Turbulent premixed flame model based on a recent dispersion model

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Abstract

Lipatnikov and Chomiak [1][2][3] highlighted a number of trends experimentally observed in turbulent premixed flames, formulated criteria for evaluating flame propagation models, and validated various models against these criteria. Furthermore, they proposed a model of premixed turbulent flame propagation [1][4][5], the Flame Speed Closure (FSC) model, which is applicable to transient flames developing after ignition and to stationary flames stabilized by a flame-holder. Their model is thoroughly validated and reproduces well the experimental trends. A drawback of the FSC model is that it includes an explicit dependence of the turbulent diffusivity $D_{t,t}$ and of the burning velocity $U_{t,t}$ on the flame development time t_{fd}, which has different definitions for the case of transient flames following ignition and for the case of stationary flames stabilized by a flame-holder. These definitions imply that the equations to be solved are in fact different for the two cases.

Ghirelli [6] recently proposed an Eulerian model of turbulent dispersion that accounts for the effect of velocity correlation (first explained by Taylor [7]) on turbulent dispersion without using any parameters that depend explicitly on time or position. Applying the dispersion model to the field of premixed combustion gives an opportunity to reformulate the FSC model without the aforementioned drawback, i.e. it gives a unified more general model able to solve both kinds of cases using a single set of equations.

Furthermore, this is the first practical application of the novel dispersion model, which may be useful in other fields of turbulent modelling where the effect of velocity correlation plays a relevant role.

The work consists of the following parts:

- Introduction: the FSC model and the growth of the flame thickness according to the turbulent diffusion law.
- Dispersion of inert tracers in variable density flows: assumptions and derivation of the dispersion model in variable density flows.
- Dispersion of combustion products: modelling of the experimentally observed dispersion behaviour of combustion products.
- Premixed flame model: an expression of the chemical source term is proposed based on the earlier expressions proposed in [1][4][5][8] as a function of the dependent variables only, i.e. without explicit dependence on time or position.
- Validation against stationary flames: the proposed flame model is implemented in OpenFOAM 1.6 and various experimental setups documented in the literature are simulated both with the present model and the TFC [8] model (The TFC model is a precursor of the FSC model, valid for flames in the “intermediate steady propagation” regime. The TFC is more easily implemented than the FSC model for stationary flames, but its results should be comparable to those of the FSC in the mentioned regime). The following literature experiments are simulated: the v-flame of Dinkelacker et Al. [9], the bluff-body flame of Sjunneson et Al. [10] and the flame stabilized by a pilot flame of Moreau [11].
- Testing against the criteria of Lipatnikov and Chomiak [1][2]: self-similarity of the flame profile, shape of the flame profile, flame thickness development, flame speed development.
- Conclusions: the proposed model has the following merits:
  - It has a single set of equations for both stationary flames and flames following ignition,
  - It does not include parameters explicitly depending on time or position,
  - It gives better results than the TFC [8] model in modelling stationary flames,
  - It satisfies the criteria of Lipatnikov and Chomiak,
  - It moves the calibration constant A of the flame models closer to unity and the turbulent Schmidt number to Sc_T=1.
- Discussion: It would be very interesting to apply the proposed flame model to compressible systems such as flames in constant volume bombs and internal combustion engines. The results of the application of the dispersion model to premixed combustion are very encouraging and therefore suggest that its applications in other fields of turbulence may produce further advancement in modelling of turbulent phenomena.

Key words: turbulent dispersion, premixed combustion, Eulerian, RANS, velocity correlation

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