Combustion - overview

The recent energy crisis has demonstrated again how strongly our civilization depended on combustion. Being able to have access to cheap energy sources and converting them into energy with high efficiency, flexible systems is mandatory in so many aspects of our society that it is difficult to imagine how to replace combustion in the near future. The situation is even more complex when global warming must also be taken into account: here the objective is to release less CO_2 which means producing less energy if efficiencies are not increased. As mentioned by Pr Sawyer at the 32nd Symposium on Combustion in Montreal, there still are many hydrocarbon sources left on earth and this is unfortunate for global warming (even if it is a chance for our economies) because burning these fuels will certainly lead to increased CO_2 concentrations: we cannot expect oil and other hydrocarbons to disappear soon enough and naturally solve the earth CO_2 problem. The least which is then expected from the combustion community is to increase the efficiency of combustion devices to their maximum level. This must not be obtained at the cost of increasing other pollutants such as NO_x, CO or soot. This challenge is certainly the most difficult faced ever by the combustion community.

The combustion projects at CTR address fundamental issues and also reflect the present constraints on combustion research. The general objective is to understand turbulent combustion in order to design combustors that have the highest efficiency and the lowest emission levels in terms of CO, NO_x and soot. An additional design difficulty is that most combustor optimizations have to account for combustion instabilities: these oscillations are quite often the limiting factor in technologies aiming at the reduction of consumption and emissions. For example, LPP (lean premixed prevaporized) systems developed for aircraft combustion chambers are prone to combustion oscillations that limit their performance. Optimizing combustors is therefore not only a steady combustion problem; it becomes fully unsteady and must also include acoustics, phenomena ignored until now.

Six combustion projects took place at CTR during the 2008 summer program. They are summarized below, starting with groups focusing on the most local phenomena (soot formation, flame / turbulence interaction) and then describing the work of groups that studied full combustors.

The project by Hewson, Lignell and Kerstein (Sandia National Laboratories) was dedicated to soot formation. Soot is a major pollutant produced in most chambers and a serious danger to human health. Computation is the only way to optimize both CO_2 and soot simultaneously but computing soot is difficult: these molecules require not only sophisticated chemical schemes but also specific turbulent transport model. Soot particles are much heavier than gas particles and diffuse much more slowly. Hewson *et al.* used DNS to analyze the turbulent transport of soot and propose models for the soot-diffusivity corrections.

The interaction between flame and turbulence was studied in the project of Vicquelin and colleagues (EM2C Paris and CORIA Rouen). Even though it is currently agreed that LES is the best method to study turbulent flames in real combustors and address the challenges described above, unanimous agreement does not exist about which type of LES model should be used to describe flame/turbulence interaction, especially if this model must also provide information on minor chemical species such as NO_x. This group addressed this problem by studying a tabulated chemistry method coupled to a PDF method. They tested the method in one-dimensional cases for laminar flames, in two-dimensional flows for flames interacting with vortices and in three-dimensional flows for a turbulent flame stabilized behind a triangular flame holder.

Sanjosé and colleagues studied a key difficulty for combustion modeling: fuels are generally injected as liquid and the modeling of liquid fuel atomization, vaporization and combustion remains the weakest part of most existing LES codes. ONERA, CERFACS and CTR worked together to compute the two-phase reacting flow within a combustor built at ONERA, Toulouse. Two different approaches (Euler - Euler and Euler - Lagrange) were used and compared to experimental data. Results confirmed the importance of the injection conditions and the necessity of coupling methods for primary atomization (see the multiphase papers in the present proceedings) with combustion codes.

The Euler - Euler approach used in the project of Sanjosé *et al.* had a major drawback: it assumes that at one given point and time, only one velocity and one size exist for liquid fuel droplets. This assumption may be acceptable in certain cases, but future Euler - Euler formulations must account for poly-dispersion of the fuel sprays. This topic was studied in the two projects of De Chaisemartin *et al.* and Freret *et al.*, which gathered two-phase flow specialists from CORIA, EM2C Paris, Iowa State University, IFP and University of Oklahoma. In the first project, De Chaisemartin *et al.* compared a new Euler - Euler solver (multi-fluid multi-velocity) to a Lagrangian code and demonstrated that this Euler - Euler methodology can predict the dispersion and evaporation of poly-disperse fuel sprays. This was done in the context of infinite Knudsen numbers, which correspond to dilute sprays and negligible collisions between droplets. In the second project, Freret *et al.* extended the same methodology to finite Knudsen numbers and studied interacting sprays. The validation was also performed by comparing Euler - Euler results with a Euler - Lagrange DNS code developed at CORIA.

Finally, TU Munich, CERFACS and EM2C Paris studied combustion instability prediction methods in a simple laminar burner installed at EM2C. The objective was to test a method developed at TU Munich to predict the stability of a given burner without having to perform a full LES of the configuration. Such a method is needed industrially for burner optimization: the inability to predict whether or not a given engine will oscillate is a significant risk in many current industrial projects. In the past, a simple method to control such oscillations was to use more fuel or to accept higher emission levels. Obviously, this is not acceptable today but strategies for efficiency and pollution can be implemented only if reliable prediction methods allow engineers certainty that their design will not lead to combustion instability, something still out of reach in many cases.

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