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Projekt

Optimierung der Brennstoffstufung im Alstom EV-Brenner

Schadstoffreduktion durch Teilvormischung

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ZUSAMMENFASSUNG

Verbrennungssysteme der neuesten Generation mit tiefen Emissionswerten und hoher Brennstoffnutzung werden durch ein kombiniertes Konzept von den zwei Hauptverbrennungskategorien (Diffusion- und Vorgemischte Verbrennung) realisiert, welches teilvorgemischte Verbrennung genannt wird.

Die heute gängigen Verbrennungsmodelle sind hingegen nicht in der Lage, diesen Grenzbereich Diffusion/Teilvorgemischte Verbrennung sinnvoll abzubilden.

Am LTNT wurde ein instationäres Flamelet-Modell entwickelt, welches gemäss bisherigen Untersuchungen ein grosses Potential besitzt, diese Verbrennung zu modellieren.

Ziel dieser Projektes ist die Weiterentwicklung des vorhandenen instationären Flamelet-Modells um diesen interessanten Bereich zwischen diffusions- und teilvorgemischter Verbrennung besser zu simulieren.

Während des zweitens Jahres dieses Projekts wurde einen neuen Ansatz entwickelt um die transiente Zeitkonstante des Models besser zu definieren. Die resultierende neue numerische Methode heisst „Flame Age Model“ (FEM). Diese neue Modellvariante wurde in diesem ersten Teil des Jahres weiter verbessert und gegen die experimentellen Daten von einer hochturbulenten Flamme geprüft. Die Resultate von dieser Arbeit wurden in einer internationalen Konferenz präsentiert. Die Kollaboration mit der privaten Firma *ALSTOM* wurde hervorgehobt und seit anfangs Mai absolviere ich mein Praktikum in dieser Firma. Ziel von dieser Arbeitserfahrung ist die numerische Simulation der *ALSTOM* AEV-Brenner mit unseren instationären Flamelet Modellen.

Goals of the project

General aims of the project

Pollutant Emissions are still a dominating subject of the worldwide energy supply based on fossil fuels. The cheapest way to prevent the production of pollutants is to avoid them in the combustion process itself.

Turbulent combustion can be classified into two main categories: non-premixed combustion (or diffusion combustion) and premixed combustion. Premixed combustion is a concept for the reduction of Nitrogen oxides, but it leaves a safety problem because a flammable mixture is present where no combustion is supposed to take place.

The newest generation of combustion systems, with low pollutant emission and high efficiency, are realized trough a combination of the mentioned two combustion categories; which is called partially premixed combustion.

Today simulation of combustion systems is a powerful tool to achieve burner optimisation and in comparison with the pure experimental method it turns out cheaper. This fact is particularly true for high-pressure burners.

The combustion models in use nowadays are not able to represent correctly this type of combustion (area between diffusion- and partially premixed combustion). At LTNT we have developed a transient flamelet model that, according to the last investigation, has got a great potential to model this new combustion area.

The Goal of this PhD thesis is to improve the transient laminar flamelet model (TLFM) developed by J. Ferreira [1] in order to simulate better this very interesting area between diffusion- and partially premixed combustion. The improved Flamelet-Model should be validated with experimental data taken from the literature and later should be used to simulate and optimise the new *Alstom* AEV-burner.

Goals for the first part of the year 2005

The two main gaols of the Winter-Spring 2005 were clearly defined:

- Improve and validate the Flame Age Model: a new transient laminar flamelet model developed from the Ferreira-TLFM.
- Begin the work collaboration with the private company of *ALSTOM*.

Work and Results

In this section I summarize the work done during the first part of this year and show briefly the achieved results.

Introduction

Flamelet models are per definition designed for diffusion flames at high Damköhler numbers, where the reaction zone consists of a thin flame sheet. The basic idea of these models is to assume that a small instantaneous diffusion flame element embedded in a turbulent flow has the structure of a laminar counter flow flame. This laminar flame structure is also called flamelet. The structure of the laminar flamelets (temperature and species distribution) may be computed independently of the turbulent code and stored in “flamelet libraries”.

In regions of the turbulent flow field where the characteristical chemical timescale is more or less equal to the characteristical turbulent one or when the reactants are already partially premixed before ignition, the classical steady flamelet models fail to capture the behaviour of the flame. One of the first transient laminar flamelet model (TLFM) was developed by Ferreira [1] in our institute. The different flamelets, in this approach, are correlated with the turbulent flow by four parameters: the mixture fraction, the scalar dissipation rate, the reaction progress variable and the turbulent time. These four parameters together with transient flamelet libraries give the possibility to simulate the unsteady extinction and re-ignition phenomenon of partially premixed fluid elements in a diffusion flame. The transient flamelet libraries in the TLFM are generated using detailed chemistry and a one dimensional laminar code named *FLATRA* [2], which computes the exact transient state solution of the species concentration and the temperature.

In Fig. 1 we can see a flow-chart representation of the Ferreira-TLFM.

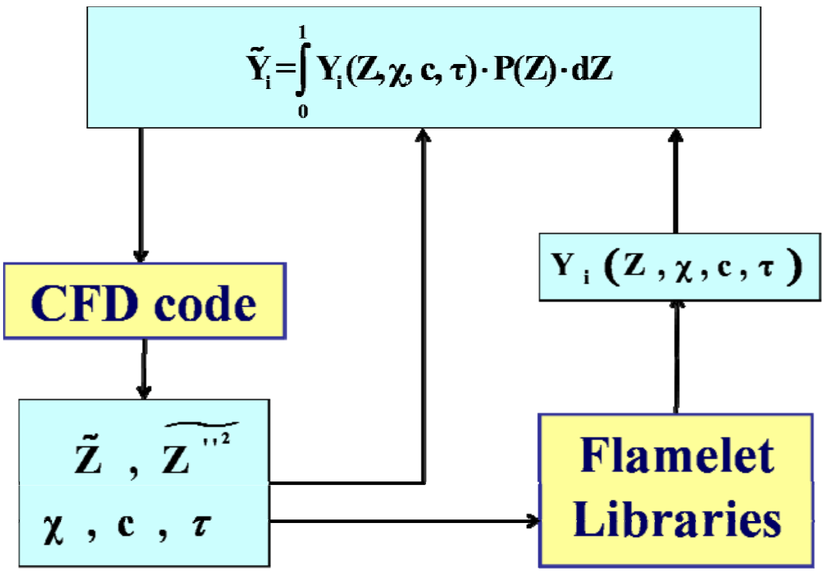

Fig. 1: flow-chart representation of the Ferreira-TLFM

For more detailed information about flamelet models and the Ferreira-TLFM refer to [1, 3, 4].

During the first two years of my PhD project I have done several improvements on the Ferreira-TLFM and I've also develop a new approach to model the unsteady terms of the model. These activities are documented in [5-7].

The activities that I've undertaken during the first six month of this year can be summarized in three parts and they are described below.

New Coupling Strategy

The numerical procedure to compute turbulent diffusion and partially premixed flames with our TLFM is split into two parts. As shown in Fig. 1, the local laminar flame structure is computed and stored with an in-house build *FORTRAN* code. The conservation equations of the turbulent flow field are instead computed with a commercial flow solver (in our case *CFX-5* [8]). The two scales of the combustion problem are then linked together with some additional coupling *FORTRAN* routines, which build the Beta-PDF and compute the mean species mass fraction quantities in the turbulent flow field.

Last year, together with my colleague S. Baykal, we had adjusted the different coupling subroutines and the simulation setup in order to be able to use correctly the *CFX-5* commercial flow solver together with our combustion model. In doing this we have immediately noticed that during a complete simulation of a turbulent flame the most time-consuming numerical steps were the calculation of the presumed distribution functions (PDFs) and the solution of the integral to compute the mean combustion variables. These two steps in the original Ferreira-TLFM were performed during every iteration of the flow solver, consuming a dramatic amount of computational resources. Simulations with numerical grids containing more then 1 Mio grid points turned out to be prohibitive and a new coupling strategy was needed.

So, with the help of my colleague S. Baykal, we have reorganized all the coupling routines and used another procedure to interpolate the flamelet structures during a simulation of turbulent flame. Instead of computing the Beta-PDF during every iteration we have decided to calculate the PDFs before the numerical procedure to compute the Navier-Stokes equations. After the flamelet generation, the flamelet profiles are convoluted with the assumed-shape PDFs as in Fig. 1, and then tabulated in look-up tables in the memory of the commercial flow solver. Therefore with this method the PDFs are computed only once and during the iterations of the flow solver only "small" interpolation steps are needed. A similar numerical strategy is also implemented in the commercial code *FLUENT* [9].

Implementation and Validation of the Flame Age Model

From the validation of the Ferreira-TLFM (see [5, 10]) it appears clear that the definition of the time evolvement in the flow field, which is related to the time evolvement in the laminar flame structure, could be better defined. Ferreira [1] compute the turbulent time evolvement with the equation of the turbulent time scale:

$$\tau_t = \tilde{k} / \tilde{\varepsilon} \qquad (1)$$

where the variables κ and ε correspond to the turbulent kinetic energy and to the turbulent dissipation rate of the turbulence model, respectively. This time constant corresponds to the lifetime of an eddy and can be interpreted as the time available for the development of the local flame structure after reignition. But in reality this definition gives too small values of the local time available for the development of the combustion process and his derivation is not supported by physical argumentations. For those reasons a new and more substantial definition of the time evolvement in the flow field is needed.

Therefore, last year, I developed a new approach to capture the unsteady behaviours of a turbulent flame, the so-called Flame Age Model (FAM). During this Spring I've improved and perfected this new numerical method and I've validated it against the Sandia piloted jet Flame D [11]. I've, in a second time, presented this work in the ECCOMAS thematic conference on computational combustion, which was held in Lisbon. The characteristics of the new Flame Age Model are reported in details in [12].

Internship in ALSTOM

After the development and the validation of the new Flame Age Model (FAM) I've begun my internship in *ALSTOM*. Goal of this internship is to apply our transient laminar flamelet models to the gas turbine burners of the company, in particularly the new AEV-burner. This internship started at the beginning of May and I should work in *ALSTOM* till the end of October.

During the first two month of this work experience I've implemented our flamelet models in the machines of *ALSTOM* and I've simulated the cold AEV-burner.

National Collaboration

This project is done in collaboration with *ALSTOM*. As mentioned in the previous chapter at the beginning of May this collaboration becomes stronger and I've started an internship in this private company.

Evaluation & Outlook

The progresses done in the first part of this year in this project are many and we can conclude that this period can be seen as positive and encouraging. A new transient laminar flamelet model was developed and validated. Beside this I've started the work-cooperation with *ALSTOM*.

For the rest of the year the goals are clear and well defined:

- Simulate the *ALSTOM* AEV burner with the new Flame Age Model and eventually with the Ferreira-TLFM.
- Make a clear comparison of the new Flame Age Model with the Ferreira-TLFM using the experimental results of the Sandia piloted jet flames.

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