Coupling radiation modelling with turbulent combustion in large eddy simulation

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Abstract

Simulation of turbulent combustion has gained high potential with the Large Eddy Simulation (LES) approach, allowing to predict unsteady turbulent reactive flows. In this approach only the largest scales of the turbulence are solved while the smallest scales are modelled. This approach permits to simulate complex industrial geometries on a wide range of Reynolds numbers. Previous works have shown the ability of LES to predict unsteady combustion behaviors such as : instabilites, ignitions and extinctions in industrial systems [1, 2, 3].

It has been demonstrated [4] that it is necessary to take into account thermal radiation losses in combustion caculations to increase their level of accuracy. The radiation is important as well for an accurate prediction of the temperature and the wall heat fluxes. Because the chemistry of polluting species is very sensitive to the temperature, the radiation is a key point for good predictions of the polluting species (CO, NO_x, soot, ...). Radiation has also an influence on the life time of combustion chambers, so it is necessary to predict accurately the wall fluxes.

In this context, taking into account radiation rises new fundamental and practical questions. The physics involved in radiation and combustion are completely different: combustion is controlled by local exchanges and finite times whereas radiation is instantaneous and based on non-local exchanges. In order to couple radiation with turbulent combustion a methodology is needed regarding both physical and numerical aspects.

In a first step, the impact of LES modelling on radiation in turbulent combustion is regarded. In LES, the resolved fields are spatially filtered and the unclosed terms are modelled. This question is treated in the more general frame of the turbulence-radiation interaction. From theoretical and numerical studies, it is shown that this interaction is weak in the LES context so that

LES solutions can be directly coupled to radiative calculations, without further modelling [5]. This result have been confirmed more recently by other studies [6, 7, 8].

In LES context the nearwall dynamic and thermal boundary layer have to benn modeled. Such models are often derived from Direct Numerical Simulations (DNS). To include the effects of radiation, DNS of an an isothermal reacting turbulent channel flow with and without radiative source terms has been performed to study the influence of the radiative heat transfer on the optically non-homogeneous boundary layer structure [9]. It has been shown that the global structure of the thermal boundary layer is not significantly modified by radiation. However, the radiative transfer mechanism is not negligible and contributes to the heat losses at the walls. The standard wall's law for temperature can thus be improved for RANS/LES simulations taking into account the radiative contribution by adding the radiative heat flux.

The objective of the study is to perform the unsteady coupling of radiation and turbulent combustion that was here quite challenging. First, the reduction of calculation time of radiation, and several strategies are proposed. In particular, a new global spectral model (FS-SNBcK) is introduced [10], ensuring a sufficient level of accuracy. The time calculation of radiation is decreased using of a tabulation technique of the spectral model. Also, larger grids for radiation are employed according to a criterium of temperature homogeneity. The radiative time calculation is finally decreased by two orders of magnitude reaching a ratio of CPU times $t_{\text{radiation}}/t_{\text{combustion}} \leq 1$, which enables the coupling with a turbulent premixed flame.

The studied configuration is a premixed V-shaped turbulent laboratory flame of propane that has been previously studied at EM2C [11] ; [12], see Fig. 2. It has been shown that radiation can decrease the level of temperature by more than $100\ K$. This effect does not change significantly the mean velocity of the flame or the production of H_2O, CO_2. However, it has been shown that the total mass fraction of CO decreases by about 20% when the radiation is considered.

As the wall temperature is unknown both experimentally and numerically a cold wall temperature ($300\ K$) is assumed. This assumption has an important effect beacause it can lead to an over-prediction of radiative heat losses. The only way to define the accurate temperature is to solve thermal heat transfer inside the solid wall. This demands to couple another solver (AVTP) developped at CERFACS to solve the thermal heat transfer in solids, this work is actually under progress.

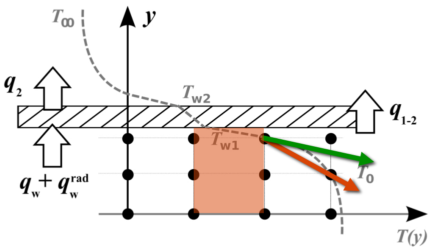

Figure 1: Calculation of the temperature profiles at the first cell are wrong without law. The law is not modified by radiation

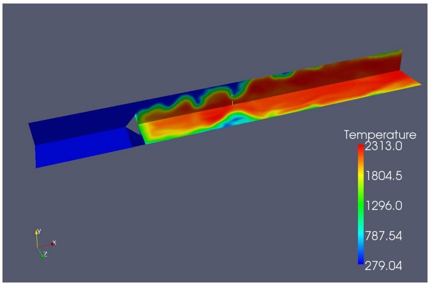

Figure 2: Instantaneous field of temperature in the studied configuration. The dimensions of the configuration are $50 \times 80 \times 300\ mm$.

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