Modeling the boundary-layer flashback of premixed hydrogen enriched swirling flames at high pressures

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We model the boundary-layer flashback (BLF) of CH_4/H_2/air swirling flames via large-eddy simulations with the flame-surface-density method (LES-FSD), in particular, at high pressures. A local displacement speed model tabulating the stretched flame speed is employed to account for the thermo-diffusive effects, flame surface curvature, and heat loss in LES-FSD[1]. The LES-FSD well captures the propagation characteristics during BLF of CH_4/H_2/air swirling flames at 2.5 bar and CH_4/air swirling flames at 1 bar (see figure 1). In the LES-FSD for lean CH_4/H_2/air flames at 2.5 bar, the critical equivalence ratio for flashback decreases with the increasing hydrogen volume fraction, consistent with the experiments[2]. This is due to the improved modeling of effects of the flame stretch and heat loss on the local displacement speed[3]. We also develop a simple model to predict the BLF limits of swirling flames. The model estimates the critical bulk velocity for given reactants and swirl number, via the balance between the flame-induced pressure rise and adverse pressure for boundary-layer separation. We validate the model against 14 datasets of CH_4/H_2/air swirling flame experiments[2], with the hydrogen volume fractions in fuel from 50% to 100%. The present model well estimates the flashback limits in various operating conditions.

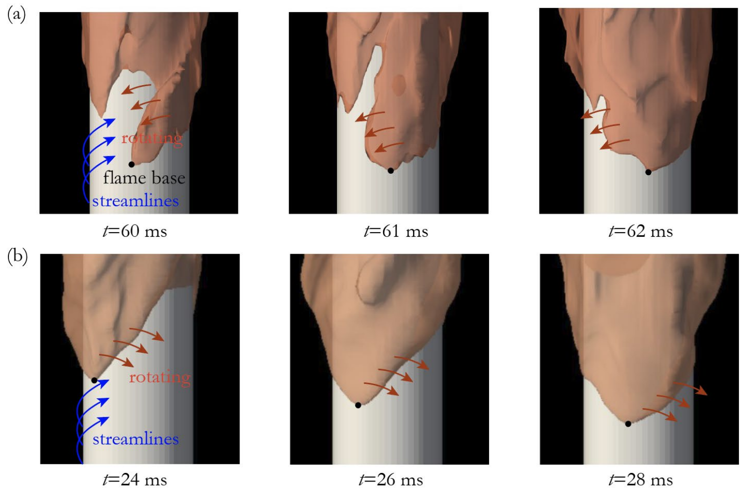

Figure 1: Propagation of the flame tongue during BLF of (a) CH_4/H_2/air swirling flames at 2.5 bar and (b) CH_4/air swirling flames at 1 bar.

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[1] Zhang et al., *Phys. Fluids* **33**, 045118 (2021).

[2] Ebi et al., *Proc. Combust. Inst.* **38**, 6345 (2021).

[3] Lu and Yang, *Proc. Combust. Inst.* **38**, 2901 (2021).