The role of presumed probability density function in the simulation of non-premixed turbulent combustion.

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Abstract

The development of methods to enhance and control combustion processes is nowadays fundamental in order to increase efficiencies and reduce emissions in a wide range of applications, such as: ultra-lean combustion and ultra-low emission in internal combustion engines; transonic and supersonic combustion in high-speed air-breathing propulsion devices; pulse detonation engines. In particular, supersonic combustion in propulsion devices is a very challenging and actual problem due to several critical aspects, such as, local extinction and reignition phenomena.

This paper provides an extension of the standard flamelet-progress-variable (FPV) [1] turbulent combustion model combined with a Reynolds Averaged Naviér-Stokes equation solver [2]. In the FPV model, all of the thermo-chemical quantities are evaluated by evolving the mixture fraction Z and a progress parameter Λ. When using a turbulence model in conjunction with FPV model, a probability density function (PDF) is required to evaluate statistical averages (e.g., Favre average) of chemical quantities. The choice of such PDF is a compromise between computational costs and accuracy level. The aim of this research is to investigate and understand the influence of the PDF choice, and its modeling aspects, in the simulation of non-premixed turbulent combustion. In particular, this is expected to improve prediction accuracy of the critical ignition and extinction phenomena.

Three different models for the determination of the joint PDF of Z and Λ have been investigated: the first is the standard one, based on the choice of a beta-distribution for Z and a Dirac-distribution for Λ (model A); the second one is based on the choice of a beta-distribution for both Z and Λ (model B); the third one is obtained using a beta-distribution for Z and the statistical most likely distribution (SMLD) for Λ [3] evaluated using as constraints the PDF normalization together with the values of the average and the variance of Λ (model C). The standard model, although widely used, doesn't take into account: (i) the interaction between turbulence and kinetics; (ii) the dependence of the progress parameter on its mean and its variance. On the other hand, the SMLD provides a systematic framework to incorporate informations from an arbitrary number of moments [4], thus providing an improvement over conventionally employed presumed PDF closure models.

Differences among the PDFs, at given fluid-dynamic conditions, are relevant for the estimation of thermo-chemical quantities. This has been tested versus well-known test cases, namely, the Sandia flames [5], demonstrating the role of the PDF functional form on turbulent combustion simulations. For example, we present some preliminary results in figure 1 and figure 2, showing a comparison between the simulations of the Sandia flame E obtained using both the standard model A and model B. In figure 1 one can see that the two models produce different flame shapes and that, in the case of model B, we obtain an improved prediction of the flame core. This, in turn, gives a better prediction of the temperature field in the sections near the burner as shown in figure 2.

In the final paper, the details of the numerical model will be presented along with a thorough analysis of the different joint PDFs. The models will be extensively validated versus the Sandia flames. Then a test case for supersonic combustion, namely, that provided by Cheng et al. [6], will be considered to assess the accuracy of these models to predict situations where local extinction and reignition phenomena are relevant.

References

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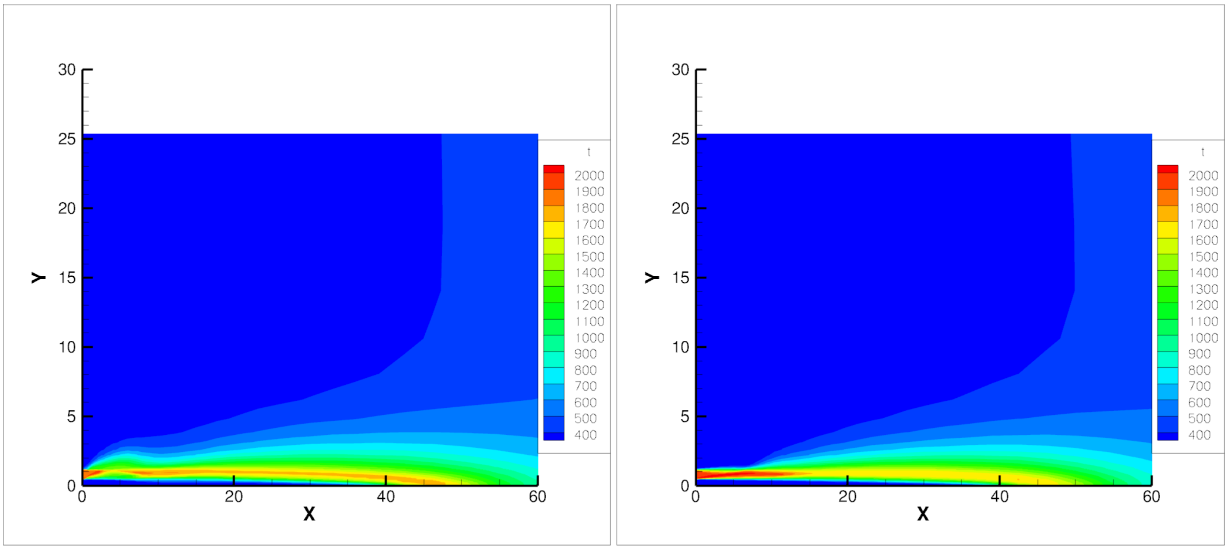

Figure 1: Temperature contours of standard model A (right) and model B (left).

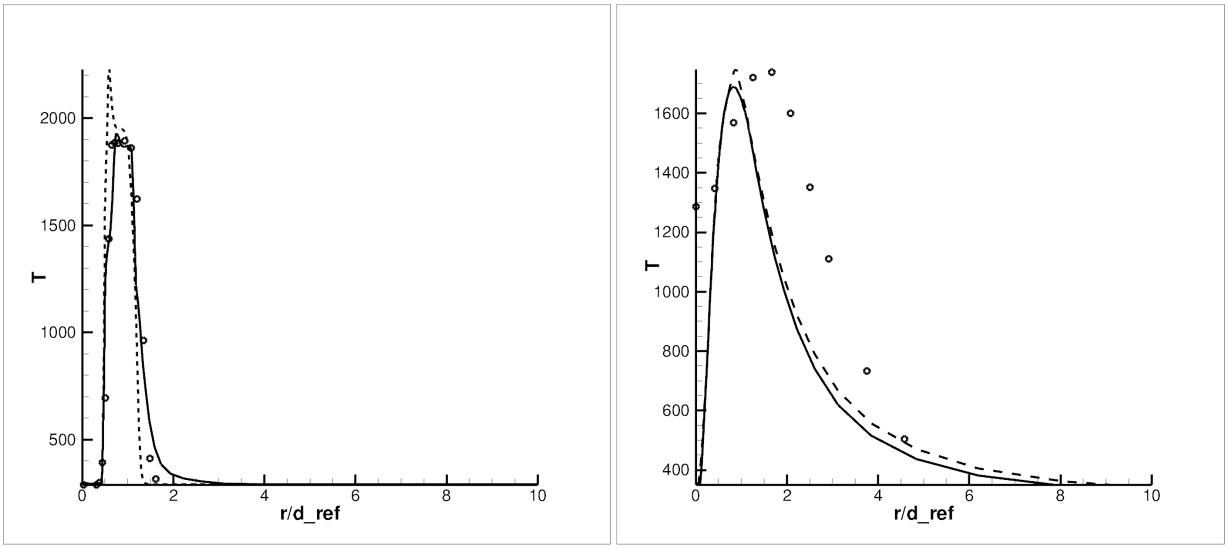

Figure 2: Temperature distribution along the radial direction in two sections taken at different distance from the burner: d_{ref}, equal to burner diameter (left), $30 \times d_{ref}$ (right). Comparison between standard model (A) (dashed line), model (B) (solid line) and experimental data [5] (symbols).

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