Combustion – overview

Combustion is presently and for the foreseeable future the major technology for providing energy carriers for transportation, and for industrial, commercial, and residential use. However, the combustion of hydrocarbon-based fuels is accompanied by the formation and emission of greenhouse gases, pollutants, and soot. Over recent years, significant progress has been made in developing advanced combustion strategies that reduce emissions and simultaneously improve combustion performance. Examples of such technologies are lean-premixed combustion concepts, implementing oxygen-diluted and kinetics-controlled combustion regimes, and extending combustor operating conditions to higher pressures. To fully utilize the potential and enable the successful implementation of these emerging combustion strategies, several research issues arise. To address some of the most pertinent issues, the combustion group at the 2012 CTR Summer Program consisted of ten teams, focusing on research topics related to (*a*) combustion modeling, (*b*) pollutant emission and soot formation, and (*c*) flame-dynamics. In the following, an overview over all research topics and contributions is given.

(*a*) *Combustion modeling:* The increasing interest in utilizing premixed, multi-regime, and vitiated combustion goes hand in hand with the need for simulation techniques that enable the accurate prediction of flame stabilization, ignition dynamics, flame structure, and heat release. Three projects focused on assessing, developing, and improving combustion models for application in high-fidelity simulations. Veynante *et al.* performed an analysis of a dynamic formulation for the source term closure in turbulent premixed combustion models. Performance of a dynamic model was analyzed in a priori and a posteriori tests, and the potential of the dynamic formulation over algebraic closures was identified. Chan *et al.* performed an a priori analysis of the unsteady flamelet equations to investigate contributions of the higher-order expansion terms along the flame-orthogonal direction. In this analysis, a DNS database of a jet-in-cross-flow configuration was considered, from which the instantaneous flamelet topology was extracted. For the first time, they performed a detailed balance analysis of the entire flamelet equations, showing that contributions due to advection and curvature effects can become important in regions of flow-field recirculation and strong velocity stratification.

(*b*) *Pollutant emission and soot formation:* By increasing the energy density and reducing the size of industrial combustors, the combustor residence time is decreased, leading to the formation of incomplete combustion products and pollutants. Among those, carbon-containing species accumulate to form soot. Soot production was examined by Attili, Bisetti & Mueller. A series of DNS computations were performed and analyzed, identifying certain fundamental combustion-physical processes required in modeling soot formation. The modeling of soot deposition on walls was the subject of the second project by Cuenot, Ribert & Trouvé. DNS were performed to develop and validate SGS-models for predicting the magnitude of the rate of soot deposition on cold walls. The prediction of pollutants is heavily dependent on the introduction of detailed chemistry in the simulation. In the third project, Ribert, Domingo & Vervisch discussed a novel approach in which both the number of transported species and the required spatial resolution are dramatically reduced without altering the fully detailed chemical scheme.

(*c*) *Combustion and flame dynamics:* Unstable combustion processes, associated with ignition/extinction, quenching, flame stabilization, and combustion instabilities, constitute major problems in industrial applications. The characterization, modeling, and analysis of flame-dynamic processes were the subject of four research projects at the 2012 CTR Summer Program. Mari, Selle & Cuenot studied the stabilization of H_2-O_2 flames in supercritical conditions on a cold splitter plate using DNS in conjunction with a conjugate heat-transfer model. In the second project, Selle, Motheau & Nicoud used LES, dynamic mode decomposition (DMD) and acoustic analysis to identify an unstable mode in a realistic combustion chamber where entropy and acoustic waves couple to generate a low-frequency instability. DMD was also used in the third project but on experimental data obtained at EM2C, Paris, to identify unstable modes in a swirl combustor where high-frequency PIV, microphones and heat release measurements were available. Finally, Poinsot *et al.* used multiple RANS and LES codes as well as acoustic analysis to investigate unstable modes in a non-reacting swirling flow which exhibits multiple instabilities and a strong sensitivity to small geometrical changes. The corresponding experiment was run before the Summer Program at ONERA, Le Fauga.

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