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Large Eddy Simulation of a Swirling Spray Flame Using Spray Flamelet Model

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Extended Abstract

Turbulent spray combustion is encountered in a wide range of energy power systems, including aero-engines, internal combustion engines, and rocket engines. Computational fluid dynamics (CFD) has emerged as a crucial tool for studying turbulent spray combustion. Among the three classical CFD technologies, Reynolds-averaged Navier-Stokes (RANS) simulation has the highest computational efficiency, but its accuracy is limited when applied to unsteady flows. In contrast, large eddy simulation (LES) efficiently captures unsteady features while offering a more computationally feasible approach when compared to direct numerical simulation (DNS) [1]. Substantial advancements have been made in the field of LES applied to turbulent spray combustion in recent years.

Strong turbulence-chemistry interactions (TCI) in turbulent spray combustion necessities turbulent combustion models. Flamelet models [2, 3] have been widely applied in various configurations because they can account for detailed chemistry with high computational efficiency. One popular approach for flamelet modeling is based on the gaseous flamelet library, but the accuracy is not guaranteed for turbulent spray combustion because it has inherent limitations in describing the effect of droplet evaporation on the flamelet structure [4, 5].

Our recently developed two-phase spray flamelet/progress variable (TSFPV) model [6] has shown sound performance in spray combustion modeling because it can consider the effect of droplet evaporation on the flamelet structure. Our previous work focused on the validation of the TSFPV model on configurations of non-swirling jet spray flames, such as the Sydney turbulent lifted methanol spray flame [7] and Sydney piloted ethanol spray flame [8]. In this work, the TSFPV model is further extended and applied to the LES of the Cambridge swirl spray flame E1S1 [9]. The non-reacting case C1 is first simulated to validate the choice of relevant numerical parameters and boundary conditions, and subsequently, the LES of the reacting case E1S1 is conducted. The droplet statistics are in good agreement with the experimental data for the reacting case, which indicates the model's accuracy. The simulation results show that the TSFPV model exhibits sound performance on swirling configurations as well as non-swirling configurations, indicating its widespread applicability and generalizability. The complex spray flame structure is analyzed and the purely gaseous combustion regimes as well as two-phase combustion regimes are observed. Strong interactions between the flame and the droplets occur for two-phase combustion regimes, which highlights the necessity to develop two-phase flamelet models.

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