FLOW STRUCTURE IDENTIFICATION WITH PIV AND HIGH SPEED IMAGING IN COLD FLOW COMBUSTOR MODEL

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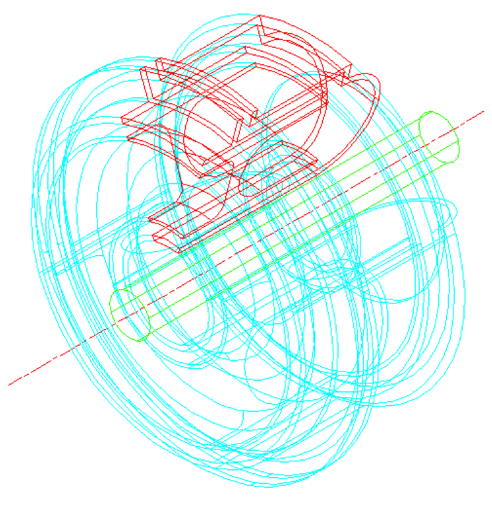
FLOXCOM – PROJECT SPECIFICATION

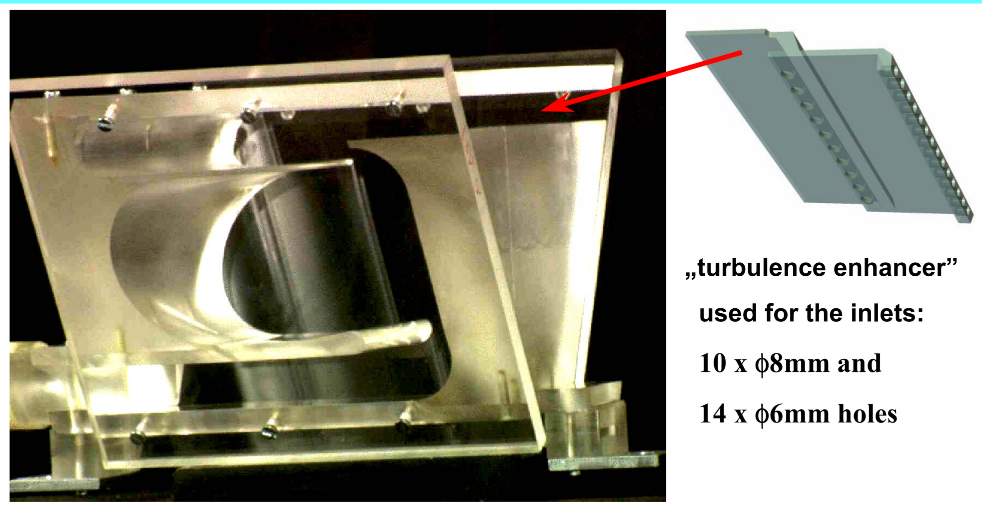
A cold flow simulation of the gas turbine combustor is performed using small, transparent laboratory model. The main target of the investigation is to get physical insight into the main vortex, responsible for the efficient mixing of fuel. Measurements performed for the laboratory model delivered details of a flow structure, important for optimisation of the combustor geometry and for verification of numerical models. Such modelling is used for constructing real combustor in the framework of FLOXCOM[1] project.

The model built of Plexiglas replicates geometry of the operational combustor sector used for experiments including combustion. The transparent walls and optical arrangement allow for the flow visualization and PIV measurements of the velocity field. Air under atmospheric pressure is used as a working gas. The flow is generated using suction pump installed at the outlet. The model is equipped with two inlets, turbulence enhancer and additional sliding plates employed to modify flow structure. The typical flow velocities are shown in the table for three inlet flow configuration.

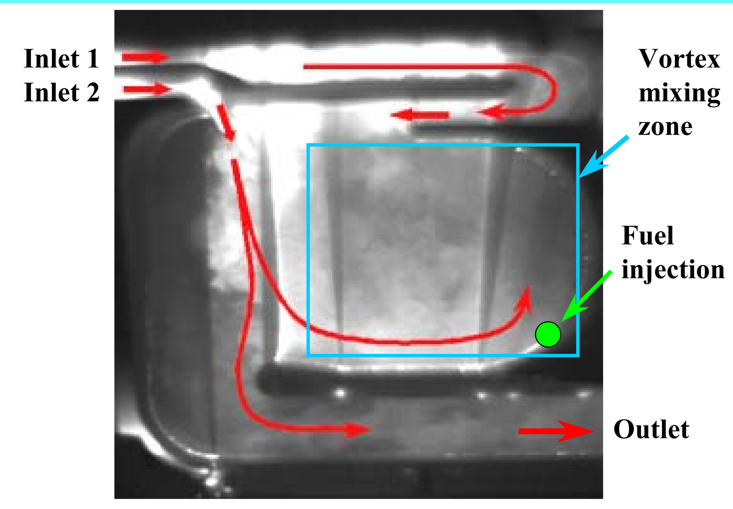
	Configuration		
	„A"	„B"	„C"
Inlet 1	9.5 m/s	20 m/s	0 m/s
Inlet 2	10 m/s	0 m/s	17 m/s
Outlet	18 m/s	18 m/s	18 m/s



Selected sector of a gas turbine combustor



Plexiglas model of the combustor sector (60°)



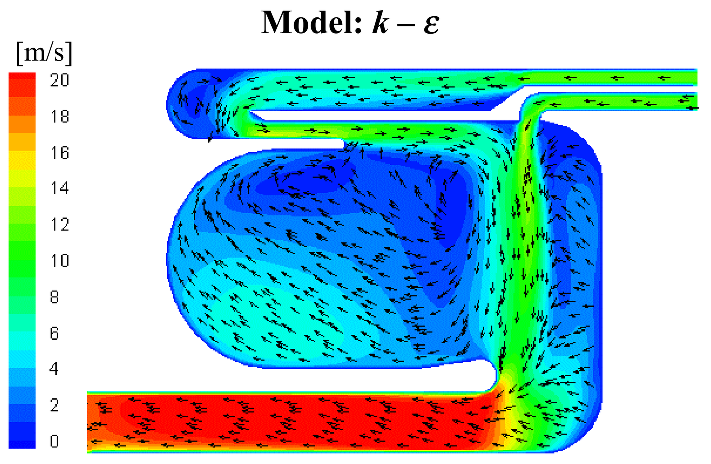
Flow visualization in the centre cross – section using high–speed camera

NUMERICAL SIMULATION

Simulation of the cold flow investigated in the model are performed with help of finite volume CFD code Fluent 6 using 3D unstructured mesh. Two approaches are employed:

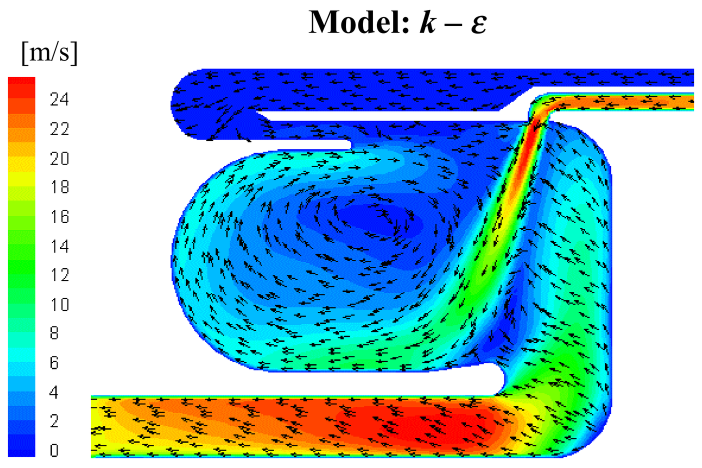
- **k – ε turbulence model, 1104768 nodes and 1042416 elements, steady state; parametric study to optimise combustor geometry, validation using PIV and hotwire probe velocity measurements**
- **Large Eddy Simulation for 869072 nodes, 814315 elements, unsteady flow with time step=0.001s. Analysis of turbulent mixing properties of the inner vortex was performed for 1 sec time period**

Model: $k-\varepsilon$



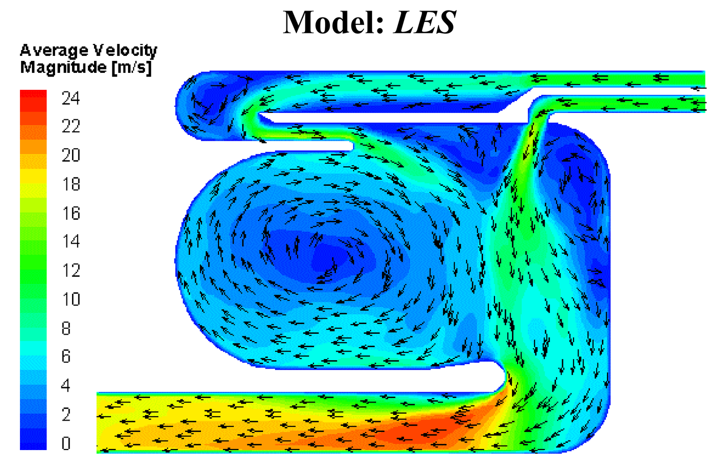
Configuration „A": velocity vectors and contours of velocity magnitude

Model: $k-\varepsilon$



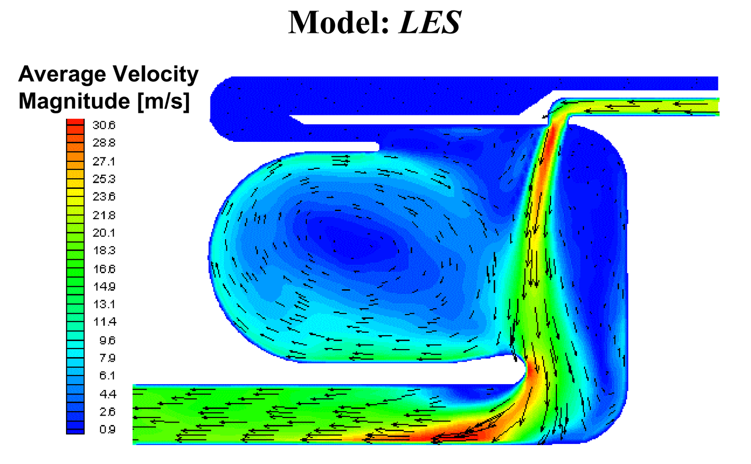
Configuration „C": velocity vectors and contours of velocity magnitude

Model: *LES*



Configuration „A": velocity vectors and contours of velocity magnitude

Model: *LES*

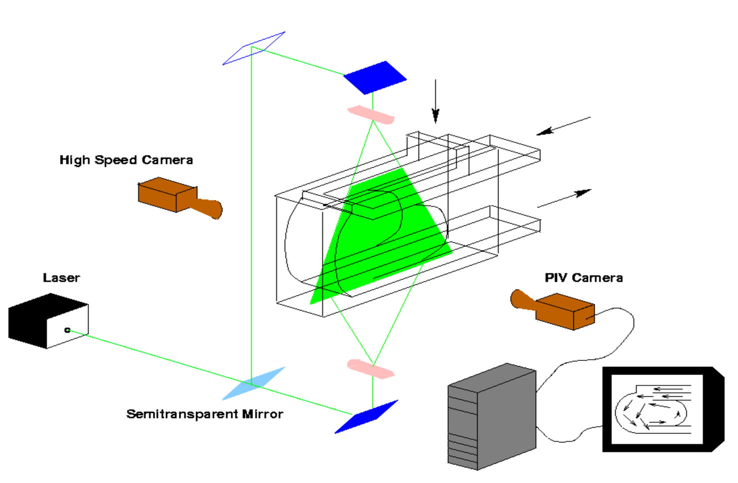


Configuration „C": velocity vectors and contours of velocity magnitude

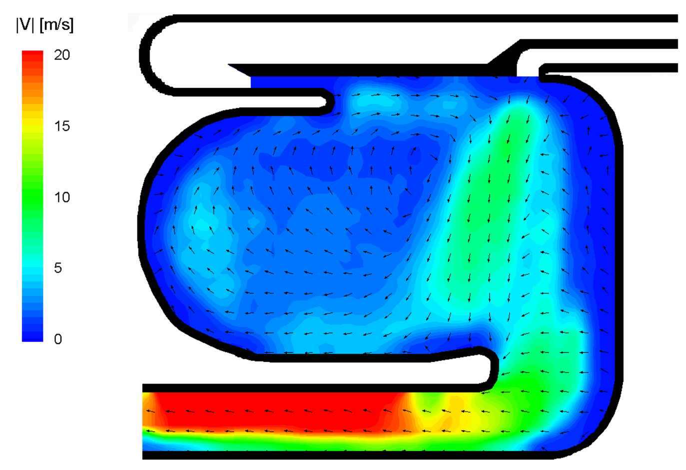
PARTICLE IMAGE VELOCIMETRY

The optical setup used in the experiments:

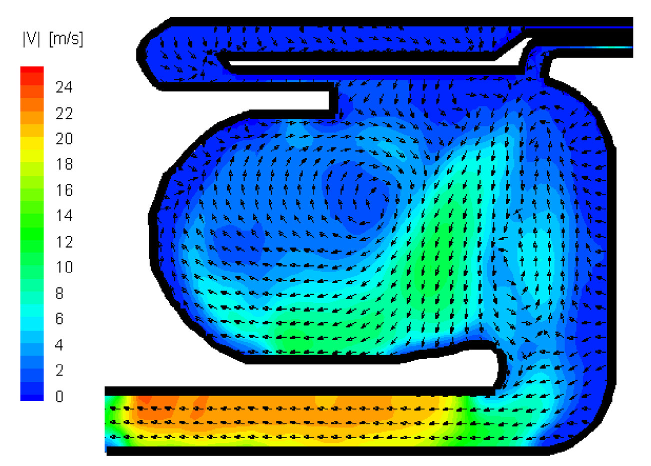
- **5W Ar+ CW laser for flow visualization and PIV and a double pulse Nd:Yag (Δt=100ns) laser for PIV,**
- **High speed camera FASTCAM Ultima 40K, sequences of 8000 256x256 pixels images at 4500 frames/sec (flow visualization and high speed PIV)**
- **High resolution PIV camera (SensiCam), sequences of 200 1280x1024 pixels pairs of images at 3.75 Hz (high resolution PIV)**
- **Hotwire anemometry, 100kHz probe for point velocity measurements.**



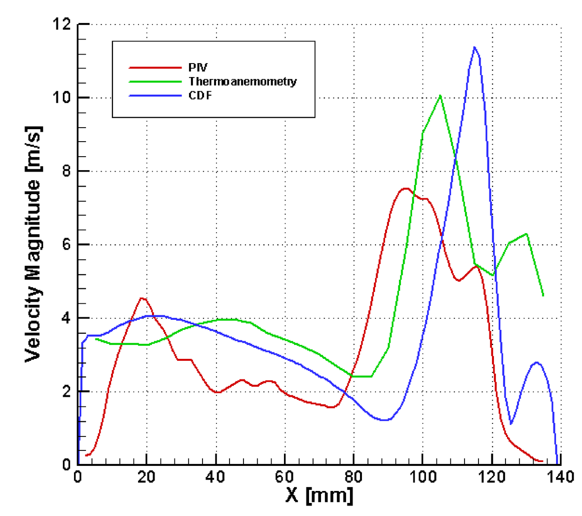
Experimental setup



Configuration „A": averaged velocity vectors and contours of velocity magnitude



Configuration „C": averaged velocity vectors and contours of velocity magnitude

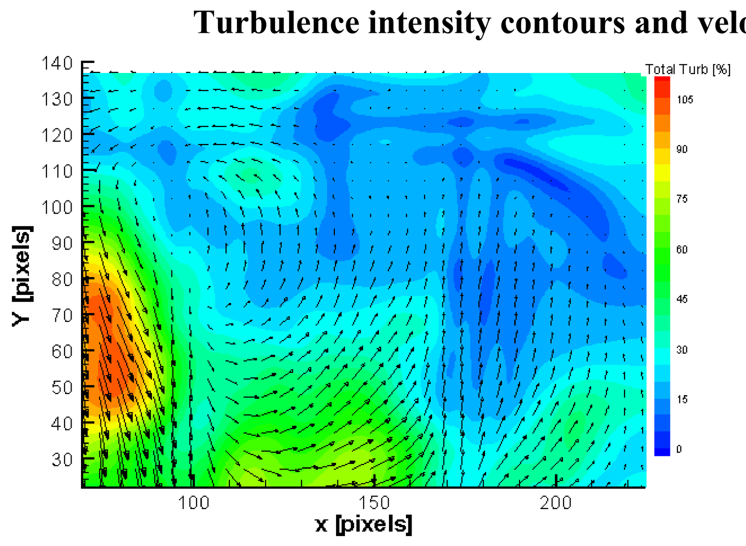


Measured and simulated velocity profiles along the centre line; configuration „A"

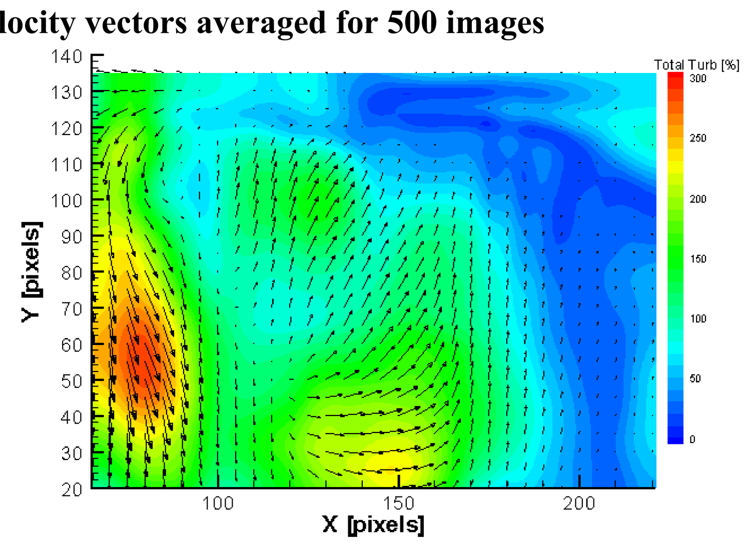
HIGH SPEED IMAGING (configuration „A")

High speed camera is used to obtain temporal characteristics of the flow. Effect of additional turbulence enhancement (plate with holes) is studied for the inlet configuration "A". Sequence of 500 velocity fields is used for the analysis. Images are obtained from high speed PIV measurements performed at 4500 fps and 2250 fps. Velocity histograms for the recirculation region indicate improved homogeneity of the flow field for the inlets with the additional „turbulence enhancer"

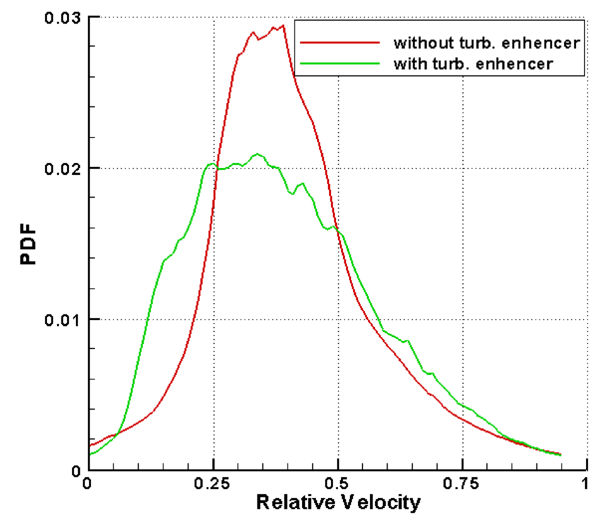
Turbulence intensity contours and velocity vectors averaged for 500 images



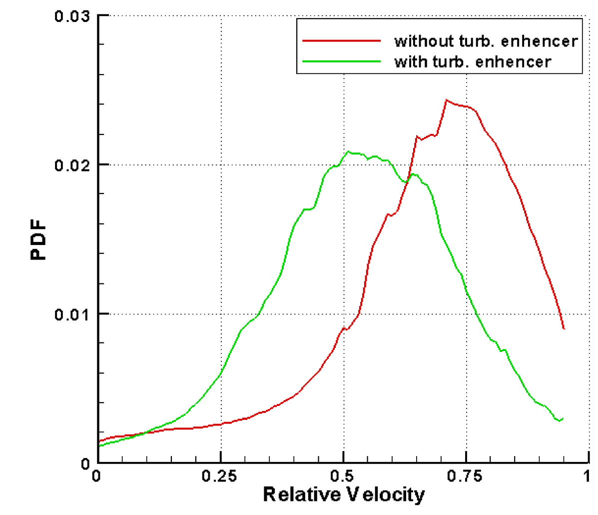
plain inlets



inlets with „turbulence enhancer"



PDF of X–component of velocity for the inner vortex

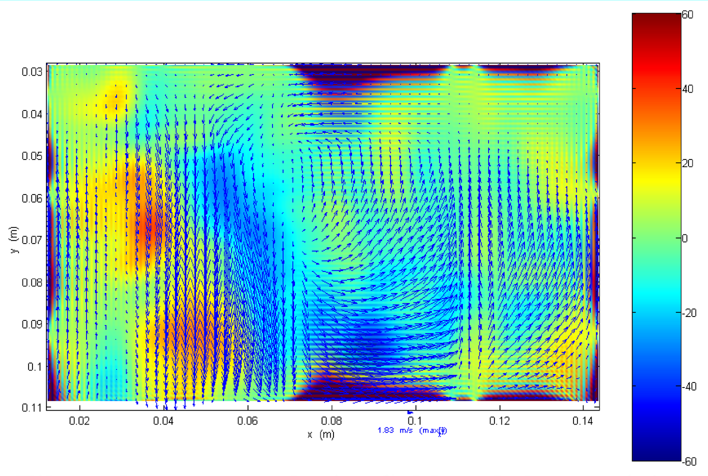


PDF of Y–component of velocity for the inner vortex

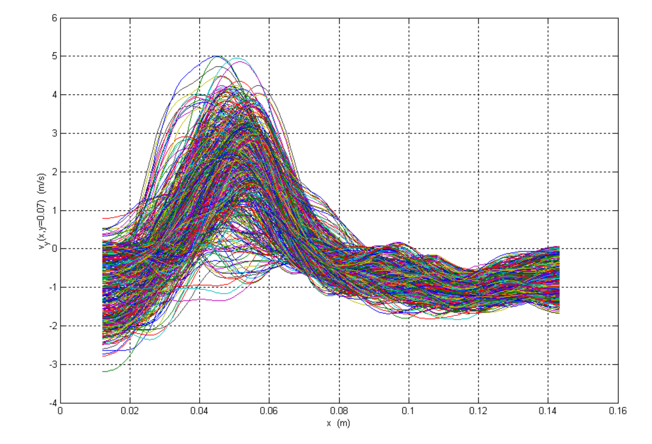
FILTERING (configuration „A")

The main goal

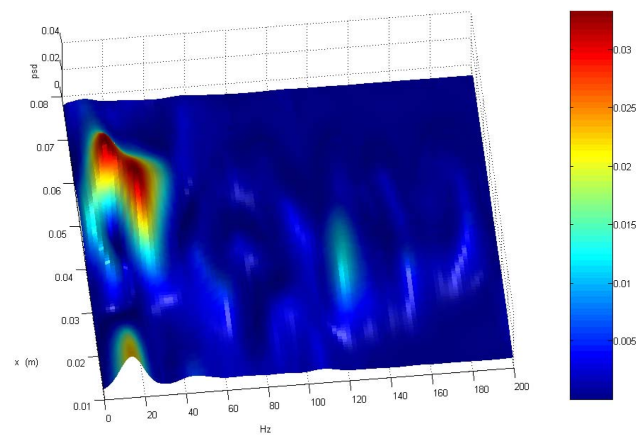
- **Understanding effects of the combustor geometry and inlet flow characteristics on the flow structure to achieve recirculating vortex and to improve turbulent mixing efficiency.**
- **Searching for quantitative measure of the flow field spatial and temporal characteristics necessary to perform combustor optimisation.**



Filtered average velocity field and the vorticity contours



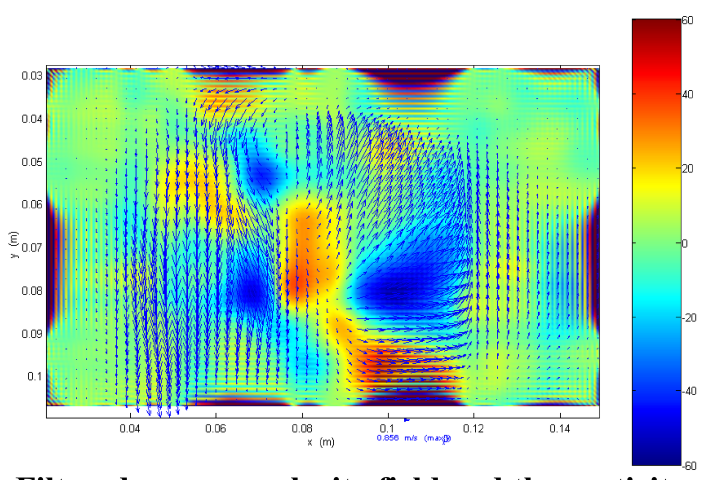
500 profiles of the Y–component of the velocity



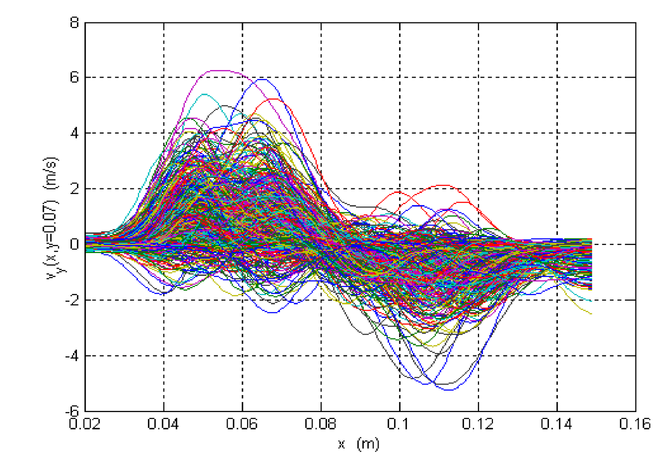
PSD of the Y–component of the velocity

Velocity fluctuation analysed for selected profile along cavity centre line. Spectral characteristics of the fluctuating field are used to quantify mixing properties.

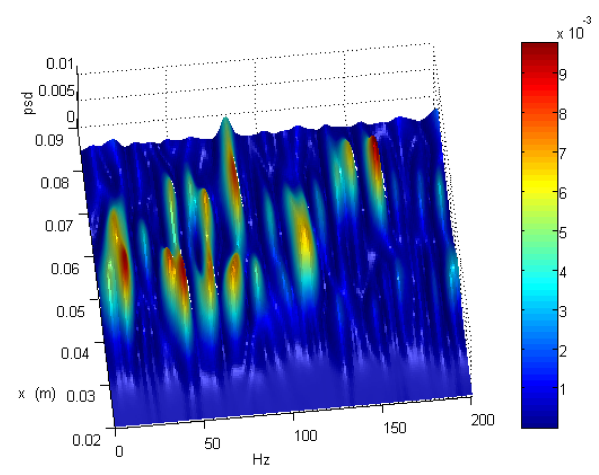
Applying turbulence enhancement at the inlet appears to influence frequency spectrum (flattening of the frequency spectrum). Such flow structure improves mixing properties of the inner recirculating vortex by increasing redistribution of fuel.



Filtered average velocity field and the vorticity contours **with „turbulence enhancer"**

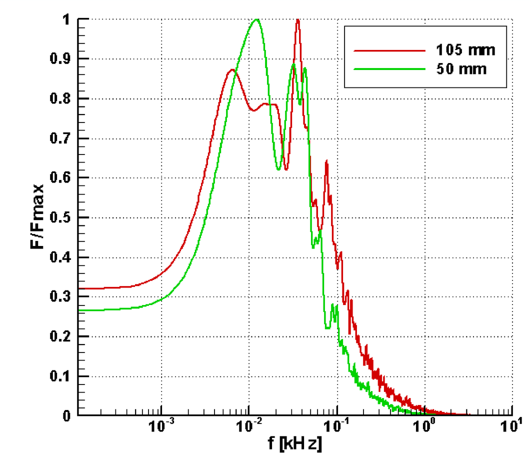


Profiles of the Y–component of the velocity **with „turbulence enhancer"**

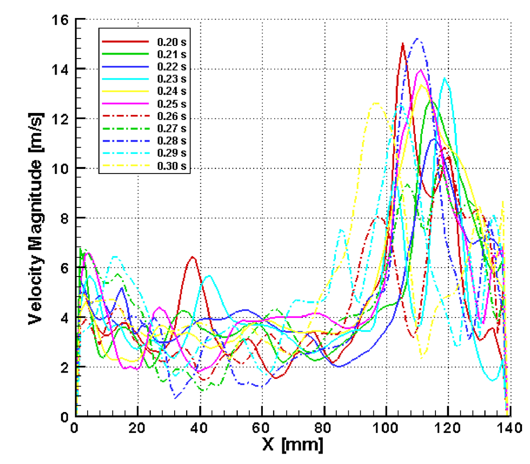


PSD of the Y–component of the velocity **with „turbulence enhancer"**

FREQUENCY



PSD of the velocity measured by hotwire anemometer



Velocity profiles for different time steps calculated by LES – model

SUMMARY

The first observations of the flow show periodical beats of the main flow jet, which interacts with the adjacent vortices. Our attempt is to find the relationship between the jet instabilities and the mixing efficiency in the cavity centre. The mixing process determines the resident time of the fuel inside the cavity and therefore is essential for the whole combustion process. Two evaluation procedures are used, cross–correlation PIV and high resolution method based on the Optical Flow method. The classical PIV system equipped with the high resolution PIV camera is used to analyse turbulent statistics of the flow. To identify main flow structure, a Fourier analysis of the velocity fields both in space and time is performed for long sequences of images obtained with the high speed camera. Parallel to the experiment, numerical simulations using Fluent are performed. Results of the numerical simulations are compared with the PIV evaluations of the main flow characteristics.

[1] **This work was performed as a part of EU 5th Framework Programme project FLOXCOM.** FLOXCOM is a low NOx combustion for gas turbines and jet engines. Its goal is minimizing man–made pollution that affects the global climate. The aim of the FLOXCOM project is to create stable combustion within the combustor with more even temperature distribution (lower peaks of temperatures). FLOXCOM replaces the high temperature primary zone that is followed by a dilution section by one large volume where fresh air, exhaust gases and fuel are mixed before combustion takes place. The stabilization of the combustion process is achieved **by creating a large vortex that recirculates combustion products back into the combustor.** A more detailed description can be found at the FLOXCOM web site <ftp://floxcom.ippt.gov.pl>