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Flamelet Modeling of Thermodiffusively Unstable Hydrogen Flames: From Laminar to Increasing Turbulent Intensity

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Premixed, fuel-lean hydrogen/air flames exhibit distinctive combustion behavior. Under technically relevant conditions, thermodiffusive (TD) instabilities may develop due to hydrogen's molecular diffusivity being significantly higher than its thermal diffusivity. Accurately including those TD instabilities is therefore essential for the development of reduced-order combustion models such as flamelet manifolds. Standard flamelet models usually neglect differential and preferential diffusion, an approximation that is acceptable for hydrocarbon fuels. However, it fails for hydrogen combustion because the unity-Lewis assumption yields incorrect laminar flame speeds and flame structures and prevents prediction of the onset and growth of TD instability structures. To remedy this limitation, Nicolai et al. [1] introduced an extension of the flamelet manifold model to account for constant non-unity Lewis numbers, while Pérez-Sánchez et al. [2] further extended the model for mixture-averaged diffusion. We extend the flamelet manifold model to include thermal diffusion due to the Soret effect and demonstrate that the improved model accurately reproduces TD instabilities in a laminar setting in both the linear and non-linear regime. Furthermore, as TD instabilities synergistically interact with turbulence [3] dependent on the turbulent intensity, we evaluate the models performance for varying Karlovitz numbers in a canonical flame-in-a-box configuration that maintains homogeneous isotropic turbulence. Benchmark DNS data from Howarth et al. [4], covering a large range of Karlovitz numbers, provide a reference for assessing model accuracy across turbulence intensities.

References

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