

LARGE EDDY SIMULATION OF PILOTED AND BLUFF-BODY DIFFUSION FLAME

Tim Broeckhoven*, Sergey Smirnov*, Chris Lacor*, Eduardo Brizuela**

* *Department of Fluid Mechanics, Vrije Universiteit Brussel, Brussels, Belgium*

** *Facultad de Ingenieria, Universidad Nacional de La Plata, Buenos Aires, Argentina*

Summary Large Eddy Simulation (LES) appears to be a very promising tool for the prediction of turbulent combustion processes. In this paper a basic mixed-is-burnt combustion model combined with a presumed pdf approach is used for simulations on two non-premixed combustion test cases. Results obtained with RANS-simulations using different turbulence models are compared with LES results.

INTRODUCTION

A variety of reasons makes it desirable to fully predict flow fields in gas combustors: cost reduction in the testing phase, increase in performance and durability of gas turbines and a reduction of pollutants. The key aspect in modeling turbulent reactive flows is the realistic representation of the turbulence-chemistry interaction. The combustion process in a turbulent diffusion flame may be viewed as a competition between mixing and chemical reaction. In [1] several advantages of using LES in combustion are put forward. LES provides a better description of turbulence-combustion interactions because the large structures are explicitly computed and instantaneous fresh and burnt gas zones, where turbulence characteristics are quite different, are clearly identified. Combustion instabilities come with large scale coherent structures which are better predicted with LES [2]. In [3] the usefulness of an assumed pdf approach in non-premixed combustion combined with LES is confirmed, whereas the use with RANS is questionable.

GOVERNING EQUATIONS AND COMBUSTION MODEL

As in any flow the laws of conservation of mass, momentum, energy and species mass fraction are valid. One of the key problems in modeling turbulent diffusion combustion is the closure of the averaged chemical source terms that appear in the species equations. A way to circumvent this, is the introduction of a 'conserved scalar', i.e. a scalar not affected by the chemical reactions. The mass fraction of the different species can then be related to this scalar through a chemistry model. The used conserved scalar is the mixture fraction Z which expresses at a certain location the mass coming from the fuel stream. This variable obeys the following conservation law:

$$\frac{\partial \rho Z}{\partial t} + \frac{\partial \rho u_j Z}{\partial x_j} = \frac{\partial}{\partial x_j} \left(\mu_{eff} \frac{\partial Z}{\partial x_j} \right) \quad (1)$$

The combustion model implemented is the mixed-is-burnt model assuming infinitely fast chemistry. The entire state of the gas is determined by piecewise linear relations $Y_i = Y_i(Z)$, $\rho = \rho(Z)$, $T = T(Z)$. Species mass fraction, mixture density and temperature are related to the mixture fraction but in turbulent flows where the governing equations are solved for the averaged variables, the simple use of averaged values in the chemical model, yield inaccurate results due to the high non-linearity of the relations. To describe the influence of turbulent fluctuations on the mean thermochemical quantities more accurately, a more sophisticated averaging procedure must be applied. In this paper a presumed pdf approach is used with a β -shaped probability density function determined by the mean mixture fraction \bar{Z} and its variance \bar{Z}''^2 . For the RANS simulations, a $k - \epsilon$ type turbulence model is used and the variance of mixture fraction is determined by solving the conservation equation (2).

$$\frac{\partial \rho Z''^2}{\partial t} + \frac{\partial \rho u_j Z''^2}{\partial x_j} = \frac{\partial}{\partial x_j} \left(\mu_{eff} \frac{\partial Z''^2}{\partial x_j} \right) + S_{Z''^2} \quad (2)$$

For the LES simulations a scale-similarity model is used for this variance where $\tilde{\cdot}$ denotes the LES filter and $\hat{\cdot}$ denotes a test filter:

$$\tilde{Z''^2} \approx C_v \widehat{\tilde{Z}^2} = C_v \left(\widehat{\tilde{Z}^2} - (\hat{\tilde{Z}})^2 \right) \quad (3)$$

TEST CASES

In this paper results of two LES-simulations on combustion test cases are presented and compared to the RANS-solution with several turbulence models and with experimental results [4, 5]. The first test case is a piloted CH_4/air diffusion flame (Sandia D) which has been studied experimentally by Barlow et al. [6] and measurements have been done at Darmstadt University of Technology. The geometry is given in figure 1.

The central fuel jet with a mean velocity of 49.6m/s consists of 75% air and 25% methane by volume and is surrounded by a co-flow of air with a free stream velocity of 0.9m/s . To stabilize the flame a high temperature region near the burner is created by a pilot flame. The Reynolds number of the central fuel jet, based on the fuel nozzle diameter and mean velocity is $Re = U_m D_n / \nu = 22400$.

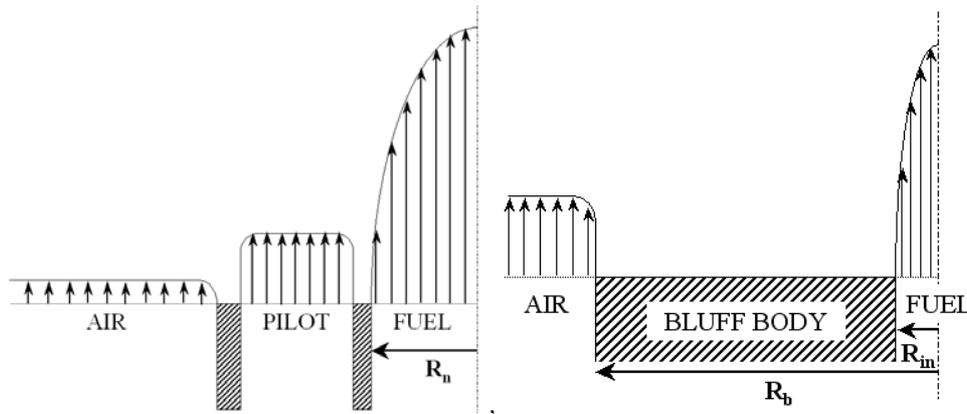


Figure 1: Geometry of the considered test cases (left: Sandia D, right : Bluff Body)

The second case is a bluff-body burner with a central fuel jet of 50% H_2 /50% CH_4 by volume which mixes with the co-flow of air [7]. The geometry is characteristic for a modern type industrial burner and is shown in figure 1. This unconfined flame remains attached because there is a recirculation zone behind the bluff body where fuel and air are intensely mixed. The chemical reaction creates a high temperature region which stabilizes the flame. This test case is more demanding of the chemistry model because local extinction may occur. The Reynolds number of the central fuel jet, based on the fuel nozzle diameter ($R_{in} = 3.6\text{mm}$) and mean velocity ($U_m = 118\text{m/s}$) is $Re = U_m D_n / \nu = 15900$.

CONCLUSIONS AND FURTHER WORK

A basic mixed-is-burnt combustion model has been tested on two well known test cases combined with both RANS and LES simulations. The influence of turbulence modeling has been investigated and discrepancies between experimental and numerical results have been identified. In future research more advanced combustion models will be used to investigate the influence of the chemistry modeling on the flow field prediction in non-premixed combustion test cases.

References

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