FLOXCOM PROJECT WP5
36 MONTH REPORT

Polish Academy of Sciences
Institute of Fundamental Technological Research

WARSAW

POLAND

http://www.ippt.gov.pl

FLOXCOM PROJECT WP5

Laser Diagnostics of Vortical Flow

- FLOW STRUCTURE IDENTIFICATION WITH PIV AND HIGH SPEED IMAGING IN COLD FLOW COMBUSTOR MODEL
- QUANTITATIVE EVALUANTION OF THE TURBULENCE ENHANCEMENT
- INETRACTION OF THE FUEL AND COOLING JETS WITH THE FLOW

Equipment

- Full Field Measurements of cold flow:
- High Speed Camera (up to 40 500 frames per second)
- PIV Camera (resolution 1280 x 1024)
- Laser CW Ar 3W
- Double Pulse Laser Nd-YAG (2 x 30 mJ)
- Suction Pump (up to 35 dm^3/s)
  - Point Measurements:
- 4 Hot Wire Sensors

CFD Modelling Using Fluent 6

3-D, uncompressible, turbulent flow

k - ε model & Large Eddy Simulation

882000 tetrahedral elements

▪

- Air 1 (trapezoid inlet) velocity: result
- Air 2 (trapezoid inlet) velocity: result
- Outflow velocity: 18 m/s (set)

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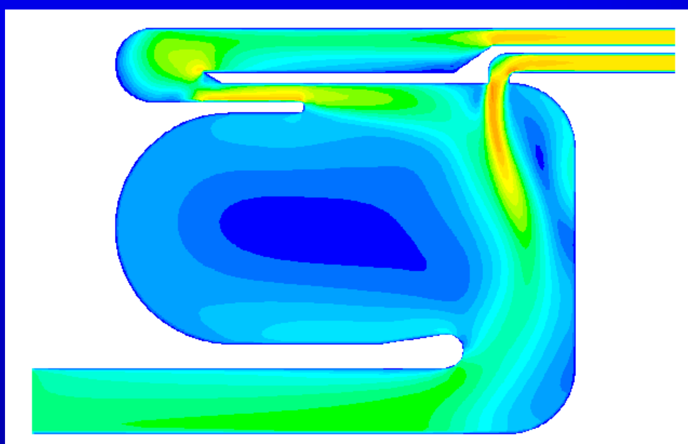
Expected results



- Instantaneous velocity and vorticity
- Turbulence transport coefficients
- Flow structure
- Mixing properties

↓

Validation of the CFD models

Optimisation of the combustor geometry

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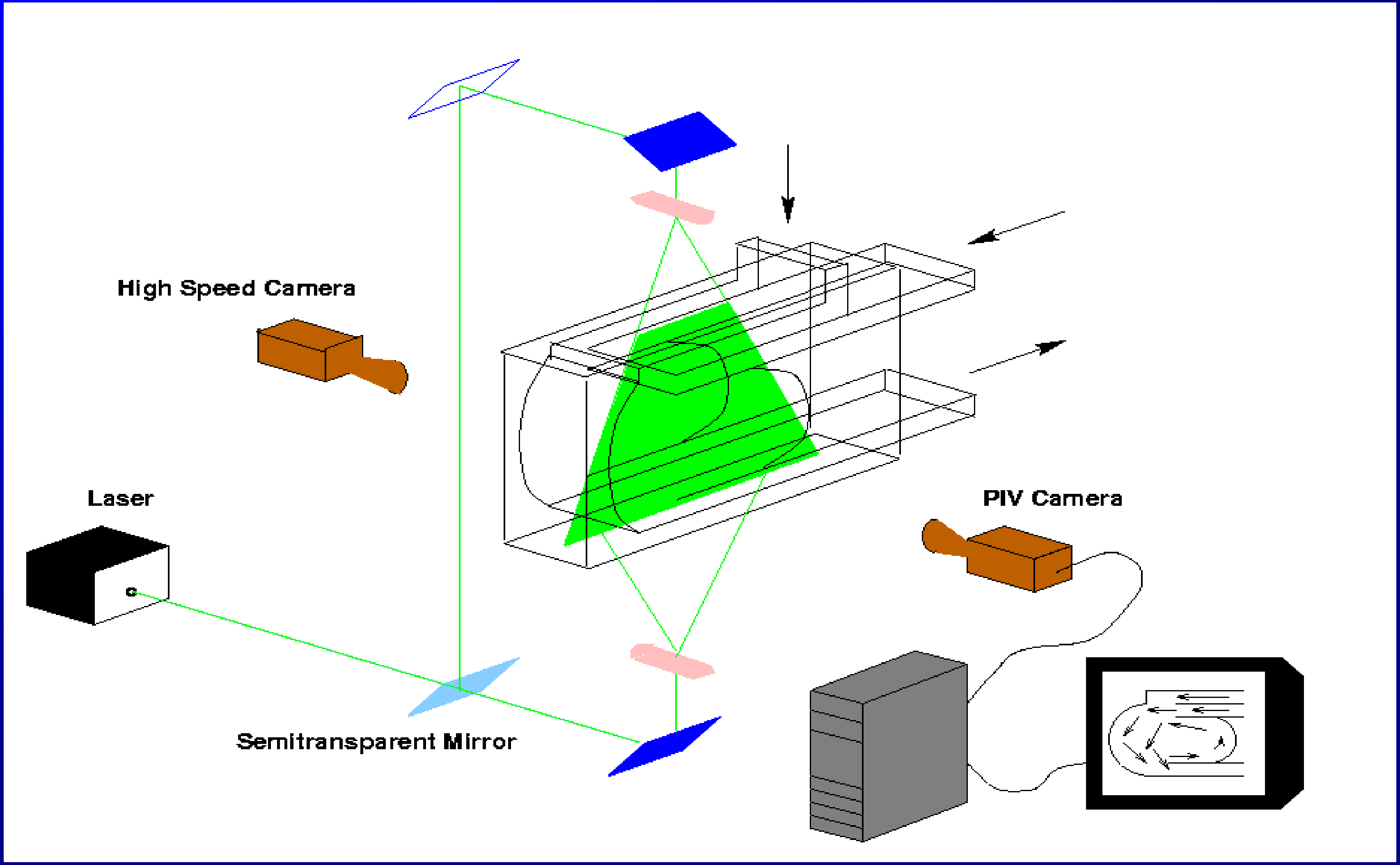
Experimental Setup



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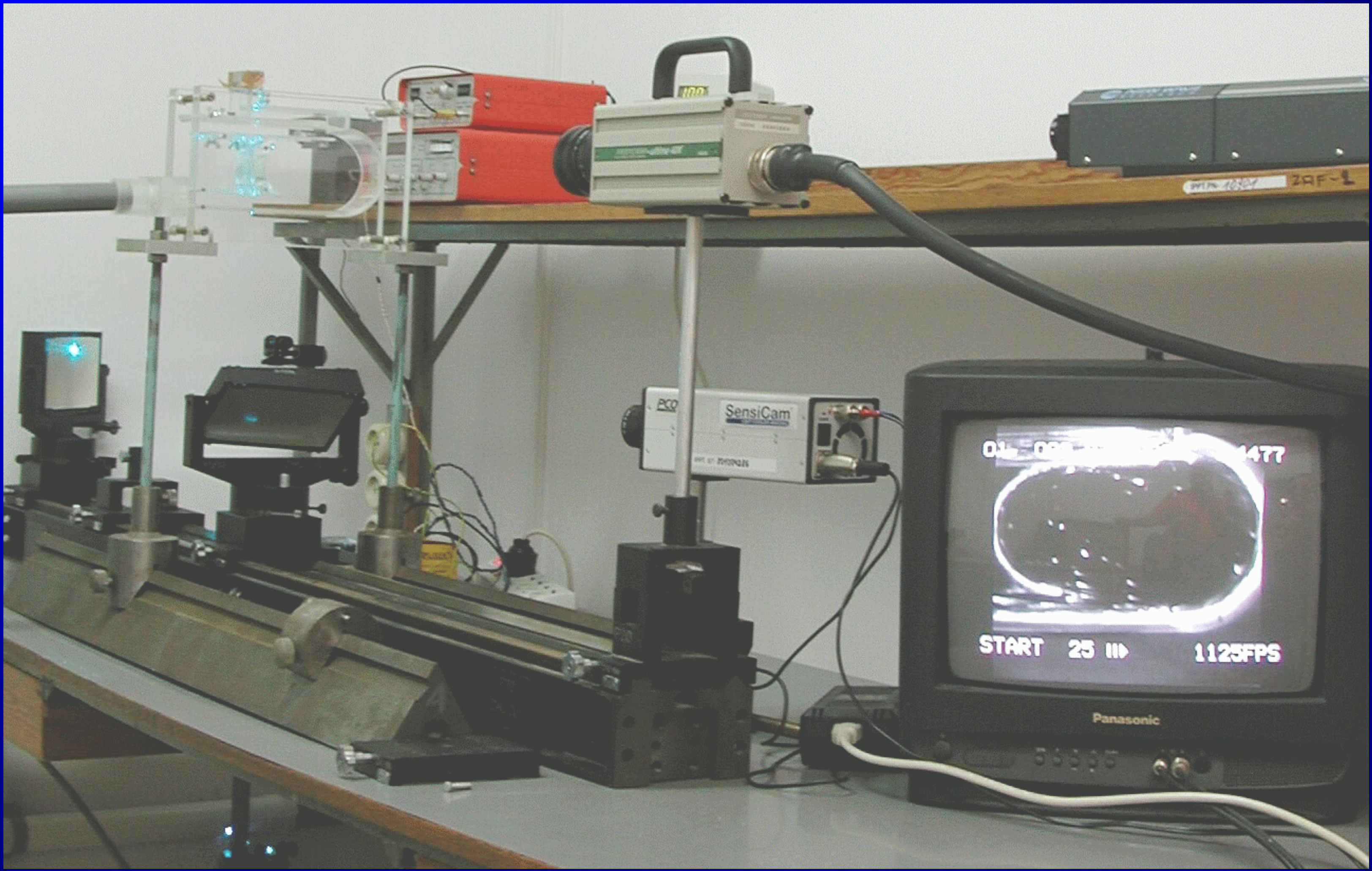

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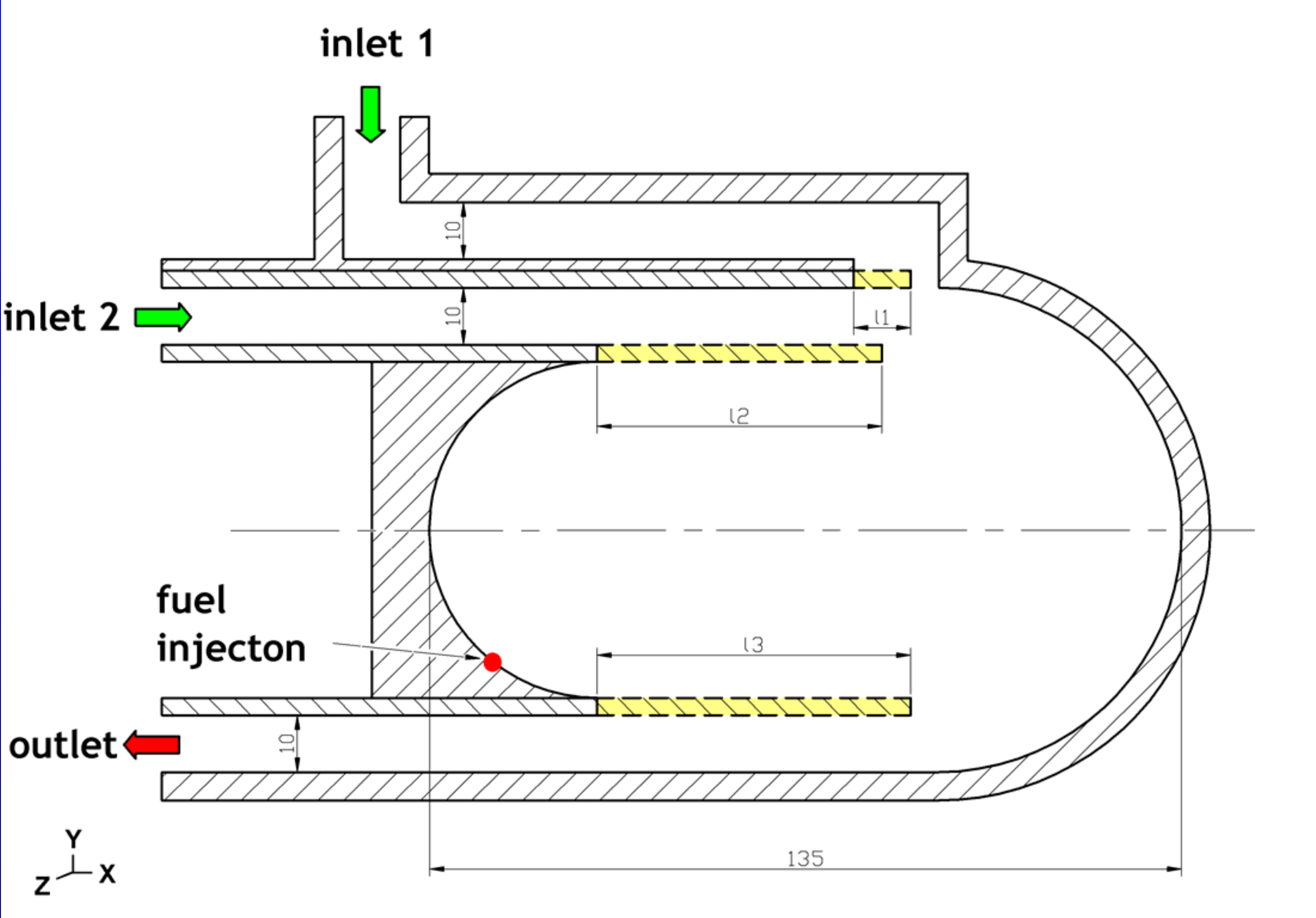
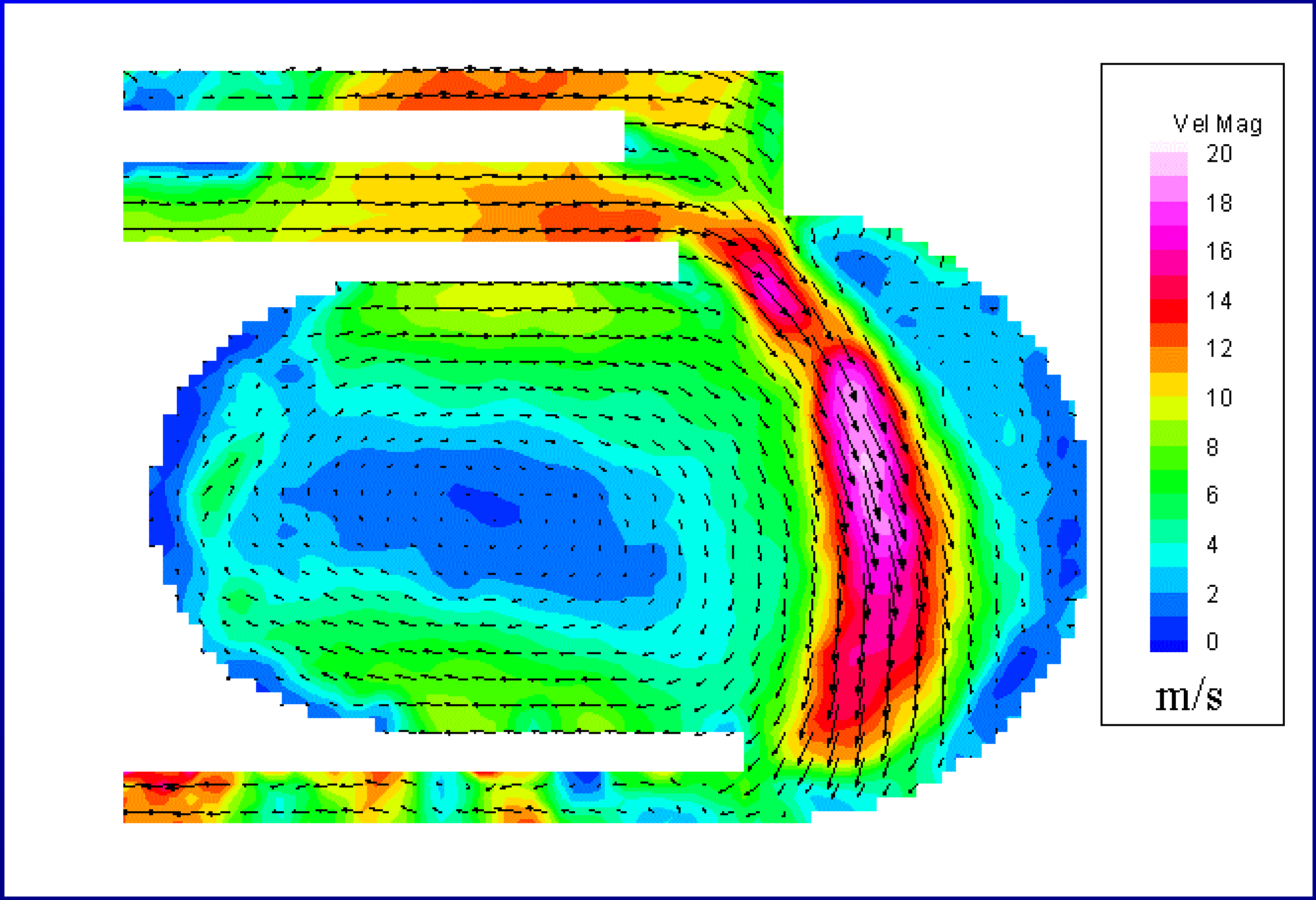
Geometry I



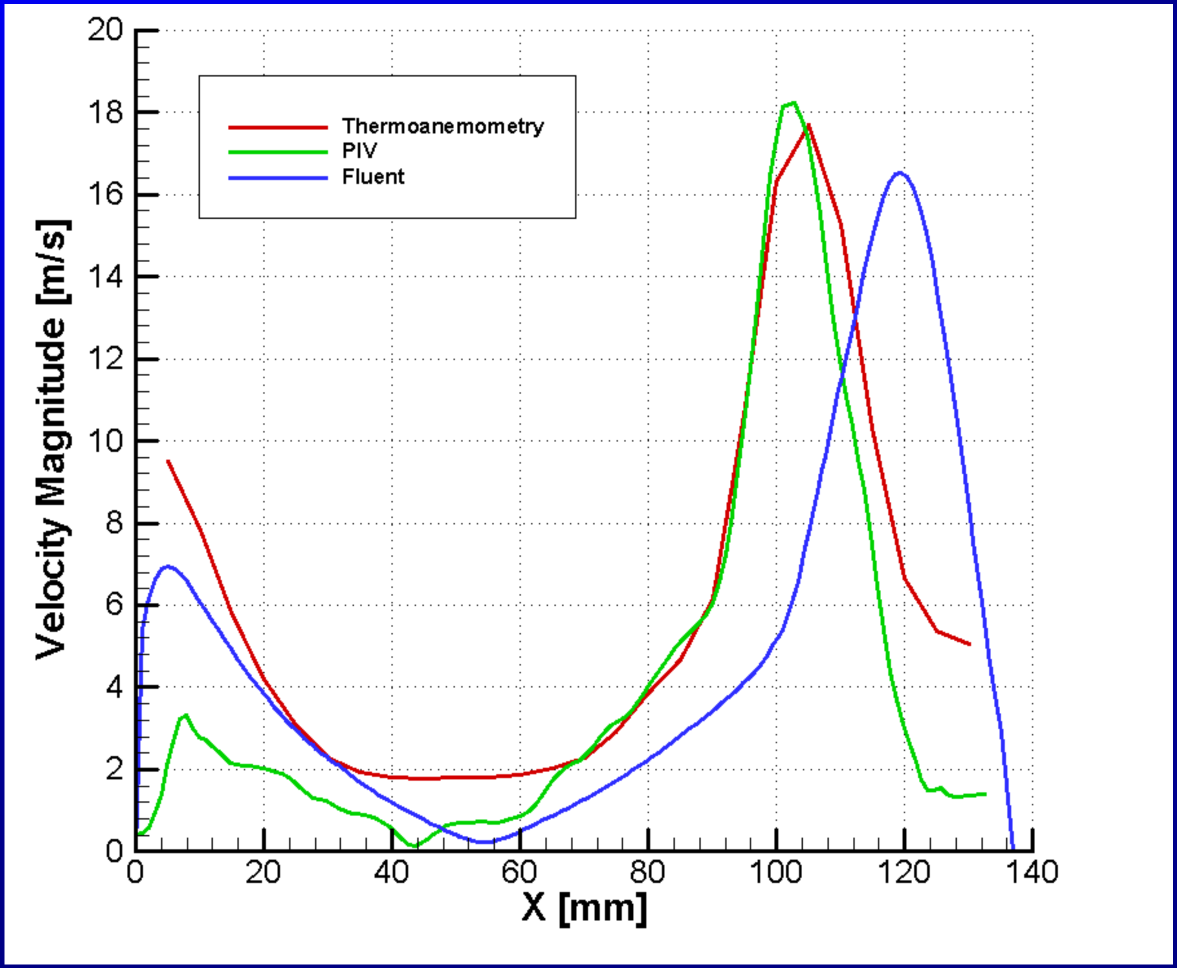
PIV: Velocity Magnitude – Averaged Field

Geometry I



Velocity Magnitude profile
Comparison of experimental and CFD results

Geometry I



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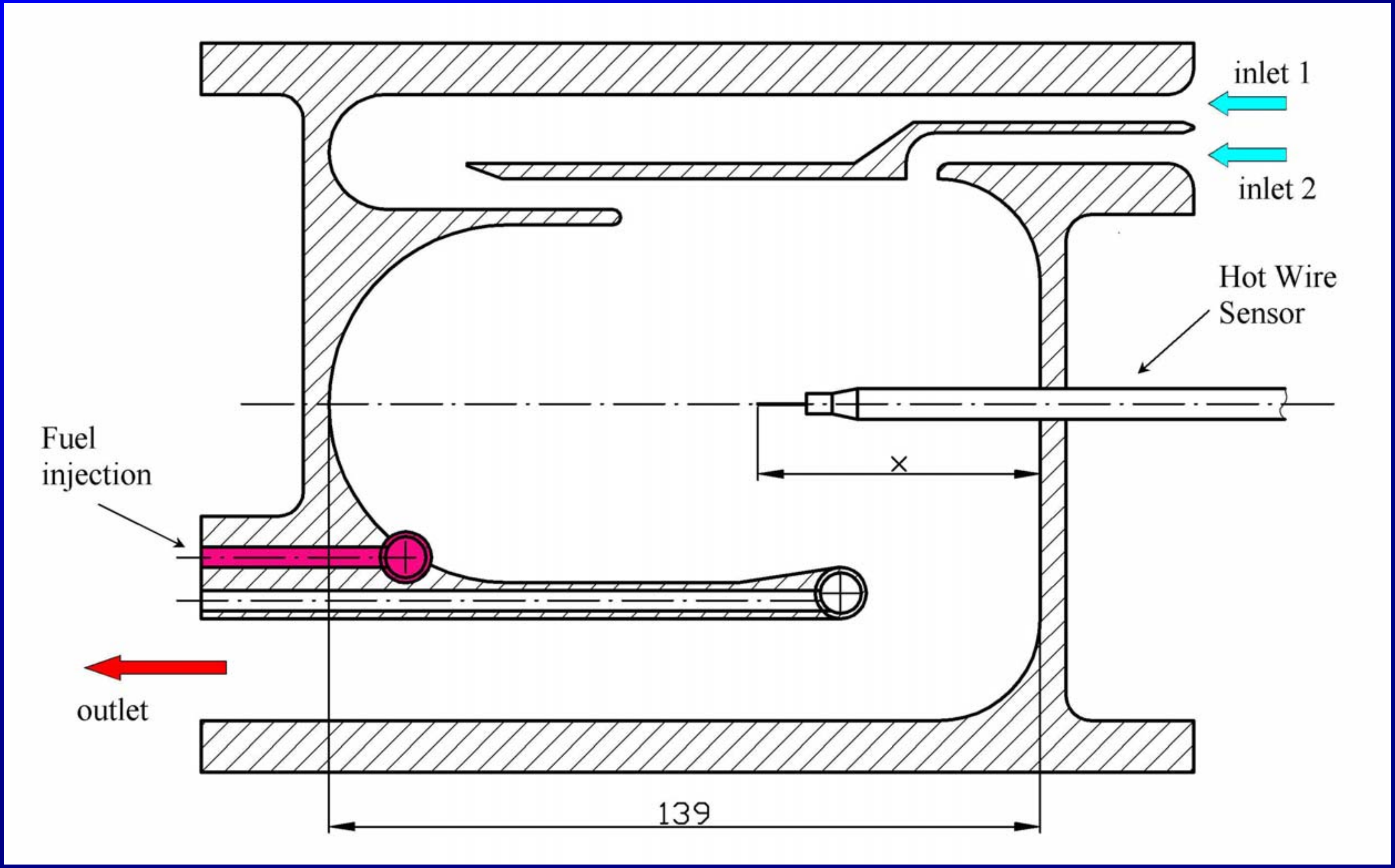
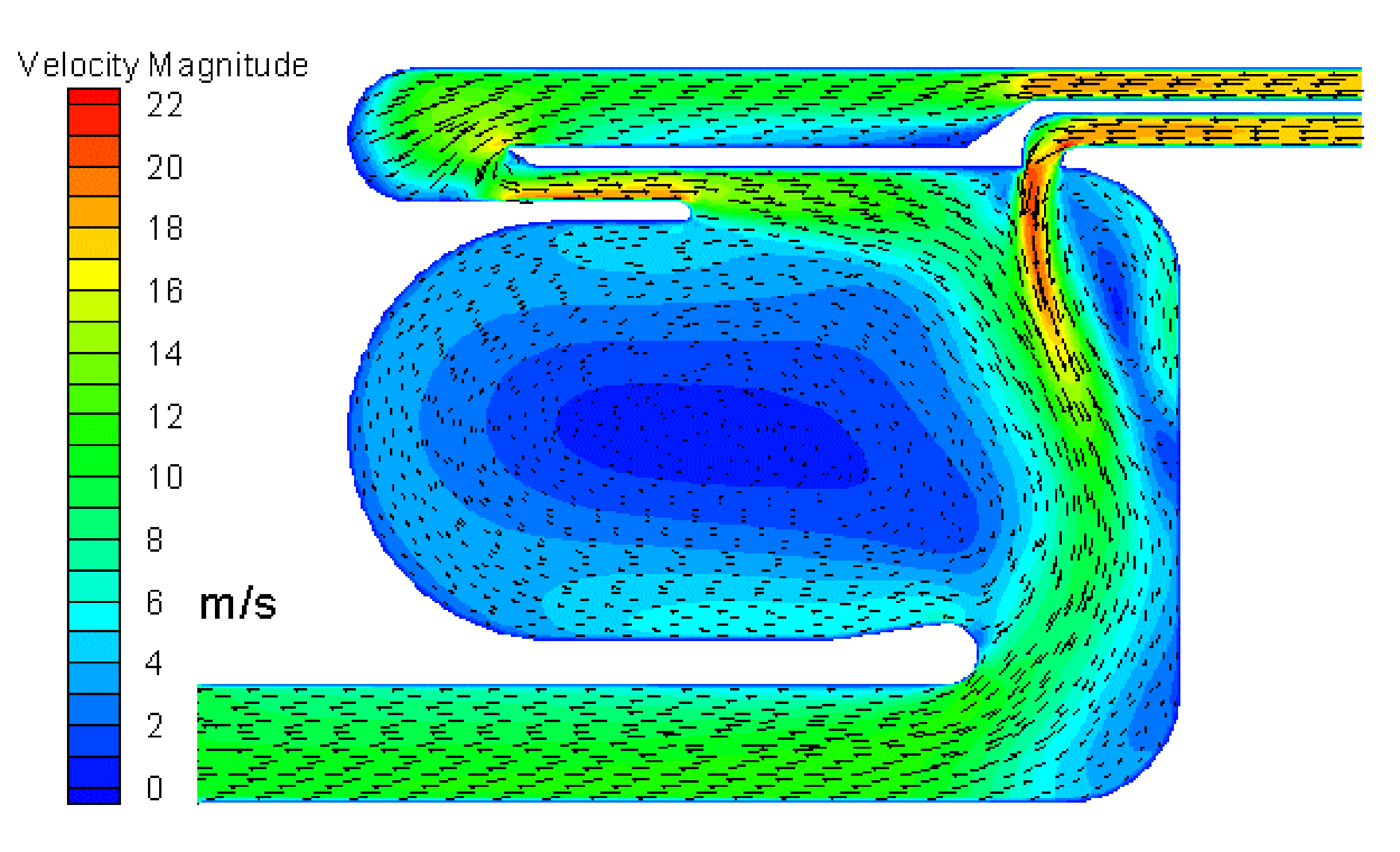
Transparent Geometry II



Fluent: Vectors & Contours of Velocity Magnitude

Geometry II



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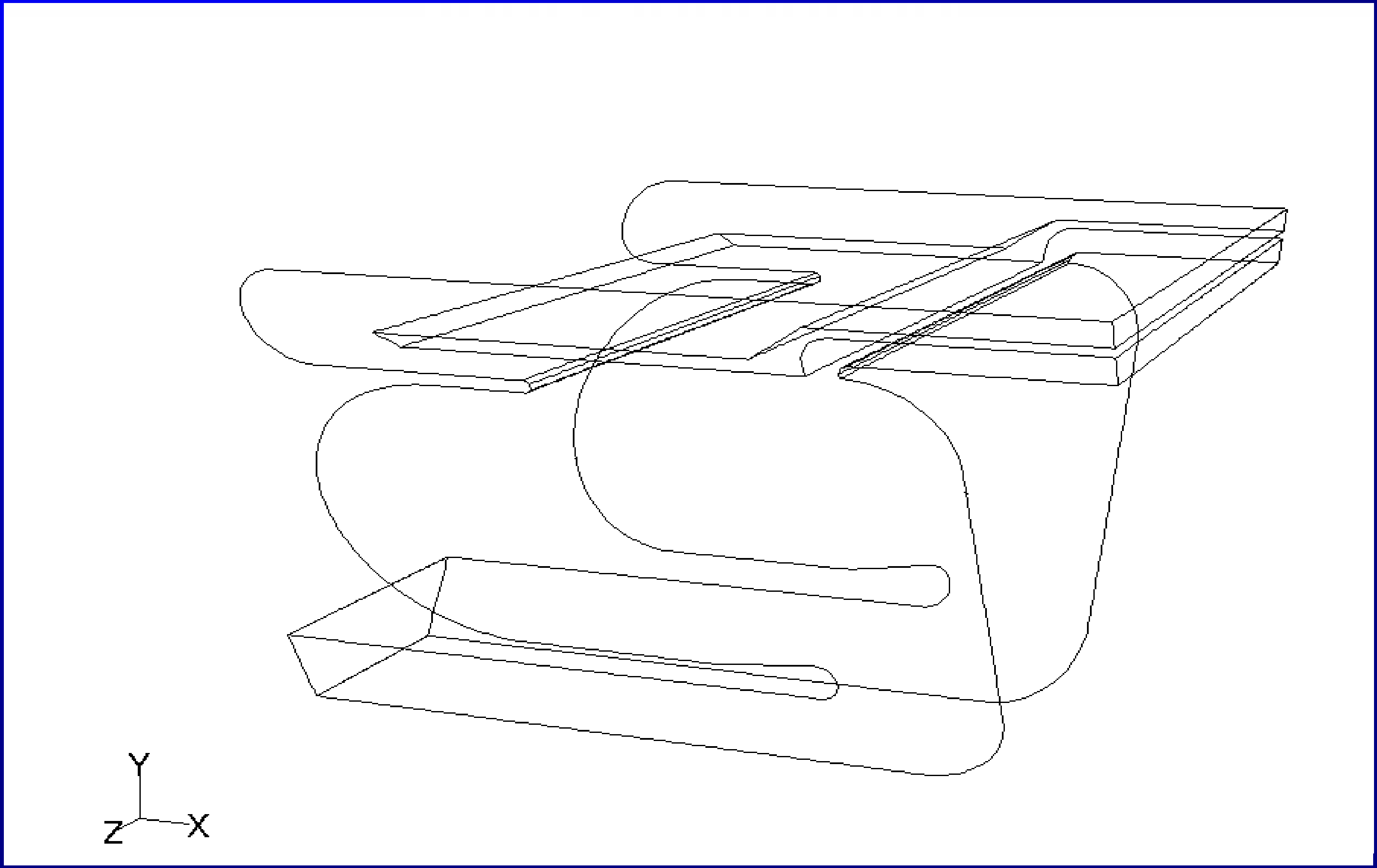
Geometry III



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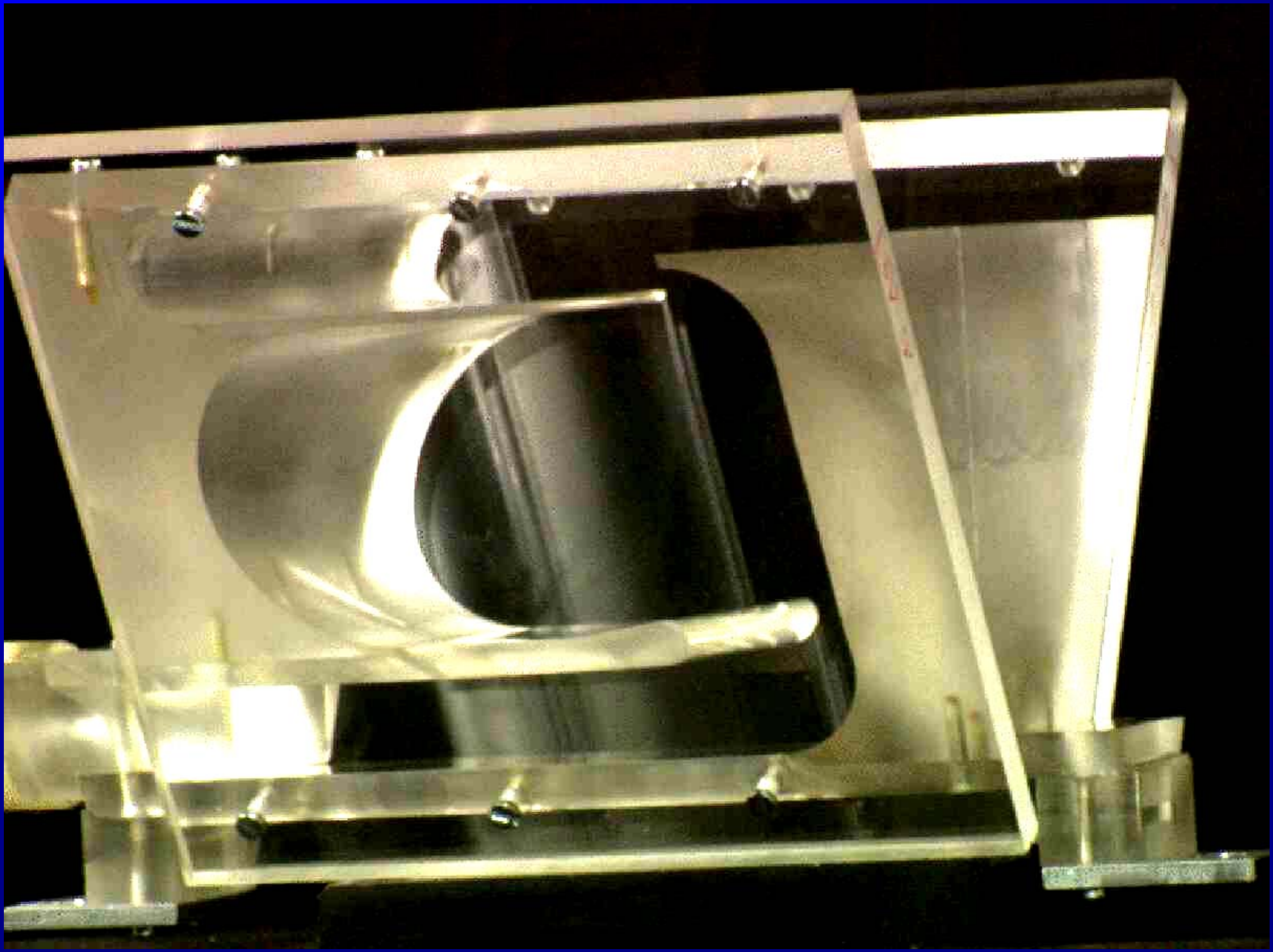
Transparent Geometry III



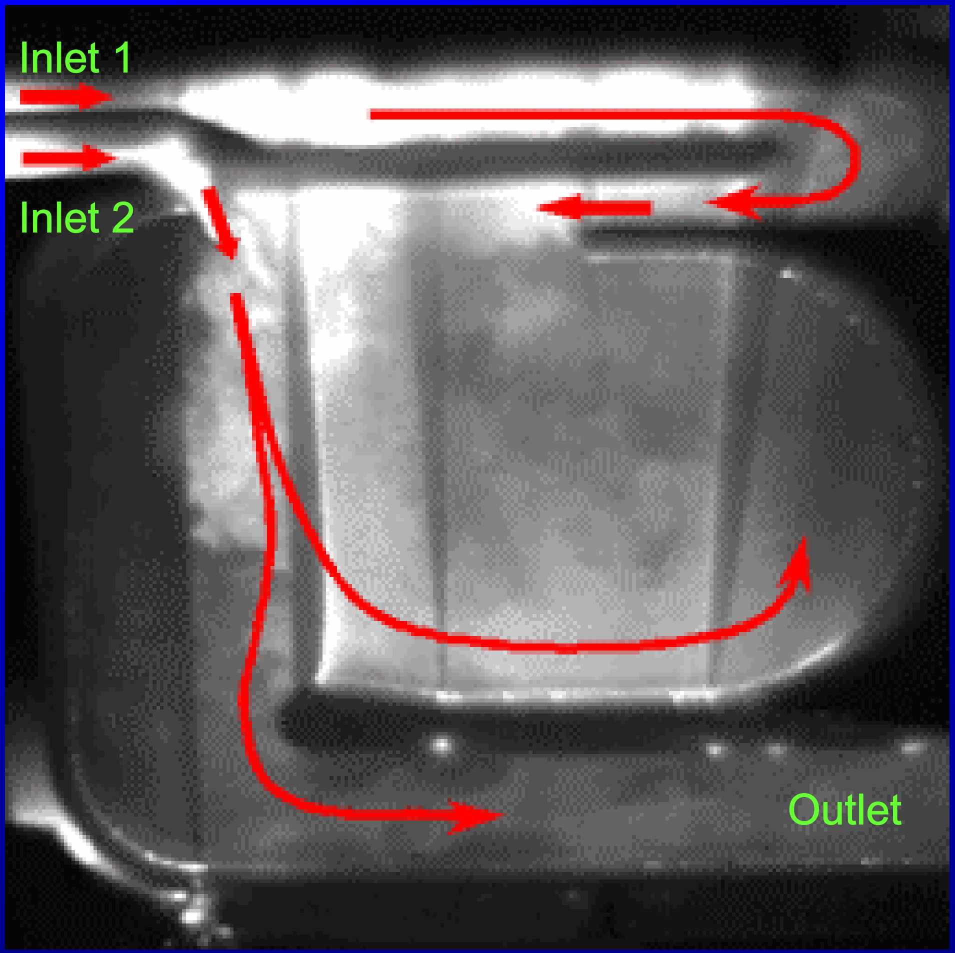
Inclined side walls

EXPERIMENT CONFIGURATION

Geometry III

	Configuration		
	„A”	„B”	„C”
Inlet 1	open v = 9.5 m/s	open v = 20 m/s	closed v = 0 m/s
Inlet 2	open v = 10 m/s	closed v = 0 m/s	open v = 17 m/s
Outlet	open v = 18 m/s	open v = 18 m/s	open v = 18 m/s

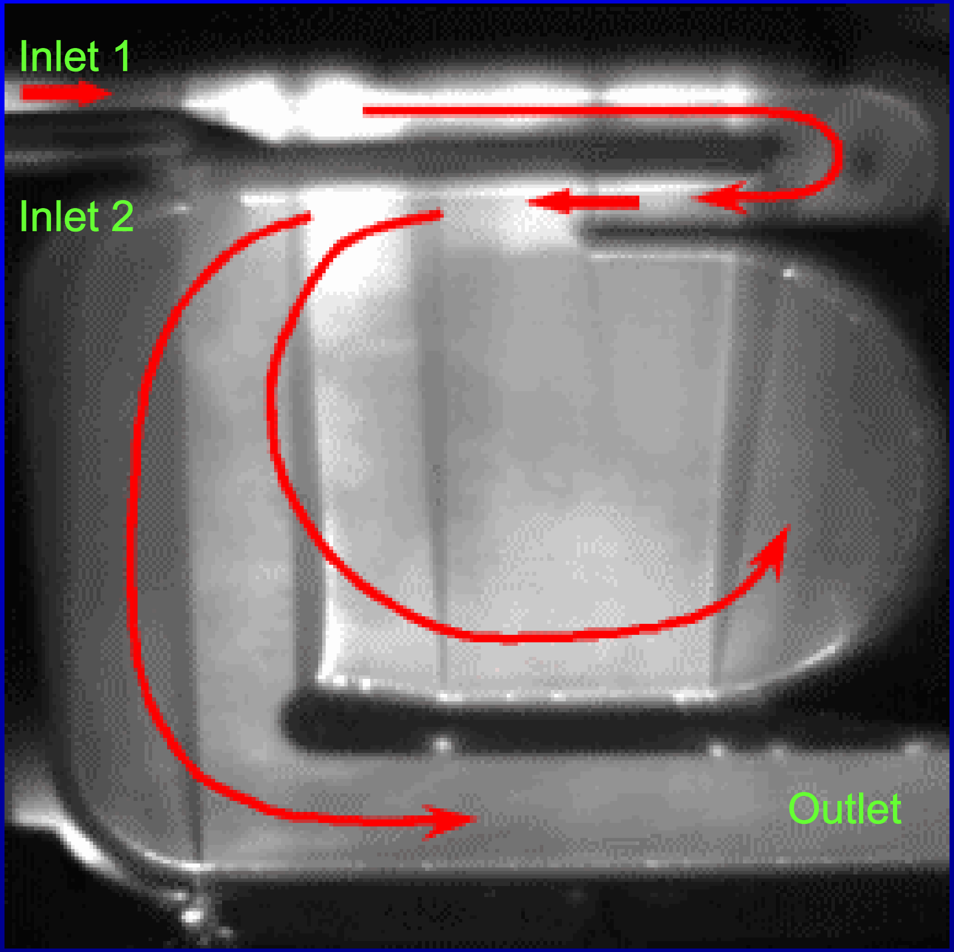
FLOW VISUALIZATION



4500fps

Geometry III
Configuration „A”

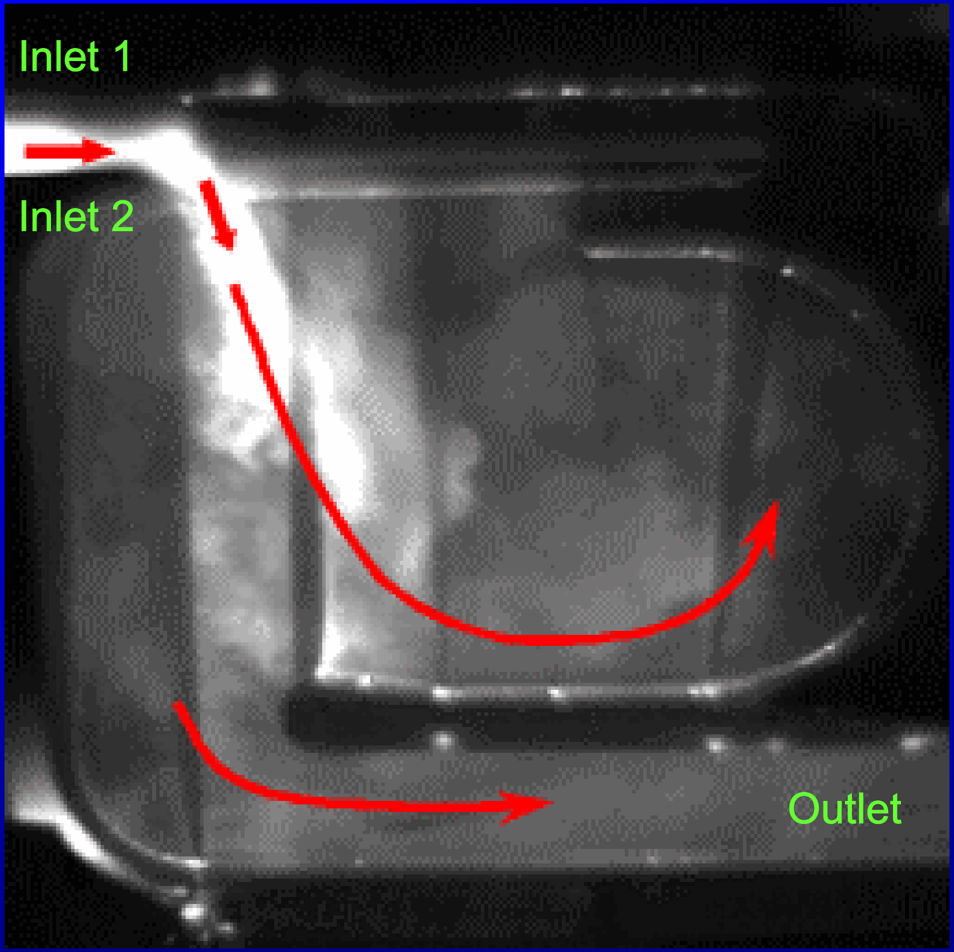
FLOW VISUALIZATION



4500fps

Geometry III
Configuration „B”

FLOW VISUALIZATION



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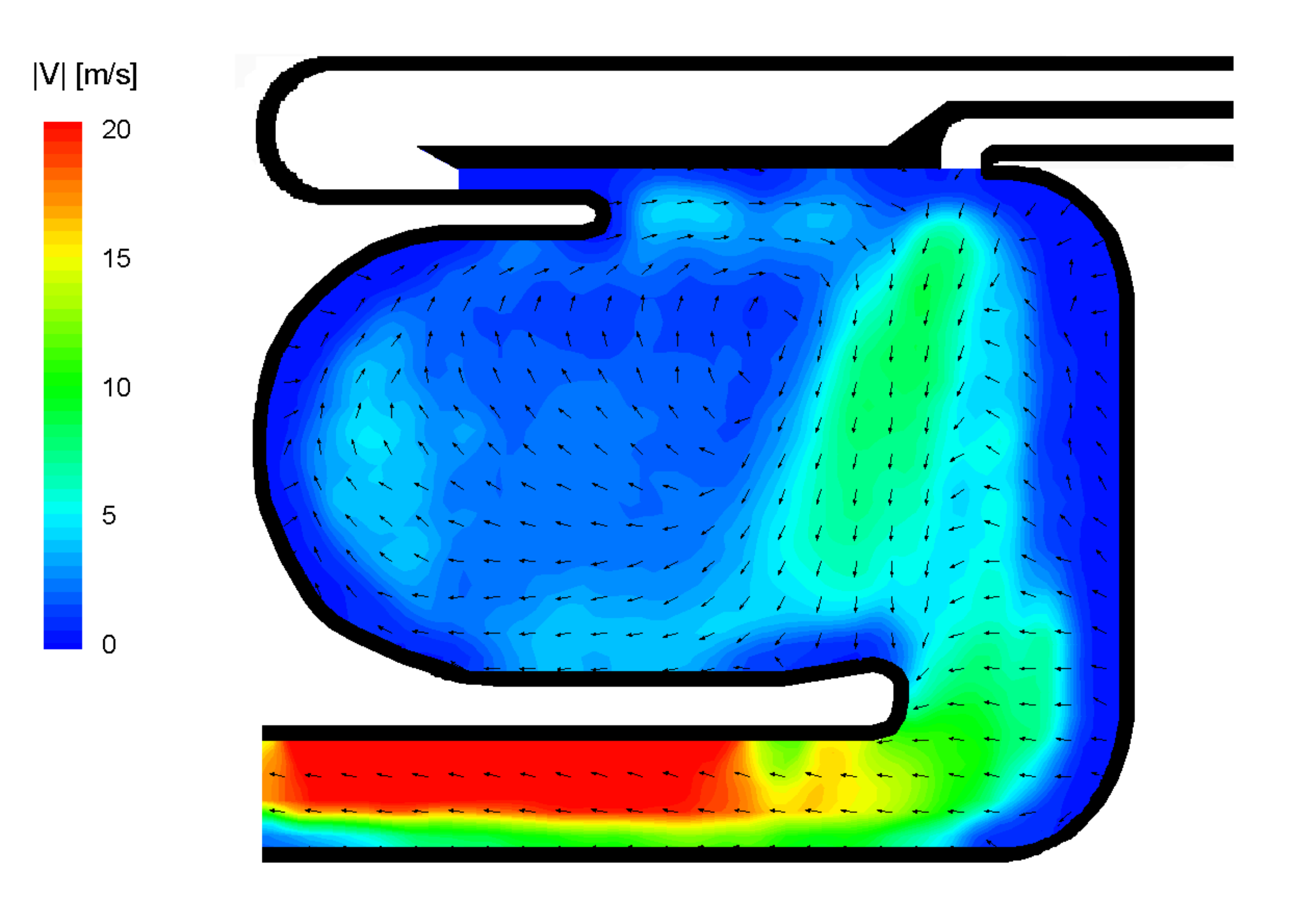
Geometry III
Configuration „C”

Selected configuration

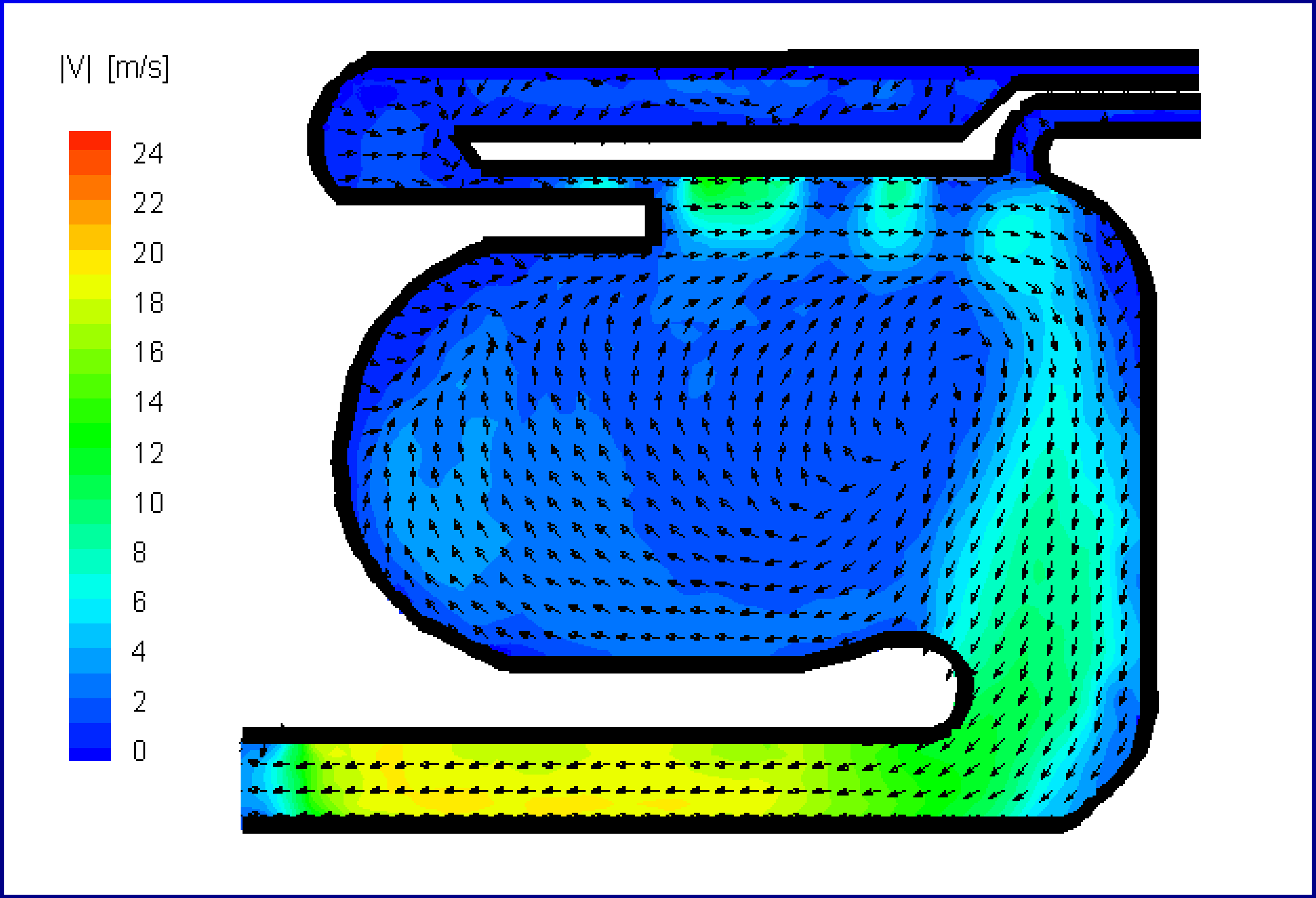
PIV Measured Vectors & Contours of Velocity Magnitude

Geometry III – configuration „A”



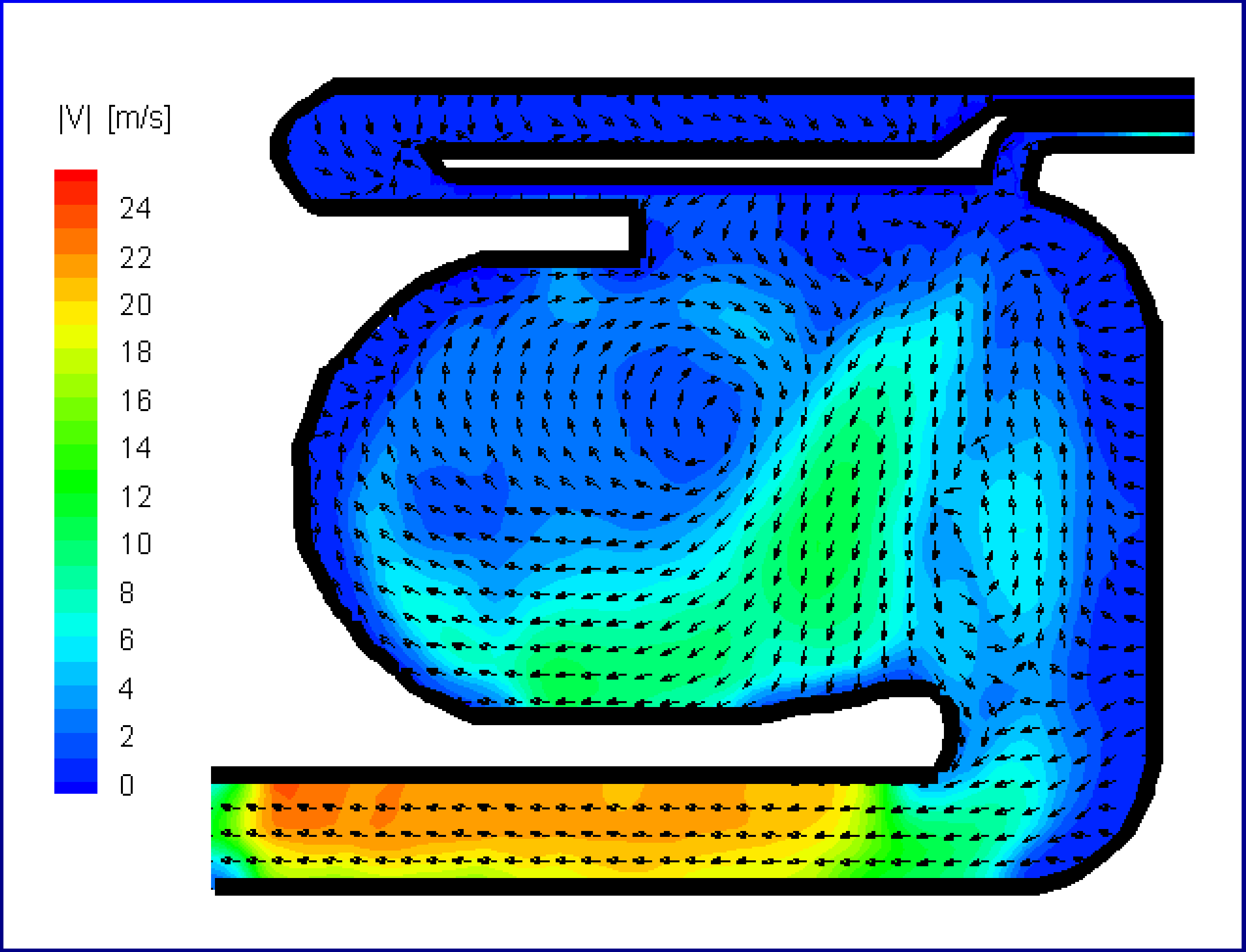
PIV Measured Vectors & Contours of Velocity Magnitude

Geometry III – configuration „B”



PIV Measured Vectors & Contours of Velocity Magnitude

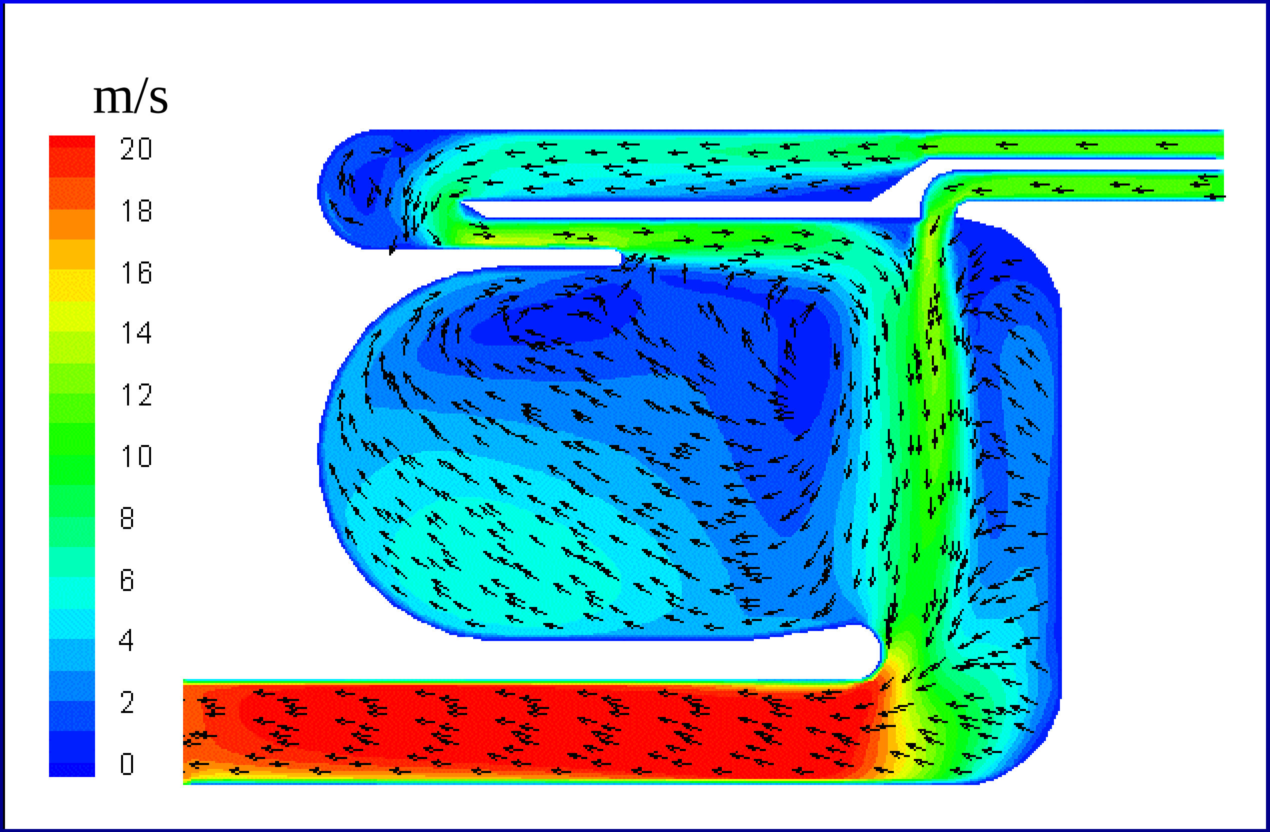
Geometry III – configuration „C”



Selected configuration

Numerical model: Vectors & Contours of Velocity Magnitude

Geometry III – configuration „A"

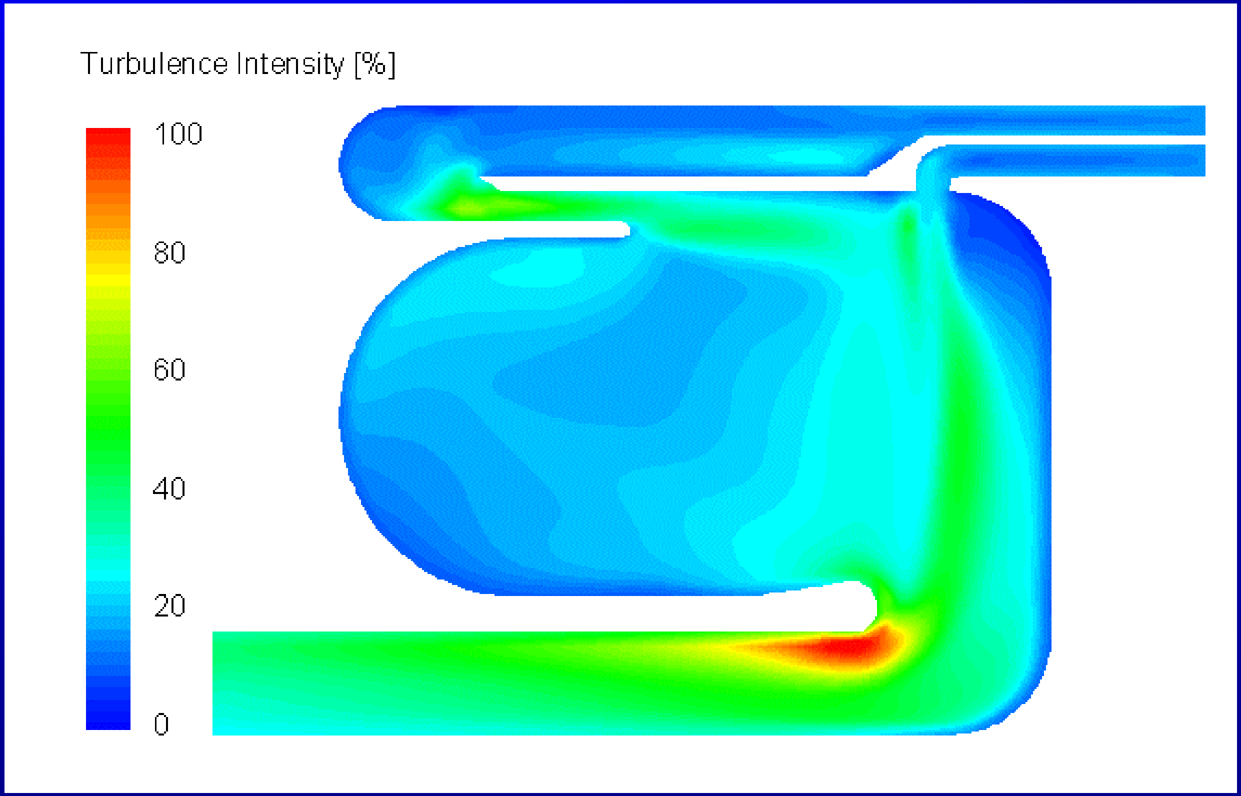


<u>Velocity</u>

Inlet 1: open
Inlet 2: open
Outlet: 18 m/s

Numerical model: Contours of Turbulence Intensity

Geometry III – configuration „A”

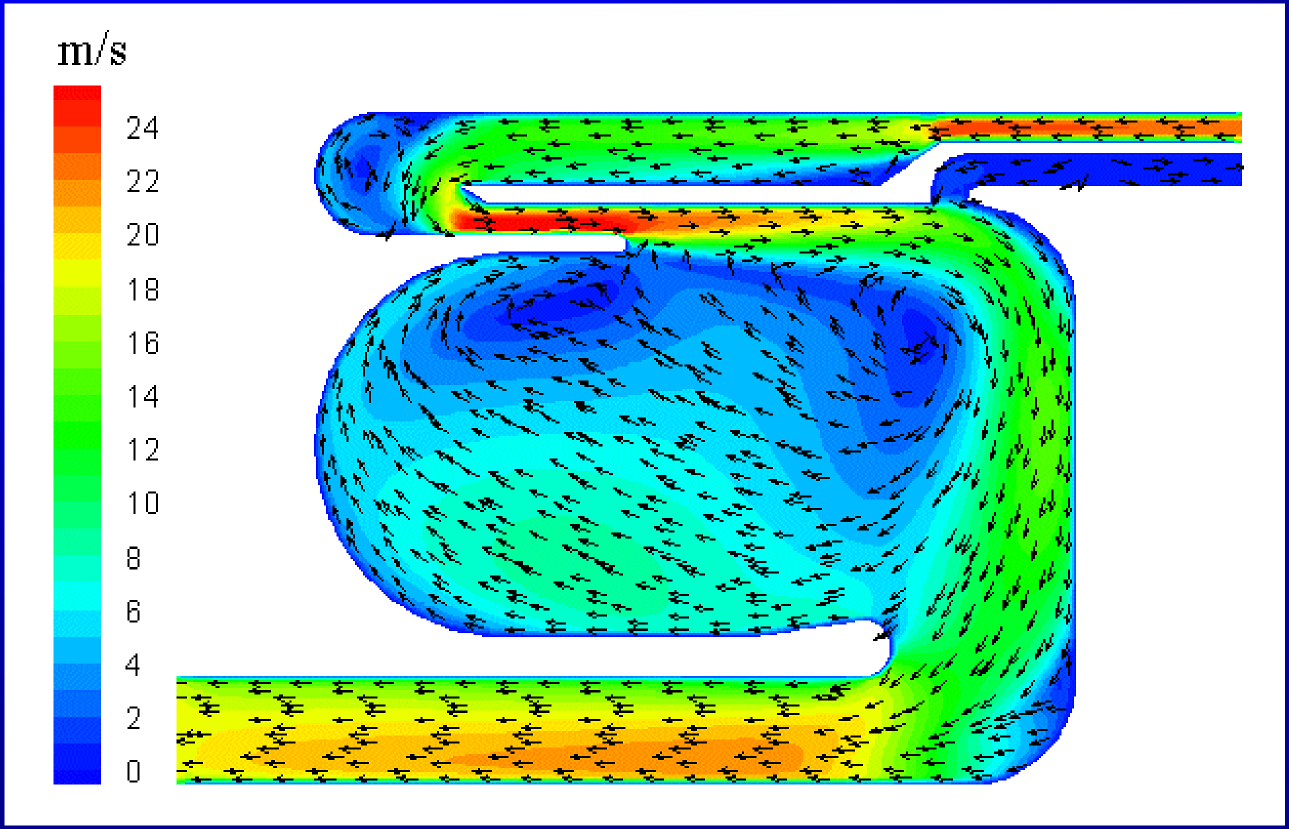


<u>Velocity</u>

Inlet 1: open
Inlet 2: open
Outlet: 18 m/s

Numerical model: Vectors & Contours of Velocity Magnitude

Geometry III – configuration „B"

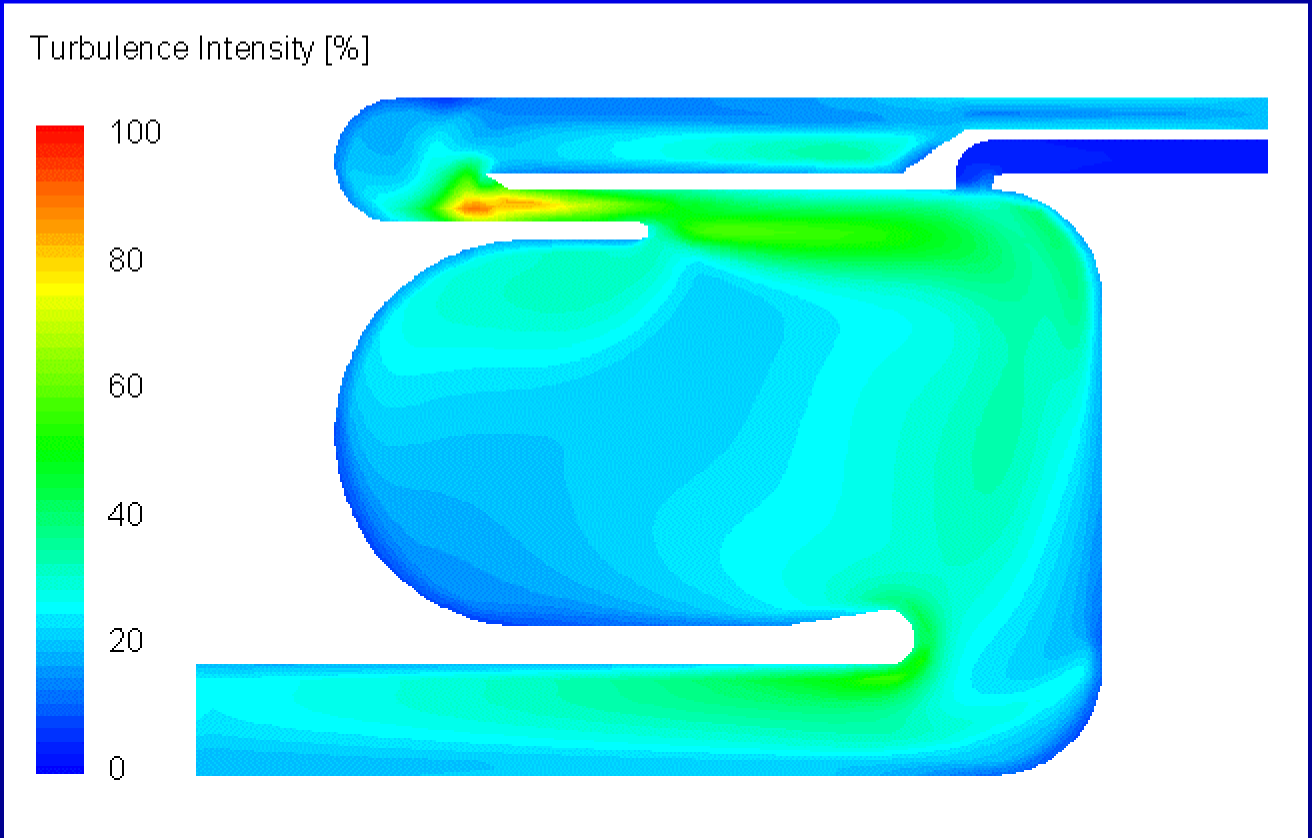


Velocity

Inlet 1: open
Inlet 2: closed
Outlet: 18 m/s

Numerical model: Contours of Turbulence Intensity

Geometry III – configuration „B”

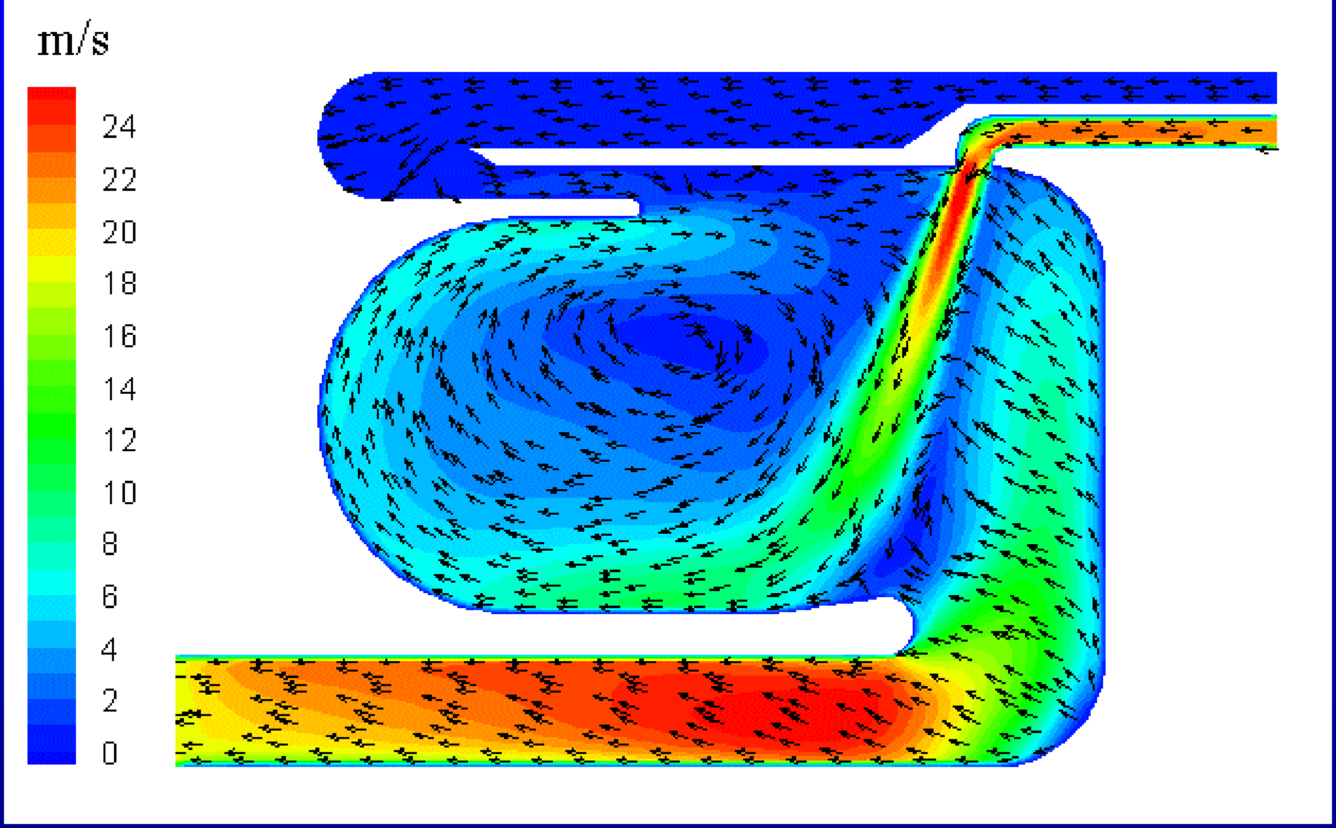


Velocity

Inlet 1: open
Inlet 2: closed
Outlet: 18 m/s

Numerical model: Vectors & Contours of Velocity Magnitude

Geometry III – configuration „C”



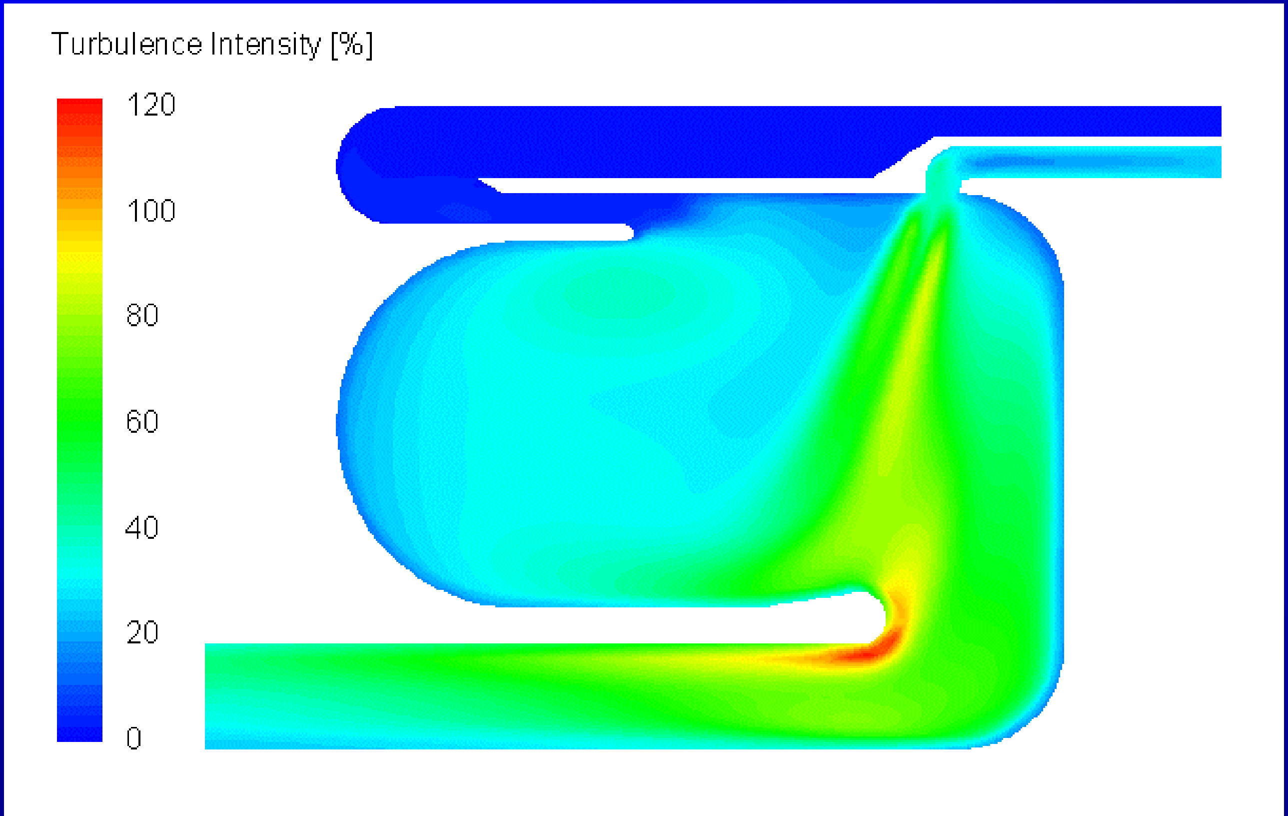
<u>Velocity</u>

Inlet 1: closed
Inlet 2: open
Outlet: 18 m/s

Selected configuration

Numerical model: Contours of Turbulence Intensity

Geometry III – configuration „C"



Velocity

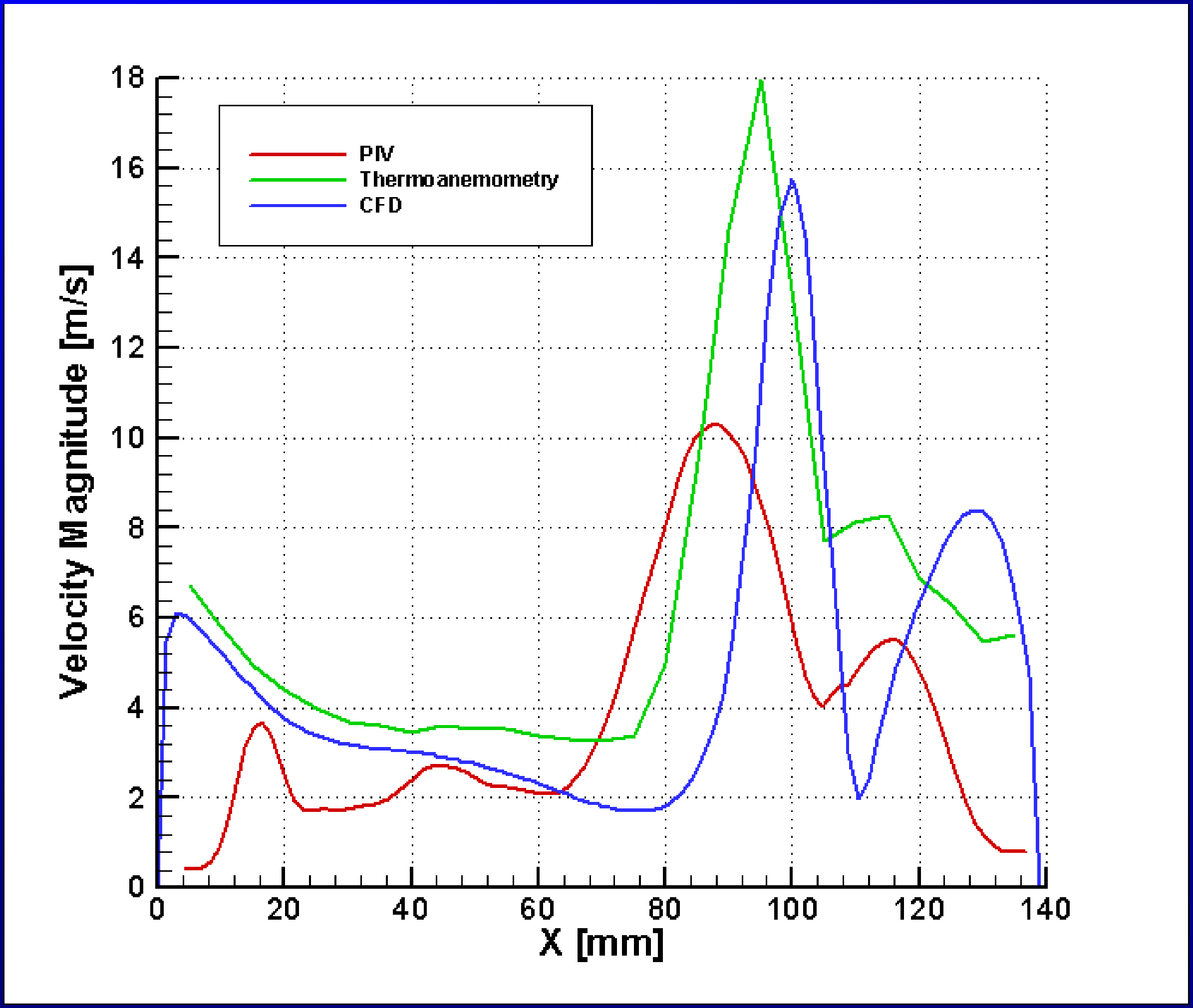
Inlet 1: closed
Inlet 2: open
Outlet: 18 m/s

Selected configuration

Velocity Magnitude profile

Comparison of experimental and CFD results

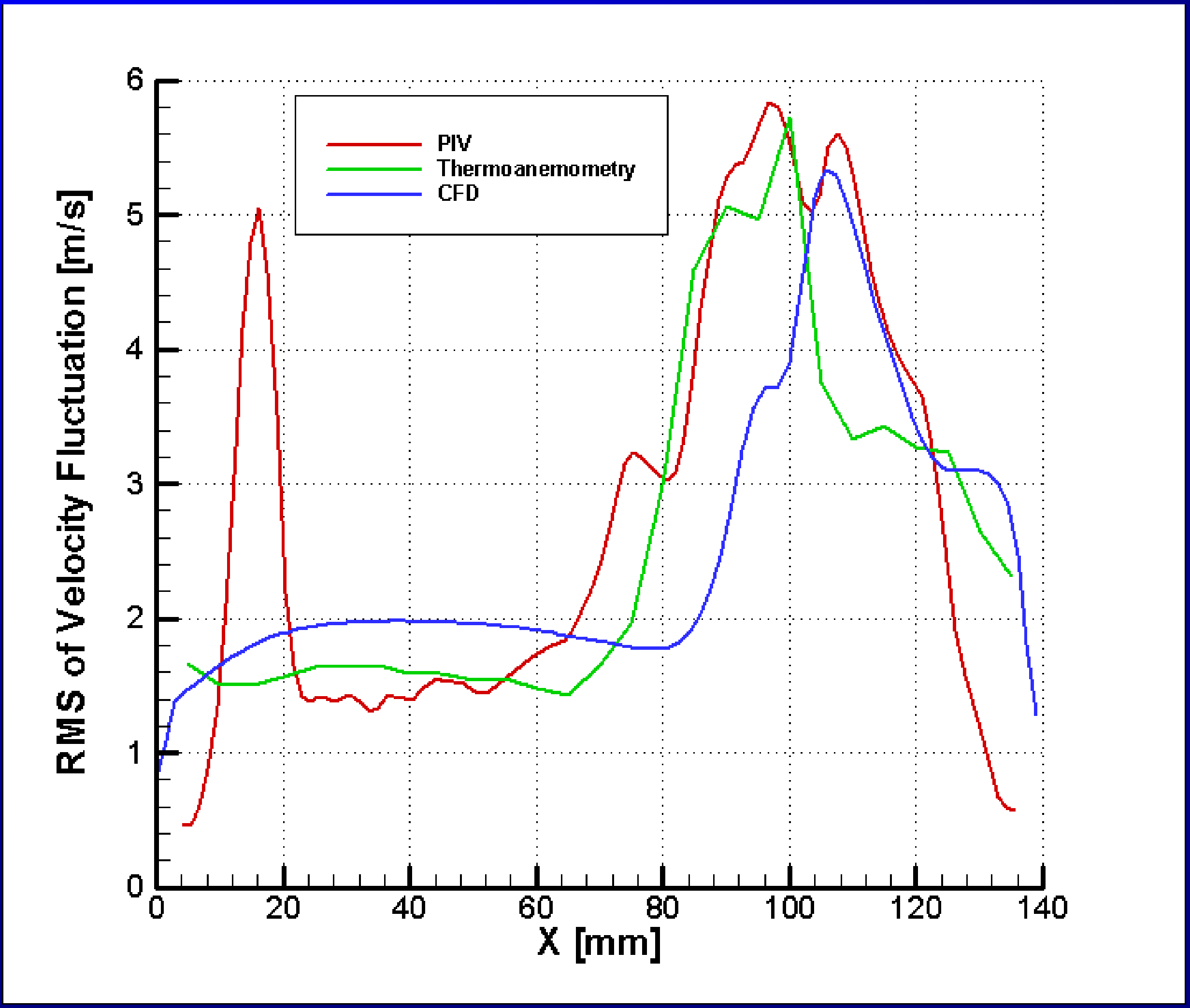
Geometry III – configuration „C”



RMS of Velocity Fluctuation profile

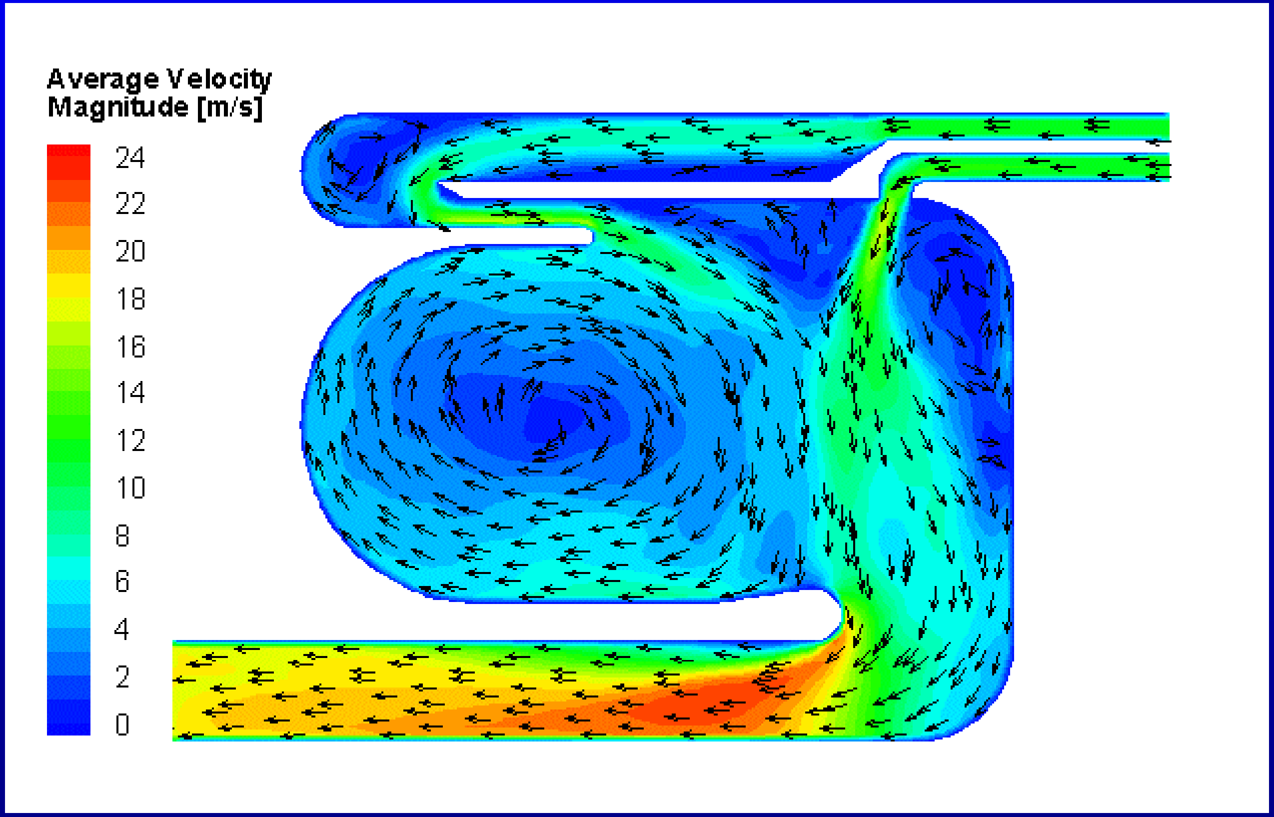
Comparison of experimental and CFD results

Geometry III – configuration „C”



Numerical simulation:
Mean fields of Velocity Vectors & Contours of Magnitude

Model of turbulence: Large Eddy simulation



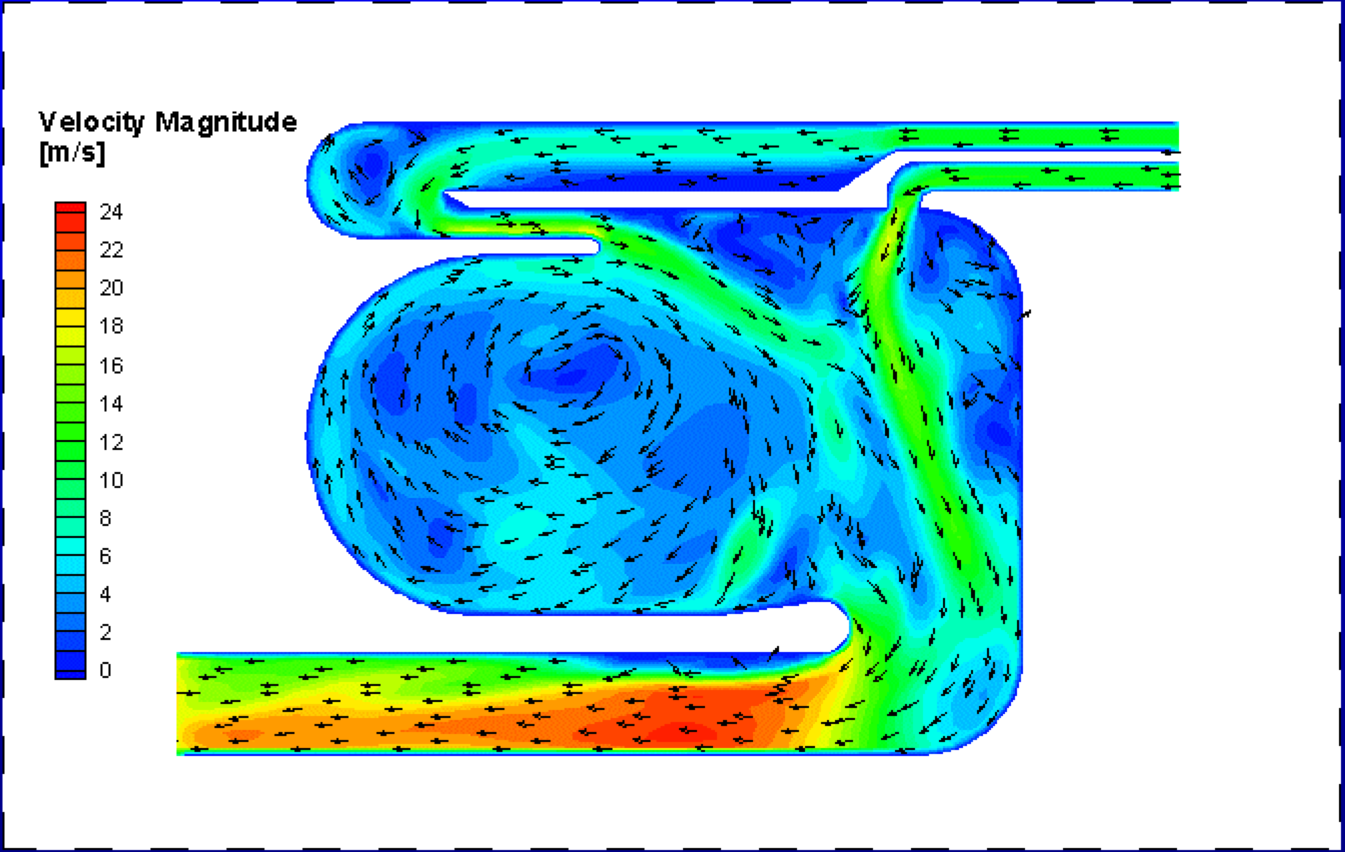
Velocity

Inlet 1: open
Inlet 2: open
Outlet: 18 m/s

Configuration „A”

Numerical simulation:
0.01s time steps for Vectors & Contours of Velocity Magnitude

Model of turbulence: Large Eddy simulation



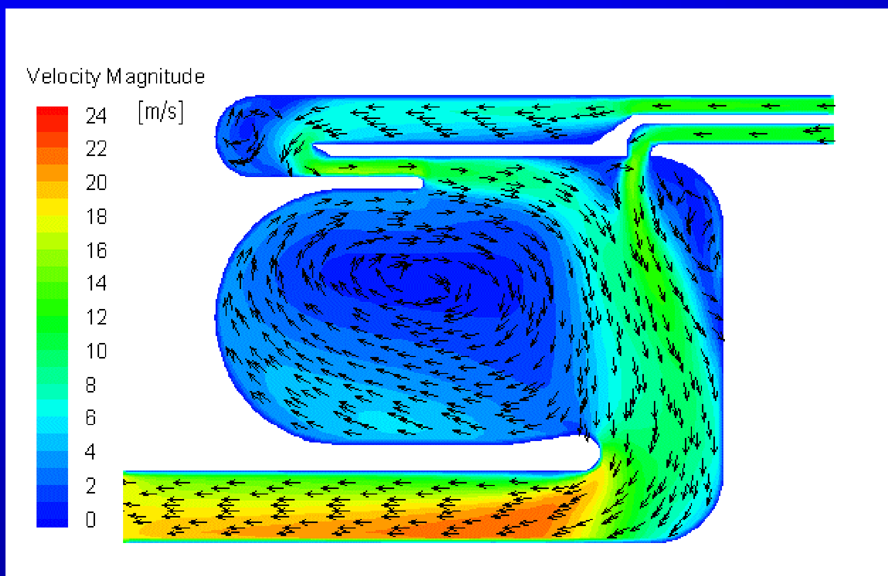
<u>Velocity</u>

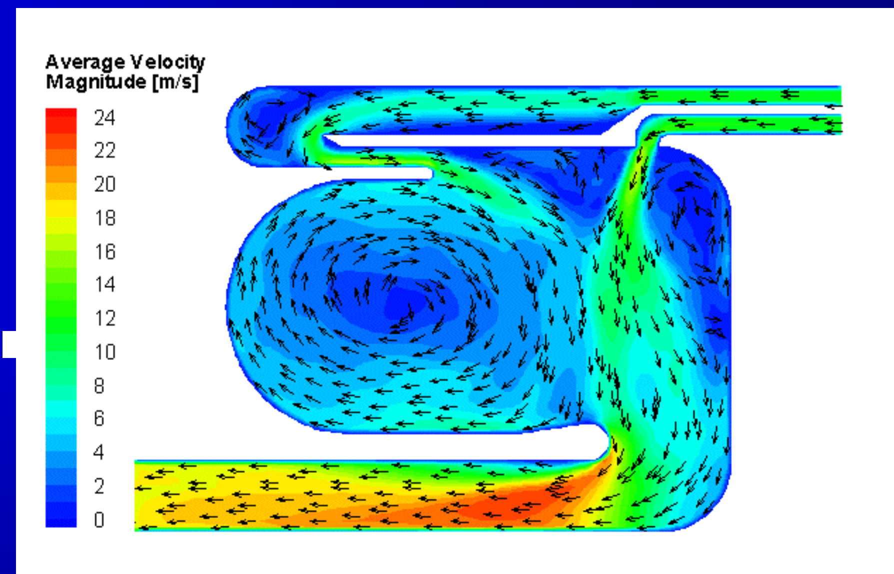
Inlet 1: open
Inlet 2: open
Outlet: 18 m/s

Configuration „A”

Comparison of Numerical Simulations

k - ε model vs. Large Eddy Simulation





k - ε

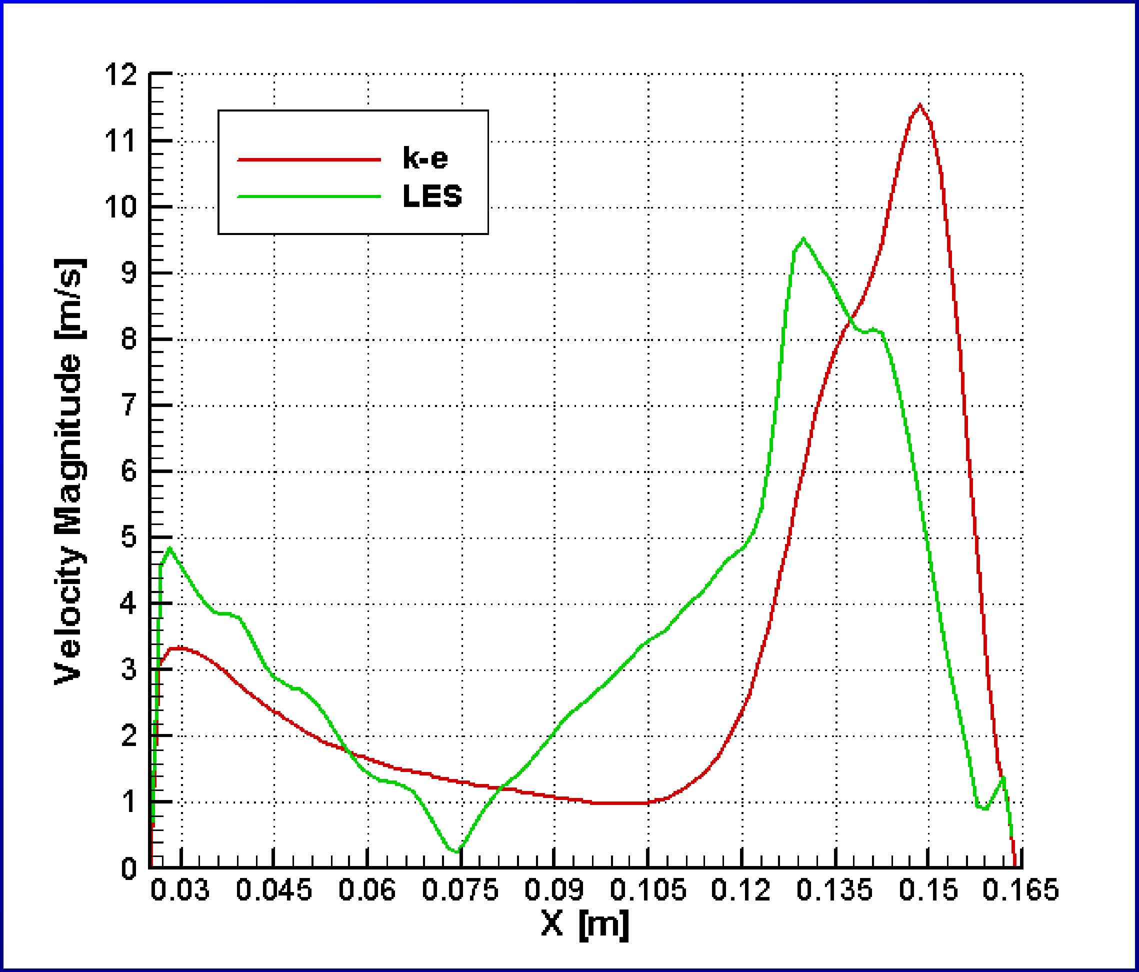
LES

Vectors and Contours and of Velocity Magnitude

Configuration „A”

Comparison of Numerical Simulations

k - ε model vs. Large Eddy Simulation

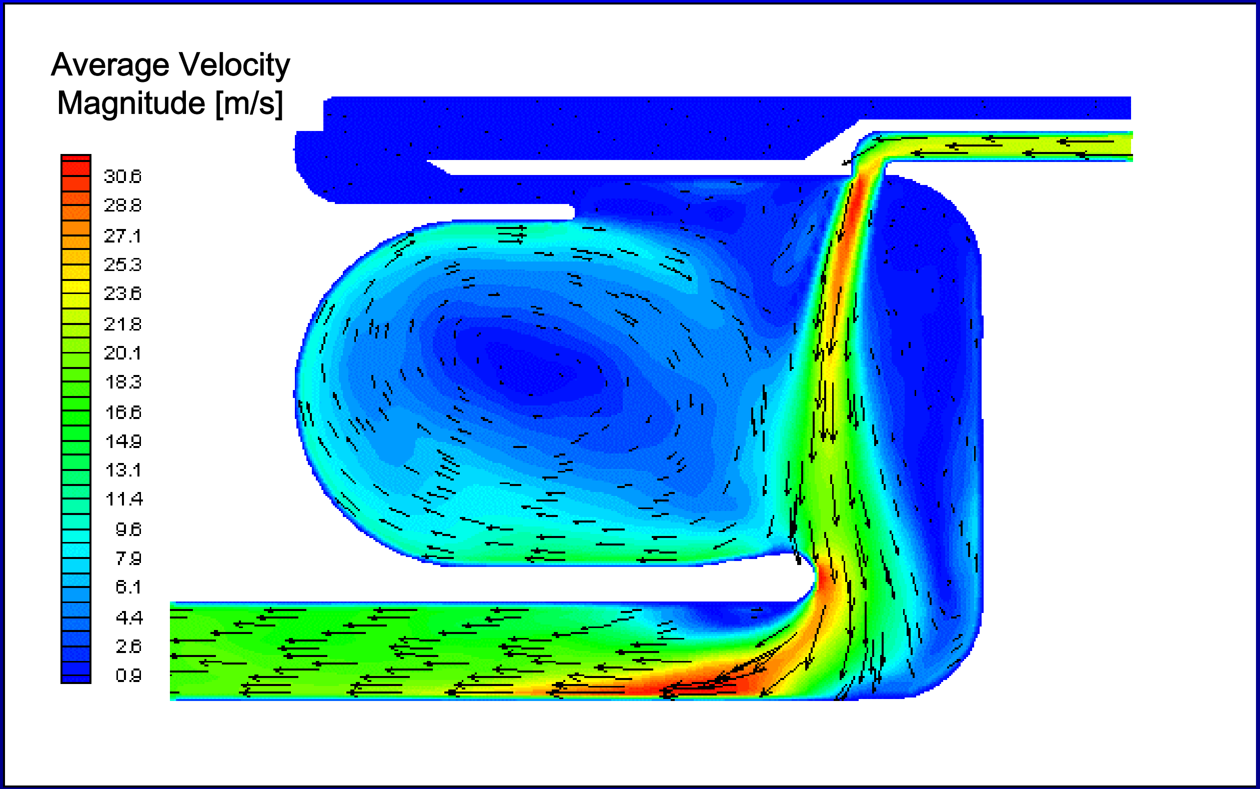


Comparison of Velocity Magnitude Profiles

Numerical simulation:

Averaged Vectors & Contours of Velocity Magnitude

Model of turbulence: Large Eddy simulation



<u>Velocity</u>

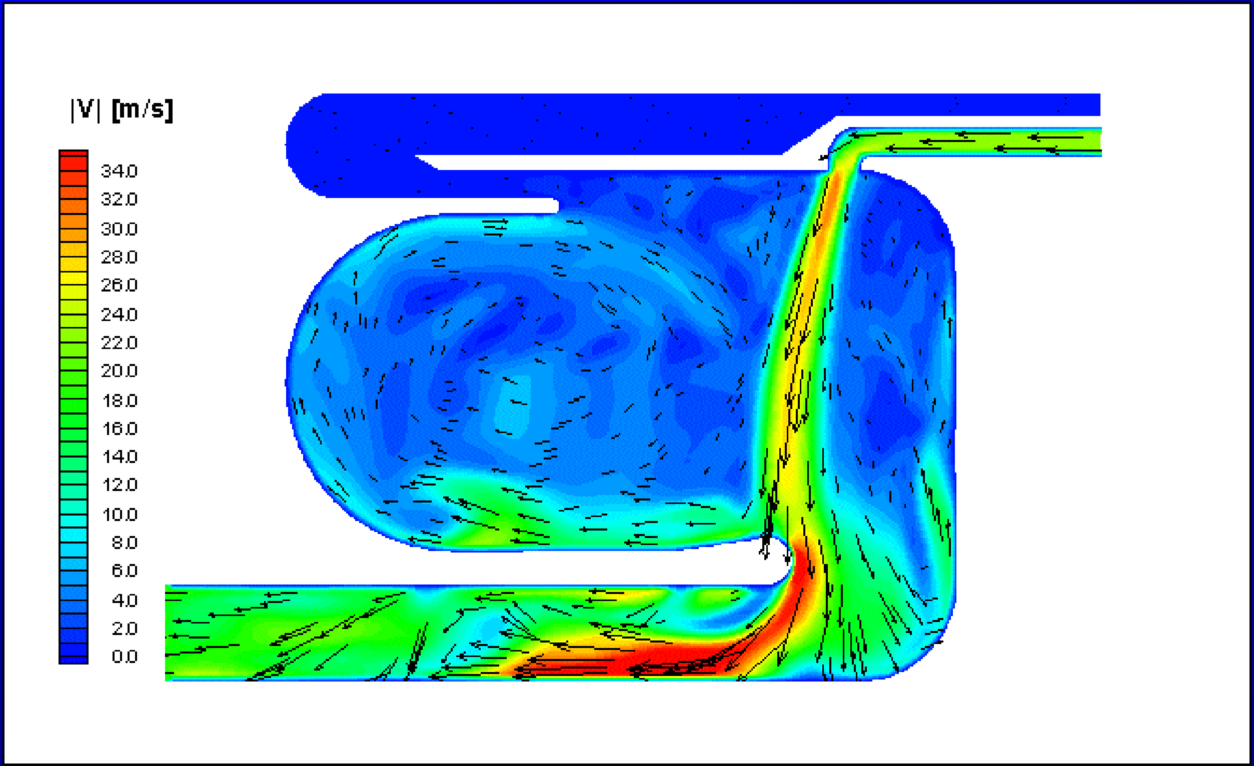
Inlet 1: closed
Inlet 2: open
Outlet: 18 m/s

Configuration „C”

Numerical simulation:

0.01s time steps for Vectors & Contours of Velocity Magnitude

Model of turbulence: Large Eddy simulation



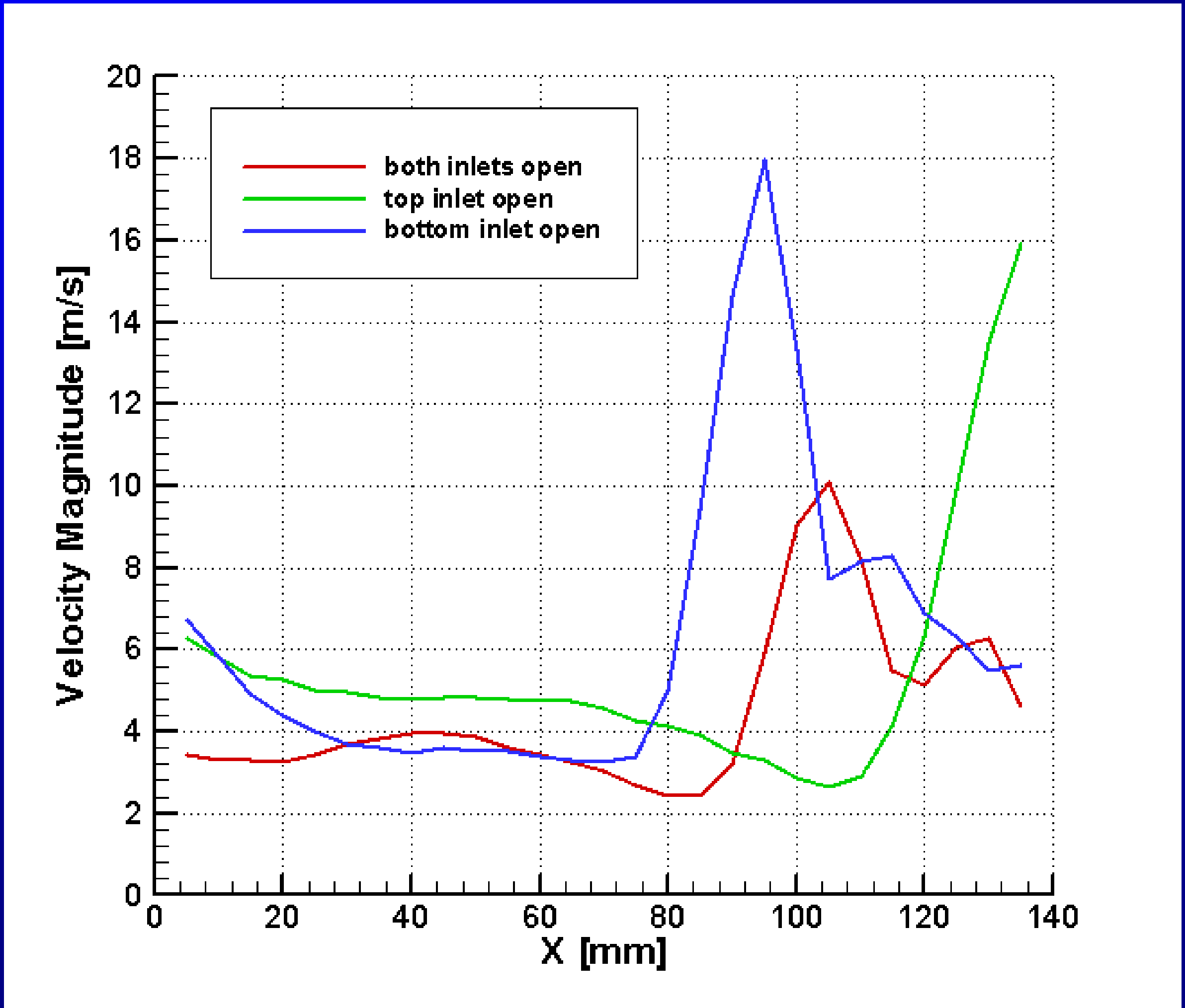
Velocity

Inlet 1: closed
Inlet 2: open
Outlet: 18 m/s

Configuration „C”

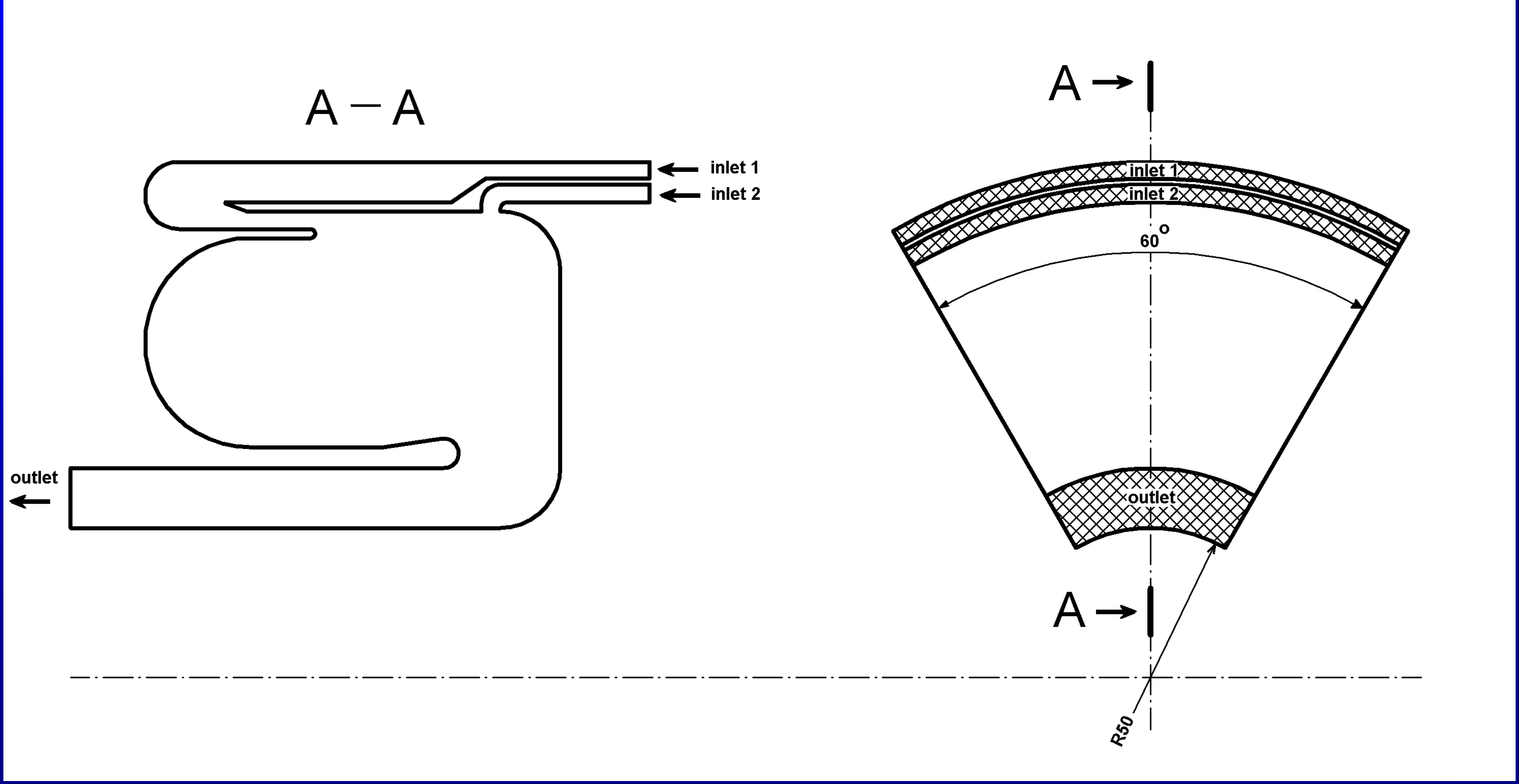
Velocity Magnitude profile

Comparison of Thermoanemometry measurements for configuration „A” & „B” & „C” of Geometry III

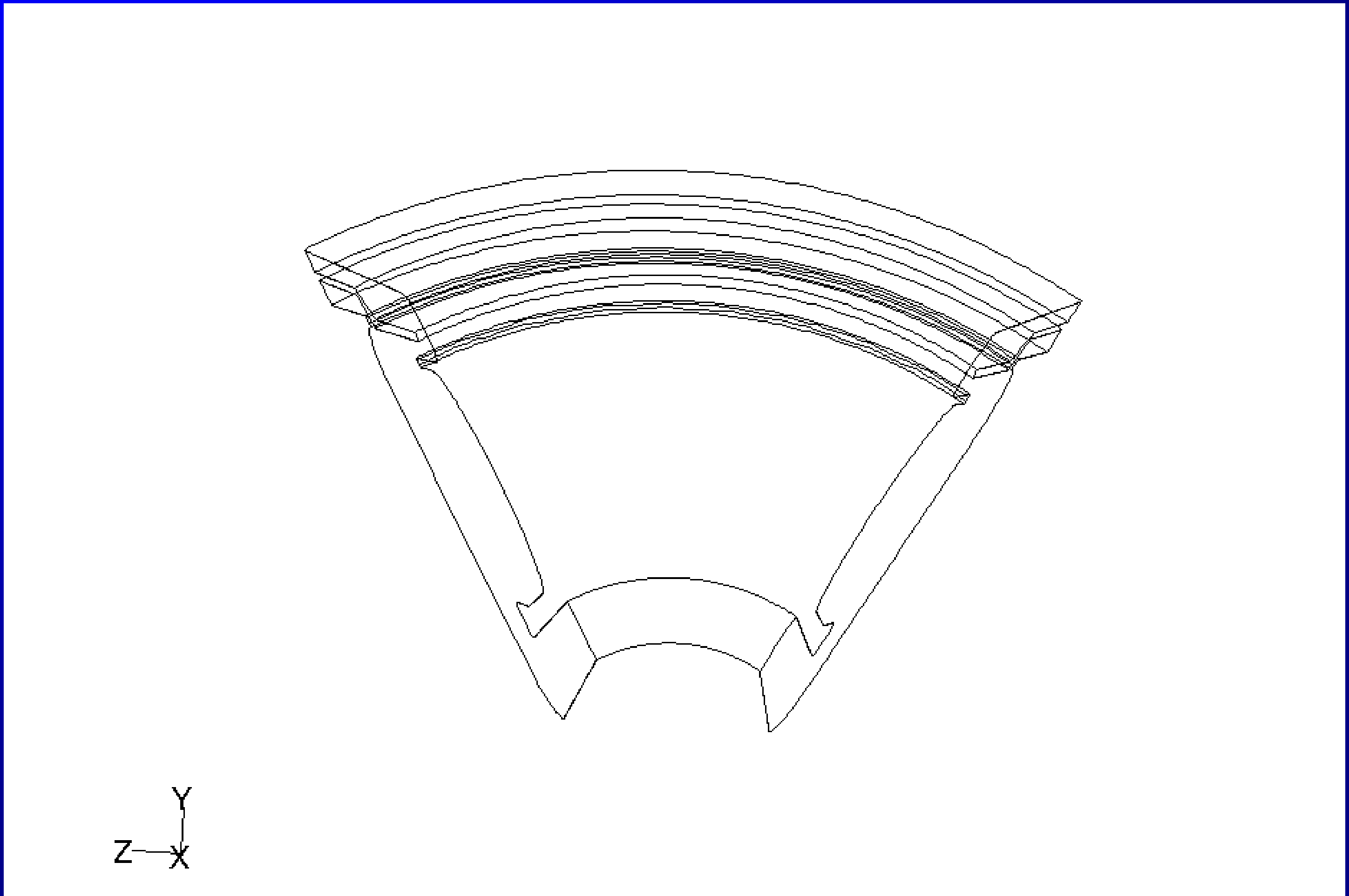


Geometry IV – cylindrical top/bottom

cross sections

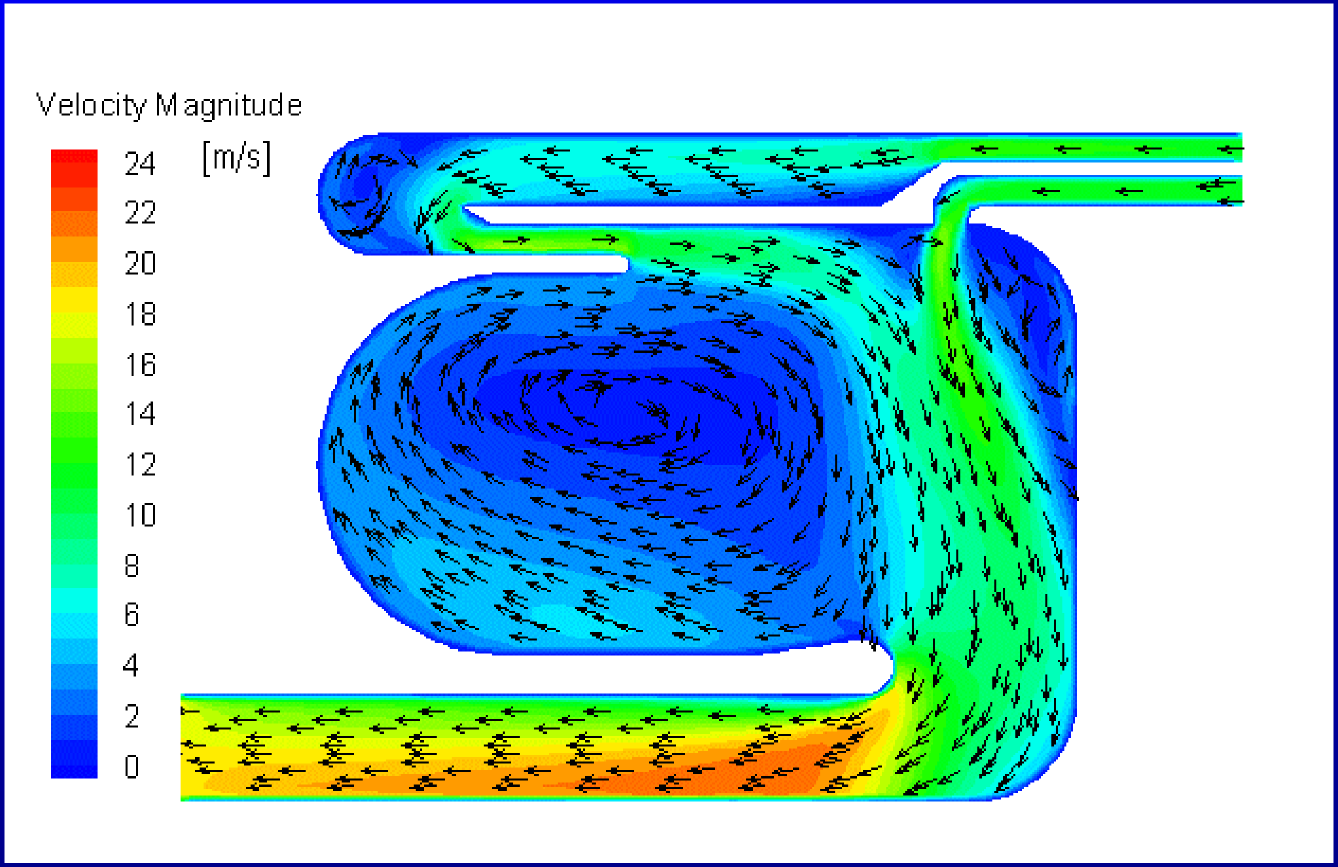


Geometry IV – cylindrical top/bottom



Numerical simulation: Vectors & Contours of Velocity Magnitude

Geometry IV

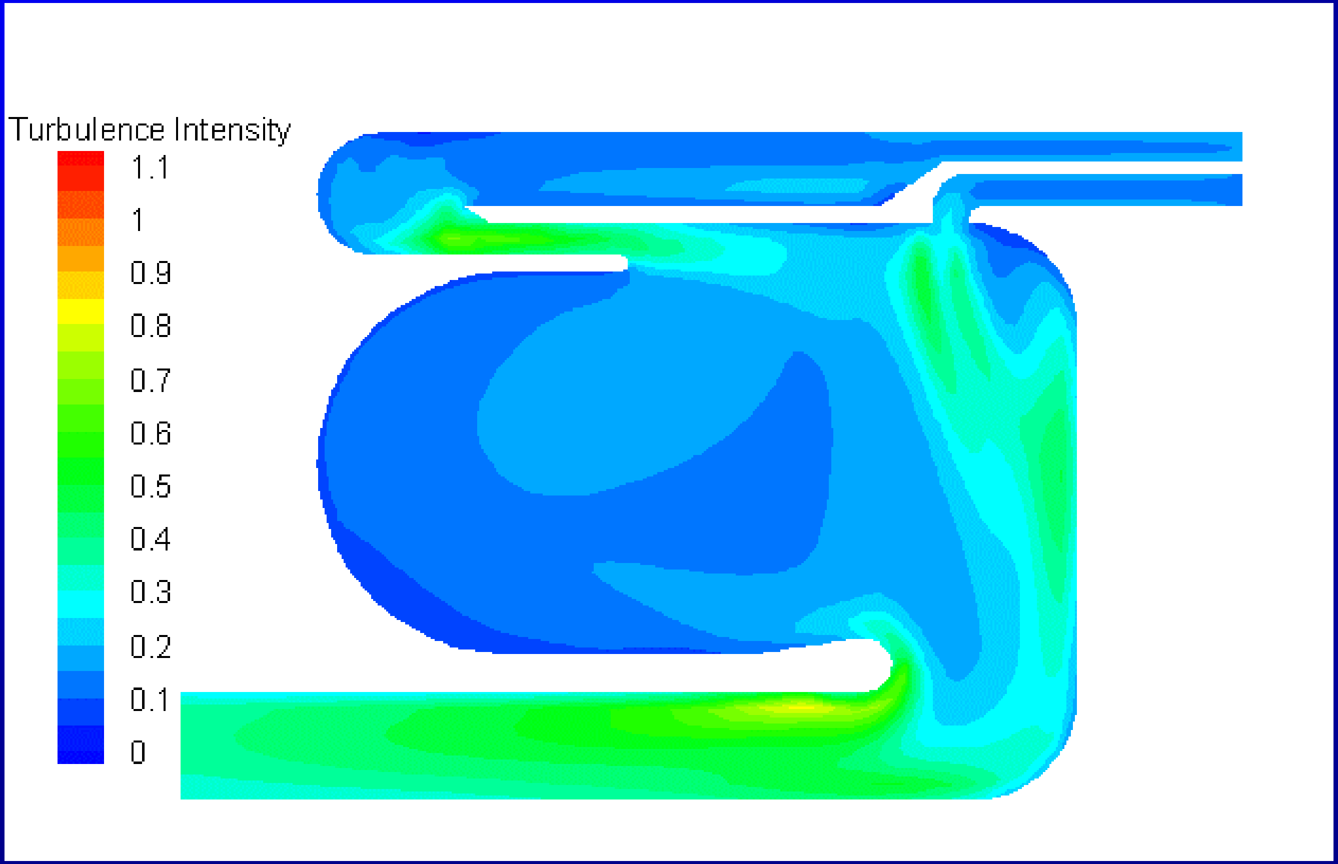


Velocity

Inlet 1: open
Inlet 2: open
Outlet: 18 m/s

Numerical simulation: Contours of Turbulence Intensity

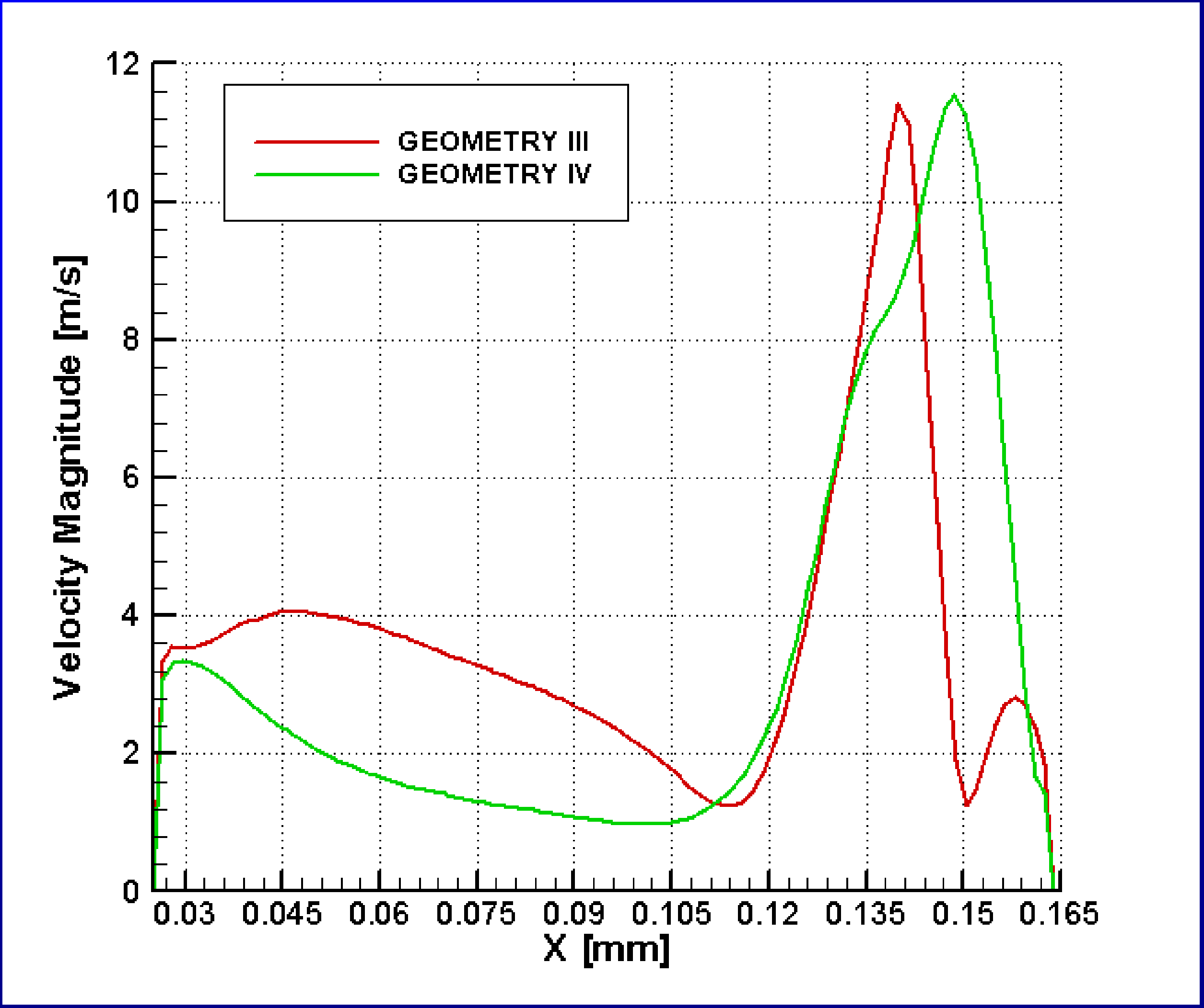
Geometry IV



Velocity

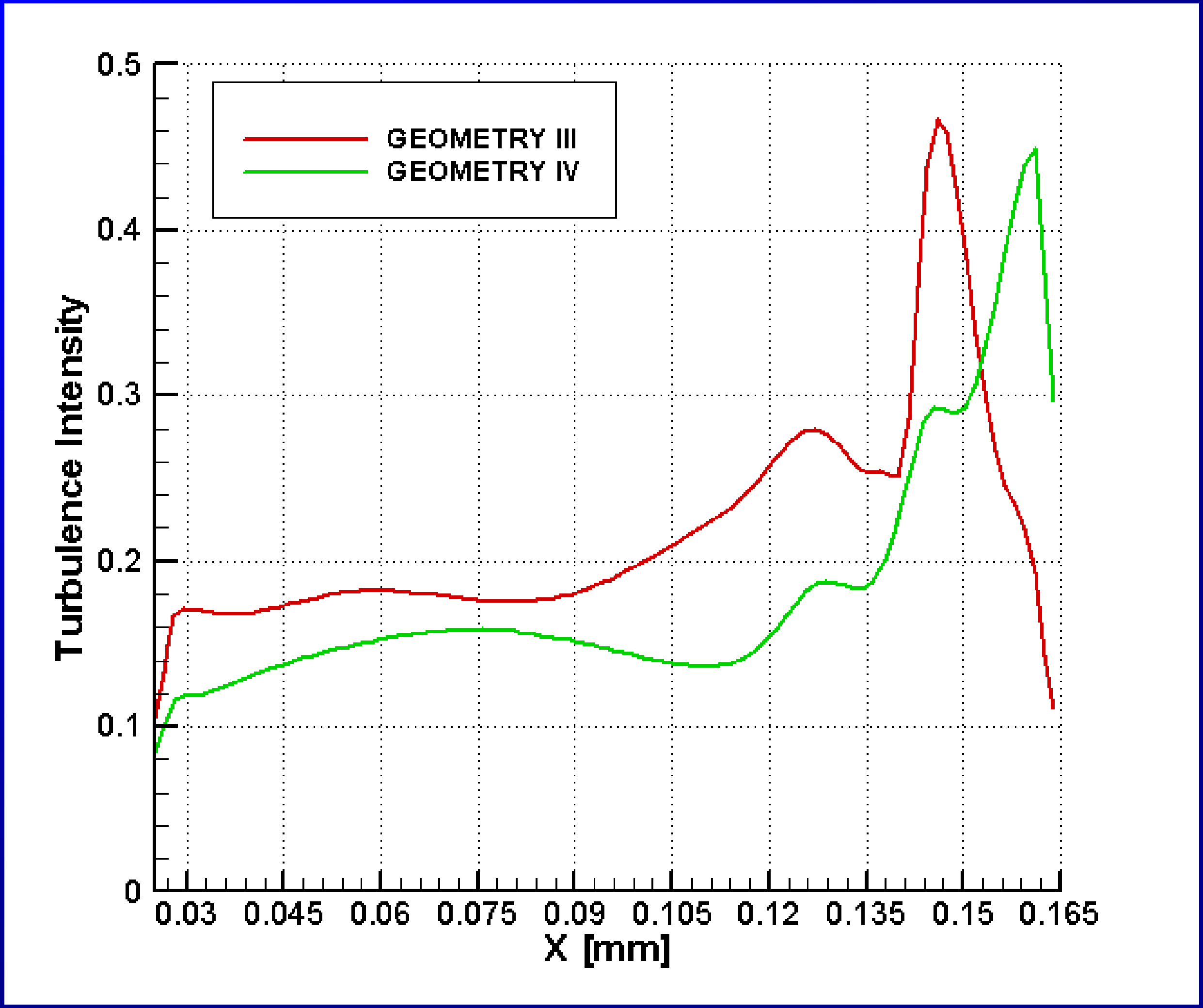
Inlet 1: open
Inlet 2: open
Outlet: 18 m/s

Comparison of Numerical Simulations for Geometry III & Geometry IV



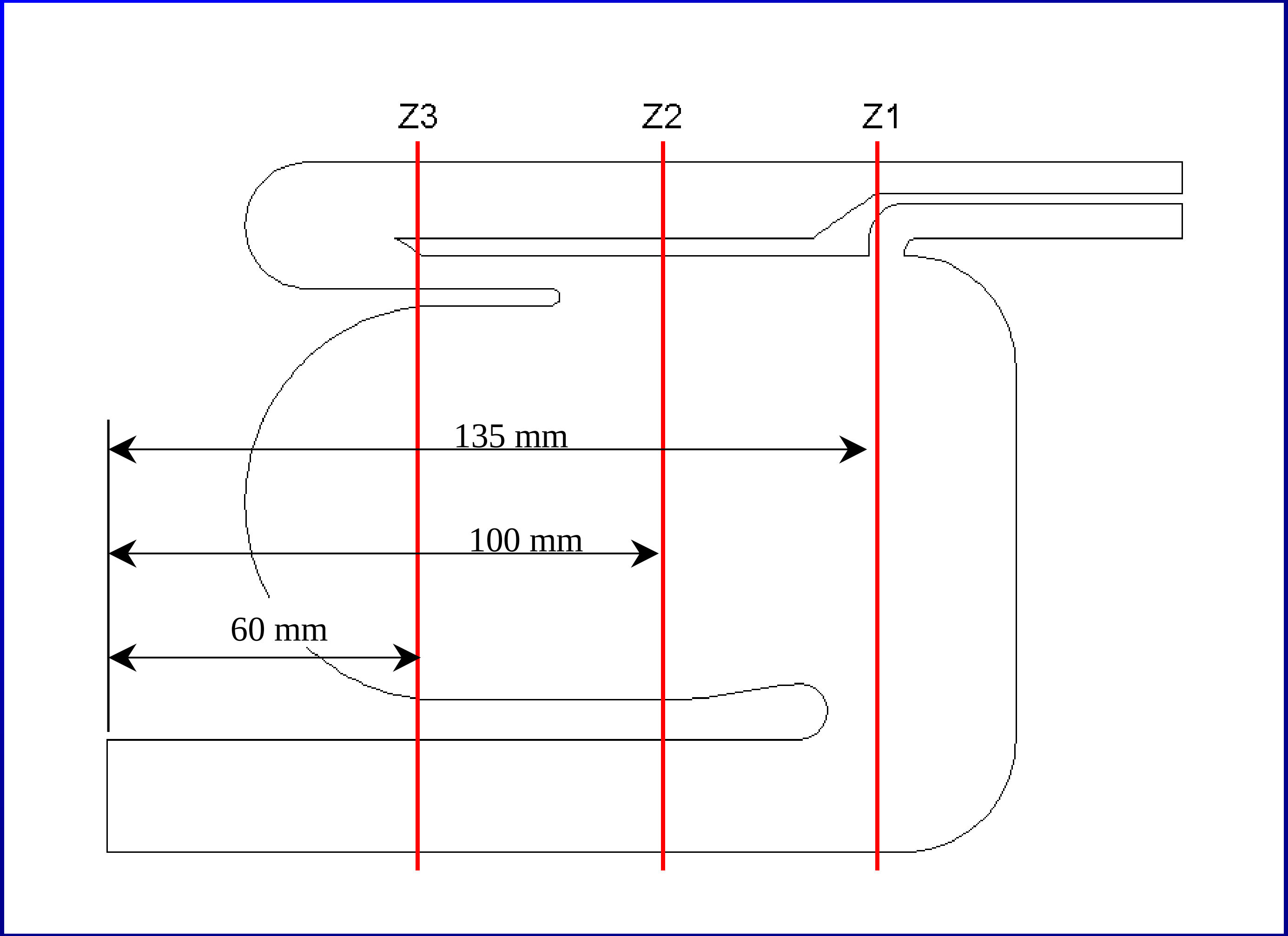
Comparison of Velocity Magnitude Profiles

Comparison of Numerical Simulations for Geometry III & Geometry IV



Comparison of Turbulence Intensity Profiles

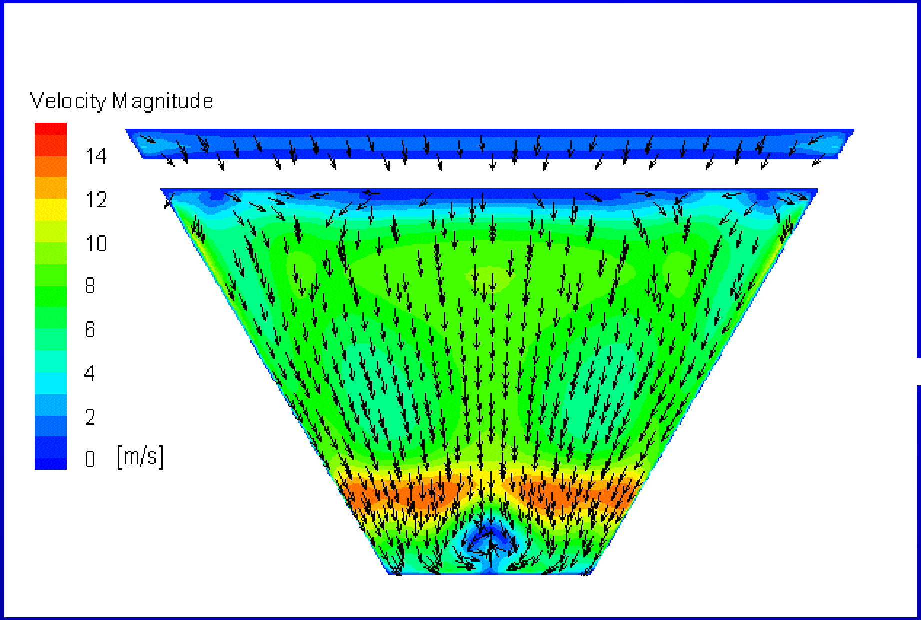
Comparison of Numerical Simulations for Geometry III & Geometry IV



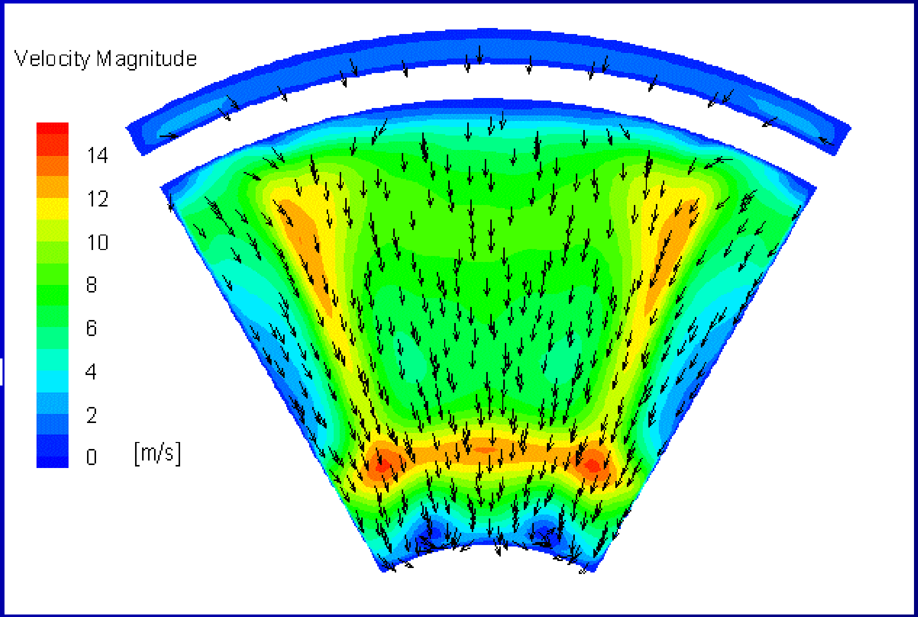
Selected cross – sections

Comparison of Numerical Simulations for Geometry III & Geometry IV

cross – section Z1



Geometry III

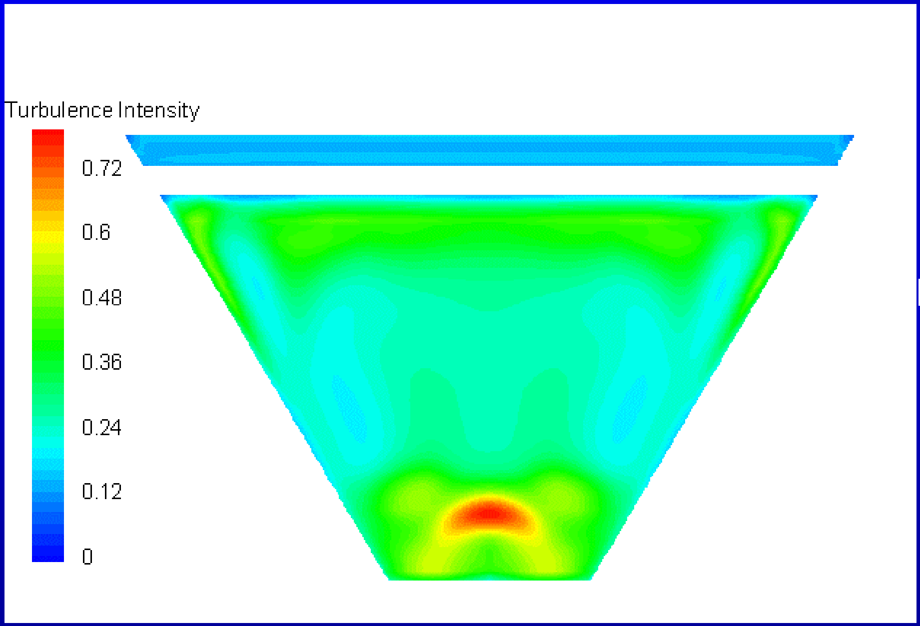


Geometry IV

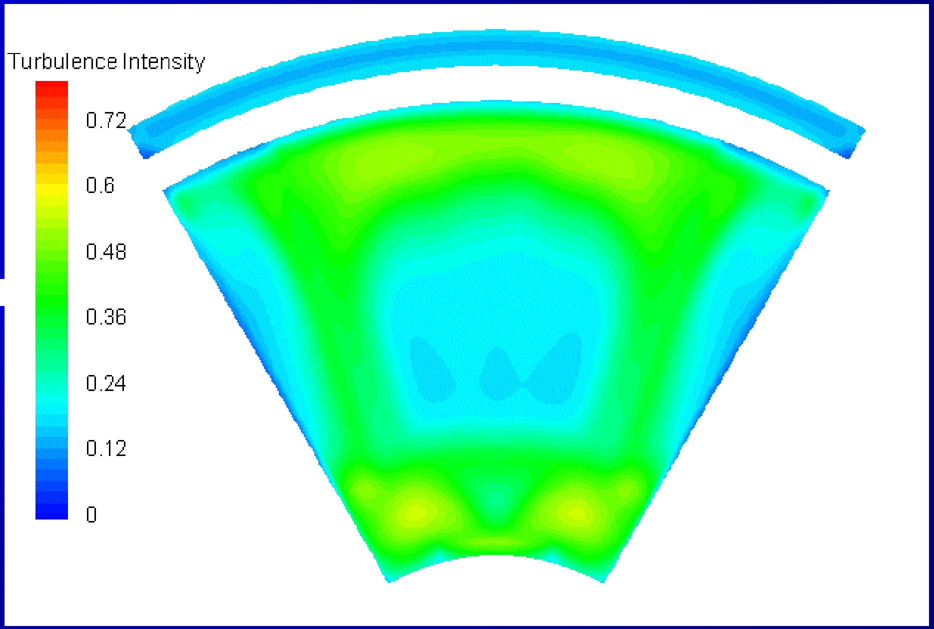
Vectors and Contours and of Velocity Magnitude

Comparison of Numerical Simulations for Geometry III & Geometry IV

cross – section Z1



Geometry III

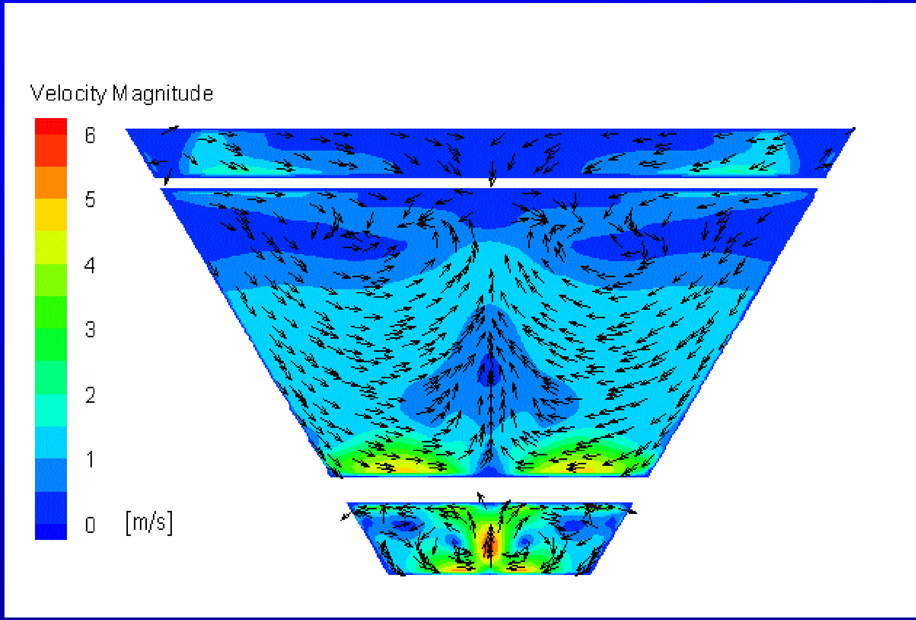


Geometry IV

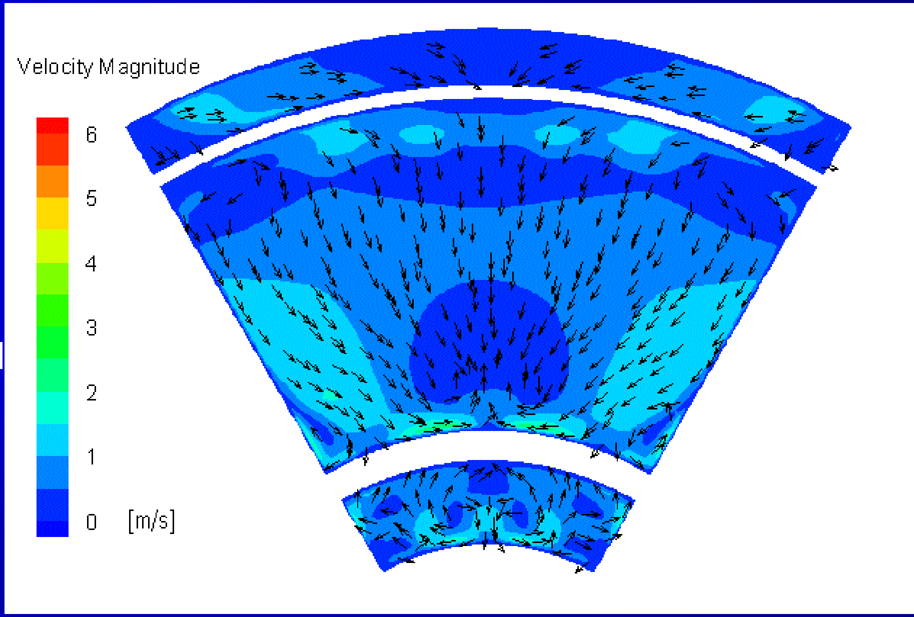
Contours of Turbulence Intensity

Comparison of Numerical Simulations for Geometry III & Geometry IV

cross – section Z2



Geometry III

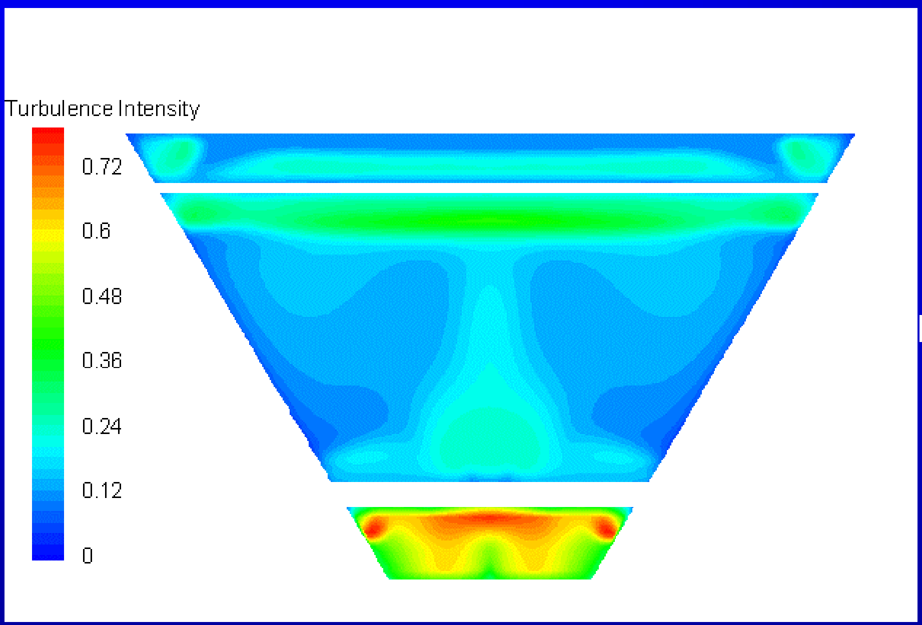


Geometry IV

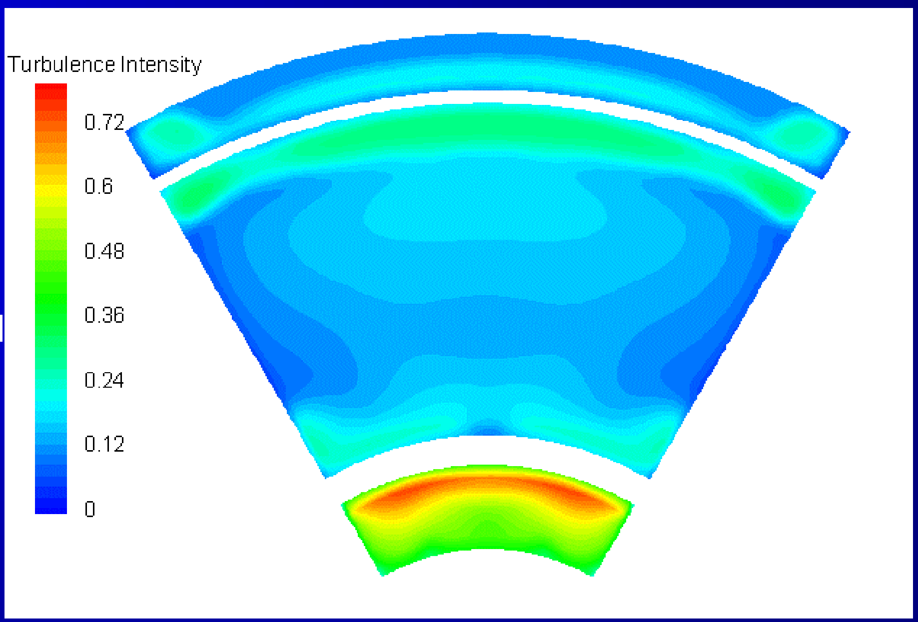
Vectors and Contours and of Velocity Magnitude

Comparison of Numerical Simulations for Geometry III & Geometry IV

cross – section Z2



Geometry III

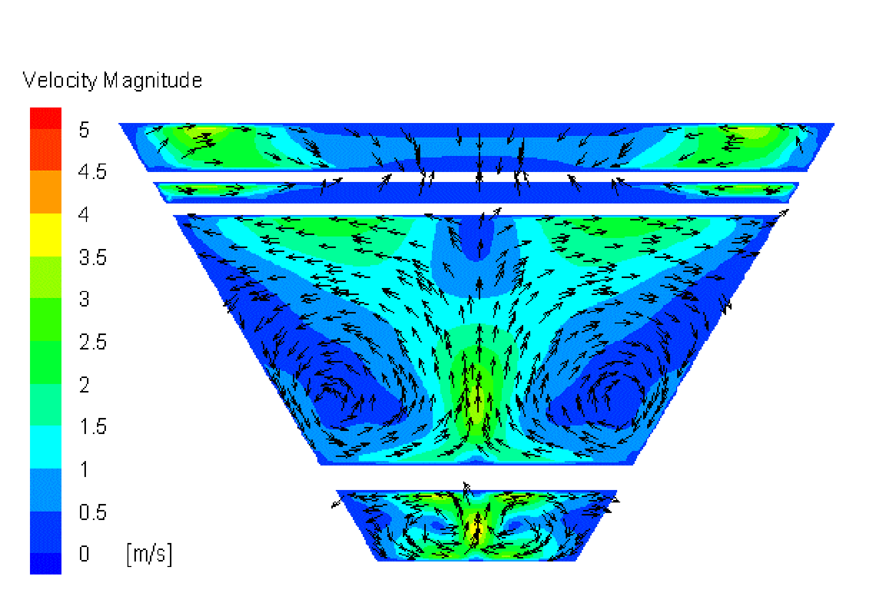


Geometry IV

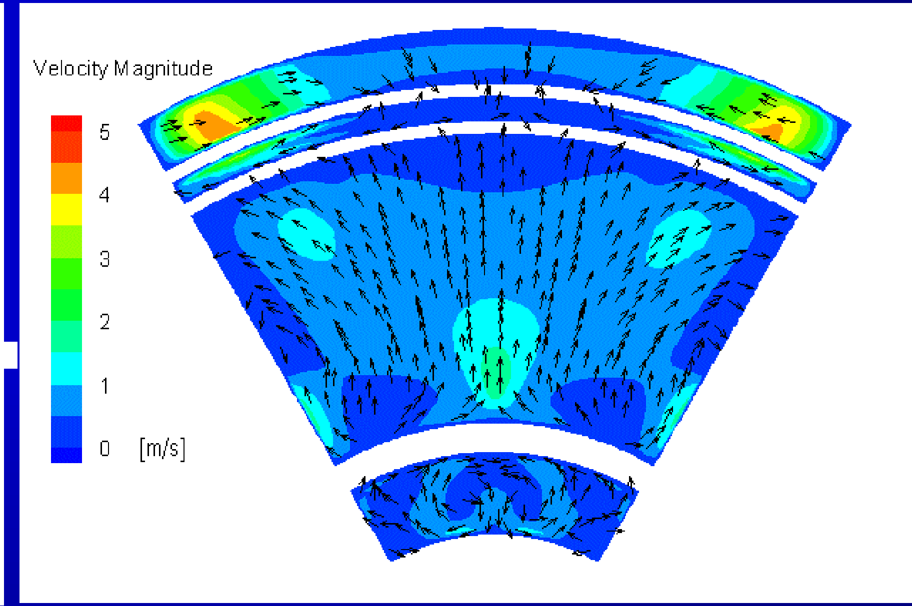
Contours of Turbulence Intensity

Comparison of Numerical Simulations for Geometry III & Geometry IV

cross – section Z3



Geometry III

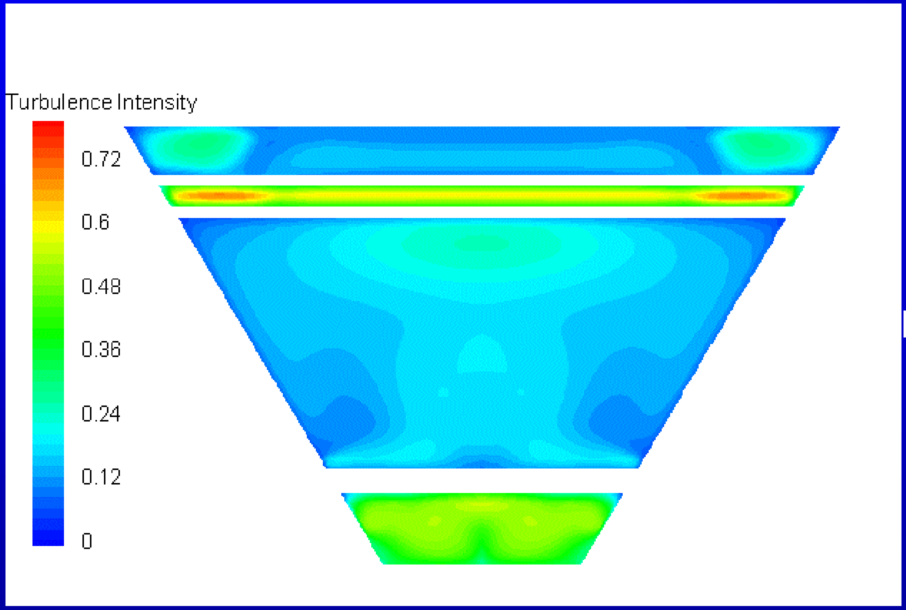


Geometry IV

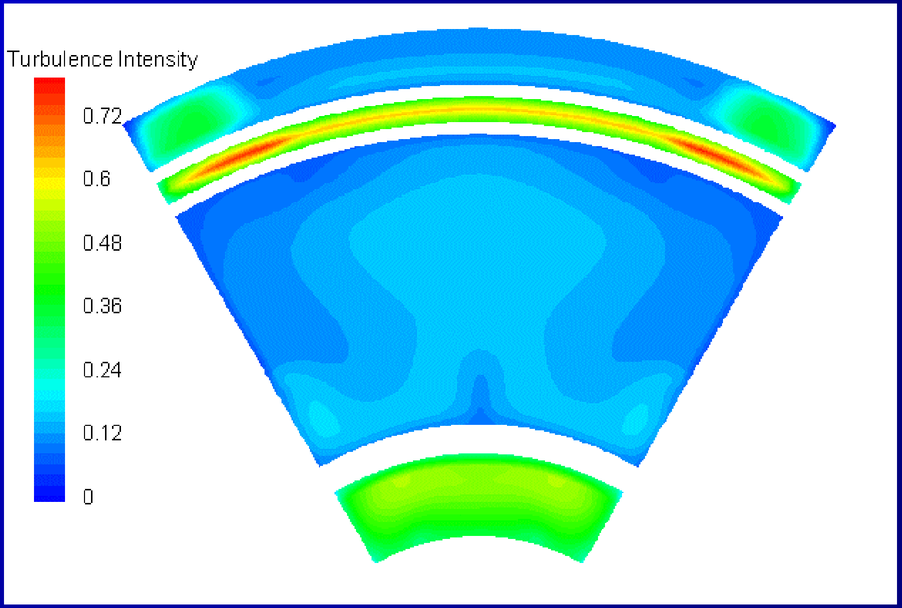
Vectors and Contours and of Velocity Magnitude

Comparison of Numerical Simulations for Geometry III & Geometry IV

cross – section Z3



Geometry III

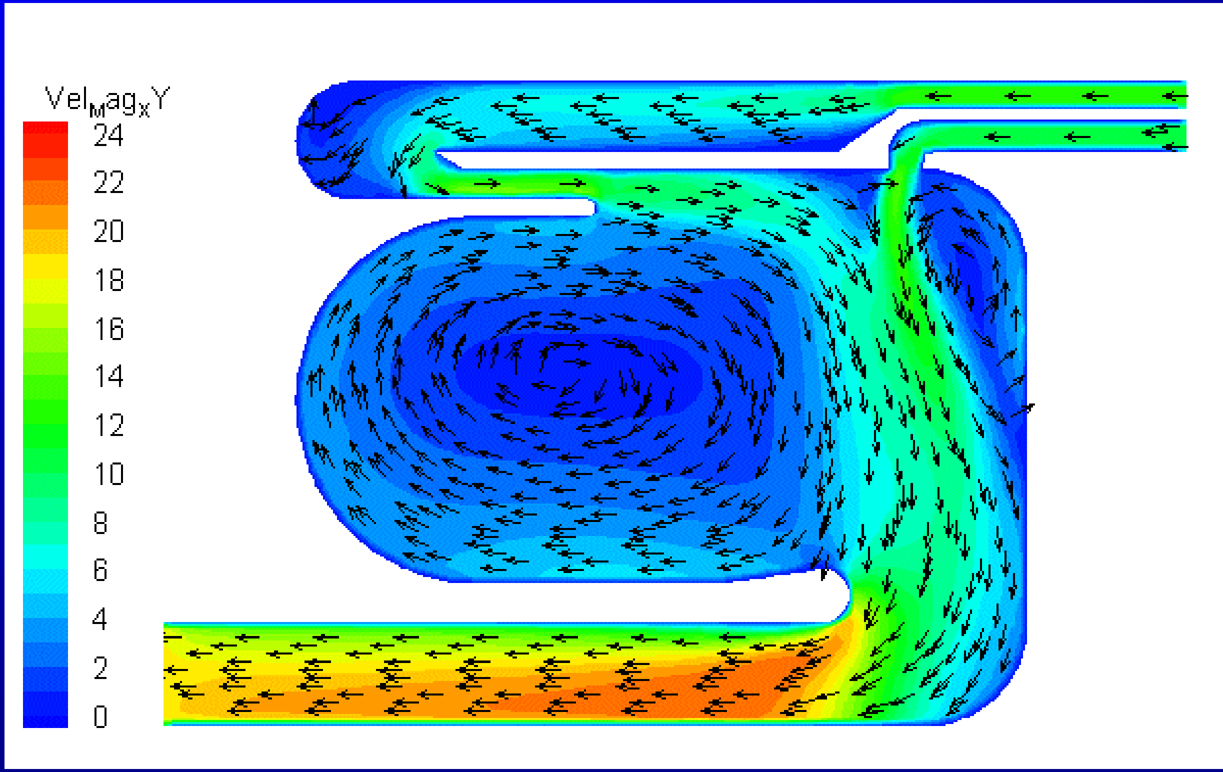


Geometry IV

Contours of Turbulence Intensity

Numerical simulation: Vectors & Contours of Velocity Magnitude

Geometry IV – with „slip" boundary condition on side walls



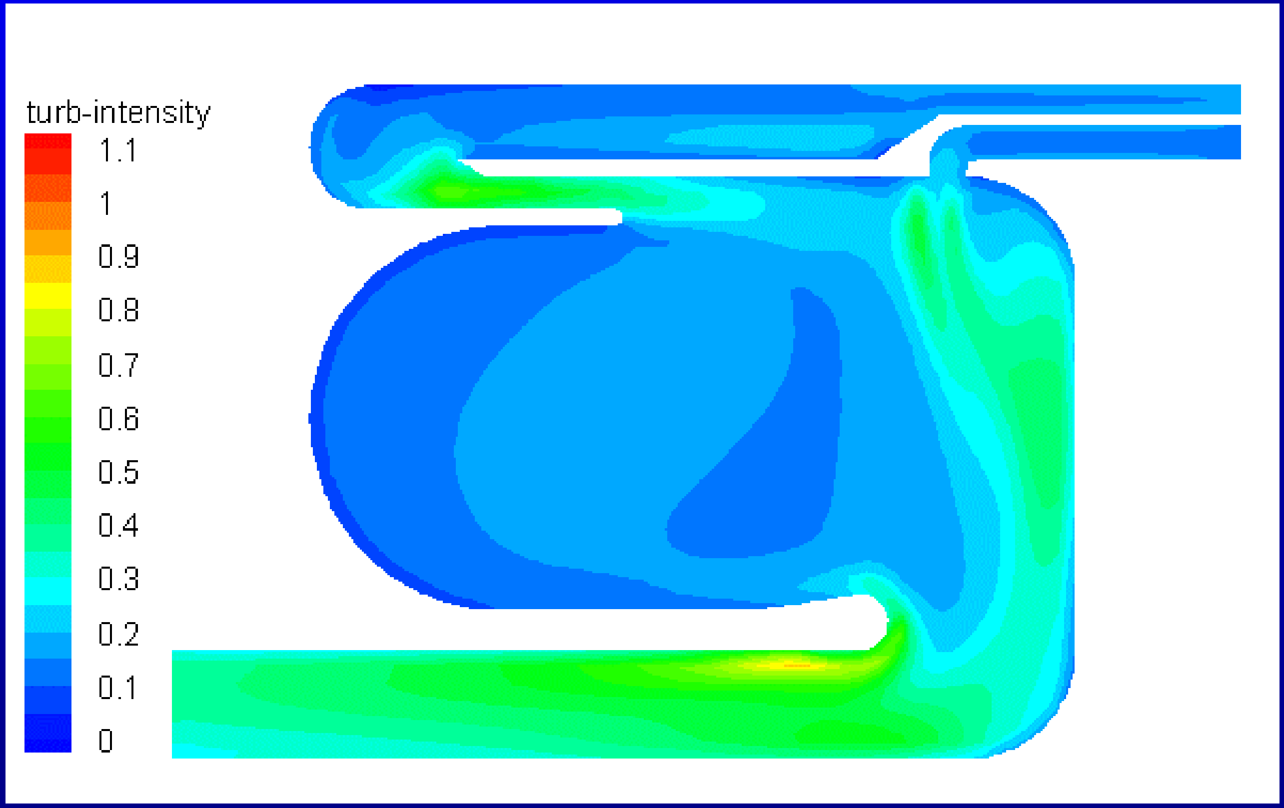
<u>Velocity</u>

Inlet 1: open
Inlet 2: open
Outlet: 18 m/s

Effect of periodic boundary conditions

Numerical simulation: Contours of Turbulence Intensity

Geometry IV – with „slip" boundary condition on side walls

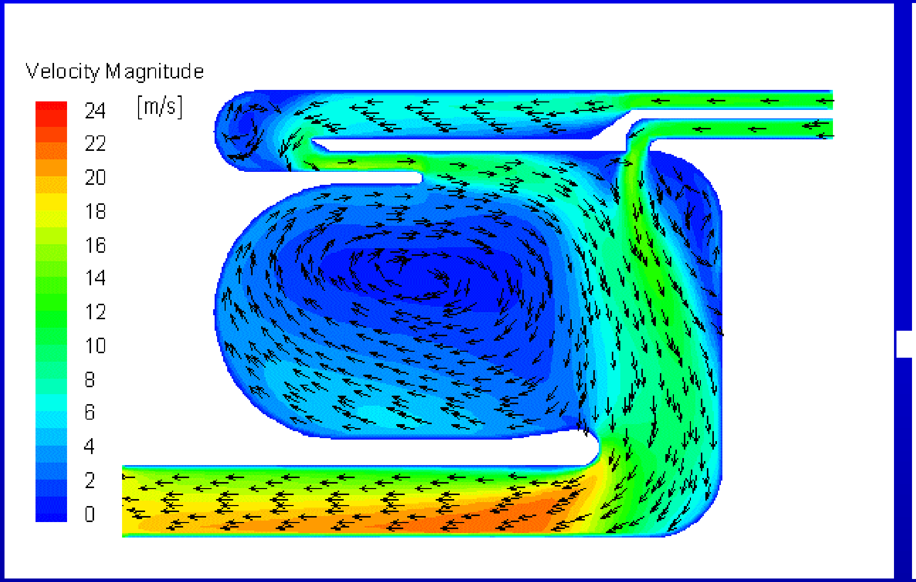


<u>Velocity</u>

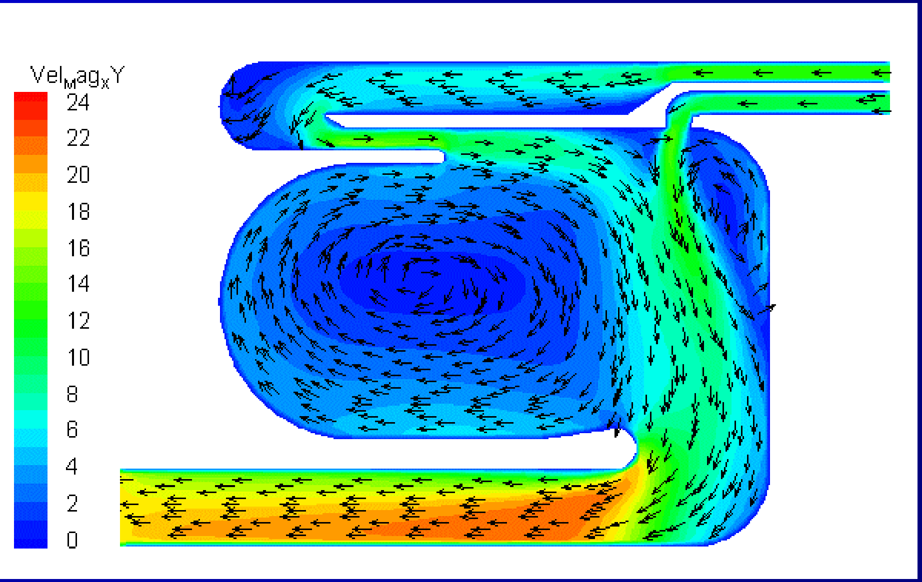
Inlet 1: open
Inlet 2: open
Outlet: 18 m/s

Comparison of Numerical Simulations for Geometry IV

central cross – section



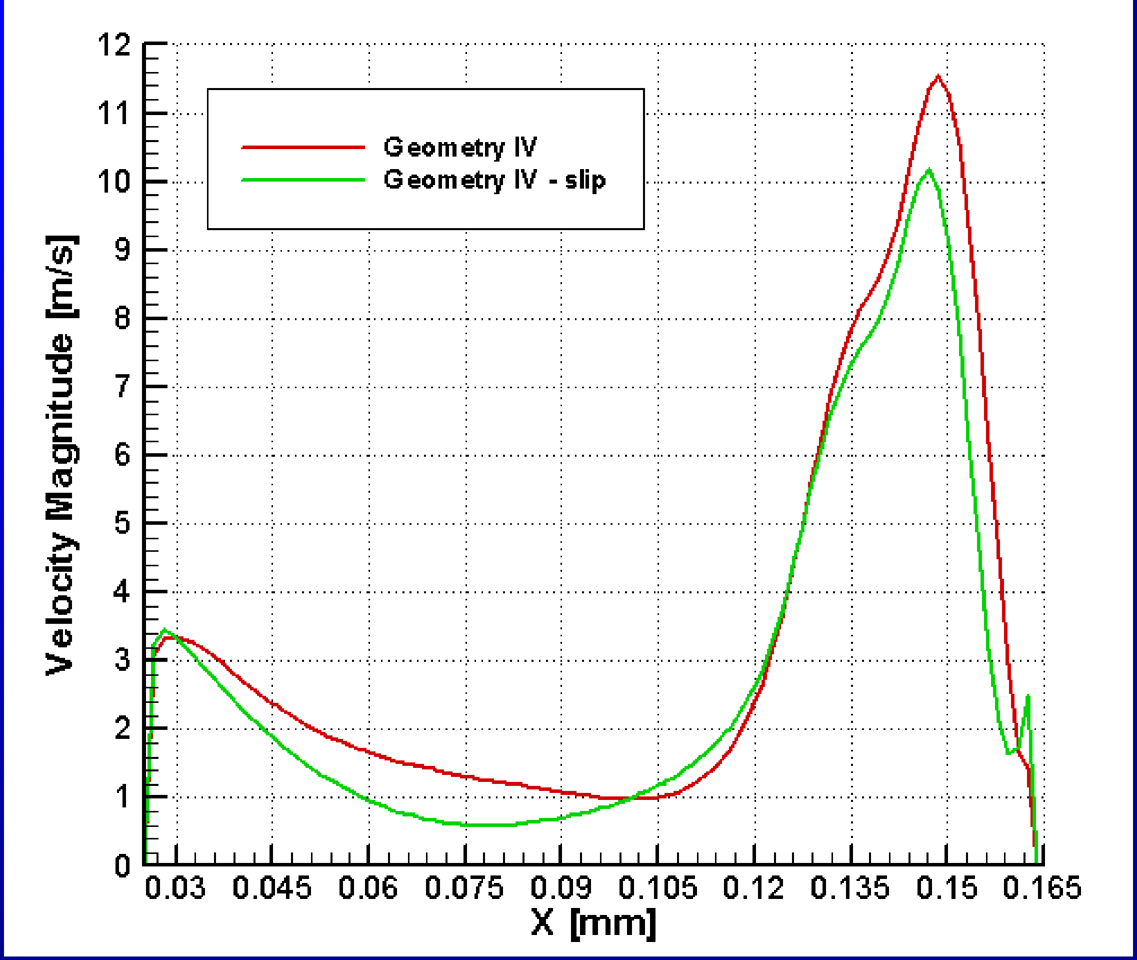
Geometry IV



Geometry IV – „slip”

Vectors and Contours and of Velocity Magnitude

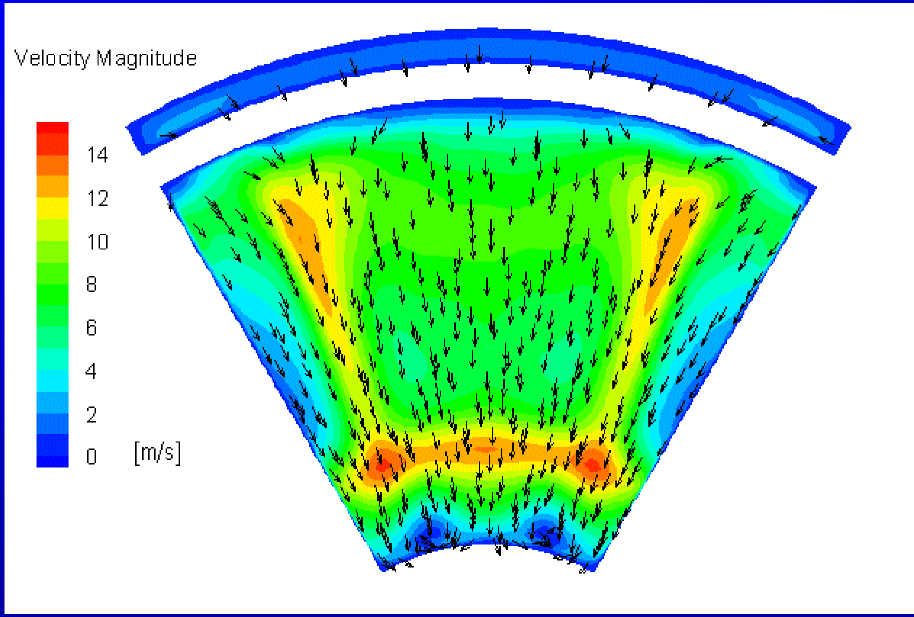
Comparison of Numerical Simulations for Geometry IV



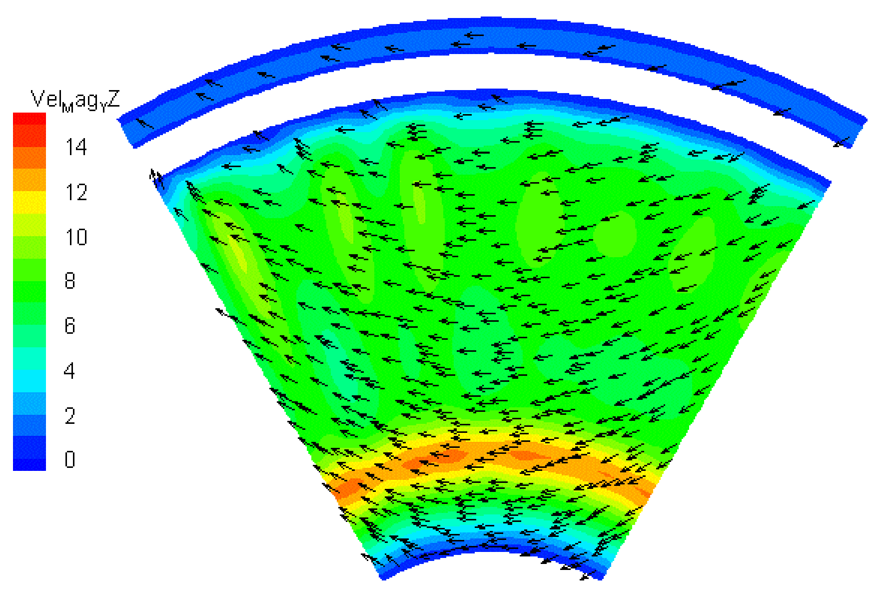
Comparison of Velocity Magnitude Profiles

Comparison of Numerical Simulations for Geometry IV

cross – section Z1



Geometry IV

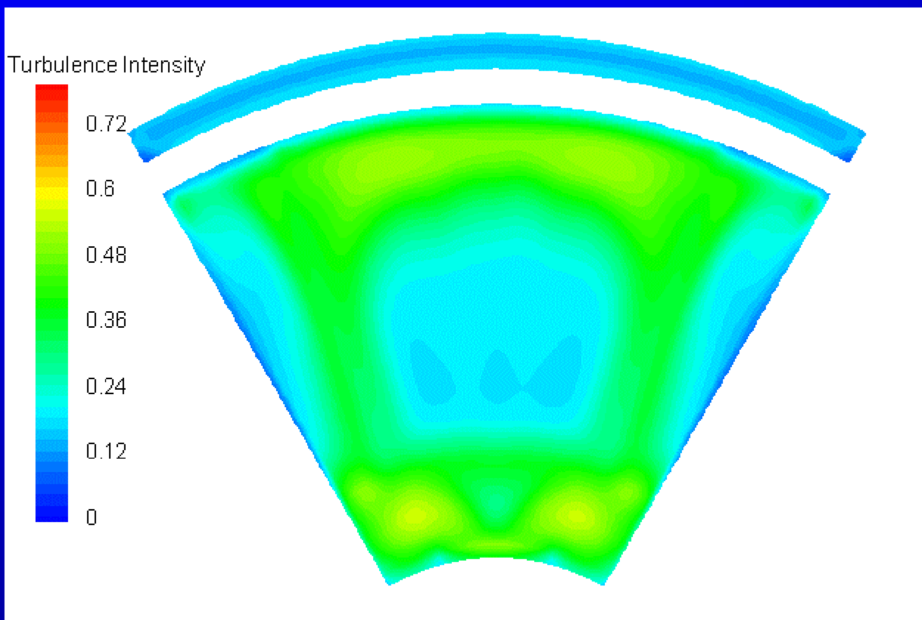


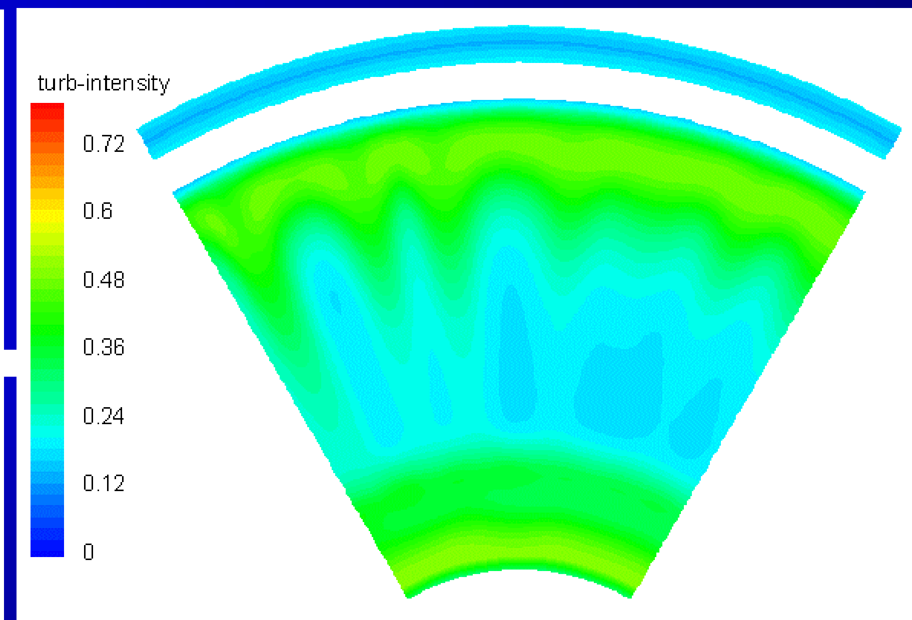
Geometry IV – „slip”

Vectors and Contours and of Velocity Magnitude

Comparison of Numerical Simulations for Geometry IV

cross – section Z1





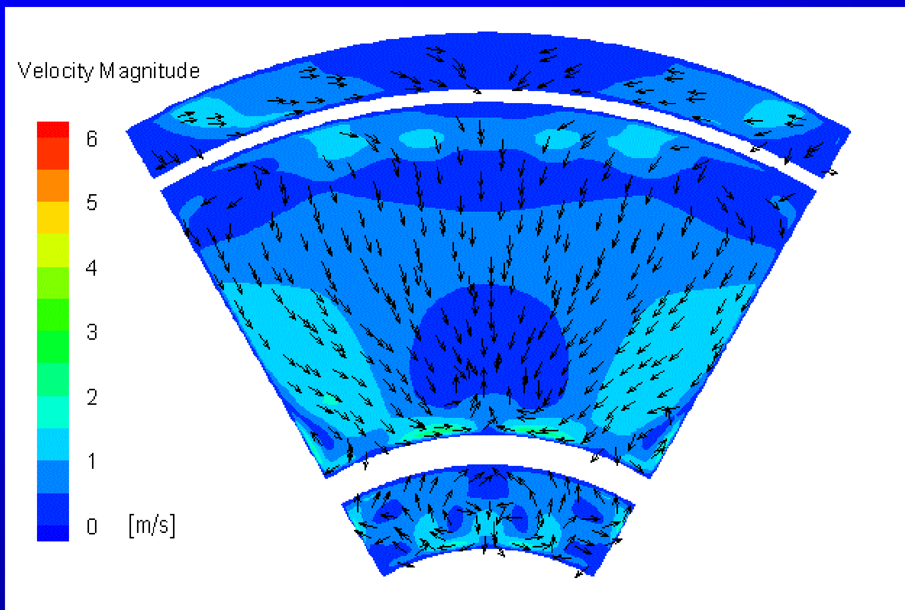
Geometry IV

Geometry IV – „slip”

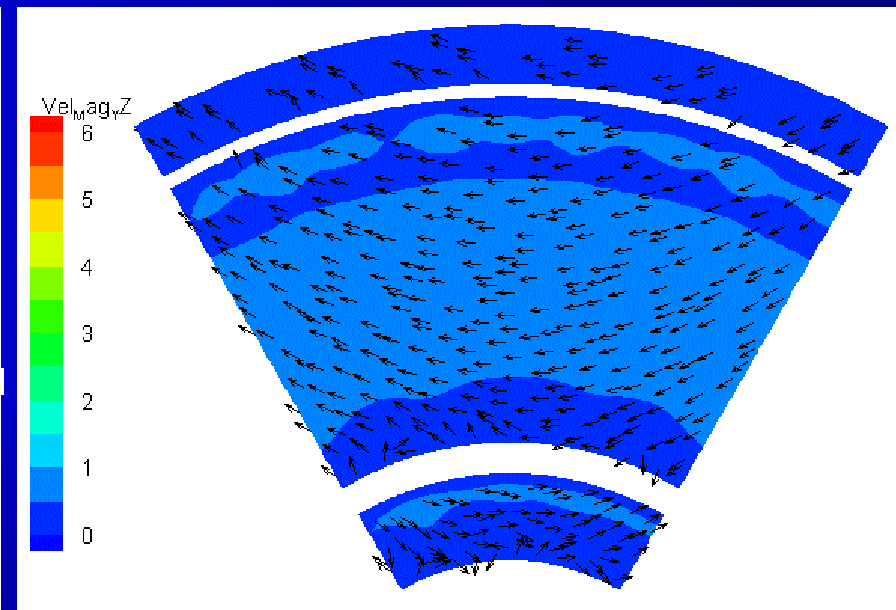
Contours of Turbulence Intensity

Comparison of Numerical Simulations for Geometry IV

cross – section Z2



Geometry IV

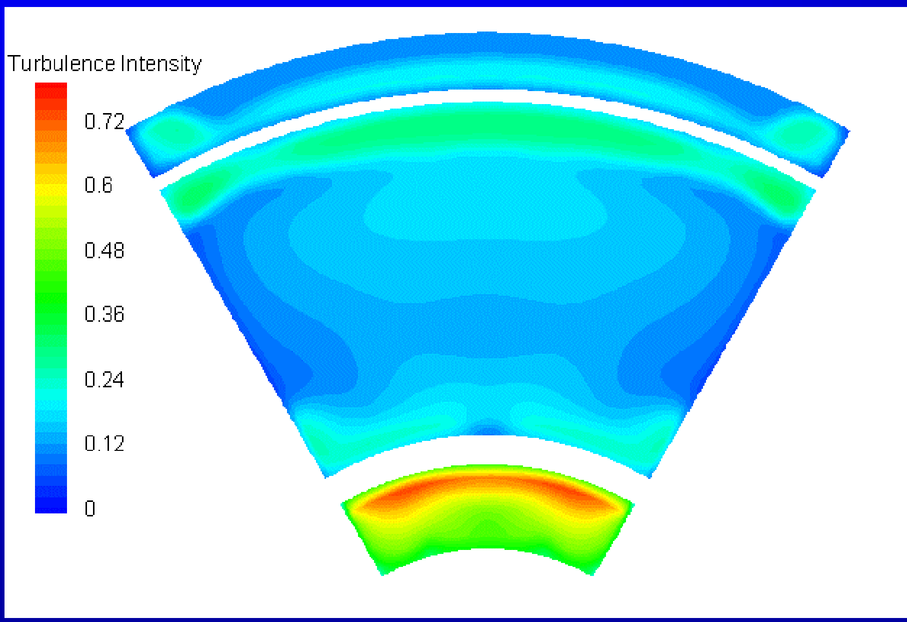


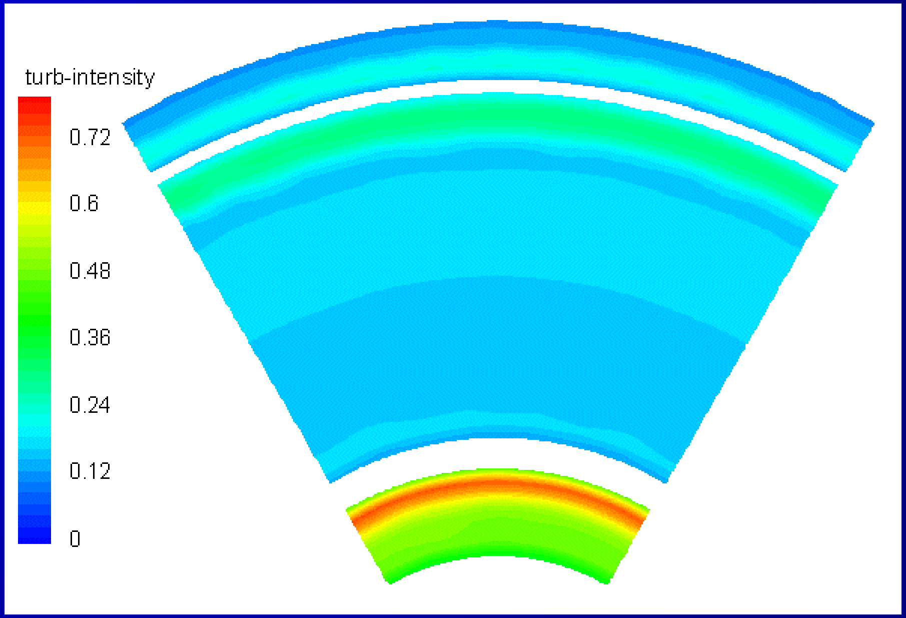
Geometry IV – „slip”

Vectors and Contours and of Velocity Magnitude

Comparison of Numerical Simulations for Geometry IV

cross – section Z2





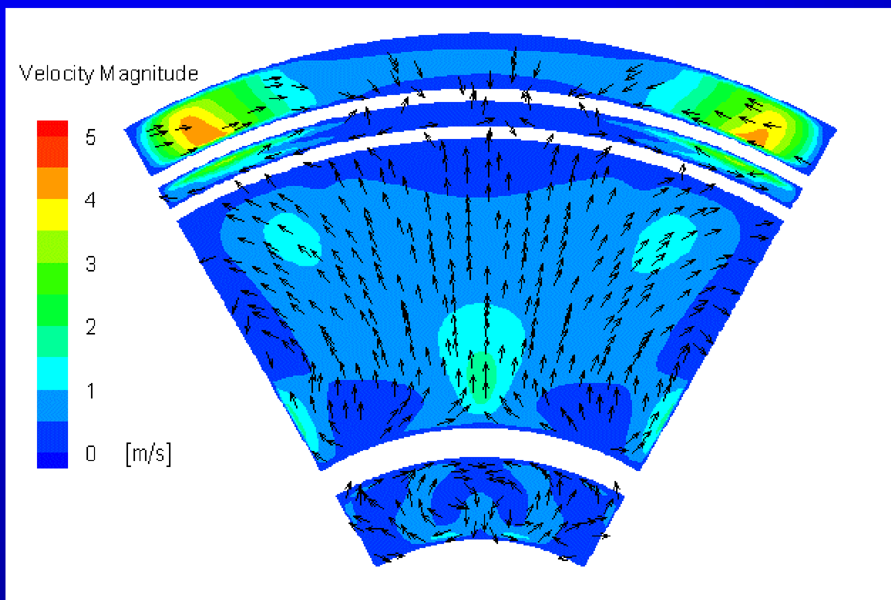
Geometry IV

Geometry IV – „slip”

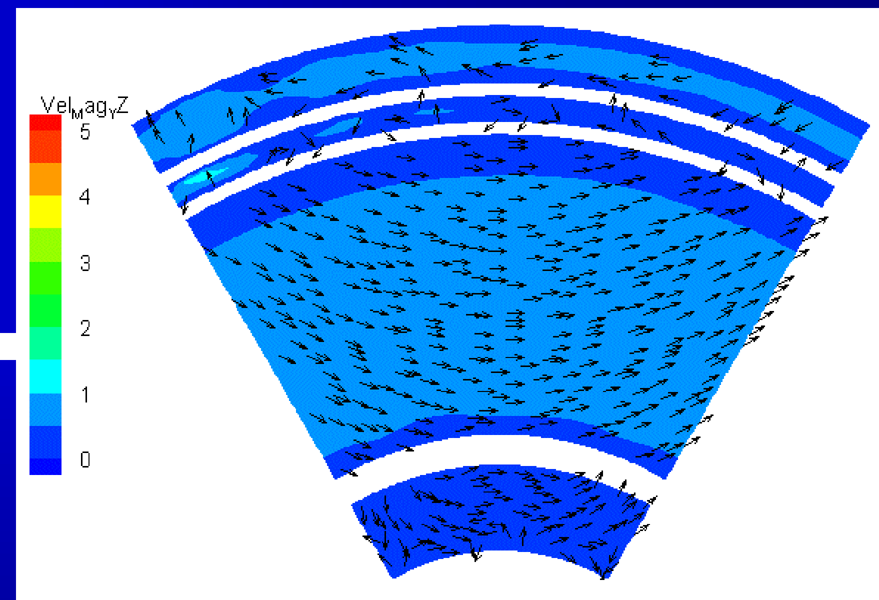
Contours of Turbulence Intensity

Comparison of Numerical Simulations for Geometry IV

cross – section Z3



Geometry IV

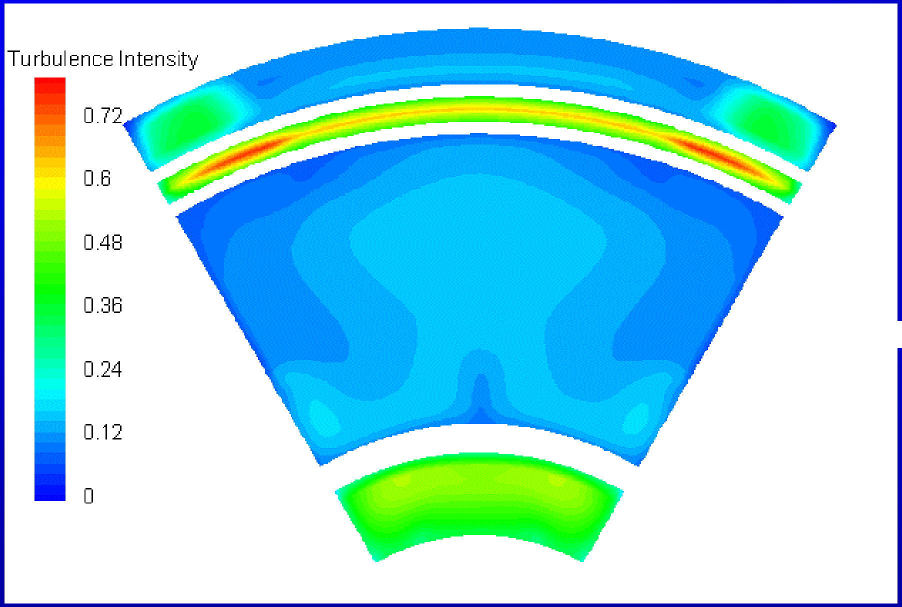


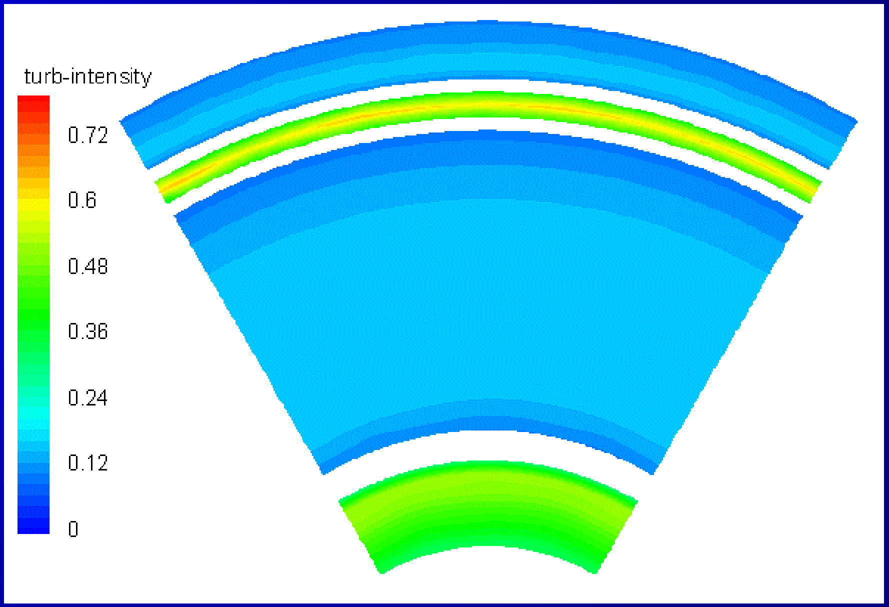
Geometry IV – „slip”

Vectors and Contours and of Velocity Magnitude

Comparison of Numerical Simulations for Geometry IV

cross – section Z3





Geometry IV

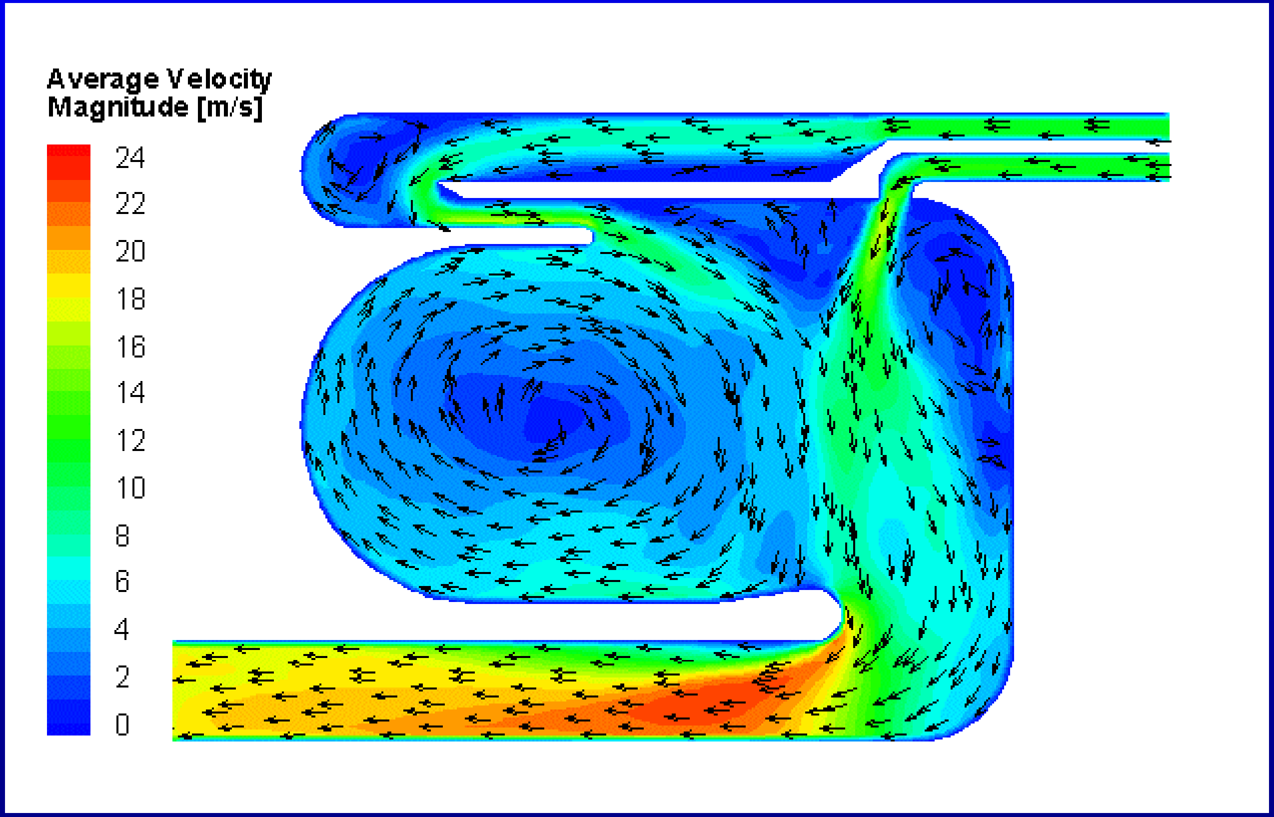
Geometry IV – „slip”

Contours of Turbulence Intensity

Numerical simulation: Vectors & Contours of Velocity Magnitude

Geometry IV

Model of turbulence: Large Eddy Simulation



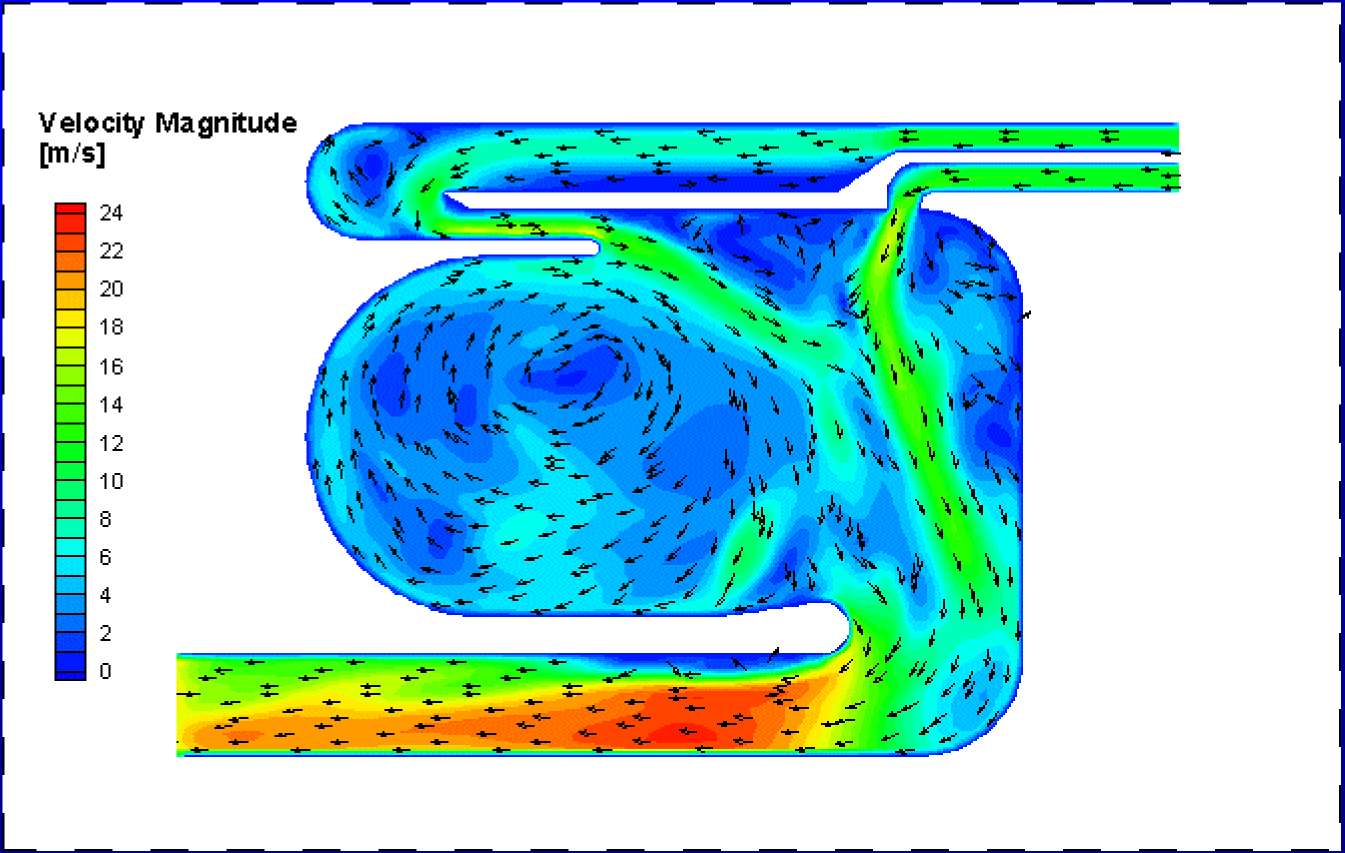
Velocity

Inlet 1: open
Inlet 2: open
Outlet: 18 m/s

Numerical simulation: Vectors & Contours of Velocity Magnitude

Geometry IV

Model of turbulence: Large Eddy Simulation

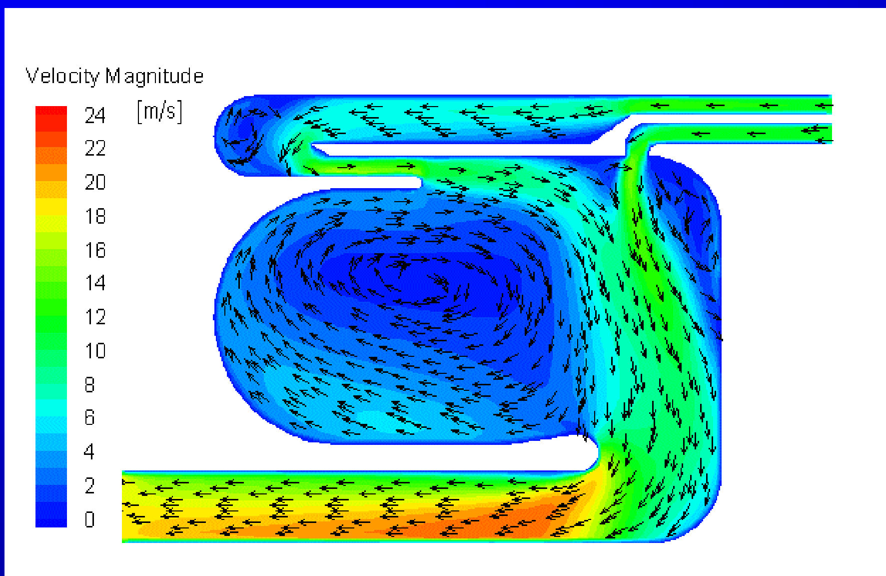


Velocity

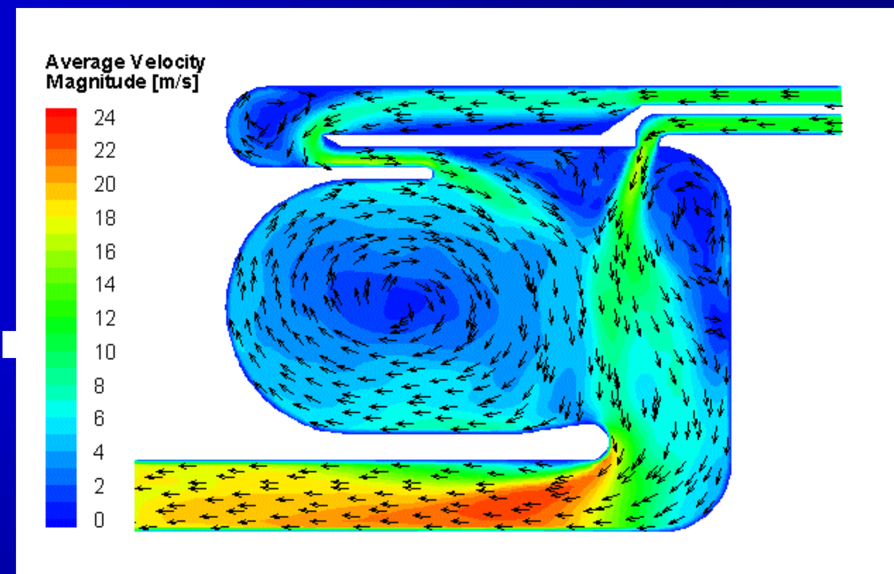
Inlet 1: open
Inlet 2: open
Outlet: 18 m/s

Comparison of Numerical Simulations for Geometry IV

k - ε model vs. Large Eddy Simulation



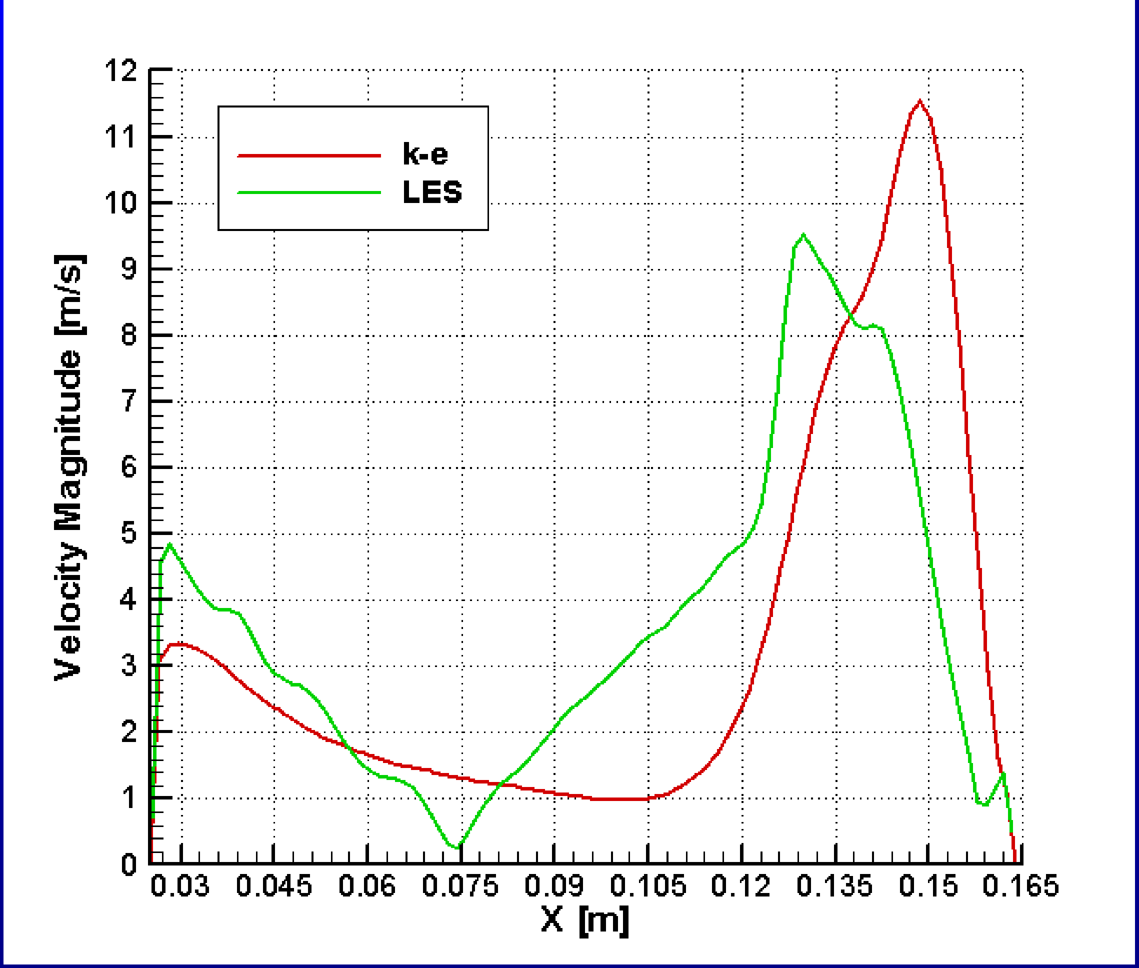
k - ε



LES

Vectors and Contours and of Velocity Magnitude

Comparison of Numerical Simulations for Geometry IV
k - ε model vs. Large Eddy Simulation

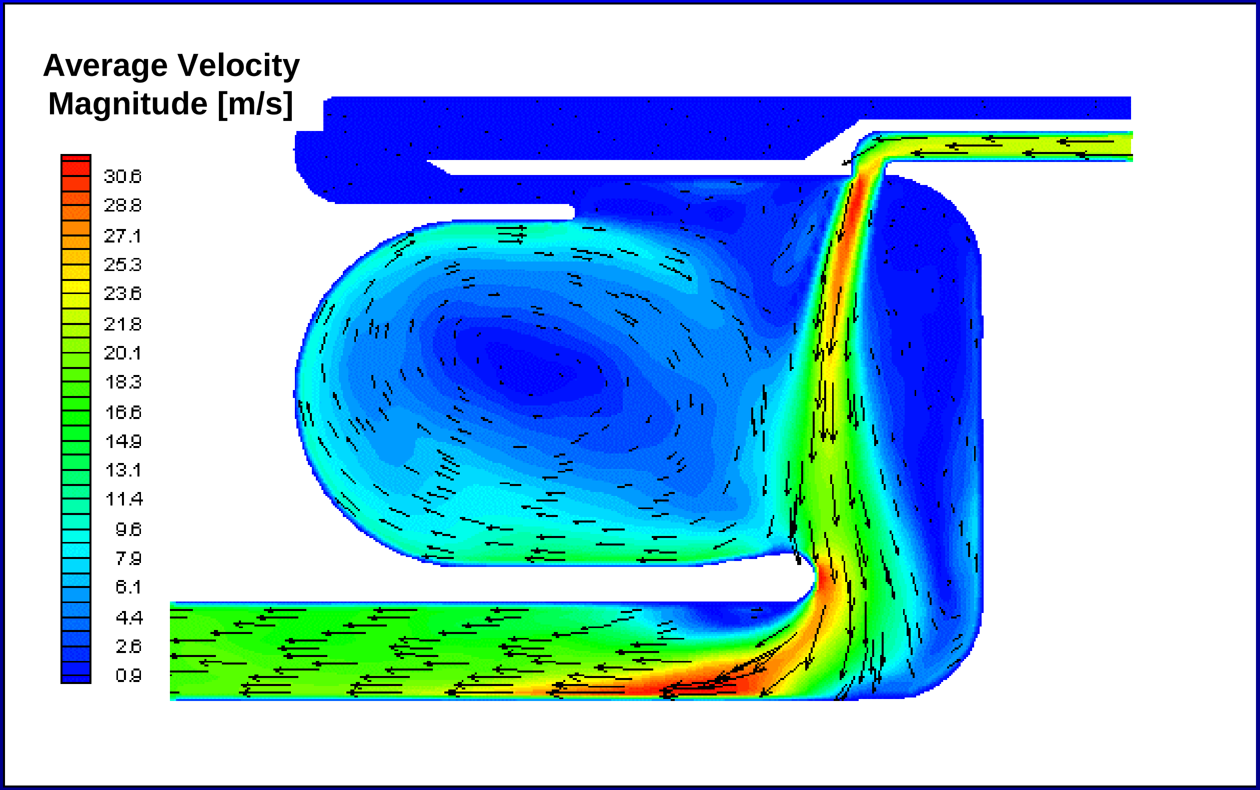


Comparison of Velocity Magnitude Profiles

Numerical simulation: Vectors & Contours of Velocity Magnitude

Geometry IV

Model of turbulence: Large Eddy Simulation



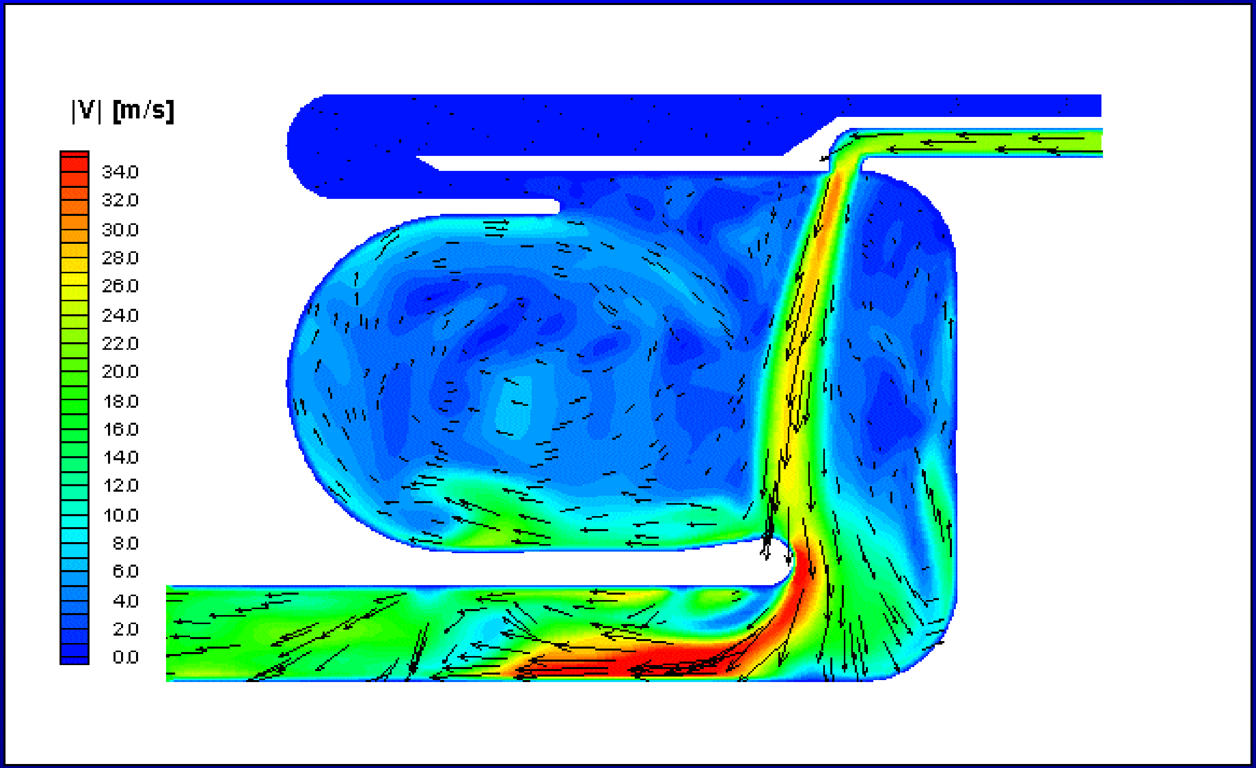
<u>Velocity</u>

Inlet 1: closed
Inlet 2: open
Outlet: 18 m/s

Numerical simulation: Vectors & Contours of Velocity Magnitude

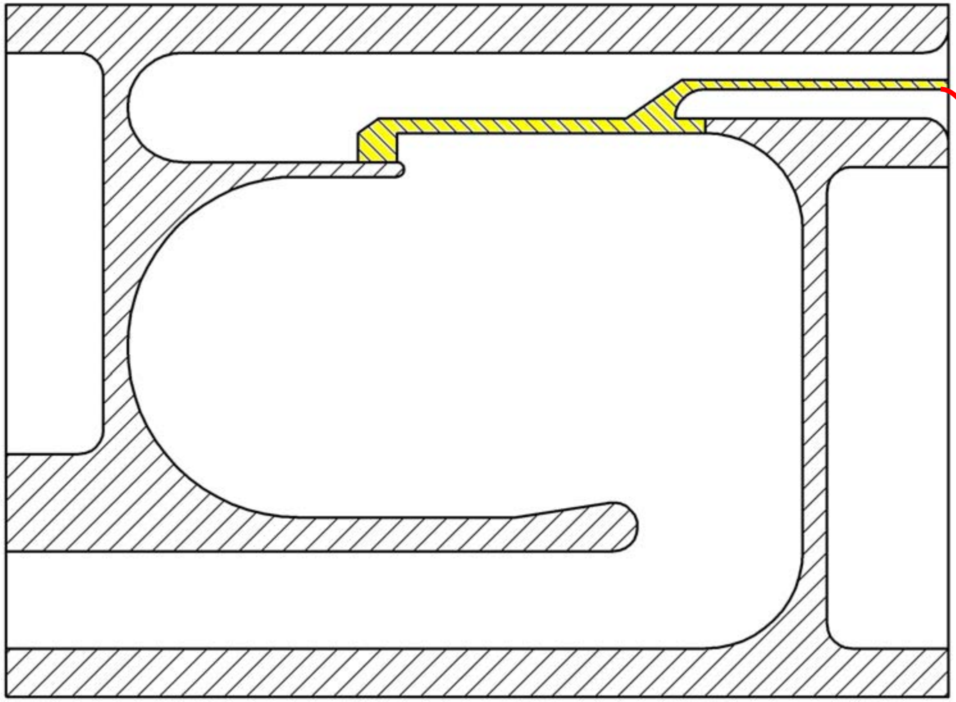
Geometry IV

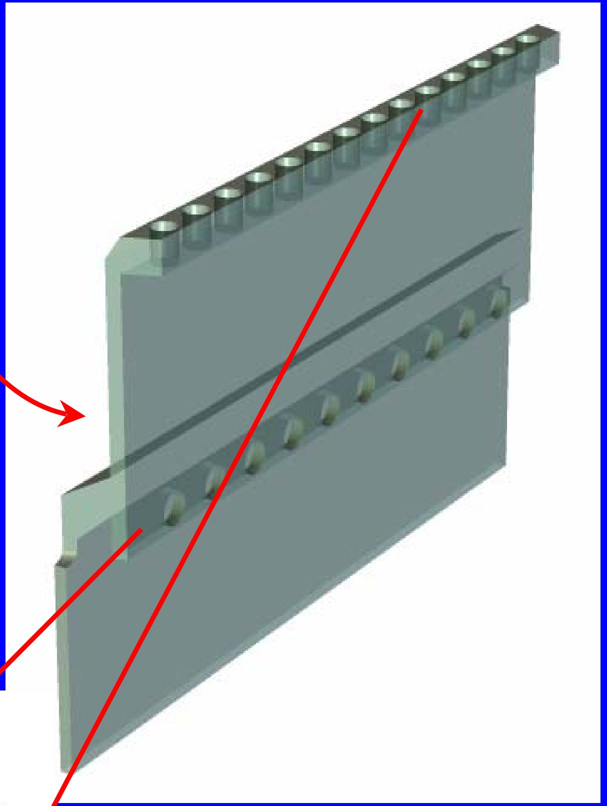
Model of turbulence: Large Eddy Simulation

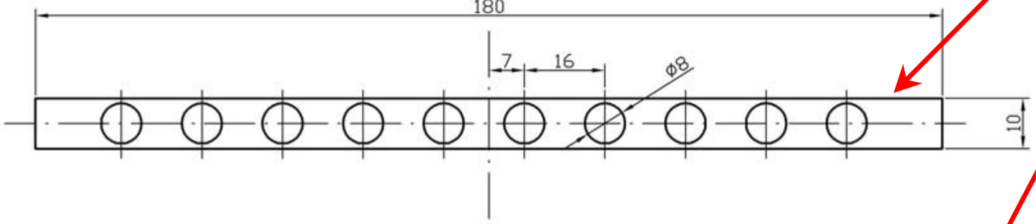


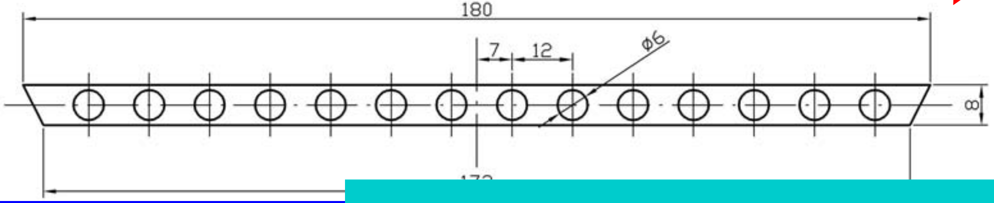
<u>Velocity</u>

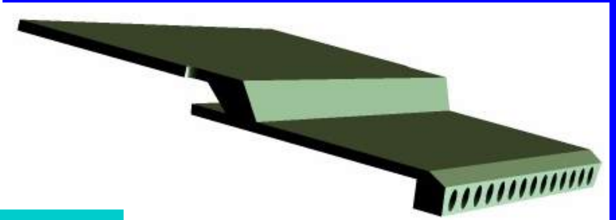
Inlet 1: closed
Inlet 2: open
Outlet: 18 m/s



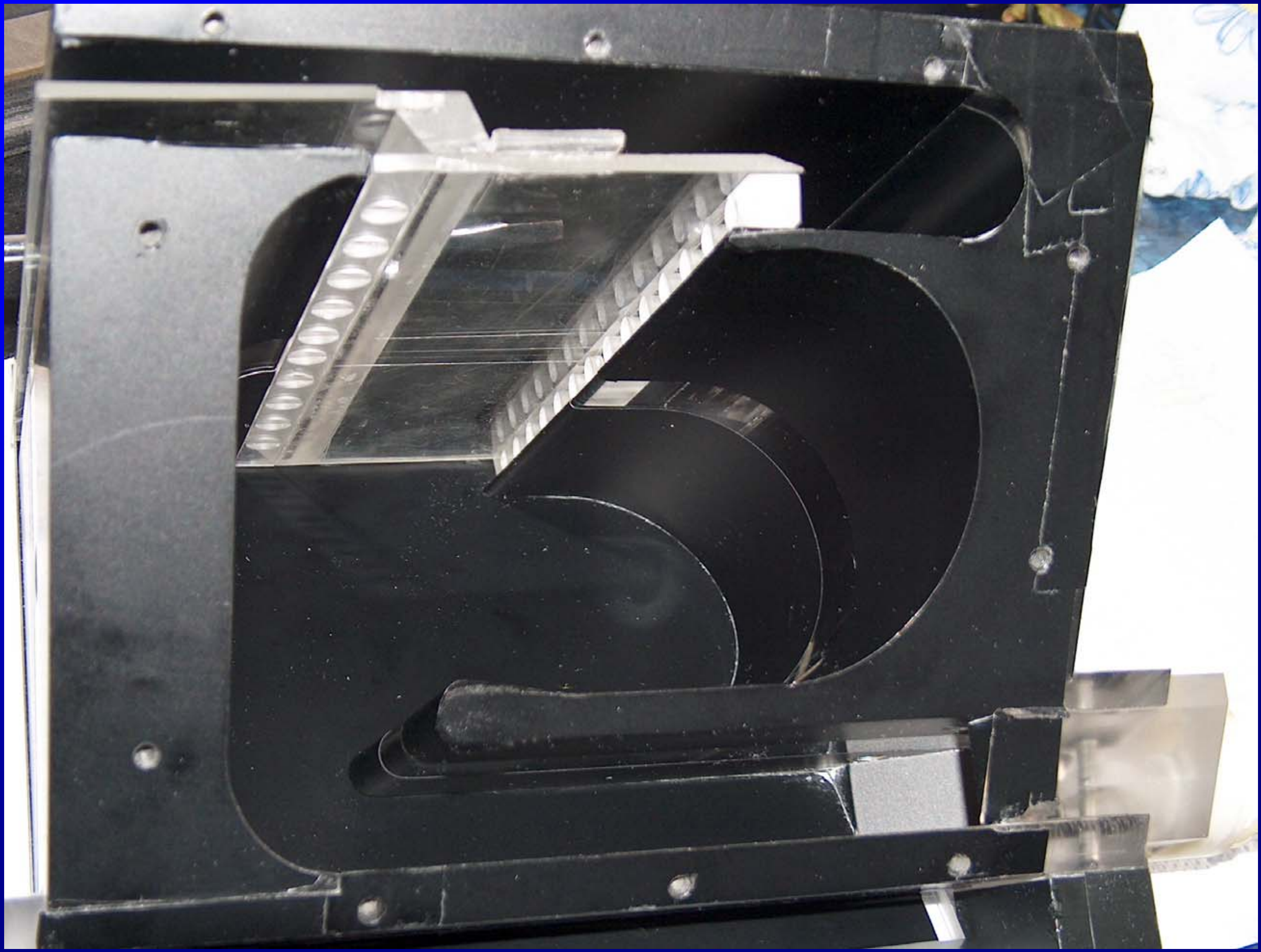




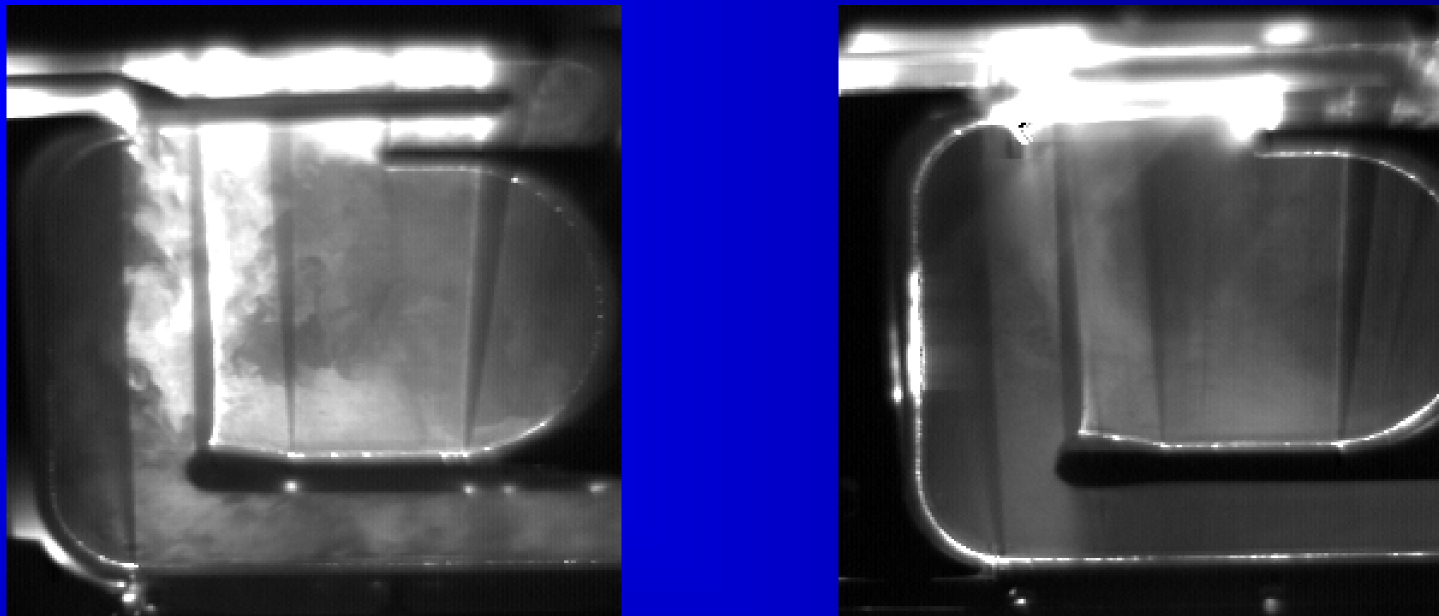




Turbulence enhancer



Turbulence enhancer

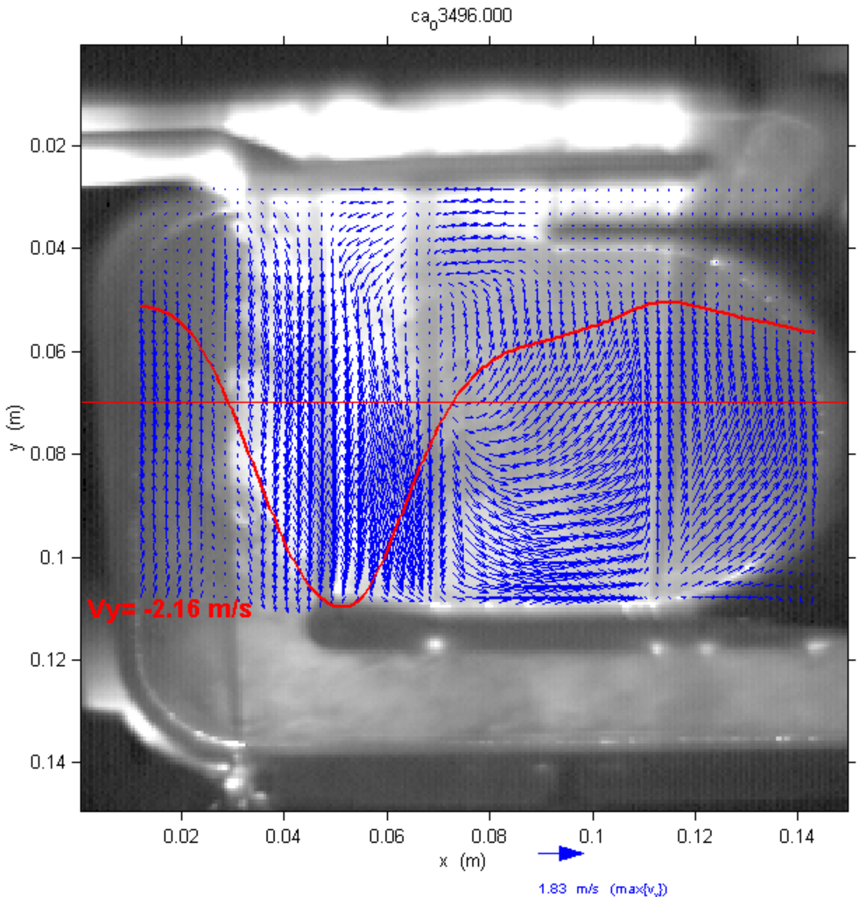


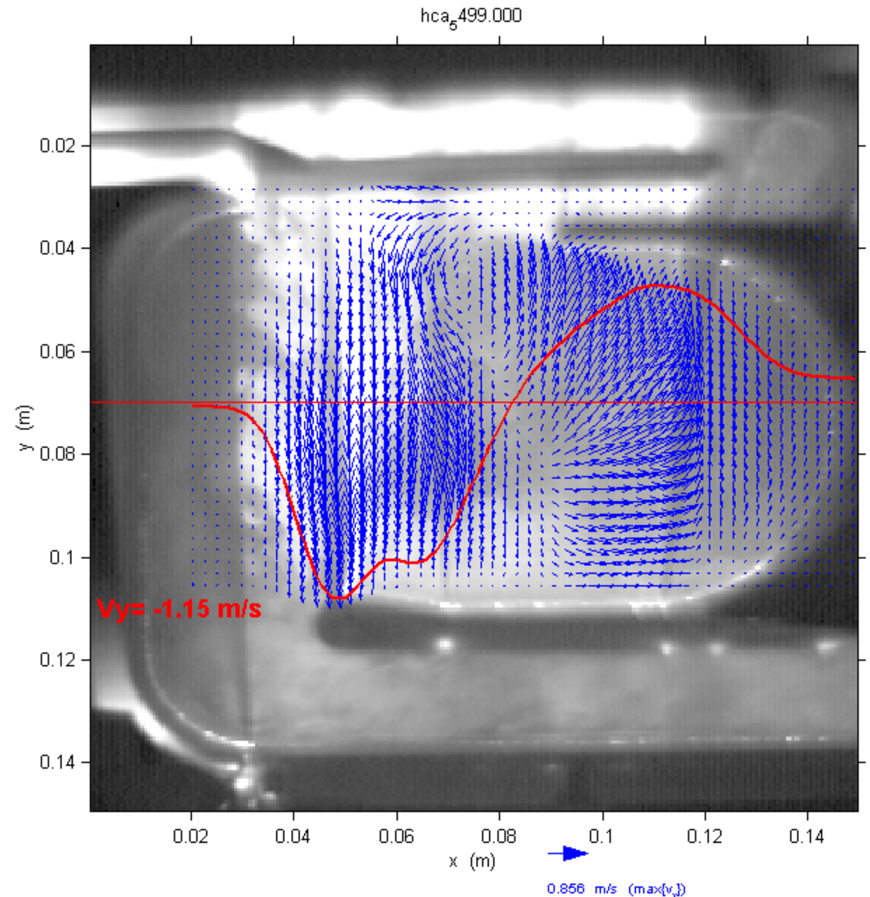
Flow visualization without (left) and with (right) turbulence enhancer.

Images used are acquired at 4500fps

Configuration „A”

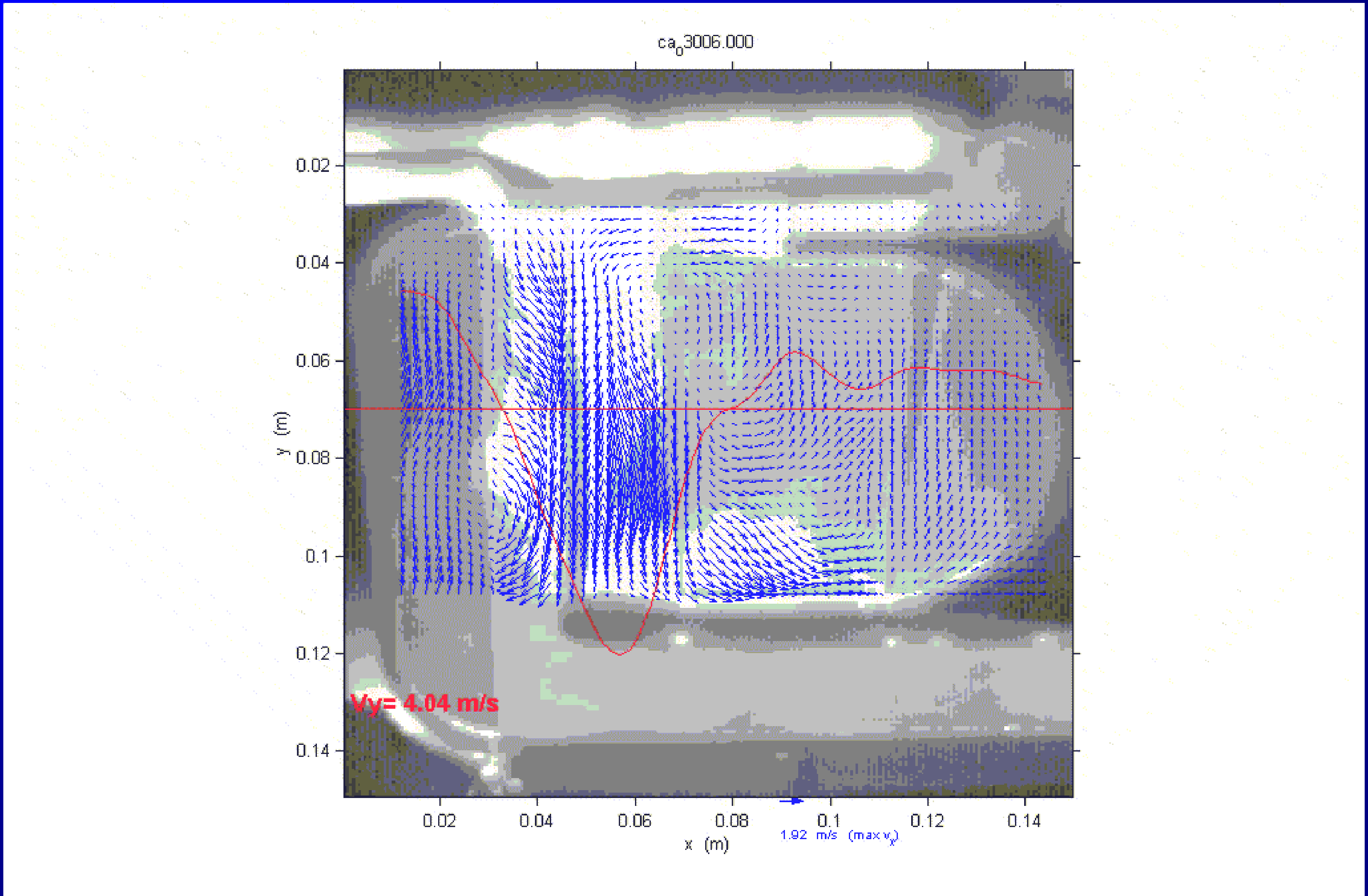
Images from High Speed Camera analysed by Optical-Flow based PIV





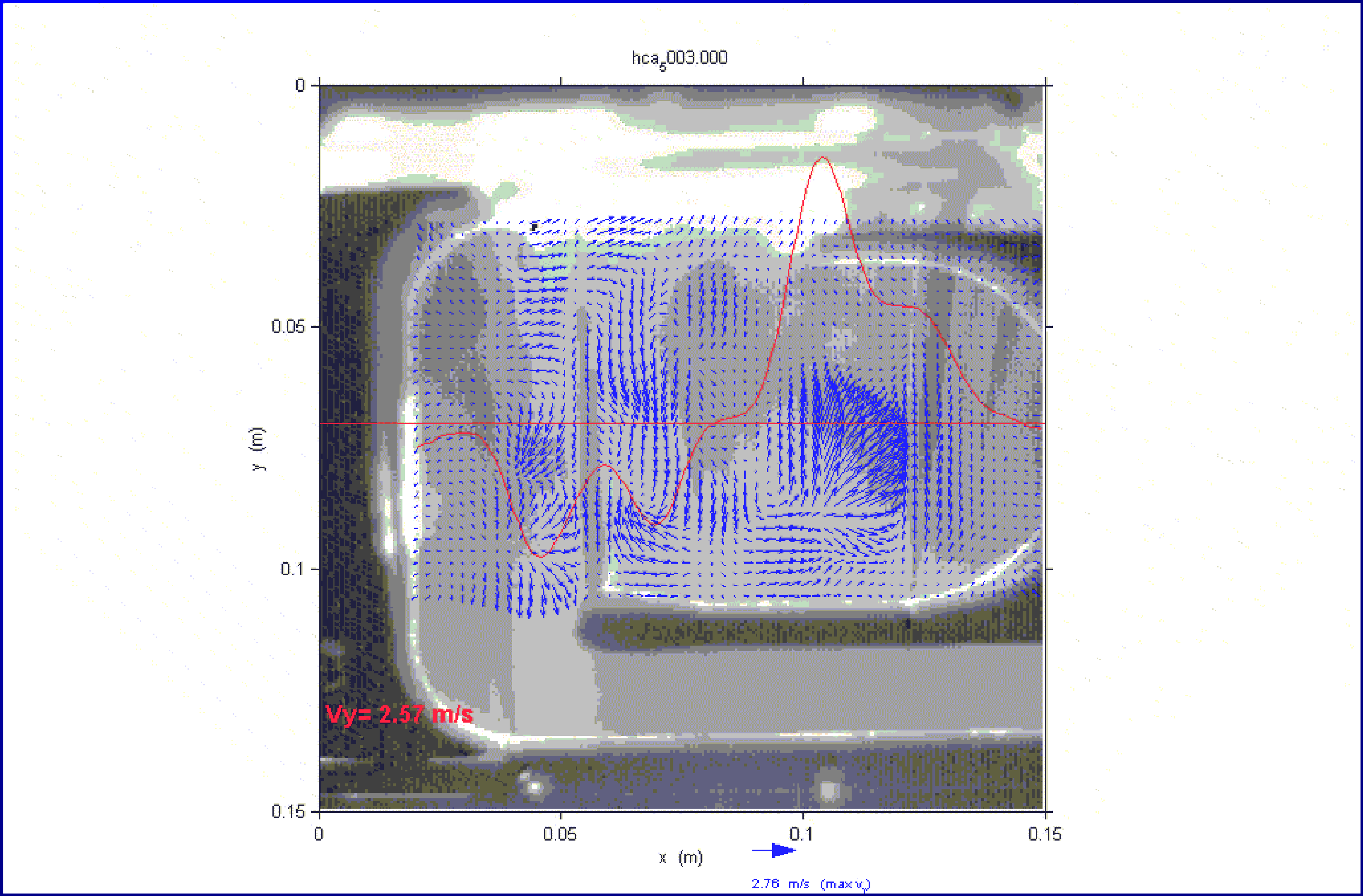
PIV measured averaged vector field and velocity profile without (left) and with (right) turbulence enhancer.
500 images used are acquired at 4500fps

Images from High Speed Camera



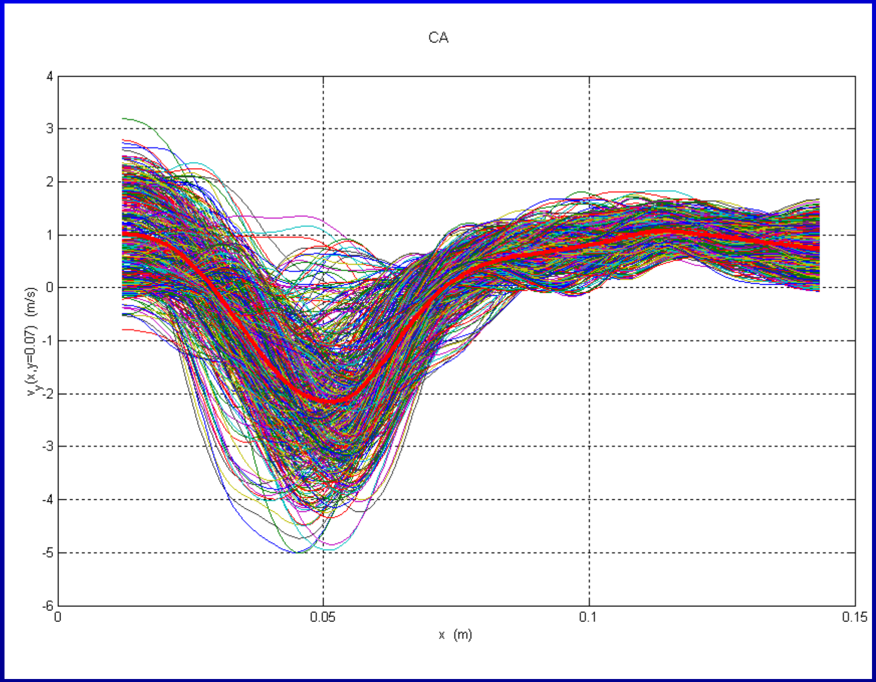
PIV measured vector fields and velocity profiles
without turbulence enhancer. 500 images acquired at 4500fps

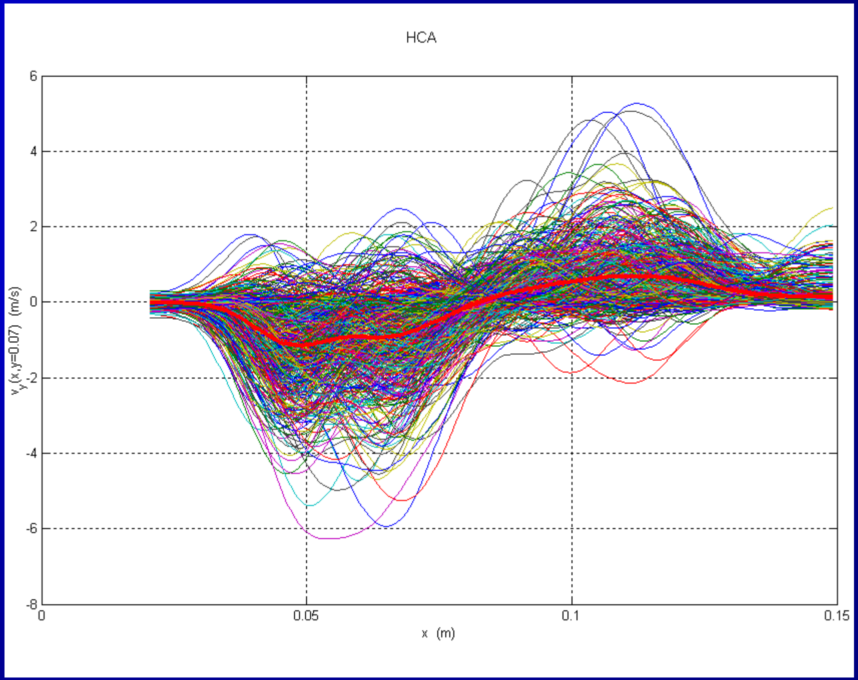
Images from High Speed Camera



PIV measured vector fields and velocity profiles
with turbulence enhancer. 500 images acquired at 2200fps

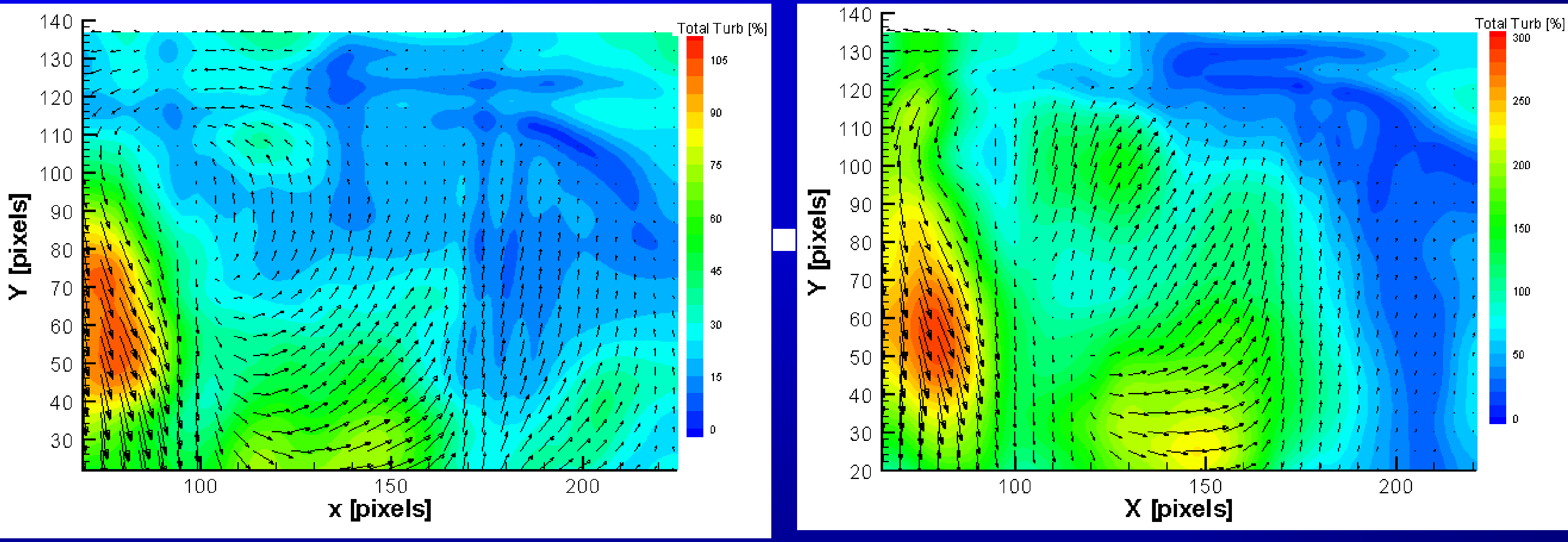
Images from High Speed Camera analysed by Optical-Flow based PIV





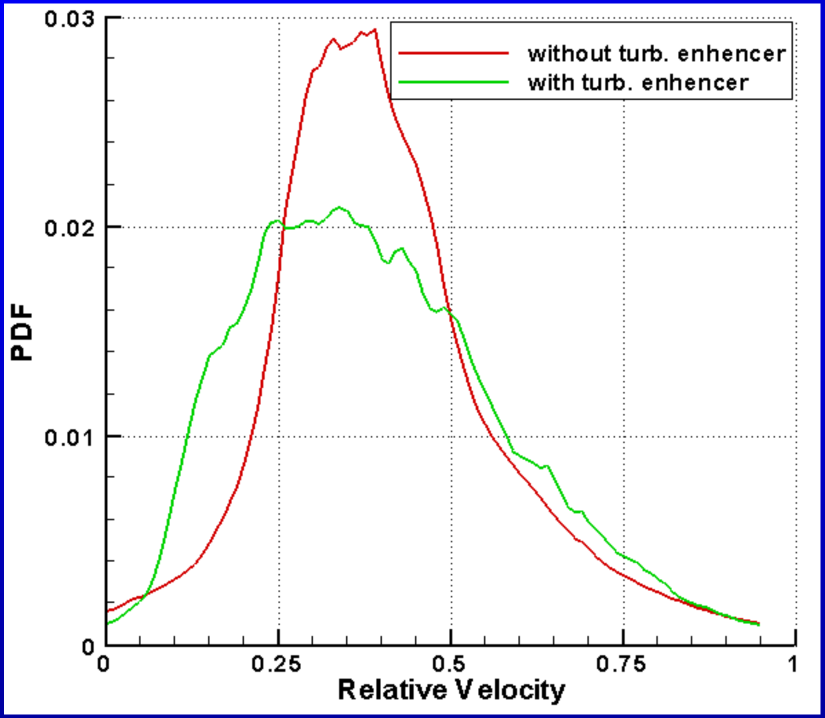
PIV measured velocity profiles of Vy
without (left) and with (right) turbulence enhancer.
500 images used are acquired at 4500fps

Images from High Speed Camera analysed by Optical-Flow based PIV

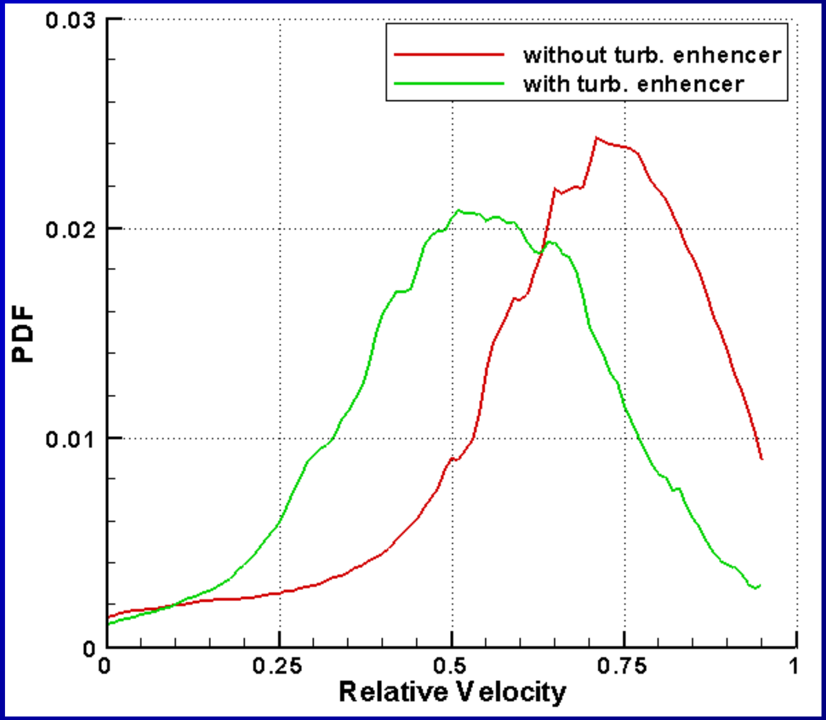


PIV measured averaged velocity field
without (left) and with (right) turbulence enhancer.
500 images used are acquired at 4500fps

Images from High Speed Camera analysed by Optical-Flow based PIV



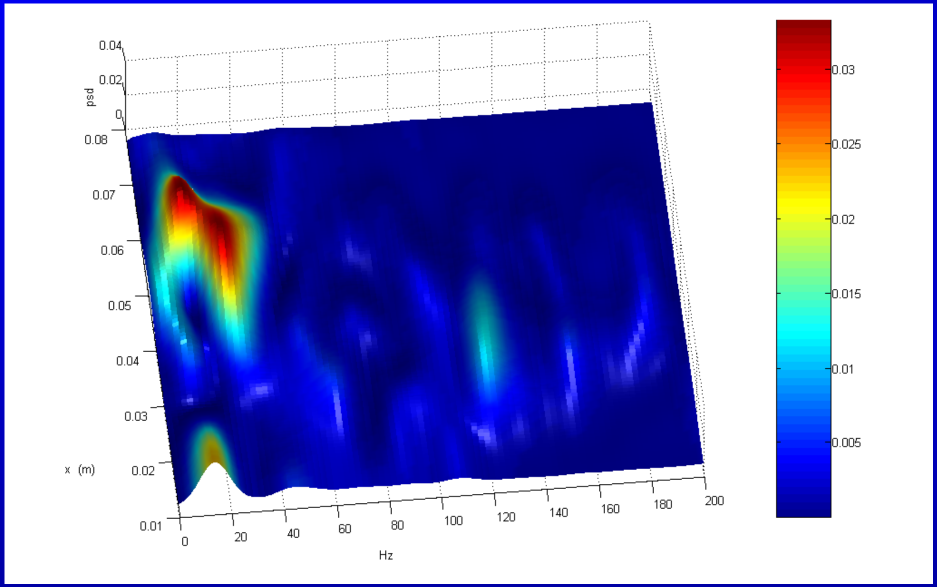
PDF of X- velocity component

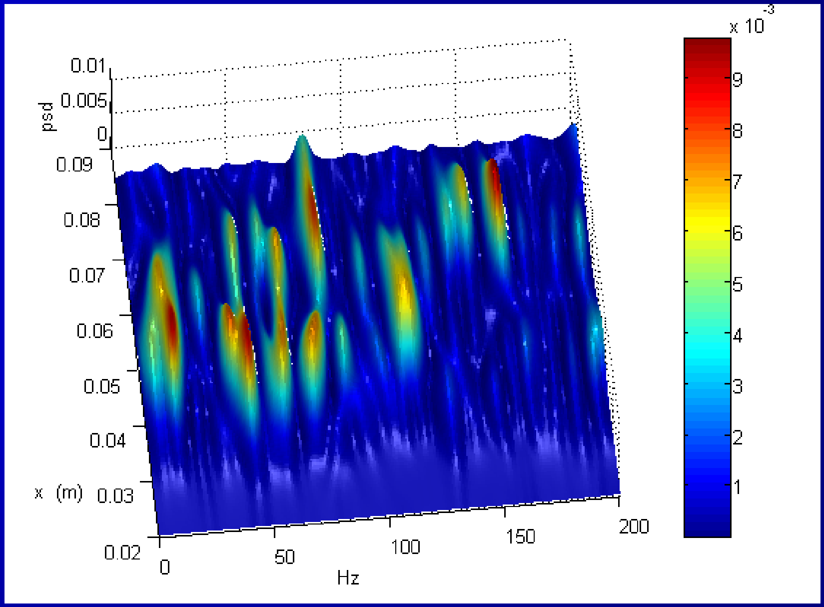


PDF of Y- velocity component

PIV measured PDF of the velocity field without and with turbulence enhancer.
500 images used are acquired at 4500fps

Images from High Speed Camera analysed by Optical-Flow based PIV



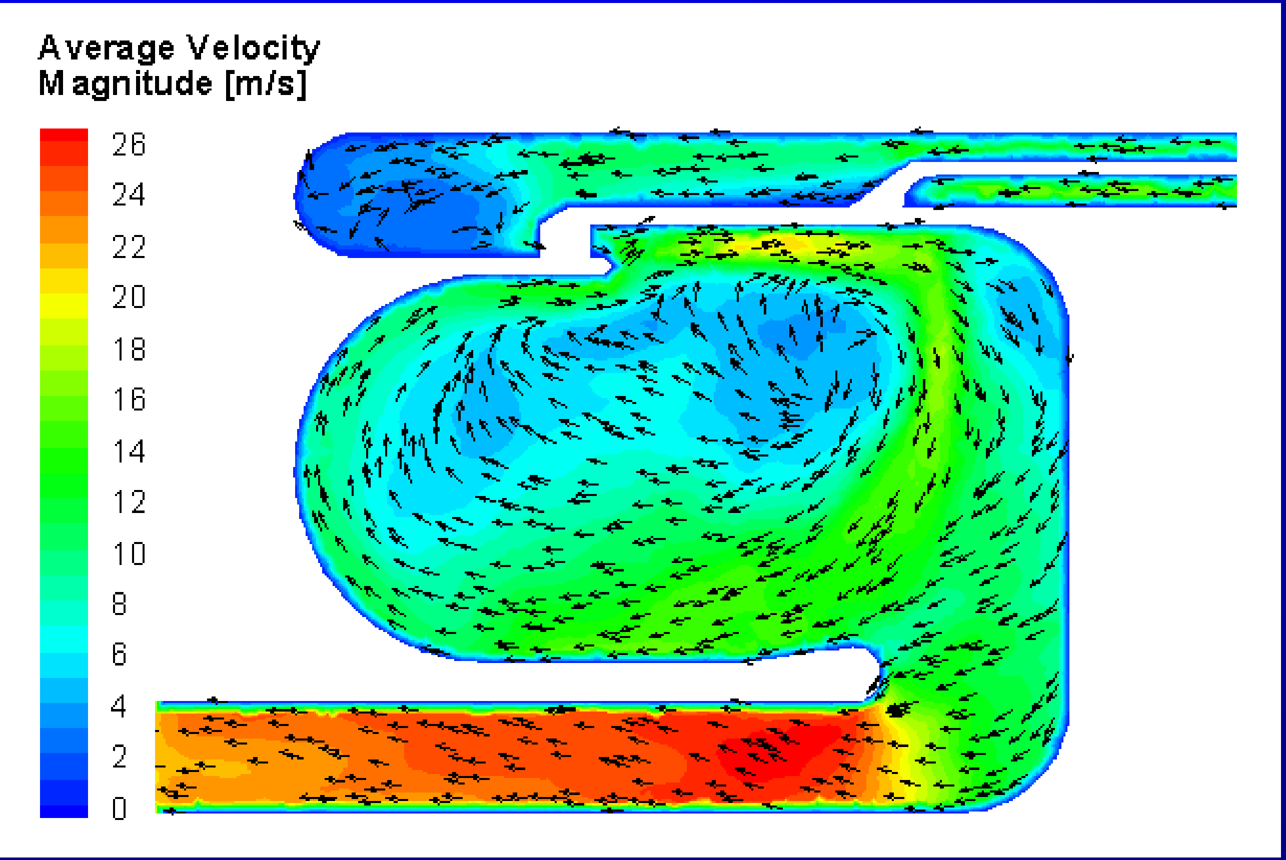


FFT filtering of PIV measured velocity fluctuations. Power Density Spectrum for Y- velocity component measured without (left) and with (right) turbulence enhancer.

500 images used are acquired at 4500fps

Numerical simulation:
Mean fields of Velocity Vectors & Contours of Magnitude

Model of turbulence: Large Eddy Simulation



Configuration **„A”**

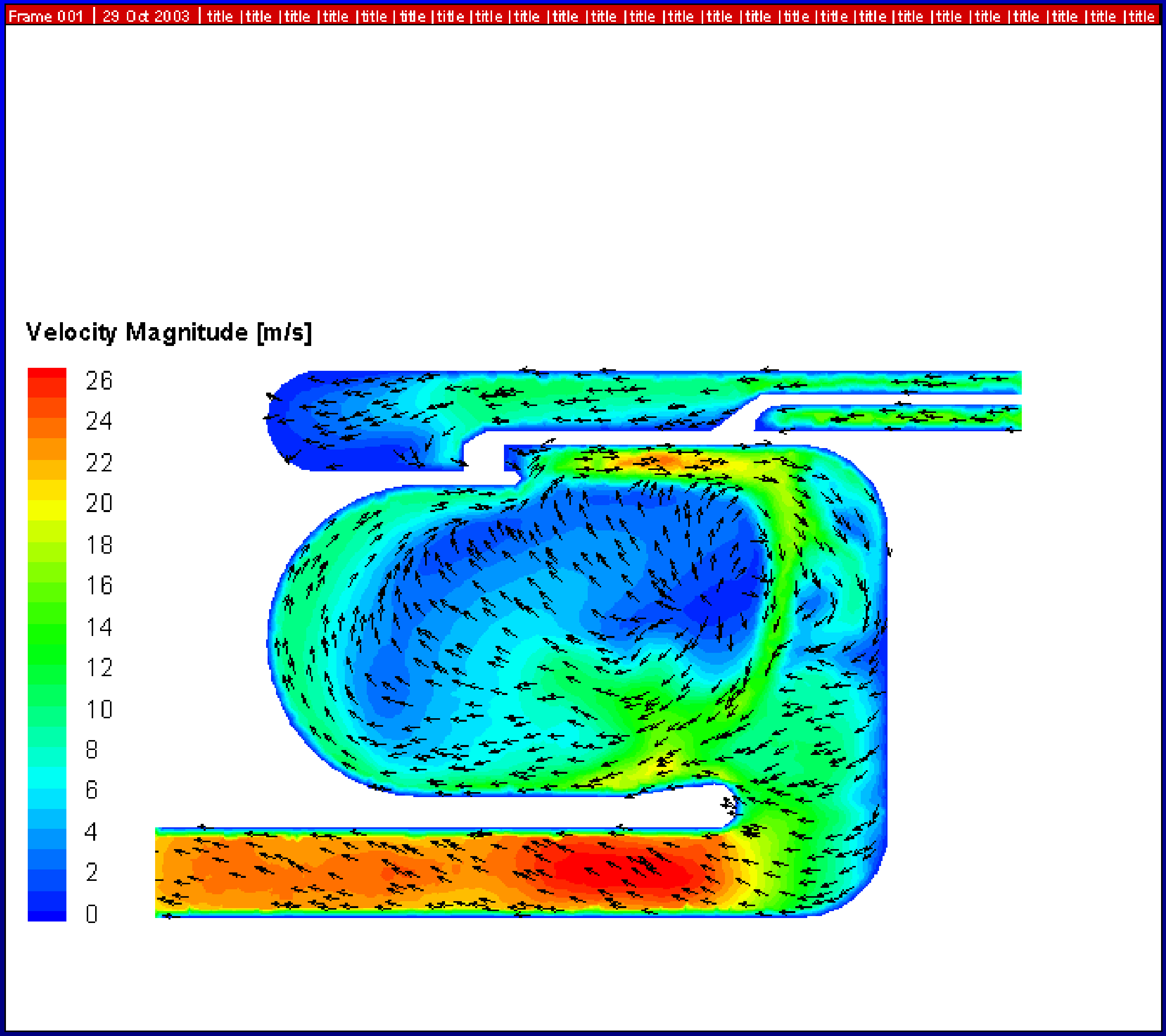
<u>Velocity</u>

Inlet 1: open
Inlet 2: open
Outlet: 21 m/s

Geometry III – with „turbulence enhancer”

Numerical simulation:
0.001s time steps for Vectors & Contours of Velocity Magnitude

Model of turbulence: Large Eddy Simulation



Configuration „A"

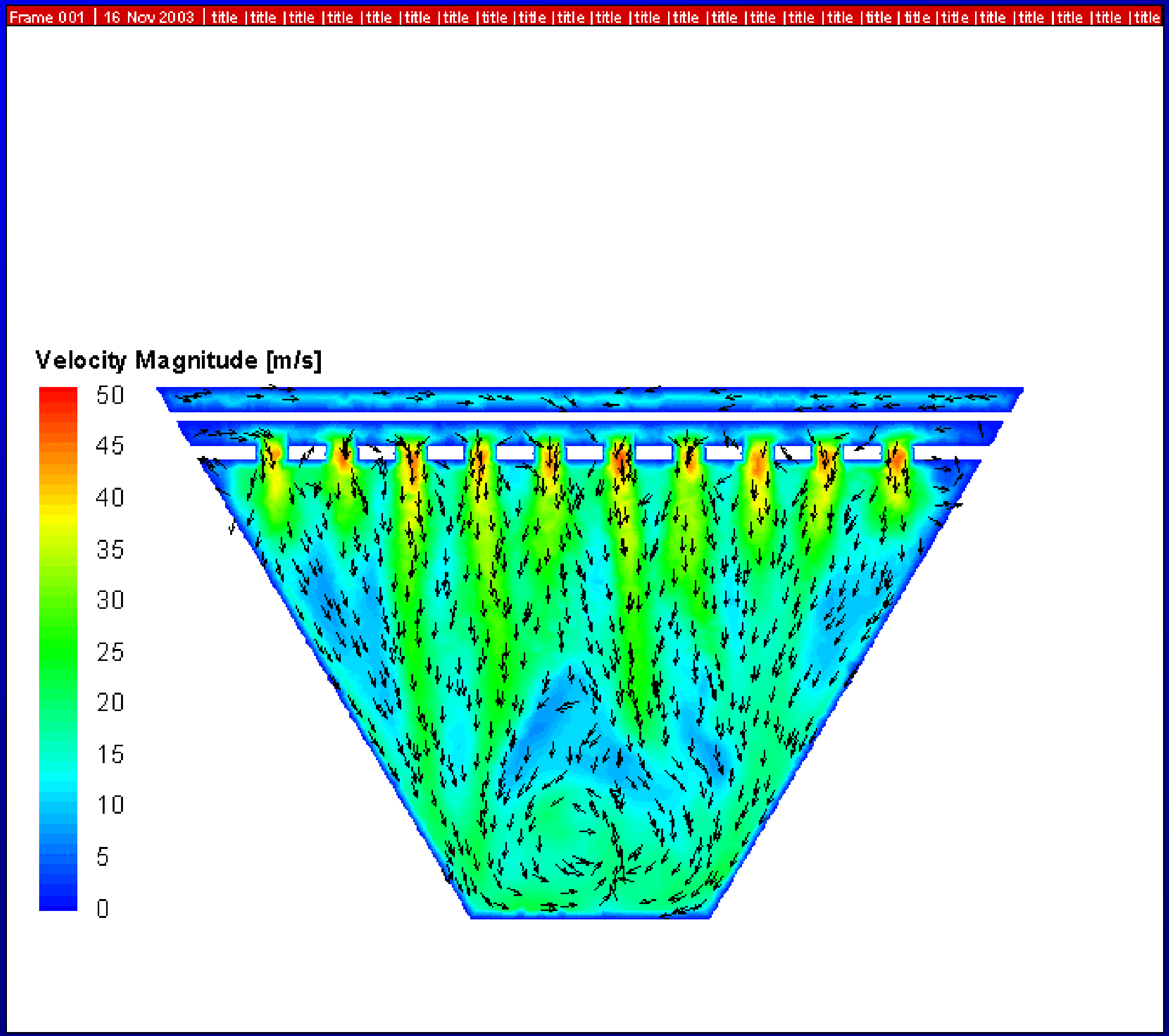
<u>Velocity</u>

Inlet 1: open
Inlet 2: open
Outlet: 21 m/s

Geometry III
with „turbulence enhancer"

Numerical simulation:
0.001s time steps for Vectors & Contours of Velocity Magnitude

Model of turbulence: Large Eddy Simulation



Configuration „A”

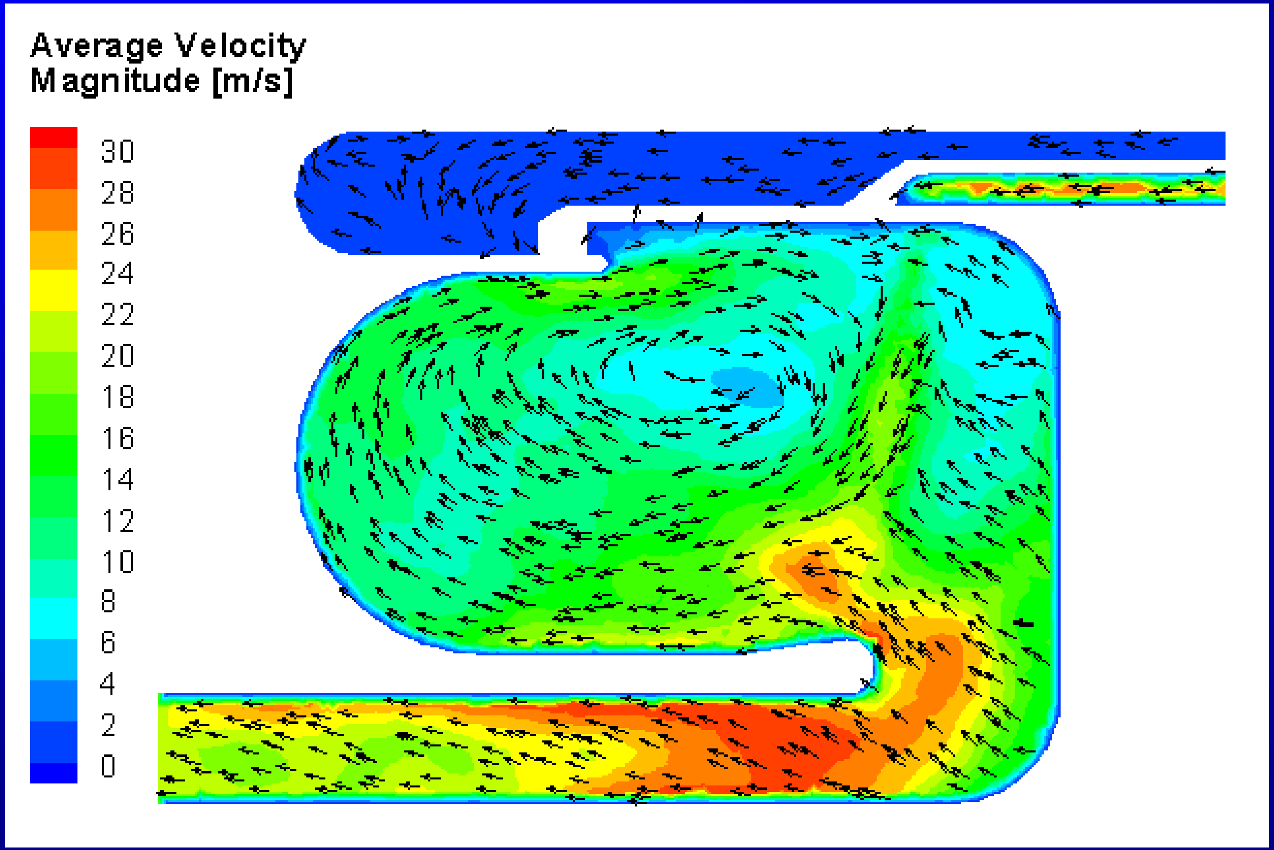
Velocity

Inlet 1: open
Inlet 2: open
Outlet: 21 m/s

Geometry III
with „turbulence enhancer”

Numerical simulation:
Mean fields of Velocity Vectors & Contours of Magnitude

Model of turbulence: Large Eddy Simulation



Configuration „C”

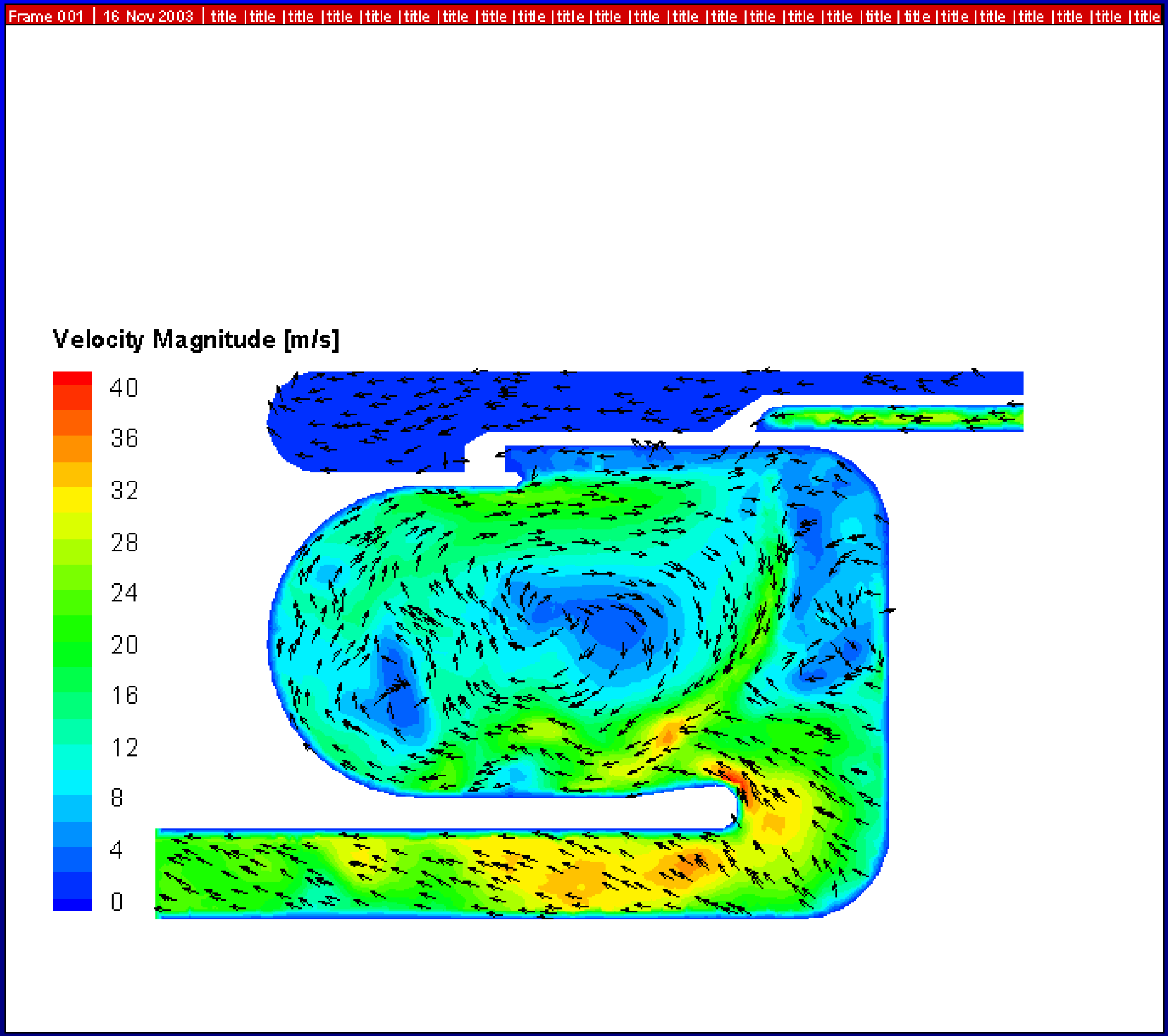
Velocity

Inlet 1: closed
Inlet 2: open
Outlet: 20.18 m/s

Geometry III – with „turbulence enhancer”

Numerical simulation:
0.001s time steps for Vectors & Contours of Velocity Magnitude

Model of turbulence: Large Eddy Ssimulation



Configuration **„C"**

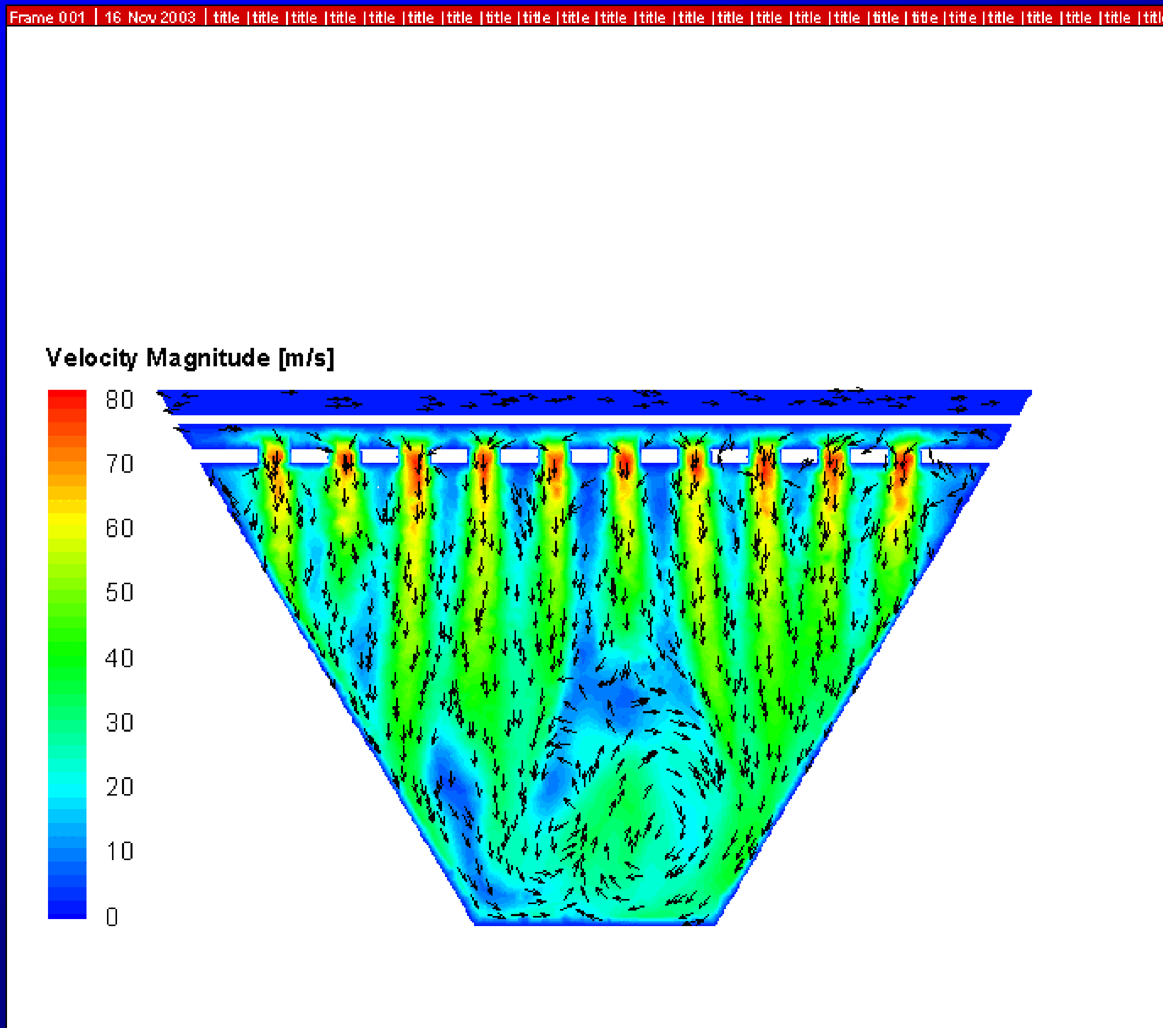
<u>Velocity</u>

Inlet 1: closed
Inlet 2: open
Outlet: 20.18 m/s

Geometry III
with „turbulence enhancer"

Numerical simulation:
0.001s time steps for Vectors & Contours of Velocity Magnitude

Model of turbulence: Large Eddy Ssimulation



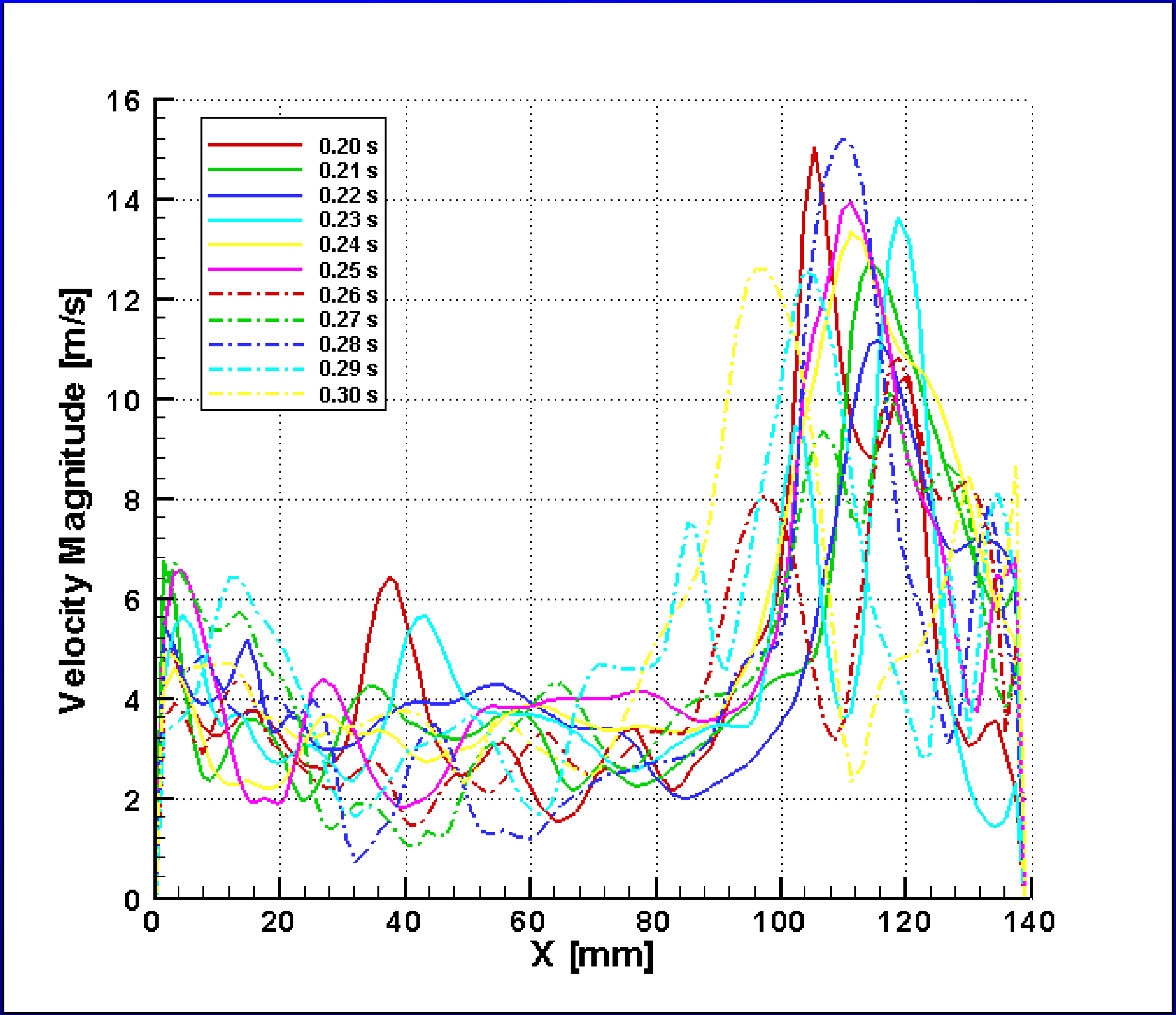
Configuration **„C”**

<u>Velocity</u>

Inlet 1: closed
Inlet 2: open
Outlet: 20.18 m/s

Geometry III
with „turbulence enhancer”

Numerical simulation:
Velocity profiles for different time steps calculated by LES-model

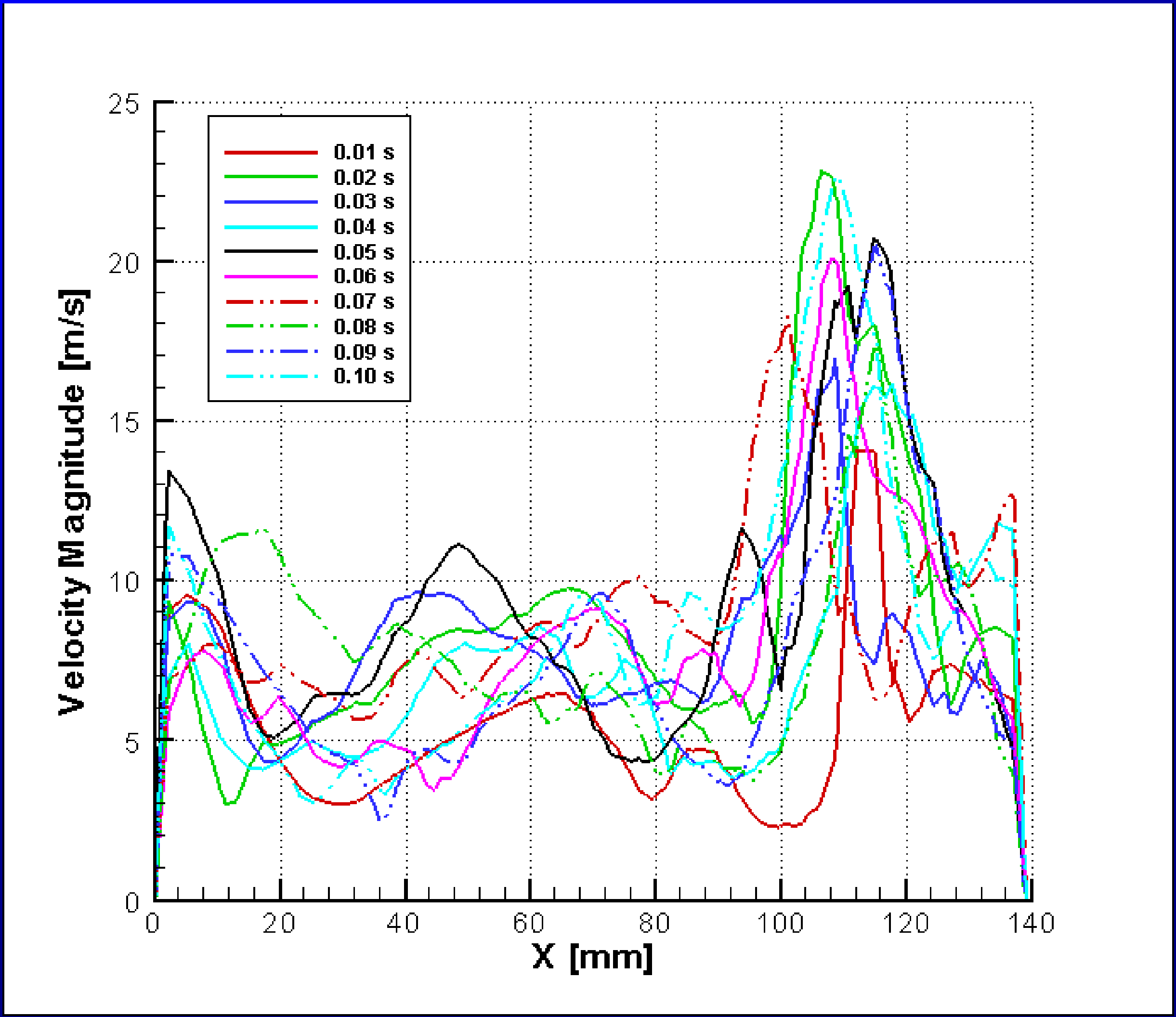


Configuration **„A"**

without „turbulence enhancer"

Geometry IV

Numerical simulation:
Velocity profiles for different time steps calculated by LES-model

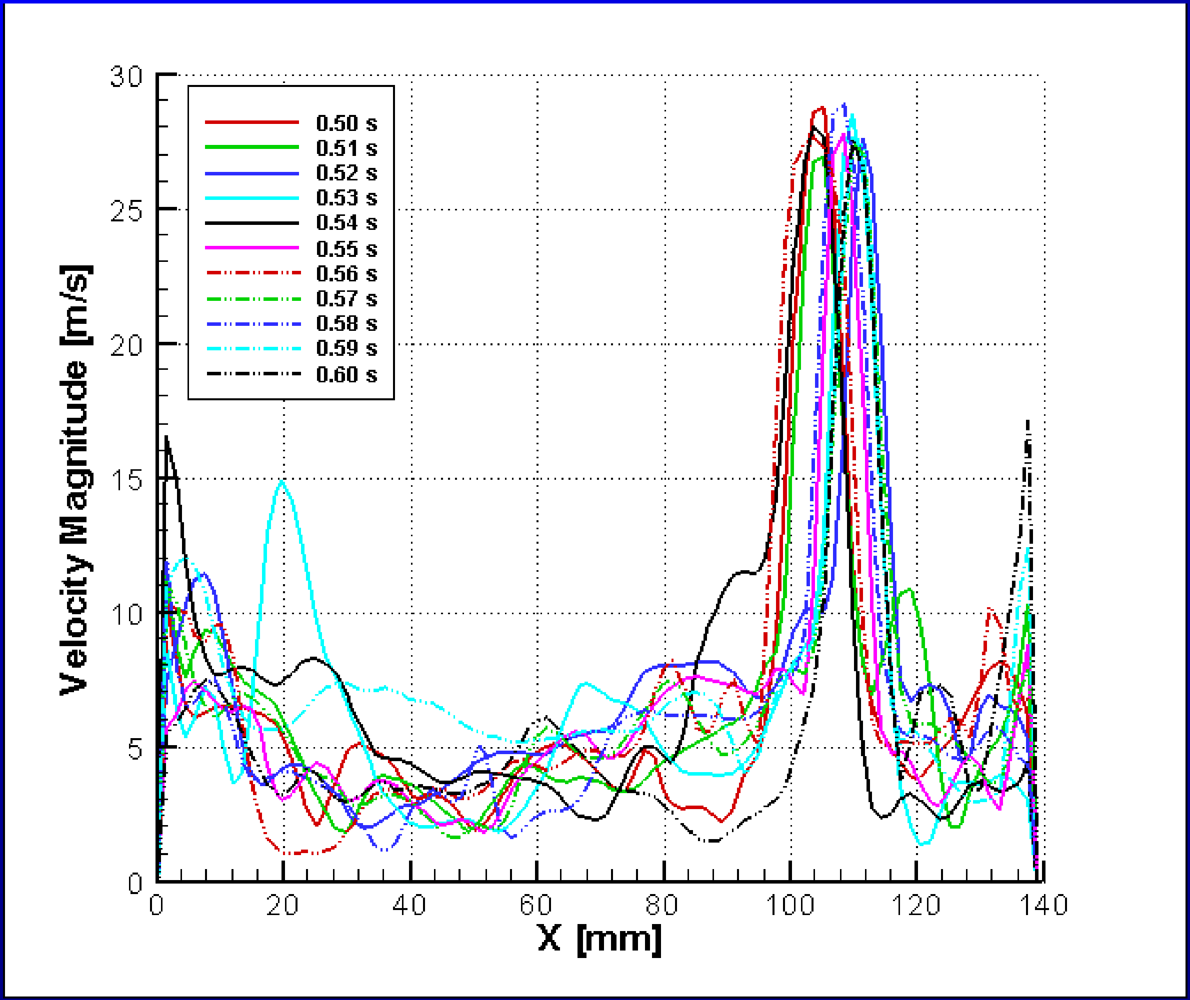


Configuration **„A”**

with „turbulence enhancer”

Geometry III

Numerical simulation:
Velocity profiles for different time steps calculated by LES-model

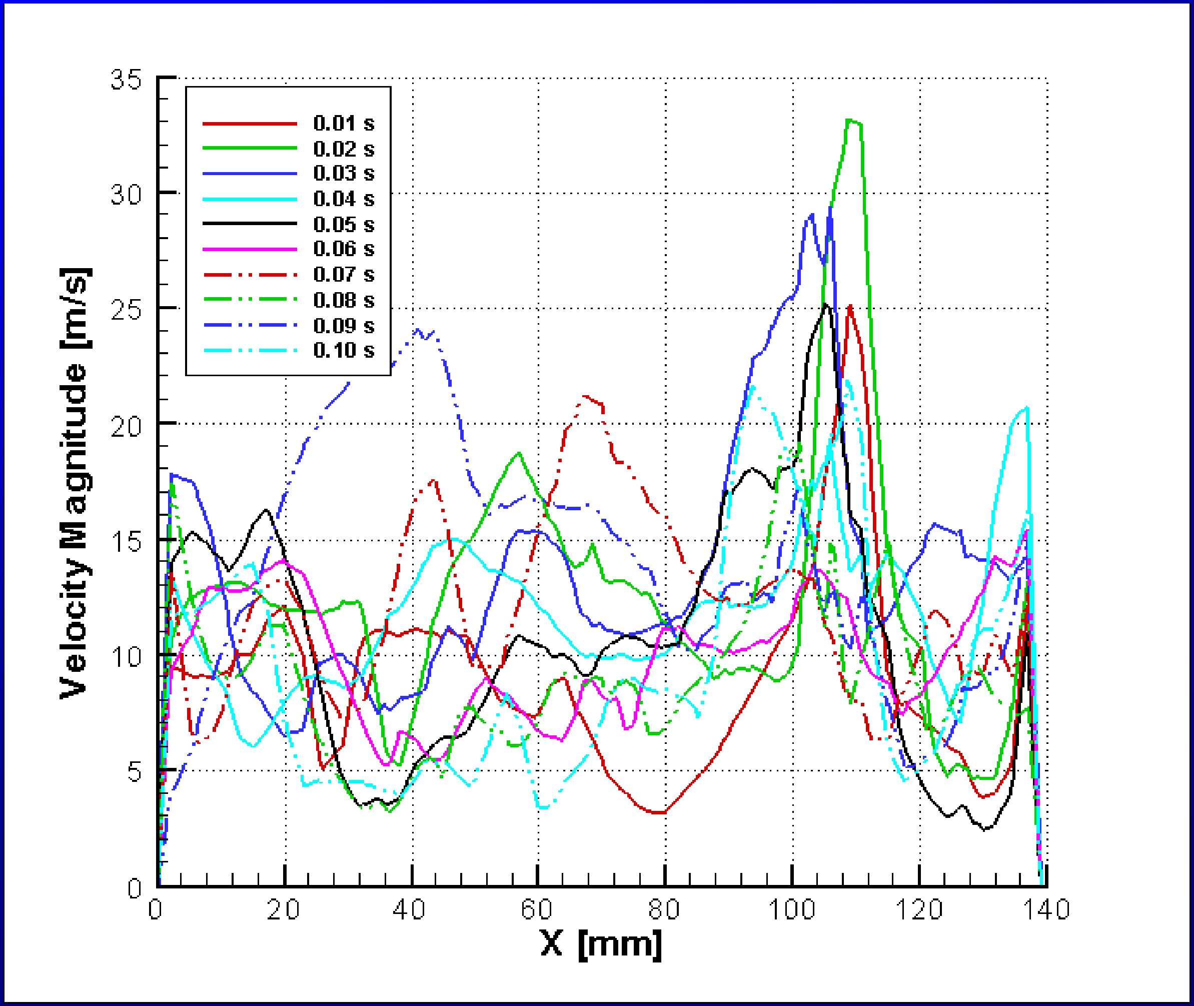


Configuration „C”

without „turbulence enhancer”

Geometry IV

Numerical simulation:
Velocity profiles for different time steps calculated by LES-model

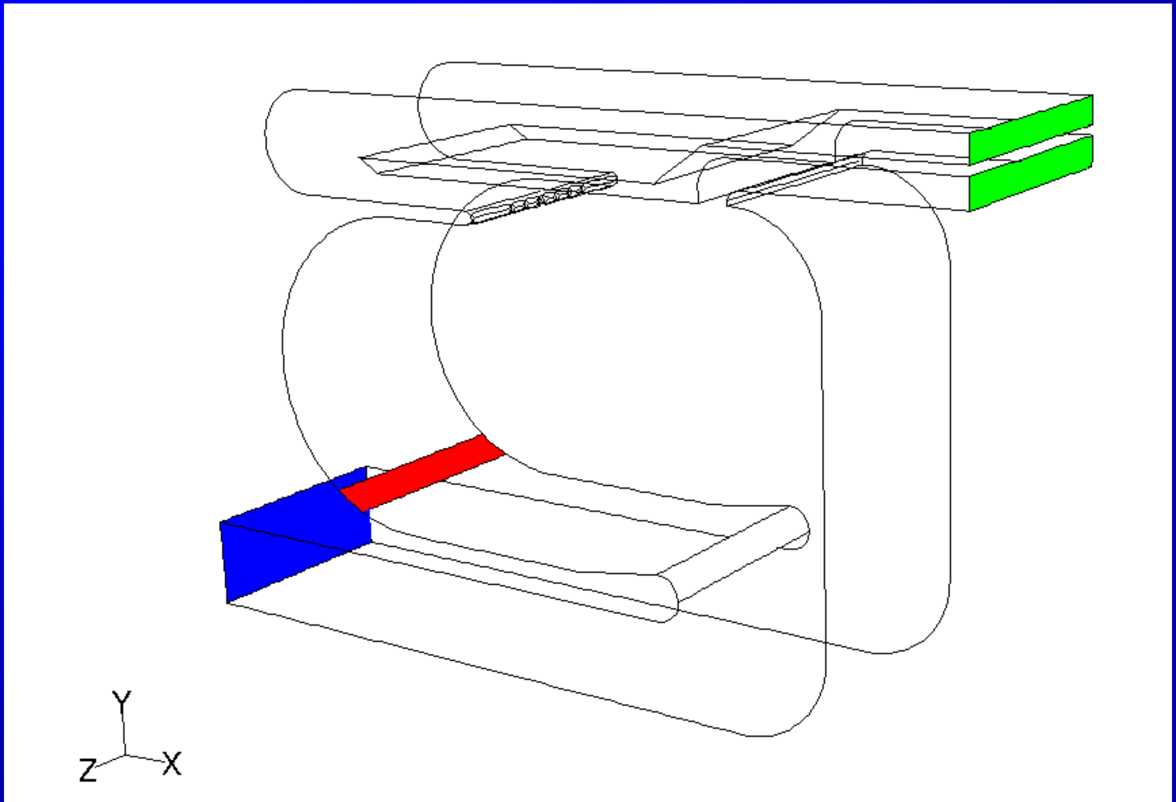


Configuration **„C"**

with „turbulence enhancer"

Geometry III

Numerical simulation of fuel injection



Configuration **„C”**

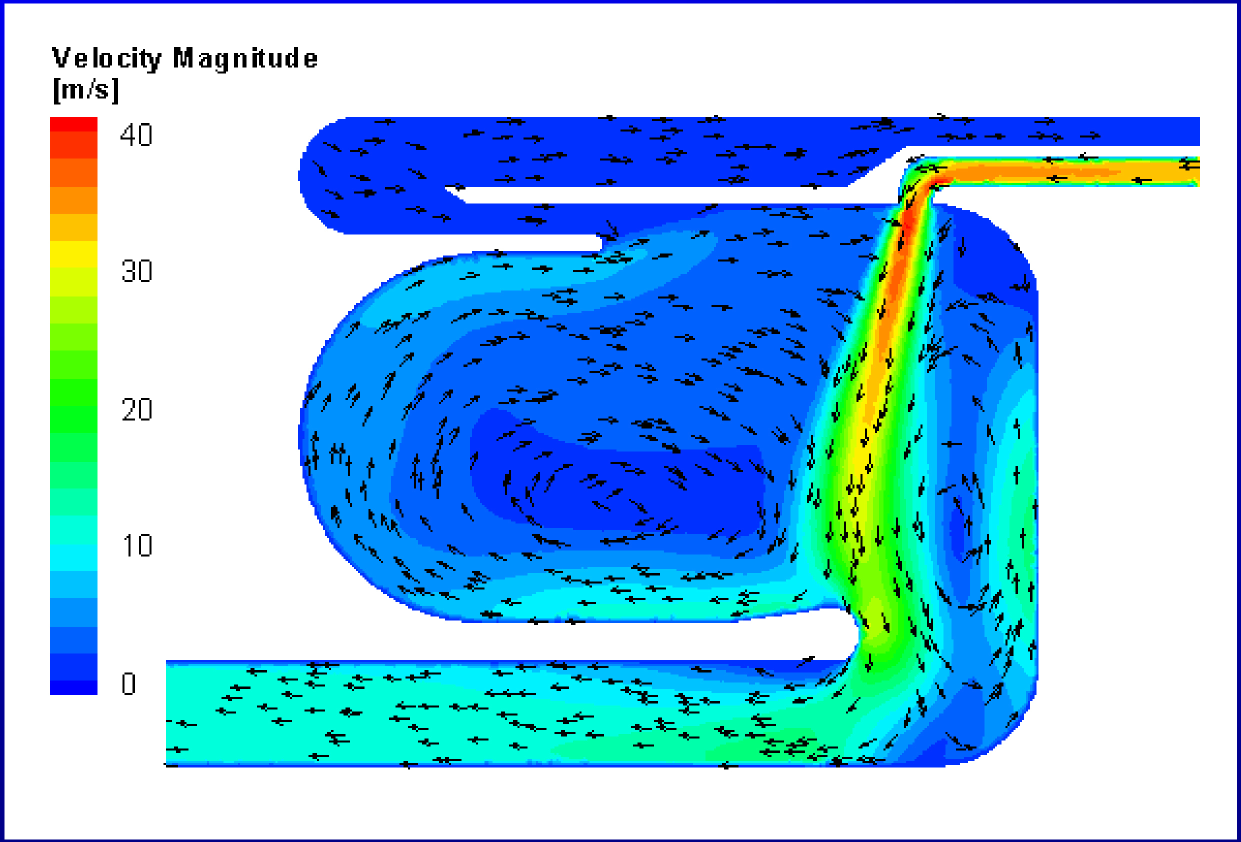
Geometry II

model: k - ε

Inlet 1: closed
Inlet 2: mass flow rate: 0.01225 kg/s with temperature 293K
Fuel injection: wall with 3273K
Outlet: outflow (ratio 1:1 to inlet)
Others walls: adiabatic walls

Simulation of fuel injection

Numerical simulation:
Vectors & Contours of Velocity Magnitude

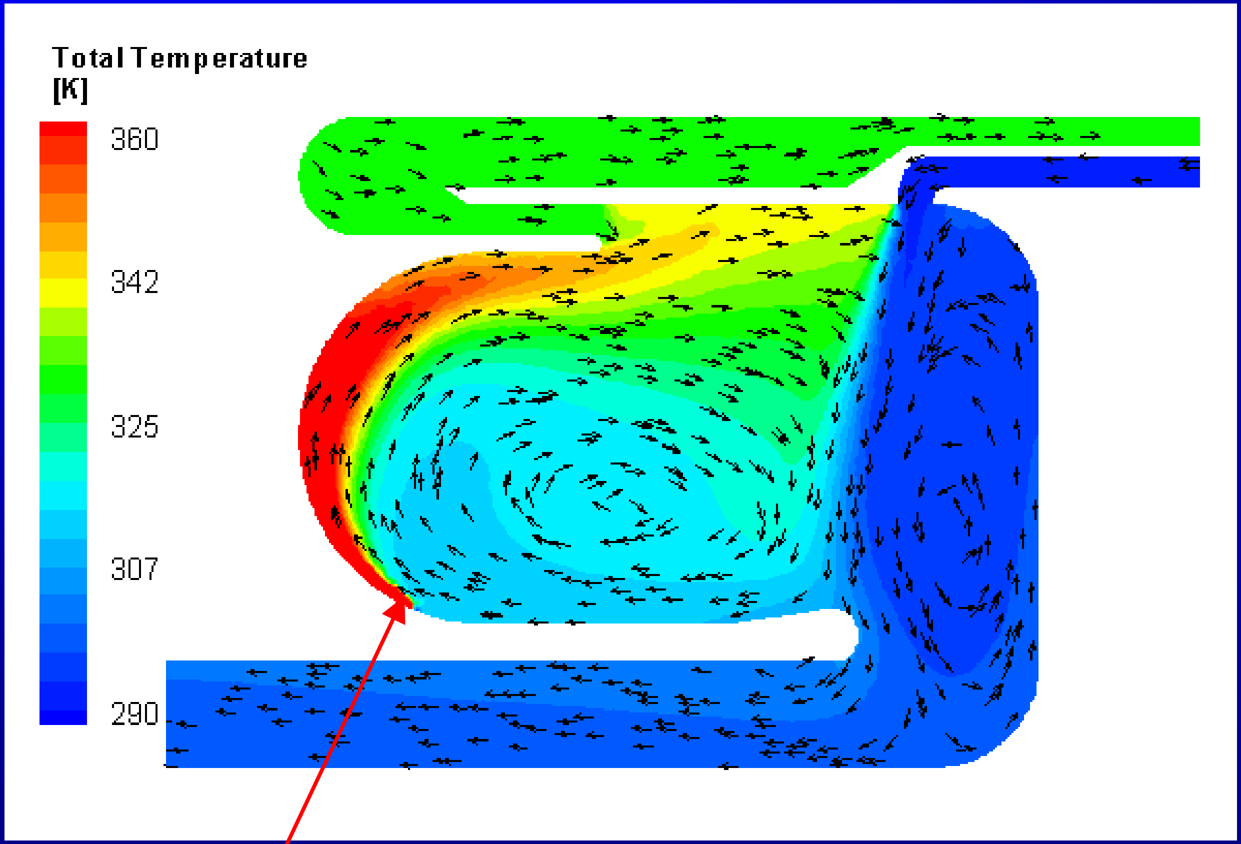


Configuration **„C"**

Geometry II

Simulation of fuel injection jet

Numerical simulation:
Vectors of Velocity Magnitude & Contours of Temperature

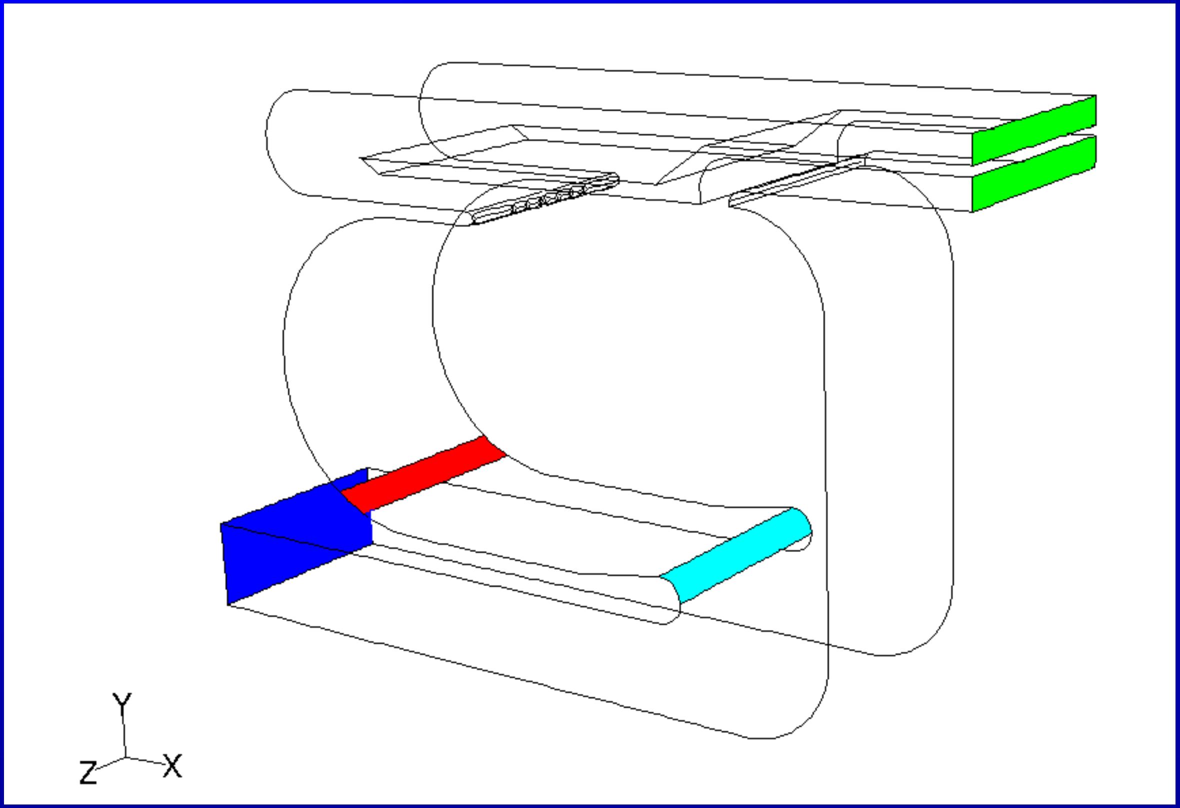


Configuration **„C"**

Geometry II

Fuel injection – hot air source

Numerical simulation of fuel injection and cooling jets



Configuration **„C"**

Geometry II

model: k - ε

Inlet 1: closed

Inlet 2: mass flow rate: 0.01225 kg/s with temperature 293K

Fuel injection: wall with 3273K

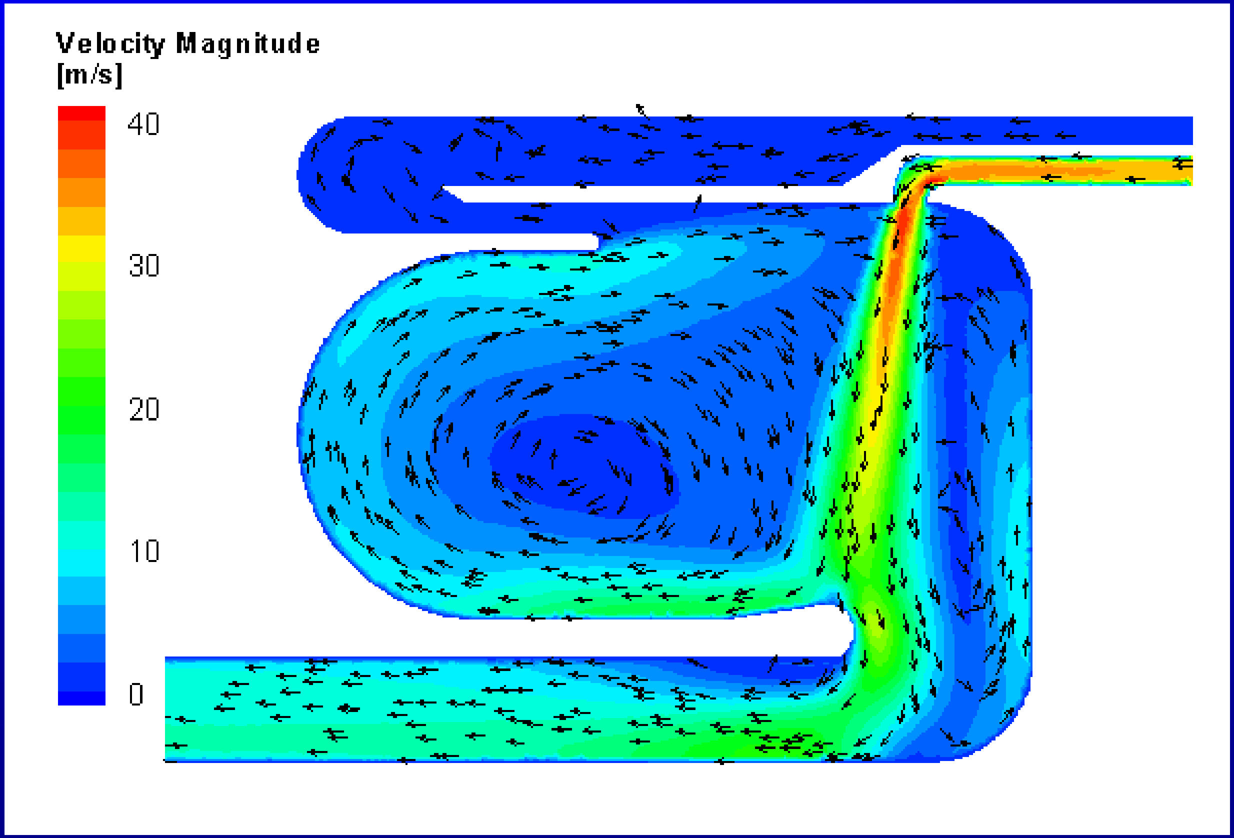
Cooling: mass flow rate 0.001225 kg/s (10% of Inlet), temp. 223K

Outlet: outflow (ratio 1:1 to inlet)

Others walls: adiabatic walls

Simulation of fuel injection and cooling jet

Numerical simulation:
Vectors & Contours of Velocity Magnitude

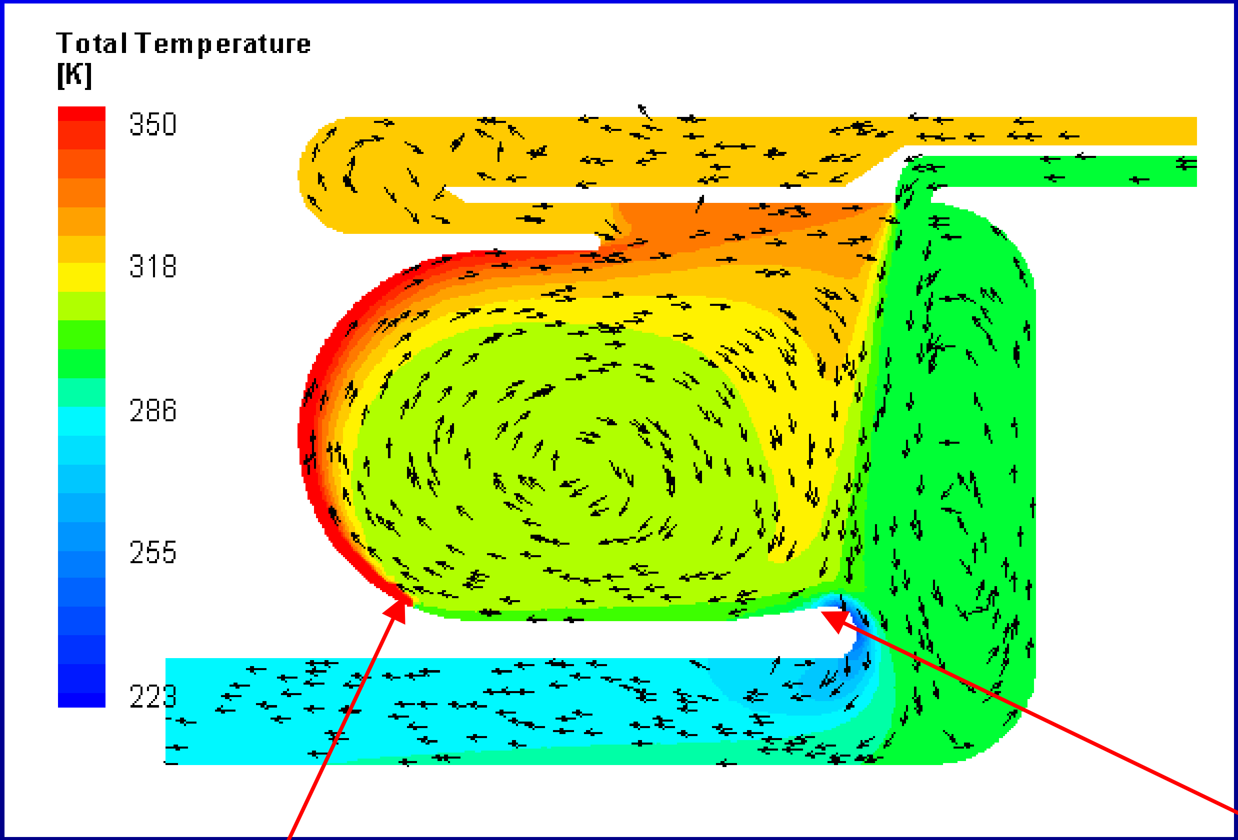


Configuration **„C"**

Geometry II

Simulation of fuel injection and cooling jet

Numerical simulation:
Vectors of Velocity Magnitude & Contours of Temperature



Configuration **„C"**

Geometry II

Fuel injection – hot air source

Cooling jet – cold air source

Deliverables

- **Turbulence enhancer improves mixing properties. Observations of the flow show periodical beats of the main flow jet, which interacts with the adjacent vortices**
- **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.**
- **PIV based on High Speed Imaging shows the relationship between the jet instabilities and the mixing efficiency in the cavity centre.**
- **Interaction of the fuel injection and cooling jet is limited and only local variation of temperature could be observed numerically and experimentally.**

FLOXCOM PROJECT WP5

http://floxcom.ippt.gov.pl

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