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Flow Characteristics in Two-Dimensional and Three-Dimensional Thermo-Diffusive Unstable Flames

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Hydrogen-based fuel burning faces challenges due to intrinsic premixed flame instabilities that affect flame morphology. This study introduces a three-dimensional (3D) Direct Numerical Simulation (DNS) dataset using a low-Mach formulation and a deficient reactant thermochemical model with NekRS, comparing flame characteristics to a well-established two-dimensional (2D) dataset [1].

Comparing the 2D and 3D flames reveals similar finger-like structures, but 3D flames exhibit 10% higher superadiabatic temperatures at cusps due to higher local curvatures enhancing local differential diffusion effects. The 3D flames also demonstrate higher mean consumption speeds, with the smallest 3D flame being faster than all 2D cases and 2.5 times its 2D counterpart's speed. The 3D flames exhibit a narrower range of flame curvature but higher displacement speeds and tangential strain rates. Overall, 3D flames show more positive stretch, leading to higher consumption speeds and reaction rates.

The study concludes that 3D flames exhibit higher temperature peaks and faster reactions compared to 2D flames, attributed to increased thermal diffusion and more positive flame stretch characteristics in 3D.

Reference
[1] Creta, Francesco, et al. Combustion and Flame 216 (2020): 256-270.

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The DNS dataset for 2D simulations was generated using Nek5000, whereas the 3D dataset was produced with NekRS. The scalability of NekRS for large simulations has been demonstrated, with the largest 3D simulations comprising approximately 6.3 billion grid points.

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