

# Combustion Models for Industrial Applications

## Reporting

### Project Information

COMBINA

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## Final Report Summary - COMBINA (Combustion Models for Industrial Applications)

Combustion accounts for the major part of the energy conversion processes conducted throughout the world. An accurate modeling of combustion processes is thus essential if the current policy objectives of increased efficiency and reduction in emissions of combustion engines and devices are to be realized. Since there is a demand for reliable and accurate simulation tools for reactive flows, the Marie Curie COMBINA (IAPP) technology transfer project was initiated. In this project NUMECA Int. (BE), Pars Makina Ltd. (TR), TU Darmstadt (DE), INSA Coria (FR), and TU Eindhoven (NL) are collaborating in developing advanced models for premixed, partially premixed and spray combustion into the unstructured, multipurpose CFD software package FINE/Open /1/.

Premixed combustion is mainly controlled by the propagation speed of the flame front, which separates the fresh from the burnt gases. This was exploited in the current project, in which a Turbulent Flame-speed Closure / BML modelling approach was implemented in FINE/Open. To be able to simulate premixed

flames with dilution or partially premixed combustion, this modeling method has been coupled with the flamelet / mixture fraction approach. In the resulting modeling method look-up tables are used, in which the thermochemical properties are tabulated for the fresh and the burnt gases. As an alternative to the hybrid BML/flamelet approach for simulating partially premixed combustion, the Flamelet Generated Manifolds (FGM) methodology devised by van Oijen and de Goey /2/ has been transferred from TU Eindhoven to NUMECA and implemented in FINE/Open /3/.

The developed models for the simulation of premixed and partially premixed combustion have been verified and validated on a series of comprehensible test cases, ranging from analytical verification test cases and specific flame configurations (e.g. TU Darmstadt's stratified flame, Bunsen burner) for validation to complex, industry-like test cases (e.g. DLR Stuttgart's premixed model combustor) /4/. Furthermore, these models have been used to simulate the combustion in a complex combustor configuration of Siemens. The BML, the hybrid BML/flamelet, and the FGM model have been integrated in FINE/Open and can be accessed through a graphical user interface (GUI) in a user-friendly manner. A Lagrangian module for the simulation of evaporating sprays has been developed in FINE/Open. The module solves for parcels of particles and accounts for two-way coupling of mass, momentum, and energy between the dispersed

and continuous phase. The Lagrangian module has been coupled with combustion models for non- and partially premixed combustion so that spray combustion processes can be simulated. The spray combustion modeling functionality has been validated on a series of elementary spray flames /5/. It has furthermore been used for the simulation of two different aero-engine combustors of Rolls-Royce. Results from both academic and industrial test cases show that the FGM method consistently leads to more physical results than when the classical flamelet method is used for the simulation of spray combustion processes.

With the purpose of providing reference data for the validation of combustion models on industry-like applications, Pars Makina /6/ has been conducting dedicated experiments for the current project. To generate data suitable for the validation of numerical spray models, measurements of cold Jet A1 fuel spray has been carried out for various discharge pressures. The spray experiments were carried out under atmospheric conditions and the spray was generated using the injector of the RR Allison combustor. The droplet size distribution has been measured using the Interferometric Particle Imaging (IPI) technique. Measurements have also been carried out in the RR Allison combustor under reacting conditions. These data have been used to assess the spray combustion module in FINE/Open. At Pars Makina a replica of TU Darmstadt's premixed TECFLAM burner has been built up successfully. Measurement have been carried out for various swirl numbers. Also these data have been used for the supplementary validation of the models for premixed combustion in FINE/Open.

A part of the aforementioned results were presented in an international workshop that was organized in the framework of the COMBINA Workshop /7/. The workshop presentations as well as more information on the COMBINA project can be found by accessing the internet page of the workshop ([http://www.numeca.com/workshop\\_combustion\\_sardinia2011/](http://www.numeca.com/workshop_combustion_sardinia2011/)).

References:

/1/ <http://www.numeca.be/en/products/finetmonen-openlab>

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/2/ Oijen, J. V., Goey, L. D. (2000): Modelling of premixed laminar flames using flamelet-generated manifolds. Combustion Science and Technology, 161(1), 113-137.

/3/ Anker, J. E., Claramunt, K., Hirsch, C. (2009): Assessment of modeling approaches for the simulation of non-premixed and partially premixed turbulent combustion processes, European Combustion Meeting, Vienna

/4/ Beishuizen, N., Anker, J.E. Claramunt, K., Hirsch, Ch. (2011): Numerical study of premixed and partially premixed flames,

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/5/ Wunsch, D., Anker, J. E., Claramunt, K., Hirsch, C. (2012): Spray combustion modeling in FINE/Open: From academic validation to industrial application, ERCOFTAC Seminar, December 7th, Université Catholique de Louvain, Louvain-La-Neuve, Belgium

/6/ <http://www.parsmakina.com/>

/7/ International Workshop on Advanced Measurement Techniques and Computational Methods for Premixed and Partially Premixed Combustion (COMBINA Workshop), Cagliari, Italy, Sept. 10-11, 2011. Internet page: [http://www.numeca.com/workshop\\_combustion\\_sardinia2011/](http://www.numeca.com/workshop_combustion_sardinia2011/)

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