September, 21st - 24th 2014
FLAME STRUCTURE 2014
8th International Seminar on Flame Structure

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Berlin Institute of Technology (TU Berlin)

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19. Mai 14

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Title of Paper:	On modelling turbulent non-premixed flames in rocket combustion chambers
Program:	Turbulent flames
Name of Institute:	Institute of Space Propulsion, German Aerospace Center (DLR)

On modelling turbulent non-premixed flames in rocket combustion chambers

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The use of CFD simulations has become a practice in the development and design of rocket combustion chambers recent years. The support of hot tests from CFD simulations can significantly reduce the development cost of new engines and prototypes. Rocket combustion chambers are different from the most of combustion devices by extremely high temperatures and pressures, and by the combustion of pure chemical reagents (undiluted by nitrogen). Generally, the combustion in liquid rocket engines is more complex than in other combustion devices due to extreme operating conditions and the strong coupling between processes in rocket engine. However, chemical reactions occur very fast in rocket combustion chambers thanks to high temperatures and pressures. This allows using the thin flame assumption, which reduces strongly the modelling efforts. One of the models based on the thin flame assumption is the Eddy Dissipation Model (EDM) used by Magnussen and Hjertager in work [1]. In the EDM model the rate of combustion is limited by the rate of propellant mixing while the chemical reactions occur infinitely fast. The mixing rate is defined by the rate of eddy dissipation, so the reaction rate is given by

$$R = A\, \varepsilon/k\; min([\mathrm{I}]/v), \quad (1)$$

where ε is the turbulence eddy dissipation, k is the turbulent kinetic energy, [I] is the molar concentration of reactant I, v is the stoichiometric coefficient of reactant I, and A is a model constant. Thus for a global reaction:

$$H_2 + \tfrac{1}{2}O_2 = H_2O, \quad (2)$$

the reaction rate is given by

$$R = A\, \varepsilon/k\; min([H_2], 2\cdot[O_2])\,. \quad (3)$$

This simple model is unfortunately too coarse for the combustion of cryogenic propellants. The EDM model is extended by additional parameters in the commercial CFD software ANSYS CFX [2,3], which is used in the current work. These parameters are a chemical time scale, an extinction temperature, a maximum flame temperature, and a mixing rate limit. These additional parameters allow to eliminate all main drawbacks of the EDM model. The conditions are very inhomogeneous in rocket combustion chambers, especially if propellants are injected at cryogenic temperatures. Therefore, the combustion in cryogenic rocket engines can be described correctly only by the parameters depending on local conditions, namely mixture composition and temperature. The CFX solver provides such functionality.

The current work is focused on the development of a CFD model suitable for modelling of rocket combustion chambers. The idea of the development is a creation of a light model (in terms of required computational power) based on the EDM combustion model and the functionality of ANSYS CFX. The accurate prediction of heat loads is one of the key problems of rocket engine design. The main goal of our modelling efforts is the accurate predictions of wall heat fluxes in a rocket combustion chamber. That is why the developed model is validated firstly using test cases where wall heat fluxes were measured [4,5], see Fig. 1 and 2. One of these test cases called Penn State test case [4] has been used for the validation of numerical models by many other researchers [6-8]. This gives us an opportunity to assess the performance of our own numerical model in the terms of accuracy and required computational resources relative to other CFD models.

The developed model agrees with experiments [4,5] very well, see Fig. 1 and 2; however, it is not free from weaknesses. The new model, as well as the parent EDM model, is inseparably linked with eddy viscosity turbulence models. The flow in rocket combustion chambers is characterized by a massive flow separation. The validity of eddy viscosity turbulence models needs further investigations for the case of rocket combustion chambers. The further steps on the model developing will be the validation of our CFD model against data from rocket combustion chambers with optical access.

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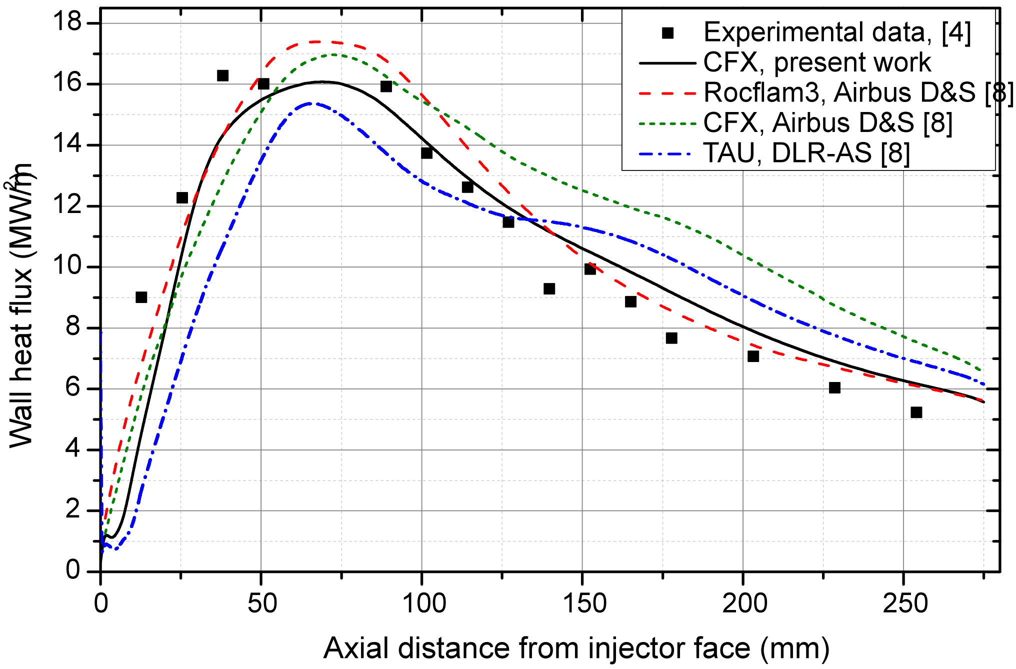

Figure 1. Comparison of the current results with experimental data [4] and simulation results of other groups [8].

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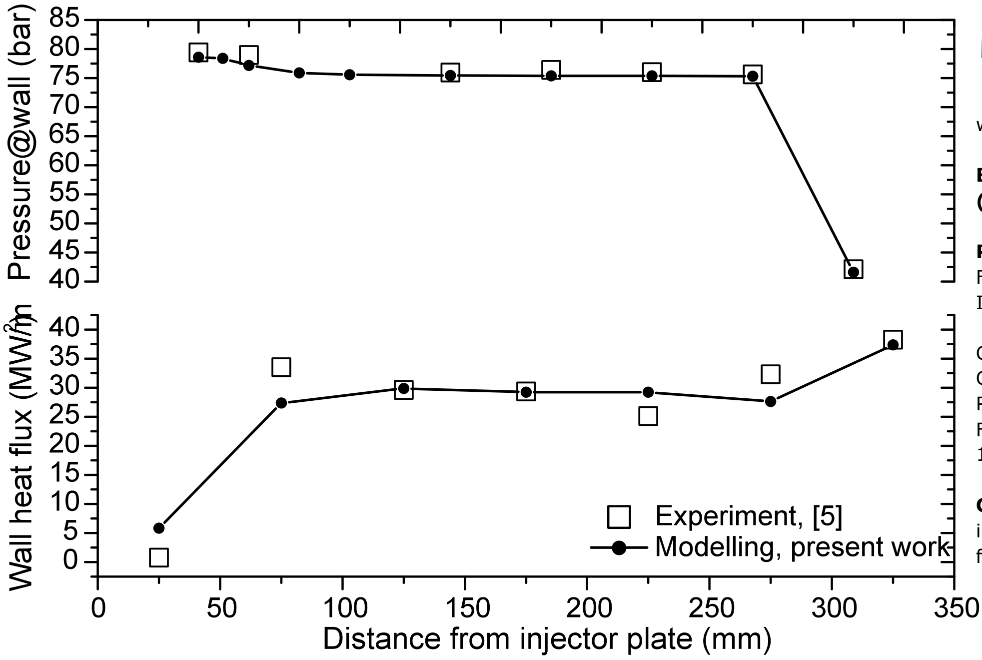

Figure 2. Comparison of the developed CFD model with experiment [5].

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