NUMERICAL STUDY OF NOISE EMISSION FROM TURBULENT H_2 AND CH_4 FLAMES

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Abstract

Direct Numerical Simulations of turbulent lean (ϕ = 0.45) premixed hydrogen-air and stoichiometric methane-air slot jet flames in an open environment of ambient air at atmospheric conditions are performed to investigate the differences in the flame dynamics and the radiated noise. The two flames are compared by keeping similar values of laminar flame speed and thickness, and their bulk velocities are selected to obtain similar lengths of the flame brush. In this configuration, noise is generated both due to heat release rate fluctuations and density gradients, leading to differences in the acoustic response of the two flames at low and high frequencies.

Introduction

Combustion noise is a significant issue for engineering combustion systems, which are subject to stringent noise reduction goals [1]. The investigation of combustion noise via high-fidelity numerical simulations is a computationally expensive task. Therefore, numerical studies in the literature are mostly based on Large Eddy Simulations (LES), while investigations relying on Direct Numerical Simulations (DNS) are quite rare, and mostly involve hydrocarbons (e.g., [2]). This study aims to tackle this issue and gain a better understanding of the differences in the acoustic radiation of hydrogen and hydrocarbon flames by performing DNS in a slot burner configuration at atmospheric conditions (300 K and 1 atm) of turbulent premixed lean (ϕ = 0.45) hydrogen (H_2) and stoichiometric (ϕ = 1.00) methane (CH_4) flames.

Methodology and numerical set-up

Numerical simulations are performed with the explicit compressible solver AVBP (www.cerfacs.fr/avbp7x). For the H_2 flame, an Analytically Reduced Chemistry (ARC) scheme based on the San Diego mechanism [3] is adopted, while the CH_4 flame is solved considering a semi-global two-step mechanism.

The turbulent premixed fuel/air mixture with bulk velocity U_b and velocity fluctuation u' = 0.25 m/s is injected through a rectangular channel of section $H \times 1.5H$ and length $3H$ into an open environment of ambient air. To sustain the flame, two laminar coflows of equilibrium burnt gases are introduced along the longer sides of the channel outlet section. For the H_2 flame, U_b = 25 m/s, leading to a Reynolds number Re = 10830 and a nominal Karlovitz number Ka = 7.6. For the CH_4 flame, the value of bulk velocity is lowered to U_b = 10 m/s to achieve a similar flame length as for the H_2 flame, resulting in Re = 5300 and Ka = 7.2.

Results

Figure 1 shows isosurfaces of progress variable colored by the normalized heat release rate (HRR), taken at $t = 3\tau$ (with $\tau = 20H/U_b$) and $c = c^*$, i.e., the value corresponding to the peak of HRR in the 1D unstretched laminar flame (0.80 for H_2 and 0.77 for CH_4). It can be clearly observed the impact of Lewis effects on the flame structure, with the H_2 flame having a more corrugated flame front and sensible local variations of HRR, while the CH_4 flame shows a more regular behavior.

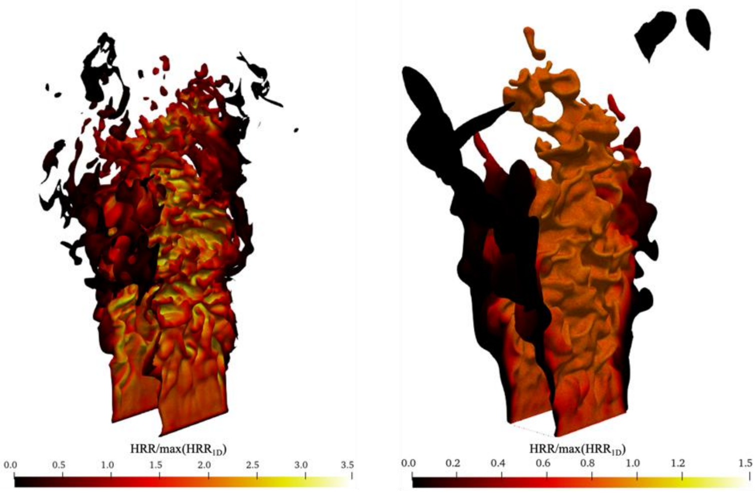

Figure 1. Isosurfaces of $c=c^*$ at $t = 3\tau$ for the H_2 (left) and CH_4 (right) flames, colored by the HRR normalized by the maximum value in the corresponding 1D unstretched laminar flame.

The mixing of the reacting flow with the ambient air leads to local variations in the density field, as it can be observed in Fig. 2, which shows the normalized magnitude of the gradient of density in the *xy* plane. While gradients can be observed in the jet shear layer between the ambient air and the combustion products for both flames, these are stronger for the H_2 flame.

Figure 3 reports the power spectral density (PSD) of volume-integrated HRR and local pressure for the two flames as a function of the Strouhal number $St = fH/U_b$. Indeed, while the CH_4 flame shows a higher HRR PSD at all frequencies, the pressure PSD is lower than the one of the H_2 flame in the low frequency regime. This can be explained by the previously observed differences in the density gradient distributions. Indeed, density variations are, together with the fluctuations of HRR, major sources of noise in reacting flows [1]. At higher frequencies, instead, the pressure PSD of the CH_4 flame better correlates with its higher HRR PSD.

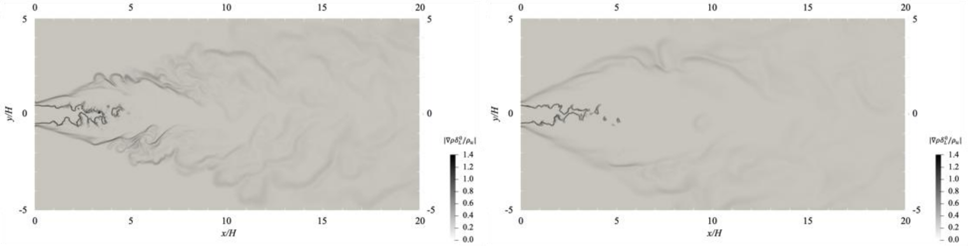

Figure 2. Gradients of density in the *xy* plane at $t = 3\tau$ for the H_2 (left) and CH_4 (right) flames, normalized by the density of unburned gases and the laminar flame thickness of the corresponding 1D unstretched laminar flame.

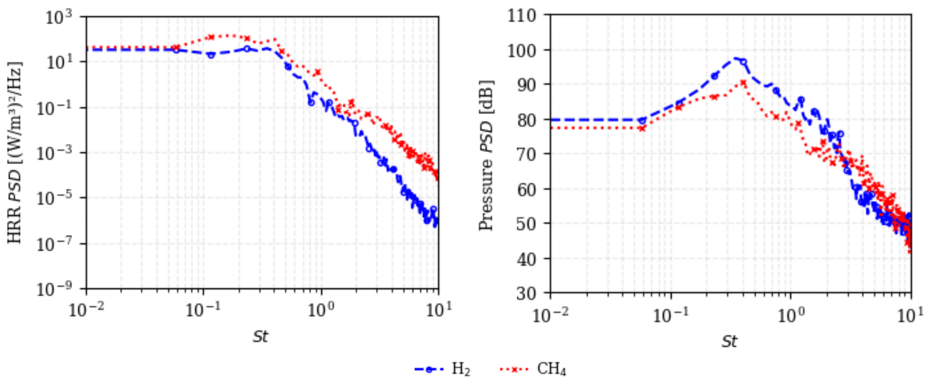

Figure 3. PSD spectra of volume-integrated HRR (left) and pressure at the location [*x*, *y*, z] = [6*H*, 8*H*, 0] for the H_2 and CH_4 flames.

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