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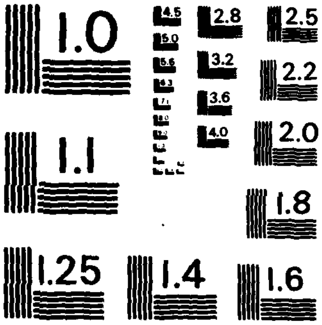

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20. ABSTRACT

One-dimensional premixed turbulent flames have been studied using the PDF method. These flames are directly relevant to the combustion in spark ignition engines, and are basic to our understanding of yet more complicated combustion phenomena. The objective of the work was to develop a theory to calculate the flame properties as functions of the governing parameters.

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FINAL REPORT

Stephen B. Pope

March 5, 1984

U.S. Army Research Office
Contract number DAAG29-82-K-0017

Cornell University

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Foreward

The work statement for this contract was modified in August 1982. Subsequently the work was on Monte Carlo calculations of one-dimensional turbulent premixed flames, rather than on two-dimensional combustor flows.

THE PROBLEM STUDIED

One-dimensional premixed turbulent flames have been studied using the PDF method. These flames are directly relevant to the combustion in spark ignition engines, and are basic to our understanding of yet more complicated combustion phenomena. The objective of the work was to develop a theory to calculate the flame properties as functions of the governing parameters.

In the PDF method used in this study, the flame is described statistically by the joint probability density function (pdf) of the velocities and of the reaction progress variable. The transport equation for the joint pdf is modelled and solved by a Monte Carlo method. Since this method is relatively new, considerable development work in modelling and in the Monte Carlo method was also performed.

SUMMARY OF IMPORTANT RESULTS

Premixed Turbulent Flames

1. An idealized oblique one-dimensional flame is governed by four non-dimensional parameters: Reynolds number Re; Damkohler number Da; flame angle θ; and burnt-to-unburnt density ratio ρ_b/ρ_u.
2. By a simple invariance argument, the dependence on flame angle θ has been determined. If the reactants enter the flame with velocity U_o at an angle θ to the normal, then the statistics of the flame are identical to those of a normal flame (with reactant velocity $U_o \cos\theta$) viewed by an observer moving parallel to the flame at a speed $U_o \sin\theta$. Thus it is sufficient to consider normal flames, $\theta=0$.
3. Modelling and calculations have been performed for the Re-Da regions corresponding to flamelet and distributed combustion. Significant differences are found between the two types of combustion. In flamelet combustion, the progress variable pdf adopts a double-delta-function distribution for moderate and high Damkohler numbers (Da>20). For $Da \geq 5$

the turbulent flame speed has the high value $S_T \approx 2.1\ u'$, where u' is the turbulence intensity. For distributedcombustion, on the other hand, even at high Damkohler number the progress variable pdf shows significant probability of partially reacted fluid. As the Damkohler number increases, this probability decreases slightly and the flame speed increases slightly. At $Da=10^4$ the flame speed is $S_T \approx 1.5\ u'$ and appears to increase linearly with $\ell n(Da)$. These results support the assumption of a double-delta-function distribution for flamelet combustion that is a corner stone of the Bray-Moss model. (See ref. 6 for more details).

4. It takes a long time for turbulent flames to attain a steady state. The calculations are performed in a transient mode, with the turbulent flame evolving from the initial condition of a laminar flame. It was observed that it takes one or two non-dimensional time units to reach the statistically stationary state. But in applications and laboratory experiments, the times of interest are normally less than one non-dimensional time unit. Consequently, the calculations suggest that such flames cannot be approximated as being fully-developed and statistically-stationary.

Related Modelling Studies

5. An improved stochastic mixing model has been developed. The new model is an improvement over Curl's model in that it yields (approximately) Gaussian pdf's. (See ref. 1).
6. A new invariance principle was deduced for modelling scalar equations. (See ref. 3). This principle can be used to develop consistent model equations and to test the consisteny of existing models.
7. In order to test the performance of the modelled pdf equation and Monte Carlo solution technique, the method was applied to the thermal wake. Results for this flow are reported in ref. 4.

LIST OF PUBLICATIONS

1. "An Improved Turbulent Mixing Model" S.B. Pope, Combustion Science & Technology, 28, 131 (1982).
2. "PDF Methods for Turbulent Reactive Flows", S.B. Pope, to be published in Progress in Energy and Combustion Science, (1983).
3. "Consistent Modeling of Scalars in Turbulent Flow", S.B. Pope, Physics of Fluids, 26, 404 (1983).
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5. "A Lagrangian Two-Time Probability Density Function Equation for Inhomogeneous Turbulent Flows", Physics of Fluids, 26, 3448 (1983).
6. "Flamelet and Distributed Combustion in Premixed Turbulent Flames", S.B. Pope and M.S. Anand, submitted to Twentieth Symp. (Int'l) on Combustion (1984).

SCIENTIFIC PERSONNEL

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D.C. Haworth (partial support, Ph.D. student)