Towards Lean Combustion

IMP Contribution

Michał Karcz

Energy Conversion Department
Centre for Thermomechanics of Fluids
Institute of Fluid Flow Machinery, Gdańsk

TLC - General Motivations

Development of Low NO_x technologies

Multi-point staged injector

Lean Premixed Prevaporized, LPP

Lean Direct Injection, LDI

Calibration CFD & Improvement of physical knowledge

RANS and LES calculations

Combustion models

Optimization tools

Development high quality diagnosis

IMP PAN GDAŃSK
POWOLANY W 1956

TLC - Overall Information

19 partners from 6 countries
(France, Germany, Italy, Sweden, Spain and Poland)

Partners:
SNECMA / RRD / MTU / AVIO / TM /
ONERA / DLR / Lund Univ. / CORIA /ECN/
ITS Karlsruhe/ EBI Karlsruhe/ Genova Univ. /
Naples Univ. / CERFACS / LITEC / Rome Univ. /
IMP Gdańsk/ ACIES

TLC - Overall Information

WP 1 : Advanced experimental diagnosis

WP 2 : Lean injection systems : experimental evaluation

WP 3 : Lean injection systems : Design & Optimisation

Task 3.5: Trapped Vortex Combustor a feasibility study (AVIO, DMA Rome, IMP Gdańsk)

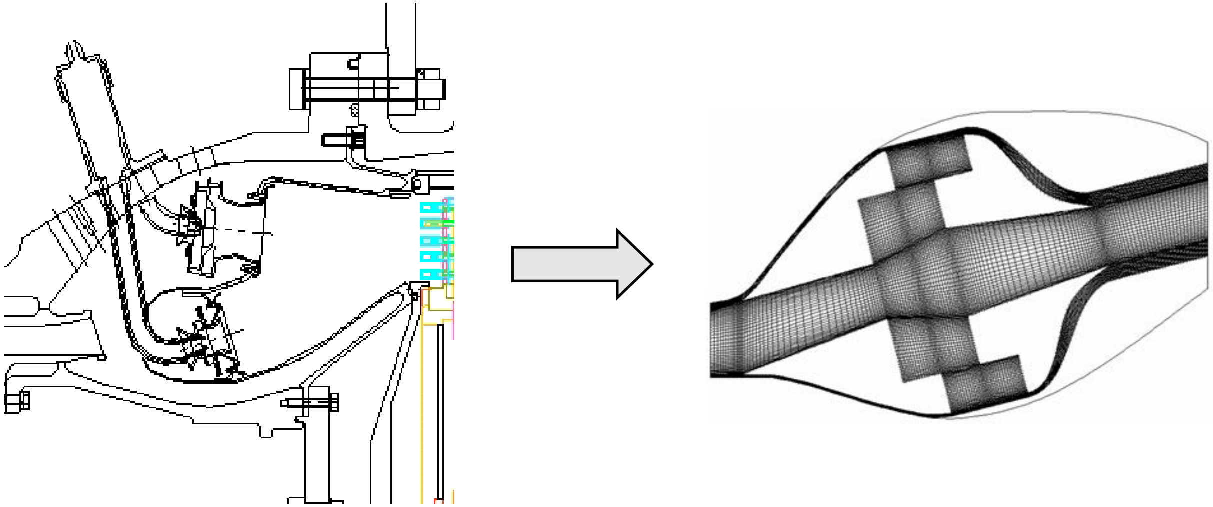
WP4 : Advanced numerical diagnosis

Task 4.4: RANS prediction of optimized LPP duct (AVIO, IMP Gdańsk)

Task 4.6.1: RANS prediction of fundamental experiment (IMP Gdańsk)

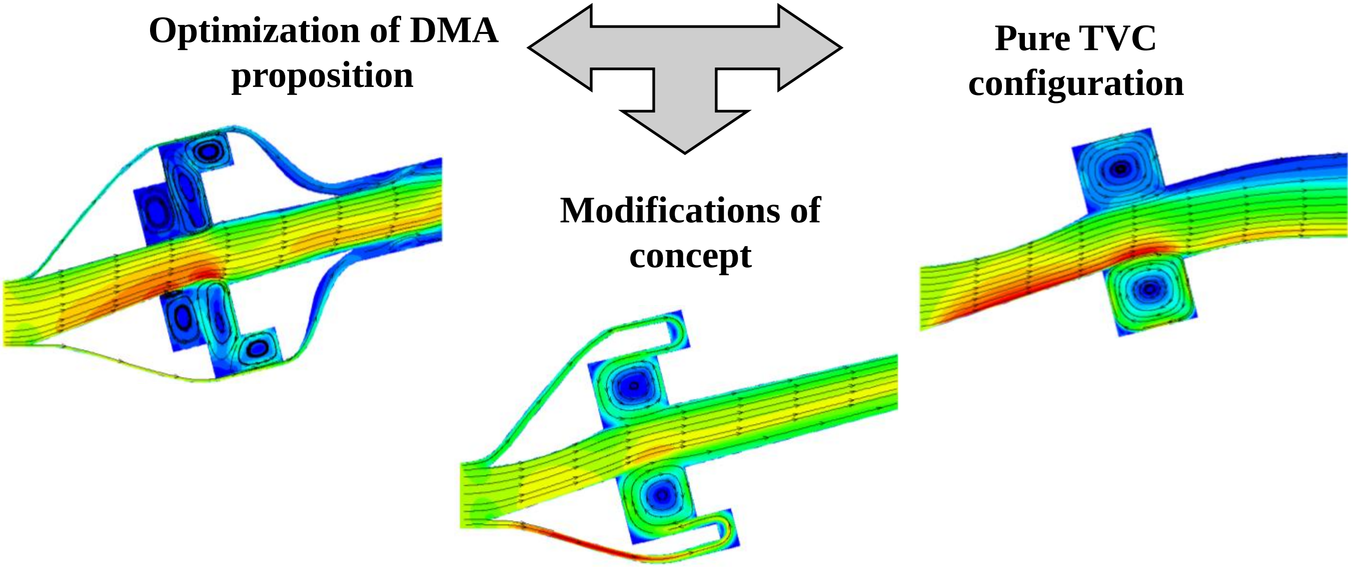
Task 3.5: Trapped Vortex Combustor A feasibility study

The scope of the task was to find out if TVC type of combustor would be used for the operating conditions of a low emission fuel staged combustor CLEAN designed, manufactured and tested by SNECMA and AVIO.



Task 3.5: Trapped Vortex Combustor
A feasibility study

Optimization of the construction to meet a basic goals i.e. low pressure drop across the burner; symmetrical and stable flow; sufficient mass flow rate trapped into the cavities

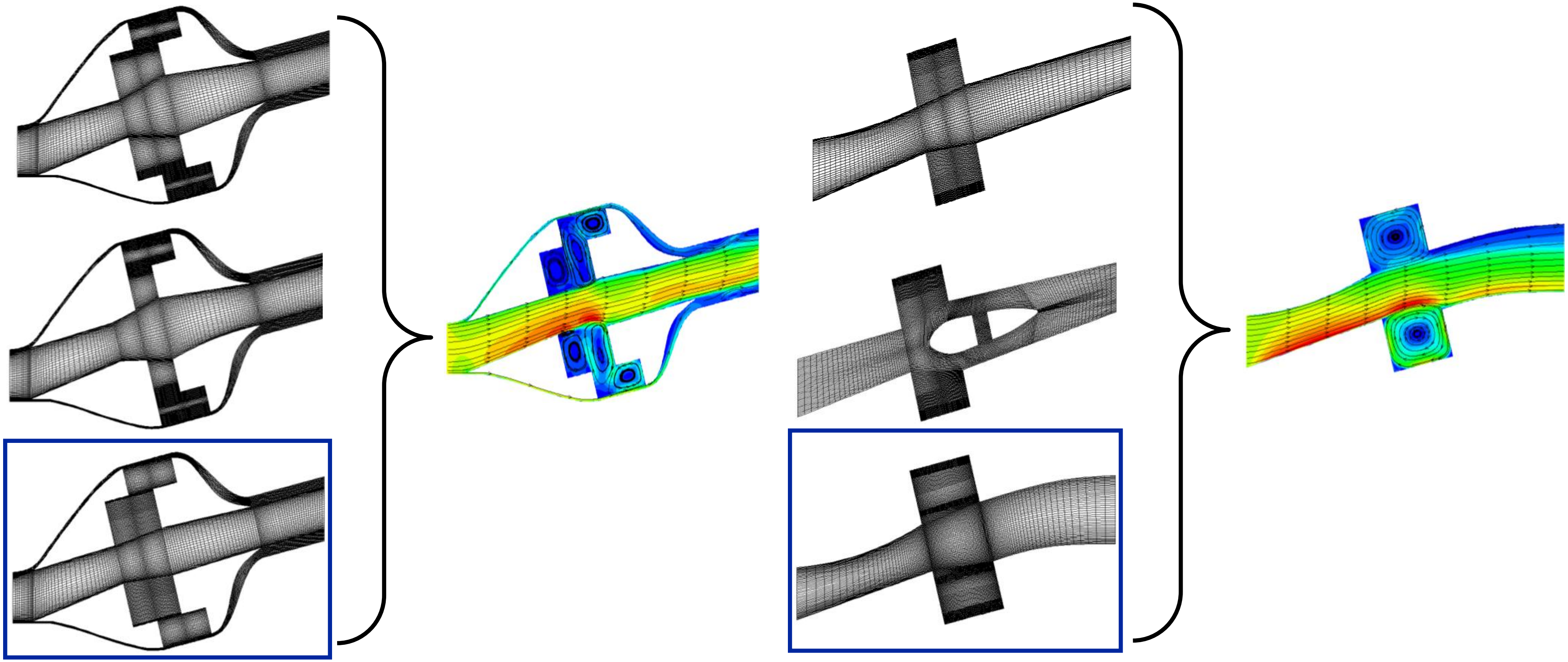


Optimization of DMA proposition

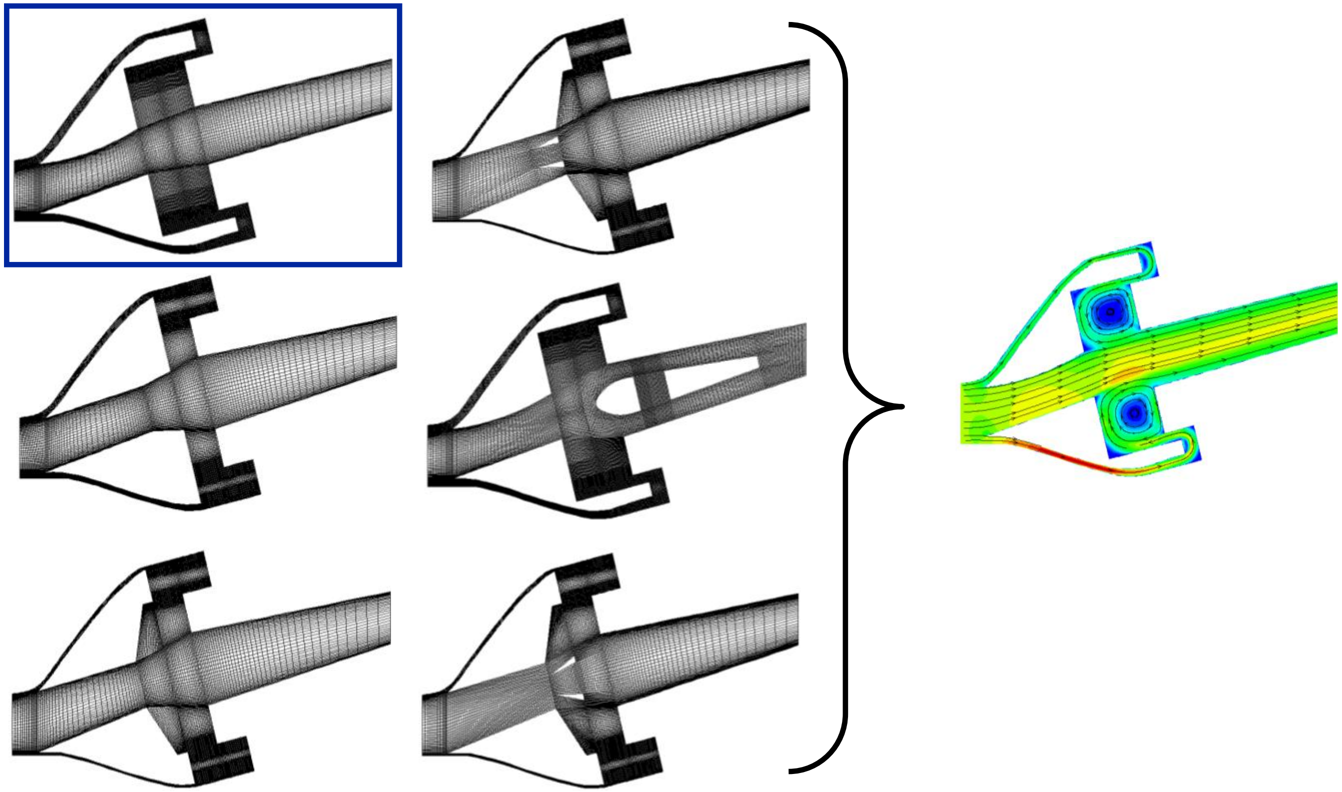
Pure TVC configuration

Modifications of concept

Task 3.5: Trapped Vortex Combustor
A feasibility study

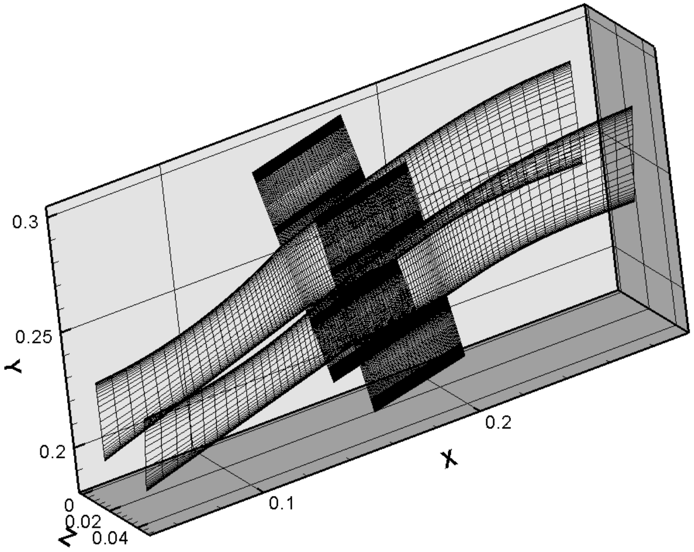


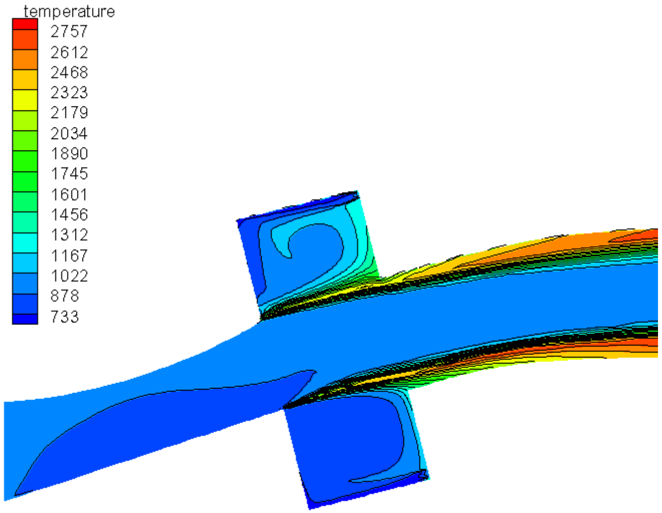
Task 3.5: Trapped Vortex Combustor
A feasibility study



Task 3.5: Trapped Vortex Combustor
A feasibility study

However only a few of considered propositions gave simultaneously acceptable level of pressure drop and air mass flow rate trapped in the cavities. Analysis have also revealed a poor TVC performance during combustion i.e. low efficiency (<90%), high emmisions level and improper temperature distribution at combustor walls and outlet

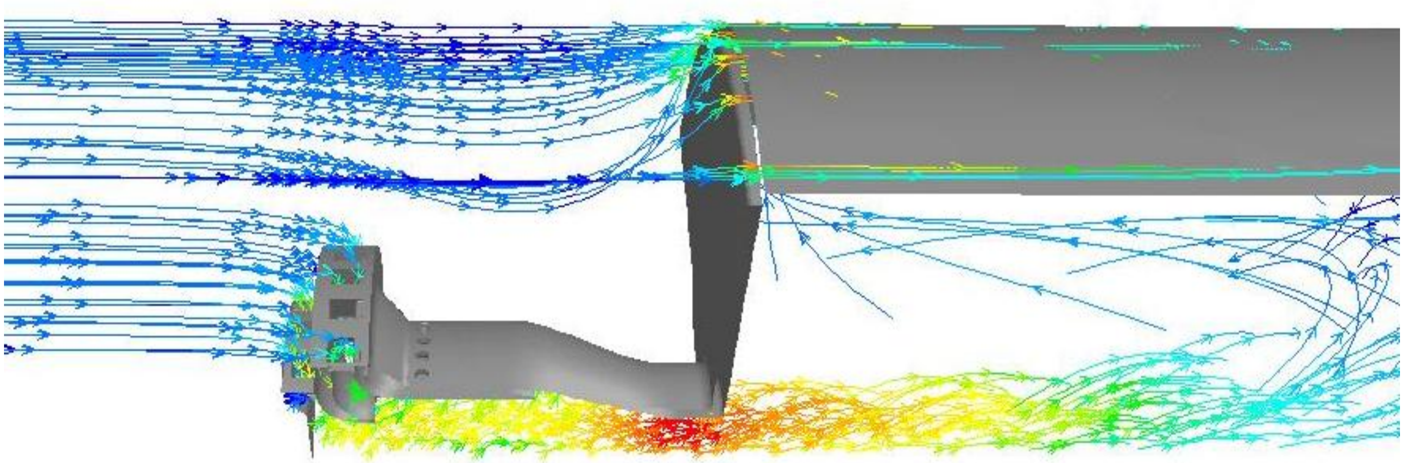




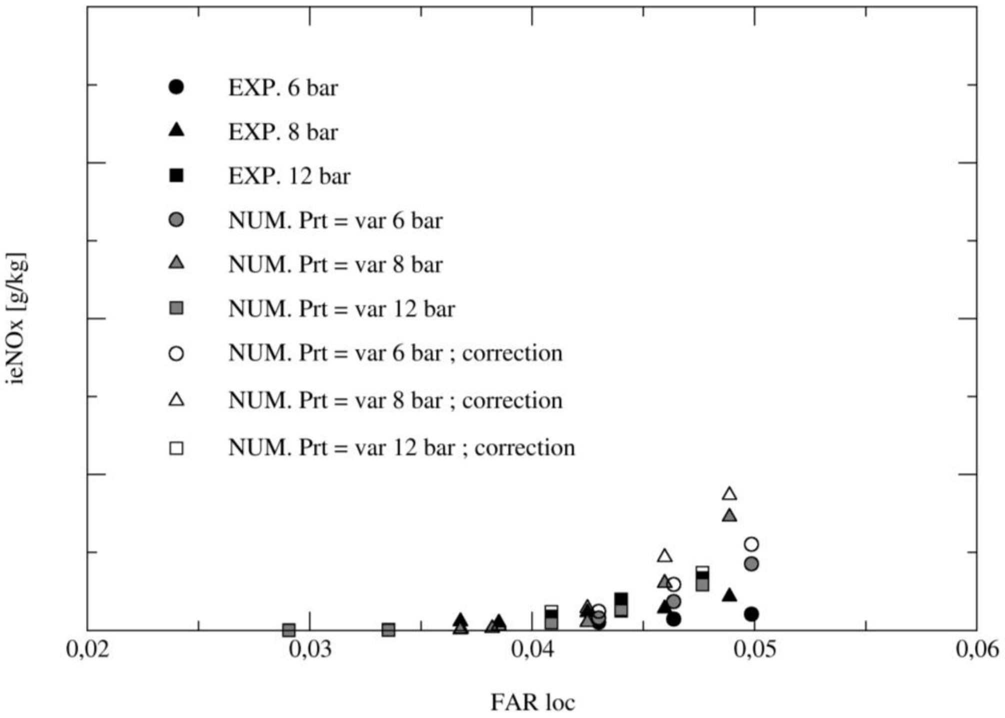
AVIO proposed a quite different solution with almost whole air flow rate being involved in creating a strong vortices. Solution was numerically tested by IMP. Such a geometry gave a much better temperature distribution. Good mixing and efficiency were obtained, however with non acceptable level of pressure drop (> 8%).

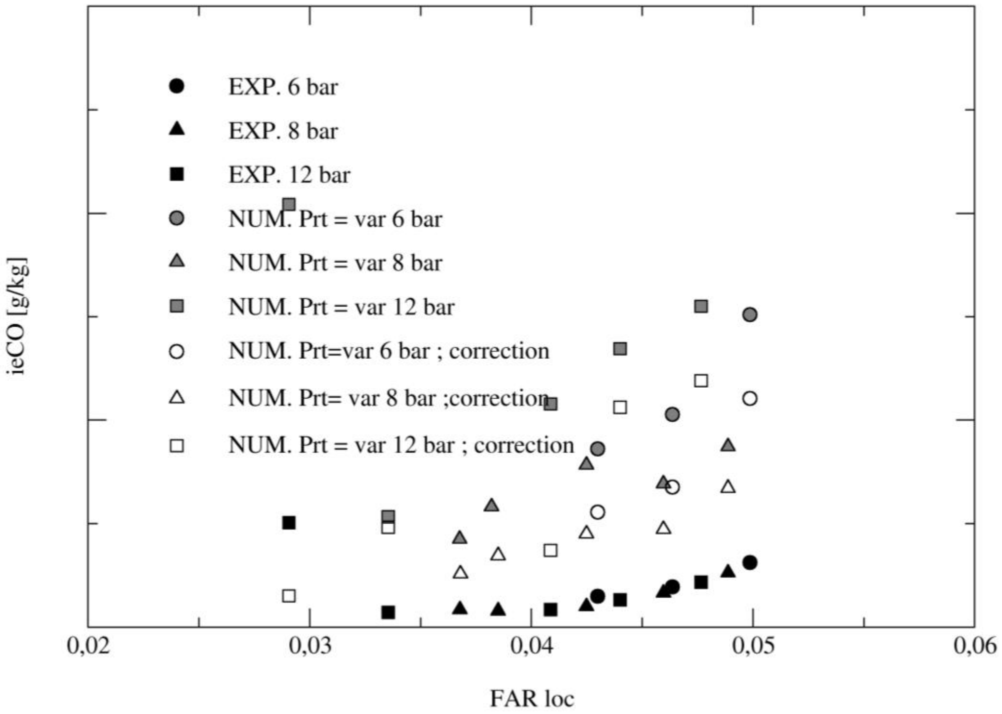
Task 4.4: RANS prediction of optimized LPP duct

The scope of the task was to perform a numerical analysis for three different geometries of LPP burner - two of them were designed and tested during previous EU funded projects.



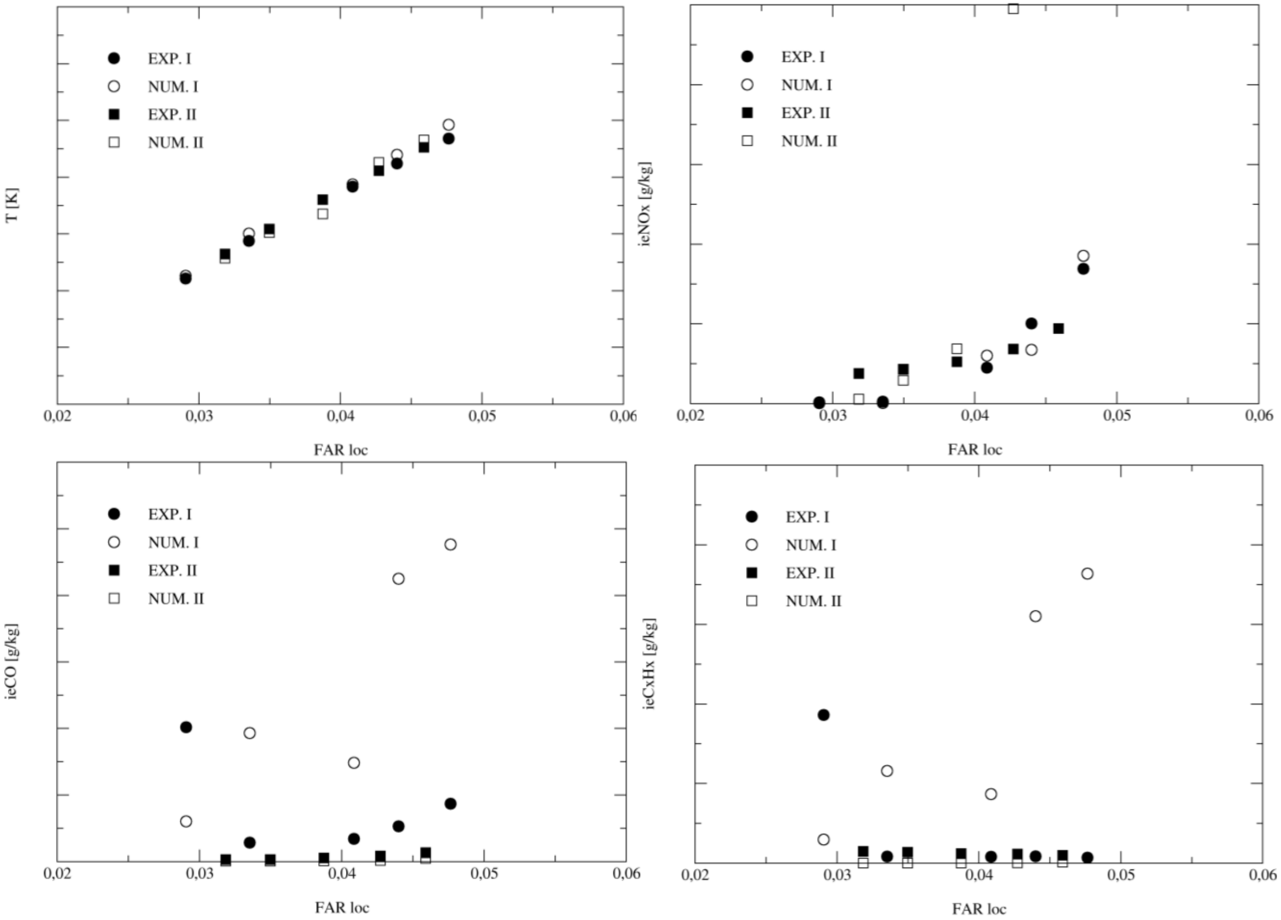
Task 4.4: RANS prediction of optimized LPP duct





Employed model uses a two-equation heat diffusivity closure (Abe et al. 1995; Karcz and Badur, 2005) and a correction term $C_r=f(T,\theta')$ (Cuoci et al., 2007) in Arrhenius equations in the framework of Eddy Dissipation Concept (Magnussen, 1981) for jet-A combustion (Kundu and Penko, 1998).

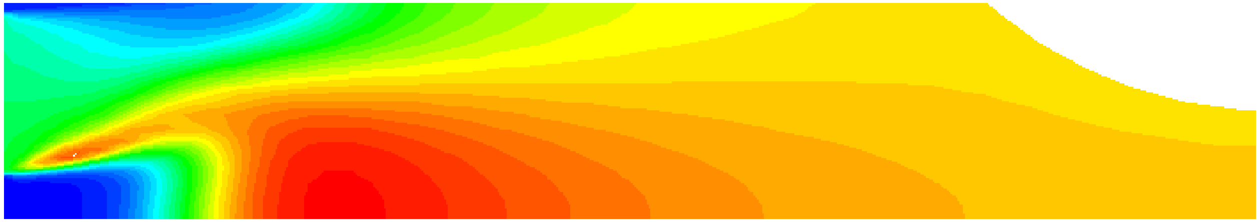
Task 4.4: RANS prediction of optimized LPP duct



LPP burners – model *vs* experimental data at 12 bar

Task 4.4: RANS prediction of optimized LPP duct

Base case



Optimized case

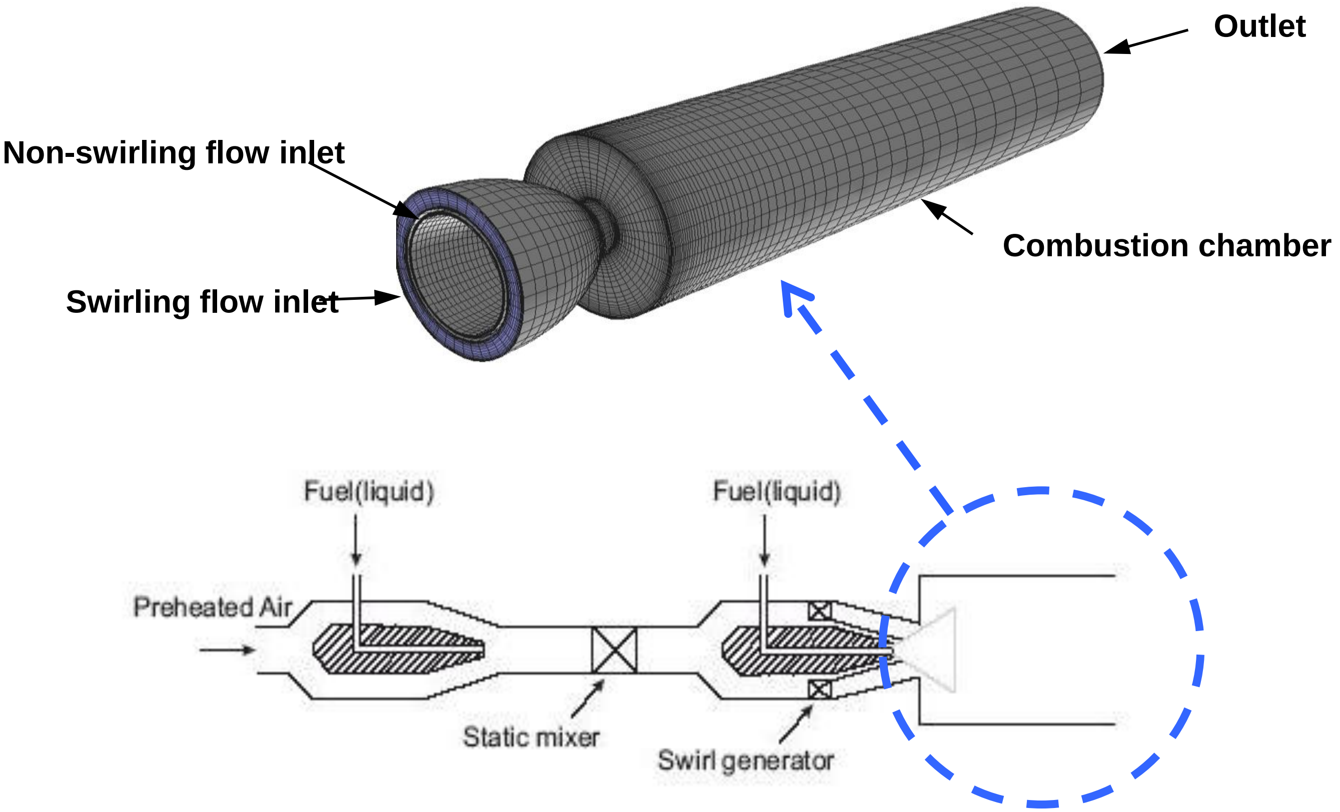
$$\varphi = \frac{\dot{m}_1}{\dot{m}_2} = \frac{R_1 \cos\alpha_1}{R_2 \cos\alpha_2} = \mu \frac{\cos\alpha_1}{\cos\alpha_2}$$

Burner	Air stream ratio φ	
	Formula	CFD
--------	0.64	0.60

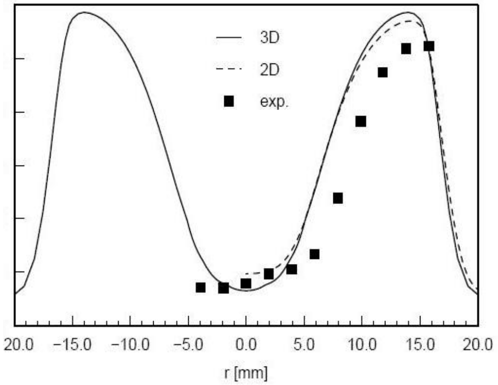
Numerical modeling confirms that the optimization by means of genetic algorithm (AVIO) finally leads to the temperature field improvement .

Task 4.6.1: RANS prediction of fundamental experiment

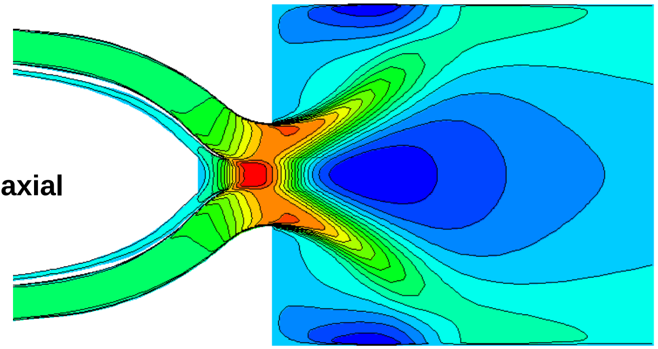
Task bases on the experimental investigations performed by ITS Karlsruhe. The main scope of the task is to reflect the influence of liquid fuel fraction on the combustor performance.



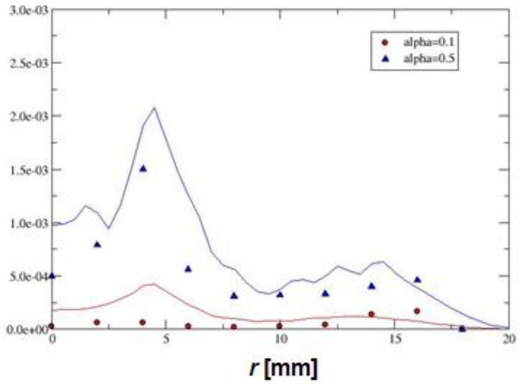
Task 4.6.1: RANS prediction of fundamental experiment

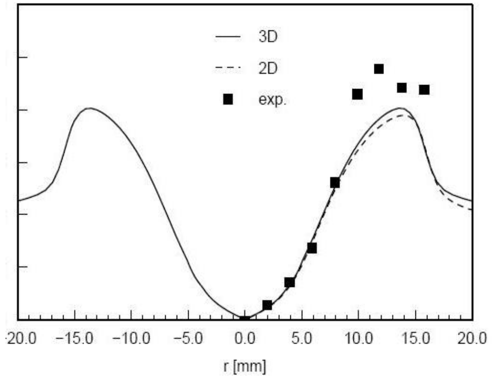


c_{axial}

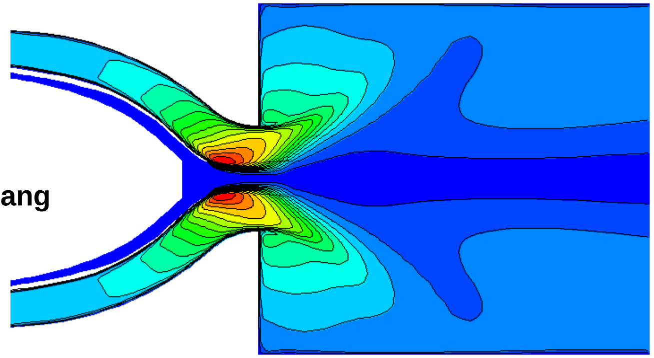


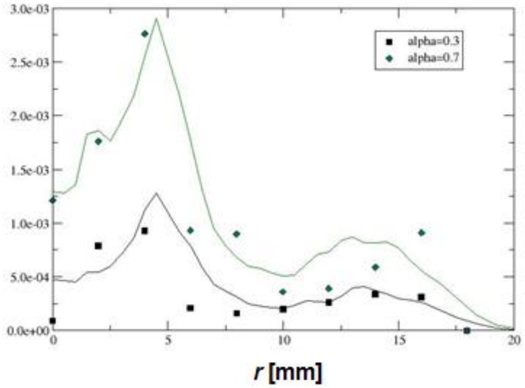
Liquid fuel flux distribution





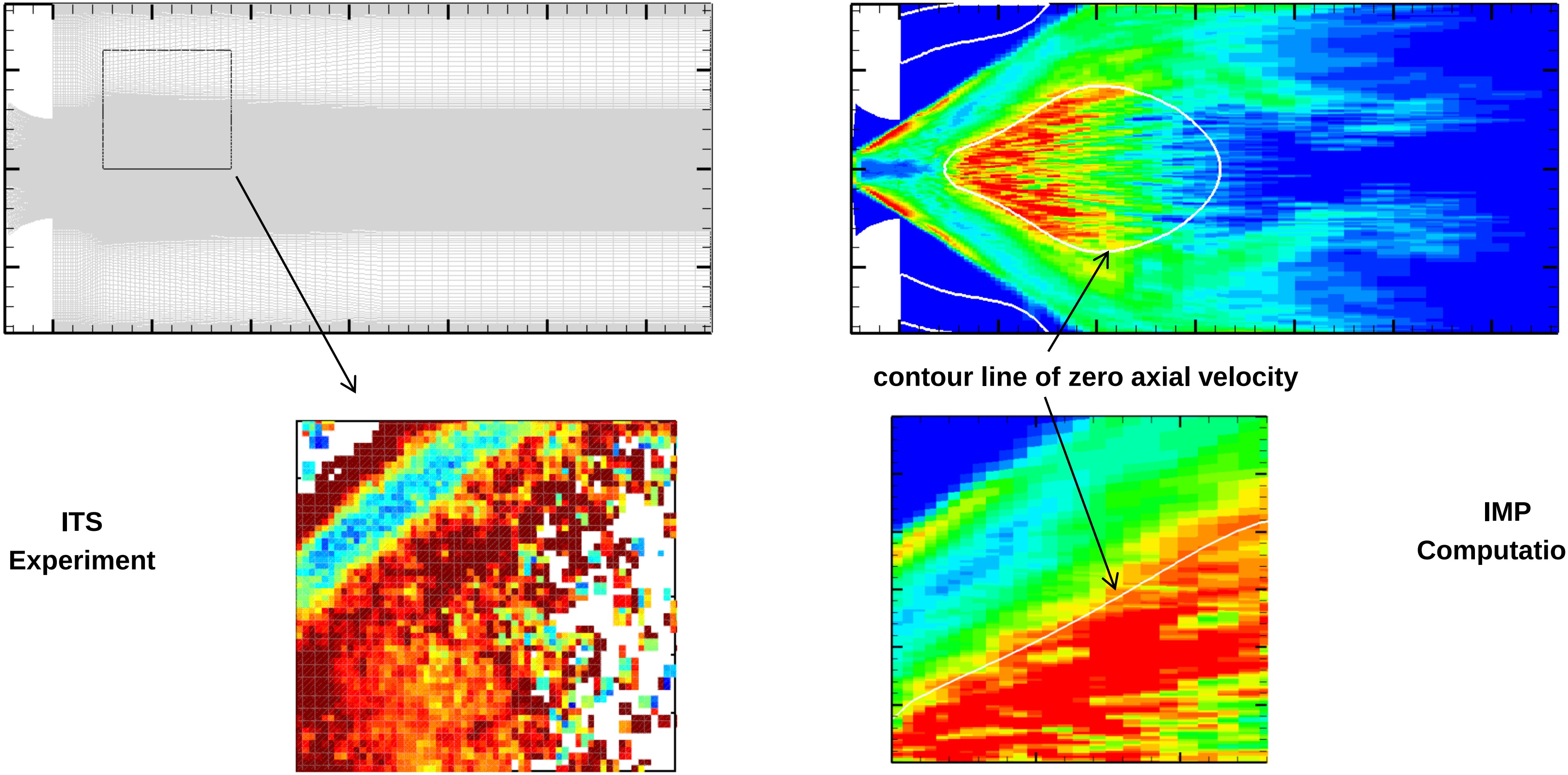
c_{tang}





Gas ans disperse phase s B.C. were adjusted to fit experimental data ITS Karlsruhe

Task 4.6.1: RANS prediction of fundamental experiment



contour line of zero axial velocity

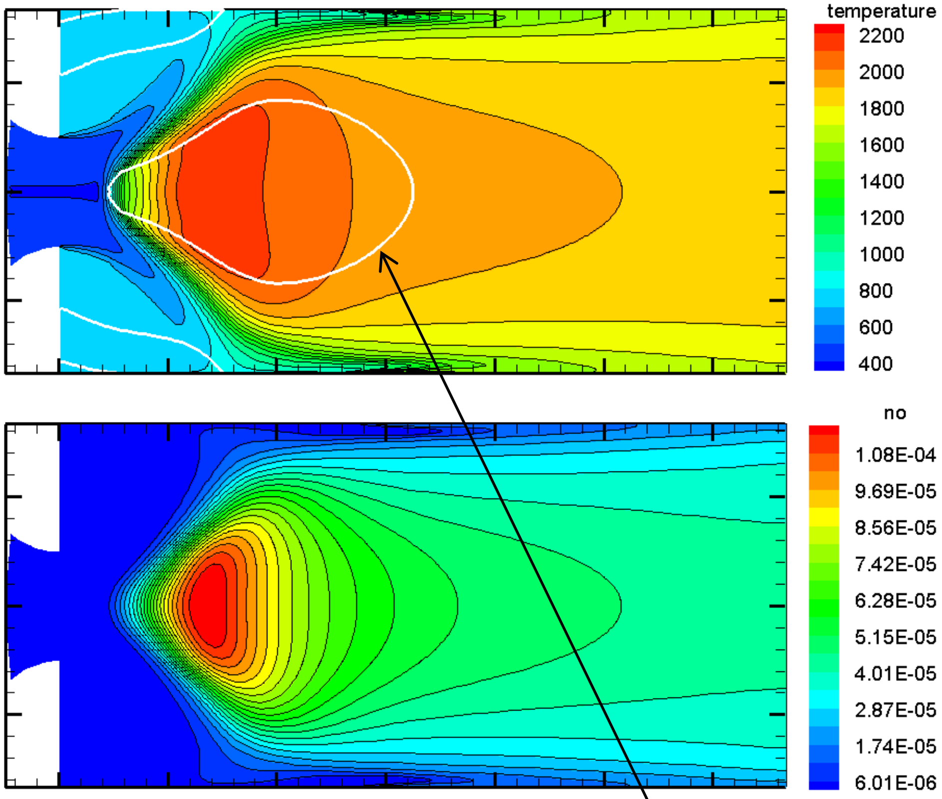
ITS
Experiment

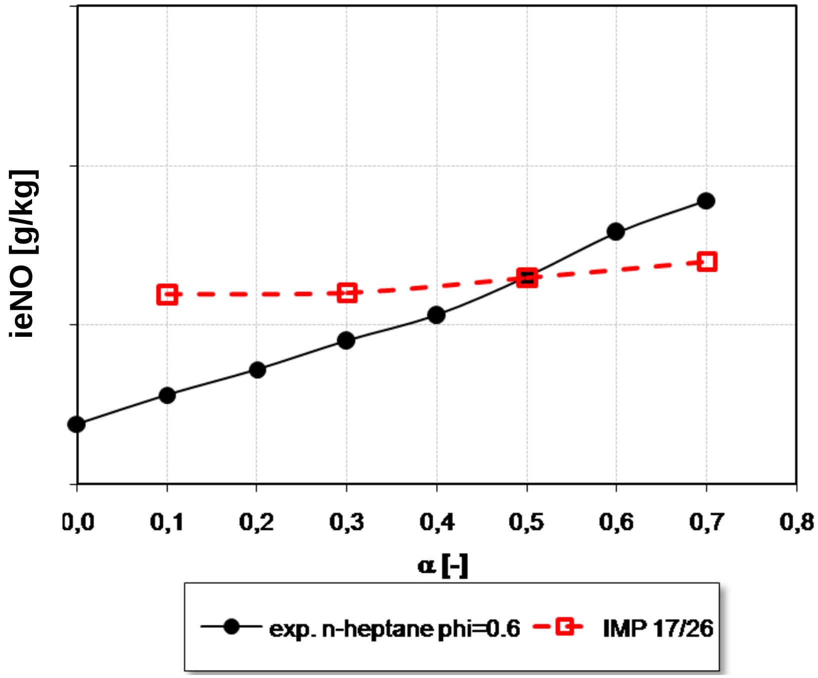
IMP
Computations

Droplet slip velocity distribution – numerics vs. experiment

Task 4.6.1: RANS prediction of fundamental experiment

Using of reduced/detailed mechanisms for n-C_7H_{16} oxidation with standard droplet treatment (heating/vaporization and combustion after mixing with the surrounding gas) does not provide a proper NOx estimation for spray combustion

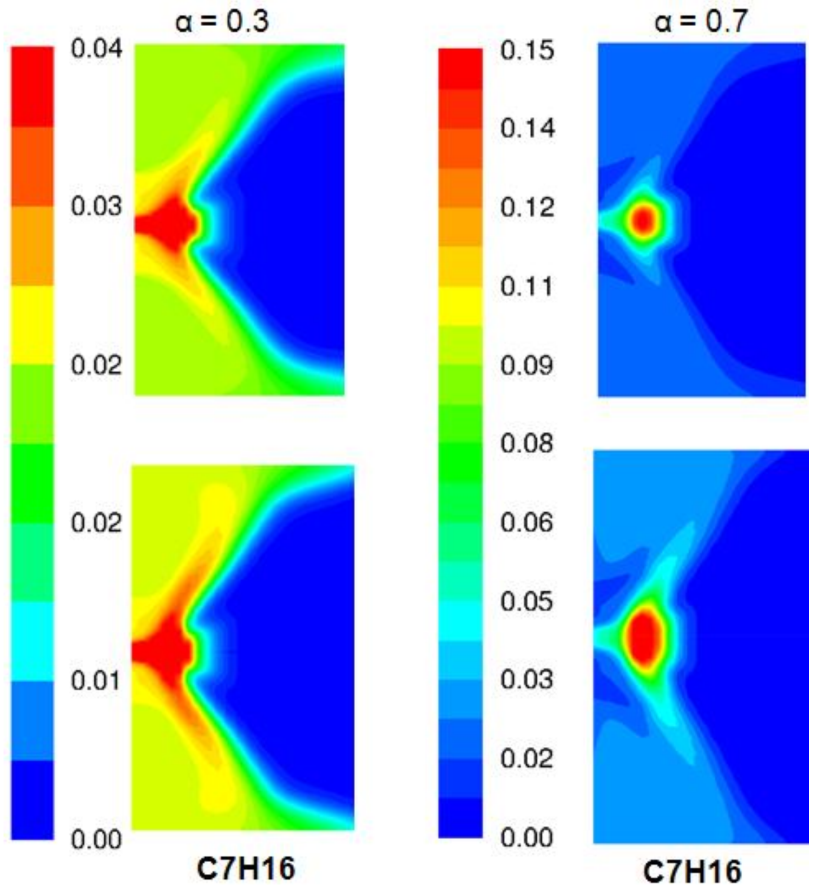




$\alpha = 0.7$ mech. 17/26

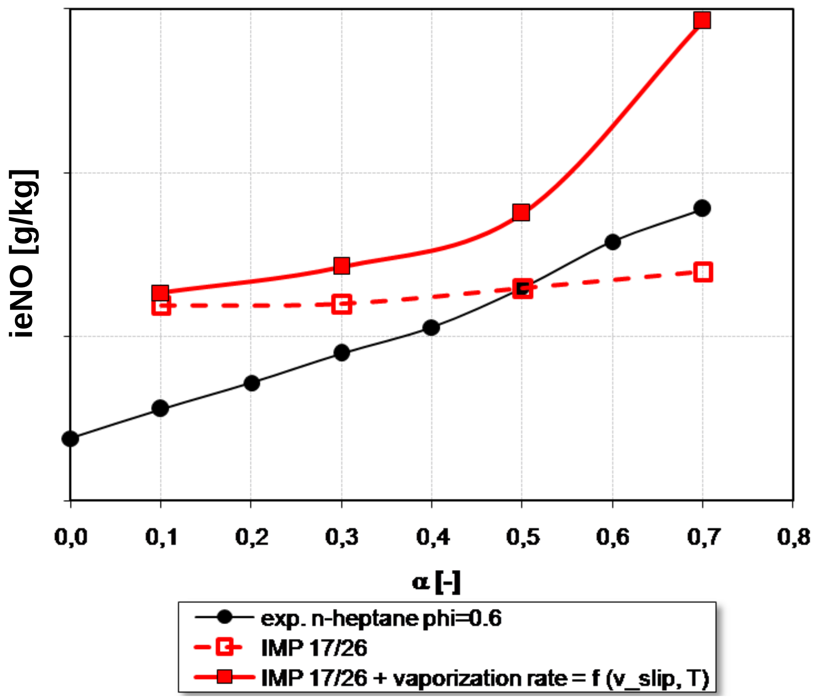
contour line of zero axial velocity

Task 4.6.1: RANS prediction of fundamental experiment



How to reflect the problem of enhanced NOx generation due to droplet combustion in real geometries?

Vaporization rate = f (*vel_slip*, *temperature*)



Thank You for your attention.