Efficient Computational Methods for Turbulent Boundary-layer H2-air Flashback Prediction

EFFICIENT COMPUTATIONAL METHODS FOR TURBULENT BOUNDARY-LAYER H_2-AIR FLASHBACK PREDICTION

S.M. Ali*, R.J.M Bastiaans

Power & Flow Group, Department of Mechanical Engineering, Eindhoven University of Technology, Den Dolech 2, 5612 AZ, Eindhoven, Netherlands

*a.syed.mughees@tue.nl

ABSTRACT

The current computational work aims to quantitatively understand the flashback phenomena to validate a practical gas turbine combustor for flexible fuel operation from 100% Natural Gas to 100% H_2 and any mixture thereof at a low emissions level. Generally, the past studies have extensively used the two configurations to study flashback, namely, jet premixed flames and divergent channel. This current study contains computational results using detailed kinetics for jet premixed H_2-air premixed flames to predict flashback. The study highlights the importance of grid sizes for accurately capturing the net hydrogen reaction rates for predicting flashback.

INTRODUCTION

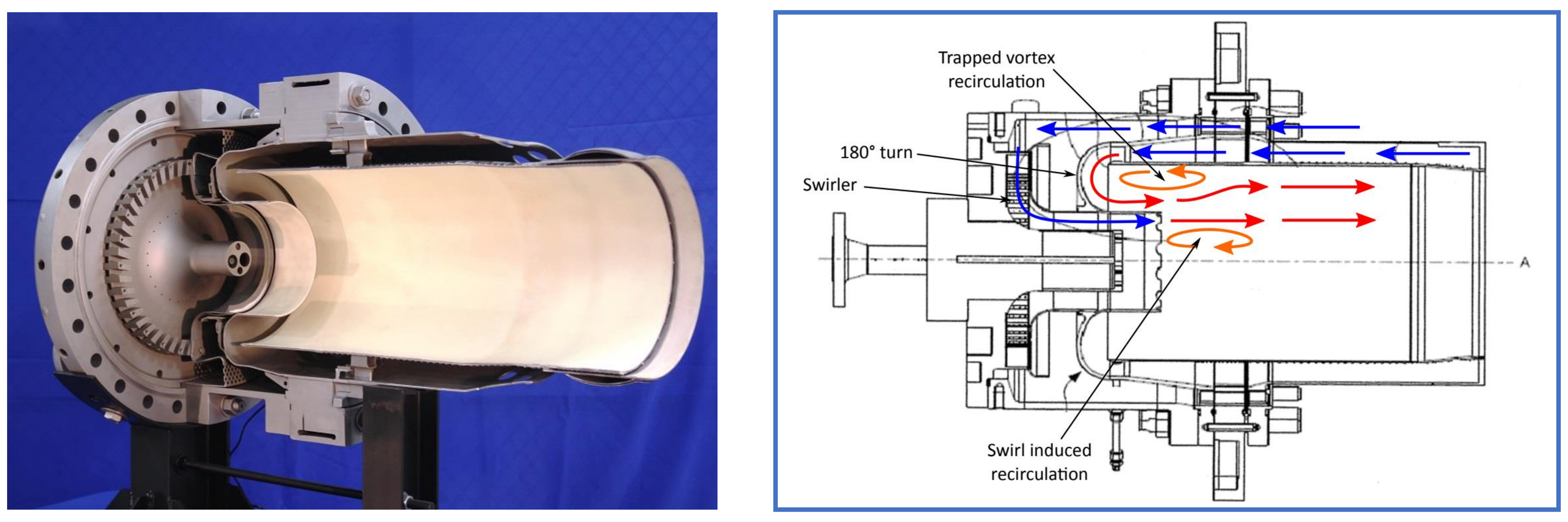

Fig. 1: Design of FlameSheet™ combustion system by Thomassen Energy retrofitted for High Hydrogen Gas Turbine Retrofit Project [1, 2]

Natural gas → Hydrogen

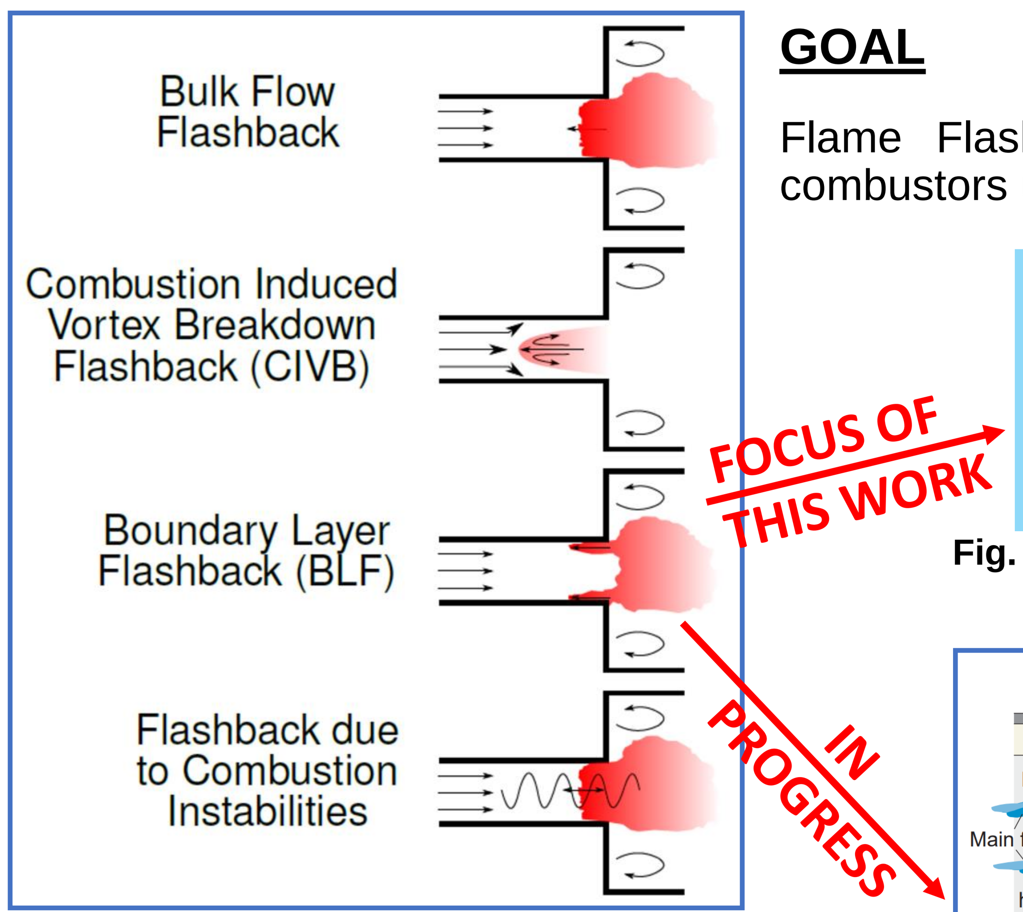

Fig. 2: Schematic representation of different flashback mechanisms occurring in gas-turbine combustors [3]

GOAL

Flame Flashback prediction in Gas-turbine combustors using H_2 as a fuel.

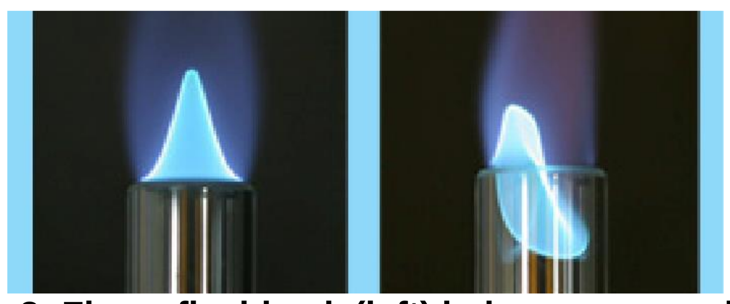

Fig. 3: Flame flashback (left) in burner caused by adding hydrogen to natural gas [4]

APPROACH

Jet premixed H_2-air flame simulations for Flashback predictions.

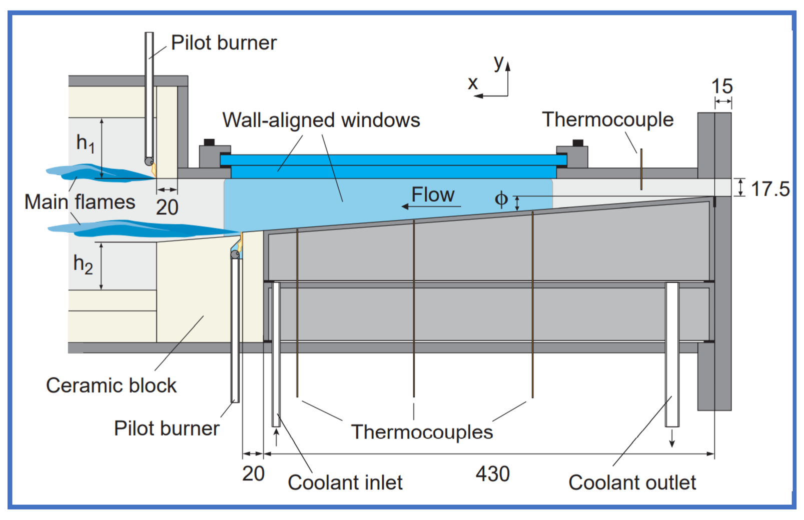

Fig. 4: Divergent channel burner configuration [5]

COMPUTATIONAL METHODOLOGY

COMPUTATIONAL DOMAIN AND BOUNDARY CONDITIONS

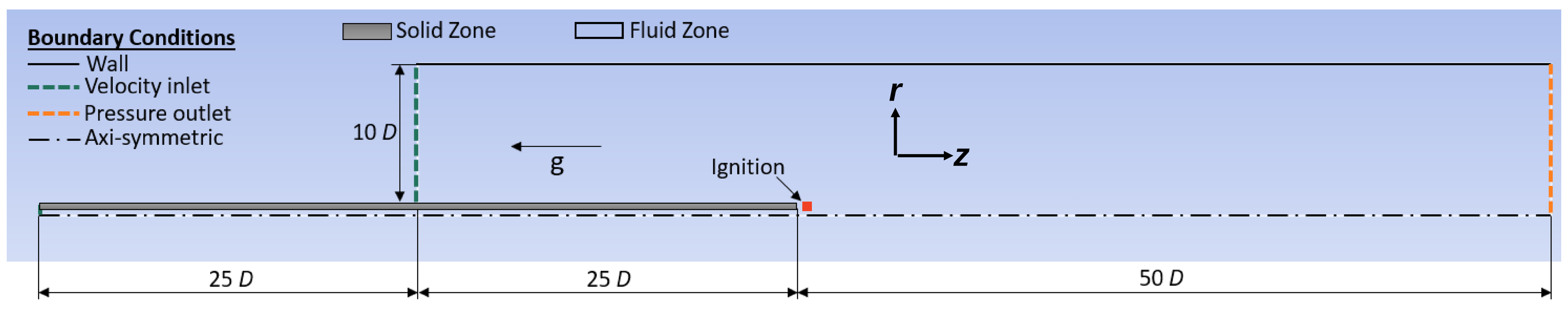

Fig. 5: Schematic of the computational domain with imposed boundary conditions

SOLVER DETAILS FOR SIMULATION

- 2D axisymmetric domain constructed as per *Elbe & Mentser (1945) data.*
- 50D (D = 2.16 mm) duct included to ensure fully developed flow.
- Details on mesh generation can be found in *Ali et. al (2021).*
- Pressure based solver was used with double precision accuracy.
- *Konnov (2019) kinetic* mechanism used.
- Properties based on kinetic theory and conjugate heat transfer included.
- Premixed mixture of H_2/Air at an equivalence ratio of 0.42.
- Stationary wall with no slip boundary.
- Convergence was achieved by fixing the residuals at value of 10^{-10}.
- Velocities decreased from 0.7 m/s with steps of 0.05 m/s, close to flashback with steps of 0.02 m/s.

RESULT AND DISCUSSION

Figure 6 shows the variation of axial flame temperature for four grid sizes for lean mixture (ϕ = 0.42) for D=2.16mm & u_{av}=0.7m/s. Comparison of temperature profile shows a difference of less than 20 K when the grid is refined from 200 to 25 μm.

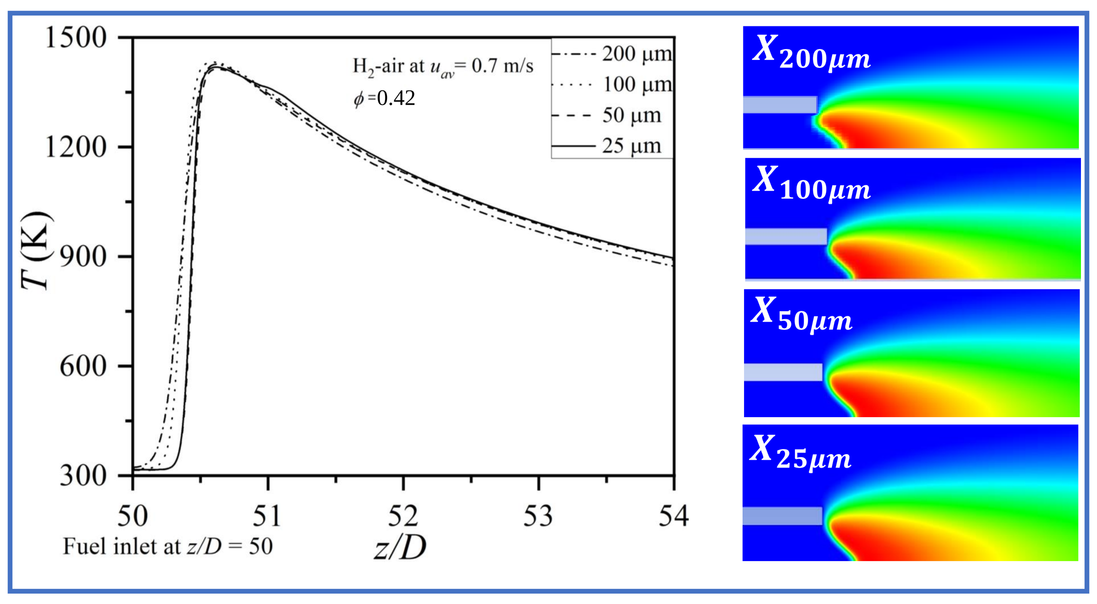

Fig. 6: Variation of axial flame temperature for four grid sizes

There is no change in axial velocity profile with mesh size reduction from 200 to 25 µm.

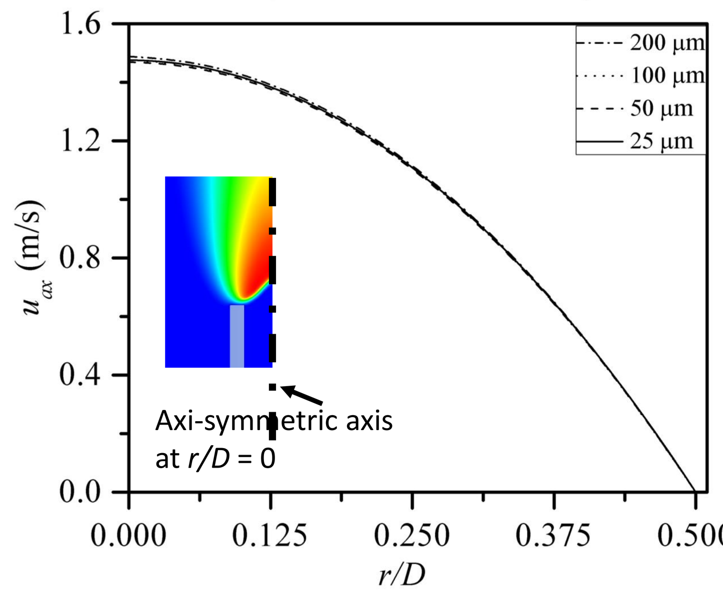

Fig. 7: Variation of axial velocity in radial direction for four grid sizes

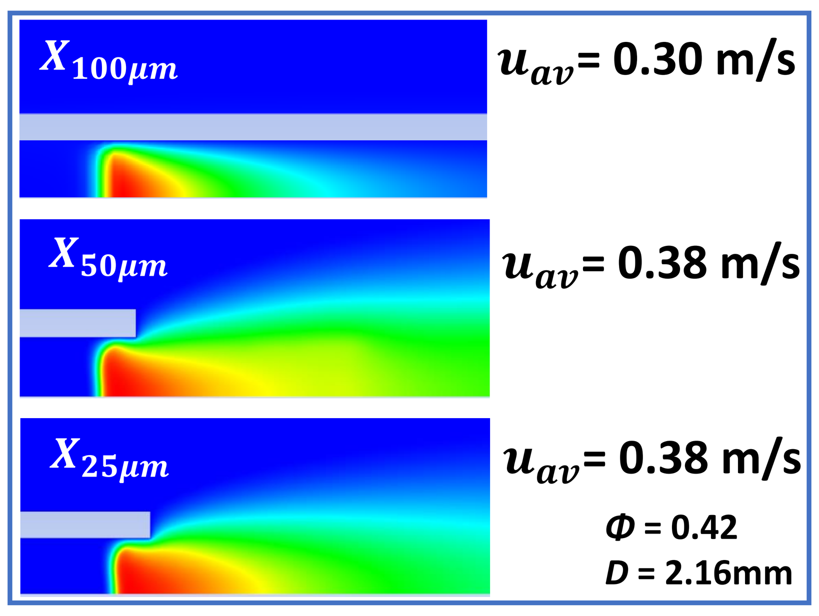

Fig. 8: Temperature profiles shows increase in flashback velocity with grid size reduction

Significant change is observed in the inlet velocity for the flashback conditions from coarse to refined mesh.

Accurately capturing the H_2 reaction rate should be the critical factor to predict flashback of premixed H_2-air mixtures. Results are inline with previous *Ali and Varunkumar (2020)* study.

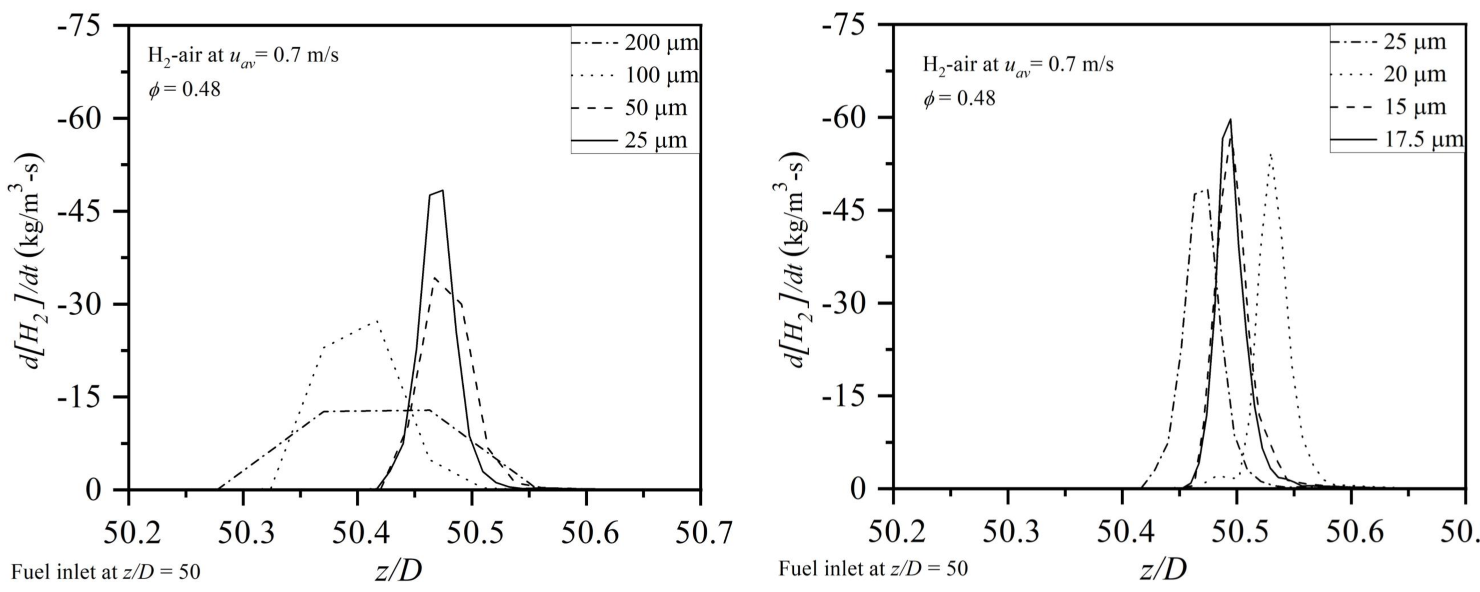

Fig. 9: Variation of Net H_2 reaction rate along the axis for eight grid sizes

The flame location does not show any change and less than 3.5 % increase in peak value for reduction in grid size from 17.5 to 15 µm. Therefore, 17.5 µm grid size should be used to predict flashback for ϕ = 0.42 in the case of detailed kinetics simulations.

CONCLUSION

Mesh refinement from 200 to 25 µm shows no change in the axial velocity profile. So, the grid size that can accurately capture the H_2 reaction rate should be used to predict flashback in detailed kinetics simulations (for instance, DNS for turbulent cases). Even though the critical velocity gradient (flashback limit) does not show any significant change for the studied H_2-air lean case (ϕ = 0.42) with a grid size reduction from 50 and 25 µm, these mesh sizes cannot be recommended as a conclusive grid sizes for higher values of equivalence ratios. A coarse mesh size close to flame thickness is recommended in cases where reaction rates are calculated using subgrid modelling methods (FGM).

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