Non-adiabatic Steady Laminar Flamelet Model (SLFM) in OpenFOAM

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Abstract

The numerical simulation of turbulent reacting flows is gaining increasing importance because of its potential impact on the development of improved combustion equipment and devices. In particular, two main benefits are of great interest: the reduction of pollutant emissions and the increasing of combustion efficiency. Unfortunately, the numerical simulation of turbulent flames is a difficult task, due to the complex interactions and coupling between spatial and time scales of fluid dynamics and chemistry. Several combustion models have been proposed in the last years to describe the interactions between turbulence and combustion. Among the models currently available for non premixed combustion, one of the most successful is the Steady Laminar Flamelet Model (SLFM) [1], which was applied with satisfactory results to several combustion systems, from lab-scale jet flames to industrial furnaces. This approach consists in a view of turbulent flames as an ensemble of stretched laminar flames and its main advantage is related to the small number of variables which need to be transported in the CFD code, since it does not require the solution of a large number of species transport equations. Therefore it can be considered as a good solution especially for industrial cases, requiring complex and large computational meshes.

This paper mainly describes the implementation of the SLFM in OpenFOAM in the context of steady state RANS simulations and its application to the simulation of lab-scale turbulent jet flames.

The flamelet look-up table required by the SLFM is built in a preprocessing step, using four independent variables: the mixture fraction, its variance, the scalar dissipation rate and the enthalpy defect. The temperature and concentrations of every species can be expressed as a function of these independent parameters. The laminar flamelets required by the SLFM are generated by solving the equations governing steady state, laminar, counter flow diffusion flames [2]. Two different methods (giving similar results) are used: a. the equations are solved in the physical space; b. the equations are mapped into mixture fraction space and then solved. The generated flamelets are chosen to cover a wide range of scalar dissipation rates (from equilibrium to extinction) and enthalpy defects. A presumed PDF (Probability Density Function) approach is used to take into account the effects of turbulence on laminar flamelet profiles.

The transport equations for the mean mixture fraction, mixture fraction variance and mean enthalpy are solved in OpenFOAM. The scalar dissipation field is estimated from the turbulence field and the mixture fraction variance. The enthalpy defect is calculated from its definition. The mean values of cell temperature, density, and species mass fraction are obtained from the PDF look-up table.

As a part of the model validation, two turbulent jet flames (experimentally studied at Sandia Laboratories) were simulated [3]. The look-up tables were generated using a detailed kinetic mechanism [4] and the radiative heat transfer was described using a simplified model for optically thin, unconfined flames [5]. Several sensitivity tests to the mixture fraction PDF shape (β-PDF, clipped-Gaussian or double Dirac delta) and to main look-up table parameters (number of flamelets, range of scalar dissipation rates and enthalpy defects, etc.) were performed. The comparison with experimental measurements, both in terms of temperature and main species concentrations, was satisfactory, confirming the validity and usefulness of the SLFM for the simulation of turbulent diffusion flames.

Key words: Combustion, diffusion flames, flamelets, turbulence-chemistry interactions

References

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