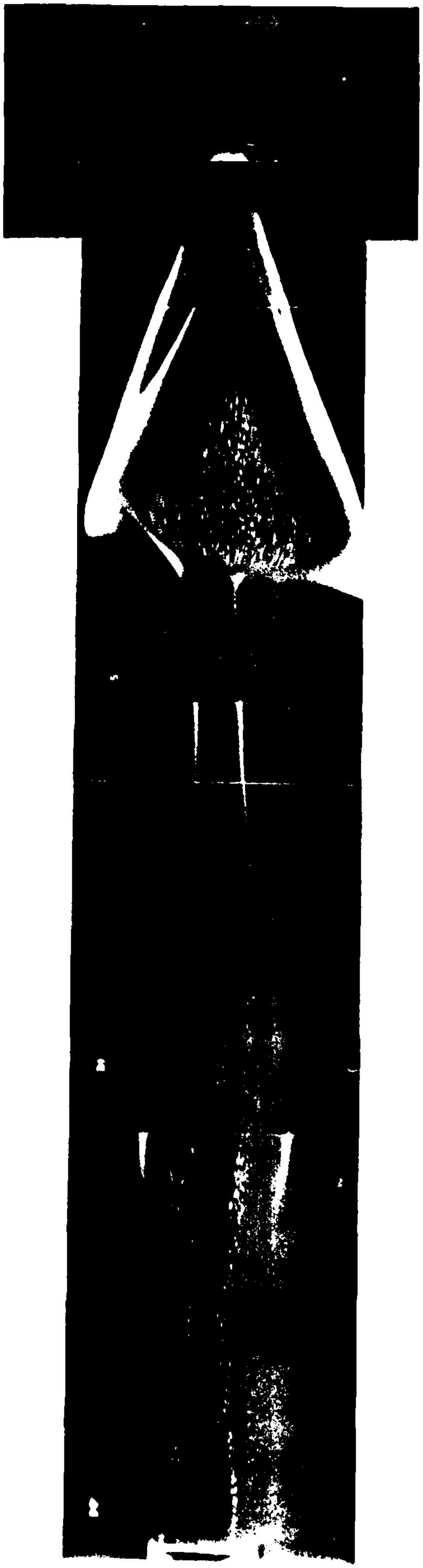


Figure 3

Figure 4a

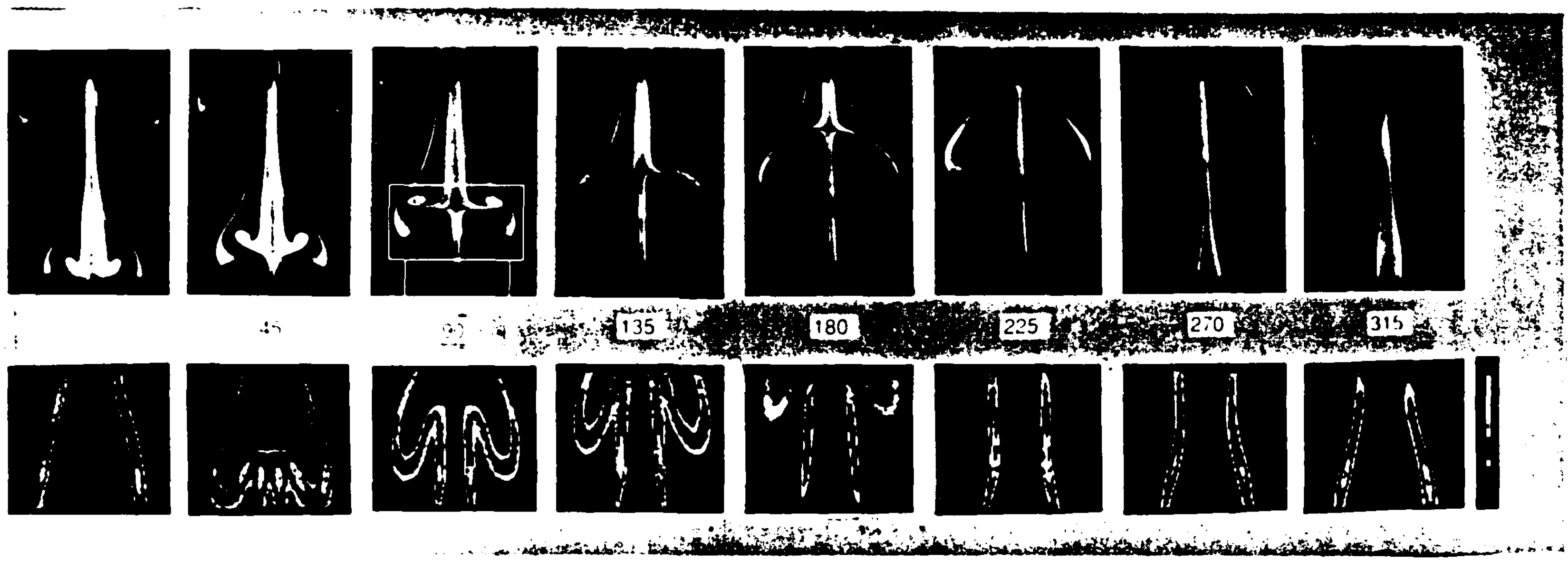


Figure 4b

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