High-Pressure LES Modeling of Lean Hydrogen Flames: An Assessment of DTFLES predictions

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The use of hydrogen as a fuel in gas turbines presents several challenges arising from its high chemical reactivity. In particular, lean hydrogen flames are characterized by a marked increase in turbulent flame speed, attributed not only to the flame wrinkling induced by turbulence but also to the onset of thermo-diffusive instabilities associated to the sub-unity Lewis number [1]. Direct Numerical Simulations (DNS) have shown that fundamental thermochemical parameters such as pressure, temperature, and equivalence ratio exert a significant influence on turbulent flame speed by altering the interplay between diffusive and advective transport across the flame front [2]. Furthermore, Berger et al. [3] highlighted the critical role of the Karlovitz number in governing the interaction between turbulence and thermo-diffusive instabilities. In this context, assessing the predictive capabilities of combustion models under gas turbine relevant operating conditions, particularly at elevated pressures, becomes essential. Within the framework of Large Eddy Simulation (LES), the Dynamic Thickened Flame Model (DTFM) is a well-established and consolidated turbulent combustion model for premixed conditions. Although the impact of flame thickening on thermo-diffusive instabilities is investigated under laminar conditions [4], its interaction with turbulence in hydrogen flames is still unclear. This study aims to evaluate the influence of the thickening factor on lean hydrogen flames under elevated pressure conditions. A canonical turbulent flame configuration, consisting of flame propagation within a cubic domain with imposed turbulence, is employed as a test case. Model predictions are validated against high-fidelity turbulent DNS datasets developed as part of the HyPowerGT European project where the initial turbulent field is extracted. The analysis first investigates the influence of domain size on flame front topology and turbulent flame speed, as previously investigated by Shuh et al. [4]. Subsequently, the interaction between turbulent eddies and thermo-diffusive instabilities is investigated by progressively increasing the level of resolved turbulence through automatic mesh refinement.

References

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