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Linear Stability Analysis of Laminar Flames with Lewis Number Greater Than Unity and Wide Range of Premixedness

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Extended Abstract

Nonlinear dynamic behavior in flames can lead to combustion instability in gas turbines having important consequences on performance and safety. Hence to effectively control this instability, studying dynamic behavior in laminar and turbulent flames is essential.

Oscillations in flames are observed in premixed, diffusion and triple flames across various studies [1]–[4]. Our previous work on laminar flames aimed at assimilating all different flames ranging from trailing-edge diffusion flame to flat premixed flames and triple flames by defining an premixedness parameter [5]. Fluctuating dynamics were observed for laminar flames with Lewis number greater than 1.5 and a wide range of the Damköhler number and premixedness parameter. The (Damköhler, premixedness) parametric space presenting oscillations spreads as the Lewis number is increased. High amplitude oscillations were observed in near premixed and premixed flames along with quasi-periodic behavior for a few cases.

This work attempts to understand the different physical mechanisms behind the nonlinear dynamic behavior of flames using linear stability analysis. Various cases of laminar flames with a range of Damköhler number and premixedness parameters for Lewis number = 1.6 were considered. For each case, a steady solution is obtained using a time-marching simulation with selective frequency damping [6]. This steady solution is used as baseflow, and the nonlinear conservation equations (thermo-diffusive model) is linearized about it. This model helps to understand the dynamic behavior of flames due to Lewis number effect and isolate instabilities arising due to Darrieus–Landau mechanism. The linearized equations are discretized using high-order Lagrange elements using the FEA package FEniCSX-dolfinx [7] and the system is converted to eigenvalue problem by assuming an exponential dependence in time. This system is solved using the SLEPc library.

For each case of partially premixed flames, a leading pair of complex eigenvalues are observed indicating an oscillatory mode. This pair of modes have positive growth rate for a subset of the combinations of Premixedness and Damköhler numbers. For fully-premixed flames, a family of complex eigenvalues is observed. A reduced number of them are unstable. This indicates a wavy pattern of oscillating flames which is consistent with the observations in the nonlinear simulation. The frequencies predicted by this analysis match well those recovered by nonlinear simulations.

The linear stability analysis helps to understand the driving physical mechanisms behind various nonlinear dynamics like limit cycle oscillations for partially premixed flames and quasiperiodic behavior for near premixed flames observed in the simulations and will be useful in developing reduced order modelling of complex combustion systems.

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