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IV. The combustion group

The combustion group conducted six projects. Three projects were related to premixed and three to non-premixed combustion. The invited participants were: Mr. M. Baum (Ecole Centrale Paris), Dr. J. H. Chen (Sandia National Laboratories); Prof. R. O. Fox (Kansas State University), Dr. D. C. Haworth (General Motors Research Laboratories), Prof. J. C. Hill (Iowa State University), Prof. S. Mahalingam (University of Colorado), Dr. T. Poinso (Institut de Mécanique des Fluides de Toulouse), Prof. I. K. Puri (University of Illinois). The local participants were: Dr. R. D. Moser and Dr. M. M. Rogers from NASA Ames Research Center, and Dr. F. Gao, Dr. A. Trouvé, and Dr. L. Vervisch from the Center for Turbulence Research.

The broad scientific objectives of this group were similar to those of the CTR 1990 Summer Program: understanding of fundamental phenomena controlling turbulent combustion and application to modeling. However, the tools used in 1992 have covered a wider range: 2D or 3D, variable or constant density, simple or complex chemistry formulations for Direct Numerical Simulation (DNS) of turbulent combustion have been used. Recent progress in numerical analysis and code development have allowed us to use tools which were well adapted to the physical problems considered by each group.

The first three projects were aimed at increasing our understanding of turbulent premixed flames.

Poinso & Haworth studied the interaction between a turbulent flame and a cold wall. Flame quenching distances as well as wall heat fluxes were measured from 2D simulations. The characteristics of flamelets reaching the wall (curvature, flame speed, quenching times) were used to build a 'law-of-the-wall' model for turbulent combustion. A simplified version of this model was derived and may be implemented in any flamelet model for turbulent premixed combustion.

A new 3D variable-density code was used by Trouvé & Poinso to investigate the modeling of the evolution equation for the flame surface density. This analysis shows the limits of present flamelet models and suggests how the exact evolution equation for reactive surfaces may be closed to provide a suitable model. The effect of the Lewis number was evidenced and its influence on source or consumption terms for the flame surface density was demonstrated.

The first objective of the work by Baum, *et al.* was to prove the feasibility of DNS with complex chemistry and the potential of this approach for pollution studies. A second goal was to check whether the DNS results previously obtained with single-step chemistry are modified by accounting for more realistic chemical schemes. The project was based on a new 2D code where a DNS technique was coupled to CHEMKIN and TRANSPORT, the SANDIA packages for reacting flows with complex chemistry. Using this tool, it was possible to investigate the structure

of H₂-O₂ turbulent flames with the Warnatz scheme (9 species - 19 reactions). This project also provides the first analysis of the effects of stretch and curvature on flames with realistic chemistry.

The first project of Chen *et al.* was related to the effects of finite rate chemistry and differential diffusion on the structure of turbulent non-premixed flames. 3D variable-density simulations were performed over a range of conditions corresponding to fast and slow chemistry. This project provided new insights on the validity of the flamelet assumption as well as on the effects of transient regimes and small scales on the inner structure of the flame zone.

Chen *et al.* investigated one of the classical assumptions used to model turbulent non-premixed flames, *i.e.* single-step chemistry. Single-step and two-step chemical schemes were compared using 2D variable-density simulations of a non-premixed flame in isotropic turbulent flow. An important result was that extinction limits appear to be quite different: while single-step chemistry lead to multiple local extinctions, two-step chemistry feature more robust flames which do not quench.

DNS of a single-step chemical reaction with non-premixed reactants in forced isotropic turbulence were used by Fox *et al.* to obtain joint pdf's and other statistical information to parameterize and test a Fokker-Planck turbulent mixing model. The simulations were performed using a constant density, 3D spectral code developed by Moser and Rogers. Physical features as well as various statistics of the reacting scalars and their gradients were examined and compared to the model.

This Summer Program has brought many new and original results. The activity on non-premixed combustion was more intense than during previous programs and opened new perspectives for modeling for those flames. The demonstration that DNS of reacting flows was possible while taking into account complex chemistry or the presence of walls also opens new fields of investigations.

Modeling was one of our first objectives in this work. A fundamental aspect of the 1992 work is the impact and the power of DNS to answer certain critical questions for turbulent combustion models. We believe that DNS of reacting flows is now reaching a point where individual terms in combustion models may be estimated from DNS (as done by Trouvé & Poinso) and that this possibility will change the way we construct models in the next few years.

Thierry J. Poinso