

TNF target flame: Lean Premixed Turbulent Hydrogen-Air Jet Flames at Varying Equivalence Ratios.

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Introduction

The interaction of turbulence and thermo-diffusive effects are investigated in turbulent lean premixed hydrogen (H₂)-air jet flames over a range of equivalence ratios ($\phi = 0.3, 0.4, 0.45, 0.5$) with Direct Numerical Simulations (DNS). All flames are at atmospheric pressure, ambient jet inlet temperatures and feature a constant jet velocity of 100 m s⁻¹ resulting in moderate Reynolds numbers (Re) of approximately 24,000, and for the $\phi = 0.3$ flame resulting in a high Karlovitz number (Ka). The flames exhibit characteristic features of lean premixed H₂ flames, such as mixture-stratification across the flame front and significant contributions of the reactivity factor to the turbulent flame speeds. The first three conditions are a numerical investigation of three experimental TNF target flames in "Lean premixed turbulent H₂/air jet flames at atmospheric pressure" introduced in [1]. In addition to the experimental operating conditions, the DNS include an operating condition at $\phi = 0.5$. The presented data includes temporally averaged fields of key quantities, spatial profiles of derived quantities such as turbulent flame speeds, and jet inflow data sampled from the precursor turbulent pipe flow.

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 of Li et al. [4] is used which consists of 9 species and 21 reactions. Species diffusion is accounted for by a mixture-averaged transport model excluding the Soret and Dufour effects. 7th-order Lagrange polynomials are used as basis functions for spatial discretization, while a 3rd-order backward differentiation method is used for temporal discretization.

Operation conditions

The flame configuration considered is a cylindrical turbulent premixed jet flame surrounded by a pilot of burnt gases. Geometric dimensions of the burner and computational domain are shown in Fig. 1. The jet consists of a hydrogen/air mixture with varying equivalence ratios. Four cases are considered, corresponding to equivalence ratios of $\phi = 0.3, 0.4, 0.45, 0.5$. Across all

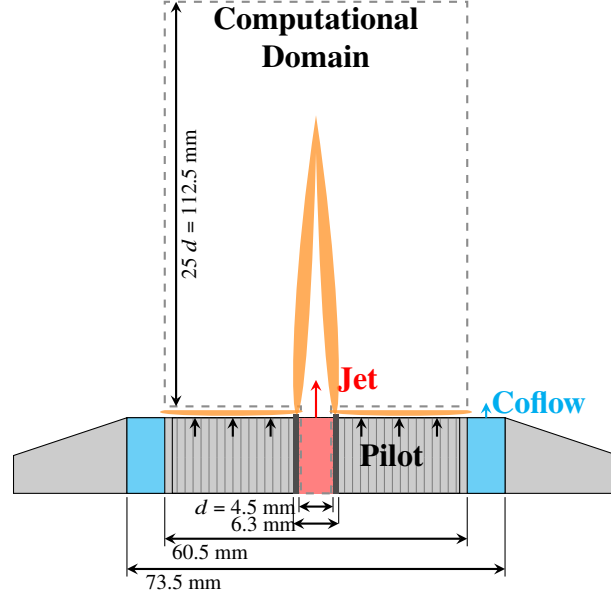


Figure 1: Schematic of the turbulent jet burner. Dashed line indicates the computational domain of the DNS.

operating conditions, pressure, jet inlet temperature, and jet inlet velocity are kept constant at $P = 1e5$ Pa, $T_{\text{Jet}} = 300$ K, and $U_{\text{Jet}} = 100$ m s⁻¹, respectively. The simulation parameters for each operating condition resulting from the equivalence ratio variation are listed in Tab. 1. In accordance to [1], the naming scheme specifies the H₂ content (H), the equivalence ratio (P), and the jet velocity (U). Global Karlovitz and Damköhler numbers are defined based on jet inlet values as $Ka_{\text{Jet}} = \sqrt{(u'^3/l_T)/(s_L^3/d_L)}$ and $Da_{\text{Jet}} = (l_T/u')/(d_L/s_L)$. Here, the root mean square (RMS) value of the velocity fluctuation is calculated as $u' = 0.075 * U_{\text{Jet}}$, the integral length scale is calculated as $l_T = 0.2 * d_{\text{Jet}}$, and s_L and d_L are the laminar flame speed and laminar thermal flame thickness, respectively.

The burner walls are assumed to be adiabatic. At the jet inlet, velocity is prescribed from an auxiliary DNS of a fully-developed turbulent pipe flow via overset meshes. An unstructured mesh is used with a grid resolution Δ satisfying $\Delta/\eta \leq 1$ and $d_L/\Delta \geq 12$. The total number of grid points is about 2.0 billion in all simulations.

Table 1: List of investigated cases with their corresponding naming, equivalence ratio, jet Reynolds number, jet Karlovitz number, jet Damköhler number and the velocity of the pilot exhaust gas.

| Case | ϕ (-) | Re_{Jet} (-) | Ka_{Jet} (-) | Da_{Jet} (-) | U_{Pilot} (m s ⁻¹) |
|--------------|------------|-----------------------|-----------------------|-----------------------|---|
| H100P030U100 | 0.3 | 25,100 | 4,260 | 0.0020 | 7.472 |
| H100P040U100 | 0.4 | 24,300 | 150 | 0.045 | 11.0 |
| H100P045U100 | 0.45 | 23,900 | 64 | 0.10 | 11.75 |
| H100P050U100 | 0.5 | 23,600 | 34 | 0.16 | 12.5 |

Exemplary results

Figure 2 shows the instantaneous temperature fields in a cutting plane. The temperatures are normalized by the adiabatic flame temperature of the corresponding one-dimensional freely-propagating flames.

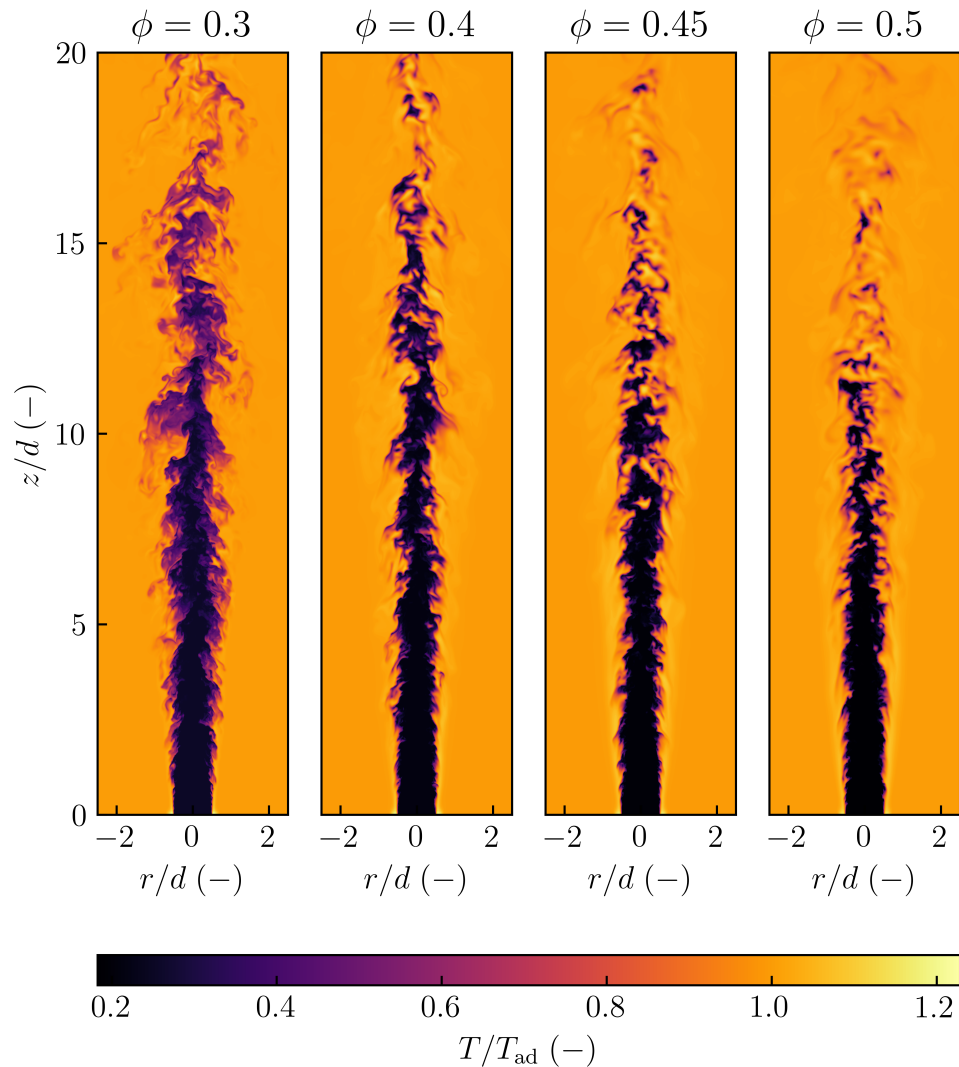


Figure 2: Flame visualization of the cases with increasing equivalence ratio from left to right. Shown are contours of the instantaneous temperature fields in a cutting plane.

Further, the provided data includes:

- Mean and RMS values of velocity, temperature, and mass fractions of H_2 , OH , H_2O_2 .
- Profiles of turbulent flame speed, flame surface area and reactivity factor along the streamwise direction.
- Turbulent pipe flow: mean and RMS values of velocity.
- Turbulent pipe flow: instantaneous velocities sampled in a plane of the pipe cross section with a frequency of $\Delta t = 10\Delta t_{DNS}$.

How to get access to the data

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

References

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