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A PRIORI TABULATION OF TURBULENT FLAME SPEEDS VIA A COMBINATION OF A STOCHASTIC MIXING MODEL AND FLAMELET GENERATED MANIFOLDS

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EXTENDED ABSTRACT

Due to the interaction between many different time and length scales, turbulent premixed combustion remains a challenging task. While the largest turbulent scales and the slow chemical processes are resolvable, the small scale turbulence/chemistry interaction has often to be modelled. Therefore, the reactive Navier Stokes equations are filtered, dividing the original solution into resolved and unresolved parts, where the latter needs closure. This is commonly done by using parameterizations that relate the unresolved parts to the resolved field. For example, the unresolved turbulent flame speed, s_t, is an important quantity[5].

This parameter is used by a lot of models in premixed combustion, e.g. level set methods, flame surface density models and other progress variable type approaches. There are different possibilities to evaluate this property. The simplest and perhaps least physical is an algebraic expression, where often s_t is a function of the unburnt (indicated by subscript u) thermodynamic state and turbulent fluctuations, say

$$s_t = f(u', Y_u, T_u, p_u), \tag{1}$$

where u', Y, T, p are the velocity fluctuation, species mass fraction, temperature and thermodynamic pressure. Recent methods use instead so-called superparametrisations to determinate it. Here a one dimensional microstructure evolution for turbulence chemistry interaction, e.g.[6], is forced by the resolved solution. Suitable integrals over the microstructure yield some of the needed closure terms like the turbulent flame speed. However this procedure is done "online", increasing the costs of such a computation considerably.

In this paper we propose a technique of a priori tabulation of s_t for a given setup (geometric scales, reaction type, etc). During the computation one enters the table with a set of quantities, e.g., a progress variable based on the normalized mass fraction of H_20, mixture fraction, local turbulent Reynolds number and so on. The different s_t for the table are computed by solving one-dimensional flame structures to a statistical steady state. The steady state assumption is tested with the Augmented Dickey-Fuller Test.

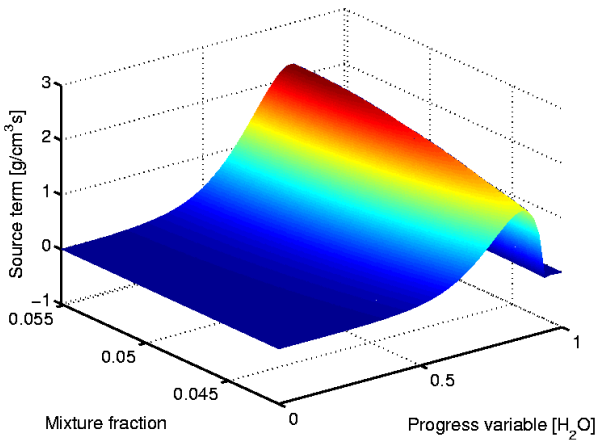

Figure 1: Tabulated source term of the progress variable over mixture fraction and H_20 using the chem1D with a detailed methane/air chemistry

In the flame structure computation we use the Linear Eddy Model[2] for the turbulent transport and FGM[4] for chemistry tabulation. Both are linked to an implicit solver for the one-dimensional Navier-Stokes equations[1].

As long as the smallest turbulent eddies do not enter the reaction zone, (laminar) chemistry and turbulence can be treated separately. For the chemistry we apply the method of flamelet-generated manifolds (FGM)[4] using the chem1D code[7]. In a first step one computes steady one-dimensional laminar flamelets with detailed chemistry and tabulates all relevant chemical details as a function of suitable progress variables, e. g. CH_4 and/or H_2O for a methane air mixture. Additional parameters for tabulation depending on their physical relevance could be mixture fraction, enthalpy, curvature, or flame stretch.

In Figure 1 the tabulated chemical source term of the progress variable for a near stoichiometric methane-air mixture using GRI chemical reaction mechanism is plotted as a function of the progress variable H_2O and mixture fraction Z.

In a second step we use the FGM generated source terms as an input for the LEM computations of the turbulent flame structures. This approach reduces the number of species within the LEM module to the number of progress variables of the FGM and allows a fast computation of a large parameter space.

Some snapshots of such a run are shown in Figure 2. Here turbulence conditions are chosen as in[3]. We evaluate the net mass burning rate via

$$\rho s_t = \frac{1}{Y_{\zeta_1} - Y_{\zeta_0}} \int_{\zeta_0}^{\zeta_1} \rho \omega_Y d\zeta, \tag{2}$$

where ρ is the density, ζ the one-dimensional coordinate and ω_Y the source term of species Y. The outcome of each LEM run is a pdf of the turbulent flame speed for a given turbulence level and composition. During the talk we will present the details of our strategy, especially the generation of a database in which the pdf's of the turbulent burning velocity are stored.

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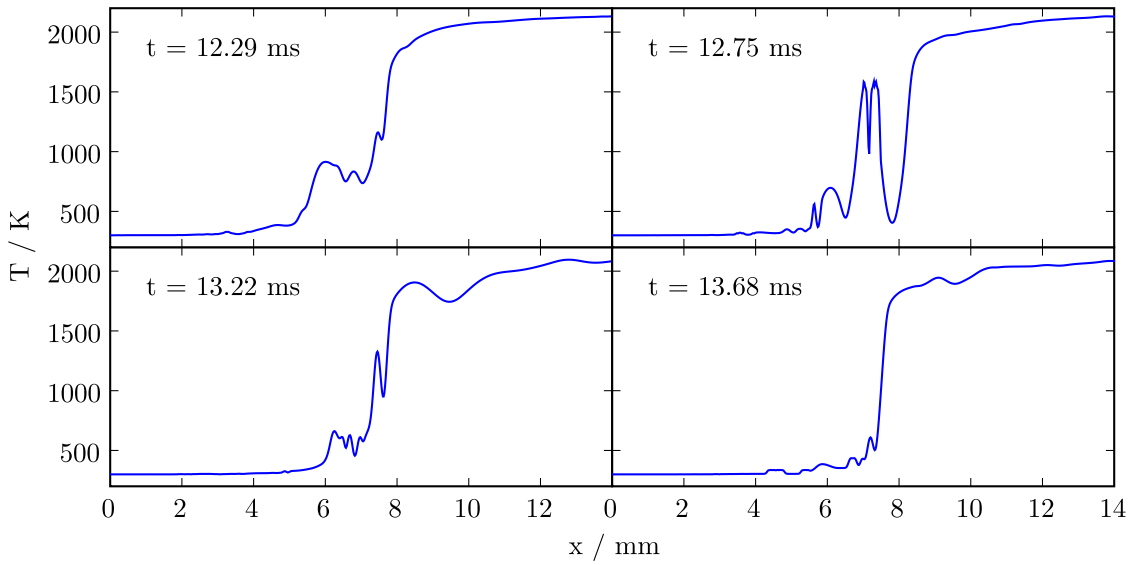

Figure 2: Time series of computed flame structures in a reference frame moving with speed s_t

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