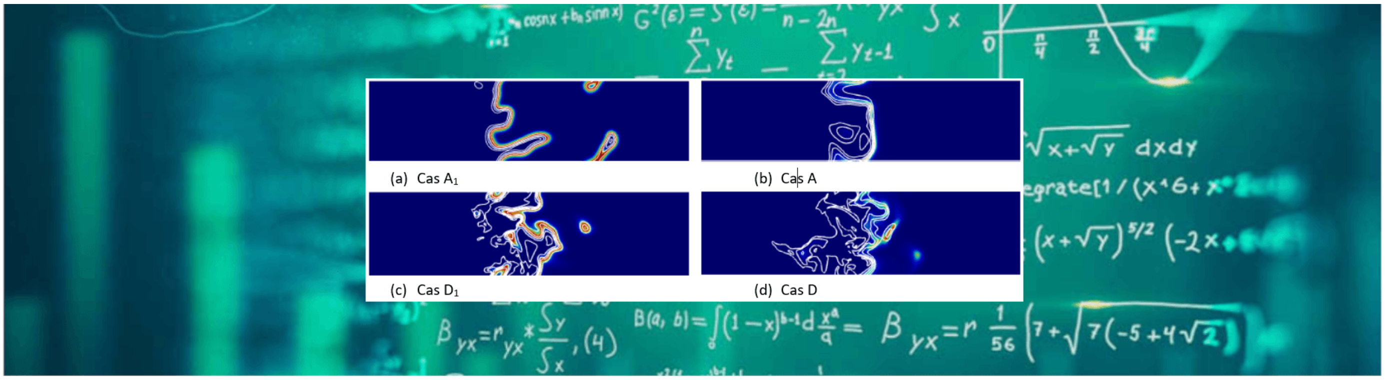
MODELLING OF HIGH KARLOVITZ COMBUSTION IN SPARK-IGNITION ENGINES



Written on 25 May 2021

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Edouard Suillaud as a PhD student at IFPEN studied how to better describe the combustion in high Karlovitz[1] number regimes such as those encountered in the new combustion chambers of spark-ignition engines. This description was limited by models that were not suitable for such regimes. The extension of the CFM model to "thin reaction zone regime" (TRZ) has produced promising results.

From one combustion regime to another, unsuitable combustion models

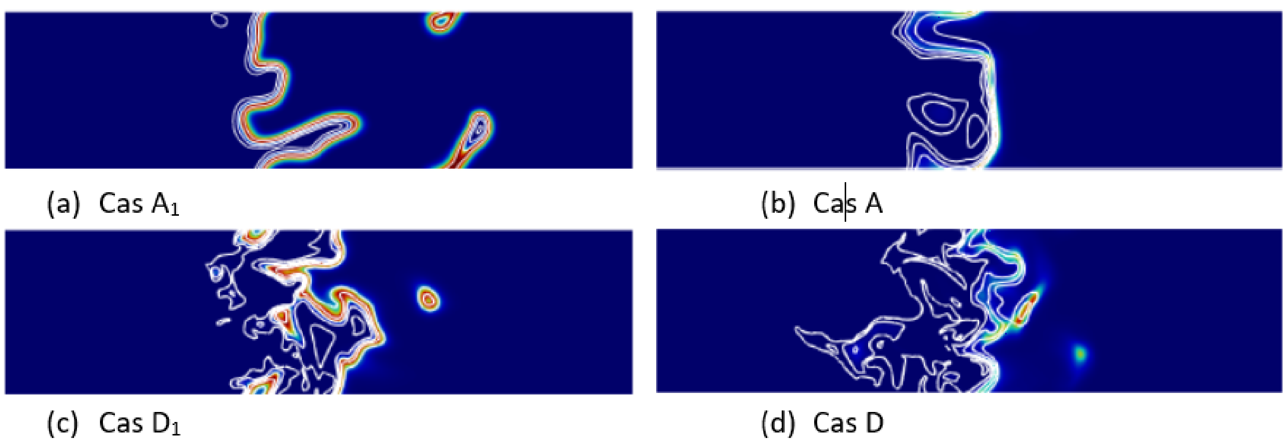
Nowadays, the car manufacturers rely on CFD[2] tools for designing and optimising SI engines. However, the current models of turbulent combustion **lose their predictivity when they simulate a highly diluted or very lean combustion** involving high turbulent intensities.

Indeed, the current models were built based on the assumptions of the flamelet regime. Yet, the combustion in a diluted/lean boosted SI engine **drifts from the flamelet regime to the thin reaction zone (TRZ[3]) regime**.

Extending the coherent flame model (CFM) to TRZ regimes

The main aim of Edouard Suillaud’s PhD study was **to provide a better description of the combustion in high Karlovitz regimes** such as those encountered in the new combustion chambers of spark ignition engines. In particular, this thesis **focused on extended the coherent flame model (CFM[4])** based on the concept of flame surface density (FSD[5]) to TRZ regimes.

DNS (Direct Numerical Simulation) of statistically planar turbulent premixed flames in three-dimensional turbulent fields were performed and analysed **to investigate the validity of the FSD concept in the TRZ regime** through the analyses of the flame surface, the flame structure, the characteristics of the flame stretch and of the displacement speed, which are considered as key factors in the modelling of high Karlovitz number flames[1]. An example of numerical result for different combustion regimes is shown in the following figure.



2D sections extracted from 3D simulations representing heat release rate and temperature iso-surfaces
Case « A » : flamelet regime ; cas « D » : TRZ regime.
Cases with unitary Lewis numbers (a) and (c); cases with non-unitary Lewis numbers (b) and (d)

The Lewis number is a dimensionless number comparing the thermal and molecular diffusivity of a species

An extension that has shown its potential

These results yielded an extension of the CFM model to TRZ regime through **the definition of a new progress variable and a modelled transport equation for a fine-grained flame surface density**. The developed CFM-HK raised the two main limitations of flamelet models in the TRZ regimes:

- It takes into account, in particular through the appropriate modelling of the displacement speed, the fact that the flame structure is disturbed by turbulence and that it can no longer be assimilated to a laminar flame structure;

- It takes into account the effect of differential fuel diffusion, which becomes a key factor in the estimation of the turbulent flame speed in the TRZ regime.

The encouraging results from *a priori* and *a posteriori* validation showed the potential of the extension of the CFM model proposed in this thesis. They were the subject of a paper submitted to the journal Combustion & Flame.

This work was supported by a grant overseen by the French National Research Agency (ANR) to the ANR-15-CE22-0014 MACDIL project coordinated by IFPEN.
This work was also granted access to the HPC resources of CINES from the GENCI (Grand Equipement National de Calcul Intensif) eDARI program, to resources of JSC (Germany) during the 17th Call of PRACE Project Access (Pra102) and to the HPC facilities at IFPEN.

[1] Edouard Suillaud, Karine Truffin, Olivier Colin, Denis Veynante, Direct Numerical Simulations of high Karlovitz number premixed flames for the analysis and modeling of the displacement speed., Combustion and Flame, Volume 236, 2022, 111770, ISSN 0010-2180,
https://doi.org/10.1016/j.combustflame.2021.111770

This thesis has been defended on 12 March 2021 before a jury composed of:
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[1]The Karlovitz number is a dimensionless number used in fluid mechanics to treat turbulent combustion problems. It measures the ratio of the chemical time scale to the turnover time of the smallest eddies in turbulent flows
[2]CFD (Computational Fluid Dynamics)
[3]Thin reaction zone
[4]Coherent flame model
[5]Flame surface density

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