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Large Eddy Simulation of a Reactive Hydrogen Jet in Crossflow: Grid Convergence, Turbulence-Chemistry Interaction and NO_x Analysis

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Hydrogen jet in crossflow (JICF) flames are studied for their relevance to propulsion and energy conversion systems, where fuel injection into a crossflow air stream is common. Although hydrogen combustion is attracting interest due to its carbon-free emissions and high reactivity, the accurate modeling of JICF flames remains particularly challenging because of transitional flow character, mixing and related linkage to flame formation. In this study, Large Eddy Simulations (LES) of hydrogen JICF, using finite-rate chemistry (FRC) and perfectly stirred reactor (PSR) assumptions, are performed on three different mesh resolutions (48, 56, and 84 million cells) to evaluate grid convergence of velocity, temperature, and species distribution predictions. In a previous direct numerical simulation study of JICF by Grout et al. [1] it was noted that such flames may pose partially stratified premixed flame characteristics in the broken reaction zones regime, indicating that premixed combustion models may be required. In addition to the PSR assumption, we utilize the Dynamic Thickened Flame (DTF) model and the results are evaluated against both experimental data provided in Steinberg et al. [2] and FRC+PSR results. The DTF model is noted to affect the local NO and temperature profiles, while the velocity fields appear relatively intact to switching on the DTF model. These changes are largely explained by the changes in the predicted local peak temperature values. The main conclusions of the research are that 1) the FRC+PSR results are grid independent and the agreement with experiments is relatively good, 2) the DTF model mostly affects the local NO_x and temperature values, while the impact of DTF on measured outlet values is noted to be less significant, and 3) reaction pathway analysis reveals the details of the local emission formation process. To our knowledge, NO_x formation pathways in this type of non-premixed H_2 JICF were less studied in the past.

References

[1] Grout et al. Direct numerical simulation of flame stabilization downstream of a transverse fuel jet in cross-flow. *Proceedings of the Combustion Institute*. 2011;33:1629–1637.

[2] Steinberg et al. Structure and stabilization of hydrogen jet flames in cross-flows. *Proceedings of the Combustion Institute*. 2013;34:1499–1507.