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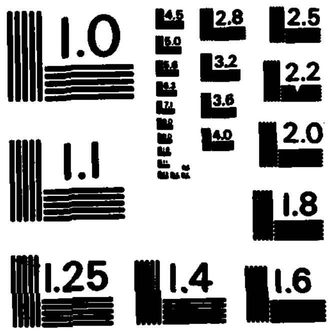

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LASER RAMAN PROBE FOR COMBUSTION DIAGNOSTICS

FINAL REPORT
April 16, 1979 through April 29, 1980

Submitted to

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The objective of this work is to apply light scattering diagnostics to the study of a well-defined combustion flow. Product gas densities are measured for a turbulent jet diffusion flame through use of vibrational Raman scattering techniques. These are combined with simultaneous temperature data from Raman scattering and near-simultaneous velocity data from laser velocimetry (developed in earlier parts of our work for ONR) to give an integrated probe system for basic flame properties.

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FINAL REPORT - TECHNICAL SUMMARY

This report presents a technical summary of work accomplished under the ONR sponsorship of Contract N00014-79-C-0381, NR 094-405, for the period of April 16, 1979 to April 29, 1980.

Abstract

The objective of this work is to apply light scattering diagnostics to the study of a well-defined combustion flow. Product gas densities are measured for a turbulent jet diffusion flame through use of vibrational Raman scattering techniques. These are combined with simultaneous temperature data from Raman scattering and near-simultaneous velocity data from laser velocimetry (developed in earlier parts of our work for ONR) to give an integrated probe system for basic flame properties.

Background

The overall goal of this phase of our ONR research effort was to measure simultaneously the fluctuation values of flame temperature, product gas density, and axial flow velocity for a turbulent diffusion flame. The key new ingredient in the work described here is the measurement of product gas (H_2O) density, which was then combined with data from our previously-developed temperature and velocity probes. This demonstration of an integrated non-intrusive probe system from compatible techniques (viz., spontaneous vibrational Raman scattering and laser velocimetry) indicates that correlations and histograms of thermodynamic and flowfield properties essential for an improved understanding of combustion devices can be achieved by optical scattering means.

Histograms (probability density functions) are of strong value in the analytical understanding of both the chemical kinetic and fluid mechanic properties of combustion systems. This is illustrated by the exponential dependence of chemical species reaction rates upon instantaneous local values of temperature (rather than on time- or space-averaged values). An example of the fluid mechanic importance of fluctuation temperature histograms is their use in defining the flow intermittency at turbulent fluid mixing layers, a result we have demonstrated with temperature histograms.

Various correlations of temperature, product gas density, and velocity are needed in order to complete analyses of important turbulent combustion flows. (Total gas density is also needed, and can be determined from product gas density plus nitrogen density data obtained in the course of measuring temperature from nitrogen Raman signals.) To obtain equations for the mean flow parameters, the time mean or the ensemble average of the relevant unsteady conservation equations is taken. A result of this process is the introduction of terms involving the mean value of various fluctuating quantities, appearing coupled together in various fashions, and leading to a difficult problem for solution of these equations known as the turbulence closure problem. Direct and correlated measurements of important fluctuation parameters will help greatly in the evaluation of key terms in these conservation equations, and will thereby aid in the overall production of a useful combustion flow model.

Achievements

A new laboratory combustor was designed and fabricated for well-characterized combustion experiments. This device is a fan-induced co-flowing jet tunnel with a 3-mm-diameter fuel tube, producing a turbulent diffusion flame along the axis of a 15 cm x 15 cm square test section. Glass viewing ports permit almost 1 m of optical access. The shear-induced turbulence is controlled by variable coaxial air flows. Low levels of baseline turbulence (found by hot-film anemometry to be about 0.2% in the test zone without fuel tube flow) were achieved through use of a converging inlet section containing screen and honeycomb partitions before the test zone as well as overall careful aerodynamic design of the tunnel.

A critical feature of coordinated probe measurements is that each probe should sample as nearly an identical test element as possible. Optical alignment becomes critical, since the volume involved is small (~0.1 mm characteristic dimension), and since different parts of the flame must be sampled. Close temporal coincidence is also required. These problems have been solved by designing the tunnel to be movable in three dimensions, permitting the use of fixed-bed optics that can be kept in alignment to very close tolerances, and by triggering the Raman laser source from a validation pulse from the velocimetry processor.

Spectral detection for the Raman data is achieved with photomultipliers and associated individually-set exit slits placed in a polychromator housing attached to a 3/4m single spectrometer. The signal from each photomultiplier is sensed by sample-and-hold circuitry immediately preceeding and immediately following each 1J Raman source laser pulse (with a repetition rate of 1 pulse every 3 s).

The accuracy of the data from this new Raman probe system was assessed by tests made with known, well-calibrated laminar pre-mixed H_2-air flames produced on porous plug burners. Roughly 5-7% standard deviations for the temperature data were found. Additional tests on the accuracy of the experimental results were made by application of newly-developed validation procedures for the N_2 and H_2O vapor data, based upon comparisons of the experimental data with values theoretically predicted from adiabatic flame calculations. These comparisons illuminated technical problems in the spectroscopic detection techniques used for the H_2O vapor channel that had been recognized in prior work, and for which additional effort finally provided solutions. The major part of this aspect of the program involved the development of new procedures to accurately assess that part of the very broad temperature-sensitive H_2O vibrational Raman scattering contour that was passed by its corresponding spectrometer exit slit, in order to obtain accurate H_2O density data. Following this development, the temperature/product gas density/velocity probe system was made operational, and the required flame data were acquired.

Publications

The following is a listing of publications supported in part by ONR that detail the research results described here.

M. Lapp, C.M. Penney, S. Warshaw, and M.C. Drake, "Unlocking the Secrets of Combustion," Industrial Research/Development <u>21</u>, 116 (1979).

S. Warshaw, M. Lapp, C.M. Penney, and M.C. Drake "Temperature-Velocity Correlation Measurements for Turbulent Diffusion Flames from Vibrational Raman Scattering Data," in <u>Laser Probes for Combustion Chemistry</u>, American Chemical Society Symposium Series, Vol. 134, D.R. Crosley, Ed., American Chemical Society, Washington, D.C., 1980, Chapt. 19.

M. Lapp, "Raman Scattering Measurements of Combustion Properties," in <u>Laser Probes for Combustion Chemistry</u>, American Chemical Society Symposium Series, Vol. 134, D.R. Crosley, Ed., American Chemical Society, Washington, D.C., 1980, Chapt. 17.

M. Drake, M. Lapp, C.M. Penney, and S. Warshaw, "Characterization of Turbulent Flames by Single-Pulse Raman Measurements," in <u>Proceedings of the 7th International Conference on Raman Spectroscopy</u>, W.F. Murphy, Ed., North-Holland Publishing Co., Amsterdam, 1980, p. 230.

M. Lapp and R.M.C. So, "The Study of Turbulent Diffusion Flames: Modeling Needs and Experimental Light Scattering Capabilities," <u>AGARD Conference Proceedings No. 281 on Testing and Measurement Techniques in Heat Transfer and Combustion</u>, 1980, Chapt. 19.

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