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Turbulent Lean Premixed Hydrogen Flames at High Pressure and High Temperature

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Premixed hydrogen flames are prone to thermodiffusive instabilities, leading to super-adiabatic temperatures, enhanced reactivity, and extinction in highly curved flame regions. These instabilities significantly increase laminar flame speed [1, 2] and interact synergistically with turbulence to amplify these effects in the turbulent regime [3, 4]. This study uses Direct Numerical Simulations (DNS) to investigate the effect of elevated pressure and temperature on lean premixed hydrogen flames, with a focus on the interaction between turbulence, thermodiffusive instabilities, and differential diffusion.

Three DNS of premixed lean hydrogen/air jet flames are compared: one at ambient conditions ($1\ \mathrm{atm},\ 298\ \mathrm{K}$), one at gas-turbine conditions ($20\ \mathrm{atm},\ 700\ \mathrm{K}$) and one at high pressure and ambient temperature ($20\ \mathrm{atm},\ 298\ \mathrm{K}$). The three cases share the same jet Reynolds number ($Re = 11{,}200$) and similar Karlovitz number ($Ka \simeq 90$) to isolate the effect of pressure and temperature. Pressure enhances thermodiffusive effects, while temperature tends to weaken them [1, 2]. By comparing flames at different temperatures under the same high-pressure condition to an ambient reference case, this setup enables the investigation of how pressure influences flame–turbulence interactions across varying levels of thermodiffusive effects.

Despite negligible variations in one-dimensional and two-dimensional flames between ambient and gas-turbine conditions, the turbulent cases exhibit some differences in flow-field structures and mixture fraction deviation from the one-dimensional solution, affecting the evolution of the flame speed along the flame. These observations suggest that a combined increase in pressure and temperature can alter the interaction between turbulence and the flame structure, and that extrapolating from lower-dimensional laminar configurations to turbulent three-dimensional flames requires caution.

References

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