The combustion and multiphase group

Over recent years, much progress has been made in the development of combustion models for numerical simulations of engineering systems. Although much of the theory is still unclear, the application of these models to real systems seems to be in reach. It is hence not surprising that industrial and commercial interests were well represented in the combustion and multiphase group. However, the main emphasis of most of the projects was in fundamental theory and modeling. The combustion and multiphase group was the largest group of this year’s summer program. It had contributions in the general areas of multiphase and combustion science and modeling, but also in fires and radiation, and combustion instabilities and control. This section includes reports on twelve projects: Two related to multiphase flows, five in the area of combustion science and modeling, two related to fires and radiation, and three on combustion instabilities and control.

The projects in multiphase flows are related to liquid gas interfaces and Lagrangian spray models. It is well known that the level set approach to simulate two-phase flows does not guarantee mass conservation of the individual phases. To insure mass conservation, the level set scalar has to be appropriately corrected, for example by a volume of fluid method. The project of Boersma et al. explores the effect of such a level set correction method on the higher order interface properties, for instance the curvature. It is found that local correction methods introduce significant errors in the interface curvature. A correction extension method is then proposed addressing this problem and leading to a significant reduction of curvature errors. LES/Lagrangian spray modeling of multiphase flows in critical in simulating practical combustion devices. In a different project, Pozorski et al. studied the impact of sub-grid turbulence on particle motion. It was shown from DNS data that filtering affects preferential concentration. A stochastic model was proposed for reconstructing the residual velocity field.

Recent breakthroughs in premixed combustion modeling has increased the computational accessibility of such systems. Bilger recently proposed a new marker field method to track combustion in low Damköhler number premixed configurations. Using a fictional scalar field, the project of Bilger et al. analyzed a direct mapping between this field and the reaction progress-variable. DNS of low-Damköhler number premixed combustion is used for an a priori testing of the model. A second project related to premixed combustion is that of Huh et al., who recently proposed a premixed turbulent combustion model based on zone-conditional averages. In contrast to Bilger’s model, this model has been formulated for the high Damköhler number case. The aim of the present project was to test closure assumptions for the turbulent burning velocity using DNS data. An entirely different approach to combustion modeling in LES is the filtered-density function approach. In such LES-FDF methods, the integration of the chemical source term is computationally expensive. Pope et al. studied the use of ISAT to accelerate this computation for LES-FDF. Using several parallel computation paradigms, they identified potential bottlenecks in using ISAT algorithms and demonstrated substantial speed-up compared with the direct integration.

From an industrial perspective, combustion models must be computationally inexpensive. With this constraint in mind, Göklin et al. proposed the constructed-PDF model as a possible extension of conventional laminar-flamelet models. By using detailed chemistry and the Linear-Eddy Model to model a simplified flow configuration, a look-up
table is created. Using this lookup table, simulations have been performed for a series of
turbulent diffusion flame, showing good agreement with experimental data. A real-world
application of combustion modeling was the objective of the project of Kim et al.. A
simulation of a Pratt & Whitney aircraft engine combustor was initiated. One of the
obstacles encountered was the modeling of the injection process, which involves a liquid
jet impingement on a wall and the formation and development of a liquid wall film. As a
result of the project, different film models have been developed and simulations for the
combustor have been initiated.

Another highly complex problem of practical interest is the simulation of accidental
fires. Tieszen et al. studied mixing in such flows by performing LES for a buoyant helium
plume. It was found that conventional sub-filter modeling was insufficient and could not
reproduce the Rayleigh-Taylor instabilities at the base of the plume. Different models
have been proposed and applied in simulations with varying filter width. Also related to
accidental fires was the project by Jensen et al.. A comparative study of different solution
methods of the radiative transfer equation was performed using the temperature fields
from simulations of a 2 m pool fire. The applied models include discrete transfer method,
different discrete ordinate techniques, and a moment method using the so called M1
closure.

Another group investigated specific issues related to the design and optimization of
combustion devices. In such systems, a major issue is to develop fast optimization
processes to be able to adjust, for example, the positions and flow rate distribution of dilution
jets in a gas turbine burner in order to reach a predefined outlet temperature profile. This
issue was the focus of the work of Debiane et al. who applied modern optimization
methods to a model flame and showed the potential of their approach to control the flame
length, temperature and NOx emission. Recent experimental experience shows that opti-
mization procedures can also be dangerous: optimizing performances and pollution often
leads to instabilities. The development of LPP devices (Lean Premixed Prevaporizers) for
gas turbines is a good example of experimental design optimization which meets most
performance and pollution objectives, but in many cases, leads to high and unacceptable
instability levels. Studying and predicting such instabilities using numerical tools was the
topic of the other projects. The computation of acoustic resonators (such as combustion
chambers) is indeed still a challenge because of the lack of an appropriate formulation of
boundary conditions. Proser and Schlitter proposed and studied a new original boundary
condition formulation based on a low-Mach number approximation to improve existing
characteristic methods for compressible codes. The objective of the project of Martin
et al. was to revisit the Rayleigh criterion which is the most commonly used tool to
describe instabilities: the recent development of compressible LES for combustion allows
now to replace this criterion by a detailed analysis of the budget of acoustic energy. Such
a budget was studied in the case of a staged turbulent combustor in which the level of
oscillation was controlled by the outlet boundary condition. Finally, as LES will still
remain very expensive for a long time, additional tools are needed for design and opti-
mization of thermoacoustic oscillations in industry: the last project (Benoit et al.) shows
how acoustic analysis can be coupled to LES to predict the growth rates of all acoustic
modes in a reacting configuration. Here the objective was to show that LES information
can be injected into a Helmholtz acoustic solver to retrieve the unstable modes and
eventually control them through different outlet conditions.

Heinz Pitsch and Thierry Poinset