TNF target flame: Multi-regime turbulent H_2/air flames at atmospheric pressure.

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Introduction

The Darmstadt H_2-Multi-Regime Burner (H_2-MRB) configuration is investigated using Direct Numerical Simulations (DNS) to provide detailed insight into the fundamental processes governing multi-regime hydrogen combustion at atmospheric conditions. The H_2-MRB is specifically designed to study combustion regimes in which both premixed and non-premixed reaction zones coexist, achieved through the mixing of three supply streams over an inclined bluff body [1]. This configuration generates a complex flow environment in which turbulence, recirculation, mixing, stratification and chemical kinetics interact and determine flame stabilization and structure. For example, experimental investigations have demonstrated that these coupled effects can significantly extend the lean operating limits, enabling ultra-lean hydrogen combustion [1].

The present DNS focuses in reproducing three operation conditions also investigated experimentally, allowing for a direct comparison between simulation and measurement. The validation against measured flow and scalar fields enables assessment of how faithfully the numerical model captures the complex flame dynamics. In addition, the DNS complement and extend the experimental data by providing fully-resolved information on velocity and thermochemical states.

DNS configuration and methods

The DNS were conducted using the low Mach number reactive flow solver *nekCRF* [2], which is based on the spectral element method code *nekRS* [3]. The chemical subsystem is solved fully-coupled without splitting of convection, diffusion and reactions using CVODE. The chemical mechanism consists of 21 reactions and includes 9 species according to [4]. Species diffusion is accounted for by a mixture-averaged transport model excluding the Soret and Dufour effects. 7^{th}-order Lagrange polynomials are used as basis functions for spatial discretization, while a 3^{rd}-order backward differentiation method is used for temporal discretization.

Operation conditions

The burner dimensions are fixed and operation conditions vary only in the mixture composition and the bulk velocities of the three supply streams. The dimensions of the burner are given in [5]. Depending on the operating condition, the equivalence ratio in the rich premixed central jet varies between $\phi = 3.5$ and $\phi = 9.0$, while the jet bulk velocity remains constant at $105.0\,\mathrm{m\,s^{-1}}$.

The central jet is surrounded by a laminar annular jet (slot1) supplying air at bulk velocities varying between $7.5\,\mathrm{m\,s^{-1}}$ (suffix a) and $12.5\,\mathrm{m\,s^{-1}}$ (suffix b). The lean premixed secondary annular jet (slot2) has an equivalence ratio of $\phi_{\mathrm{slot2}} = 0.26$ and a constant bulk velocity of $20\,\mathrm{m\,s^{-1}}$. A summary of the inflow conditions for all operating conditions is given in Tab. 1.

Table 1: Operation conditions

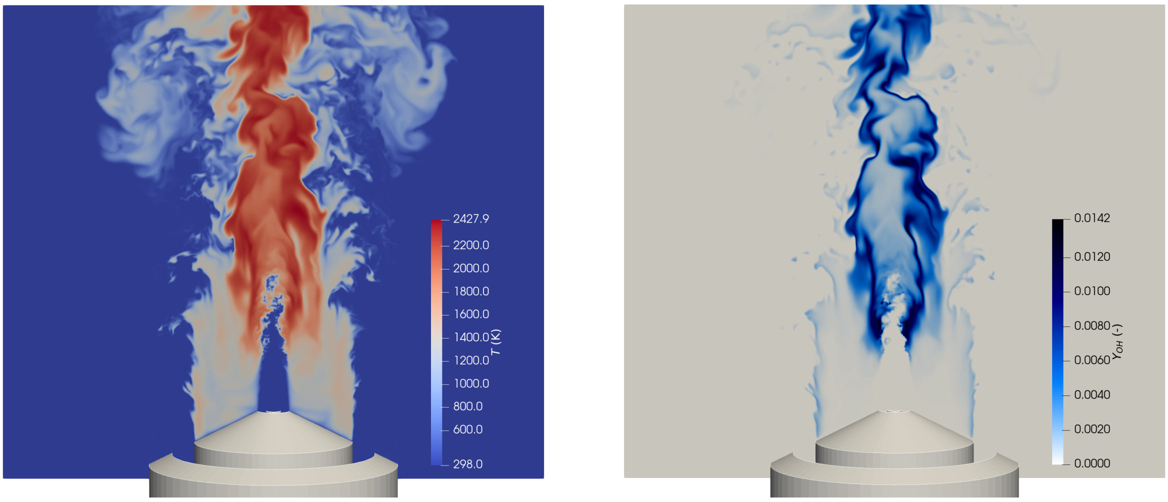
Case	ϕ_{jet} (−)	U_{jet} ($\mathrm{m\,s^{-1}}$)	U_{slot1} ($\mathrm{m\,s^{-1}}$)	U_{slot2} ($\mathrm{m\,s^{-1}}$)	$\mathrm{Re}_{\mathrm{jet}}$	$\mathrm{Re}_{\mathrm{slot2}}$
H100-350-026-a	3.5	105.0	7.5	20.0	9500	11400
H100-350-026-b	3.5	105.0	12.5	20.0	9500	11400
H100-900-026-b	9.0	105.0	12.5	20.0	6400	11400

The axially symmetric computational domain has a diameter of 120 mm. In streamwise direction, it extends 90 mm above the jet nozzle. The outlet is treated with an open boundary condition, while the lateral boundaries impose no-flux and no-shear conditions. The burner body is modeled as a no-slip wall with a fixed temperature of 333 K. Turbulent inflow for the central jet and slot2 is generated in a separate DNS of the corresponding pipe and annular duct flows and are applied at the inlet boundaries via overset meshes. For slot1, a top-hat profile is prescribed for velocity. In addition, a coflow of $10\,\mathrm{m\,s^{-1}}$ is applied at the outer part of the domain.

The mesh spacing is non-uniform and locally refined to satisfy the flow-scale criteria $\Delta < \pi\eta$, based on the Kolmogorov length scale η, and the flame-scale criteria $\Delta < 12\delta_{\mathrm{L}}$, based on the laminar flame thickness δ_{L}. The total number of grid points is about 1.9 billion in all simulations.

Exemplary results

Fig. 1a present exemplary instantaneous fields of temperature (a) and OH mass fraction (b) for the H100-350-026-b case. For each operation condition, the dataset includes the full information about the thermochemical state (temperature and species mass fractions) and the velocity field. Besides instantaneous data, temporally-averaged results are available including root mean square values for all variables. In addition, the inflow data of the auxiliary pipe and annular slot is available and was sampled in a plane of the cross section with a frequency of $\Delta t = 10\Delta t_{\mathrm{DNS}}$.



(a) Temperature

(b) OH mass fraction

Figure 1: Slices of the domain showing the instantaneous flame structure.

How to get access to the data

Upon request. Contact Christian Hasse (hasse@stfs.tu-darmstadt.de)

References

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