Combustion — overview

The potential of using large-eddy simulation (LES) for the prediction of turbulent combustion has been widely recognized, and LES methods have found utilization in industrial applications. However, with the increasingly stringent emission regulations, the consideration of new combustion regimes, and the utilization of flexible fuels, new research opportunities arise. These include the modeling of pollutant formation and emission reduction, the fundamental combustion-physical analysis of flame-stabilization and energy-transfer mechanisms, and the description, control, and identification of combustion dynamics. The combustion group of the 2014 CTR Summer Program consisted of ten groups from academia, research laboratories, and industry, addressing some of these critical research topics. In the following, an overview of all research topics is given.

Soot emission and pollutant reduction: The subject of emission modeling was studied by two research teams. Motivated by the need for predicting soot emissions in aeronautical combustors, Cuenot, Riber, and Franzelli evaluated the capability of using a two-equation soot model in conjunction with different gas-phase combustion models to describe the soot formation in LES of a swirl-stabilized gas-turbine combustor. They were able to show that a hybrid method, which combines a reduced chemistry representation with a tabulation method for the soot-precursor description, represents a suitable approach for soot modeling of engineering relevant applications. The focus of the project by Farcy, Vervisch, and Domingo was on the non-catalytic reduction of nitrogen oxides. To examine the interaction between flow physics, turbulence, ammonia-spray injection, and chemistry, LES of an industrial-scale incinerator was performed. Two different strategies were proposed to reduce the computational cost. The first strategy considered the system down-sizing by rescaling relevant flow parameters to preserve Damköhler and spray characteristics. In the second approach, a low-order model was developed that was informed by LES data. Comparisons with LES results showed that this one-dimensional model provides an adequate representation of the NO_x reduction, yet at substantially reduced computational cost, thereby providing interesting opportunities in application to control and early-stage design optimization.

Fundamental combustion analysis: Direct numerical simulation databases of two different flame configurations were utilized to examine fundamental mechanisms associated with flame stabilization and inter-scale energy transfer. The research team of Hawkes investigated the stabilization of a lifted flame. By developing diagnostics to isolate the edge-flame motion, they were able to show that the edge-flame propagation is the main stabilization mechanism in this configuration, and variations of the lift-off height could be attributed to the interaction of the flame base with large eddies, supporting previous experimental observations. A joint effort, headed by Hamlington, Poludnenko, and Towery examined the energy transfer and non-linear turbulence/flame interaction with relevance to combustion-induced backscatter. These efforts considered a DNS database of a turbulent premixed flame, and diagnostics tools were developed and utilized to quantity counter-gradient diffusion, conditional spectral energy transfer, and backscatter, providing fundamental insights towards the development of improved subgrid closure models.

Combustion instabilities and control: A main focus area of this year's combustion group was dedicated to the analysis, identification, and control of thermo-acoustic instabilities and combustion dynamics. Courtine *et al.* performed numerical simulations and analysis to demonstrate the presence of a self-sustained intrinsic thermo-acoustic (ITA) oscillation in a confined premixed flame. These results provided new insight on the acoustic self-excitation and identified shortcomings of classical time-lag models. Silva *et al.* developed system-identification tools to simultaneously evaluate heat release, combustion dynamics, and combustion noise of acoustically excited flames. In application to an ITA feedback system, they demonstrated the importance of a two-way coupled approach for the noise computation. In two projects, Juniper and Magri applied adjoint-based sensitivity analysis to thermo-acoustic systems. Magri *et al.* used asymptotic multi-scale methods to describe the two-way coupling between hydrodynamics and acoustics. This method was utilized in an adjoint analysis to identify unstable modes and passive feedback mechanisms in two different gas-turbine combustor configurations. Juniper *et al.* introduced adjoint methods as an efficient way for the gradient evaluation in uncertainty quantification; two different methods based on discrete and hybrid adjoint approaches were developed and applied to a nonlinear Helmholtz problem. Bauerheim *et al.* performed, for the first time, uncertainty quantification of a model gas-turbine combustor to examine the risk factor, which is defined as the probability of an acoustic mode becoming unstable. Using an active subspace technique, they were able to reduce the number of uncertainty parameters by more than an order of magnitude. Comparisons of simulation results for two different operating conditions showed that this method provides comparable results to that of the computationally more demanding Monte Carlo method.

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