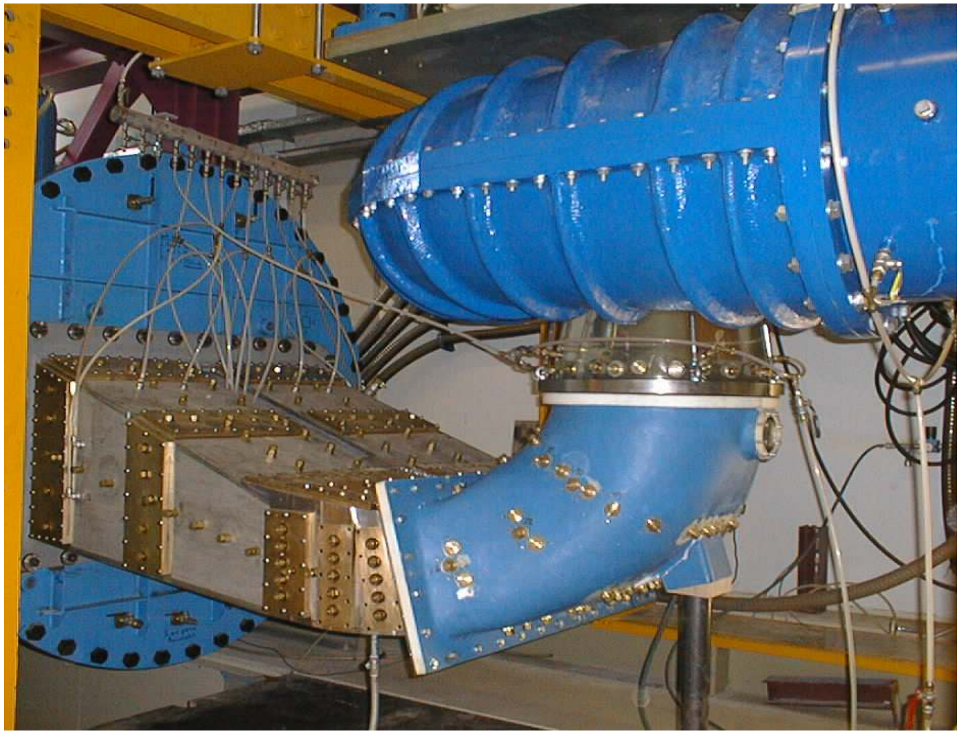
Metode moderne pentru cercetarea in Masini Hidraulice

Dr. Gabriel Dan CIOCAN
Associate Professor



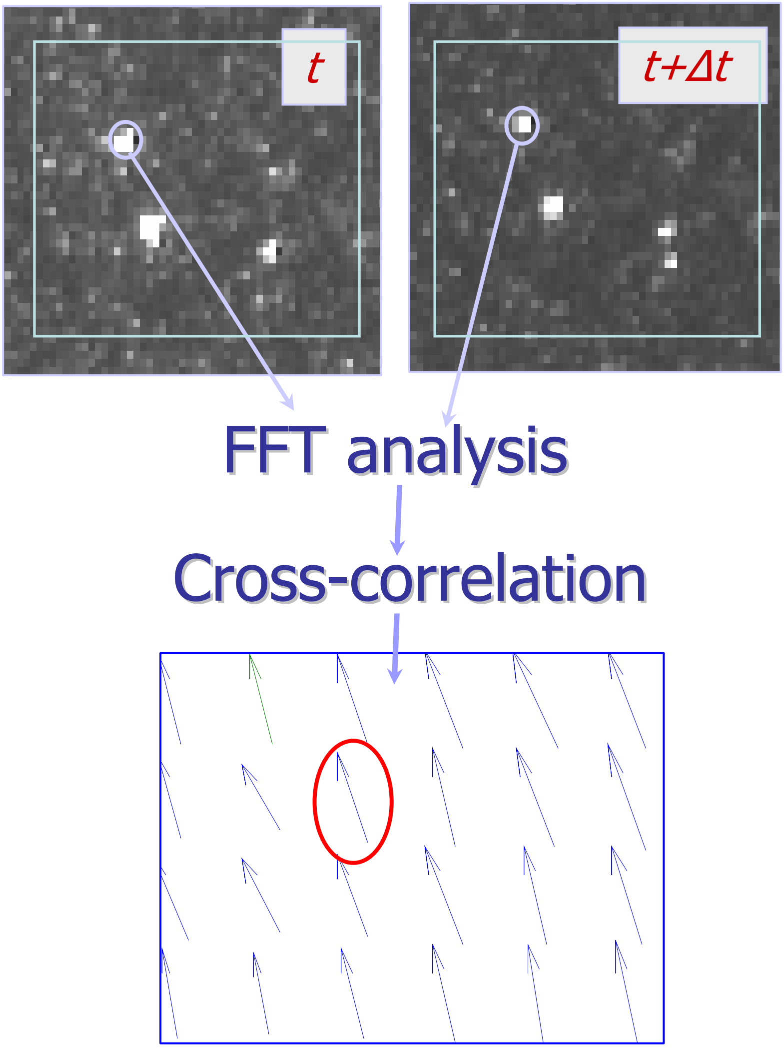
Contents

New Experimental Methods and New Theoretical Developments:

✓ *Optical Methods:* *3D PIV Method*
2 Phases PIV 2D & 3D
Endoscopic PIV

✓ *Miniature sensors :* Parietal wall friction
Pressure unsteady probes

3D PIV Principle



FFT analysis

Cross-correlation

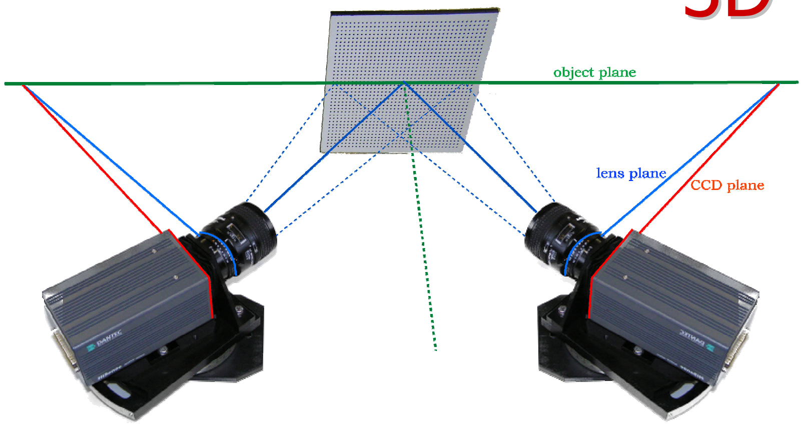
✓ *Acquisition Parameters*

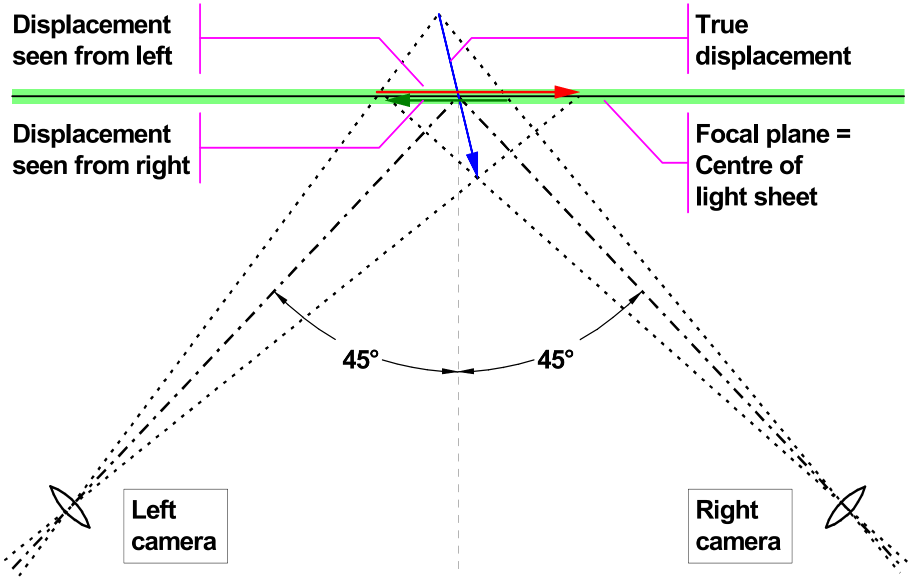
- time interval
- seeding density
- energy distribution in the laser-sheet
- laser-sheet alignment

✓ *Vectors Fields Validation*

- masking
- correlation quality
- moving average interpolation

3D PIV Principle





Displacement seen from left

True displacement

Displacement seen from right

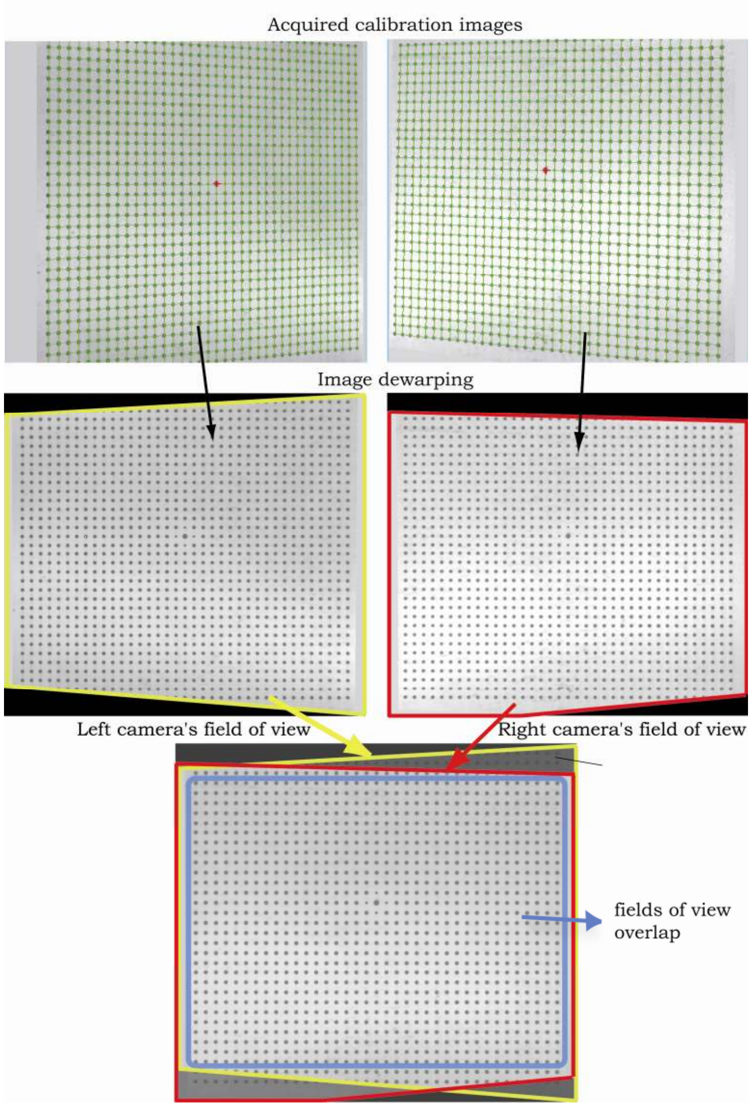
Focal plane = Centre of light sheet

45°

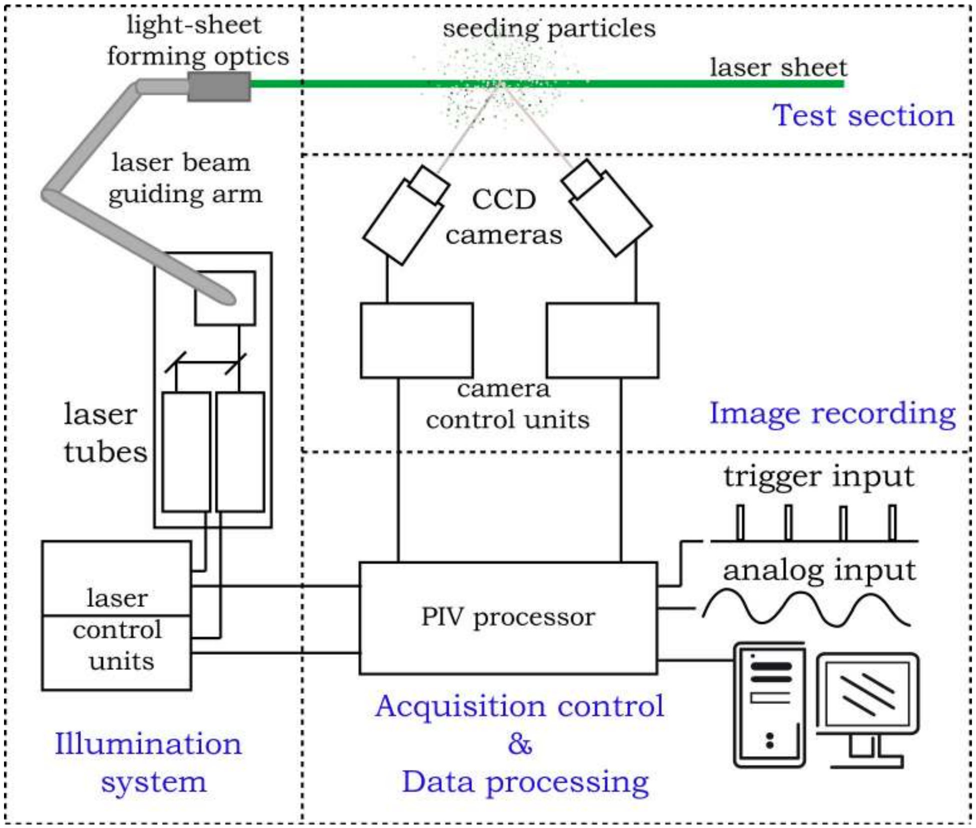
45°

Left camera

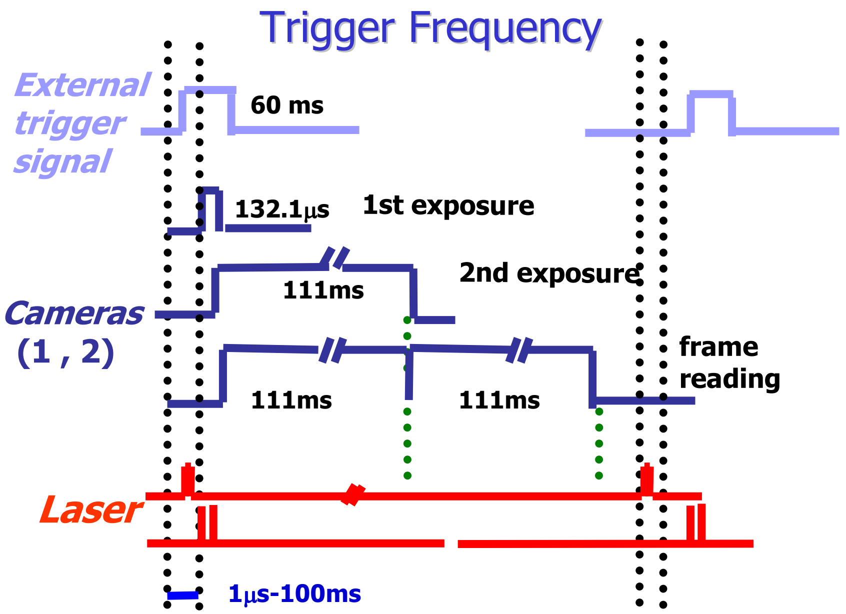
Right camera



PIV System



System Architecture

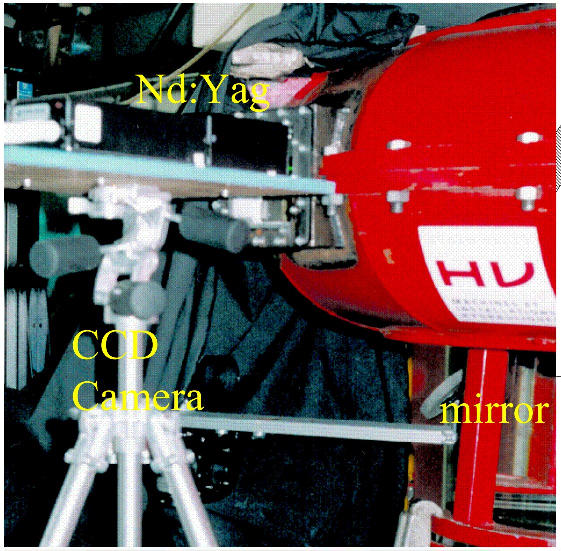


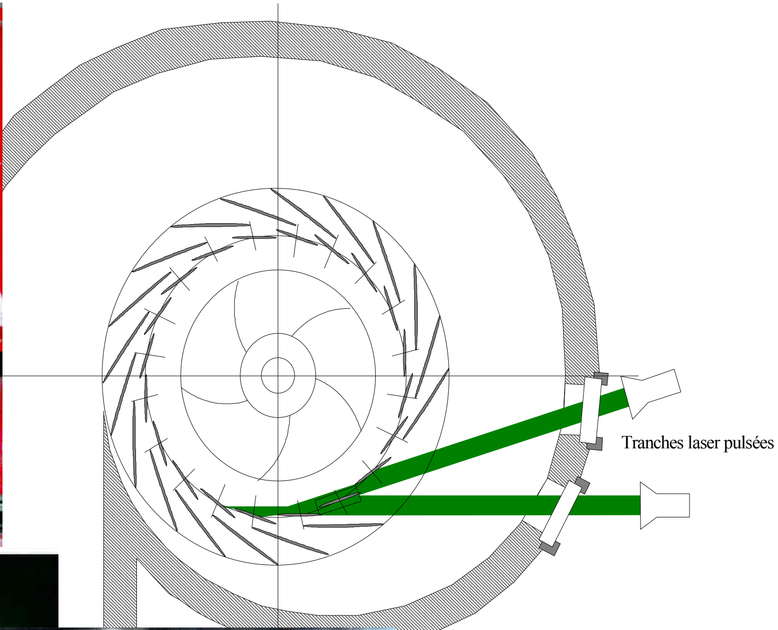
Synchronization delay 5÷50 ms

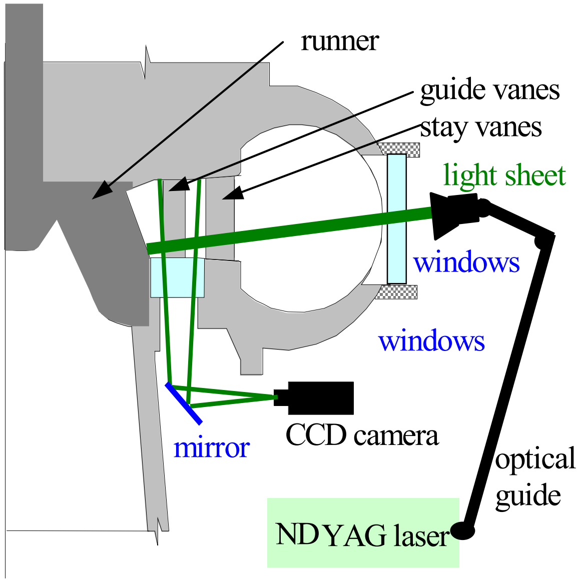
Maximum Acquisition Frequency 4.5 Hz

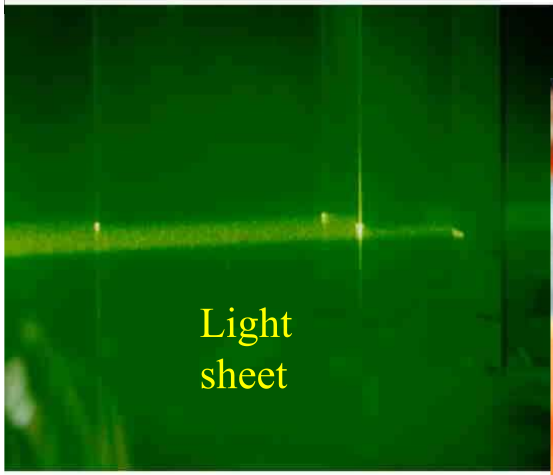
Timing Diagram

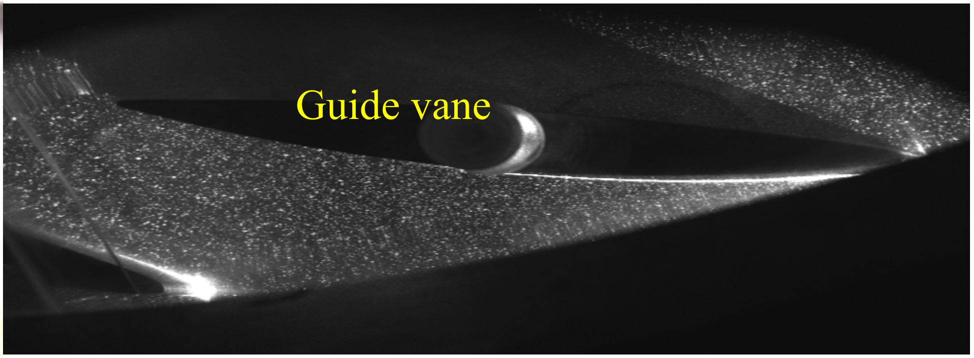
Rotor-Stator Interaction



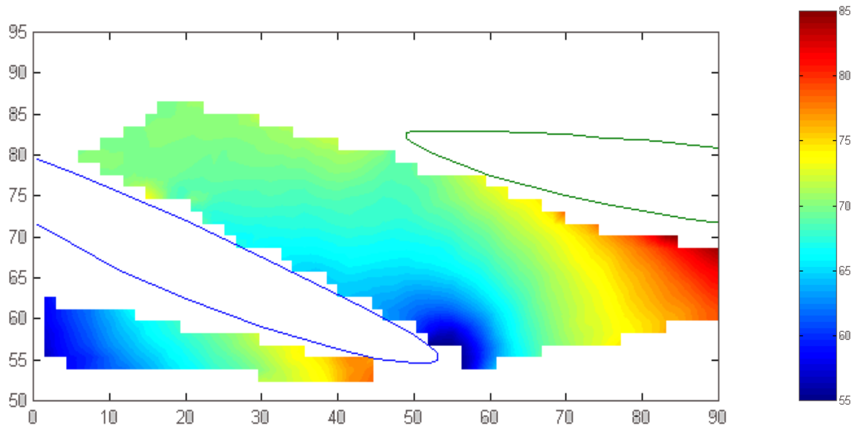




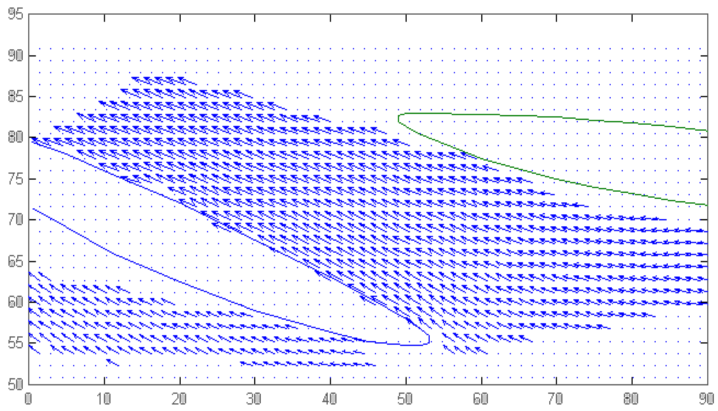




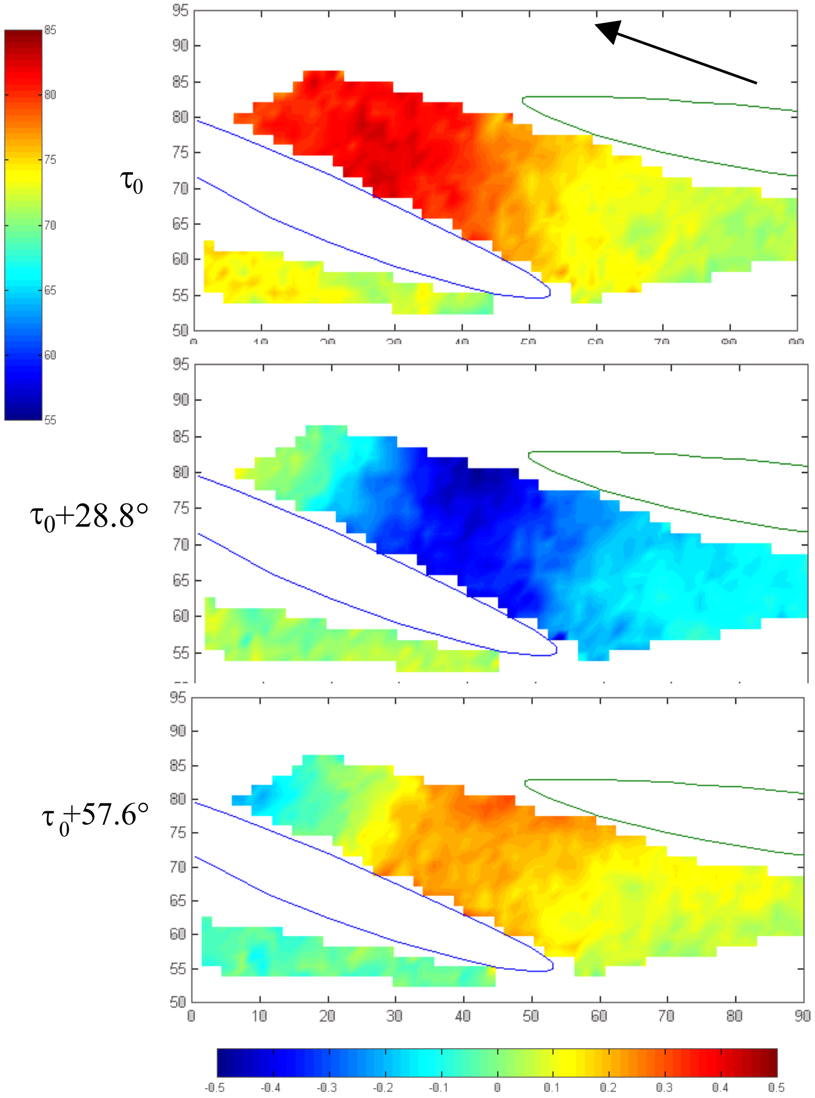
Turbine Rotor-Stator Interaction



Angle of the Velocity Vector

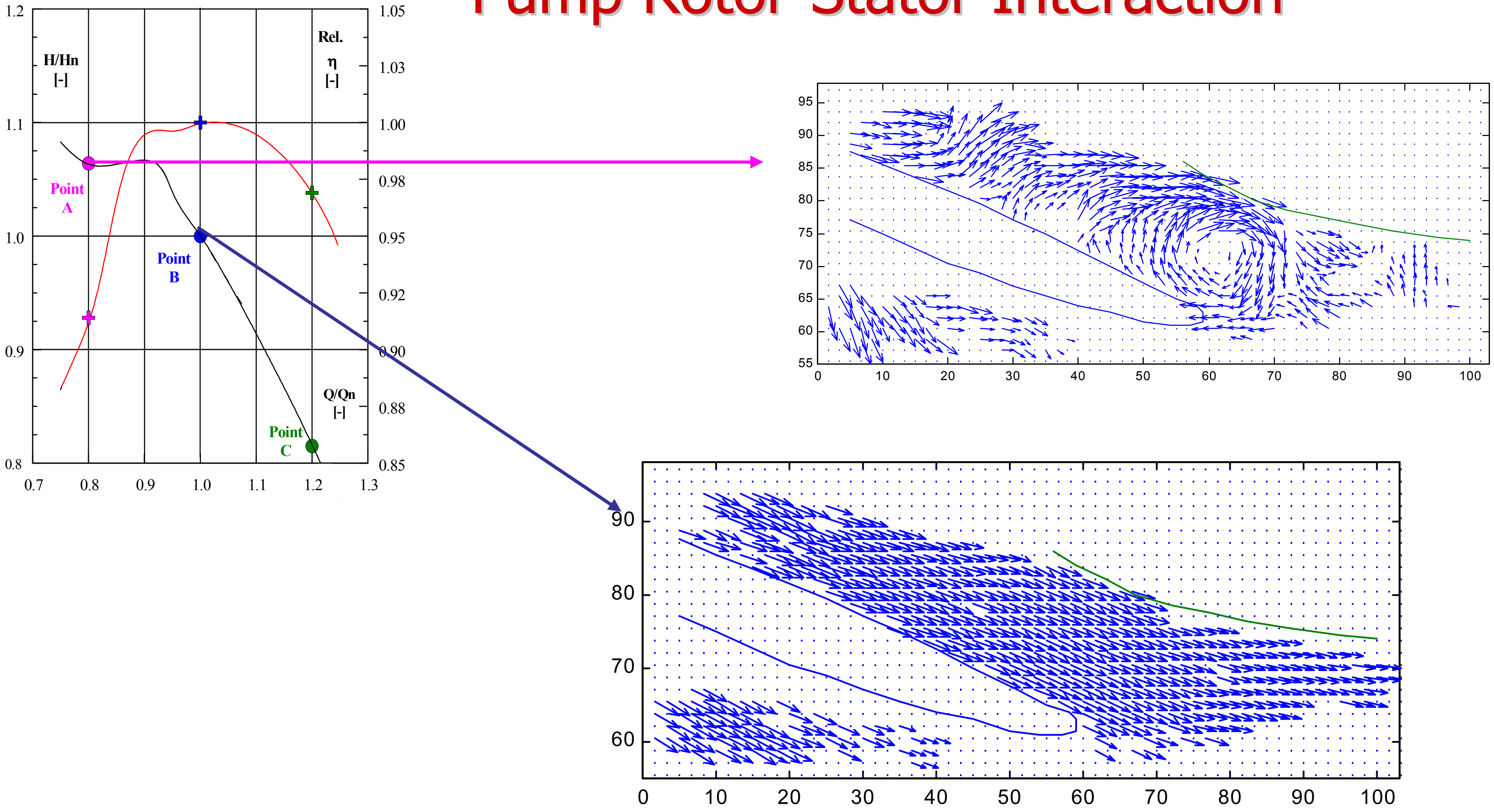


Mean Velocity Field



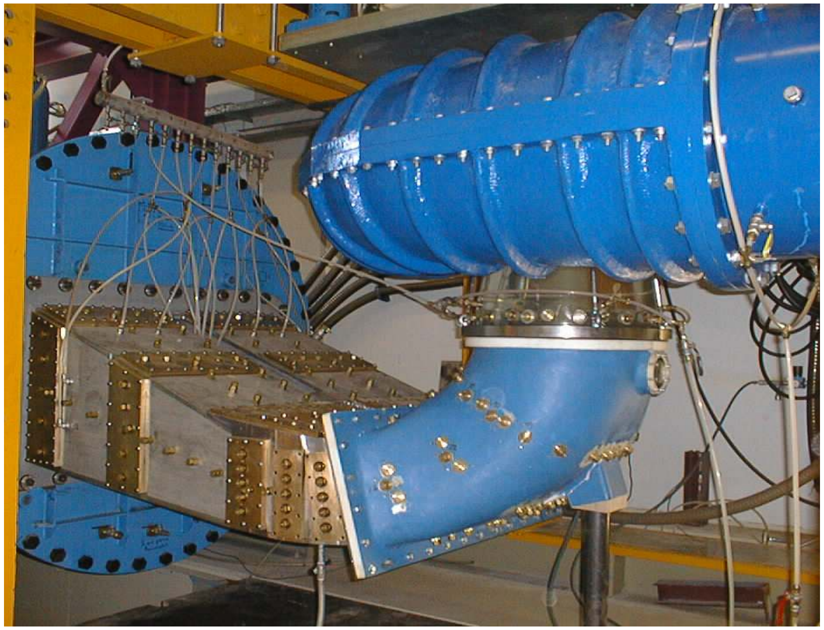
$\tilde{c}-\bar{c}$

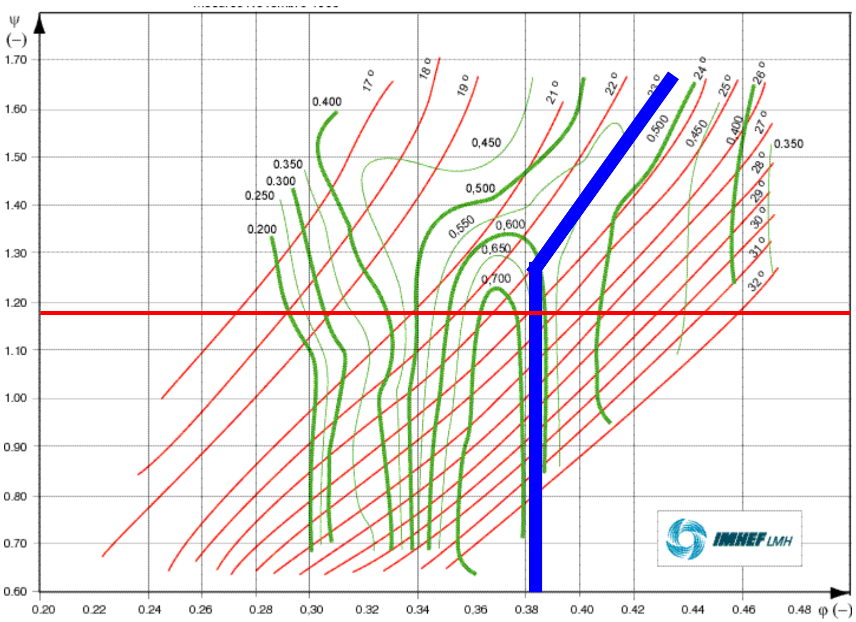
Pump Rotor-Stator Interaction

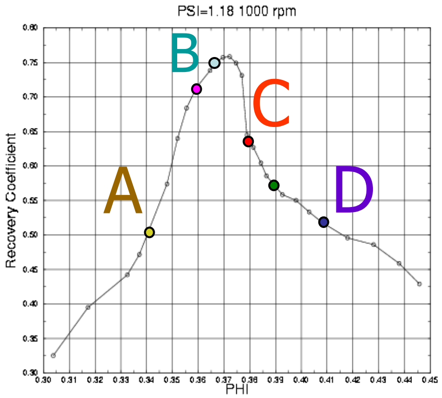


Ciocan G.D., Avellan F., Kueny J.L.; "Optical Measurement Techniques for Experimental Analysis of Hydraulic Turbines Rotor - Stator Interaction"
ASME Fluids Engineering Division Summer Meeting, 2000

FLINDT Project







$$\chi = \frac{\frac{1}{\rho}\Delta p_{asp}}{\frac{1}{2}\left(\frac{Q}{A_{ref}}\right)^2}$$

ALSTOM Power Hydro

EDF Electricité de France

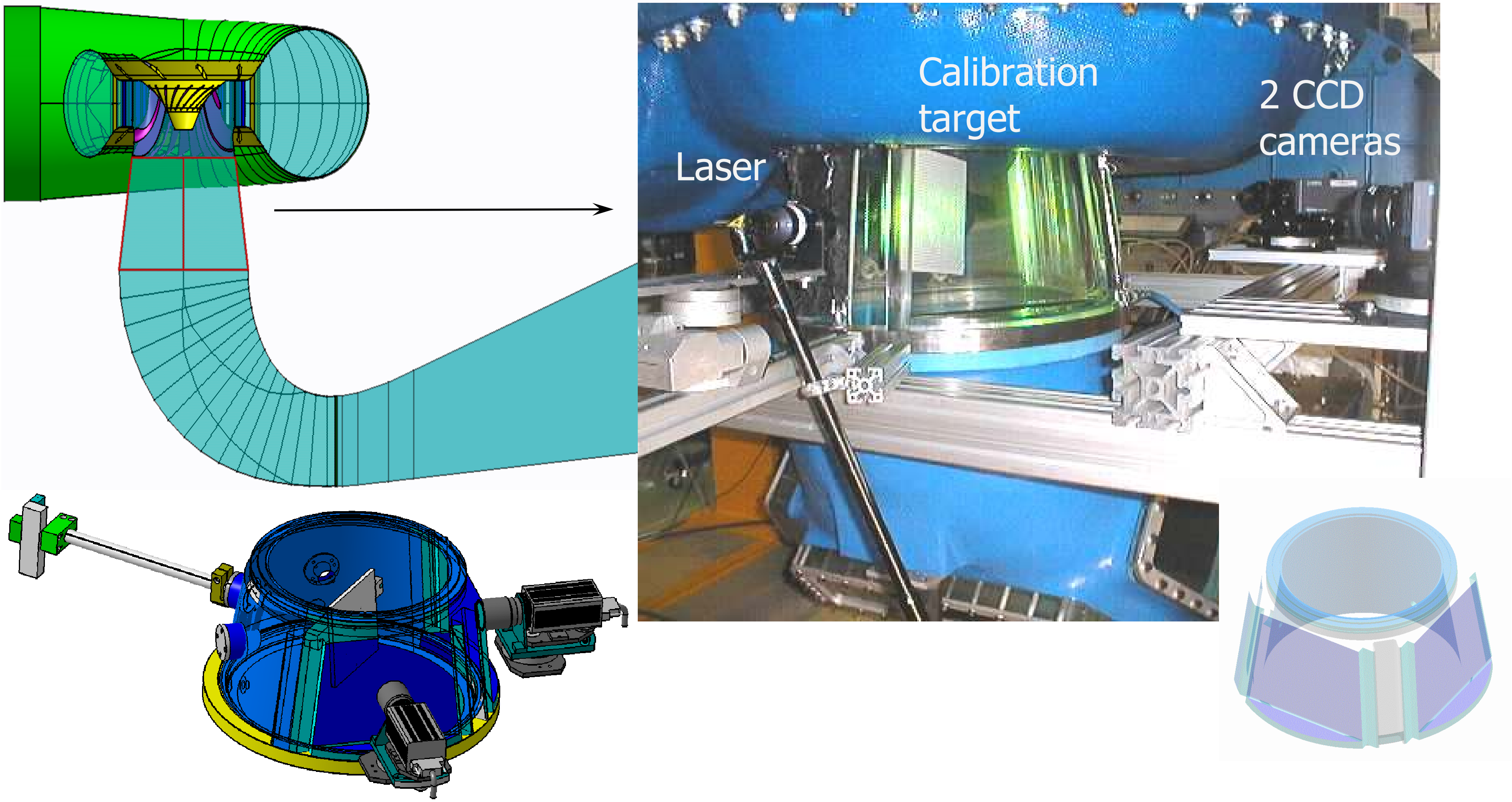
Power Systems
GE Hydro

VATECH
VA TECH HYDRO

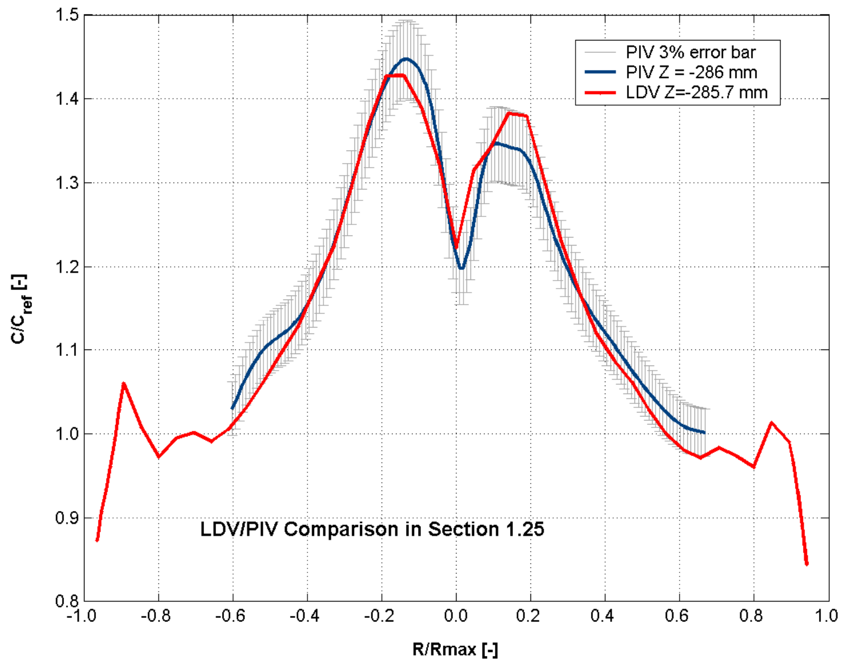
VOITH SIEMENS
HYDRO POWER GENERATION

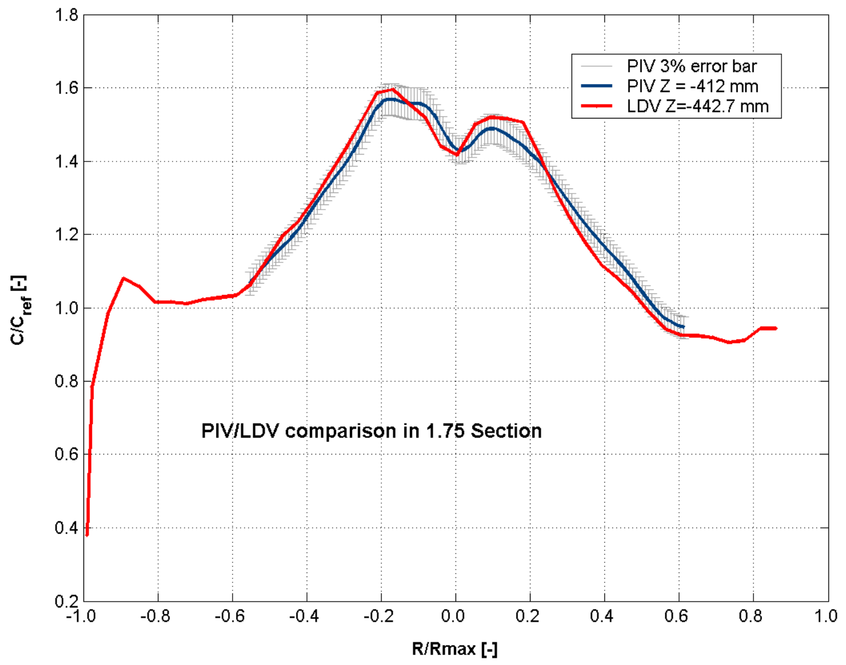
Ciocan G.D., Avellan F., "Flow Investigations in a Francis Draft Tube: Advanced Experimental Methods"
3rd Conference of Romanian Hydropower Engineers, Romania, 2004

3D PIV in the Cone

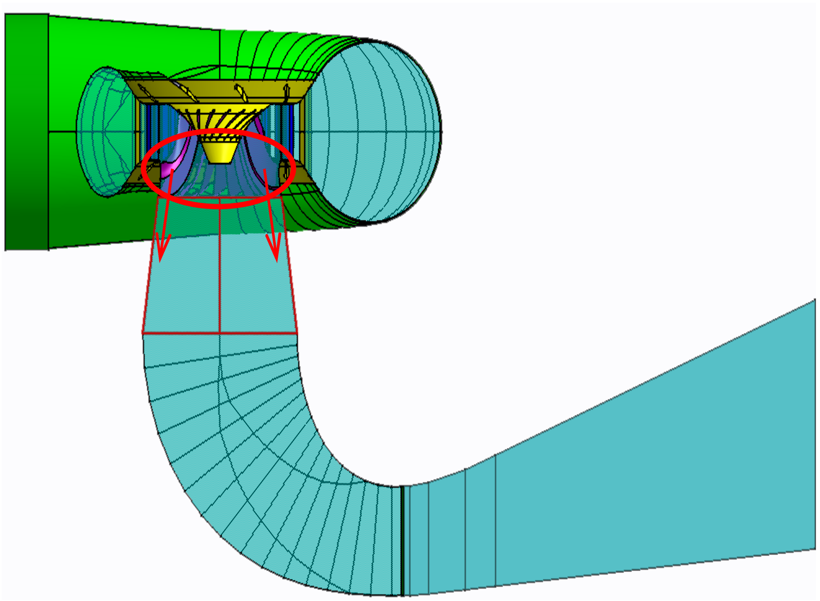


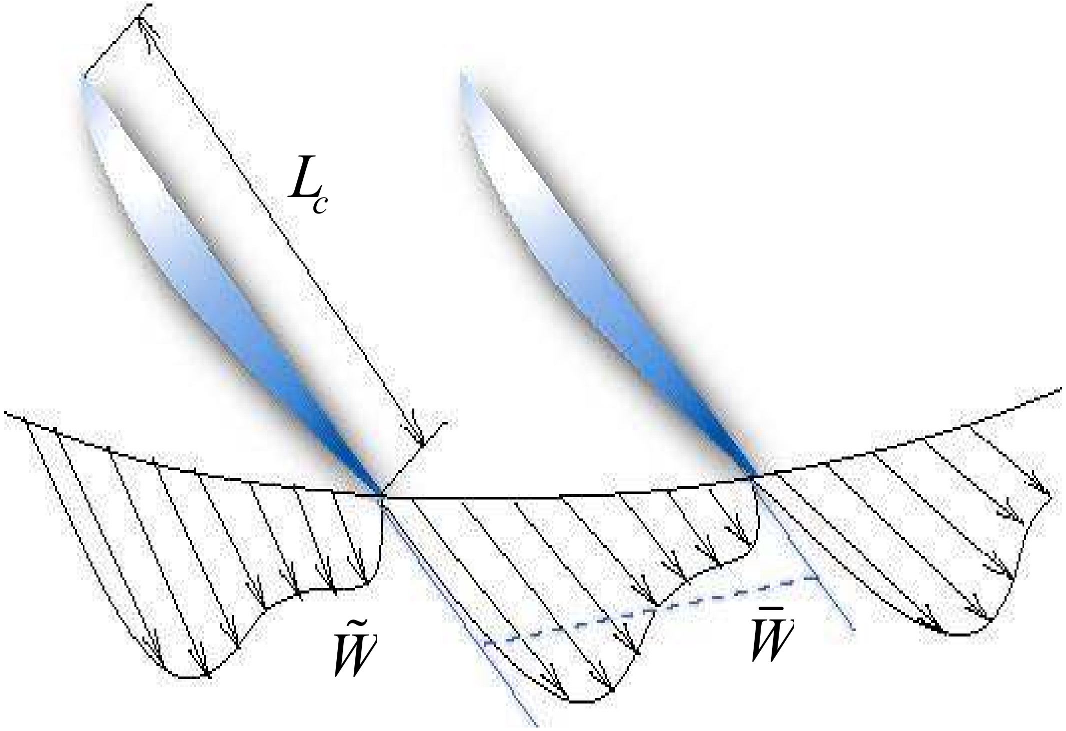
3D Particle Image Velocimetry





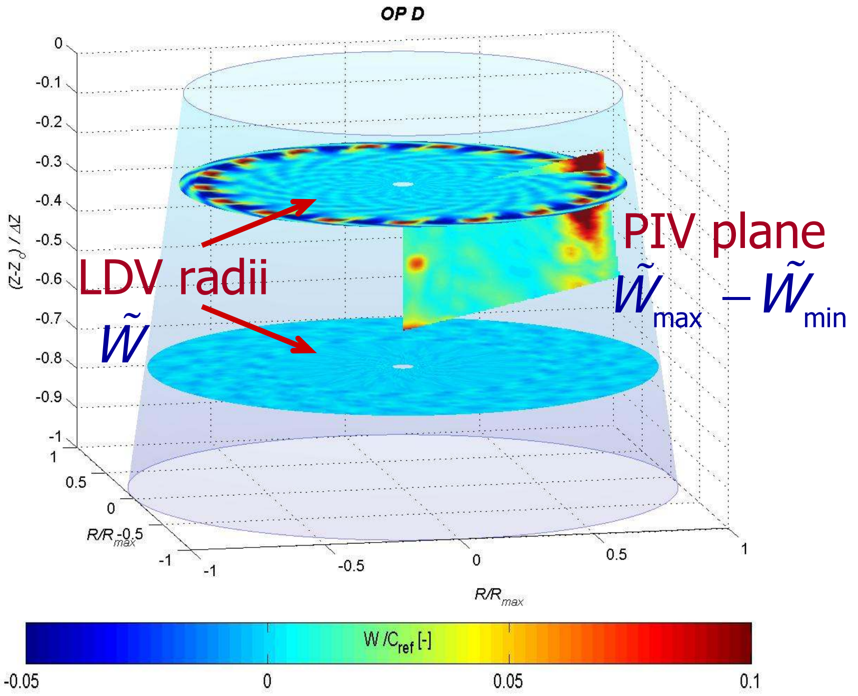
Sheared flow mixing





- Blade-to-blade flow field non-uniformity
- Pressure/suction side boundary layers shearing
- Led by the relative flow

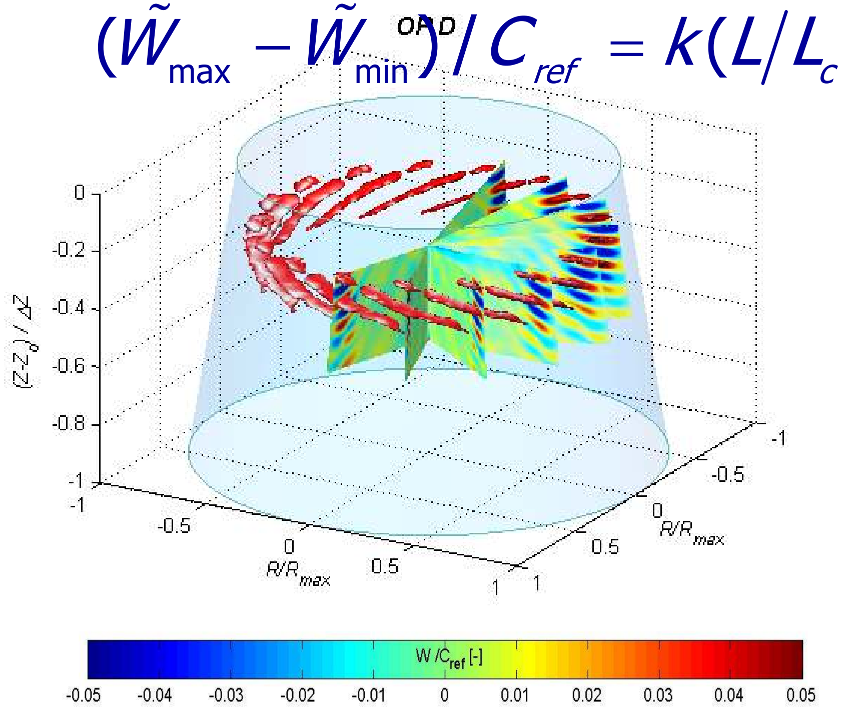
Sheared flow mixing



LDV radii $\tilde{W}$

PIV plane $\tilde{W}_{\max} - \tilde{W}_{\min}$

$$(\tilde{W}_{\max} - \tilde{W}_{\min}) / C_{ref} = k(L/L_c)^{-1}$$

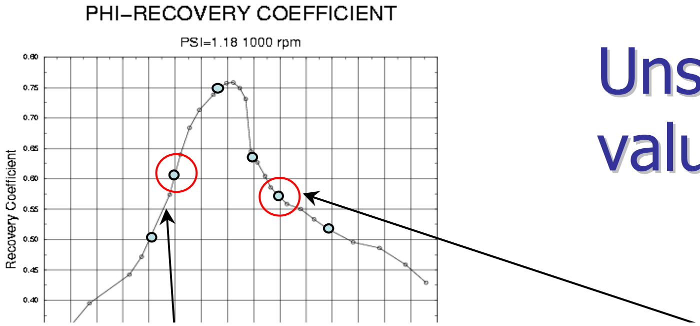


LDV – phase average velocity fields
PIV – fluctuation amplitude field

Blade-to-blade channel flow velocity propagation & dispersal in the cone

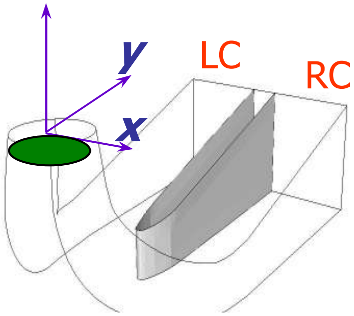
Iliescu M.S., Ciocan G.D., Avellan F.: "Experimental Study of the Runner Blade-to-Blade Shear Flow Turbulent Mixing in the Cone of Francis Turbine Scale Model", 22nd IAHR Symposium on Hydraulic Machinery and Systems, 2004

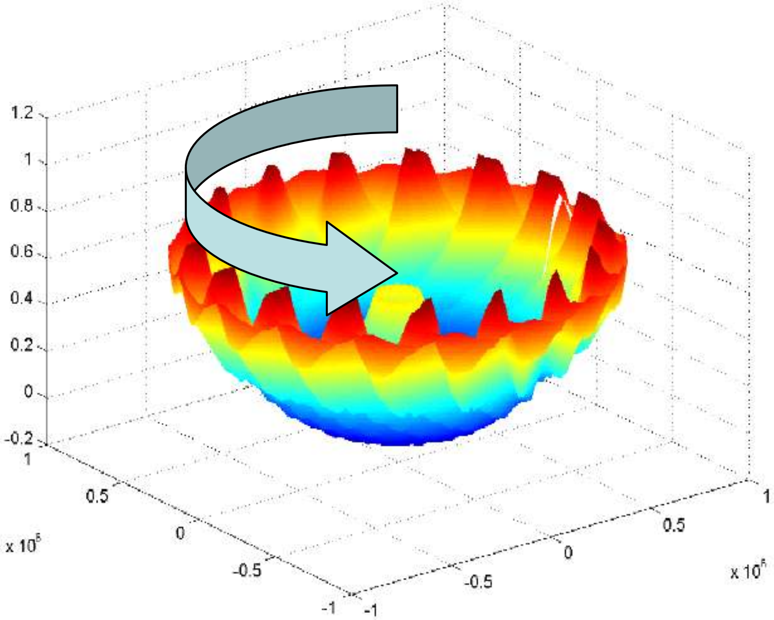
LDV Runner Outlet – Phase Average

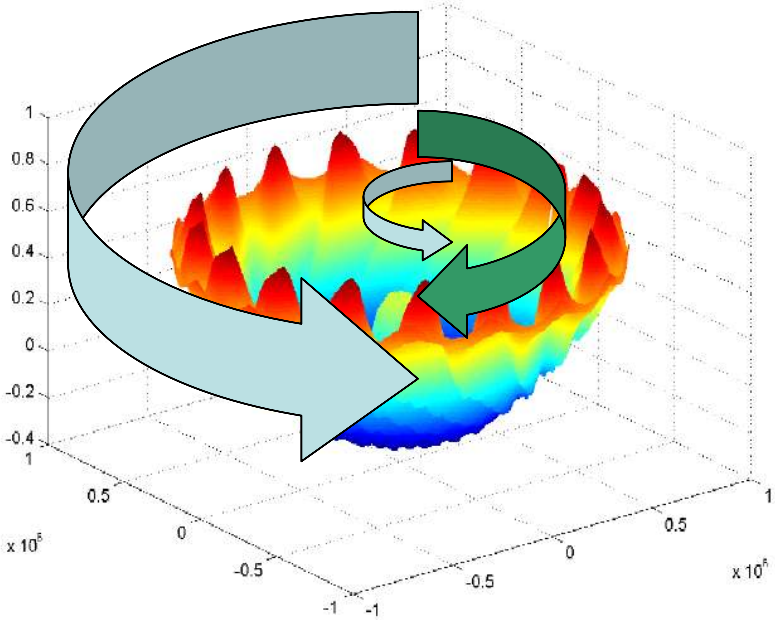


Unsteady values

$$\tilde{c}_w^{\,T} + \overline{c}_w$$



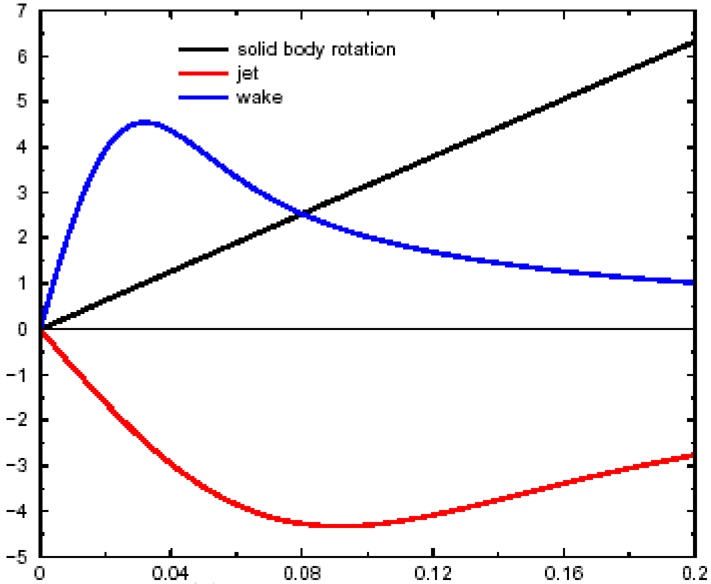




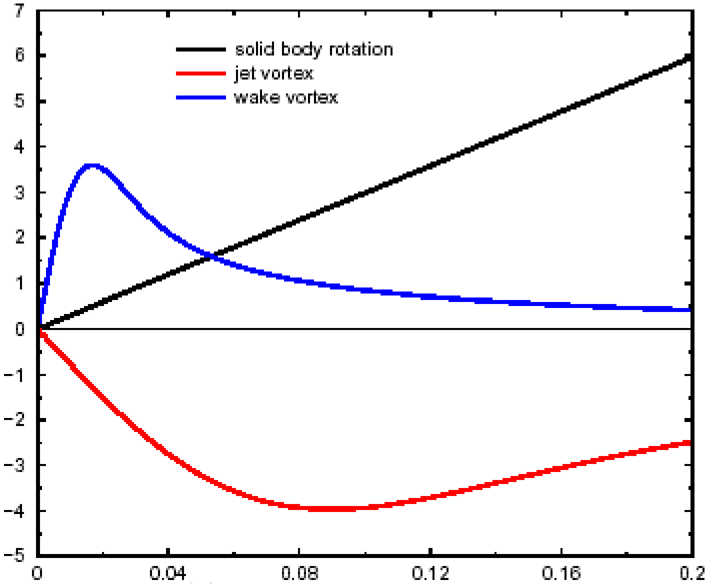
Analytical Description of the Velocity Profile

$$v_u = \Omega_0 r + \Omega_1 \frac{R_1^2}{r}\left[1 - \exp\left(-\frac{r^2}{R_1^2}\right)\right] + \Omega_2 \frac{R_2^2}{r}\left[1 - \exp\left(-\frac{r^2}{R_2^2}\right)\right] \qquad (1)$$

$$v_a = U_0 + U_1 \exp\left(-\frac{r^2}{R_1^2}\right) + U_2 \exp\left(-\frac{r^2}{R_2^2}\right) \qquad (2)$$

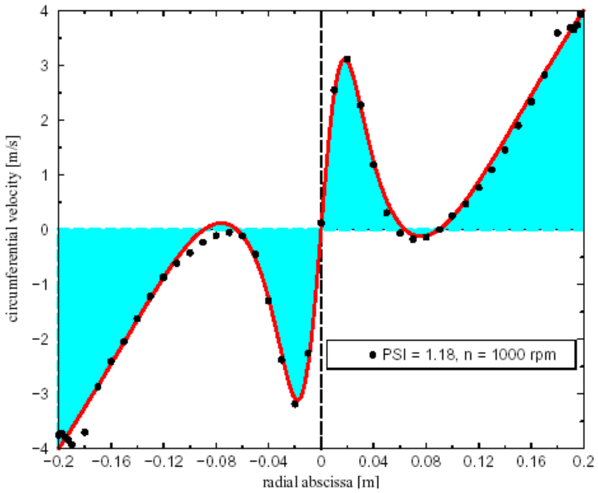


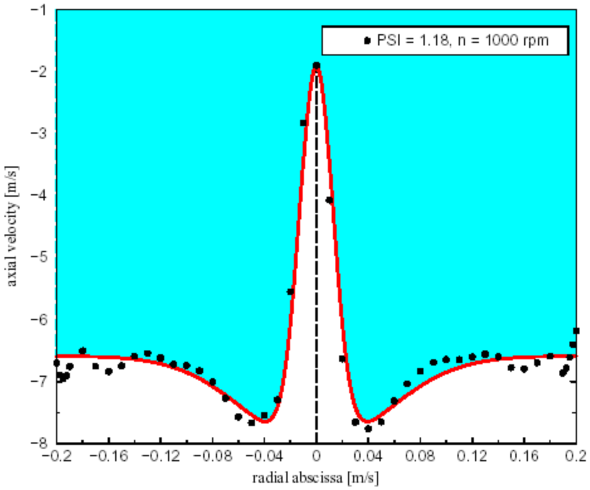
(a) Vortices for $\varphi = 0.340$

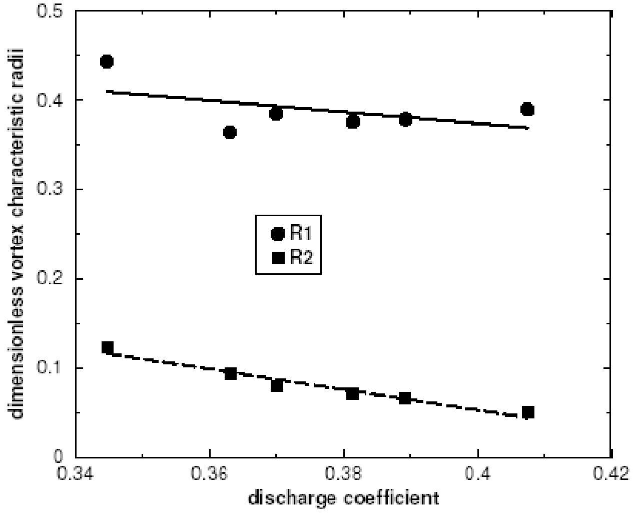


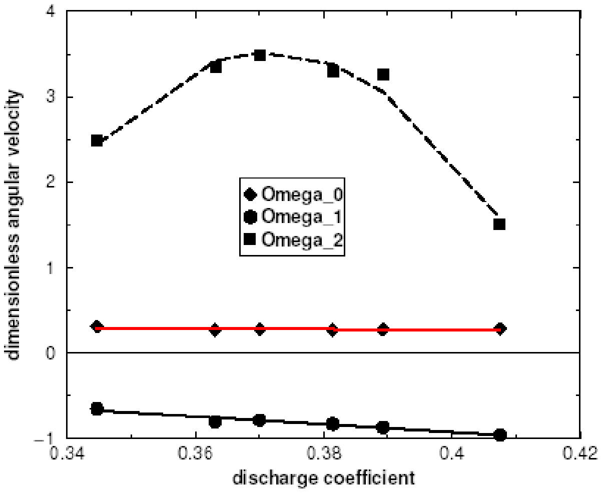
(b) Vortices for $\varphi = 0.370$

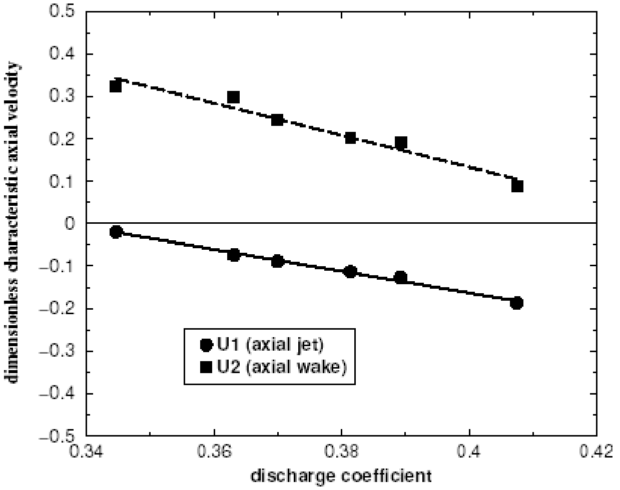
Analytical Description of the Velocity Profile



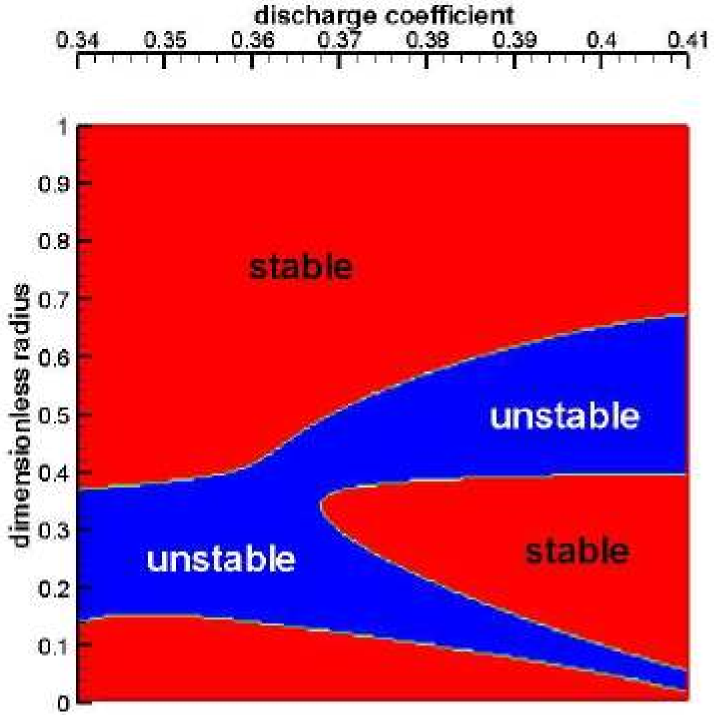




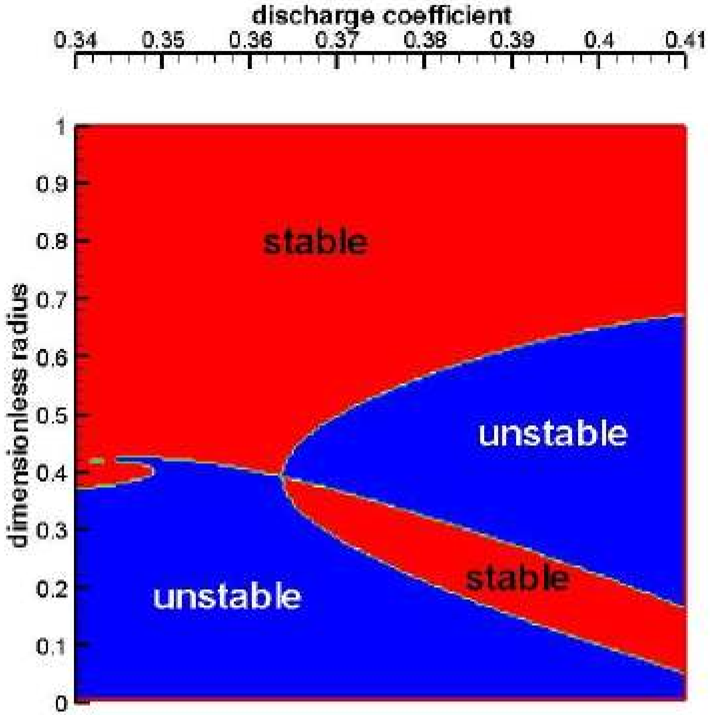




Étude de stabilité du profile de vitesse



Critère de stabilité Howard-Gupta
Perturbation axisymétrique



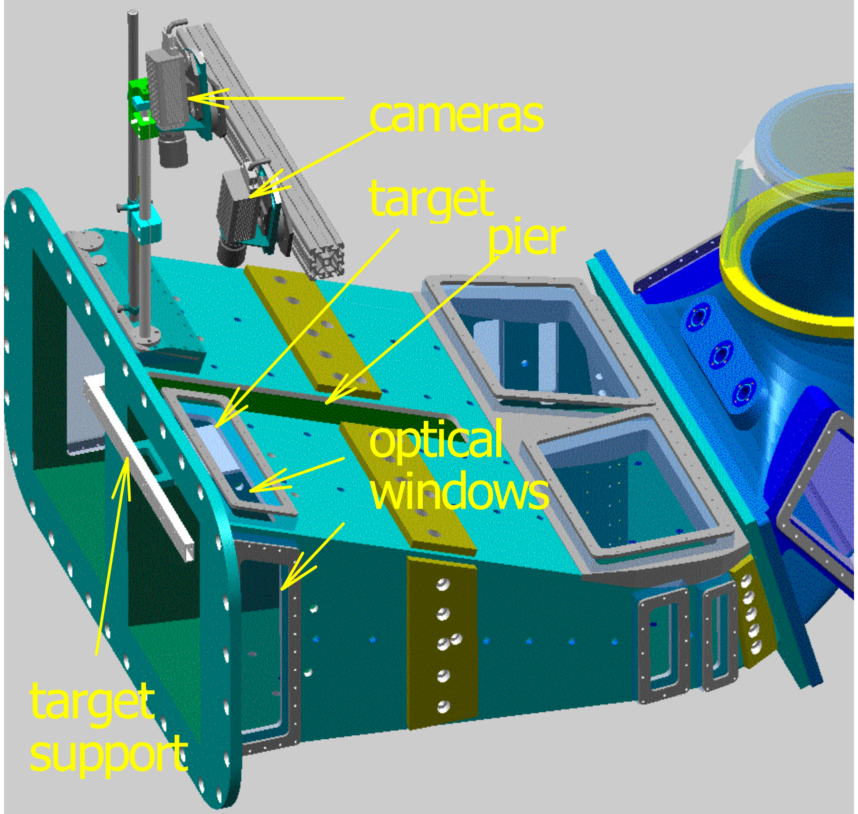
Critère de stabilité Leibovich-Stewatson
Perturbation non axisymétrique

Accuracy

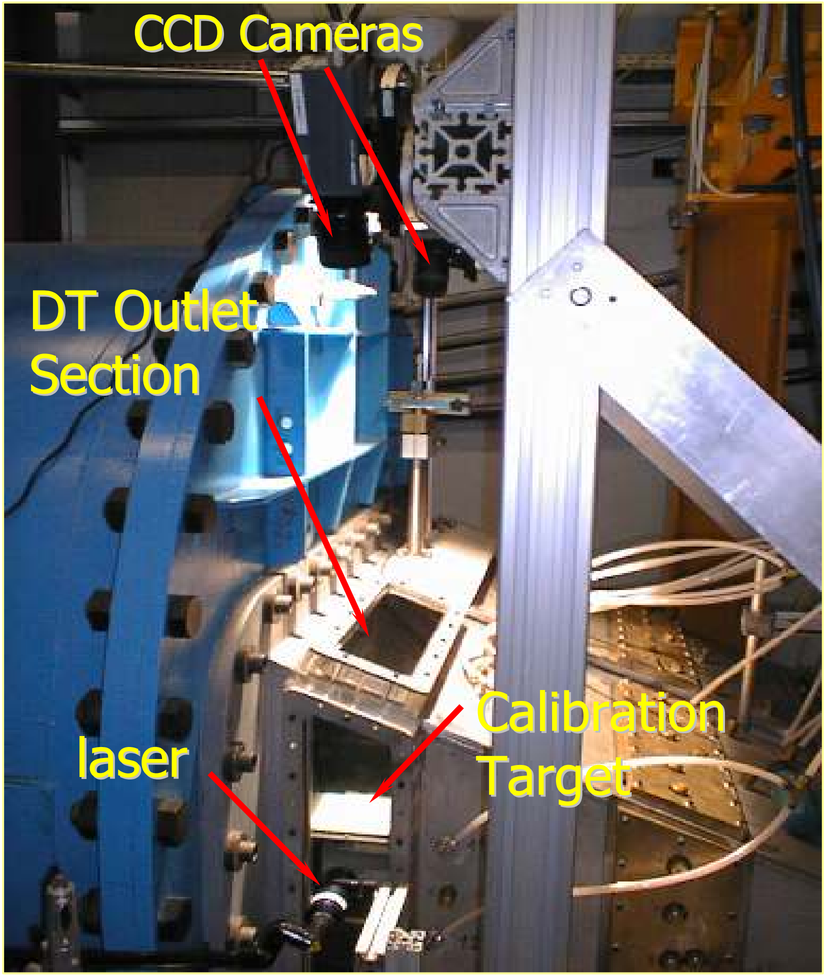
Measured discharge	Energy Coeff.	Speed [rpm]	Computed discharge	Error [%]
0.340	1.18	1000	0.344	+1.1
0.360	1.18	1000	0.363	+0.8
0.368	1.18	1000	0.372	+1.0
0.380	1.18	1000	0.381	+0.2
0.390	1.18	1000	0.389	-0.2
0.410	1.18	1000	0.409	-0.3
0.368	1.00	1000	0.368	+0.1
0.380	1.00	1000	0.380	+0.1
0.370	1.11	1000	0.369	-0.1
0.368	1.30	1000	0.371	+0.8
0.380	1.30	1000	0.386	+1.5
0.410	1.30	1000	0.407	-0.6
0.370	1.11	500	0.370	+0.1
0.340	1.18	500	0.345	+1.6
0.368	1.18	500	0.369	+0.2
0.380	1.18	500	0.379	-0.3
0.410	1.18	500	0.406	-0.9

- **Discharge computed from fitted axial velocity profile agrees within less than 1% with the measured discharge**
- **The energy coefficient does not influence the velocity profiles at constant discharge**
- **Reynolds number effect is negligible (same velocity profiles at different runner speed)**

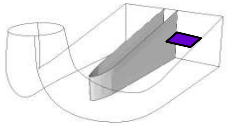
3D-PIV Draft Tube Outlet

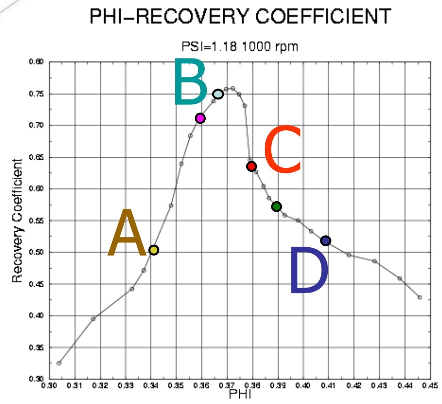


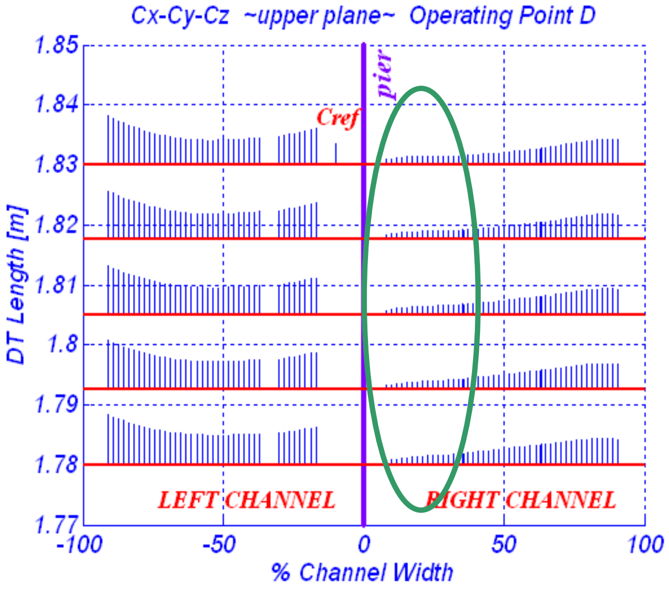
Experimental Setup

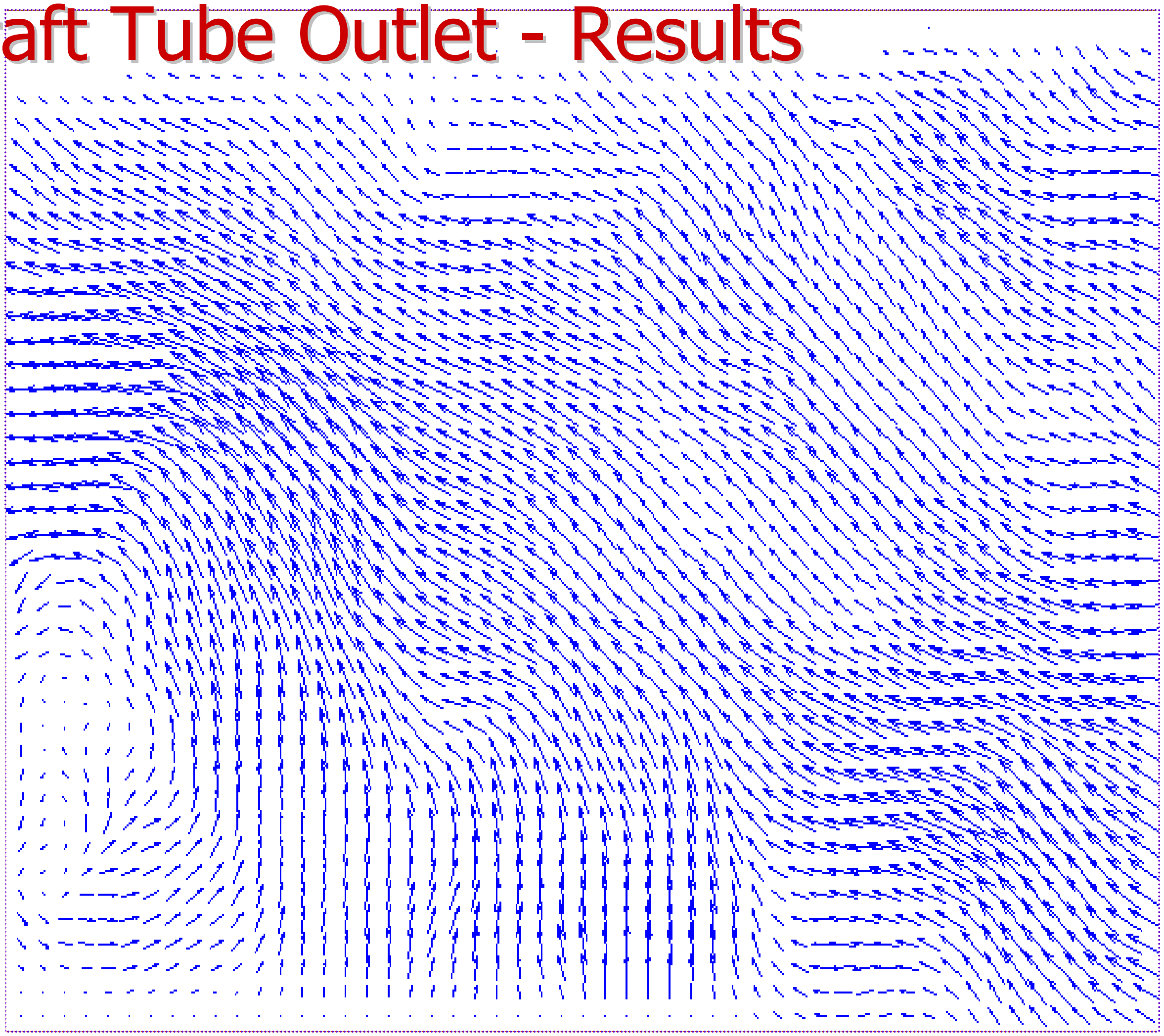


3D-PIV Draft Tube Outlet - Results



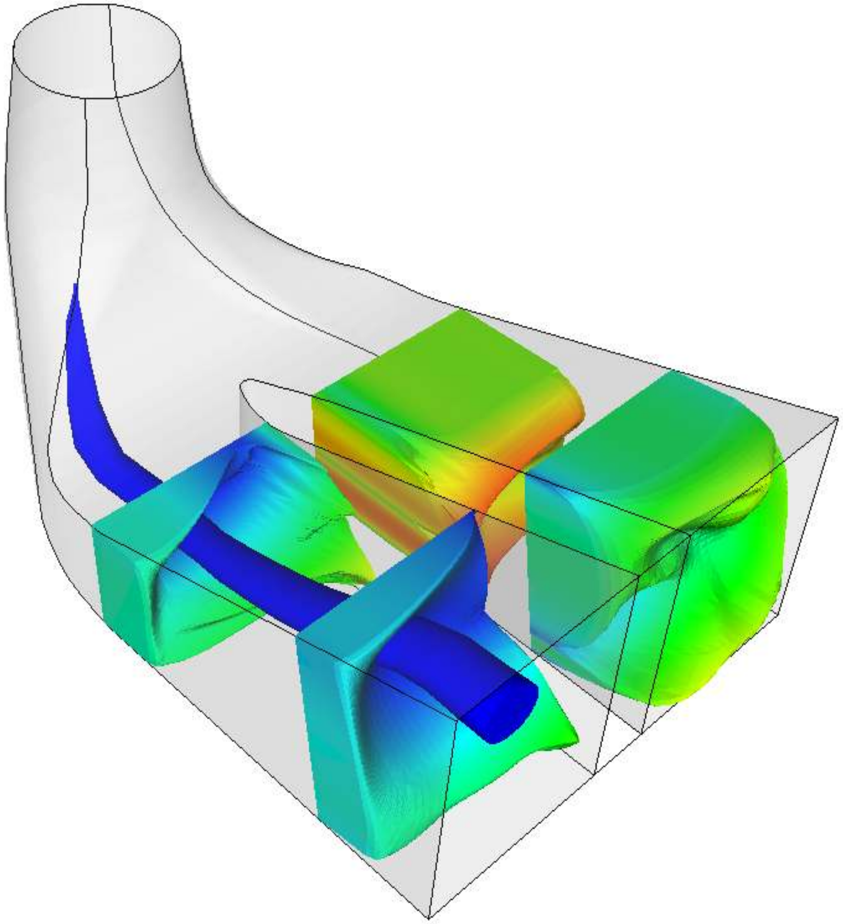


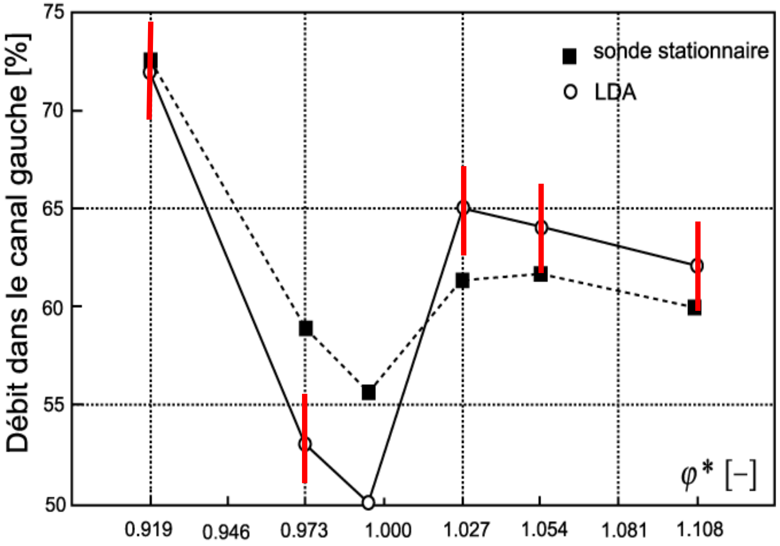




Instantaneous 2D Vector Fields

Flow rate distribution

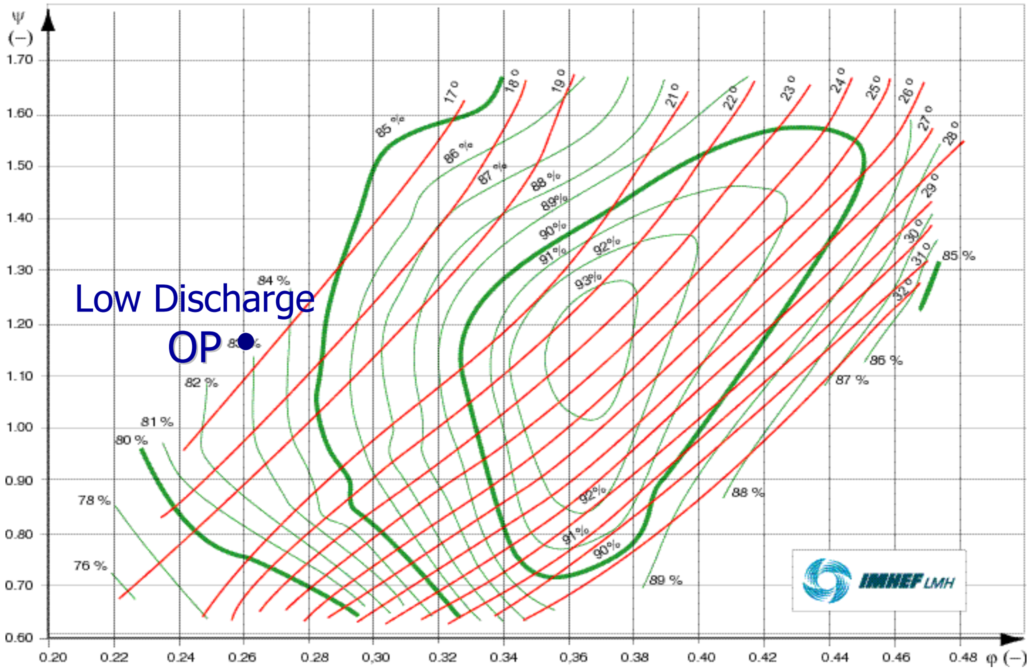


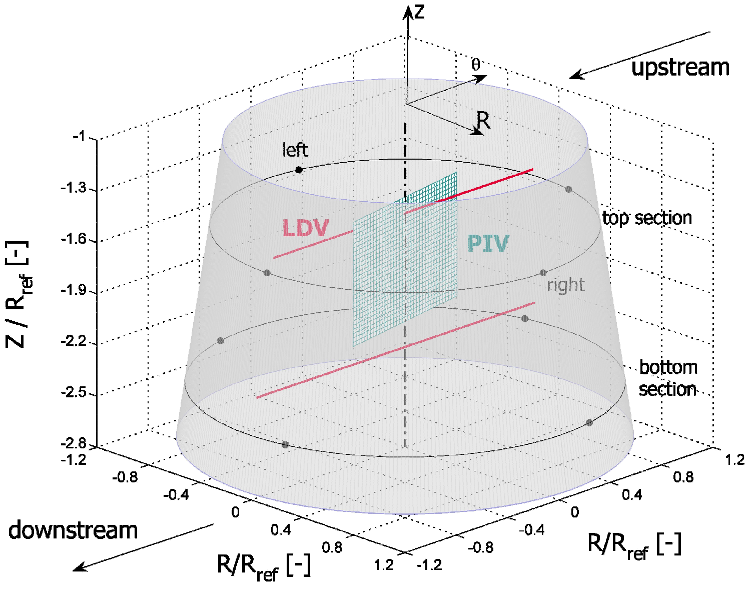


Accuracy of the flow rate estimation: ~ 4 %

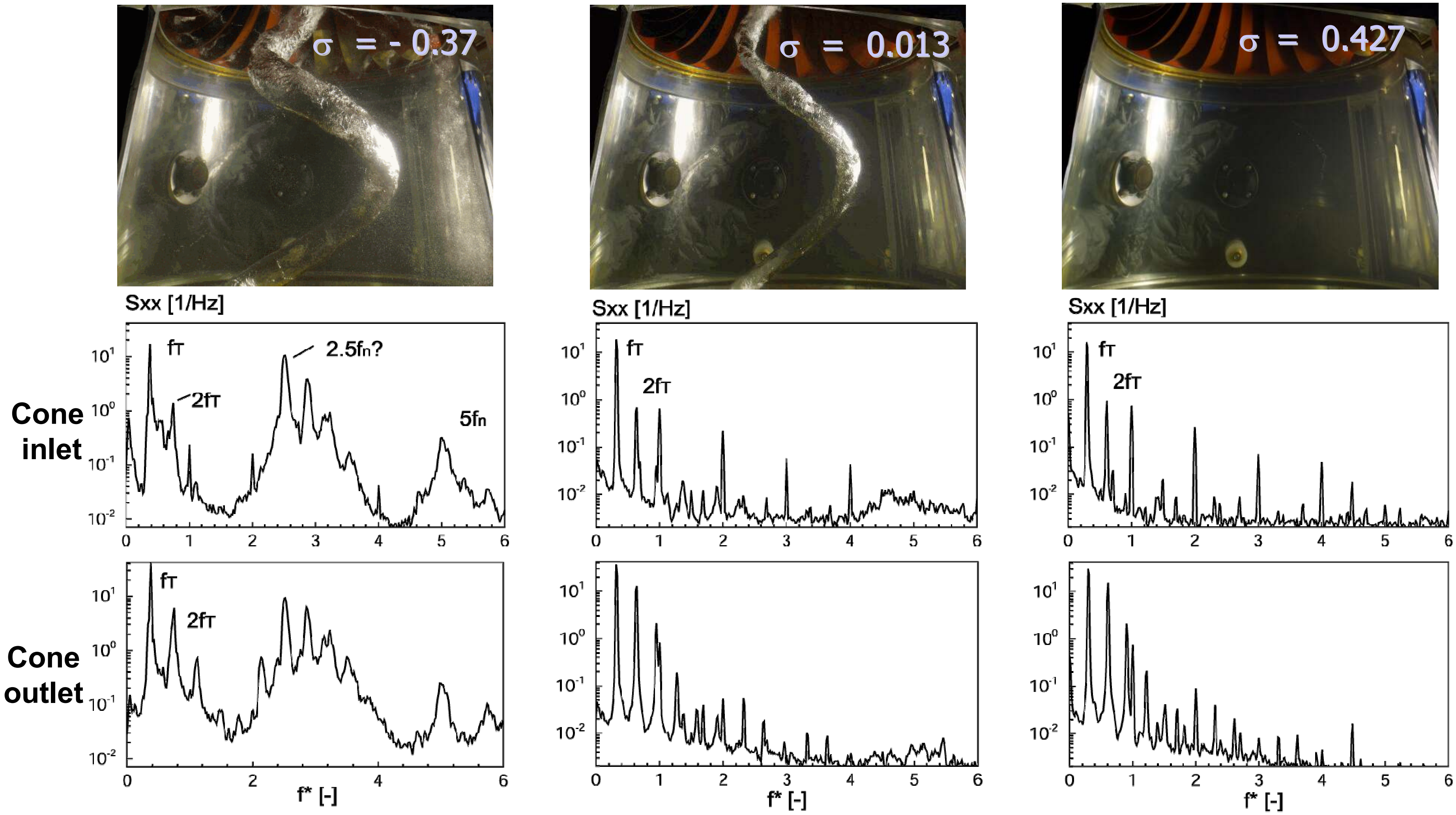
Iliescu M.S., Ciocan G.D., Avellan F., "3D PIV and LDV Measurements at the Outlet of a Francis Turbine Draft Tube"
Joint US ASME-European Fluids Engineering Summer Conference, 2002

Partial Flow Rate Operating Point

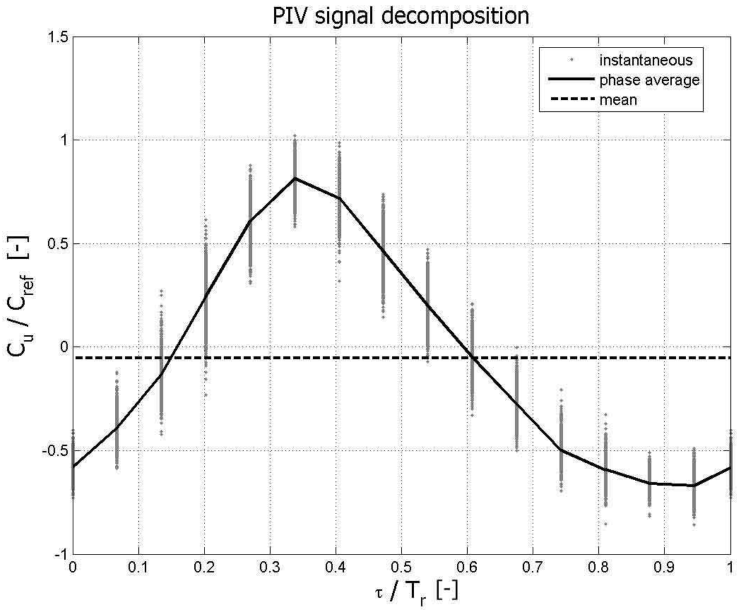




Unsteady Pressure Field



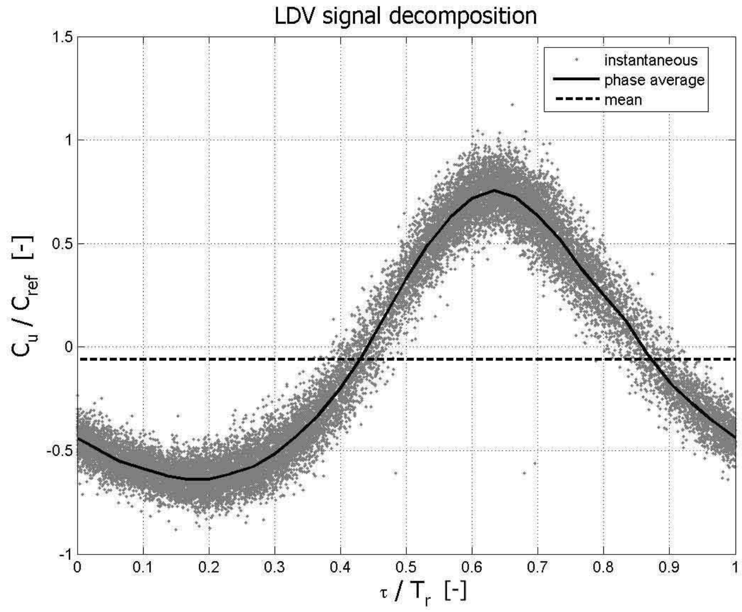
Phase Average on the Rope Passage



Phase average - PIV

$$C_i(t) = \bar{C} + \tilde{C}(\tau) + C'(t)$$

$$\bar{C} = \langle C_i \rangle = \lim_{N\to\infty} \frac{1}{N}\sum_{i=1}^{N} C_i(t)$$



Phase average - LDV

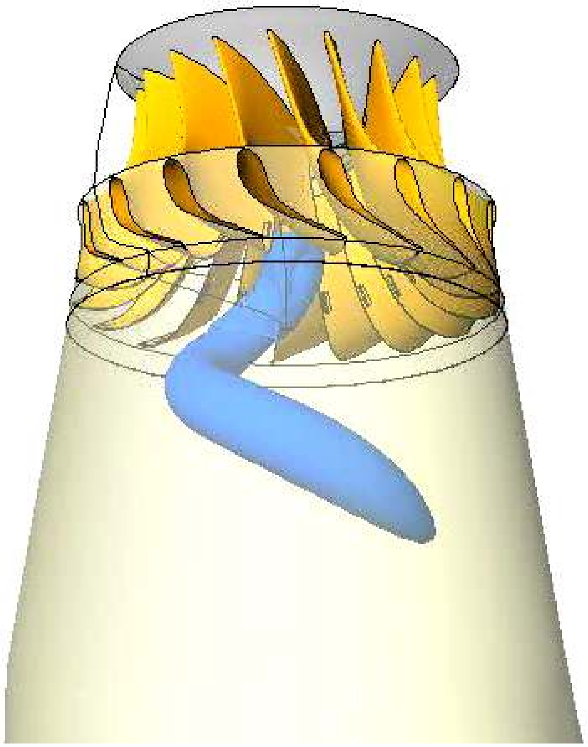
$$\tilde{C}(\tau) = \lim_{N'\to\infty}\frac{1}{N'}\sum_{i=1}^{N}(C_i(\tau)-\bar{C})$$

$$\bar{\tilde{C}} = 0$$

$$\langle C' \rangle = \lim_{N\to\infty}(C_i(t)-\bar{C}-\tilde{C}) = 0$$

Unsteady Simulation of Rotating Rope

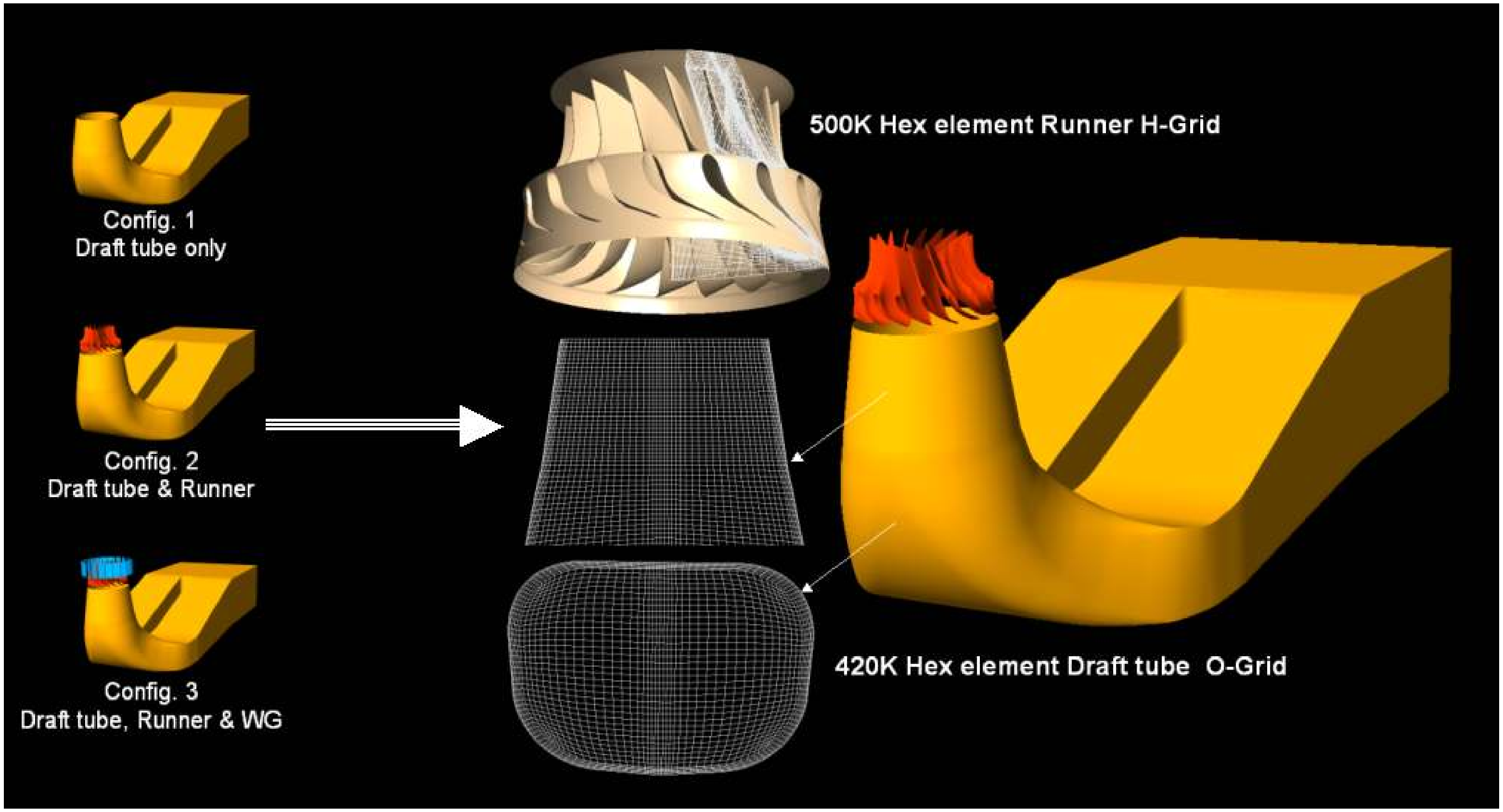
time = 0.00000



–Vortex rope without vapors

Ciocan G.D., Iliescu M.S., Vu T., Nennemann B., Avellan F., "Experimental Study and Numerical Simulation of the Flindt Draft Tube Rotating Vortex"
Accepted for Journal of Fluids Engineering, 2005

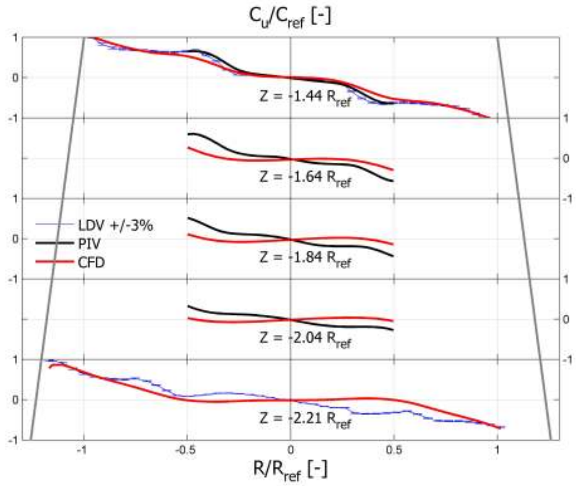
Computation Flow Domain & Mesh

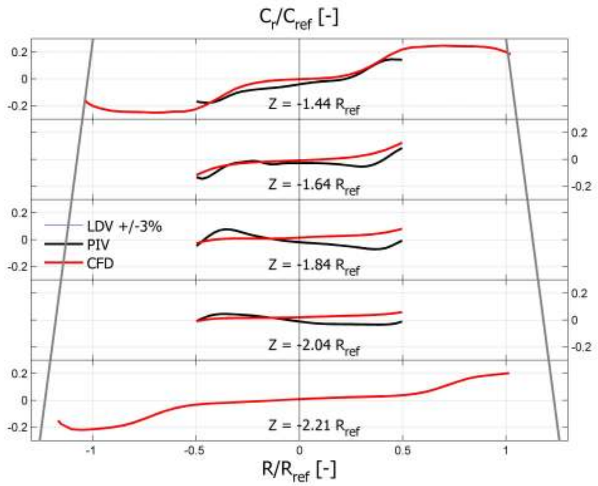


1.2 million node multi-block structured mesh
Inlet condition obtained from previous stage calculation

Average Velocity Profiles

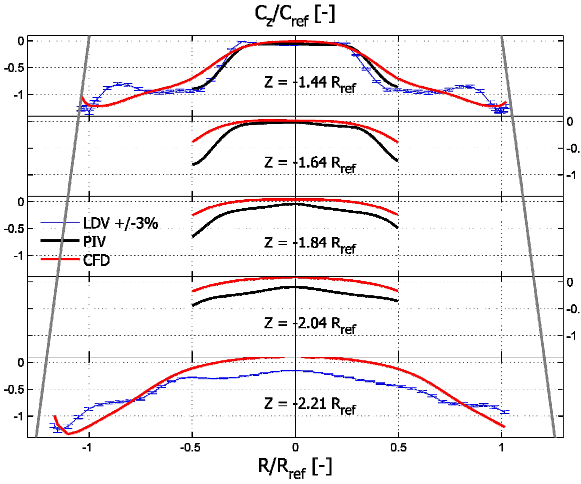
C_u

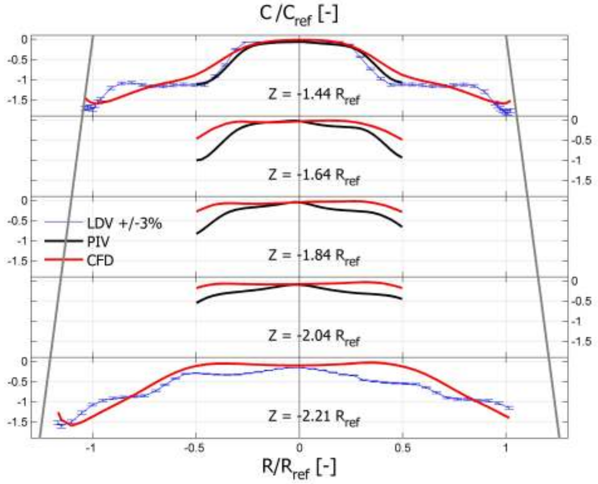




C_r

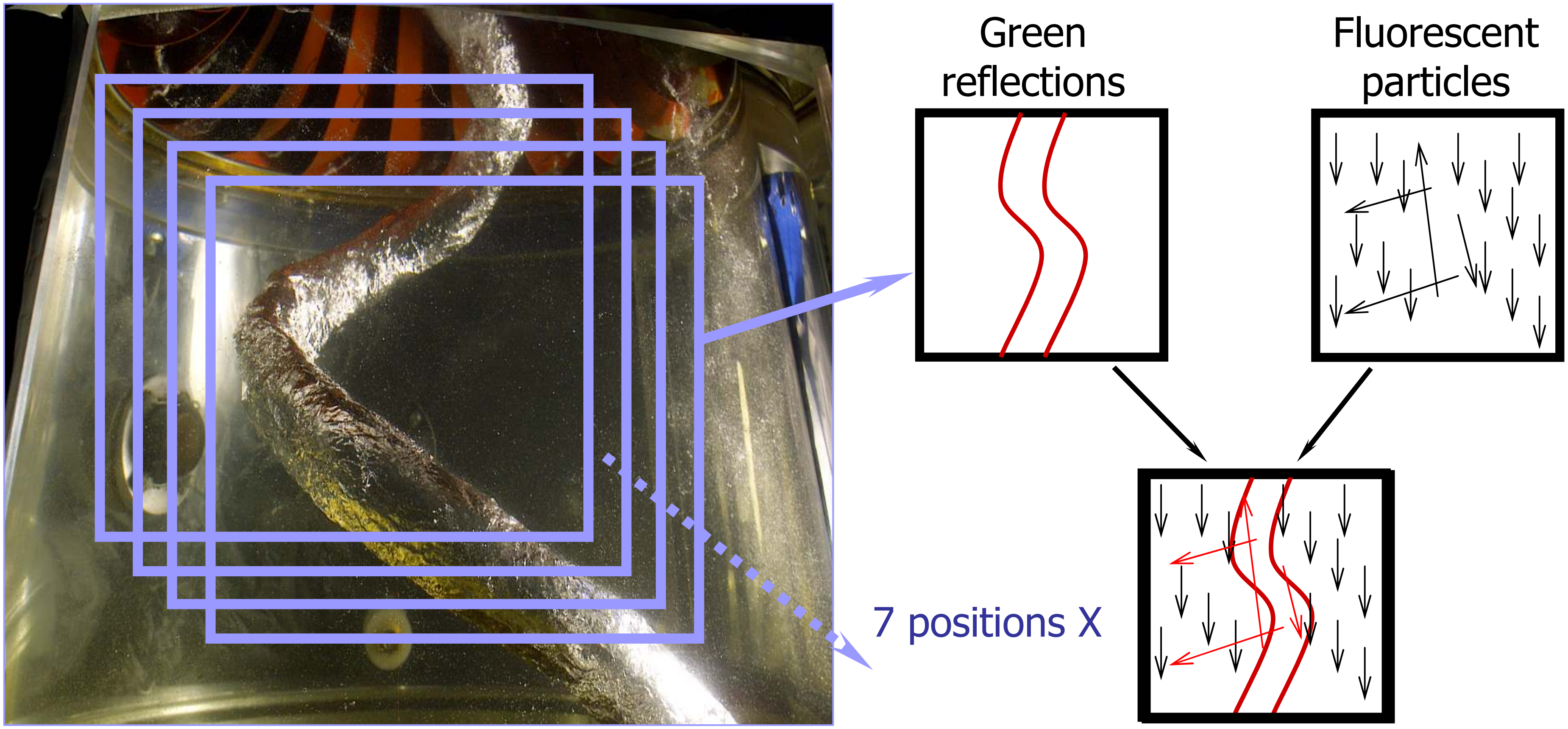
C_z





C

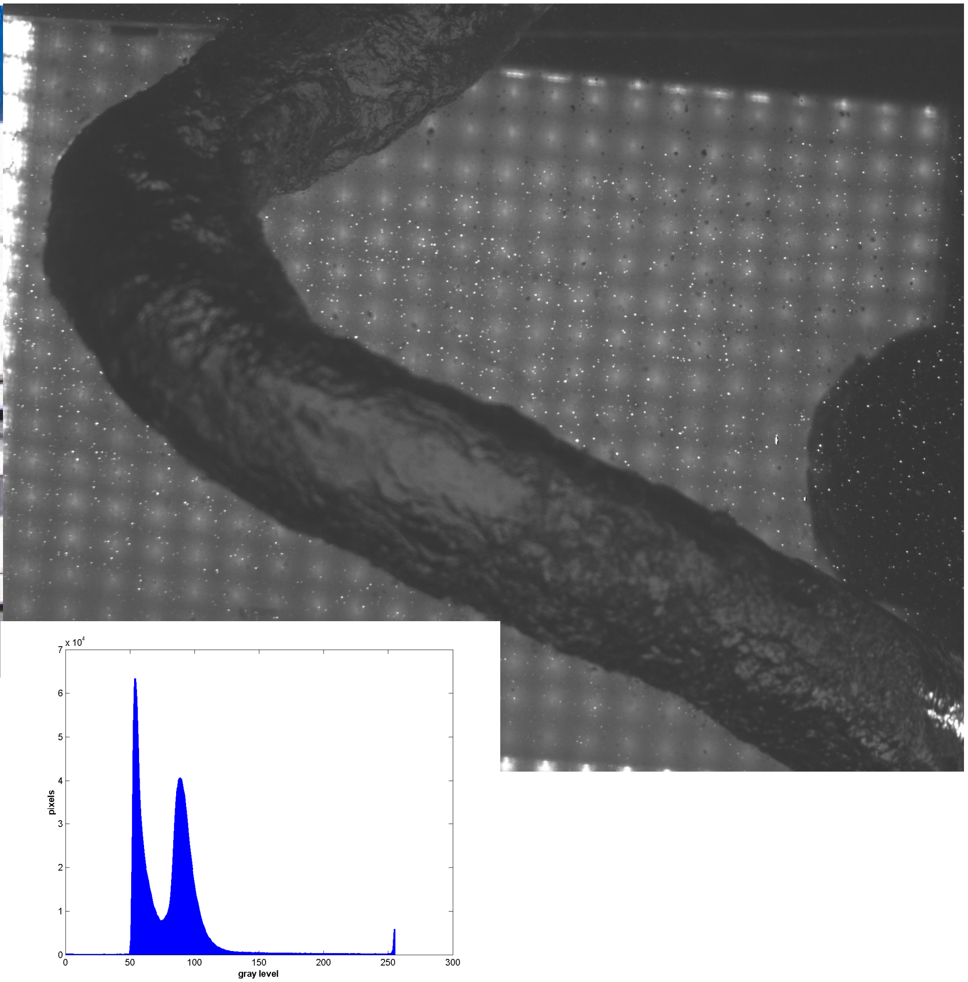
PIV 2phases - Principle



Synchronous with pressure signal for different azimuthal positions of the rope

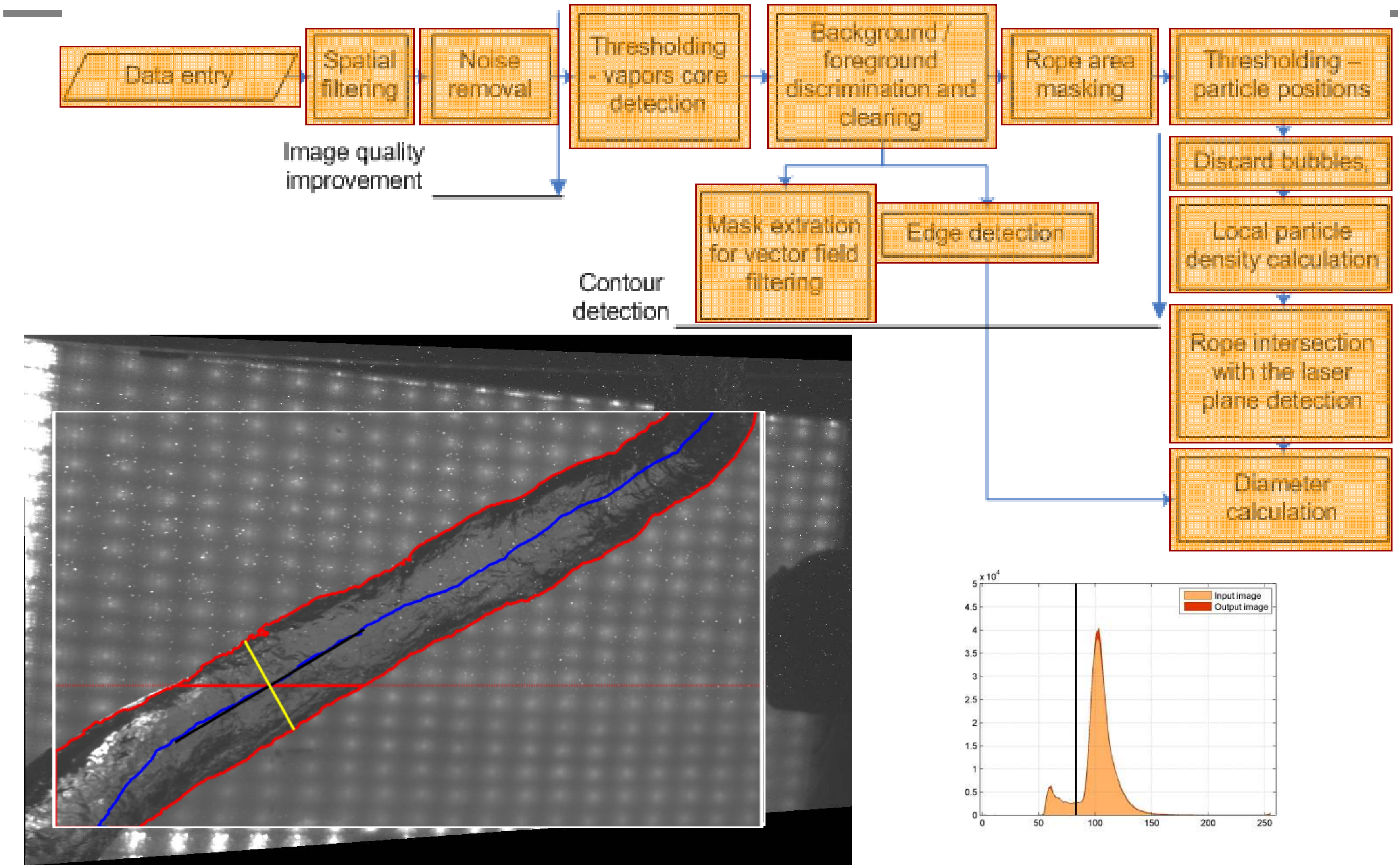
Rope shape + 2D velocity field

3D 2phase PIV



• Laser	532 nm
• LED	587 nm
• fluorescent particles	580 nm
• filters	>570 nm

Metode moderne pentru cercetarea in Masini Hidraulice



Data entry

Spatial filtering

Noise removal

Image quality improvement

Thresholding - vapors core detection

Background / foreground discrimination and clearing

Mask extration for vector field filtering

Edge detection

Contour detection

Rope area masking

Thresholding – particle positions

Discard bubbles,

Local particle density calculation

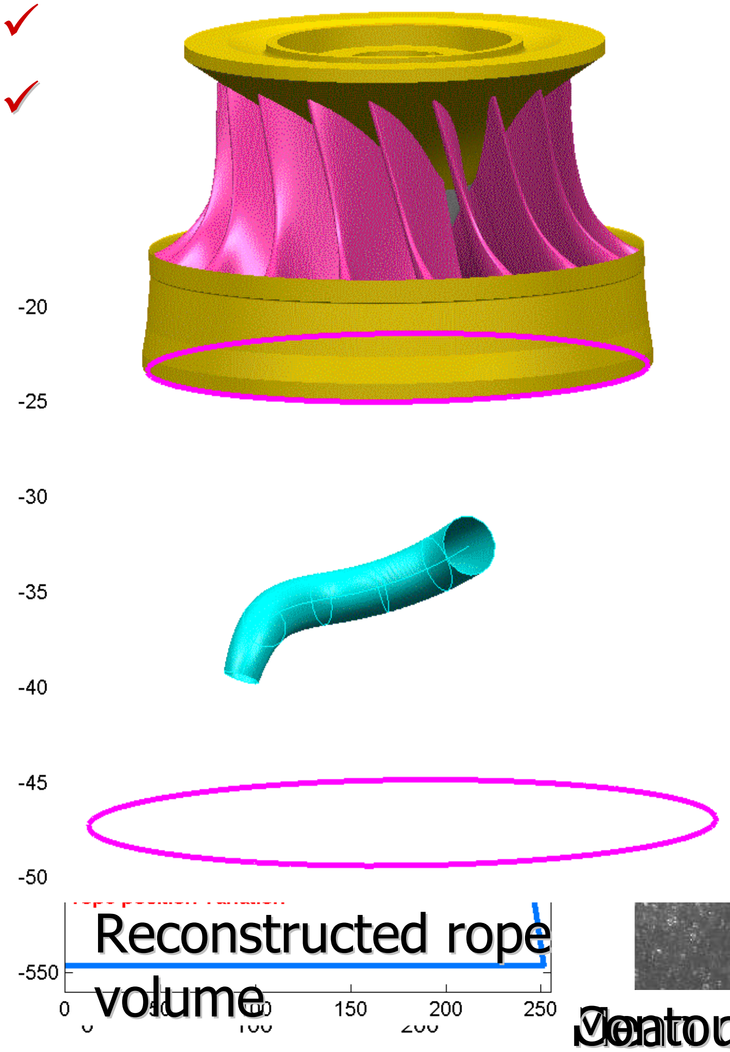
Rope intersection with the laser plane detection

Diameter calculation

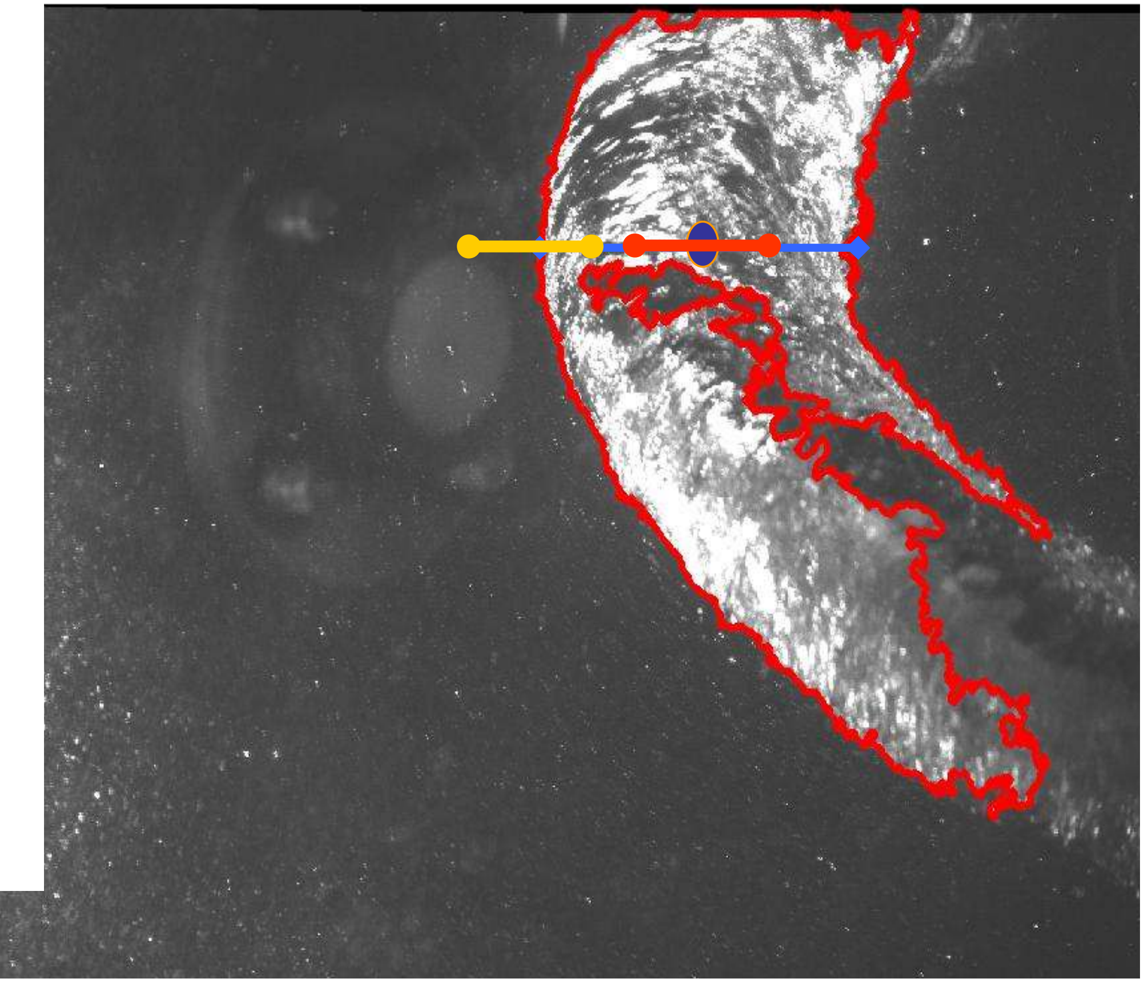
Rope Dynamics

Contour Validation Criteria

- ✓
- ✓



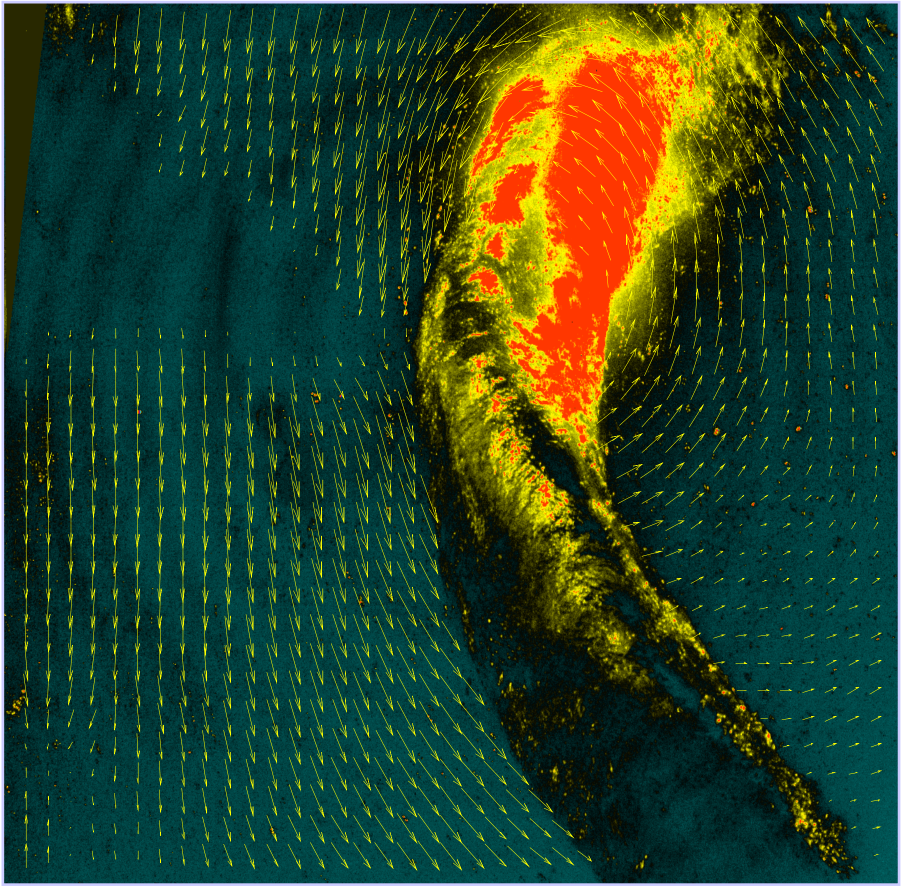
Reconstructed rope volume



Contour and position fluctuations

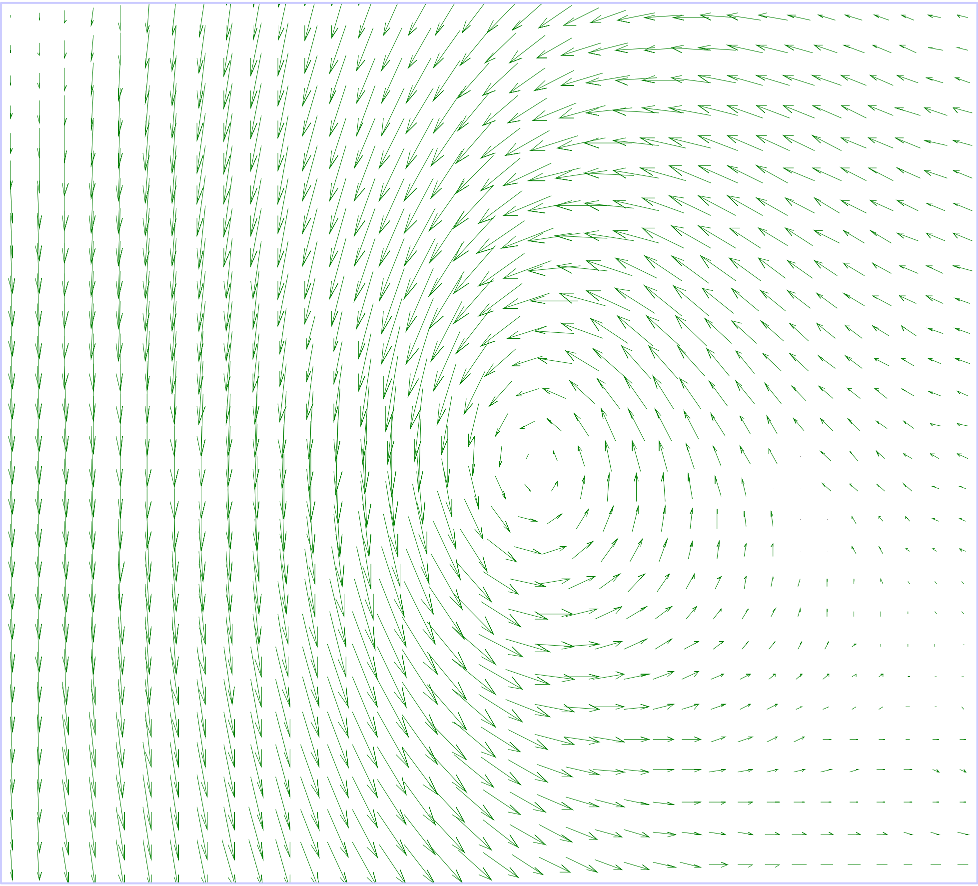
Sample Results

σ = -0.370



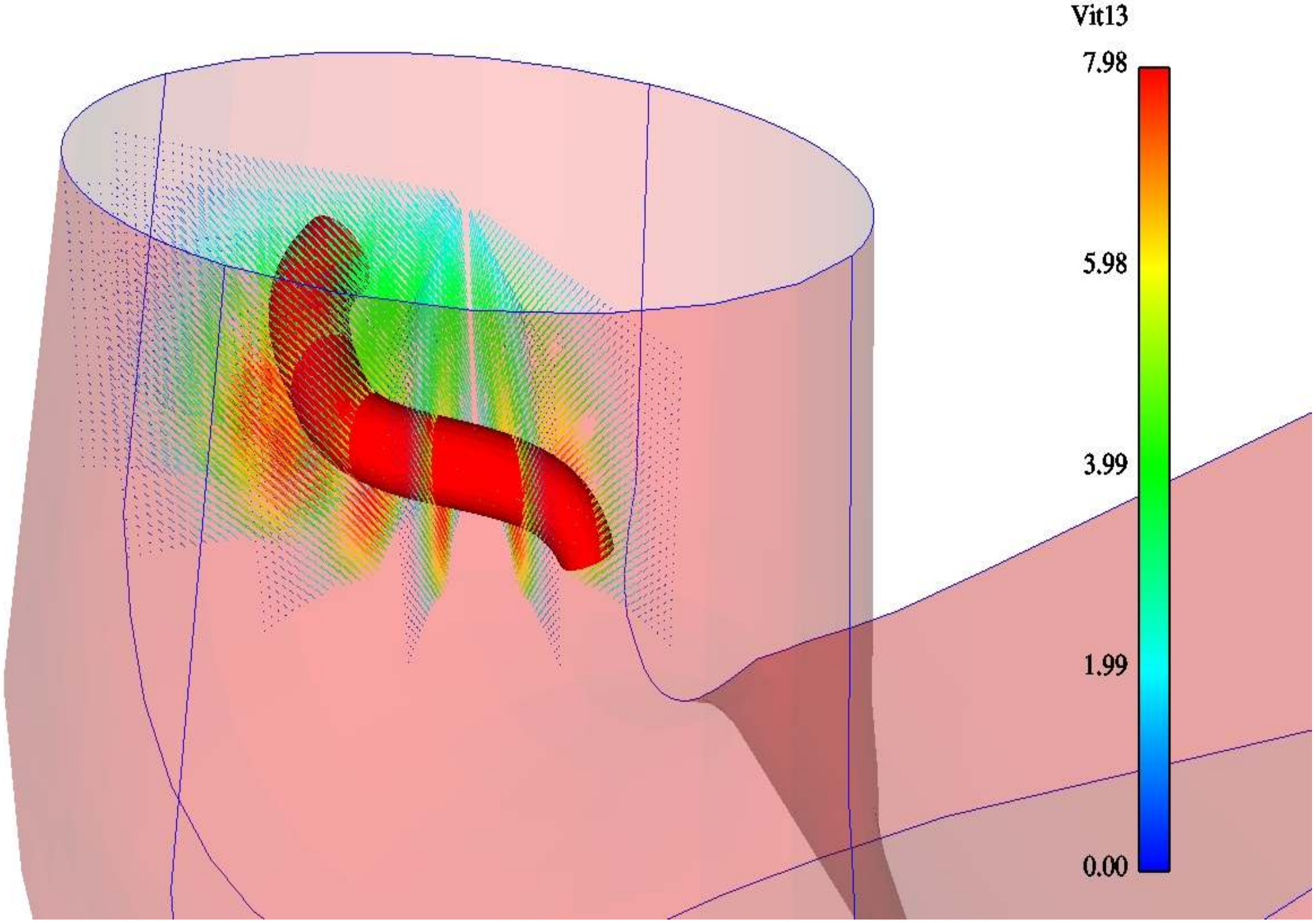
Rope Configuration

σ = +0.427



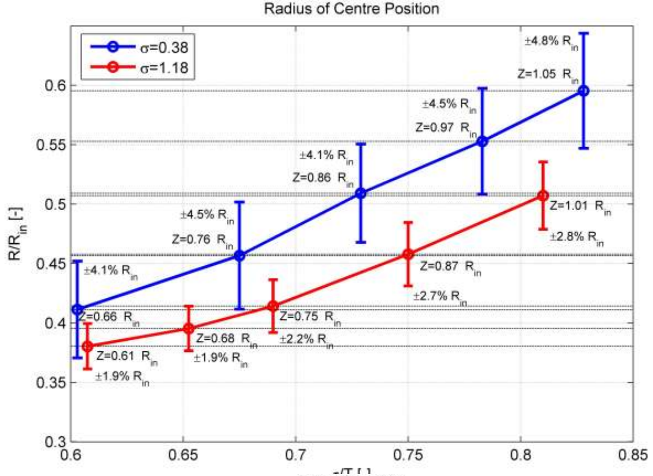
Vortex Configuration

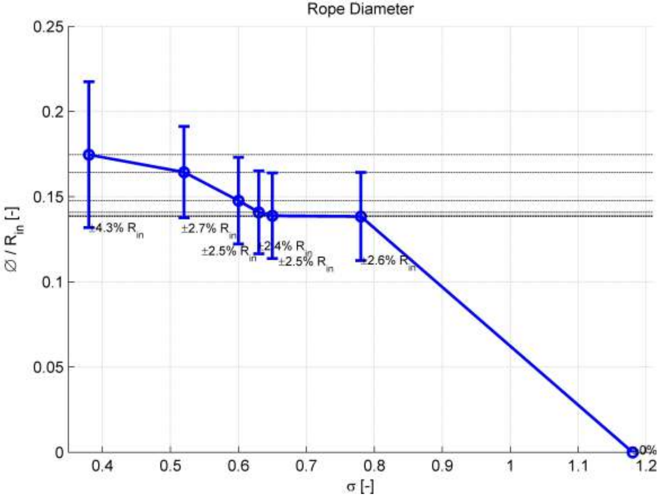
Phase Average Reconstruction

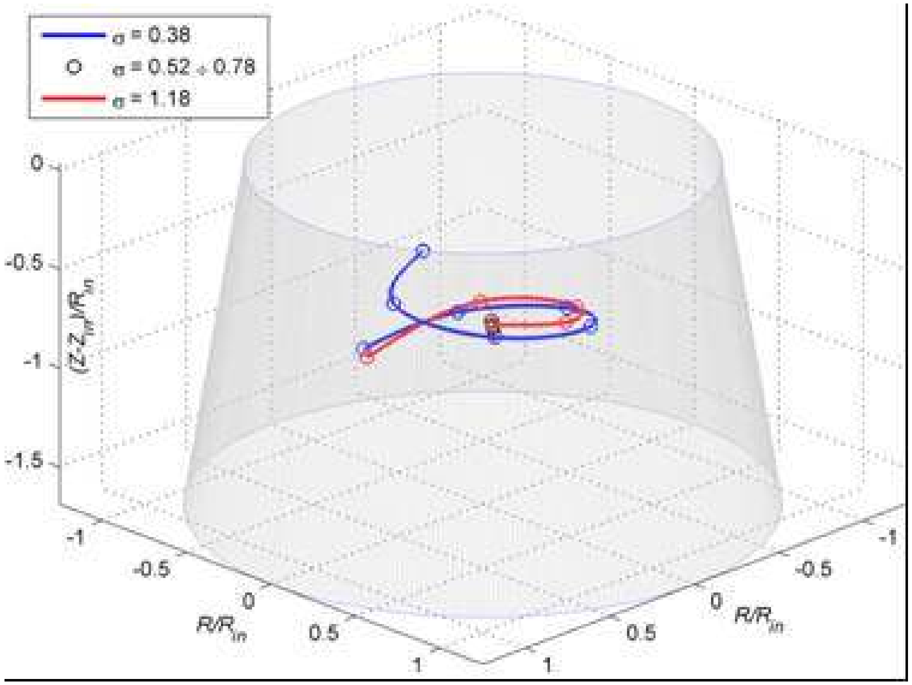


Iliescu M.S., Ciocan G.D., Avellan F.; "Two Phase PIV Measurements of a Partial Flow Rate Vortex Rope in a Francis Turbine"
- proposed for Journal of Fluids Engineering, 2006

Quantitative Rope Characterization



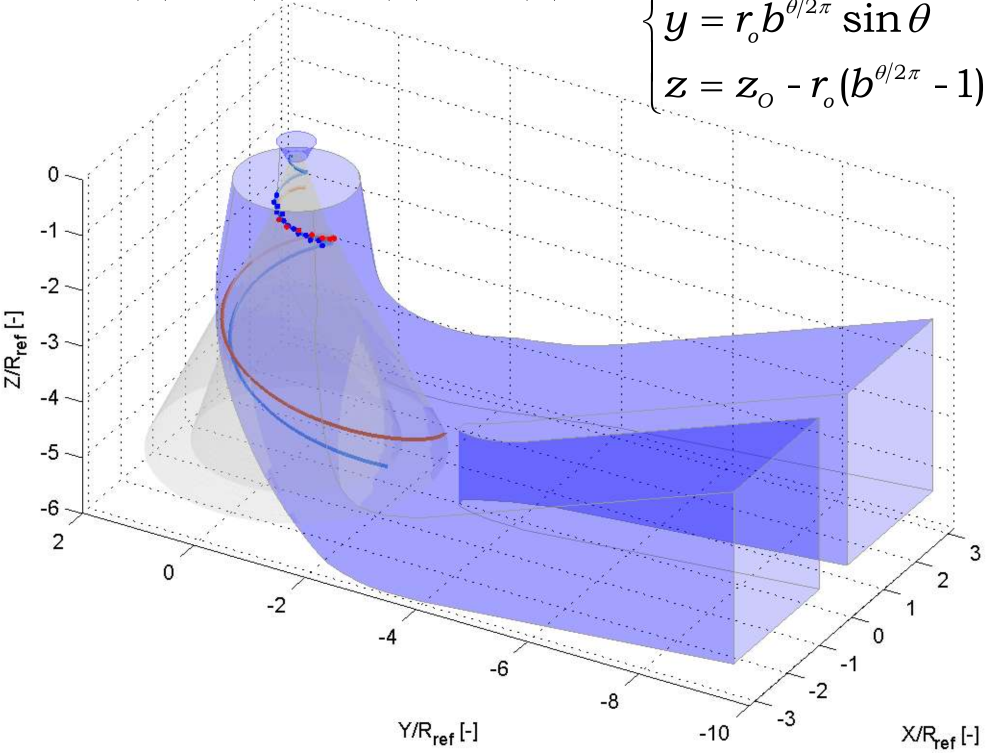


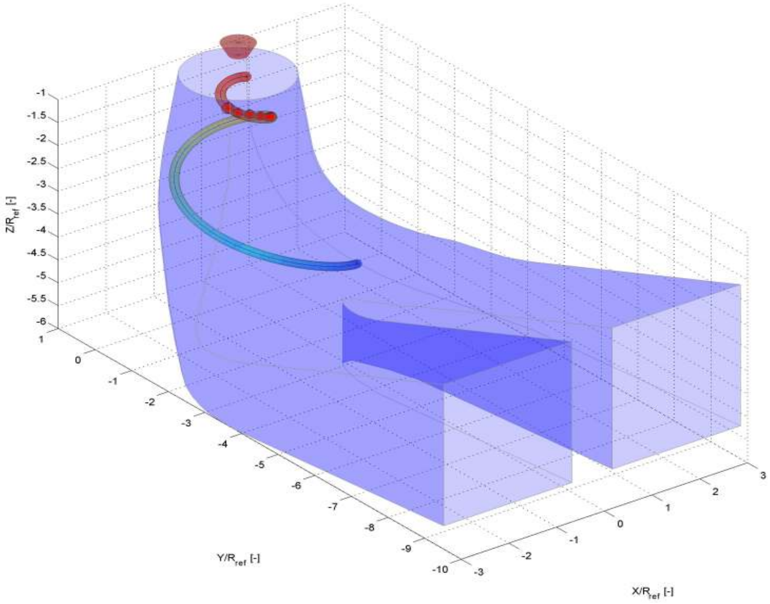


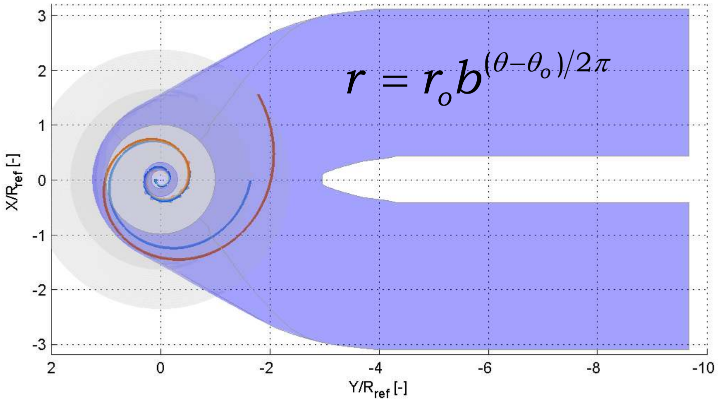
2 Phases PI

$$\vec{r} = \vec{r}(\theta) = x(\theta)\vec{i} + y(\theta)\vec{j} + z(\theta)\vec{k}$$

$$\begin{cases} x = r_o b^{\theta/2\pi} \cos\theta \\ y = r_o b^{\theta/2\pi} \sin\theta \\ z = z_O - r_o (b^{\theta/2\pi} - 1)/\tan \end{cases}$$



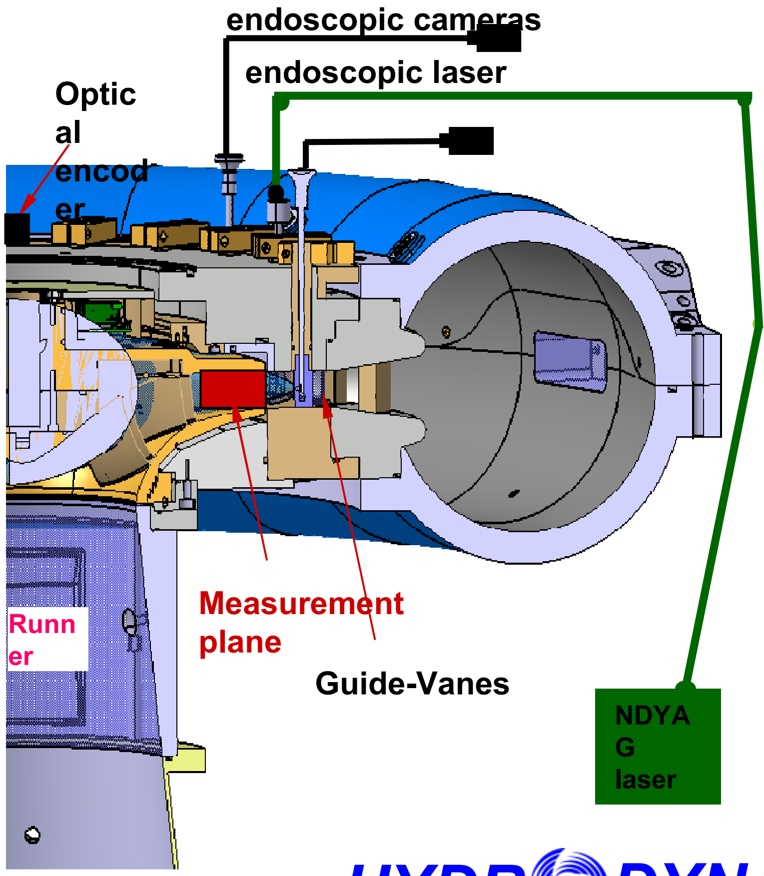


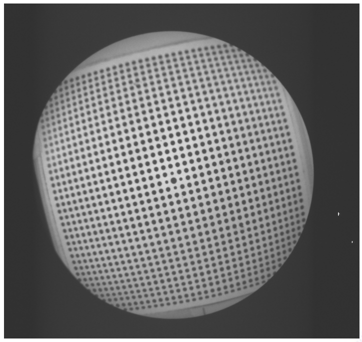


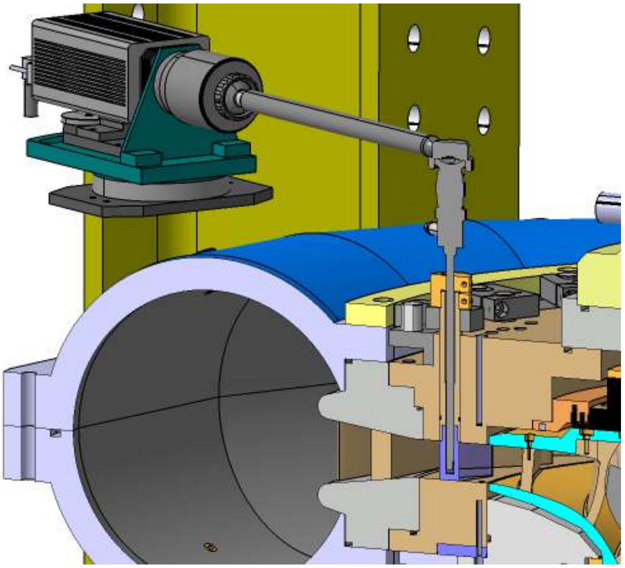
$$r = r_o b^{(\theta-\theta_o)/2\pi}$$

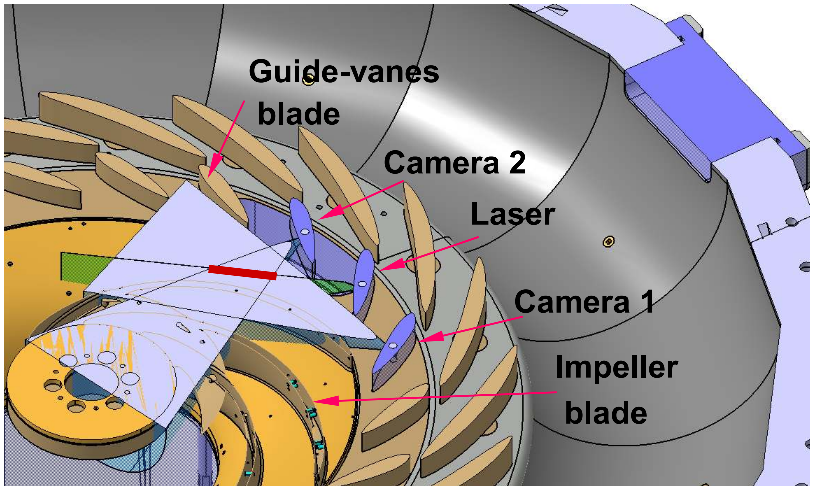
		Cavitation-free vortex	Vapors-core vortex
Initial radius	r_o	0.09	0.15
Initial depth	z_o	-0.615	-1.2
Rate of radial growth	b	3.2	4
Cone angle	β	17°	25.5°

Endoscopic PIV in the Runner





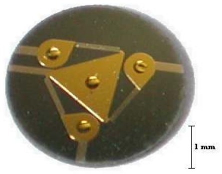


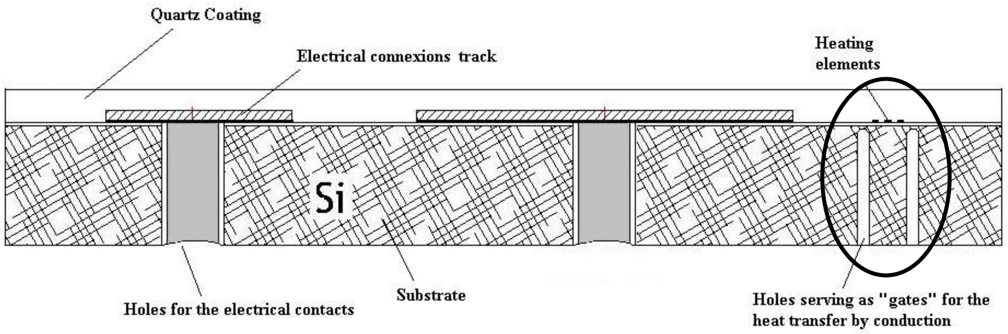


HYDRODYNA

1. Design and Fabrication of the Miniature Probe

SERIE I





Validations:

- Isolation between the surface of the probe, which comes in contact with the water, and the hot-film;

- There were chosen the materials for the hot film, the refilling holes.

Results:

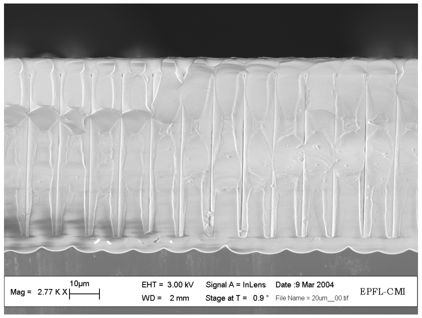
- a high thermal conduction, even with the gates;

- the detachment of the quartz on the electrical connexions;

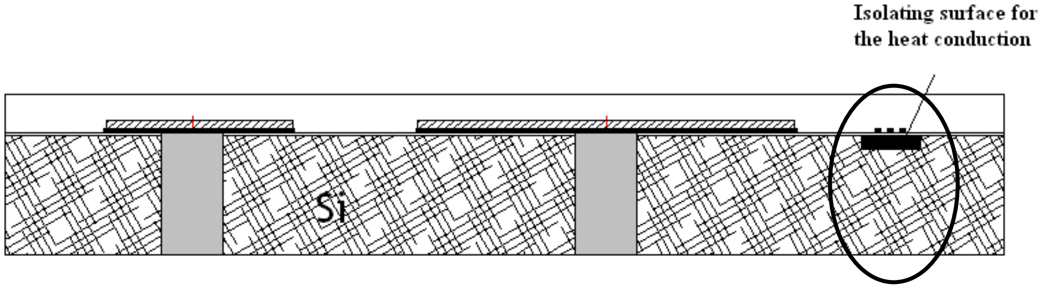
- a very short " life time" in the water (~2-3 days), due to the high thermal conduction

1. Design and Fabrication of the Miniature Probe

SERIE II



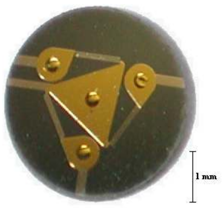
Example of refilled Si pillars performed at CMI

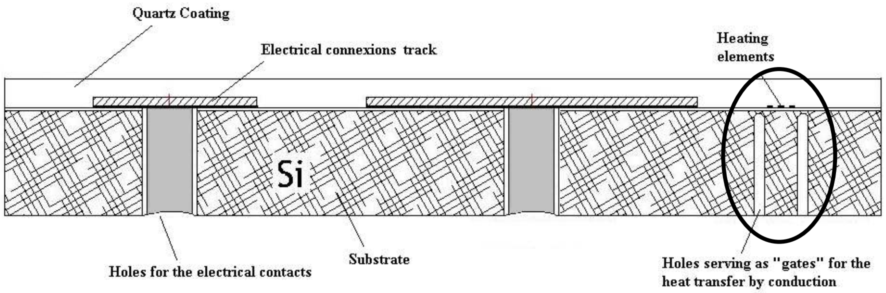


New studied parameters:

- *The thickness of the silicium pillars, for optimizing the refill with the SiO2 layer.*
- *The optimally forms and dimensions of the pillars in order to realise a compact and solid substrate*

1. Design and Fabrication of the Miniature Probe

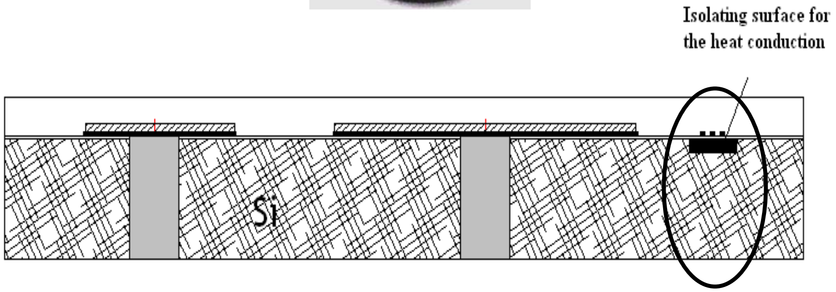




Serie I

Results:

- ✓ *high thermal conduction;*
- ✓ *detachment of the quartz on the electrical connexions;*
- ✓ *very short " life time" in the water (~2-3 days).*



Serie II (3 wafers)

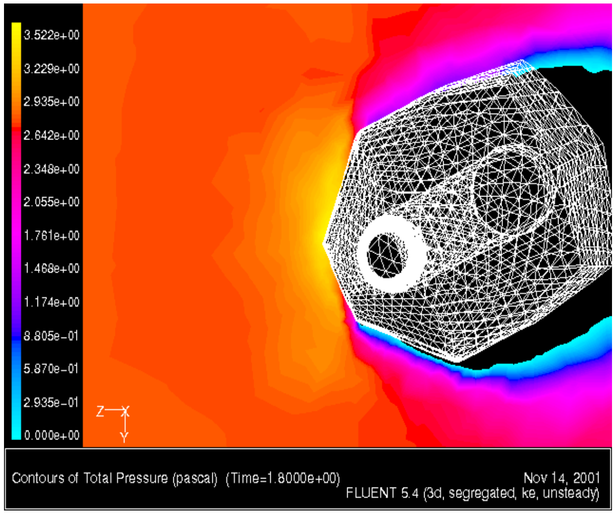
Similarities

- ✓ *Hot films, refilling holes, substrate, electrical connexions materials;*
- ✓ *Design*

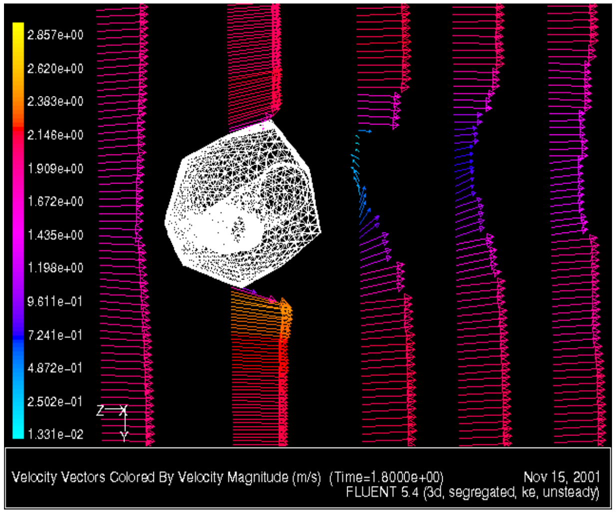
Differences:

- ✓ *Thermal isolation's realisation: gates against isolating surface*
- ✓ *New studied parameters:*
  1. *Thickness of the silicium pillars;*
  2. *Optimally forms and dimensions of the pillars*

Unsteady Pressure Probes



Contours of Total Pressure (pascal) (Time=1.8000e+00) Nov 14, 2001
FLUENT 5.4 (3d, segregated, ke, unsteady)

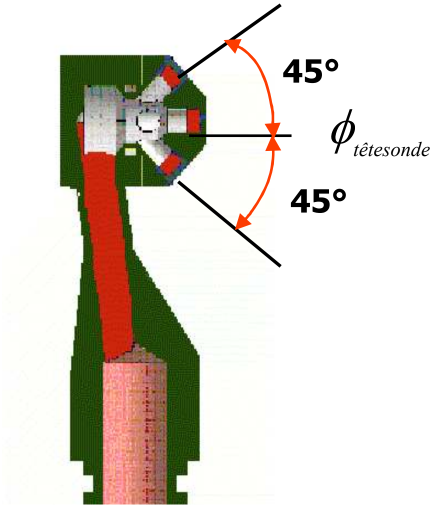


Velocity Vectors Colored By Velocity Magnitude (m/s) (Time=1.8000e+00) Nov 15, 2001
FLUENT 5.4 (3d, segregated, ke, unsteady)

Probe:

- ✓ angles 90° & 90°
- ✓ diameter 10 mm

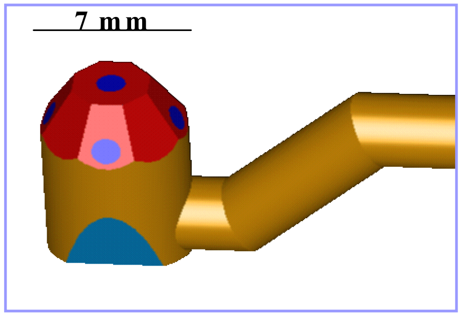
1 calcul $\alpha = 0^\circ$, $\tau = 0^\circ$
2 calcul $\alpha = 25^\circ$, $\tau = 0^\circ$



- ✓ shape of the probe head = pyramid
- ✓ probe opening angle = 90°
- ✓ external diameter of the probe = 9.24 mm
- ✓ sensors: UNISENSOR 0-5 bar, D=2mm, H=1.5 mm

Unsteady Pressure Probes

Unsteady total pressure probe INPG



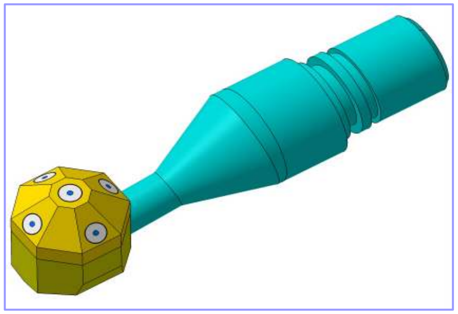
Angles : 55° & 55°
Sensitivity: 3 units F /50° α
3 units G /50° τ

Unsteady total pressure probe LMH

United Sensor Geometry

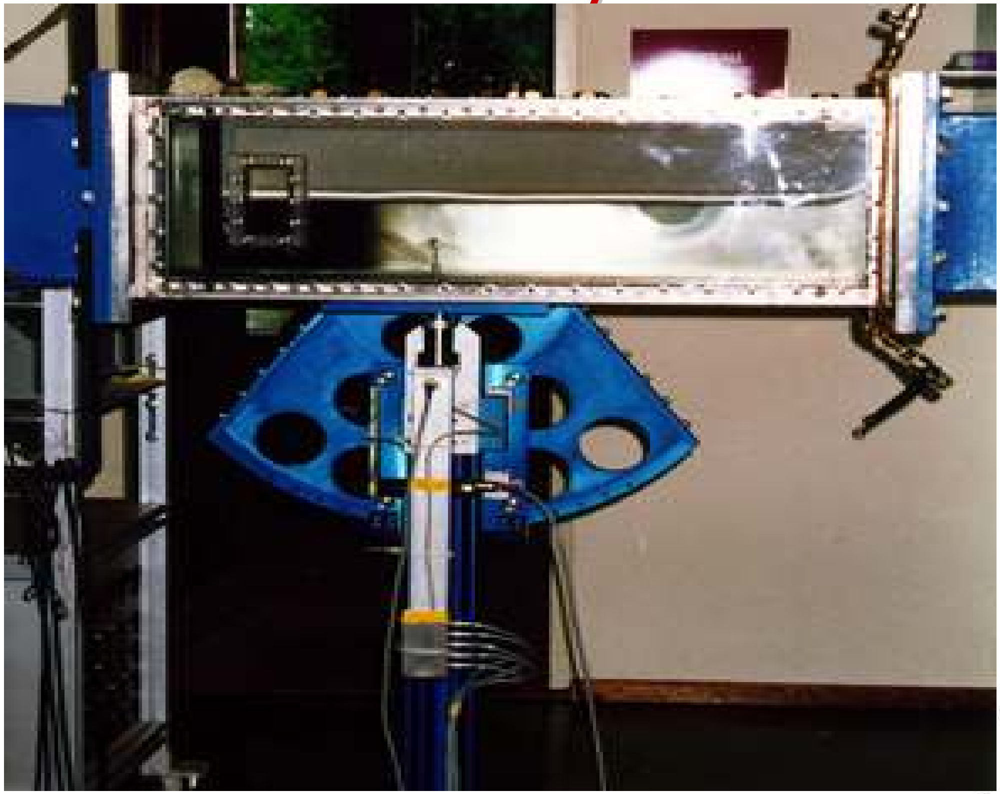
Angles: 100° & -90°
Sensitivity: 8 units F /50°α
1.4 units G /50°τ

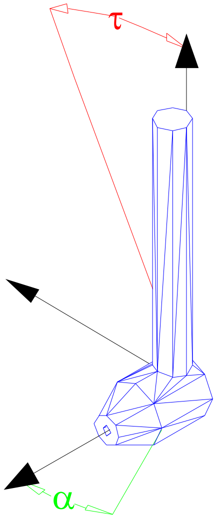
Unsteady total pressure probe LMH

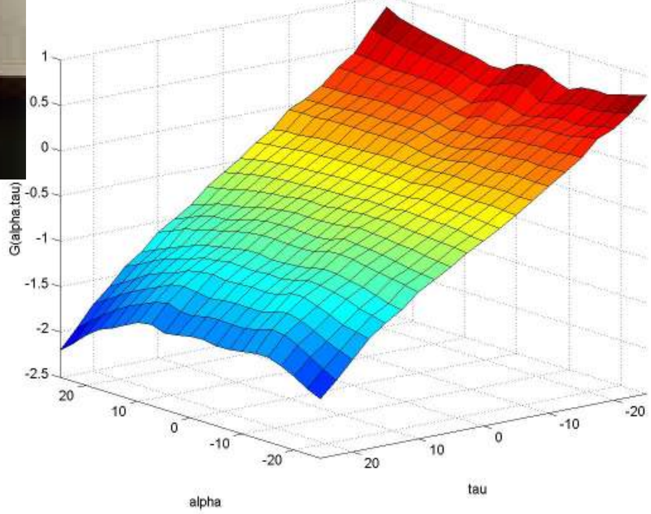


Angles: 90° & -90°
Sensitivity: 4 units F /50°α
4 units G /50°τ

Unsteady Pressure Probe





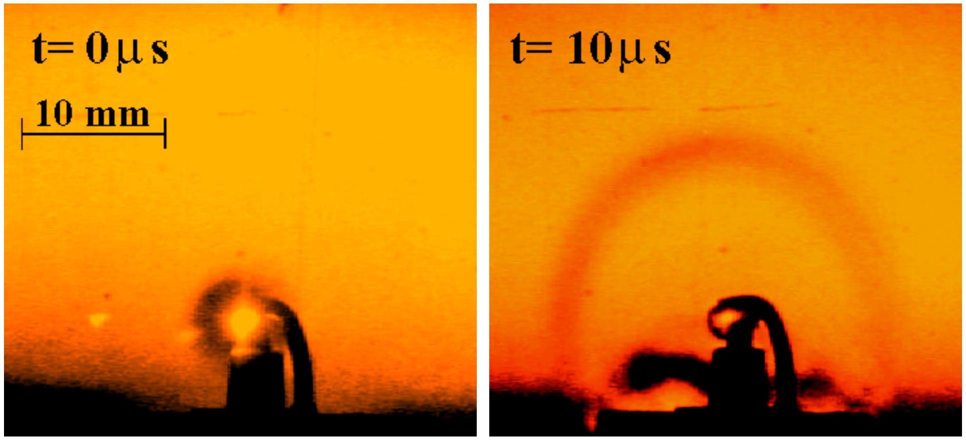


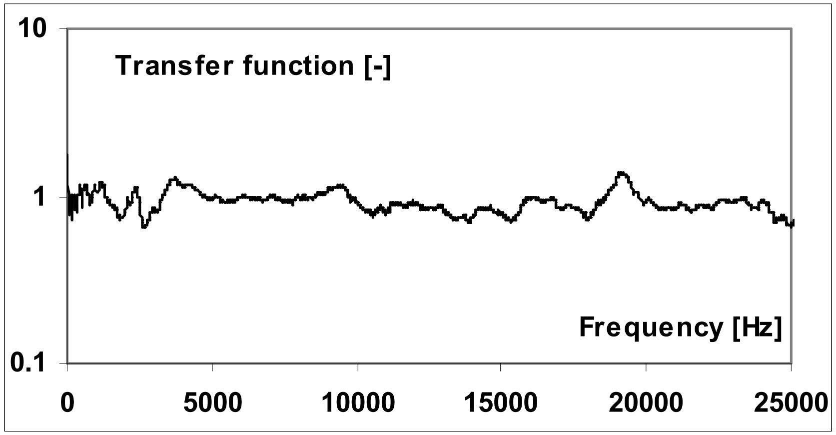
Calibration

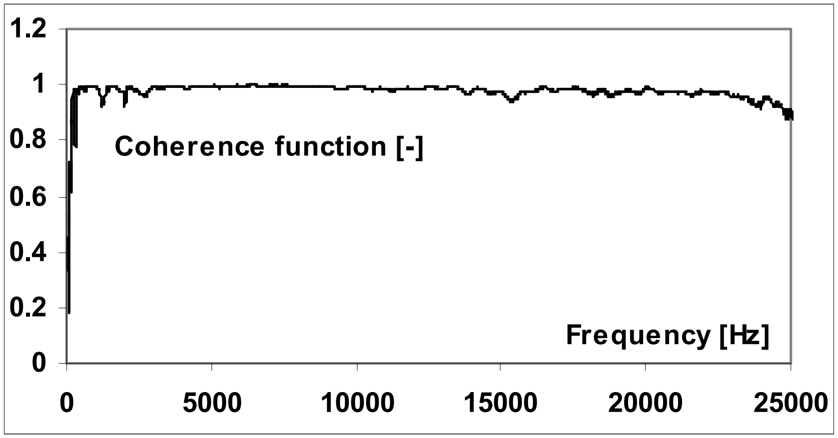
Dynamic calibration

- Pressure wave obtained by bubble implosion

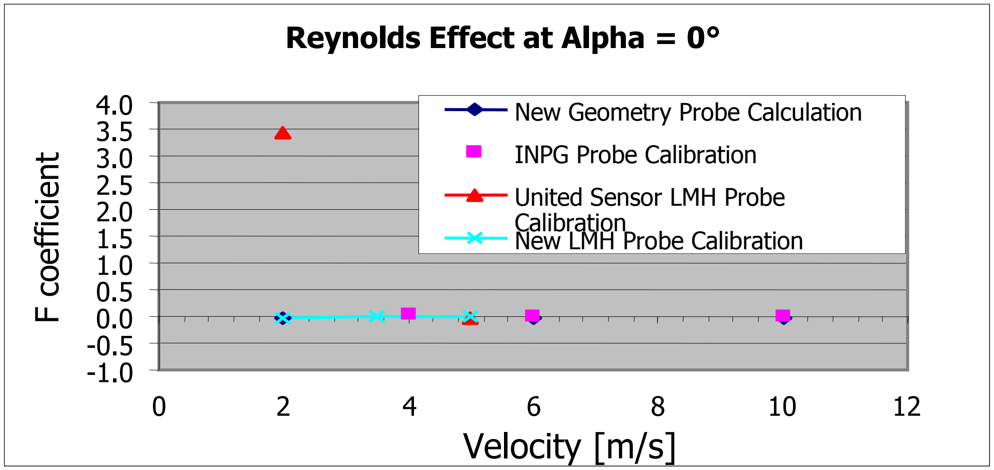
- Linear by 25 kHz

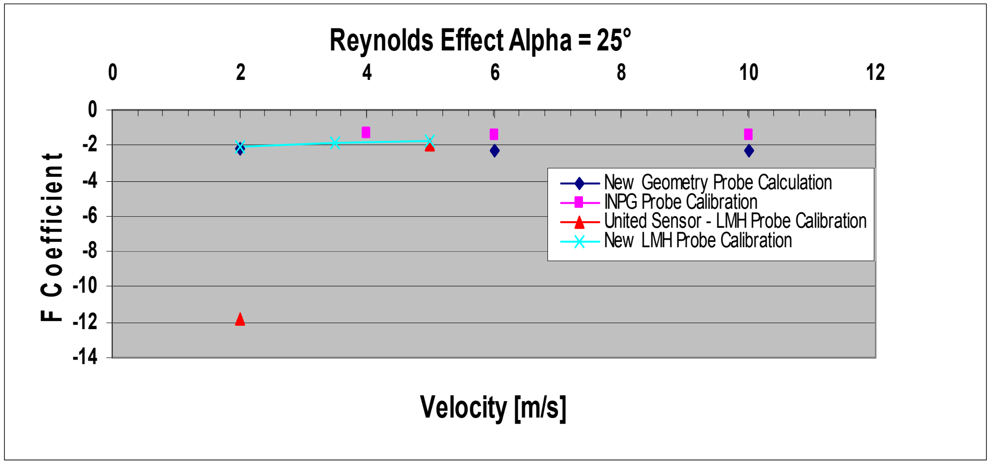






Reynolds Effect





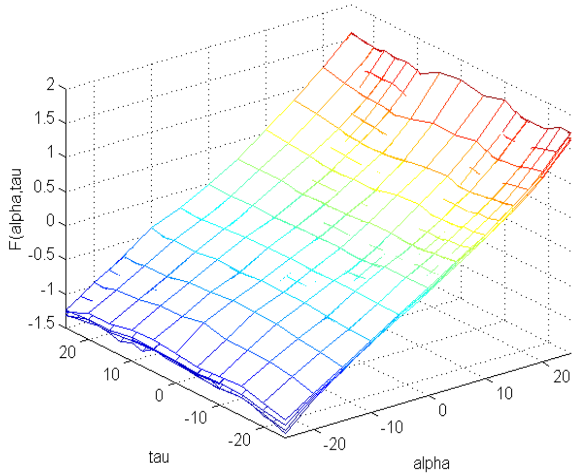
Probe numerical simulation :

- ✓ *between 2 & 10 m/s*
- ✓ *variation F à 0° = 0%*
- ✓ *variation F à 25° less 4%*

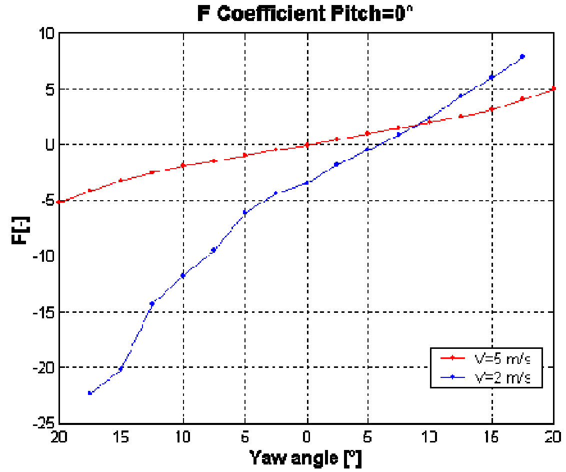
Probes calibration:

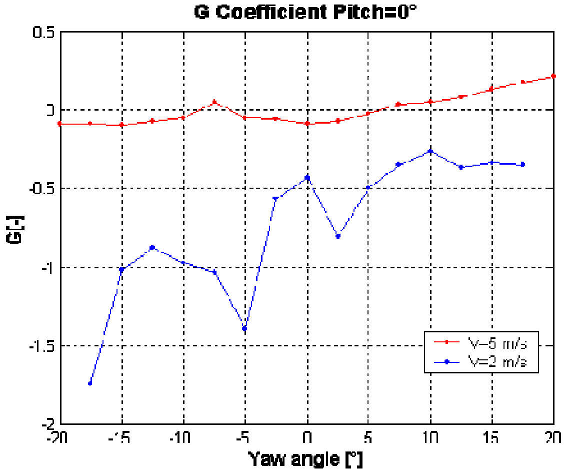
- ✓ *between 2 & 5 m/s*
- ✓ *variation F à 0° = 0%*
- ✓ *variation F à 25° less 2%*

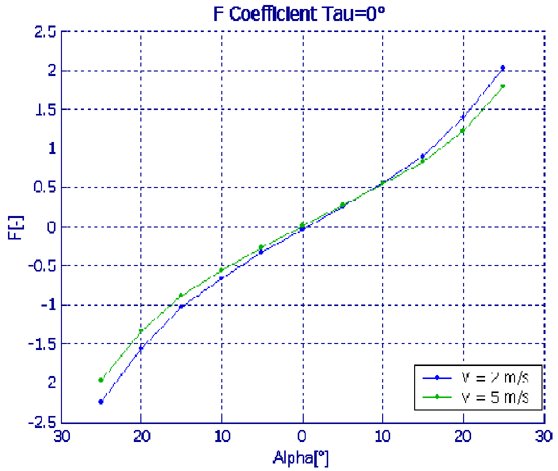
Reynolds Effect

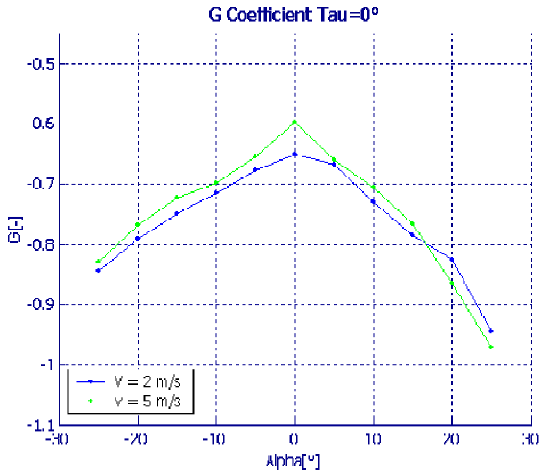


Sonde INPG 4 -10 m/s





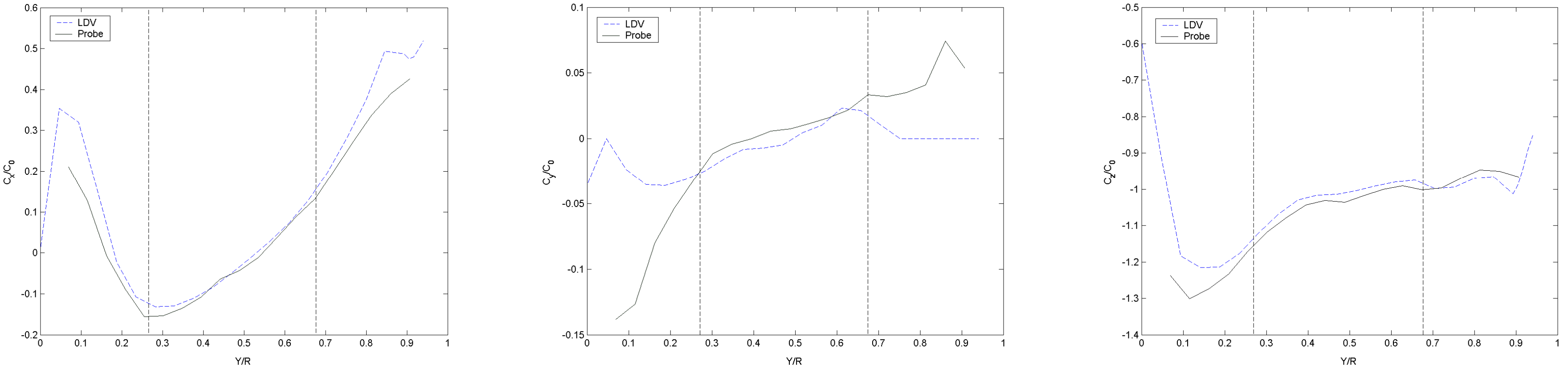




Sonde United Sensor - LMH 4 - 8 m/s

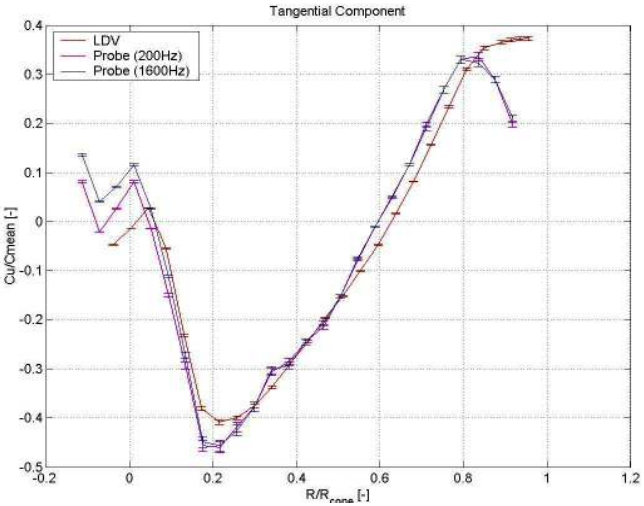
Sonde LMH 2 – (5) m/s

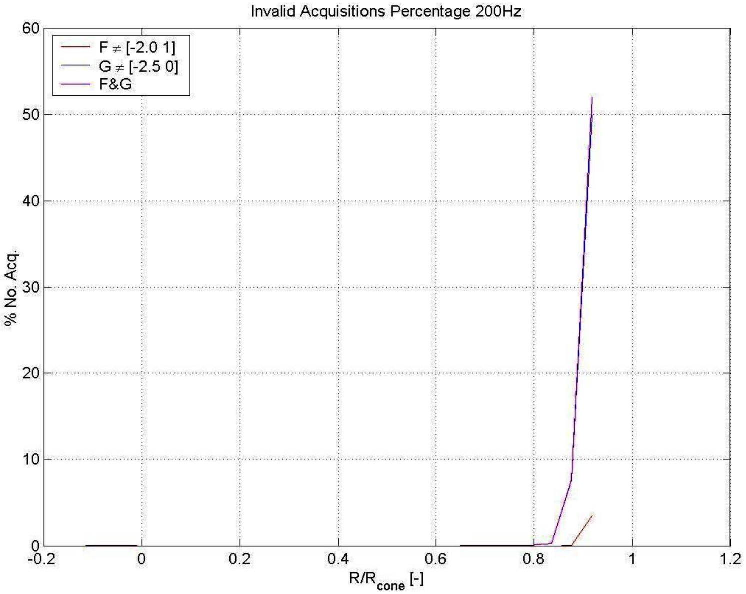
Unsteady pressure measurements

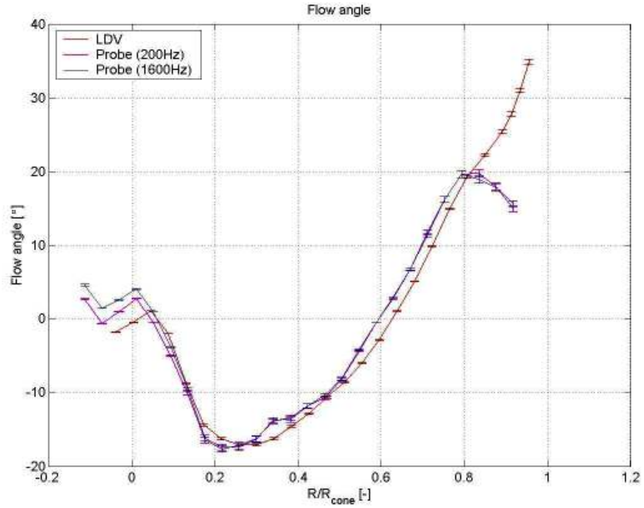


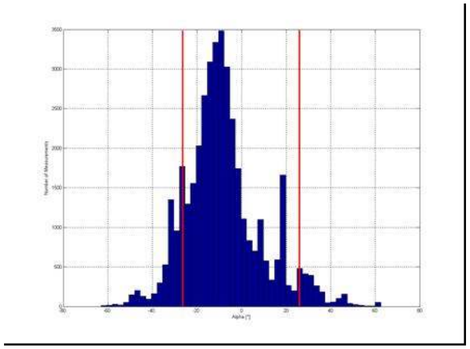
- ✓ *Validity domain of the probe accuracy*

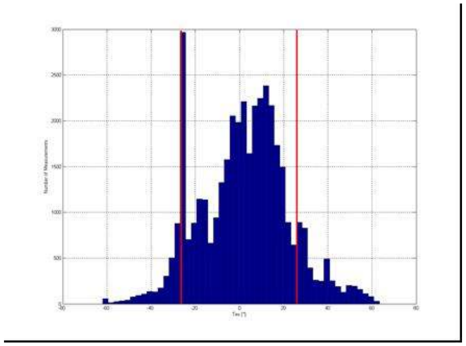
Unsteady pressure measurements











Conclusion

- ✓ Strong needs in the hydraulic machinery development:
  - ✓ New market needs
  - ✓ New developments with strong environmental, exploitation and operation constraints

- ✓ Can by insured by:
  - ✓ New high accuracy tools development: theoretical, experimental and numerical
  - ✓ Multidisciplinary approach to solve new topics