Combustion — overview

The 2016 CTR Summer Program brought together eight international and national research groups from France, UK, India and the US, working jointly on research aspects related to the analysis, simulation, and modeling of combustion processes. While prevailing topics on combustion modeling, emissions, and thermoacoustics were the main thrusts of collaboration, emerging topics on data analysis, combustion noise, and optimization were introduced to the combustion group. These different research efforts were grouped into three overarching research topics on (i) fuel preparation and ignition, (ii) combustion modeling and pollutant emissions, and (iii) combustion instabilities and noise emissions. In the following, an overview of all research topics and main research findings is given.

(i) Fuel preparation and ignition. The injection, evaporation, and subsequent combustion of liquid fuel plays a critical role in controlling combustion performance and emission production. Reliable modeling of the two-way coupling between the spray and turbulent-flow environment remains a major challenge. By addressing this aspect, Zhao and coworkers performed an analysis of subgrid dispersion models for turbulent spray-flame simulations. In this investigation, a turbulent DNS-counterflow spray flame was considered, that was operated at different conditions. An analysis of a commonly employed modeling approach identified deficiencies in closure-free and stochastic Lagrangian models for certain operating conditions. A new regularized deconvolution model was developed, showing advantages for obtaining improved predictions of subgrid velocity and scalar fields.

The robust ignition of a reactive mixture in spark-ignition engines and for relight in gas-turbines is dependent on the turbulent flow environment and requires the consideration of dependencies on the local equivalence ratio, energy deposition, and ignition duration. By addressing these challenges, the project by Qadri *et al.* had the goal of developing efficient model strategies for optimal ignition placement. To this end, an adjoint looping method was developed that uses the unsteady adjoint solution of the non-linear Navier-Stokes equations for gradient-based optimization. The method was demonstrated in application to a jet-diffusion flame, showing that for the conditions investigated, the optimal ignition placement is aligned with the location of the stoichiometric mixture.

Of relevance to improving our fundamental understanding about coherent structures in turbulent reacting flows, Nair *et al.* examined the flow-field of reacting and non-reacting jets using a finite-time Lyapunov exponent analysis. Comparisons of the computed structures between non-reacting and reacting flows showed extended structures in the jet far-field for the reacting flow. The dependence of this method on a windowing provides interesting opportunities for isolating combustion-physical processes that evolve on distinct time scales.

(ii) Combustion modeling and pollutant emissions. The subject of combustion modeling and the representation of multicomponent transportation fuels was addressed in two projects. Felden *et al.* performed large-eddy simulations of a NASA lean-direct injector to examine the impact of different strategies for describing transportation fuels in high-fidelity combustion simulations. To this end, a surrogate approach and a hybrid chemistry method were considered. Analysis of both modeling approaches in 1D-simulations and code-to-code comparisons using different combustion models provided new insight into the description of realistic transportation fuels.

The project by Ribert *et al.* was concerned with the consistent evaluation of the pressure from the Favre-filtered state-equation in compressible LES-calculations. Their analysis showed that the naïve filtering of the state equation without consideration of cross-correlations can introduce significant errors in the pressure field. Using a filtering technique that utilizes the Reynolds-filtered species mass fractions for evaluating the mean molecular weight, it was shown to provide improved approximations of the pressure field. These results are particularly relevant for application to oxygen-rich combustion and flames that operate at low-dilution rates.

(iii) Combustion instabilities and noise emissions. A main topic of the summer program was the analysis and simulations of combustion instabilities and combustion noise. Ghani *et al.* performed large-eddy simulations of a triangular flameholder to examine the effects of wall-heat transfer on combustion instabilities. Comparisons of modeling results for adiabatic and non-adiabatic simulations showed appreciable differences in the screech-tone characteristics, that were attributed to differences in thermal dissipation mechanisms.

Selle *et al.* analyzed an existing LES-database of a rocket combustor to examine transverse combustion instabilities. Acoustic-energy analyses and dynamic-mode decomposition were performed to isolate triggering mechanisms of transverse combustion instabilities, and physical explanations were provided.

The generation of broadband noise from a model gas-turbine combustor was studied by O'Brien *et al.* In this project, compressible LES of a gas-turbine model combustor was performed, and experiments on this burner were conducted at DLR Berlin. Comparisons with measurements for velocity field and acoustic spectra showed reasonable agreement. Modal analysis was conducted to obtain insight into the physics driving the combustion dynamics and the identification of relevant core-noise mechanisms.

On behalf of the entire combustion group, I would like to thank all participants of the 2016 CTR Summer Program for many fruitful discussions and ideas that helped in paving new pathways and contributing to advancing the field of combustion research.

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