Hybrid RANS/PDF calculations of a swirling bluff body flame (SM1)

R. De Meester, B. Naud, and B. Merci

In: Combura 2010 Book of Abstracts – page 9-10

R. De Meester, B. Naud, and B. Merci (2010). Hybrid RANS/PDF calculations of a swirling bluff body flame (SM1) Book of Abstracts of Combura 2010, 12-13
October 2010, Maastricht, The Netherlands, p 9-10

Hybrid RANS/PDF calculations of a swirling bluff body flame (SM1)

R. De Meester[1], B. Naud[2], and B. Merci[1]

[1]*Department of Flow, Heat and Combustion Mechanics, Ghent University, Belgium,*

[2] *Modeling and Numerical Simulation Group, Energy Department, Ciemat, Spain*

reni.demeester@ugent.be

1. Introduction

The objective of this paper is to study the capability of hybrid RANS/PDF calculations in combination with tabulated chemistry techniques to capture local extinction and mixing of unburnt and burnt mixtures. This study is performed for the specific case of the swirling bluff-body flame SM1 [1]. LES results of this flame have been reported in [2], but this was with flamelet chemistry and a presumed scalar PDF, whereas here a transported (scalar) PDF is used in order to study turbulence – chemistry interaction. A comparable quality of results is obtained.

2. Experimental Set-up

Experiments have been performed by Sydney University and Sandia National Laboratories [1]. The bluff body (50mm diameter) contains the central fuel jet, consisting of CH_4 (3.6mm diameter). Swirling air is provided through a 5mm wide annulus surrounding the bluff-body. The burner is placed inside a wind tunnel with a square cross section.

3. Numerical Description and Modeling

All steady, axisymmetric calculations are performed with the same code PDFD [3]. The 0.3m long computational domain starts at the burner exit and extends 0.15m in the radial direction. A non-uniform rectangular grid of 160x128 cells is used. A non-linear k-ε turbulence model [4] is used, as it takes into account the effect of streamline curvature and rotation on turbulence.

Two pre-tabulated combustion models are compared, assuming equal diffusivities and unity Lewis number. First, we use a single steady laminar flamelet with a strain rate of $100s^{-1}$, calculated in the opposed-flow diffusion flame configuration using the detailed mechanism GRI2.11. In the flamelet, mixture fraction is the only independent parameter, determining density, temperature, viscosity and all species mass fractions. Second, a REDIM [5] is used which can be seen as an extension of the ILDM concept to incorporate the effect of coupling of reaction and diffusion processes. Here, the REDIM concept was used to reduce the mechanism of [6] for CH_4 to a 2-dimensional manifold with mixture fraction and $Y(CO_2)$ as independent parameters. The largest difference between the flamelet and the REDIM is the extra independent parameter $Y(CO_2)$, describing reaction progress.

The turbulence – chemistry interaction, is modeled with a transported scalar PDF, using a turbulent Schmidt number $\sigma_T=1.5$. Two micro-mixing models are compared: the Modified Curl's CD model [7] and the EMST model [8].

4. Results

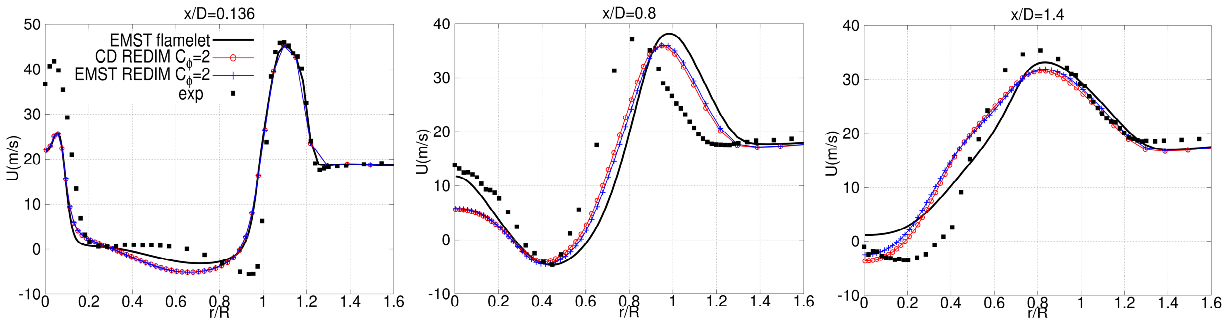

Figure 1: Profiles of mean axial velocity

The flow field of SM1 contains two recirculation zones: one close to the bluff body and one further downstream near the central axis. Both recirculation zones are captured to some extent with both combustion models. A substantial difference in flow fields is seen between the flamelet and the REDIM. This is due to the difference in density field predicted by the two combustion models. The difference between the flamelet and REDIM calculations is even more pronounced for the mean mixture fraction and YCO_2. The predictions of the REDIM calculations are satisfactory, except for in the region in between the two recirculation zones.

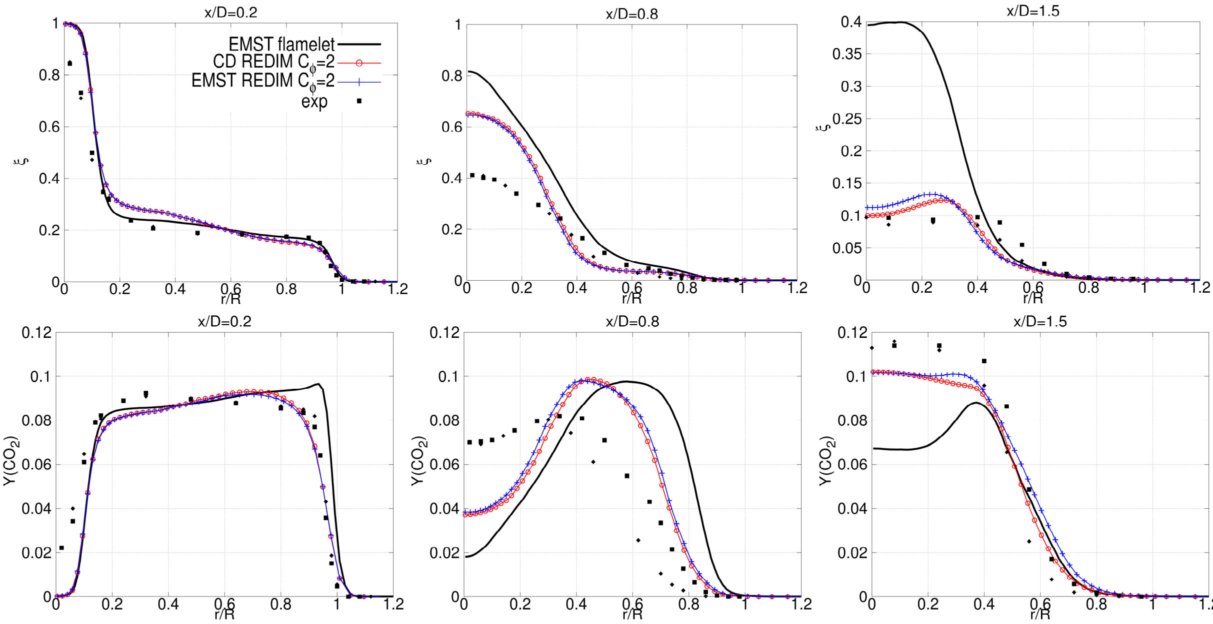

Figure 2: Profiles of mean mixture fraction and YCO_2

The REDIM clearly benefits from the second independent parameter describing reaction progress, as this makes it possible to describe mixing of two mixtures at any point in the reaction progress. Whereas with the single flamelet there is only mixing along the flamelet. (Fig. 3) For the REDIM calculations, there are only minor differences between the two mixing models in physical space (Fig. 2). However, in composition space, there is more scatter with the CD model leading to better predictions of the conditional means and fluctuations. (not shown).

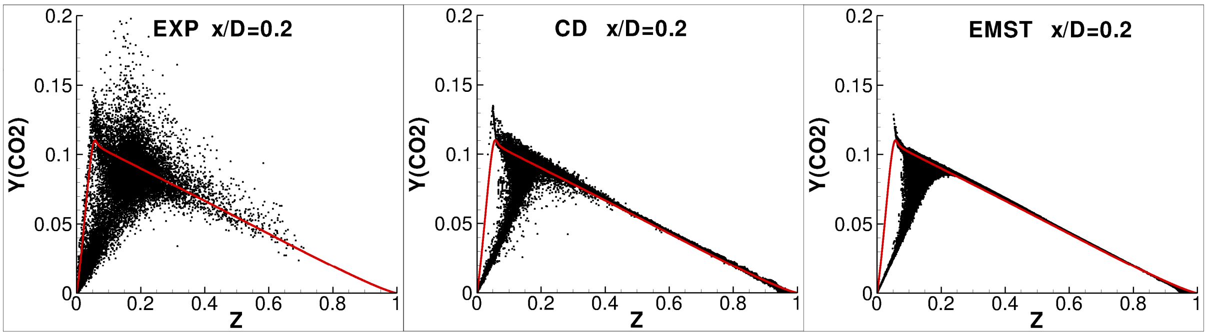

Figure 3: Scatter plot of YCO_2 at x/D=0.2 for the experiments and REDIM calculations with CD and EMST. Flamelet for strain rate 100 s^{-1}(red line) also shown

Acknowledgements

This work is funded by the Special Research Fund of Ghent University under project BOF07/DOC/210 and is also supported by the Comunidad de Madrid through Project HYSYCOMB, P2009/ENE-1597 and by the Spanish Ministry of Science and Innovation under Project ENE2008-06515-C04-02. Many thanks to Prof. U. Maas for providing the REDIM tables and for the many enlightening discussions on REDIM

References

[1] Masri, A, Kalt, P., Al-Abdeli, Y.M. and Barlow, R.S. , *Comb. Theory and Mod.* 11 653-673, 2007
[2] Kempf, A., Malalasekera, W., Ranga-Dinesh, K.K.J. and Stein, O., Flow Turb. and Comb.81 523-561, 2008
[3] Naud, B., Jimenez, C., Roekaerts, D., *Prog. in Comp. Fluid Dyn.*6 (1-3) 146-157, 2006
[4] Merci, B. and Dick, E., *Int. J. of Heat and Mass Transfer* 46 469-480, 2003
[5] Bykov, V., Maas, U., *Comb. Theory and Mod.* 11 839–862, 2007
[6] Warnatz J., Maas, U., Dibble R, Combustion, 2nd edition, Springer,1999
[7] Janicka, J., Kolbe W., Kollman, W., *J. Non-Equil. Thermodyn.*4 47–66, 1979
[8] Subramaniam, S., S.B. Pope, *Comb.and Flame* 115 487–514, 1998