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Towards Exascale DNS of Lean Premixed and Multiregime Hydrogen Flames

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Hydrogen and other renewable fuels exhibit fundamentally different combustion behaviors, exposing critical limitations in current models, which are not suited for high-fidelity simulations of these reactive flows. Addressing this requires the development of new, physically grounded combustion models. Simultaneously, the shift in HPC demands a new generation of CFD software, which are optimized for massively parallel, GPU-driven architectures, to fully exploit emerging computational capabilities.
Utilizing a new GPU-based spectral element solver NekCRF [1-3], we perform finite-rate chemistry DNS of a lean, turbulent premixed piloted jet flame. This unique dataset offers fundamental insights into the complex interplay between thermo-diffusive instabilities and turbulence, a key mechanisms that must be captured to enable the next generation of combustion models. The analysis centers on the interaction of turbulent structures of varying intensity, characterized by a range of Reynolds and Karlovitz numbers, with inherently unstable hydrogen flames. Additionally, the computational capabilities of NekCRF are demonstrated through simulations of a hydrogen-fueled Multi-Regime Burner. In this case, the focus lies on understanding the development of thermo-diffusive instabilities under the influence of technically relevant mixture stratifications.
By leveraging GPU acceleration and employing a novel spectral element solver, this research not only advances our understanding of hydrogen combustion but also showcases a paradigm shift in computational efficiency, offering a promising avenue for developing sustainable and efficient energy solutions.

References

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