microphone was buried deeper within the surface. It would serve no useful purpose to further trace this attenuation in the interior model structure at this point, which is complex and peculiar to the model design.

This work has demonstrated that flow instabilities at hypersonic speeds generate intense pressure fluctuations on the cone surface, which do penetrate the surface to some distance and which persist with regularity even when the cone executes maneuvers relative to the flight vector such as pitch and roll. At a boundary-layer edge Mach number M_e of about 7, the results of Refs. 2, 4, 5, etc., indicate that the frequency of these oscillations scales with f and the edge velocity U_e as $f \doteq U_e/2\delta$; it should be noted,[13] however, that this scaling is invalid for $M_e < 2.5$. Finally, it must be also noted that these are Mach number ranges (e.g., $M_e \simeq 3$) for which monochromatic oscillations do not appear[3,14] and that at still lower M_e levels the laminar waves would be incapable of producing pressure fluctuations intense enough to be detected on the surface.

Acknowledgment

This work was supported by U.S. Air Force Contracts F04701-77-C-0113 and F04701-72C-0027.

References

[1]Potter, J. L. and Whitfield, J. D., "Boundary-Layer Transition Under Hypersonic Conditions," AGARDograph 97, Pt. III, May 1965.

[2]Demetriades, A., "Hypersonic Viscous Flow Over a Slender Cone, Part III: Laminar Instability and Transition," AIAA Paper 74-535, June 1974.

[3]Kendall, J. M. Jr., "Wind-Tunnel Experiments Relating to Supersonic and Hypersonic Boundary Layer Transition," *AIAA Journal*, Vol. 13, March 1975, pp. 290-299.

[4]Demetriades, A., "Boundary Layer Stability Observations at Mach No. 7," *Transactions of ASME, Journal of Applied Mechanics*, Vol. 99, Jan. 1977, pp. 7-10.

[5]Demetriades, A., "New Experiments on Hypersonic Boundary Layer Stability Including Wall Temperature Effects," *Proceedings of the 1978 Heat Transfer and Fluid Mechanics Institute*, Stanford University Press, Stanford, CA, 1978, pp. 39-55.

[6]Stetson, K. F., Thompson, E. R., Donaldson, J. C., and Siler, L. G., "Laminar Boundary Layer Stability Experiments on a Cone at Mach 8, Part 1: Sharp Cone," AIAA Paper 83-1761, July 1983.

[7]Stetson, K. F., Thompson, E. R., Donaldson, J. C., and Siler, L. G., "Laminar Boundary Layer Stability Experiments on a Cone at Mach 8, Part 2: Blunt Cone," AIAA Paper 84-0006, Jan. 1984.

[8]Mack, L. M., "Linear Stability Theory and the Problem of Supersonic Boundary-Layer Transition," *AIAA Journal*, Vol. 13, March 1975, pp. 278-289.

[9]Demetriades, A. and Laderman, A. J., "Hypersonic Boundary Layer Transition as Detected with a Submerged Acoustic Sensor," Final Report, Boundary Layer Acoustics and Transition Program, Ford Aerospace and Communications Corp., Newport Beach, CA, March 1979.

[10]Nickell, J. C. and Demetriades, A., "Evaluation of Boundary Layer Transition Sensors in a Hypersonic Wind-Tunnel Environment," Paper presented at 27th International Instrumentation Symposium, Instrument Society of America, April 1981.

[11]Martellucci, A. and Laganelli, A., "Hypersonic Viscous Flow over a Slender Cone, Part I: Effect of Reynolds Number, Blowing and Angle of Attack on Viscous Layer Properties," AIAA Paper 74-533, June 1974.

[12]Stetson, F. K., Thompson, E. R., Donaldson, J. C., and Siler, L. G., "Laminar Boundary Layer Stability Experiments on a Cone at Mach 8, Part 3: Sharp Cone at Angle of Attack," AIAA Paper 85-0492, Jan. 1985.

[13]Laufer, J. and Vrebalovich, T., "Stability and Transition of a Supersonic Laminar Boundary Layer on an Insulated Flow Plate," *Journal of Fluid Mechanics*, Vol. 9, No. 2, 1960, pp. 257-299.

[14]Demetriades, A., "Supersonic Boundary Layer Stability over a Rough Wall," Final Report, AFOSR Grant 80-0267, Jan. 1985.

Effects of Electric Fields on the Flame Propagation Velocity of Methane-Air Flame

R.I. Noorani*
The University of Southwestern Louisiana Lafayette, Louisiana
and
R.E. Holmes†
Texas A&M University, College Station, Texas

Introduction

THIS Note presents the experimental results of the effects of longitudinal and transverse electric fields on the flame propagation velocity of premixed methane-air flame in a vertical tube. This is the second and final report of an earlier investigation[1] in which the effects of electric fields on blowoff limits of methane-air flame were reported.

Observations of changes in flame geometry and propagation velocities under the influence of electric fields have been made for many years. Evidence indicating an increase in flame propagation velocity is incomplete and contradictory.[2-5] Under similar conditions, electric fields are known to have increased, slowed down, or extinguished combustion. The position effects of electric fields on blowoff limits of methane-air flame have encouraged the authors to undertake the present investigation.

Apparatus and Procedures

The experimental configuration for the determination of flame propagation velocity of methane-air flame is shown in Fig. 1. The experiment was conducted at room temperature (76 deg) and atmospheric pressure (760 mm Hg).

The experimental apparatus consists of a vertical pyrex glass tube (151 cm long, 5 cm i.d.), a polyethylene mixing pump, platinum electrodes, capillary tubes, a mercury reservoir, photodiodes, and other components, as shown in Fig. 1. A manometer was used to indicate the amount of evacuation of the vertical flame tube and to make sure that no undetected leaks developed in the system.

Two TIL-63-type photodiodes were used to detect light signals from propagating flames. A longitudinal electric field was obtained by placing two aluminum rings (1.54 cm wide and 5 cm in diameter) around the glass tube, 5 cm apart. The upper ring was then connected to the positive terminal of the high-voltage supply. A transverse electric field was established between two 110-cm-long, 2.54-cm-wide segments of aluminum pipe placed diametrically opposed to each other outside the pyrex tube and held by masking tape. The two electrodes so formed were connected to the positive and ground terminals of the high-voltage supply.

Before an experiment, the barometer and manometer readings were taken. The gas and air, dried by passing through a drying tube containing calcium chlorides, were then admitted into the flame tube. The mixture composition was measured accurately by admitting the components slowly through the needle valves and measuring the partial pressures with the mercury manometer.

The mixing of gas and air was done by the mixing pump which was operated for about 15-20 min for stoichiometric mixtures and 25-30 min for rich or lean limit mixtures.

Received Jan. 18, 1985; revision received June 19, 1985.

*Assistant Professor, Department of Mechanical Engineering.
†Associate Professor, Department of Mechanical Engineering.

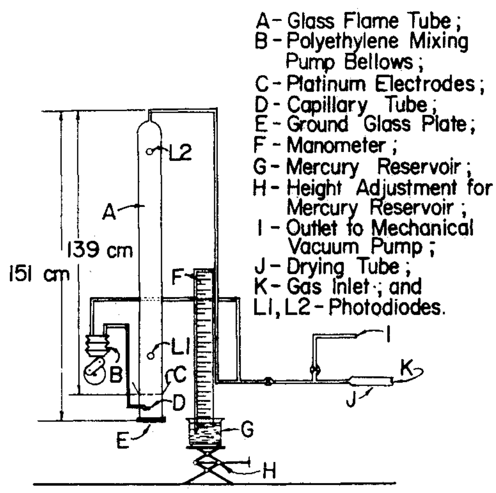

Fig. 1 Experimental apparatus for flame propagation velocity.

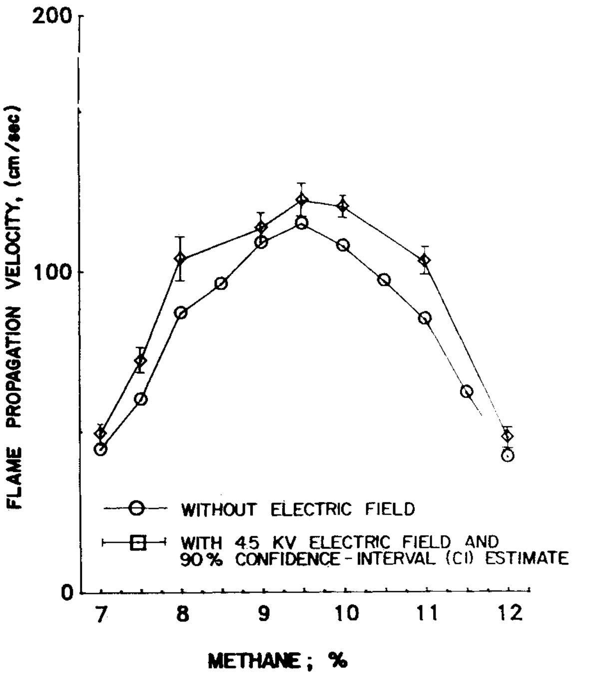

Fig. 2 Flame propagation velocity vs methane percentage, with and without longitudinal electric field.

After mixing, the ground glass plate was removed and the mixture was ignited either by a spark between the two platinum electrodes or by holding an alcohol burner under the flame tube. The alcohol burner was used especially for igniting lean and rich limit mixtures. The delay time between removing the glass plate and firing the spark was kept reasonably short (less than 2 s).

The photodiodes L_1 and L_2 detected the light emitted by the passing flame front, and the propagation velocity was found from the distance between the photodiodes and oscillographically observed time interval between the signals.

Following the above procedures with the setup of both longitudinal transverse electric fields, the flame propagation velocities were calculated with 4.5 kV electric fields, as a function of methane percentage.

Results

Figures 2 and 3 show the results of the measurements of flame propagation velocities, with and without electric fields.

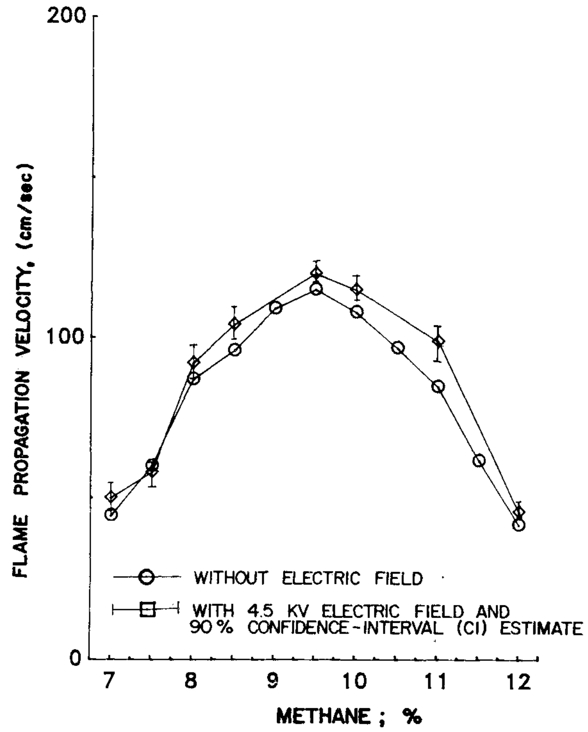

Fig. 3 Flame propagation velocity vs methane percentage, with and without transverse electric field.

In order to ascertain that the effect of electric fields on flame propagation velocity is a real phenomenon and not due to experimental scatter, an uncertainty analysis was made on the experimental data with electric fields. The data for Figs. 2 and 3 have been analyzed with a 90% confidence internal estimate. Although the flame propagation velocities appear to increase both under longitudinal and transverse electric fields, the results are not always consistent and, sometimes, the data fall within the experimental scatter.

Conclusions

The effects of longitudinal and transverse electric fields on the propagation velocity of a flame in a vertical tube filled with a methane-air flame are investigated. Although the flame propagation velocities under both electric fields increase slightly over zero electric fields, the results are not consistent and convincing. The slight increase in flame propagation velocities may be due to acceleration of ionized gas by the electric fields.

With regard to burning velocity, which is the relative velocity at which cold unburned reactants move into a flame, it is impossible to draw conclusions, whether electric fields raise the overall burning velocity in the absence of any measurement of the surface area of the flame front. Although longitudinal electric fields have been found to increase the extinction limits of premixed methane-air flame in a previous investigation,[1] no positive effect of the electric fields on flame propagation velocity could be found in the present investigation.

Acknowledgment

The authors are pleased to thank Dr. Warren M. Heffington of Texas A&M University for permission to use some of his experimental facilities to conduct the experiment.

References

[1]Noorani, R.I. and Holmes, R.E., "Effects of Electric Fields on the Blowoff Limits of Methane-Air Flame," *AIAA Journal*, Vol. 23, Sept. 1985, pp. 1452-1454.

[2]Fowler, R.G. and Corrigan, S.J.B., "Burning Wave Enhancement by Electric Fields," *The Physics of Fluids*, Vol. 9, 1966, p. 2073.

[3]Jaggers, H.C. and von Engel, A., "The Effects of Electric Fields on the Burning Velocity of Various Flames," *Combustion and Flame*, Vol. 16, 1971, p. 275.

[4]Fox, J.S. and Mirchandani, I., "Influence of Electric Fields on Burning Velocity," *Combustion and Flame*, Vol. 22, 1974, p. 267.

[5]Salamandara, G.D., "Flame Propagation in an Electric Field," *Fizika-Goreniyai Vzryva*, Vol. 5, No. 2, 1969, pp. 189-194.

Readers' Forum

Errata: "Turbulence Modeling for Three-Dimensional Shear Flows over Curved Rotating Bodies"

J. Galmes and B. Lakshminarayana
The Pennsylvania State University
University Park, Pennsylvania

[AIAA 22, pp. 1420-1428 (1984)]

THERE was an inadvertent omission in this paper. The derivation of equation 5 quoted by the authors is given in Ref. 23. In the review of the literature related to this topic, we would like to include the papers by Raj[24,25] on the modeling of the effects of rotation in the dissipation equation and Ref. 26 on the modeling effects of rotation on the pressure-strain term.

[23]Raj, R., "On the Investigation of Cascade and Turbomachinery Rotor Wake Characteristics," Ph.D. Thesis, Chap. III, Pennsylvania State University, University Park, PA, 1974.

[24]Raj, R., "Form of the Turbulence Dissipation Equation As Applied to Curved and Rotating Turbulent Flows," *Physics of Fluids*, Vol. 18, Oct. 1975, pp. 1241-1244.

[25]Raj, R. and Lumley, J. L., "A Theoretical Investigation on the Structure of Fan Wake," *Journal of Fluids Engineering*, Vol. 100, March 1978, pp. 113-119.

[26]Raj, R., "Pressure Gradient—Velocity Correlations for Flows with Two and Three-Dimensional Turbulence," *Physics of Fluids*, Vol. 20, Dec. 1977, pp. 1989-1992.