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Large eddy simulation/probability density function simulations of bluff body stabilized flames

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ABSTRACT

This work presents large eddy simulation/probability density function (LES/PDF) simulation results for the Sandia/Sydney series of bluff-body stabilized CH_4/H_2 flames. Results are presented for the flames HM1, HM2 and HM3, using the 19-species ARM2 reduced chemical mechanism, and comparison is made with previous numerical simulations of the same flames. When compared to previous numerical studies of these bluff-body flames, the present simulation shows considerable improvement, particularly in the downstream regions of the flow. The simulations are shown to be sensitive to the treatment of heat transfer to the bluff-body face, with better agreement in the temperature profiles achieved with the addition of a Dirichlet temperature boundary condition.

1. Introduction

In the study of computational methods for turbulent reactive flows, the probability density function (PDF) chemistry modeling approach [1] is highly effective, due to the fact that there is no need for modeling of highly non-linear chemical source term [2]. In a large eddy simulation/probability density function (LES/PDF) algorithm [3], this advantage of the PDF chemistry model is coupled to the advantages of LES codes, which need no modeling for the large hydrodynamic scales which do not exhibit universal behavior [4]. As a result, modern LES/PDF codes are highly successful at simulating laboratory scale turbulent reactive flows [5,6,8,9,22].

In the present study, we apply a state of the art LES/PDF algorithm to the Sandia/Sydney series of CH_4/H_2 bluff body stabilized flames [11], in particular the flames HM1, HM2 and HM3. These flames feature a hydrodynamically complex flow with a recirculation region attached to the bluff body face – a stabilization mechanism used in many technical applications – and local extinction for the cases HM2 and HM3. These features make the Sandia/Sydney bluff body flames both physically relevant and a natural application for an LES-based simulation, as opposed to a Reynolds-averaged Navier–Stokes-based solution.

The Sandia–Sydney bluff body series of flames, especially HM1, have previously been simulated by a variety of computational methods. Reynolds-averaged Navier–Stokes/Probability Density Function (RANS/PDF) solutions, using detailed chemistry (all the species in the chemical mechanism are tracked independently, subject to conservation of chemical elements), have been performed by Liu et al. [12] and Merci et al. [13]. A variety of large eddy simulation solutions exist, with chemistry modeling provided either via a steady-state flamelet model in the LES code, used by Kempf et al. [14], the direct quadrature method of moments used by Raman et al. [9], or via a particle probability density function (PDF) method, similar to the one used in the present study, either with detailed chemistry such as in the study of James et al. [15], or with a two-dimensional PDF sample space, consisting of mixture fraction and a reaction progress variable, in the work of Raman et al. [16,9].

Of the above mentioned works, [12] and [13] are the only ones which have performed simulations for the higher velocity flames HM2 and HM3 – the rest yield results for HM1 only. Previous researchers have found that the agreement with experimental data is best for the flame HM1, and deteriorates progressively for the faster flames HM2 and HM3, and also that the agreement is worse for locations which are far downstream in the axial direction.

In the present work, we perform LES/PDF simulations of the bluff body flames with reduced chemistry, using the ARM2 chemical mechanism, and compare our results with those of Liu

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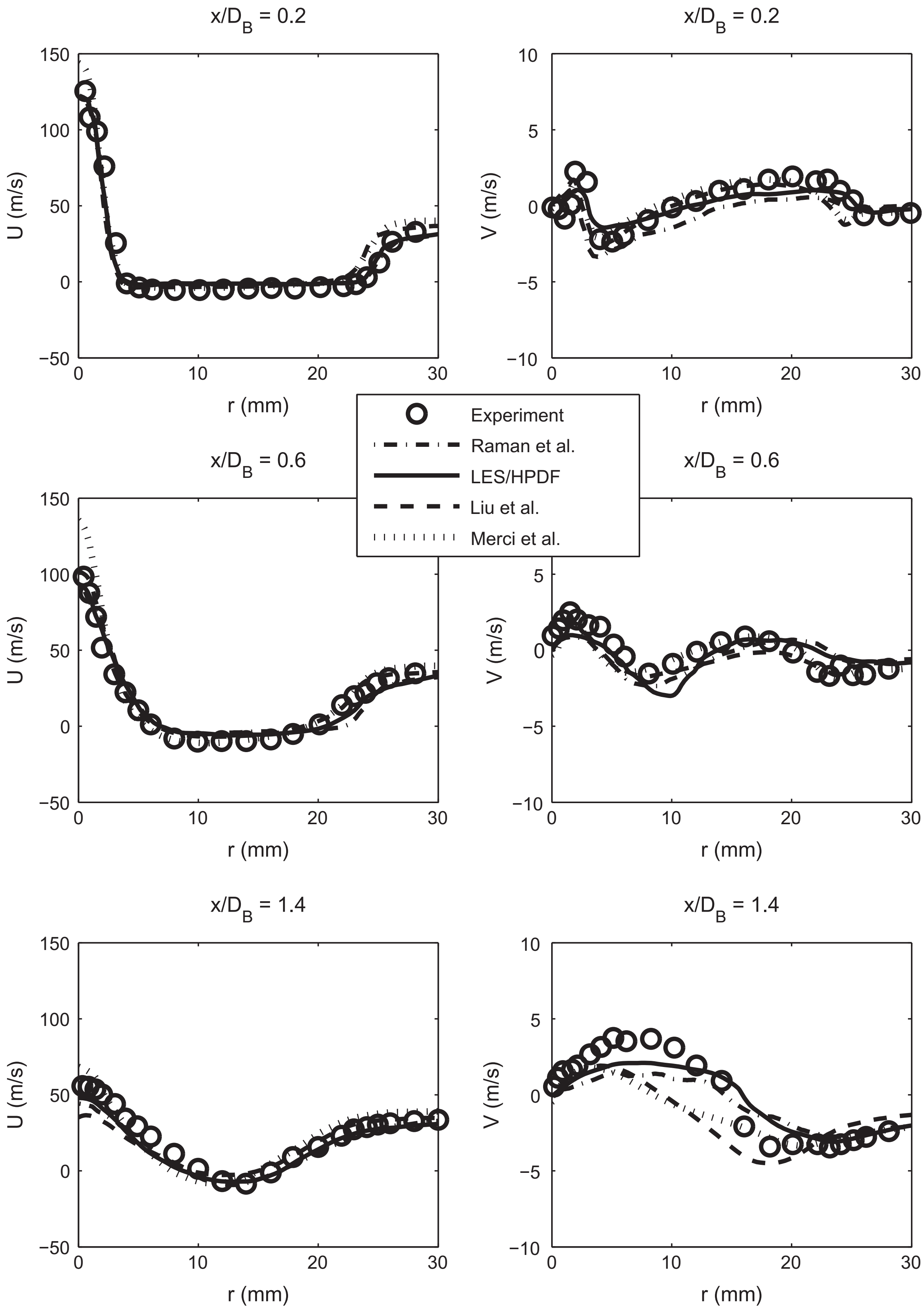

Fig. 1. Mean velocity plots for the HM1e simulation. Left: radial plots of the Favre-averaged axial velocity at three different axial locations: $x = 0.2D_B, x = 0.6D_B$, and $x = 1.4D_B$. Right: plots of the Favre-averaged radial velocity at the same locations. As noted in the text, the LES/HPDF profiles are scaled by a factor of 108/118, in order to account for the velocity difference between flames HM1 and HM1e.