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Identification of global modes in a hydrogen non-premixed flame using numerical simulations

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A typical non-premixed injection system consists of a circular nozzle supplying fuel, surrounded by a co-flowing oxidizer [1]. Efficient combustion in such configurations requires a high level of mixedness between fuel and oxidizer, which can be enhanced by inducing large-scale vortices. One effective strategy involves applying suction at the jet periphery (annular counterflow). The modification of the initial flow pattern induced by suction is relatively small, but it can trigger a global instability mechanism near a nozzle lip. During the transition to global instability, the coherent toroidal vortices emerge and are accompanied a radial ejection of thin fluid streams (side-jets), which further promote mixing. This flow pattern prevents the flame from attaching to the nozzle [2] and blowing out the flame [3], effectively stabilizing the lifted flames. Depending on the flow conditions, two types of global instability can be identified [4]: Mode I, a shear layer mode observed under strong suction where global oscillations originate in the shear layer; and Mode II, a jet column mode that can occur with a relatively weak suction or even without suction due to a density difference between the jet and the ambient flow.
In this study, high-fidelity large eddy simulations (LES) are employed to identify inlet conditions conductive to the onset of both global modes and to examine their impact on lifted hydrogen flames. The analysis focuses on the velocity ratio $I = -U_{suc}/U_j$ (U_j - the centerline fuel jet velocity, U_{suc} - the suction velocity) and the density ratio $S = \rho_j/\rho_{cf}$ (ρ_j - the fuel density, ρ_{cf} - the co-flow density). Both light ($S < 1$) and heavy ($S > 1$) jets are examined under varying suction strengths ($0 \leq I \leq 0.3$), including configurations without suction slots. To promote the emergence of global Mode I, water vapor is introduced into the oxidizer stream, in line with the current trends in wet combustion technique.

References

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