Controlling spatio-temporal evolution of square and rectangular flames via inlet conditions

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Abstract: This paper focuses on a numerical analysis of turbulent diffusion flames issuing from square and rectangular nozzles. The computations are performed applying the large-eddy simulation (LES) method combined with the Eulerian stochastic field (ESF) model for combustion modelling. Depending on the nozzle aspect ratio and the Reynolds number the flame dynamics significantly differ both in terms of the lift-off height and the flame shape. We analyze to what extent these global parameters are sensitive to small-scale changes of the inlet parameters such as turbulence intensity and the turbulence length and time scales.

Keywords: Turbulent Flames, Large-eddy Simulations, Flow Control.

1 Introduction

Passive flow control methods are relatively simple and not expensive ways of improving mixing processes. They play a significant role in various applications (atomizers, heat exchangers, air-conditioning systems, etc.) but are particularly important in combustion where the mixing of a fuel and oxidizer is a crucial factor. In this research we focus on the mixing process and combustion dynamics of flames issuing from square and rectangular nozzles. Compared to classical circular jets or flames, it turns out that those emanating from non-circular nozzles characterize naturally enhanced mixing, particularly, large-scale mixing phenomena were found substantially intensified [1]. We analyze sensitivity of rectangular flames to different inlet conditions including: (i) inlet velocity (Reynolds number); (ii) varying aspect ratio of a nozzle, $AR = 1 - 2$; (iii) inlet turbulence characteristics - intensity and length/time scales. As shown in [2], in case of isothermal constant density rectangular jet flows the first two parameters influence a global jet dynamics, whereas the third one affects a small-scale mixing provided that the Reynolds number is relatively small. In the present investigations we analyze to what extent these findings translate to the flame dynamics. The computations are performed applying the large-eddy simulation (LES) method combined with the Eulerian stochastic field approach for combustion modelling.

We consider a nitrogen diluted hydrogen flame with the fuel and oxidizer compositions corresponding to the so-called Cabra flame [3], i.e., the fuel: $X_{H_2} = 0.25$ $X_{N_2} = 0.75$; the oxidizer: $X_{O_2} = 0.1474$, $X_{H_2O} = 0.0989$ and $X_{N_2} = 0.7534$. The fuel and oxidizer temperatures are $T_f = 305$ K and $T_o = 1045$ K. The jets issuing from the nozzles (see Fig. 1) auto-ignite and the arising flames stabilize as lifted or attached, depending on the Reynolds number ($Re = U_b D_e/\nu = 23\,600$ and $Re = 10\,000$, where U_b is the bulk velocity, ν is the kinematic viscos-

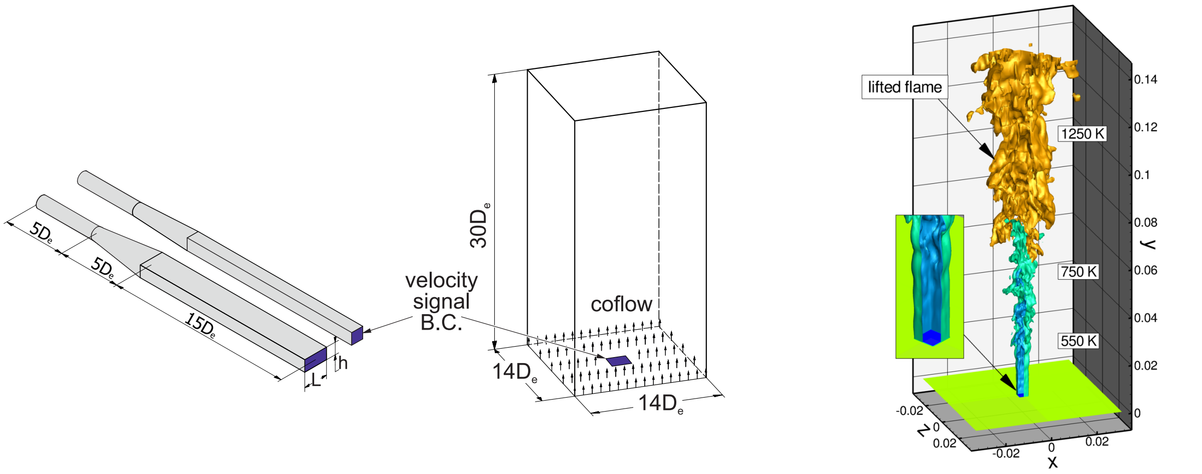

Figure 1: Sketch of the computational domains (a), (b); temperature iso-surfaces in the flame issuing from the square nozzle (c).

ity, $D_e = 2\sqrt{S/\pi} = 4.57\ mm$ is an equivalent diameter, with S being the nozzle cross-sectional area). The D_e is kept constant while changing the nozzle aspect ratio defined as $AR = L/h$, where L and h are the dimensions of the nozzle exit depicted in Fig. 1a).

The computational procedure is as follow. In the first stage, the precursor simulations of the flow inside the pipes are performed using ANSYS Fluent software. At this stage, we modify the inlet conditions to the pipes and this leads to different flow characteristics at their outlets. At the same time the unsteady velocity signals from the outlets of the pipe sections are acquired. Then, these signals are used as the inlet boundary conditions in the second stage of the simulations (Fig. 1b), where the computations are carried out using an in-house LES code SAILOR for low Mach number reactive flows. It is based on the projection method for pressure-velocity coupling with a high-order compact difference method for the spatial discretization on half-staggered meshes. The chemical reactions are modelled applying the detailed chemistry model of hydrogen oxidation with 9 species and 21 reactions. The accuracy of the SAILOR code was verified against the experimental data of cabra et al. [3] for a circular nozzle, see [4]. The preliminary results obtained for the square flame (Fig. 1c) show substantial altering of the lift-off height and flame dynamics already at slight changes of the inlet parameters.

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