Numerical Methods Applied to Fluid Flow Metering

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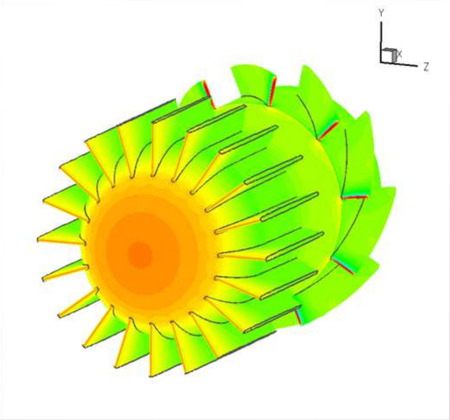
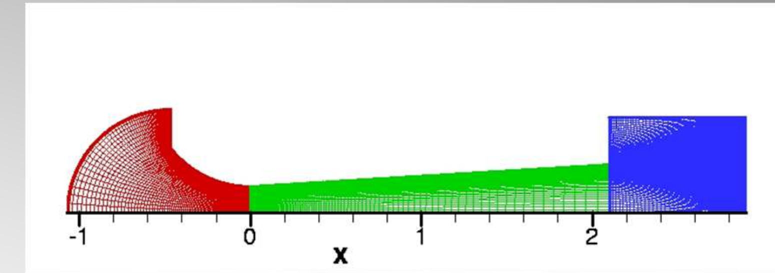
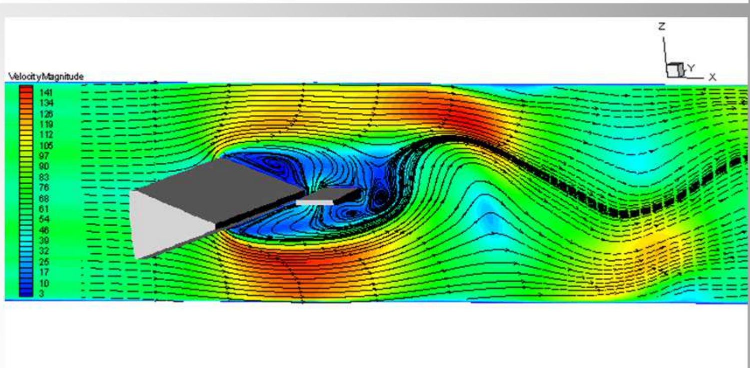
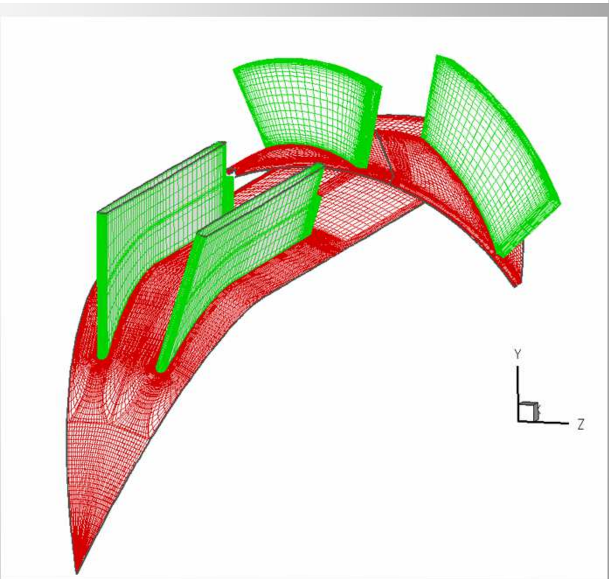


Overview

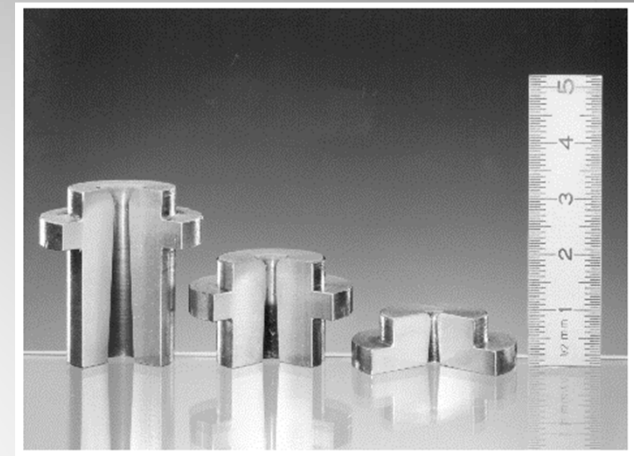
Introduction
Basics
Choice of right “tools”
Various case studies
Validation and verification
Recommendations, future work
Conclusions







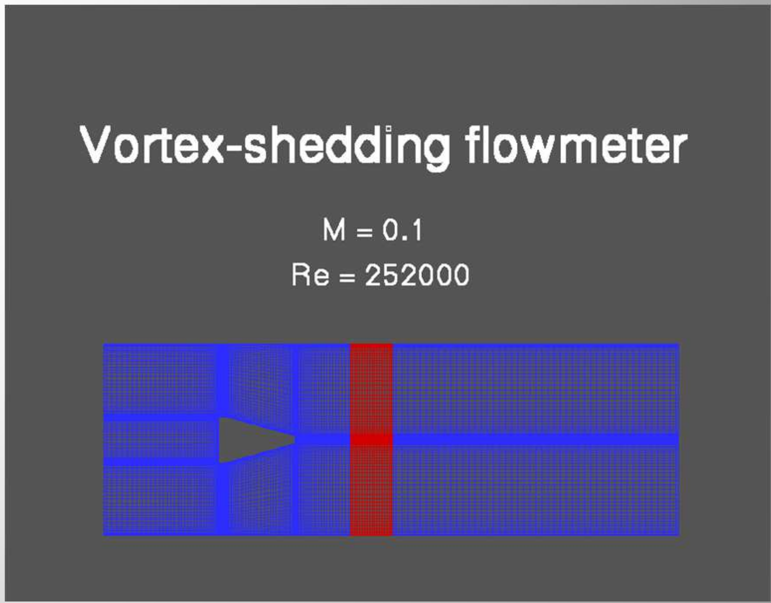
Introduction



The beginning: critical flow Venturi nozzles (CFVN)

Next configuration: vortex flow meters

And after that: turbine flow meters
ultrasonic flow meters
rotary piston flow meters
cavitation nozzles
flow straighteners
......



Goals

Problems

Basics

Main goal: numerical simulation of flow fields in flow metering configurations

In all cases, scale sufficiently large to give Kn = $\lambda/L < 0.01$

with $\lambda \cong 10^{-8} - 10^{-9}$ m => continuum

Notice: Kn ~ M/Re

a) flows with M/Re > 1 called rarefied

b) incompressible gas ($M \rightarrow 0$) can not be rarefied

c) small Re flow could mean rarefied fluid

d) large Re flows are always continuum

Basics

Physics of the flow:

compressible (Ma ≥ 0.3) => mixed hyperbolic-parabolic, coupled

incompressible => mixed elliptic-hyperbolic-parabolic, decoupled

laminar (Re ≤ 2300 !)

turbulent => turbulence model (k-ε, k-ω, RNG, realizable, SST, RSM, LES, DES, DNS)

steady

unsteady – periodic (deterministic) or stochastic

simulation method must have low numerical dissipation, since

$$\mu_{Tot} = \mu_{Phys} + \mu_{Num} \Rightarrow 1/Re_{Tot} = 1/Re_{Phys} + 1/Re_{Num}$$

Basics

Considerations in numerical simulation methods (CFD):

2-D or 3-D configuration

grid generation: structured multiblock (mutigrid?)

unstructured tetrahydral, hexahydral, polyhydral

hybrid

moving (deforming) grids (adapting to flow)

overlapping grids (chimera), immersed body grids

quality of grids: smoothing, continuity, resolution in time and space

Computation: time and space accuracy, damping

Boundary conditions

Multiprozessing (parallel processing)

Basics

Choice of correct tools:

hardware (minimum requirements)

competence of staff

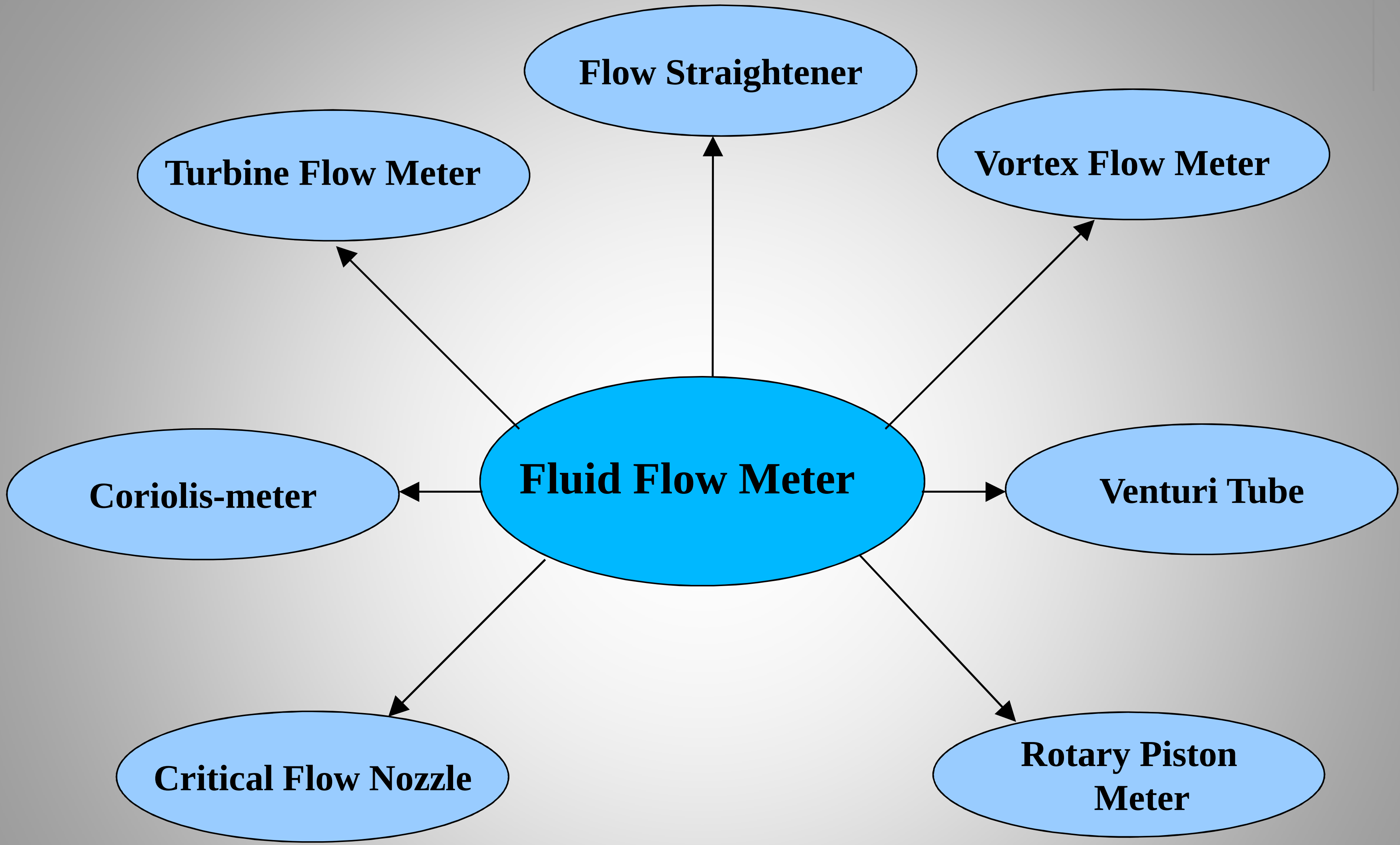
Software: system

preprocessing (grid generation)

simulation system (CFX, Fluent, adapco Star CCM+, my own programs ACHIEVE, trace, Flower, ….)

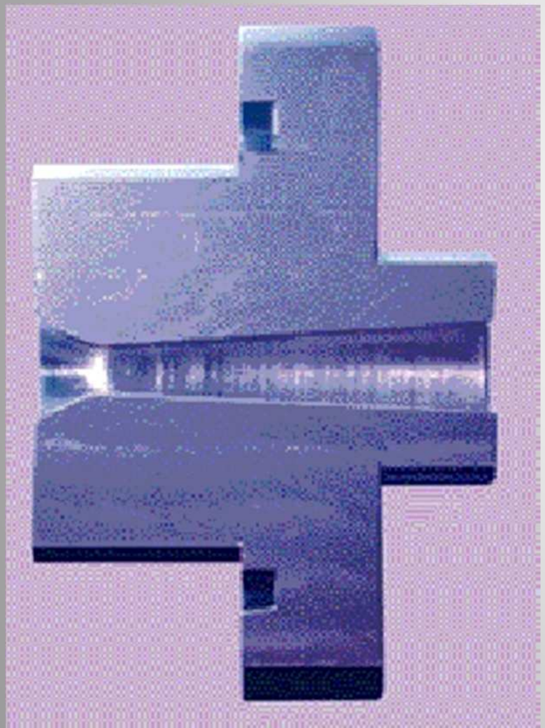
postprocessing (included, Tecplot, …)

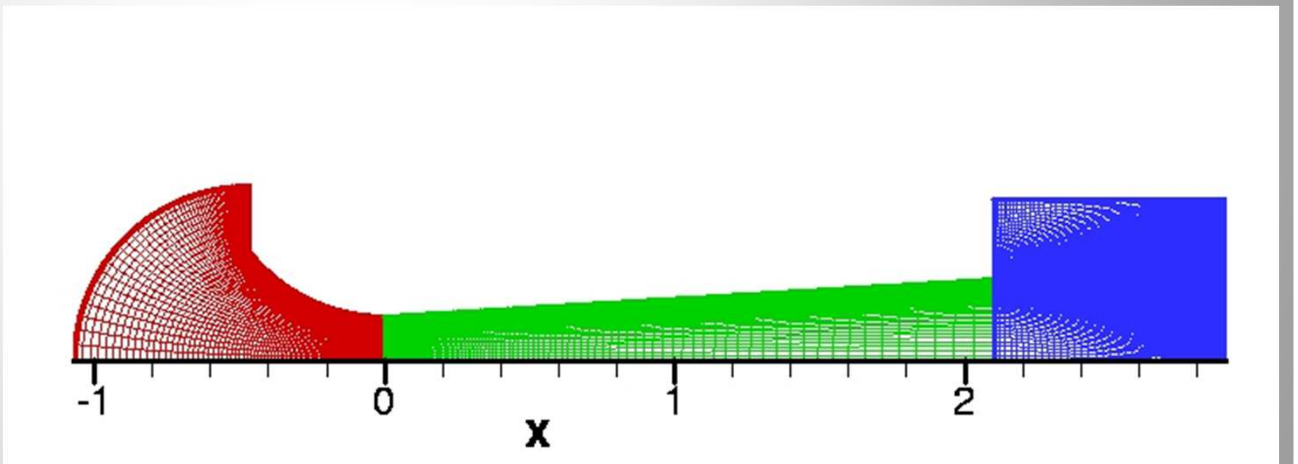
The correct choice will „make you or break you“ !


Flow Straightener
Turbine Flow Meter
Vortex Flow Meter
Coriolis-meter
Fluid Flow Meter
Venturi Tube
Critical Flow Nozzle
Rotary Piston Meter

CFVN 1 - ISO

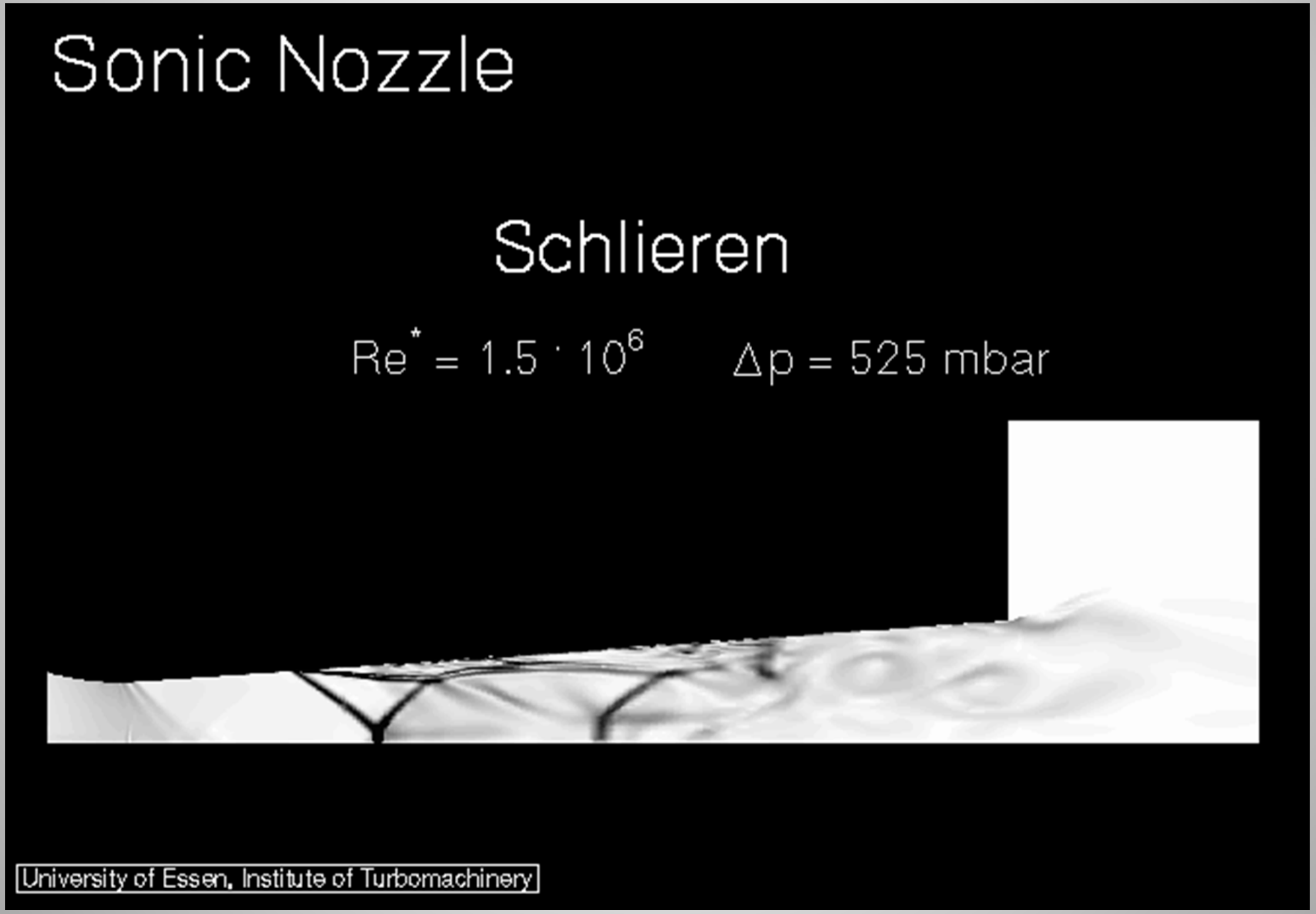
Shape: ISO 9300, toroidal version
different Reynolds numbers and pressure ratios
2-D axisymmetric, 3 blocks, structured, laminar





CFVN 1 - ISO

Resulting Flow, Movies, Re=1.5 10^6

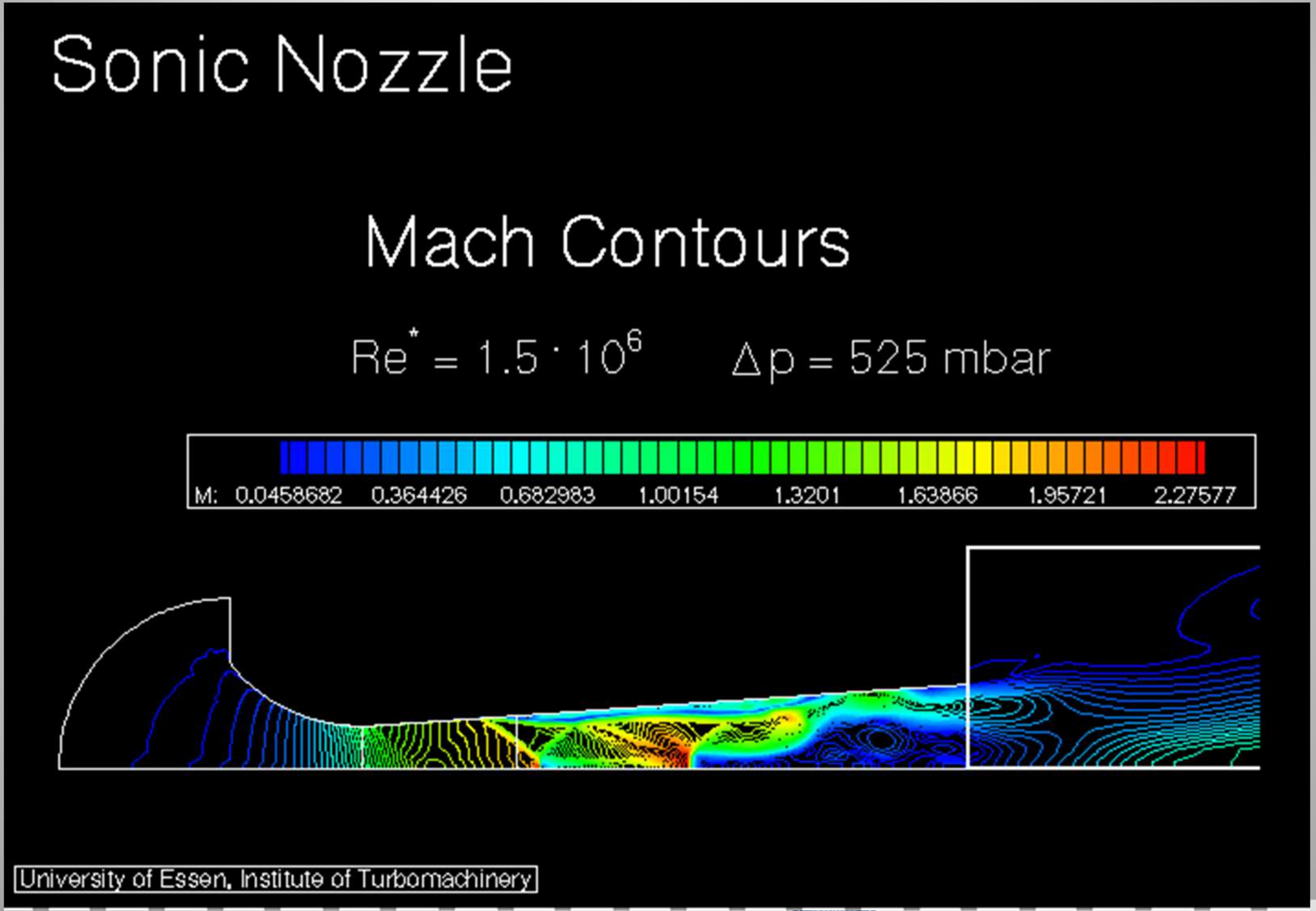


CFVN 1 - ISO

Resulting Flow, Movies, Re=0.1 10^6

CFVN 1 - ISO

Resulting Flow, Movies, Re=1.5 10^6



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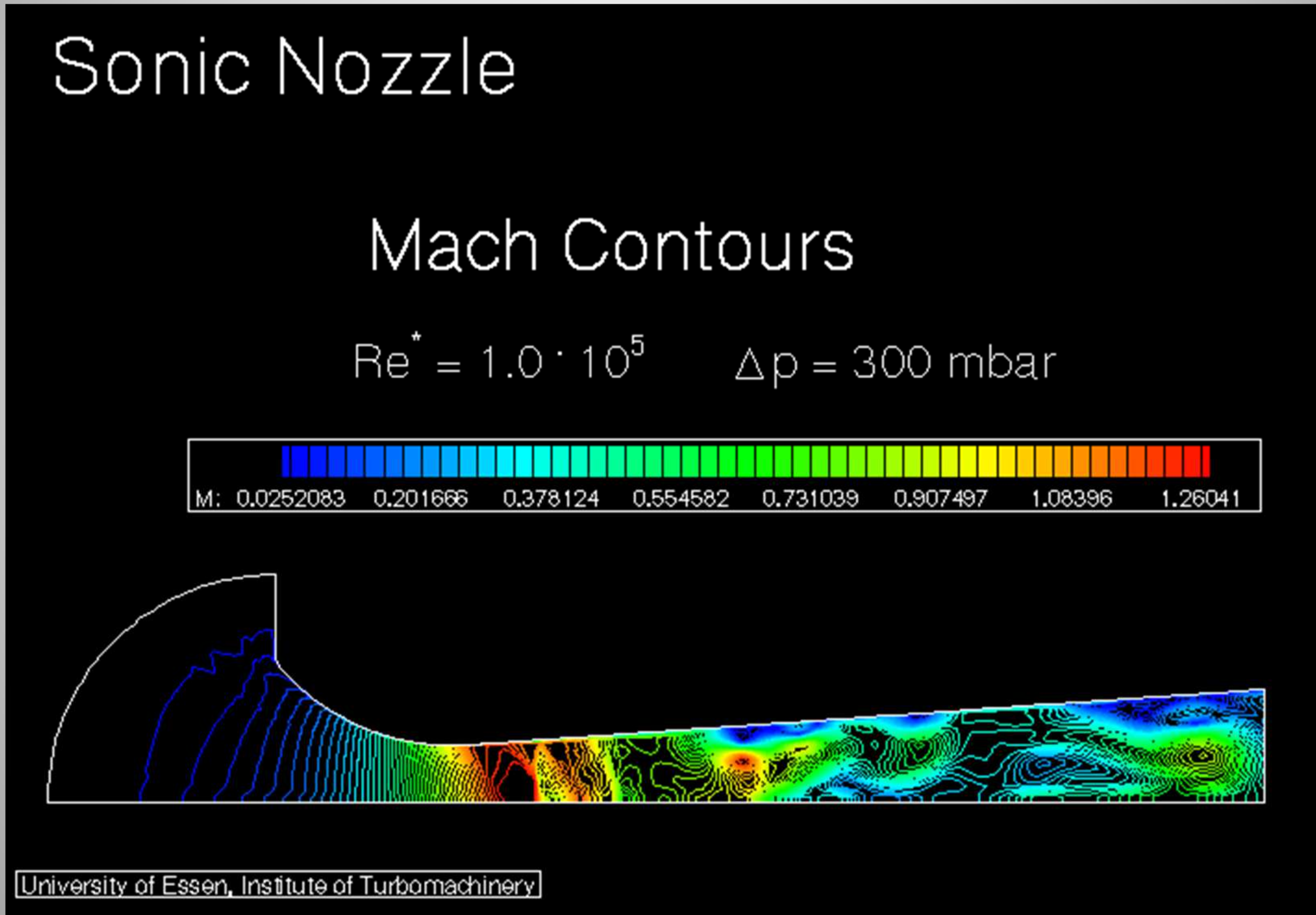
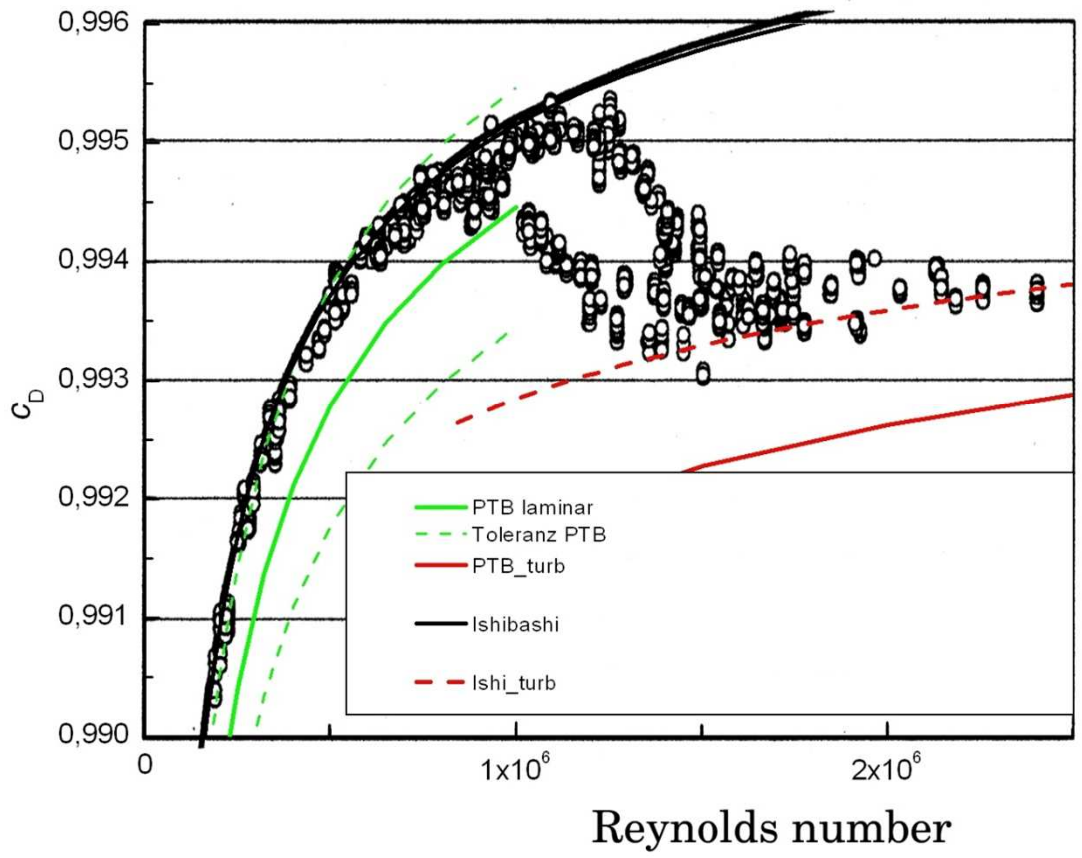


CFVN 1 - ISO

- Unsteady effects (Elster, eon)
- Premature unchocking
- National Calibration Standard at Pigsar (Pigsar, Elster, PTB, eon)
- Real gas effects in CFVN (eon)
- Influencing of flow fields in CFVN (steps, suction)
- Micro nozzles (PTB)
- Reynolds number effects in CFVN (transition laminar-turbulent)
- Geometric factors (PTB)
- Theoretical determination discharge coeff. C_D (PTB)
- Shock location, influence of condenzation (NRLM)

All simulations with ACHIEVE – accuracy !!

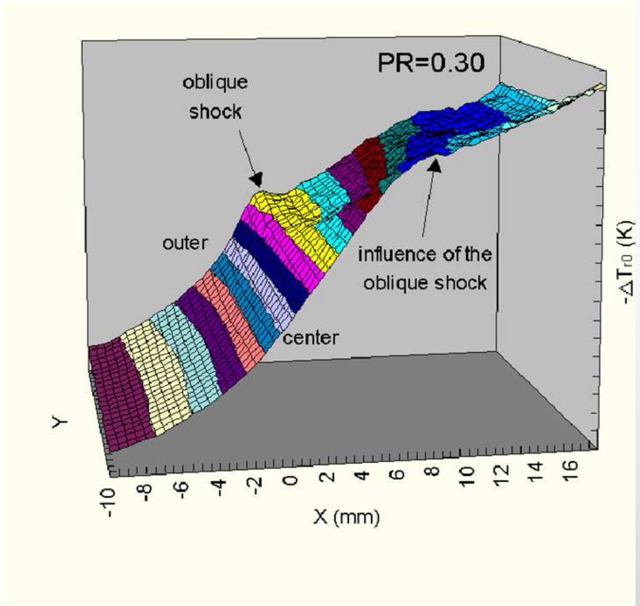
CFVN 1 - ISO

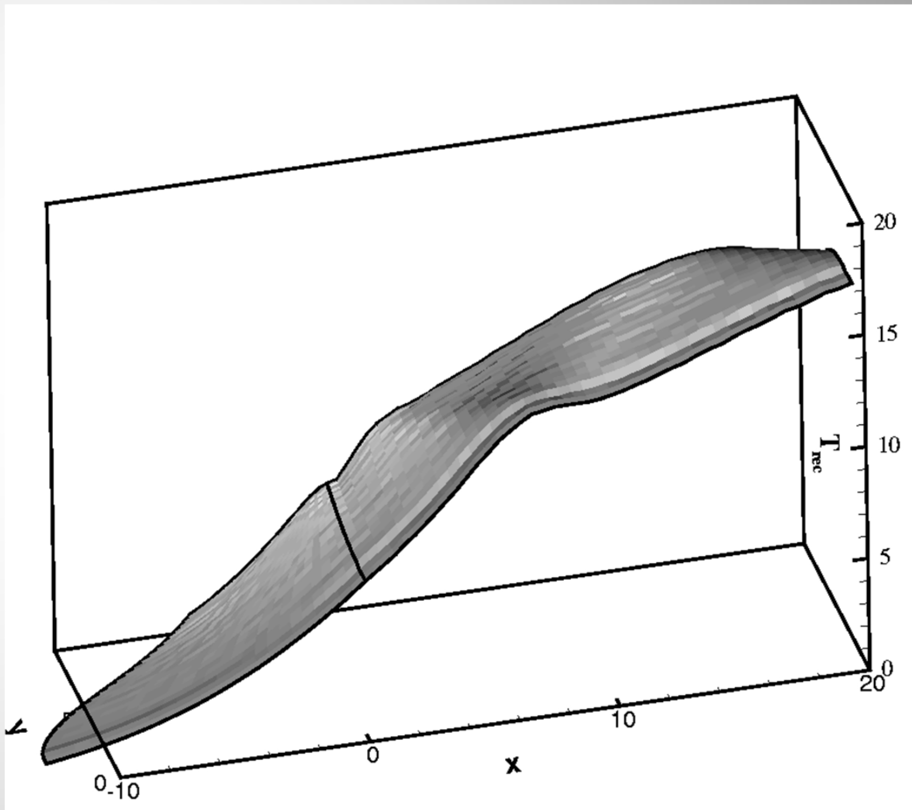


0,996
0,995
0,994
0,993
0,992
0,991
0,990
c_D
0
1x10^6
2x10^6
Reynolds number
PTB laminar
Toleranz PTB
PTB_turb
Ishibashi
Ishi_turb

CFVN 1 - ISO

Experimental verification by Ishibashi (NRLM)

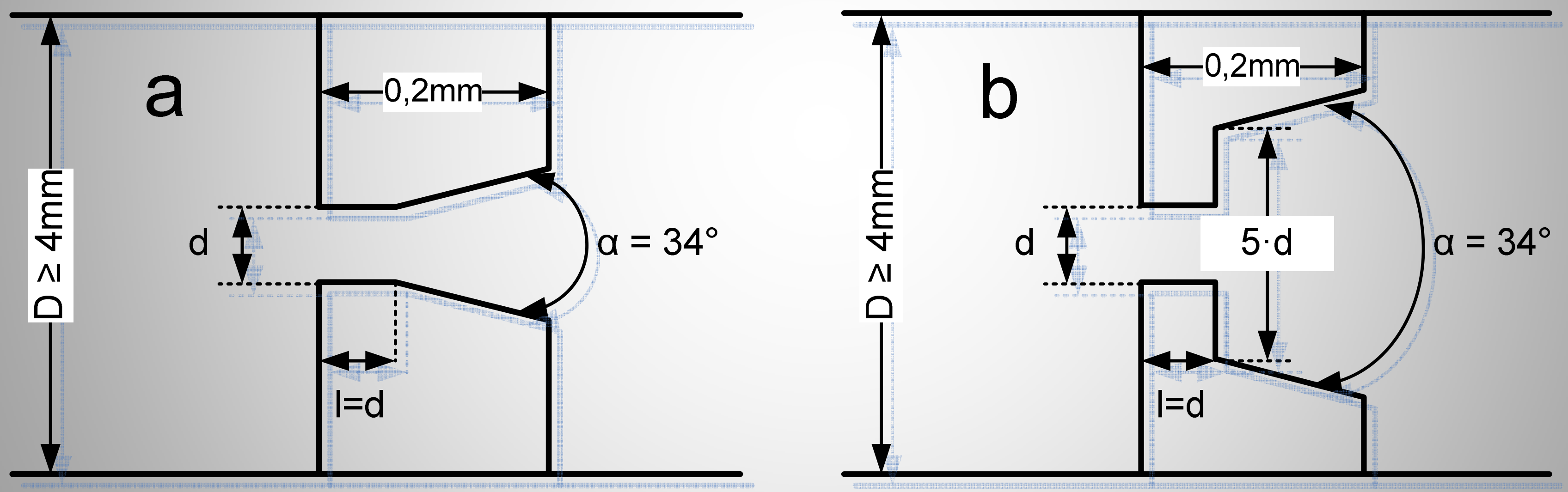




CFVN 2 – micro nozzle

Aim of present study: comparison of high resolution CFD simulations with experimental results (PTB)

Two basic shapes: punched and drilled



Utilized in forward (L to R) and backward (R to L) orientation

CFVN 2 – micro nozzle

Present cases:

throat diameter D in [μm]	Reynolds -number Re_d	B.L. thickness δ in [μm] ->	ratio of δ/d	Knudsen number Kn
15	197	5,348	0,3565	0,0153
25	328	6,904	0,2762	0,0092
35	459	8,169	0,2334	0,0066
50	656	9,764	0,1953	0,0046
80	1049	12,351	0,1544	0,0029

In our case: $Kn = 1.28\ \kappa^{0.5}\ Ma/Re$

Simulation Parameter

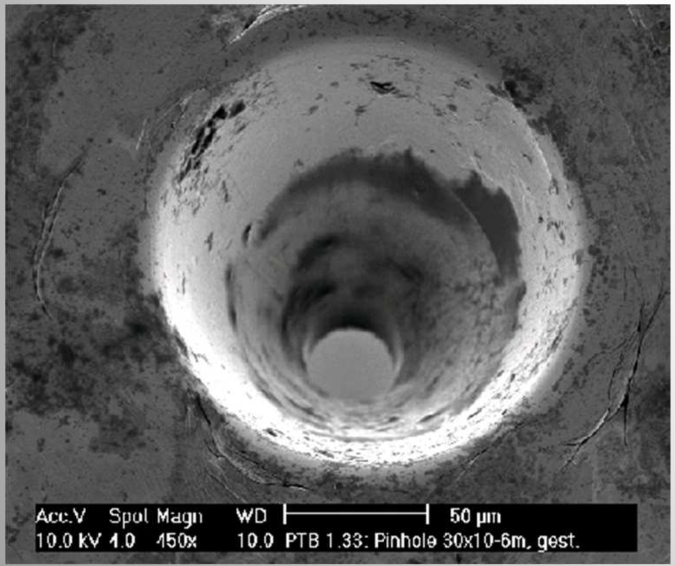
Simulation carried out using ACHIEVE solver developed by author

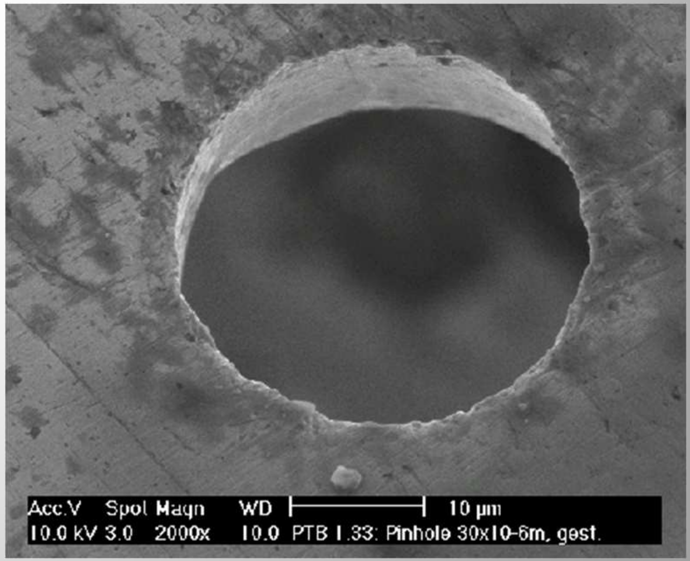
Grid generated by elliptic PDE developed in house

Configuration:

D = 15, 25, 35, 50 and 80 μ , P_0 = 0.101325 MPa, T_0 = 300 K

Pressure ratios p_{out}/P_0 = 0.3 and 0.4

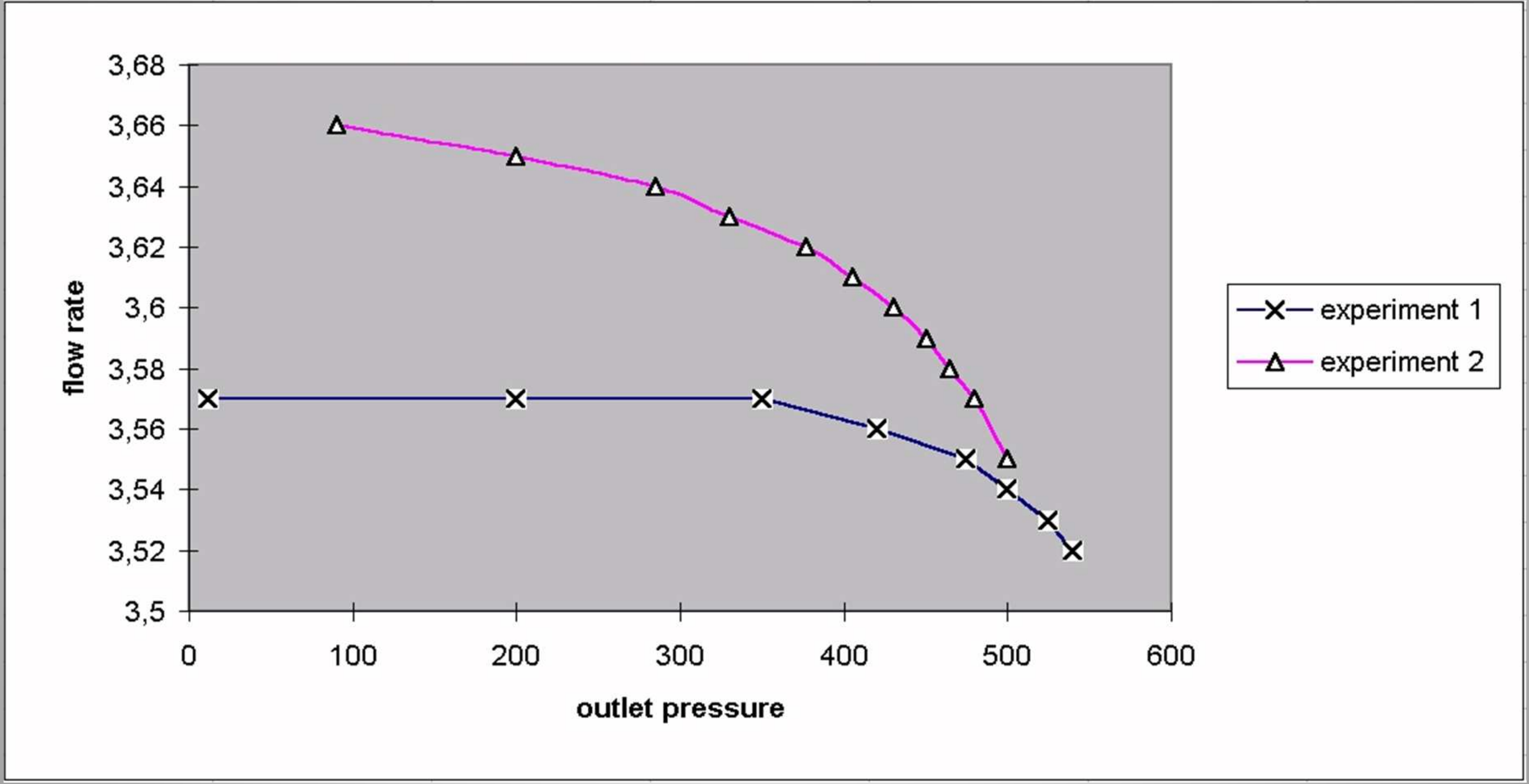




Experimental Work at PTB

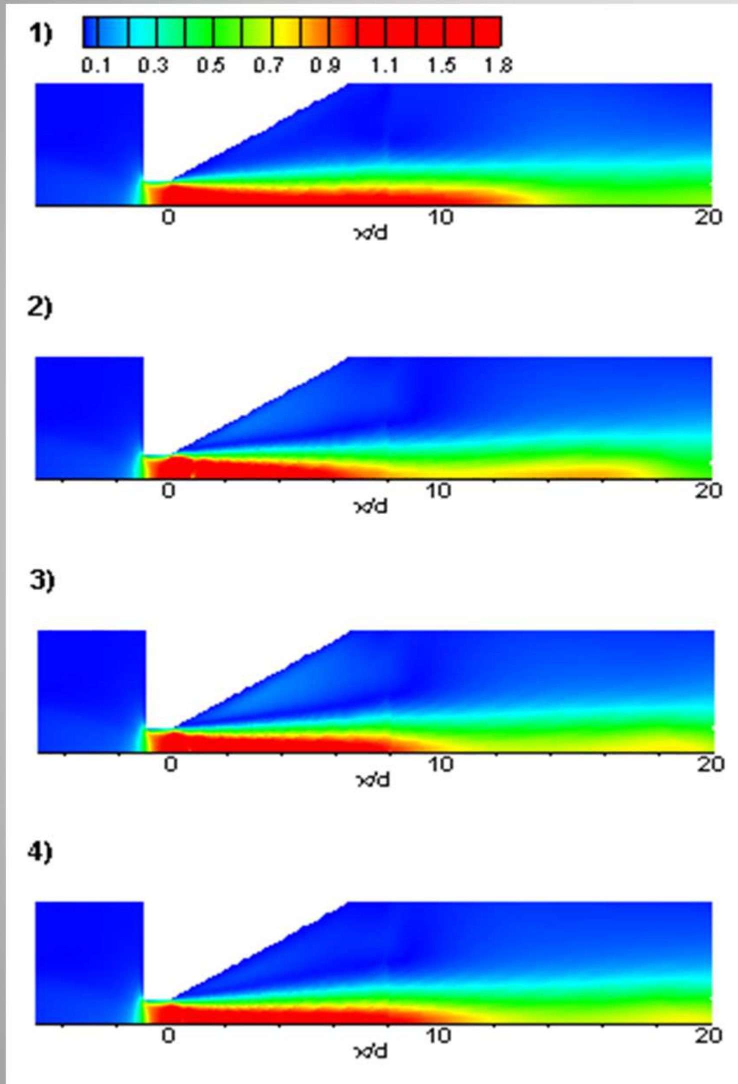
Results for D = 25 µm:

1. **Forward nozzle: choking at p/P_0 = 0.35 (ideal nozzle 0.528…)**
2. **Backward nozzle: no apparent choking**



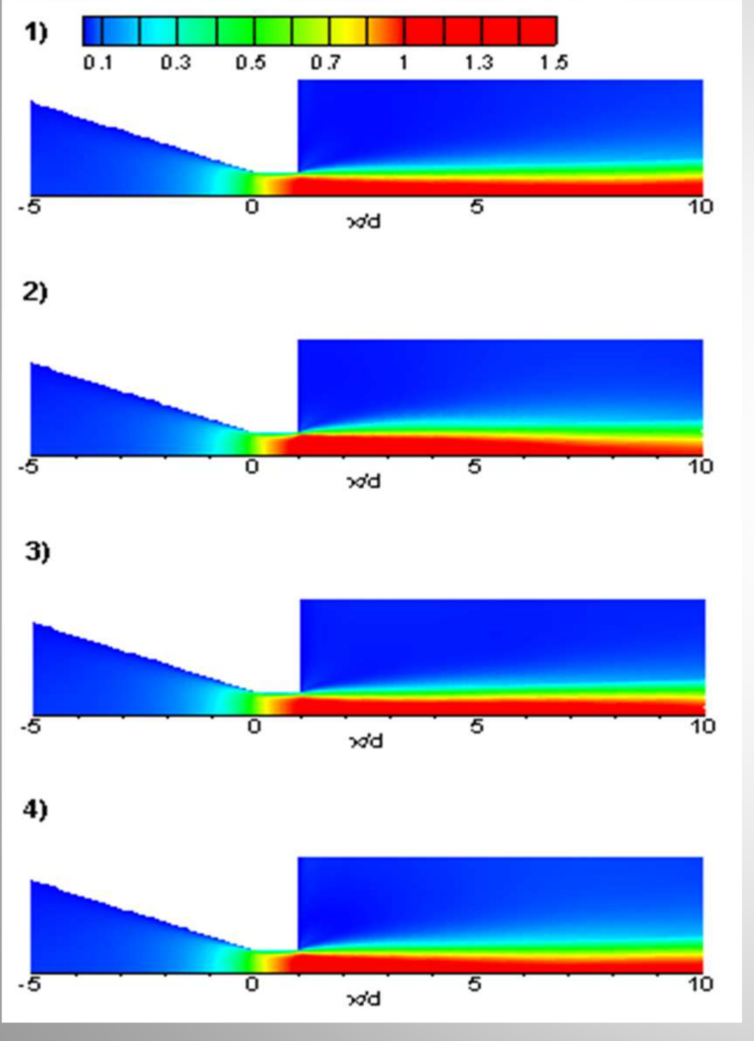
Task for numerical simulation: explain phenomenon !!

Numerical Simulations - Results



Forward orientation, $p_{out}/p_0 = 0,3$

Numerical Simulations - Results

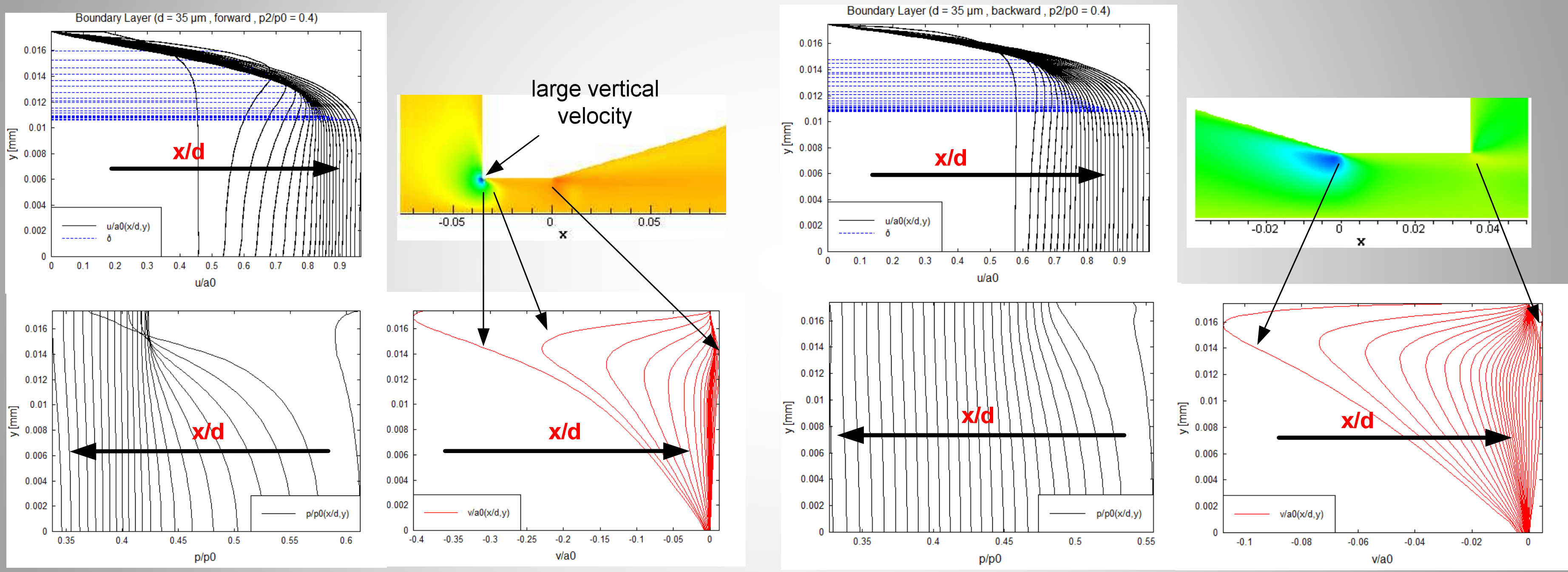


Backward orientation, $p_{out}/p_0 = 0,3$

Numerical Simulations

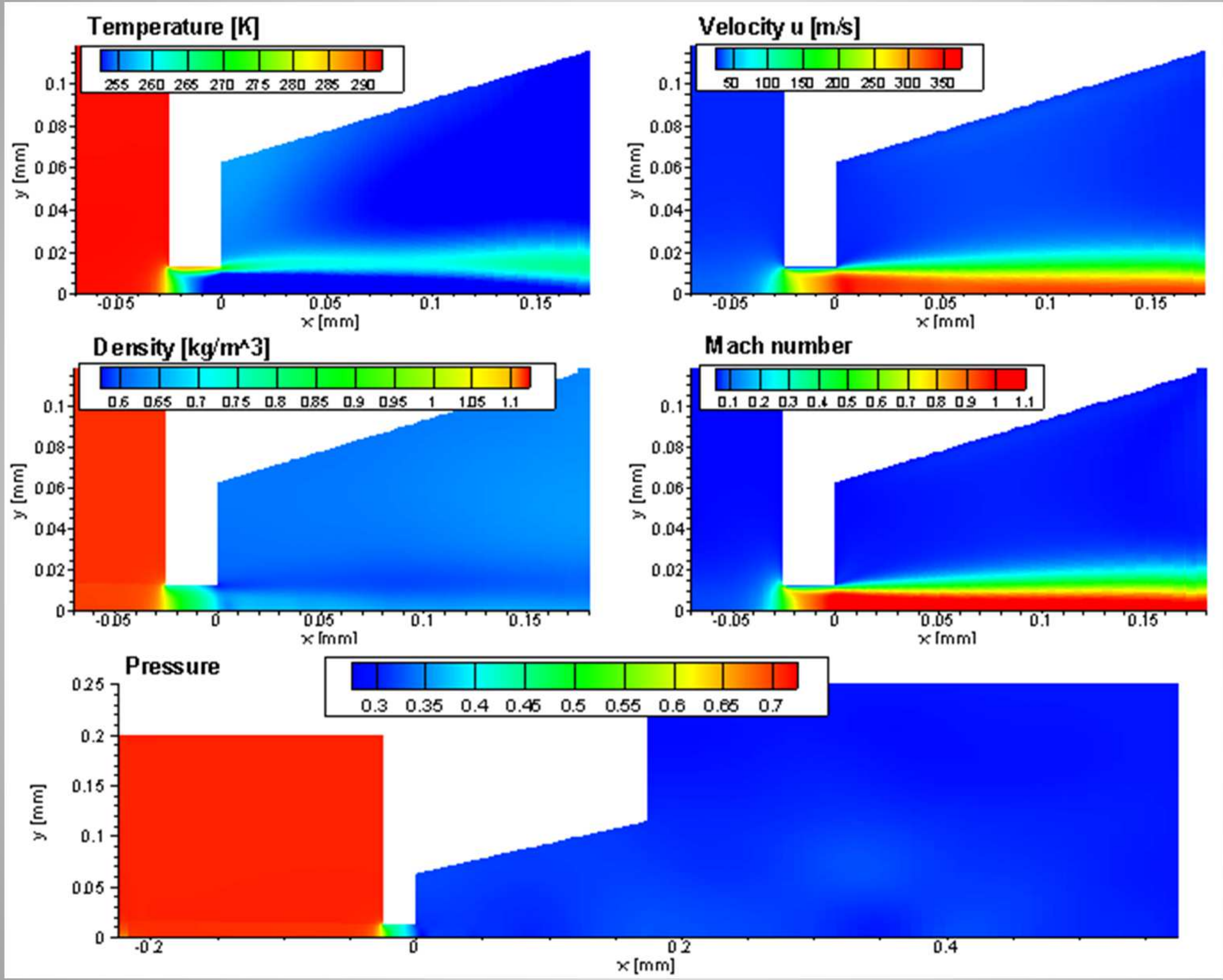
Boundary layer in cylindrical part

$p_{out}/p_0 = 0,4$



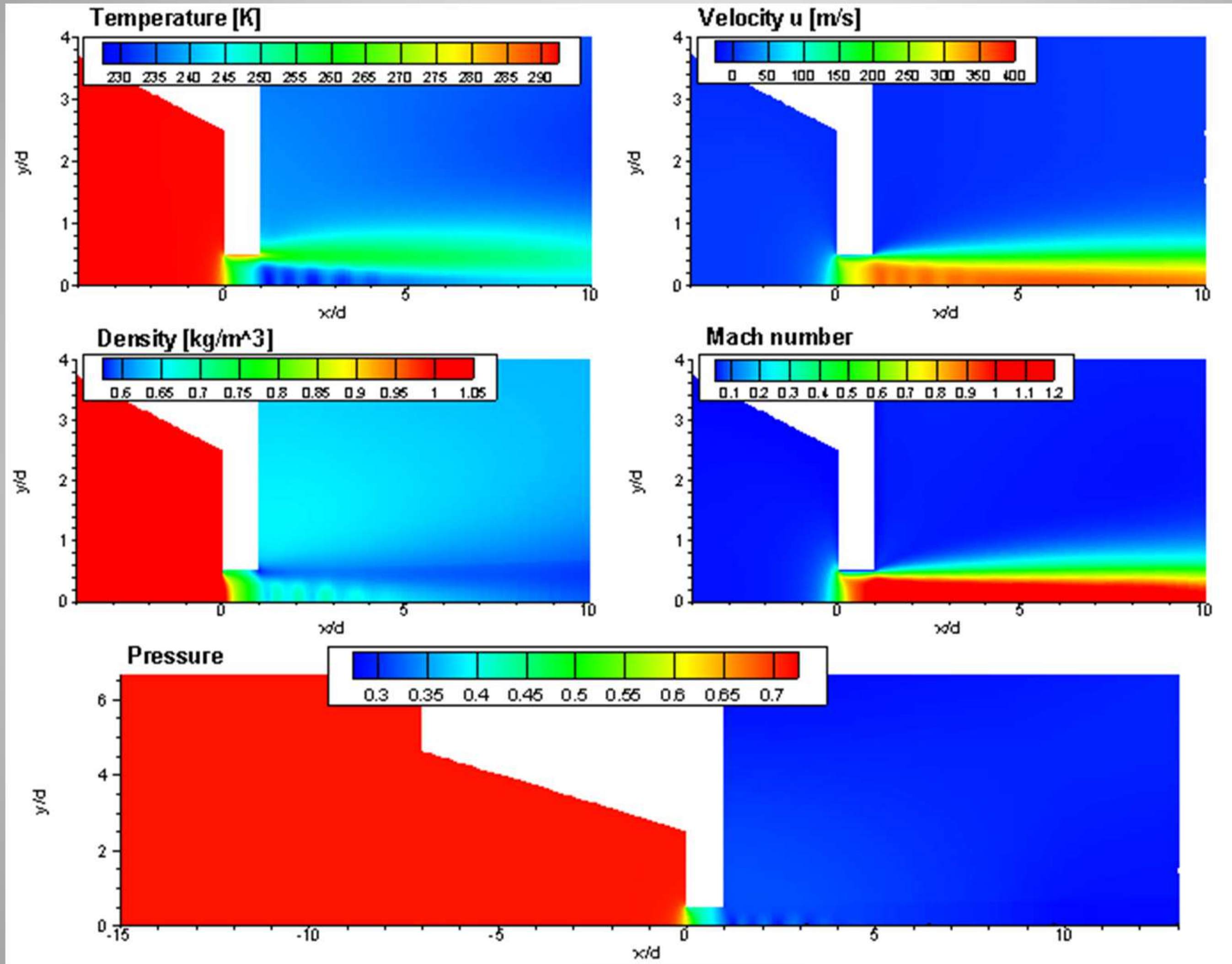
Numerical Simulations - Results

Drilled nozzle, $p_{out}/p_0 = 0,3$



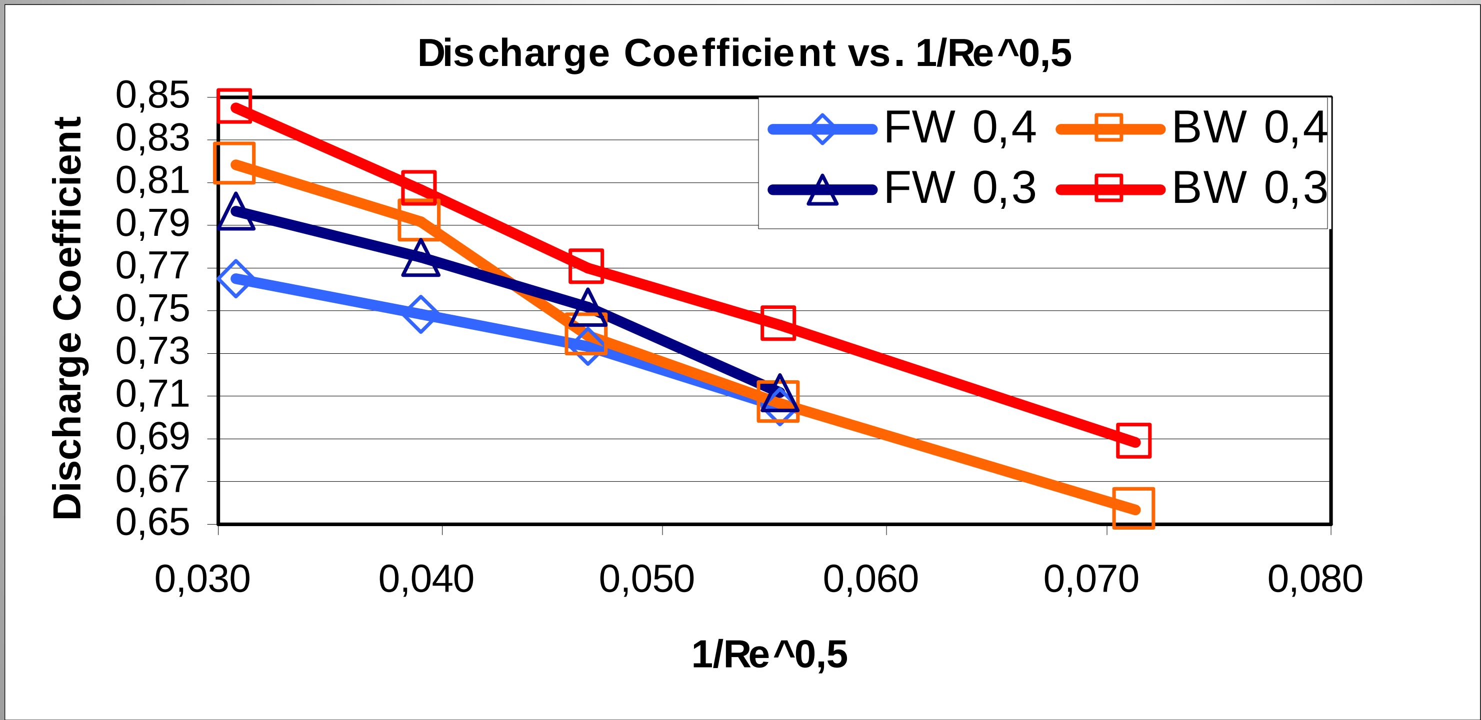
Numerical Simulations - Results

Drilled nozzle, $p_{out}/p_0 = 0,3$



Summary

p_2/p_0		0,4			0,3		
Nozzle		$C_{d,\,exp}$	$C_{d,\,num}$	Deviation	$C_{d,\,exp}$	$C_{d,\,num}$	Deviation
Forward	25	0,662	0,705	6,45 %	0,664	0,711	7,07 %
Backward	25	0,670	0,707	5,47 %	0,676	0,743	9,97 %
Forward Drilled	25	0,660	0,692	4,90 %	0,662	0,722	9,12 %
Backward Drilled	25	0,663	0,697	4,96 %	0,667	0,724	8,57



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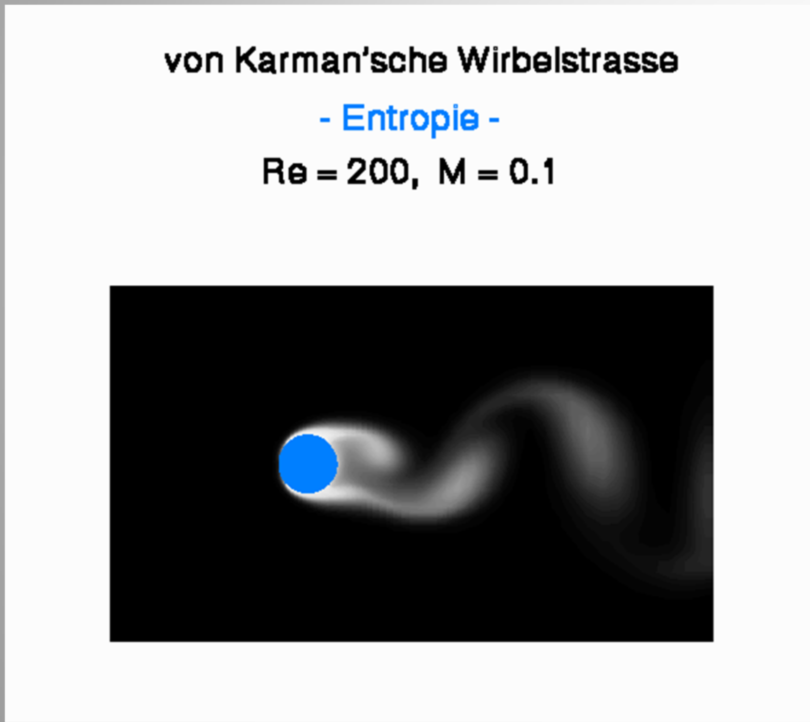
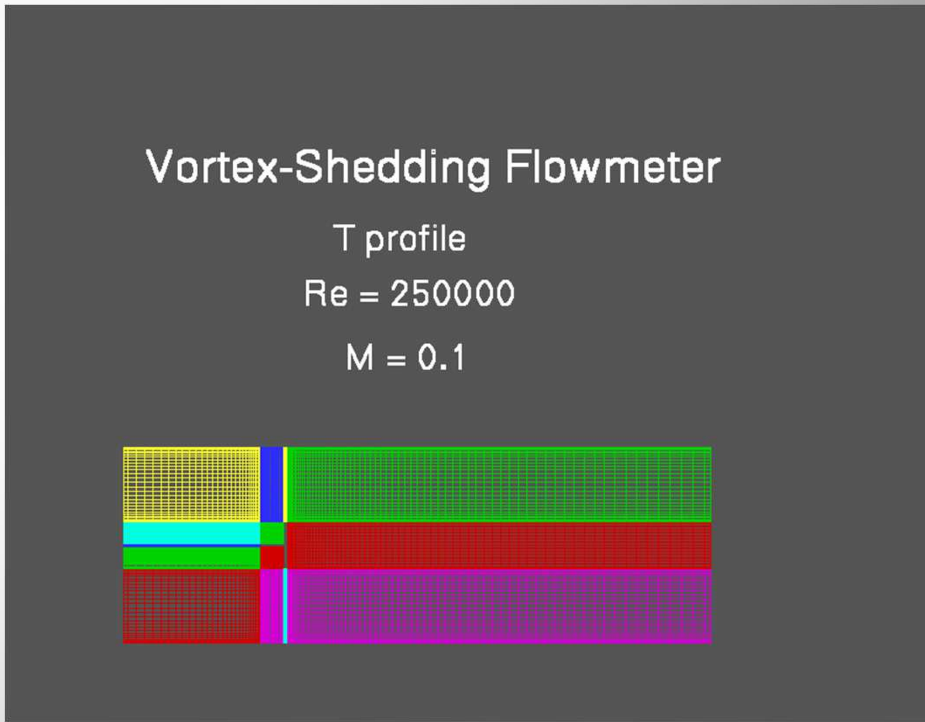
Vortex Flow Meter

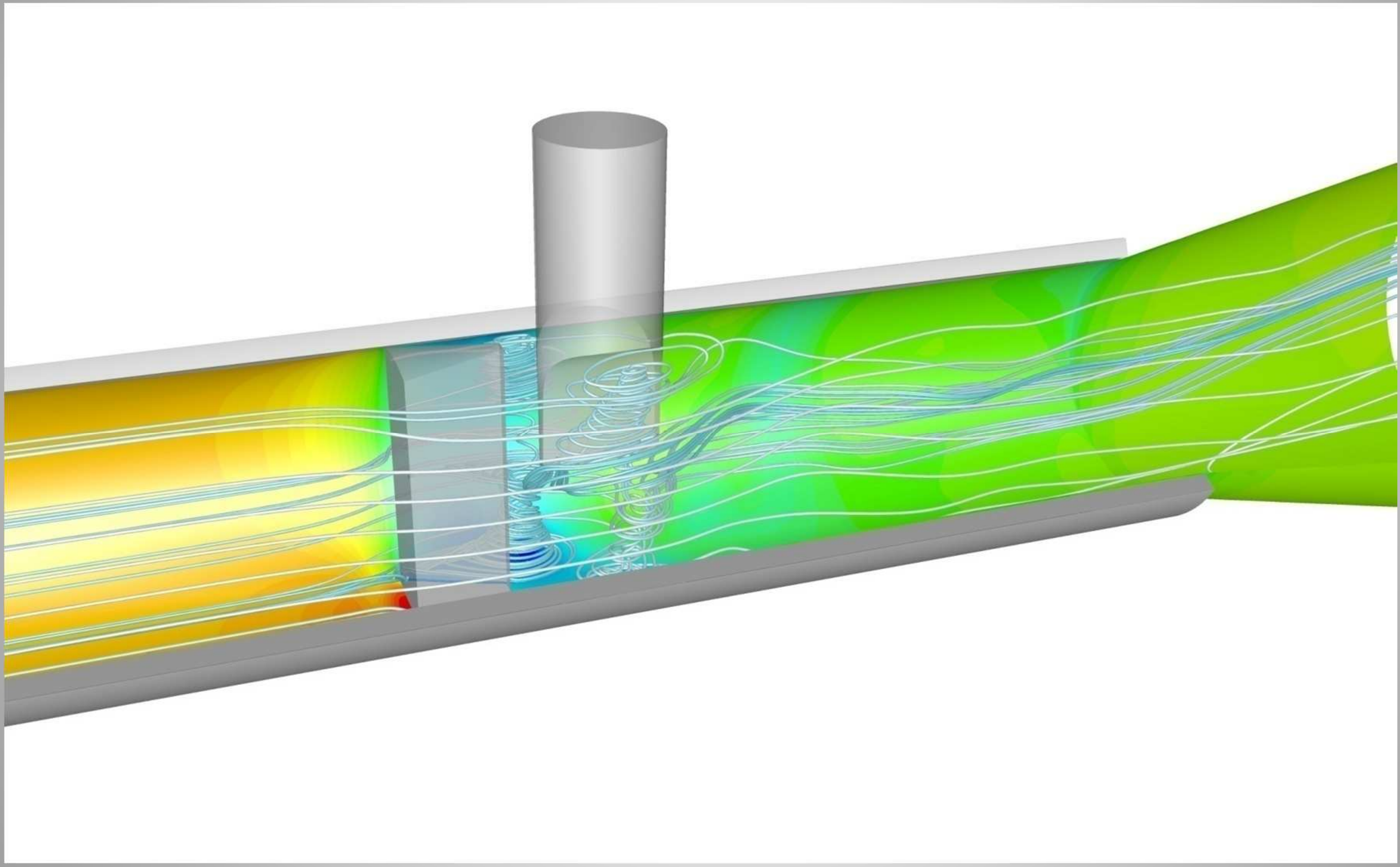
Principle: von Karman vortex street;   f ~ u axial

=> K-factor defined as K=f/Q should be constant

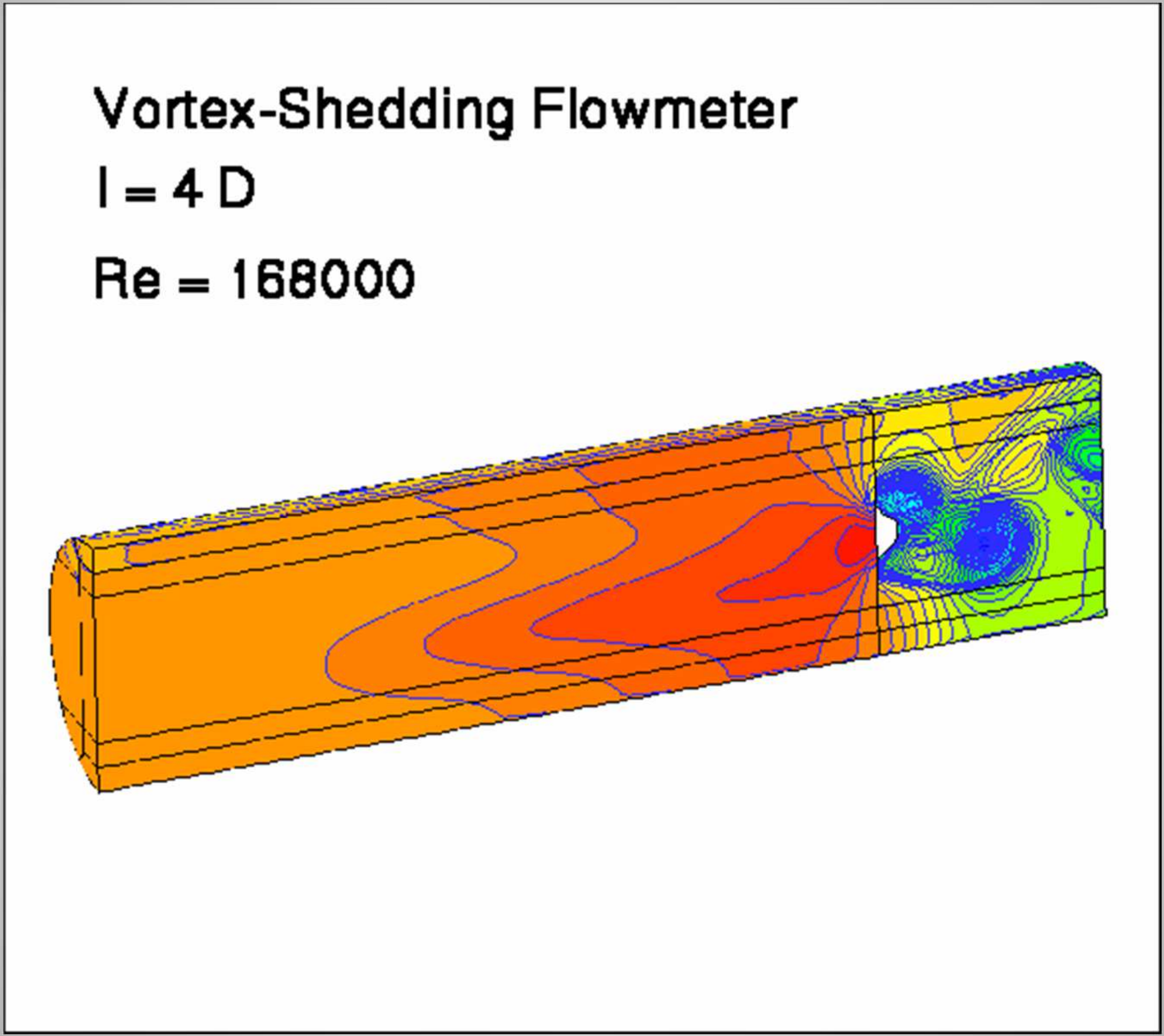




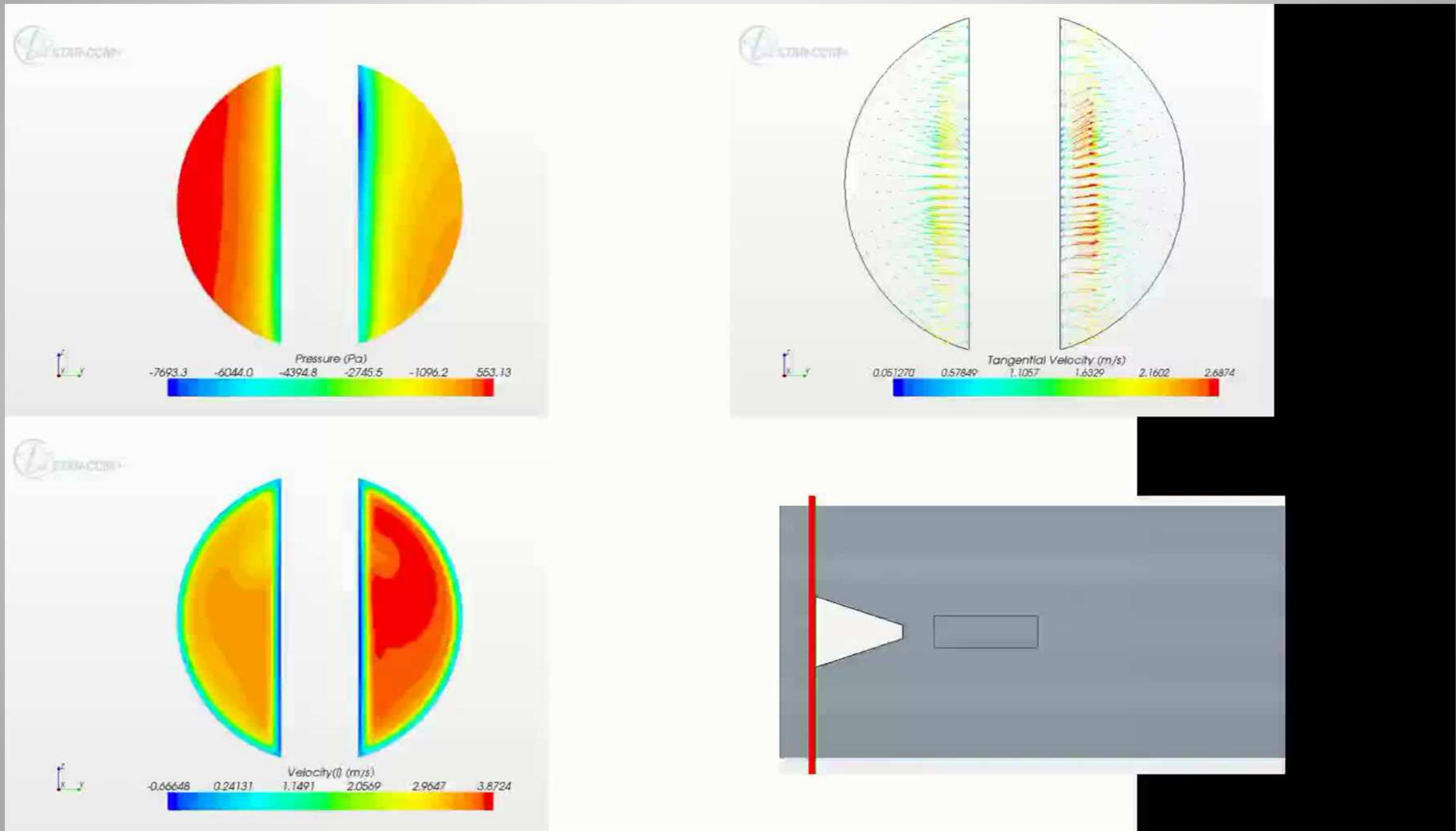
Vortex Flow Meter



Vortex Flow Meter



Vortex Flow Meter

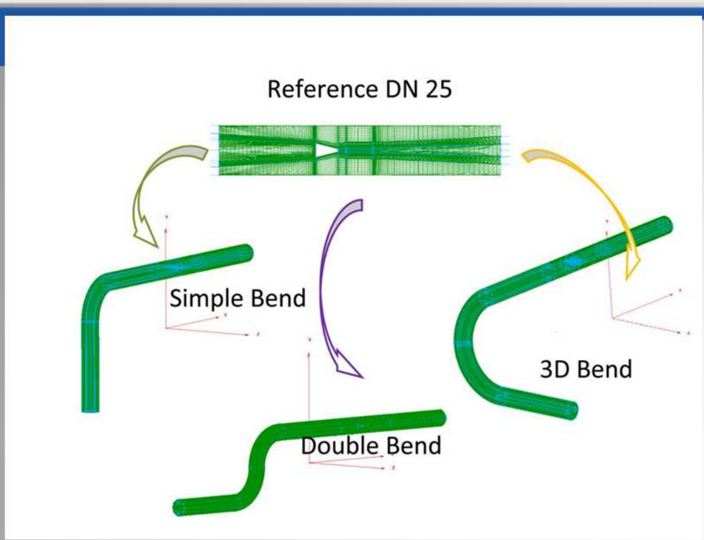


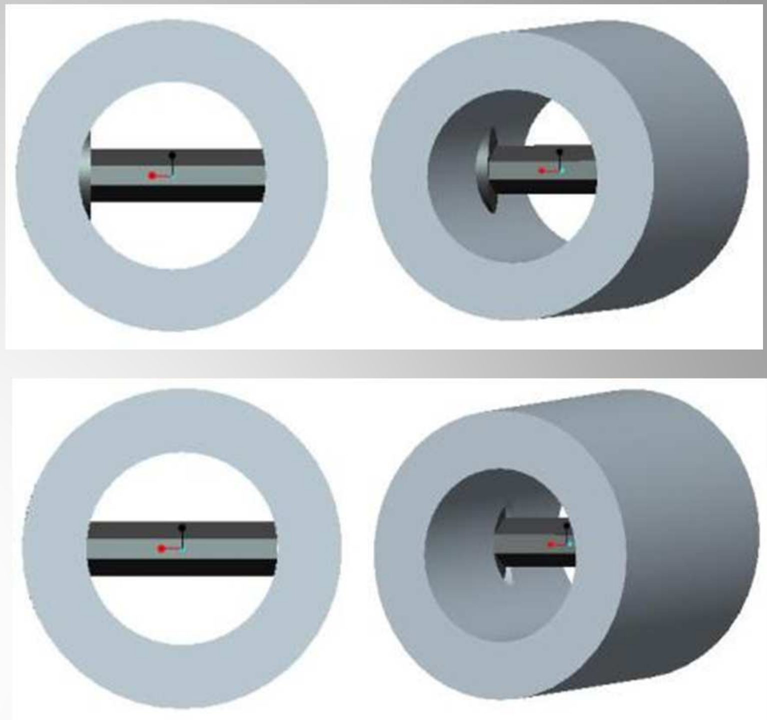
Vortex Flow Meter

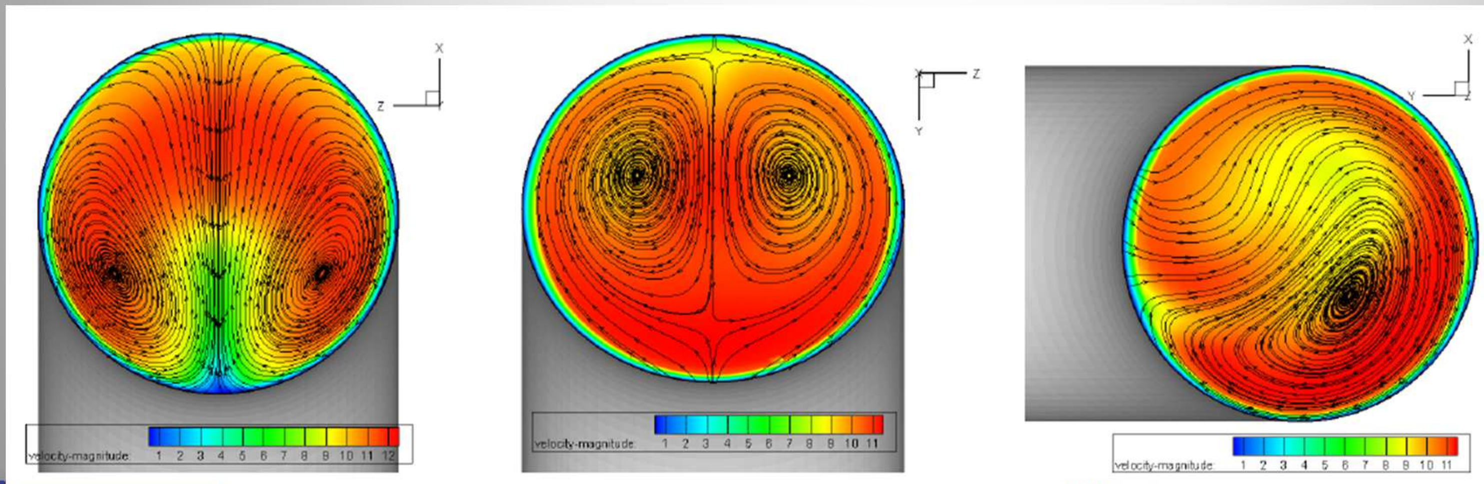
- Secondary and tertiary vortices, exp. – num., (Uni-Essen)
- Pulsating flow, exp. – num., (Krohne)
- Influence of upstream disturbances (bends), exp.- num. (Krohne)
- Installation effects, bluff body and sensor, exp. – num., (ABB, Flowtec, Krohne)
- Effects of long time wear, exp. – num., (ABB, Flowtec)
- Optimization of geometry, exp. – num., (Krohne)
- Investigation of geometric flexibility (diffuser, nozzle, conical adaptor), (Krohne)
- Alternative bluff bodies (screws, rippled bodies)
- Upstream valves (butterfly, ball)

Simulations with ACHIEVE, Fluent, adapco Star-CCM+

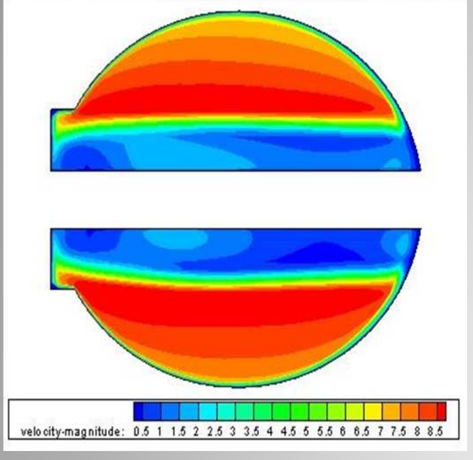
Vortex Flow Meter

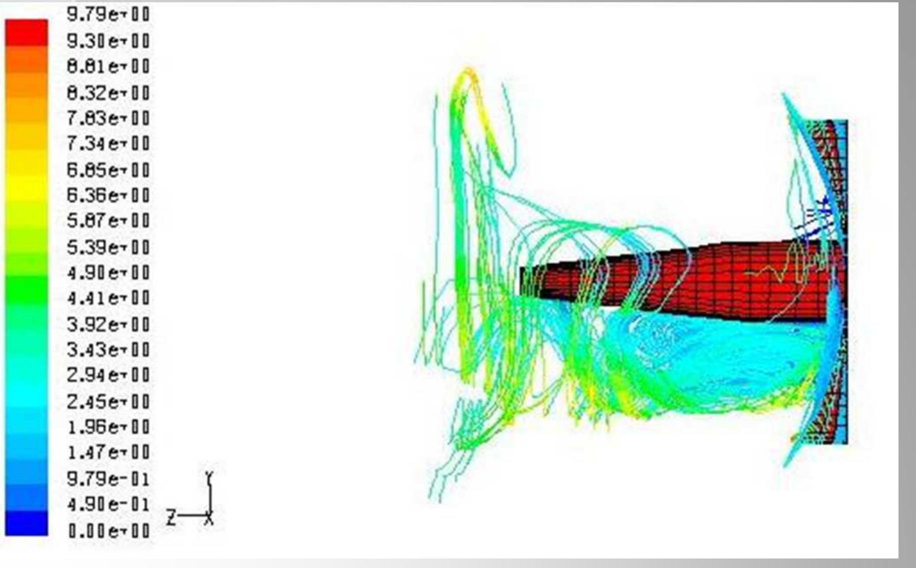


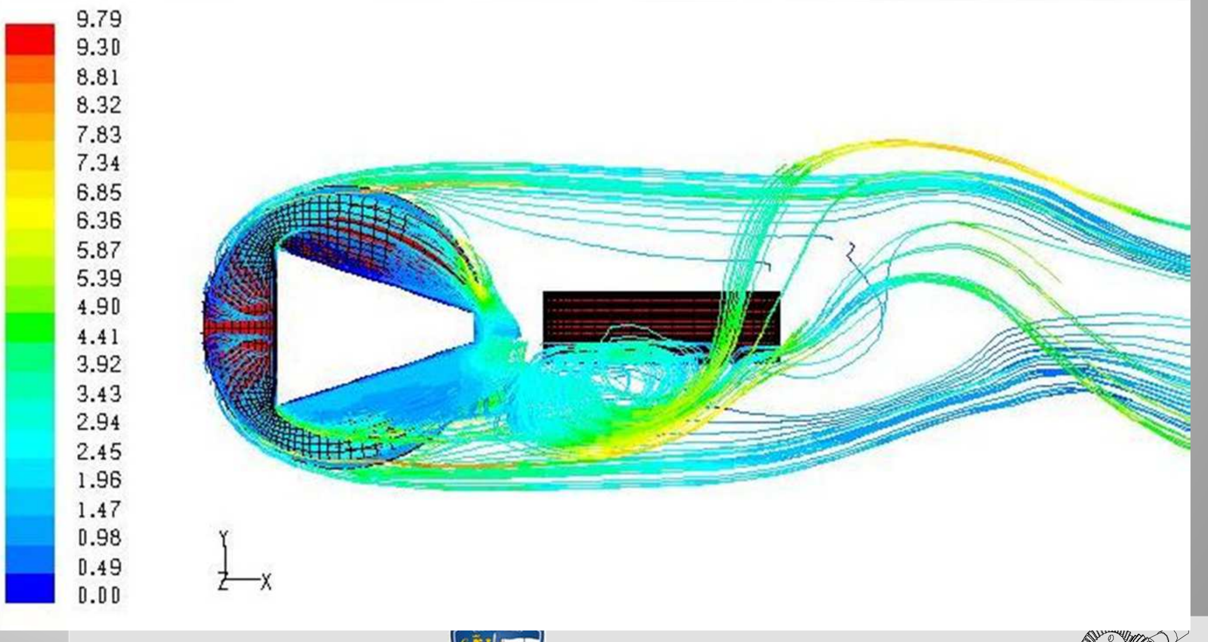




Vortex Flow Meter







Vortex Flow Meter

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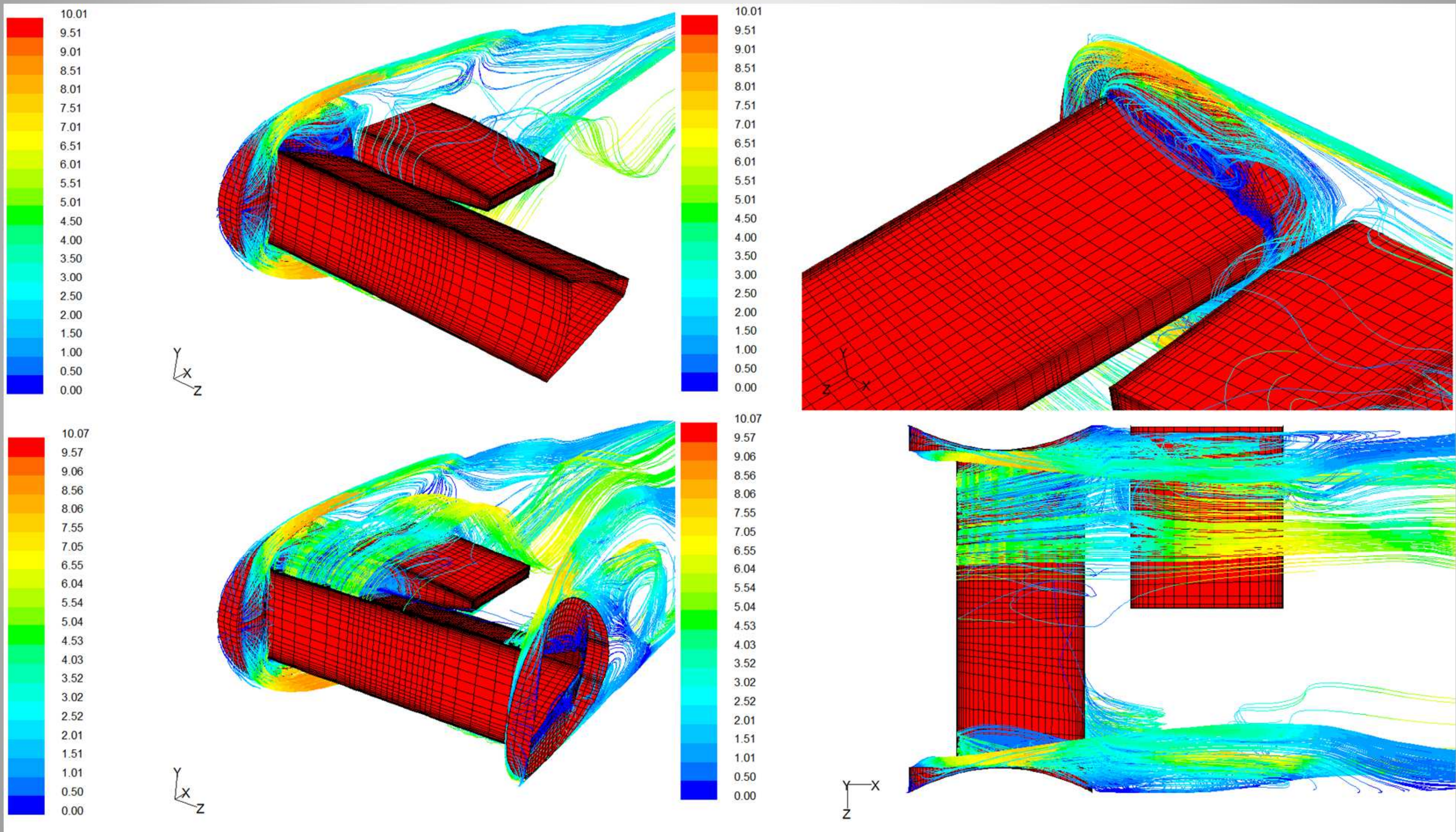
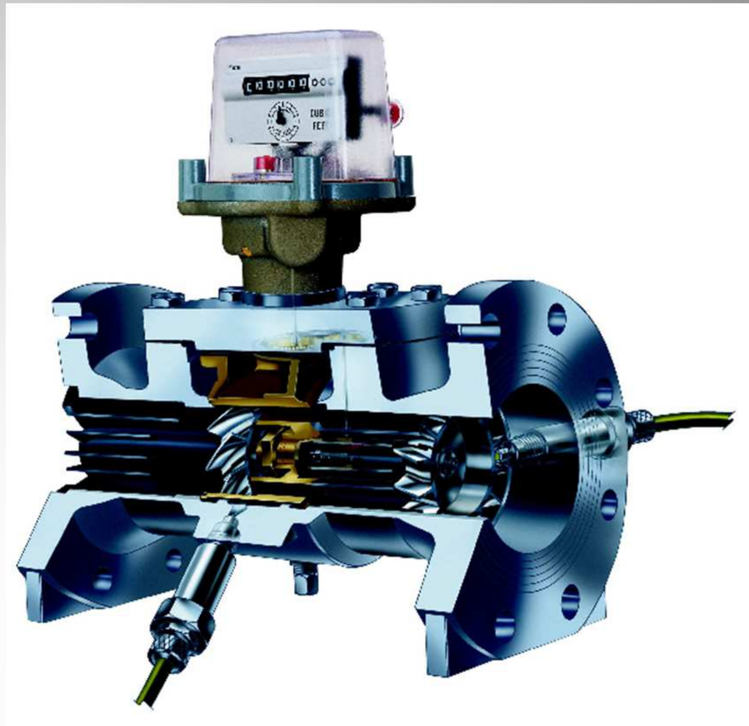
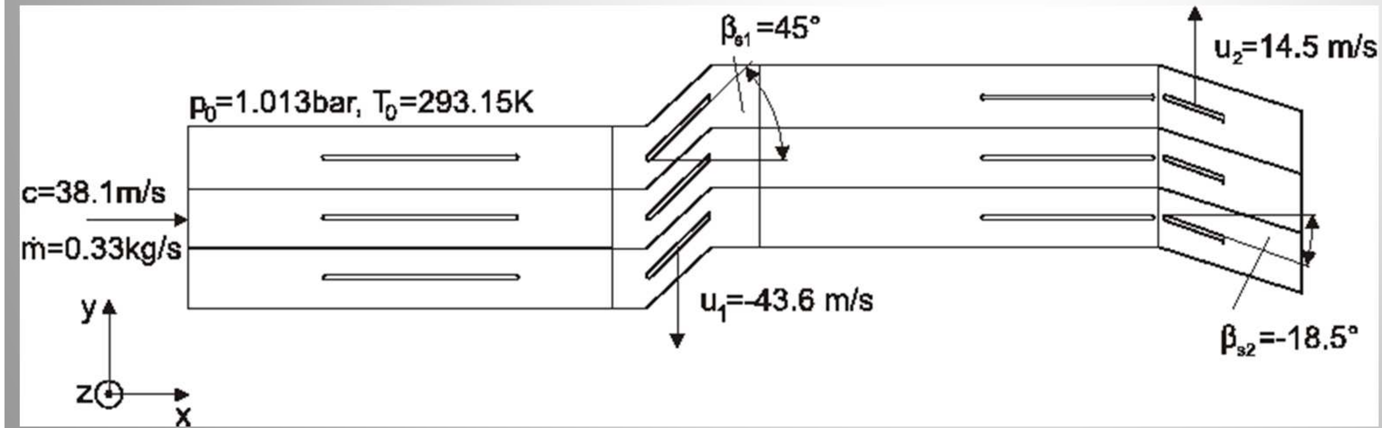
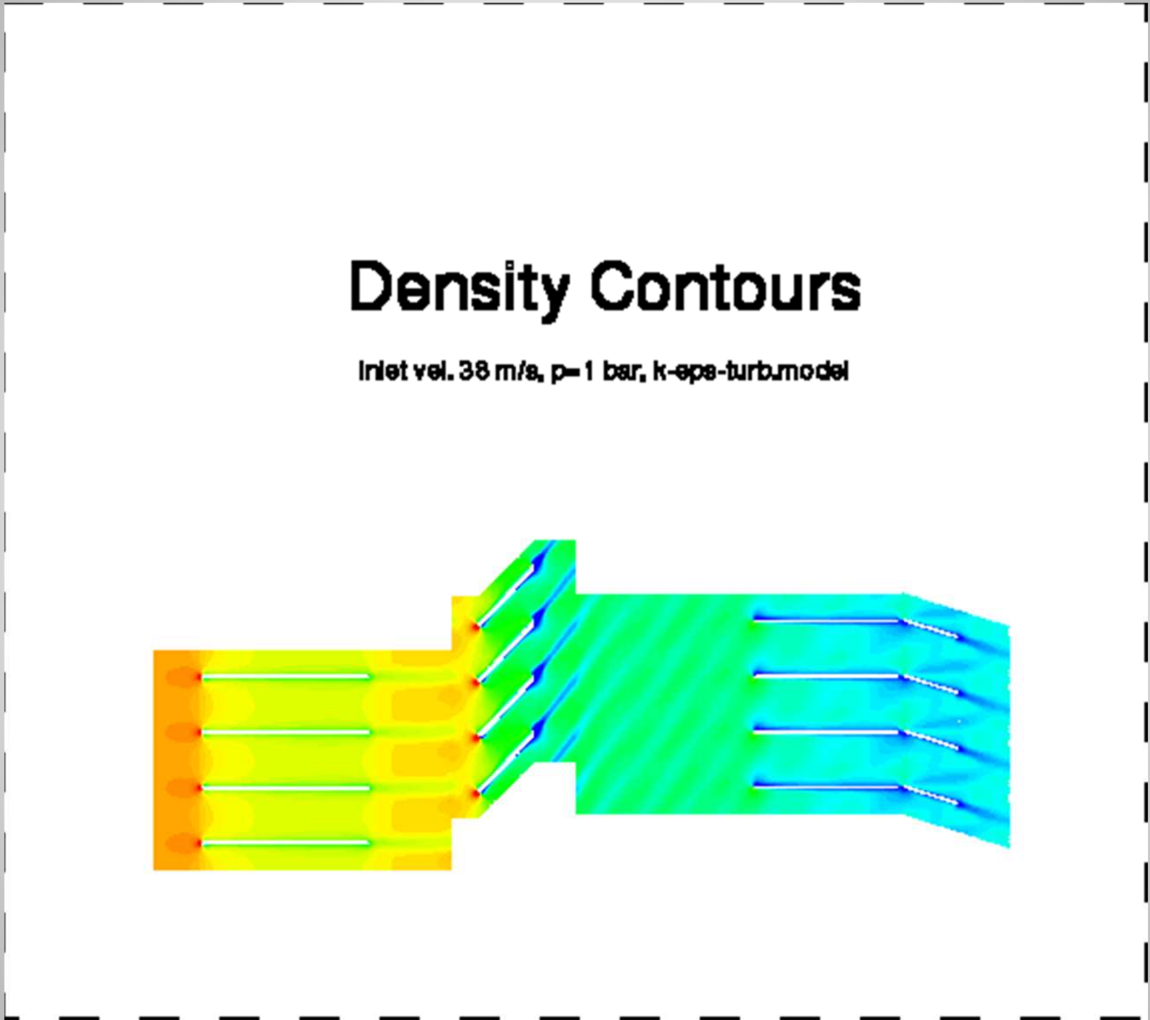


Turbine Flow Meter





Turbine Flow Meter

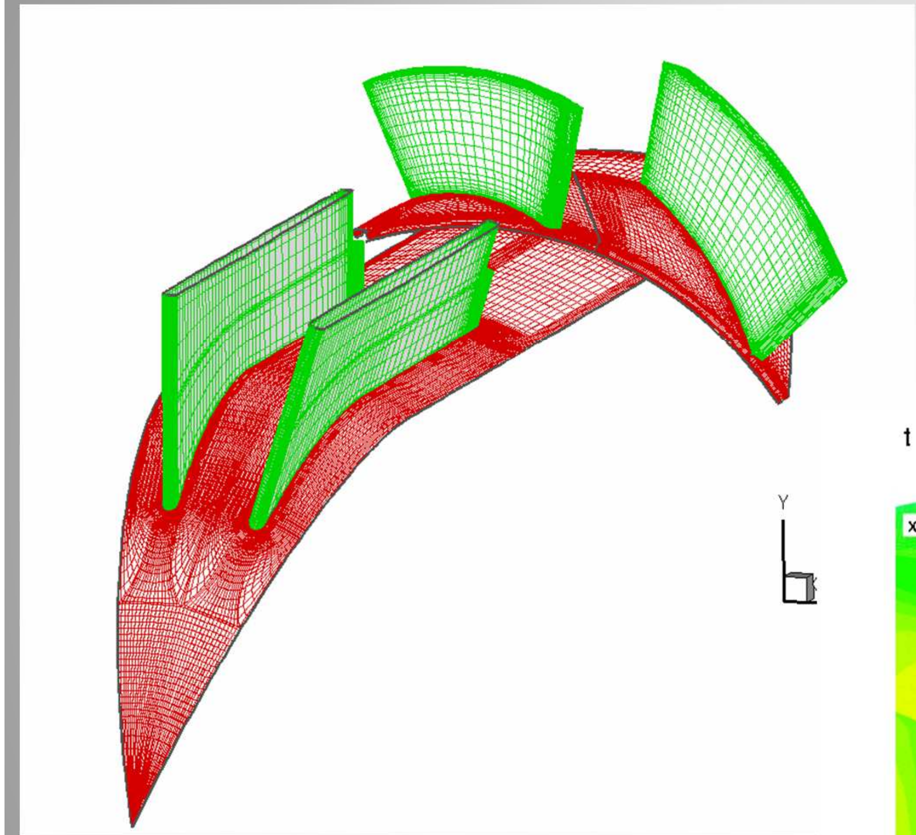


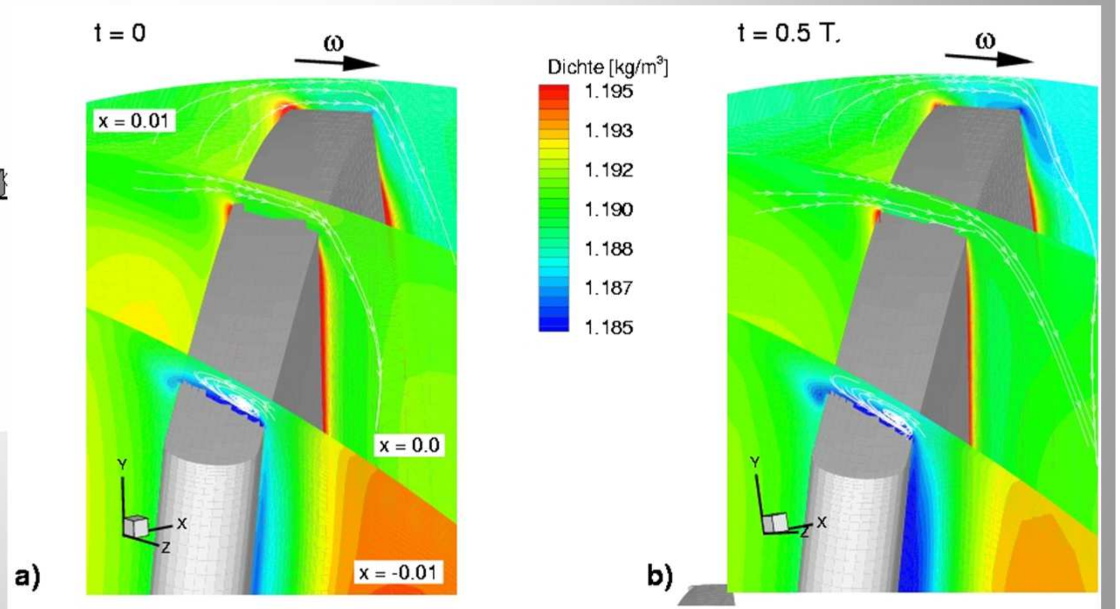
Turbine Flow Meter

- Flow field analysis (Elster)
- Q-min-effects, determination of rotational speed (Elster)
- Optimization of stator (flow straightener) (Elster)
- Development of two-stage straightener (VemmTech)
- 3-D upstream disturbances, full 360-deg. simulation (RMG)
- Investigation of laminar-turbulent transitional effects

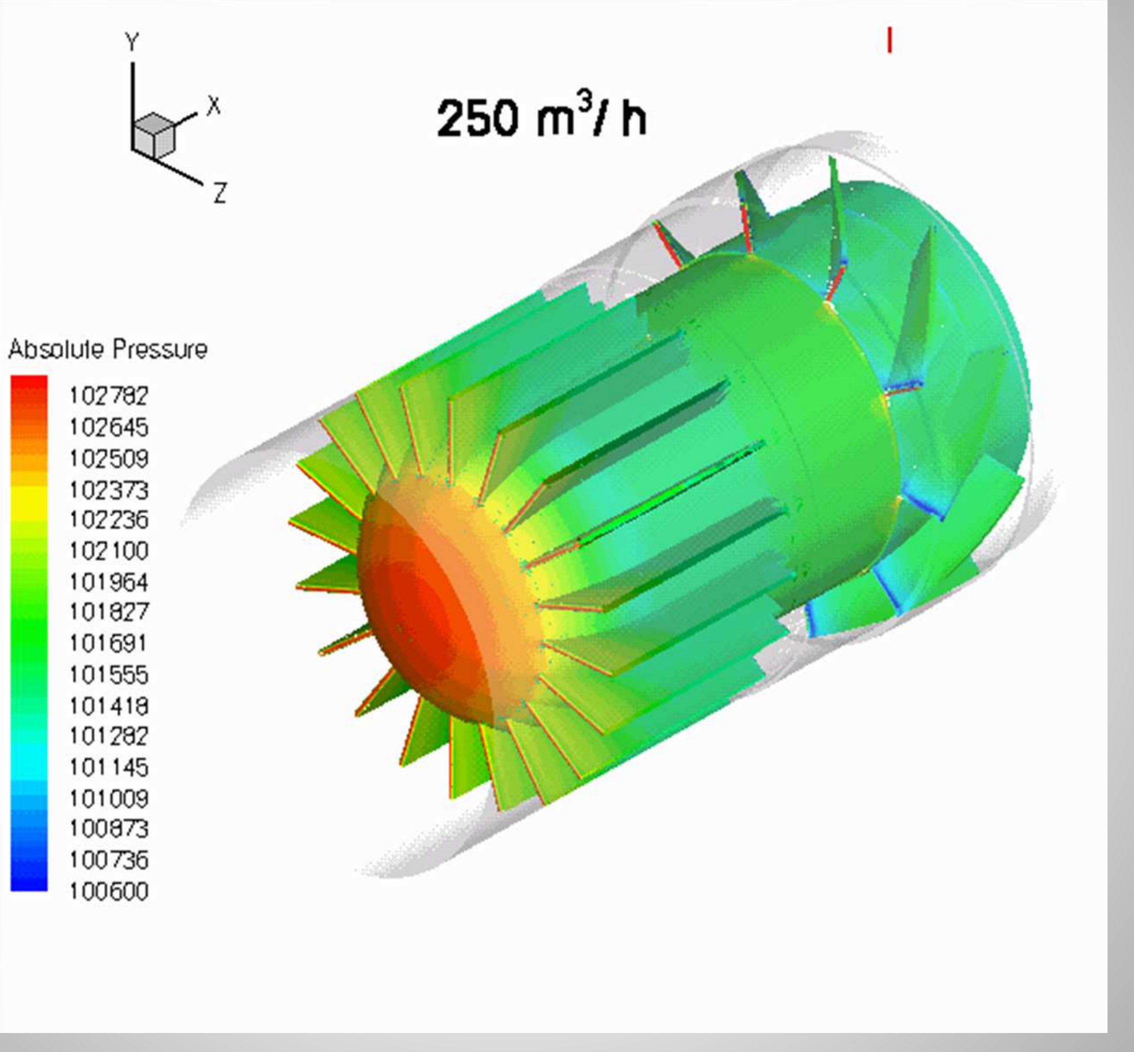
Simulations with ACHIEVE, Fluent, adapco Star-CCM+

Turbine Flow Meter

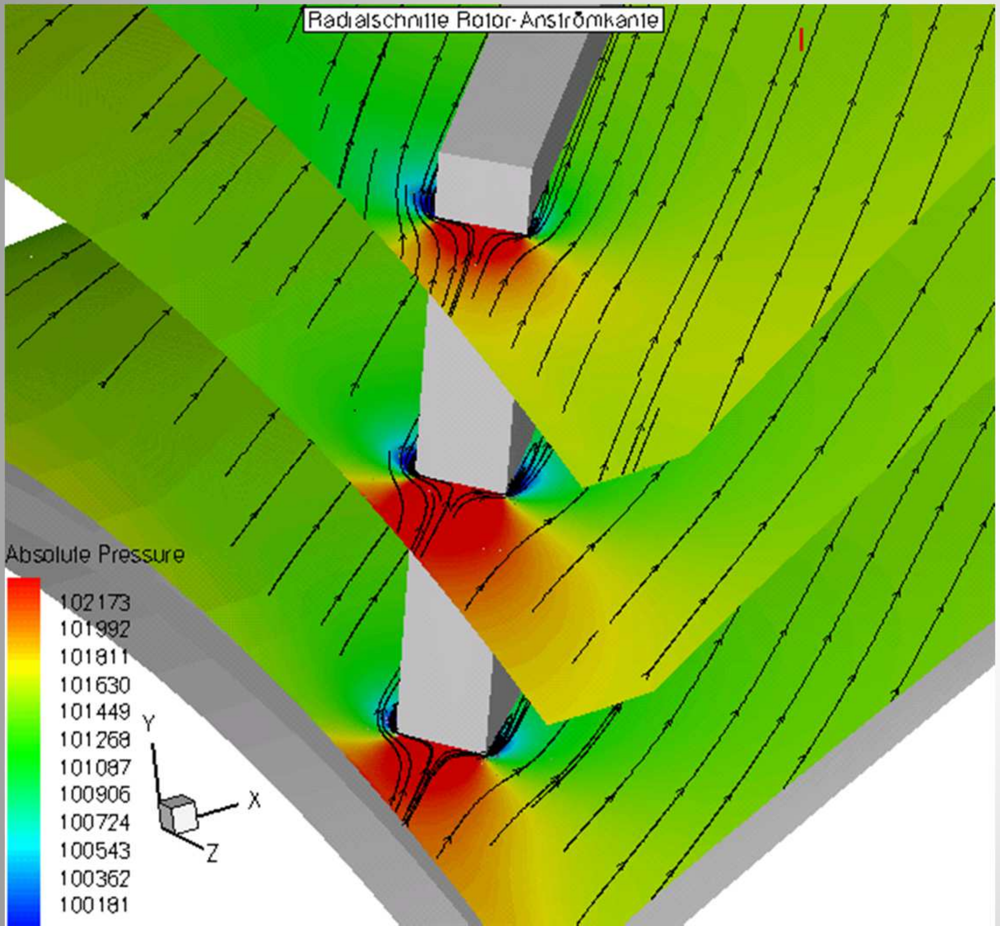


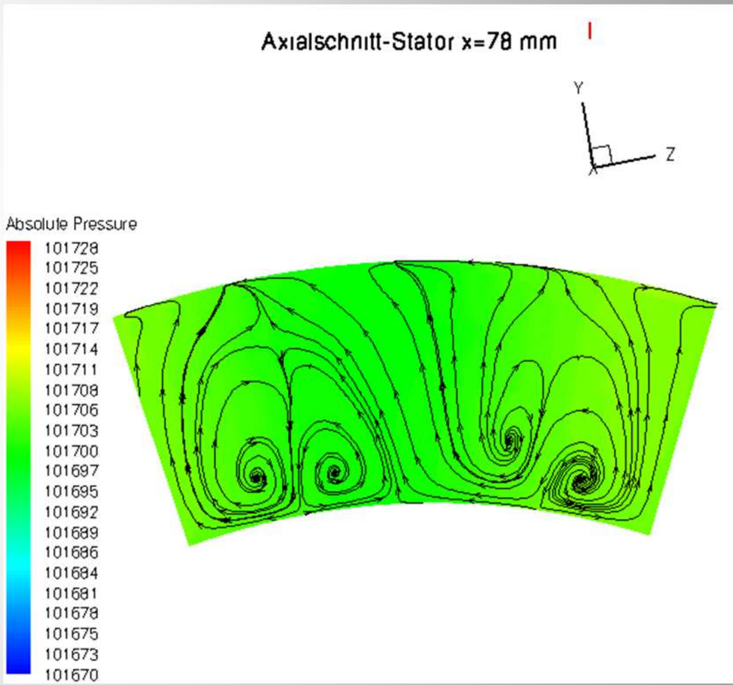


Turbine Flow Meter



Turbine Flow Meter





Turbine Flow Meter

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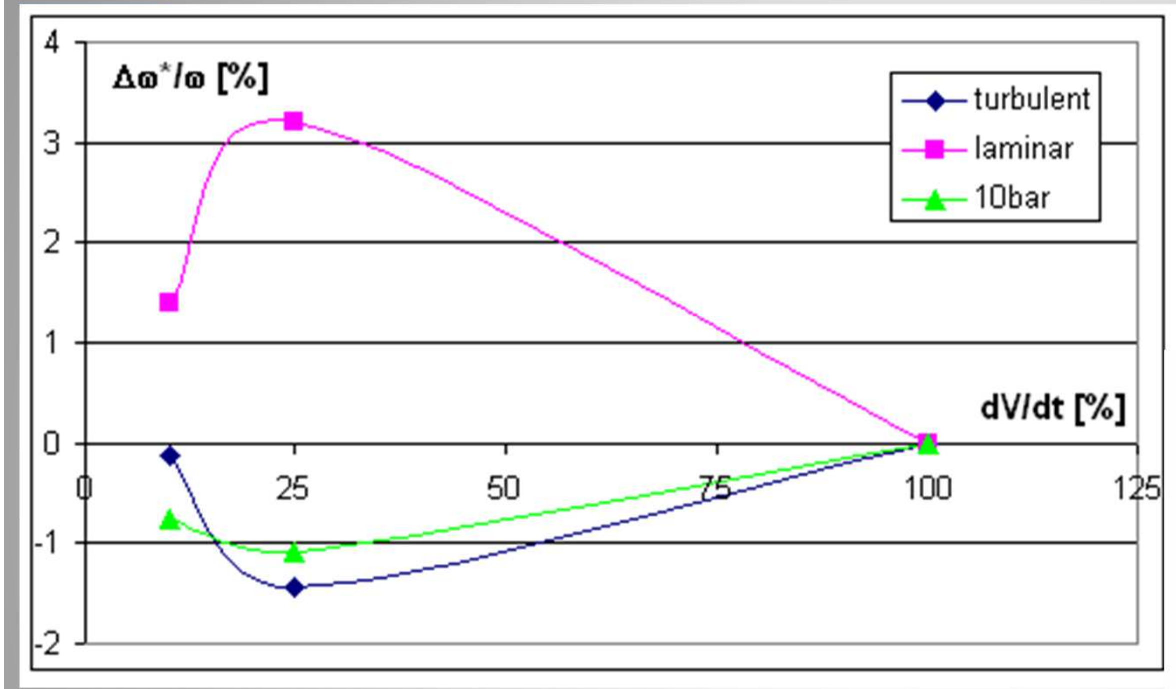
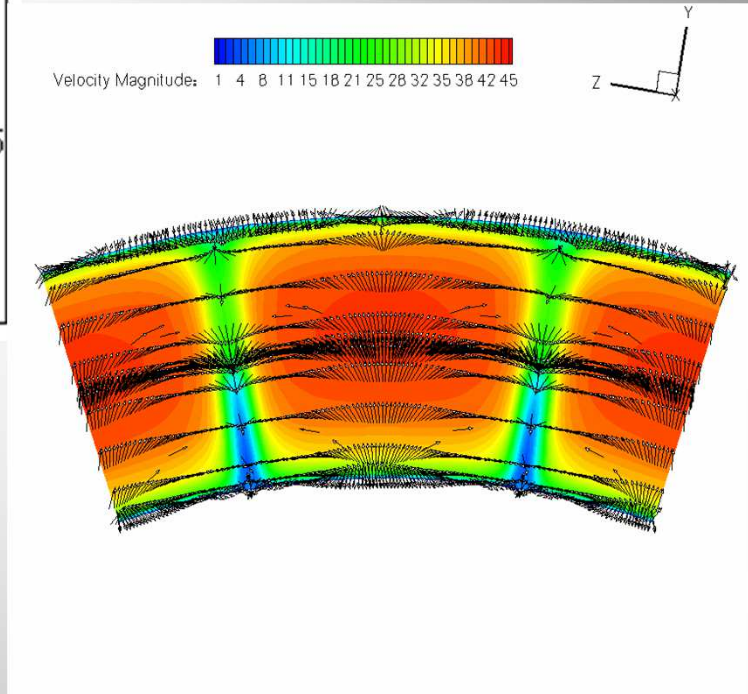


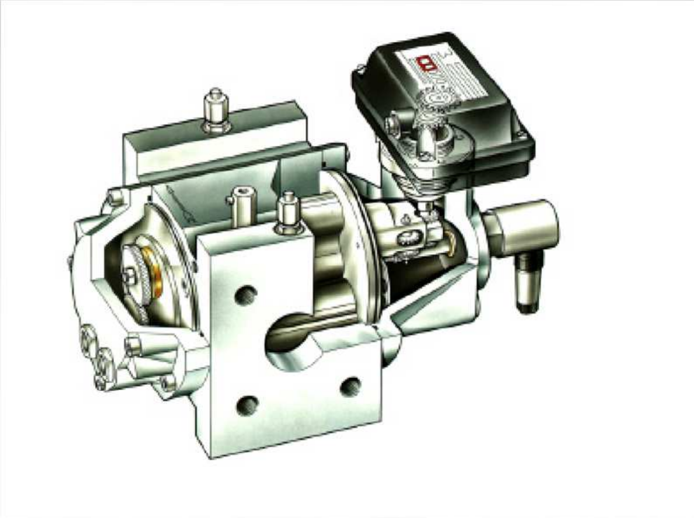


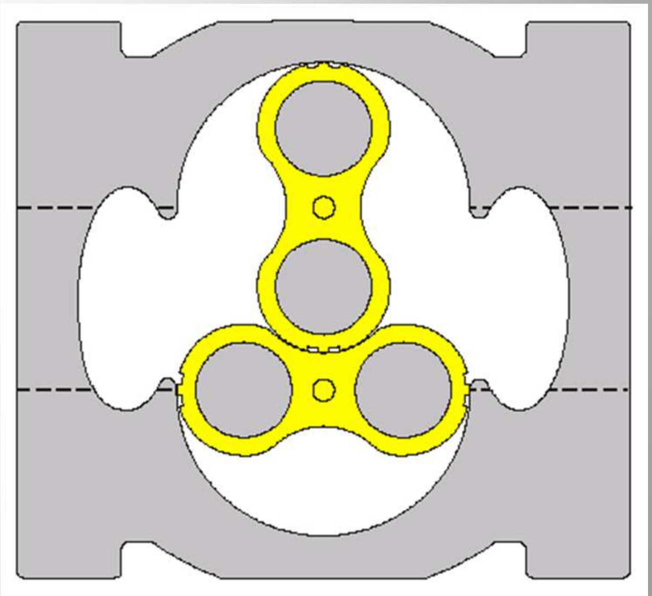
Rotary Piston Flow Meter

Motivation
Numerical investigation of the uncertainty & deviation
A) 2-D
- gap flow piston-casing
- pressure losses
- geometrical factors
- unsteady effects

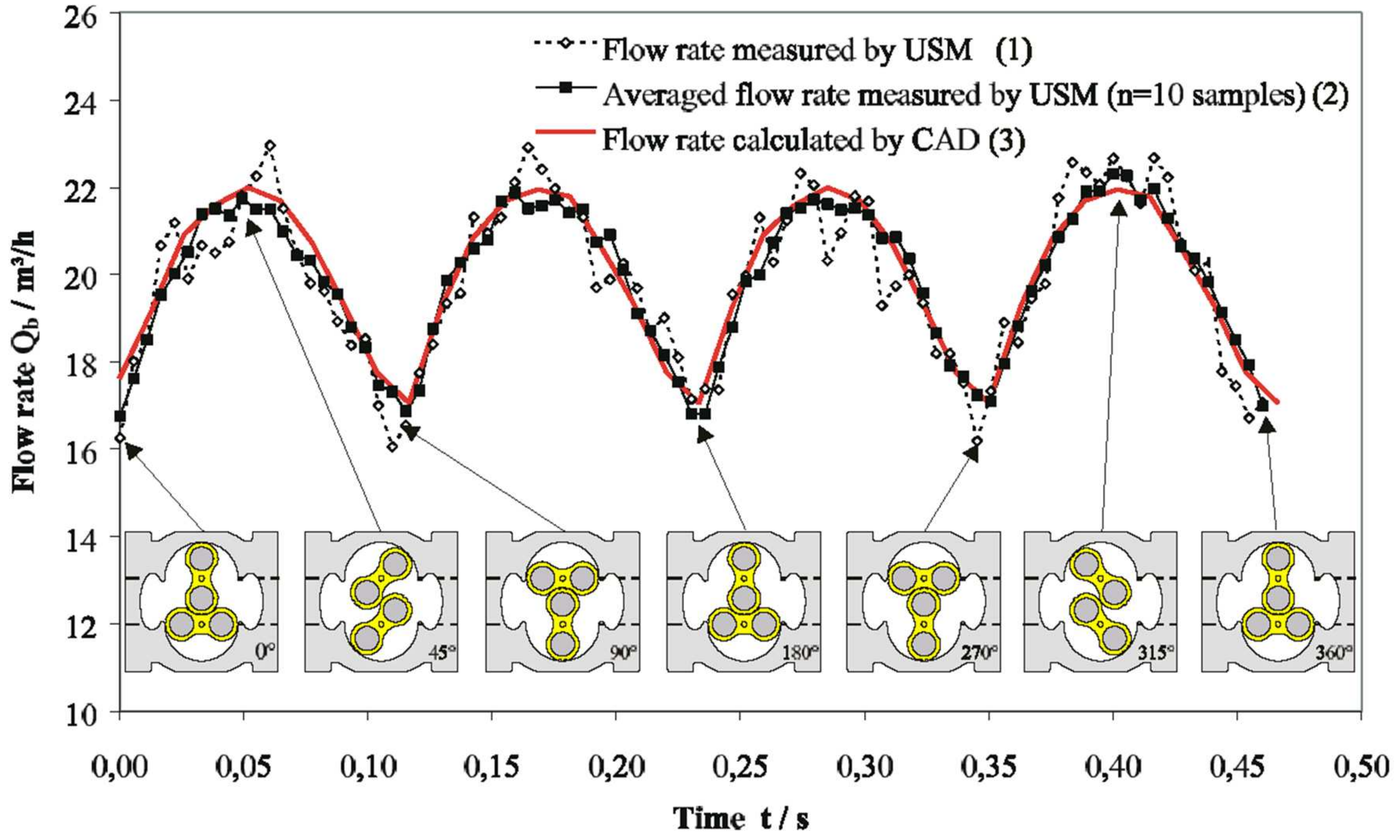
B) 3-D
- unsteady solution
- flow in ind. cham.
- 3-D effects

Future Work

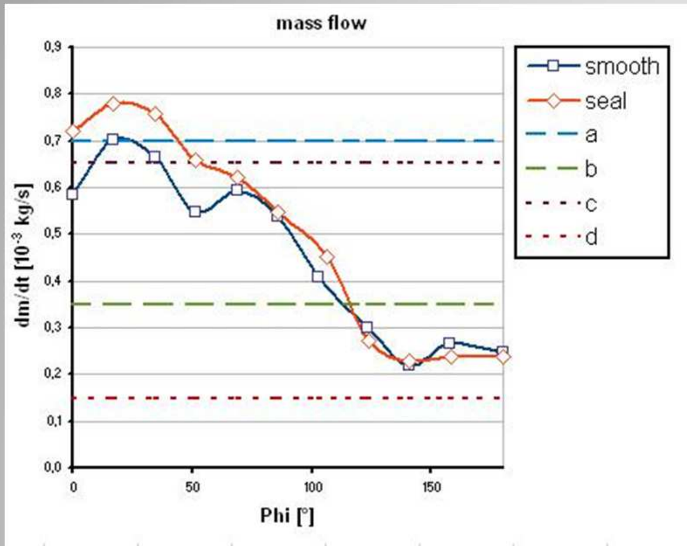


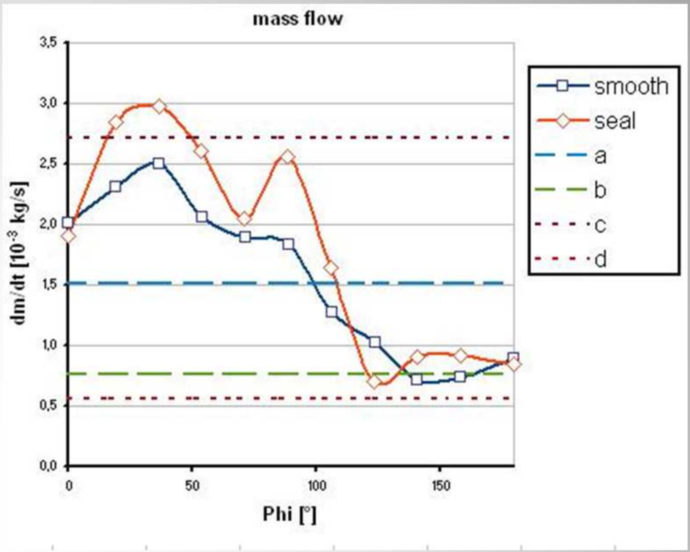


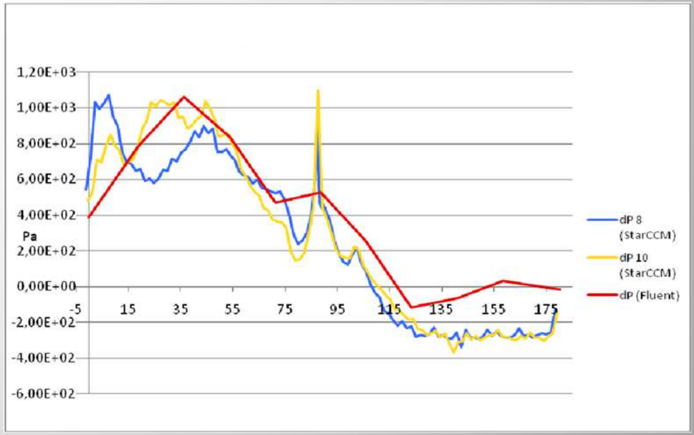
Rotary Piston Flow Meter



Rotary Piston Flow Meter

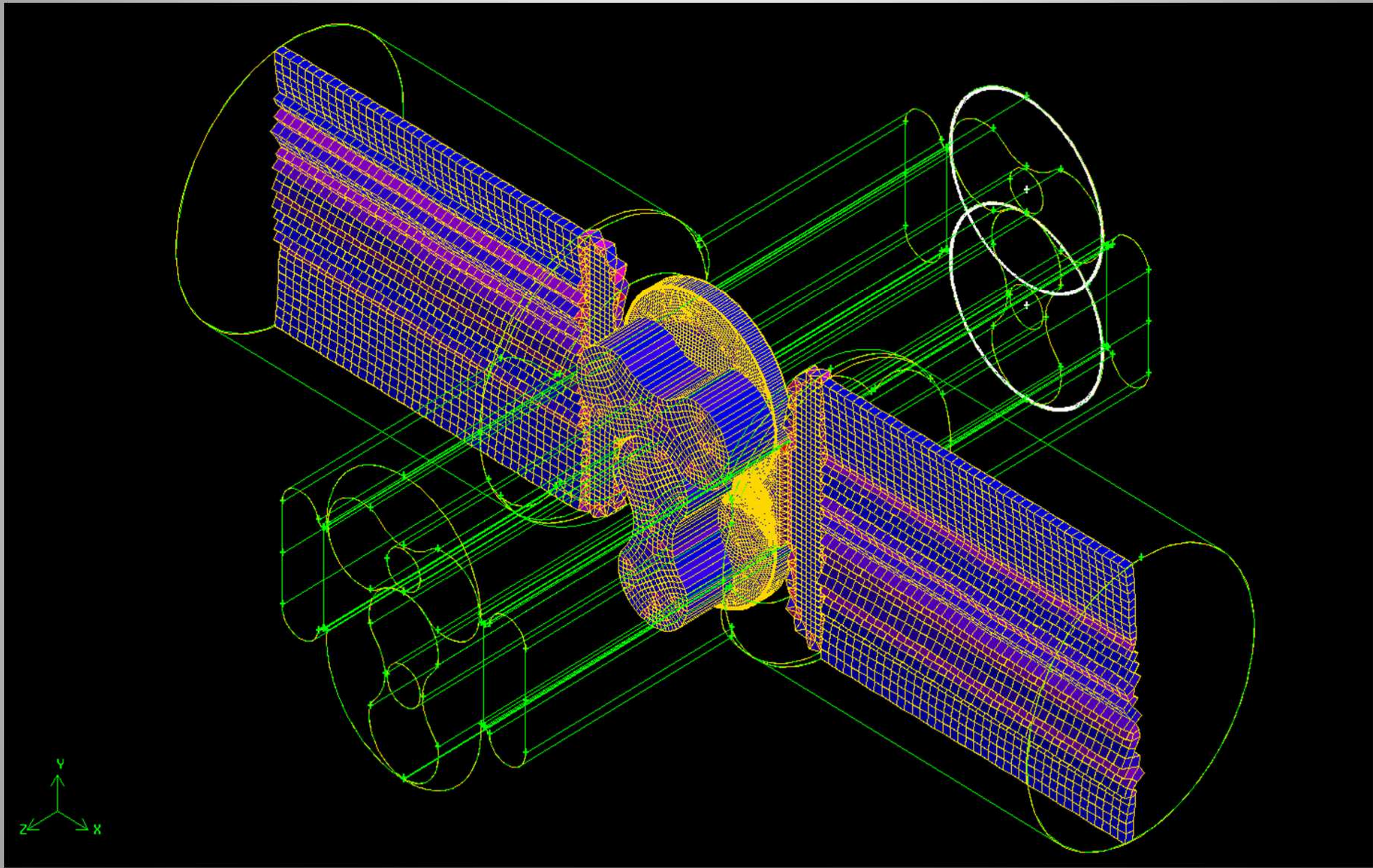




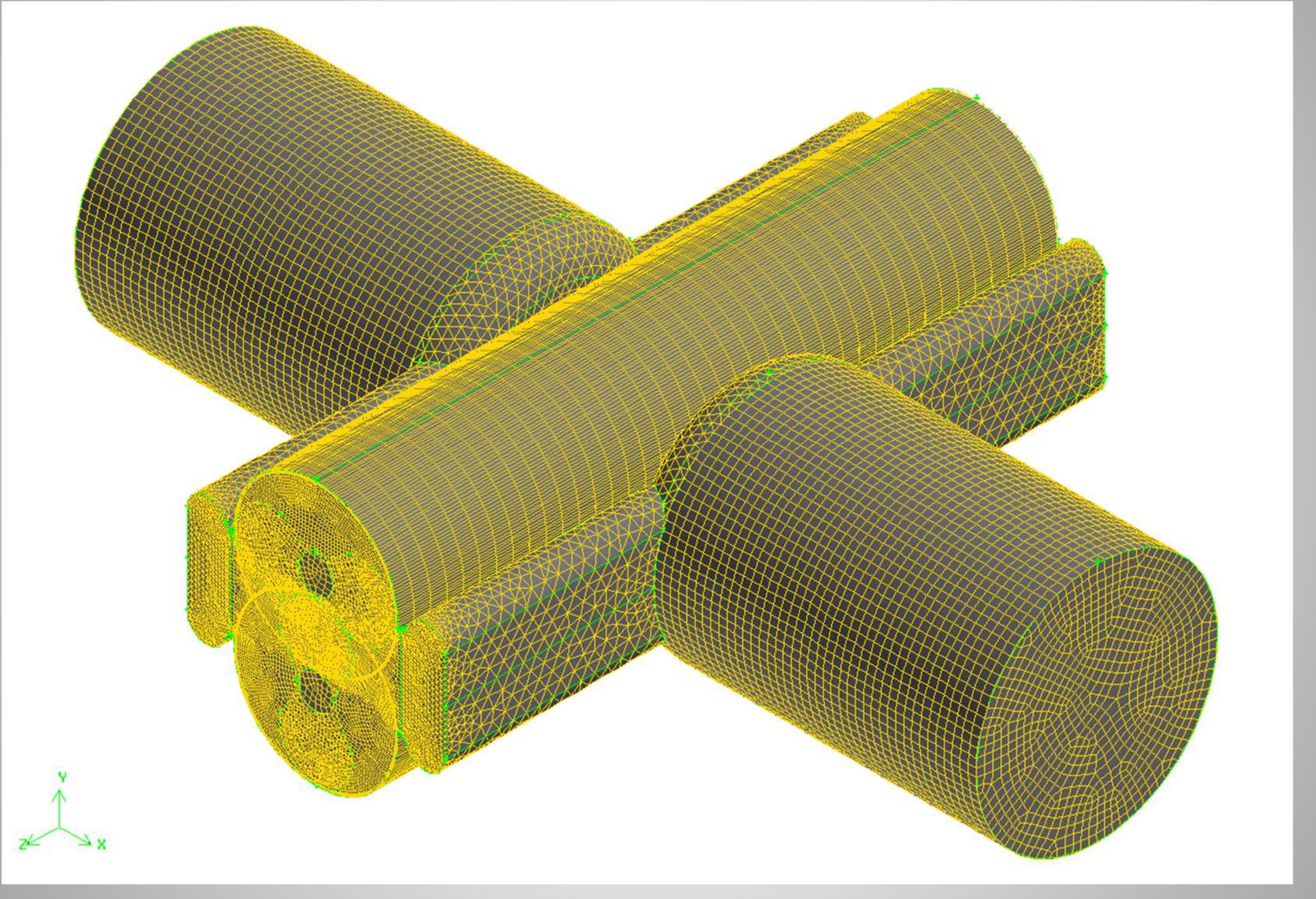


a) inviscid case, with constant velocity across the gap, $Q = u_w H$
b) highly viscous case with linear velocity profile, $Q = ½ u_w H$
c) case with maximum $\Delta p > 0$
d) case with minimum $\Delta p < 0$

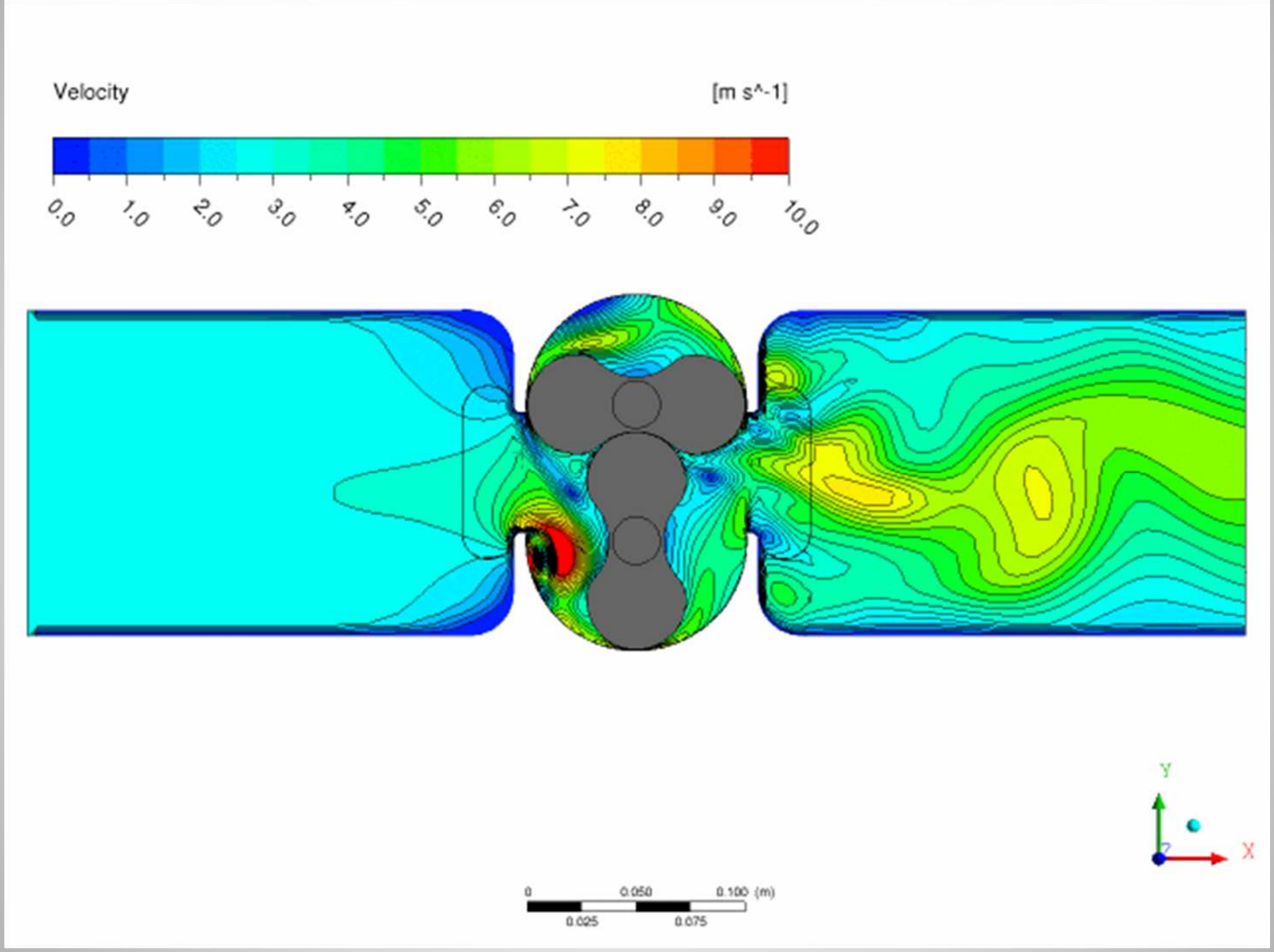
Rotary Piston Flow Meter



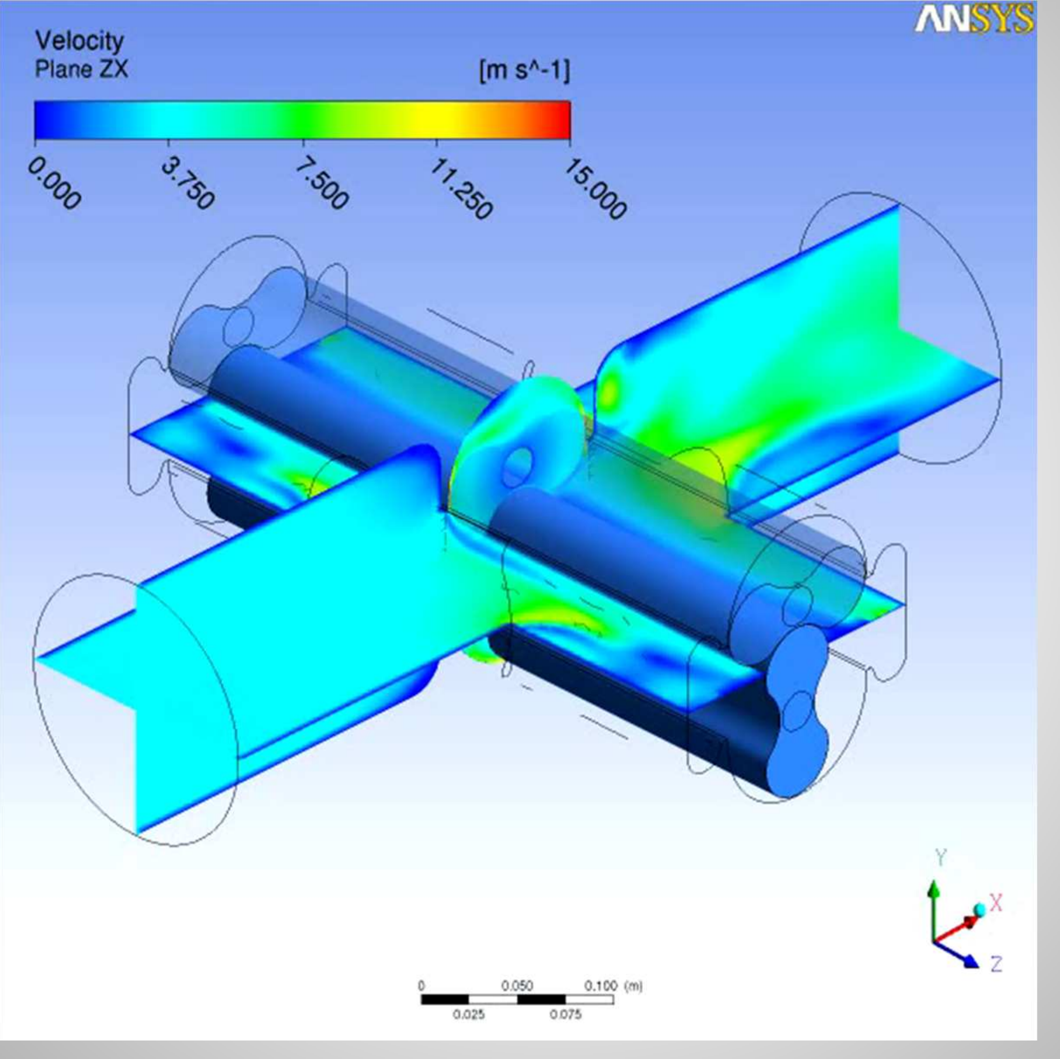
Rotary Piston Flow Meter



Rotary Piston Flow Meter



Rotary Piston Flow Meter



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Conclusions

Reliable numerical simulation of komplex flows in flow metering configurations possible using low numerical dissipation schemes

Commercial codes should be used with care –

it is not all gold that shines

OpenFoam looks promising in many cases

Present simulations were able to provide an explanation of many flow behaviour questions

Much higher resolution simulations in future – there is never enough computer power (CPU and RAM)