

CFD Computations of a Cavitation Vortex Rope

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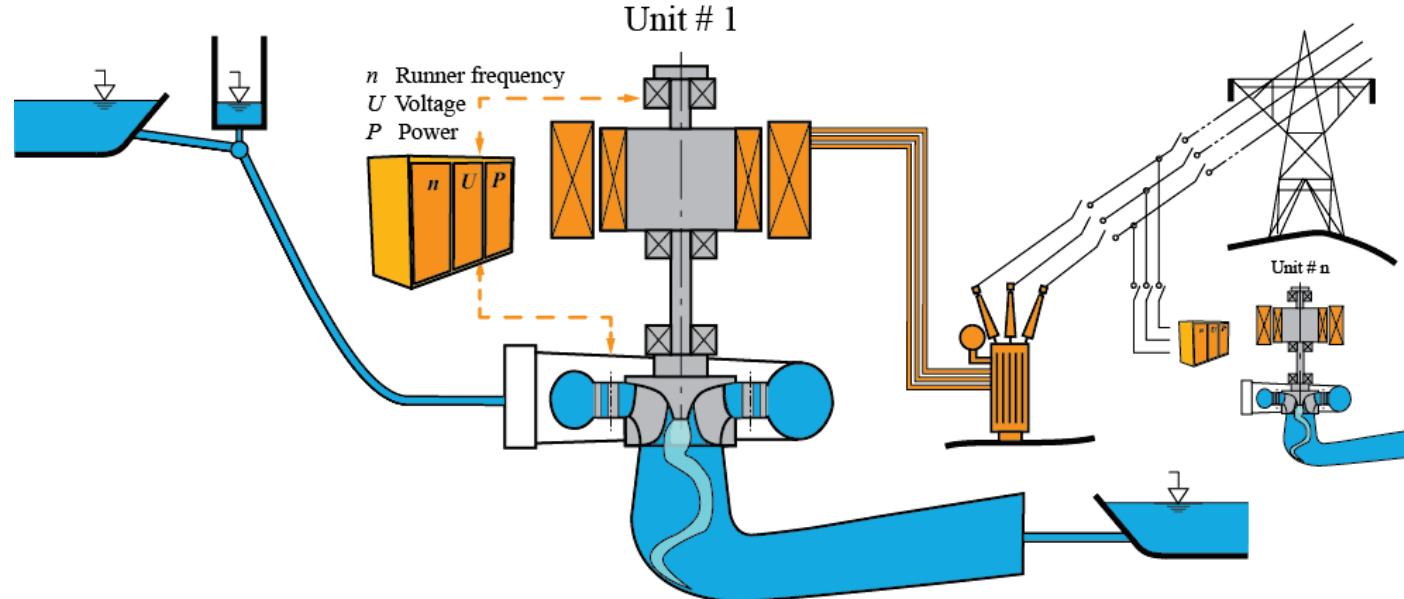
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- 1) CONTEXT**
- 2) OBJECTIVE**
- 3) METHODOLOGY**
- 4) TEST CASE**
- 5) MODELLING**
- 6) NUMERICAL SET UP**
- 7) RESULTS WITHOUT CAVITATION**
- 8) RESULTS WITH CAVITATION**
- 9) CONCLUSION AND OUTLOOK**

FP7 ENERGY no: 608532 HYPERBOLE

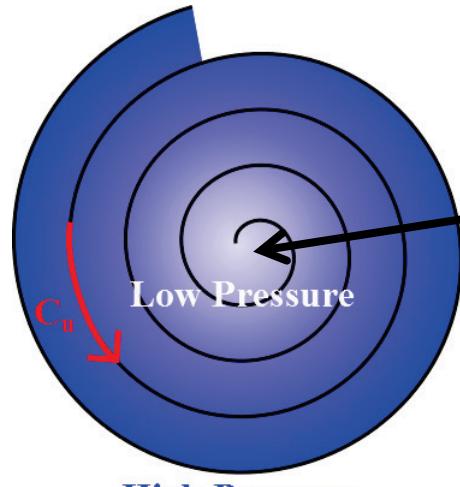
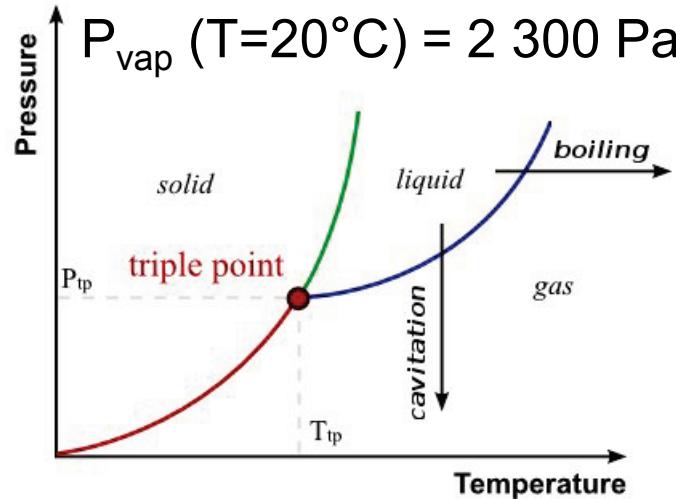
HYdropower plants PERformance and flexiBLE Operation
towards Lean integration of new renewable Energies

Hydropower Plant Layout

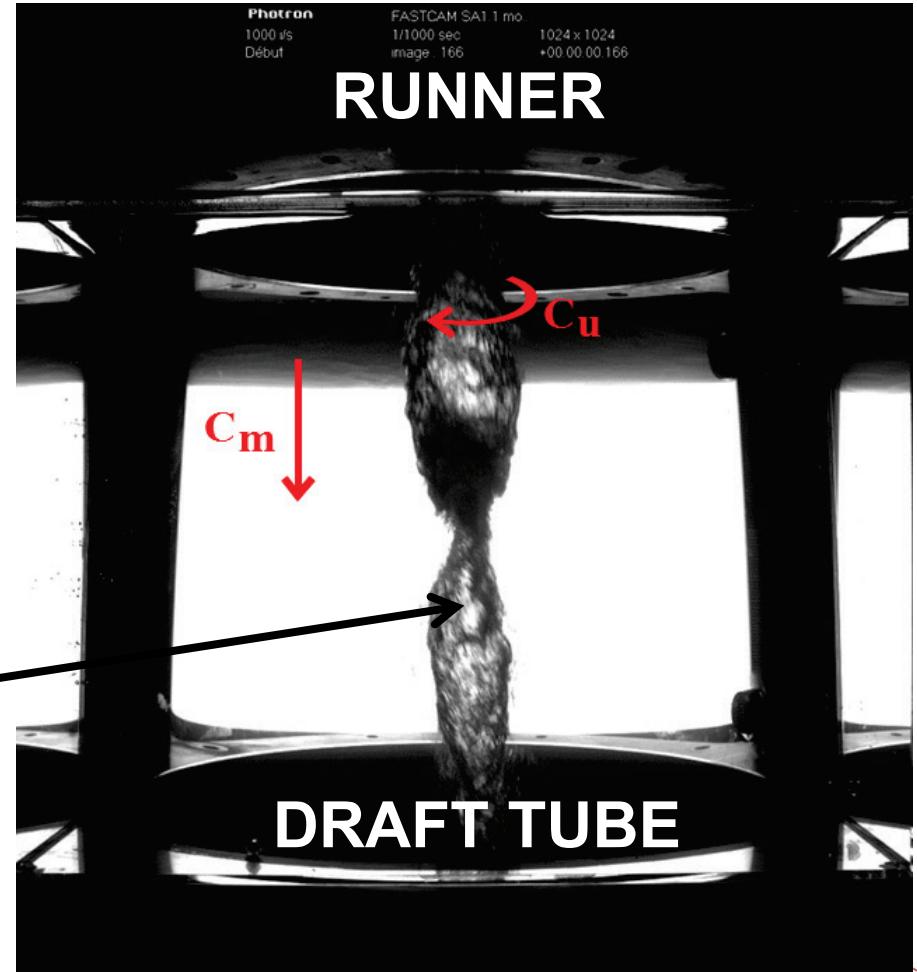


<https://hyperbole.epfl.ch>

WHAT IS CAVITATION ?



WHAT IS VORTEX ROPE ?

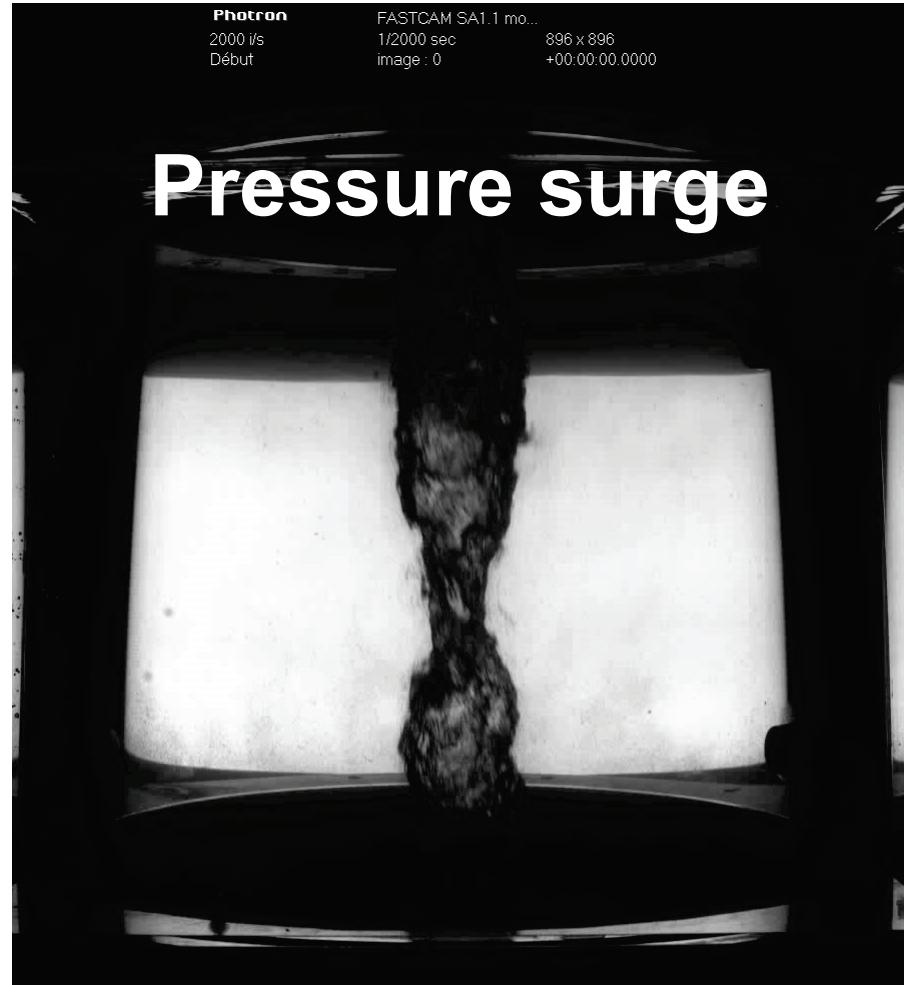


OBJECTIVE

Photron
2000 i/s
Début

FASTCAM SA1.1 mo...
1/2000 sec 896 x 896
image : 0 +00:00:00.0000

Pressure surge



Model test



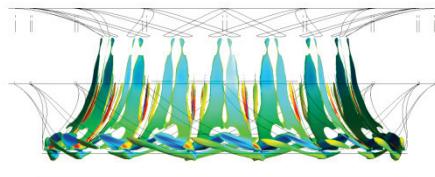
Scale transposition



Prototype



3D Modelling



$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{C}) = 0$$

TODAY

$$\nabla \cdot (\rho \vec{C} \otimes \vec{C}) = -\nabla p + \nabla \cdot (\underline{\tau} + \underline{\underline{\tau}})$$

$$\frac{\partial r_g}{\partial t} + (\vec{C} \cdot \nabla) r_g = \frac{1}{\rho_g} S$$

Simulations of the model test and comparisons with experimental results



1D Modelling

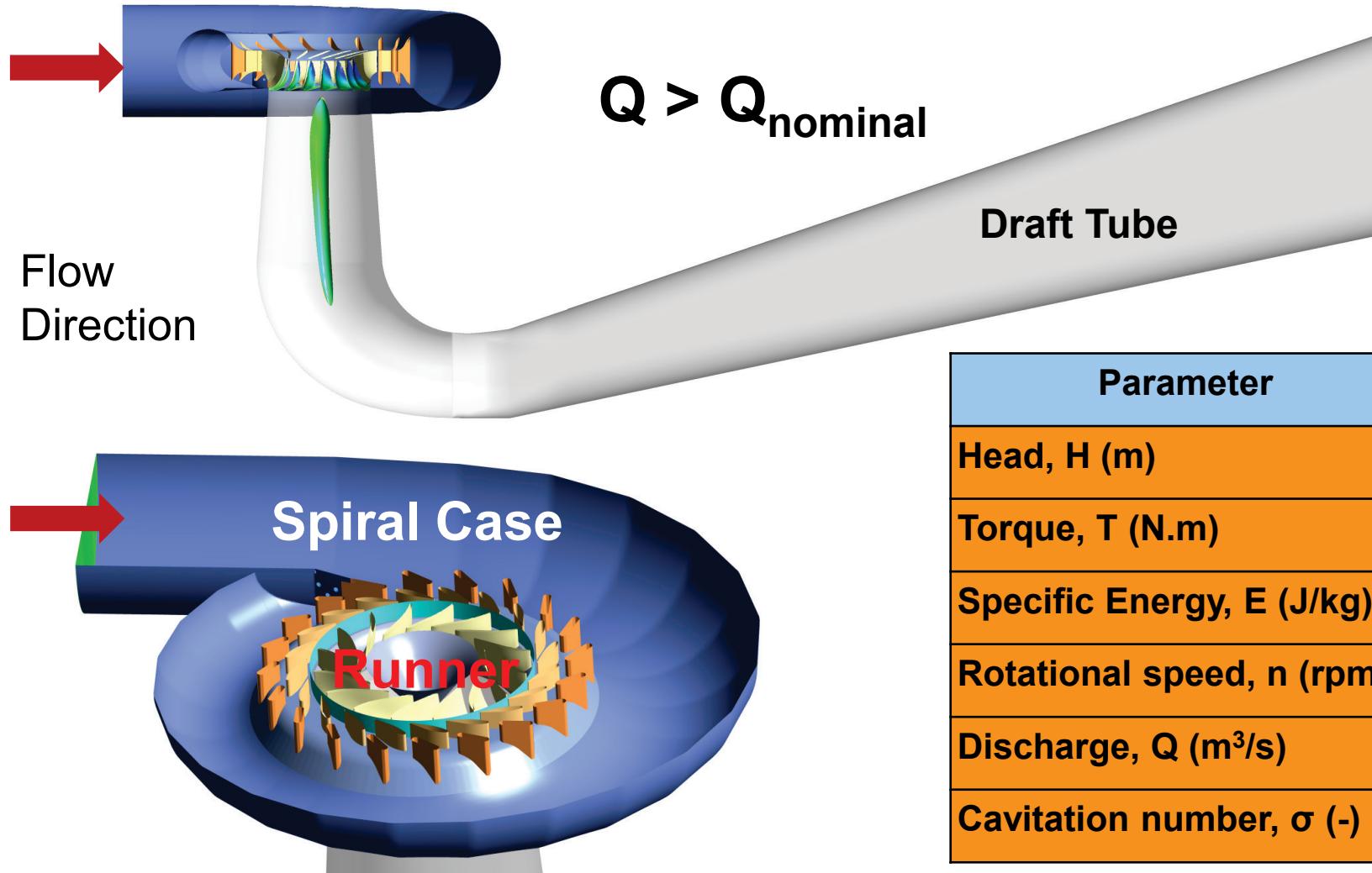
$$Q_1 - Q_2 = \epsilon \frac{dU_1}{dt} + C_c \frac{dh}{dt} + \lambda \frac{dQ}{dt}$$

$$L' \frac{\partial Q}{\partial t} + J' \frac{\partial Q}{\partial x} - R'_d Q + \frac{\partial h}{\partial x} + R'_\lambda Q - R'_\mu \frac{\partial^2 Q}{\partial x^2} = 0$$

IN A NEAR FUTURE

Prototype

TEST CASE: FRANCIS TURBINE AT OVERLOAD



Parameter	Value
Head, H (m)	26.8
Torque, T (N.m)	1400
Specific Energy, E (J/kg)	263
Rotational speed, n (rpm)	800
Discharge, Q (m^3/s)	0.515
Cavitation number, σ (-)	0.11

Reynolds-Averaged Navier Stokes Equations (RANS)

Mass

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{C}) = 0$$

Momentum

$$\frac{\partial \rho \vec{C}}{\partial t} + \nabla \cdot (\rho \vec{C} \otimes \vec{C}) = -\nabla p + \nabla \cdot (\underline{\underline{\tau}} + \underline{\underline{\tau}_t})$$

Gaz volume fraction

$$\frac{\partial r_g}{\partial t} + (\vec{C} \cdot \nabla) r_g = \frac{1}{\rho_g} S$$

Turbulence stresses are modelled using the Boussinesq's assumption.

The eddy viscosity is computed using the k- ω SST model.

Cavitation model

Vaporisazion term

$$S = S_V = F_V N_V \rho_V 4\pi R_B^2 \sqrt{\frac{3}{2} \frac{|P_{vap} - P|}{\rho_L}} \text{ if } P < P_{vap}$$

Condensation term

$$S = S_C = -F_C N_C \rho_V 4\pi R_B^2 \sqrt{\frac{3}{2} \frac{|P_{vap} - P|}{\rho_L}} \text{ if } P > P_{vap}$$

$$N_V = (1 - \alpha_V) \frac{3 r_{nuc}}{4\pi R_B^3}$$

$$N_C = \frac{3\alpha_V}{4\pi R_B^3}$$

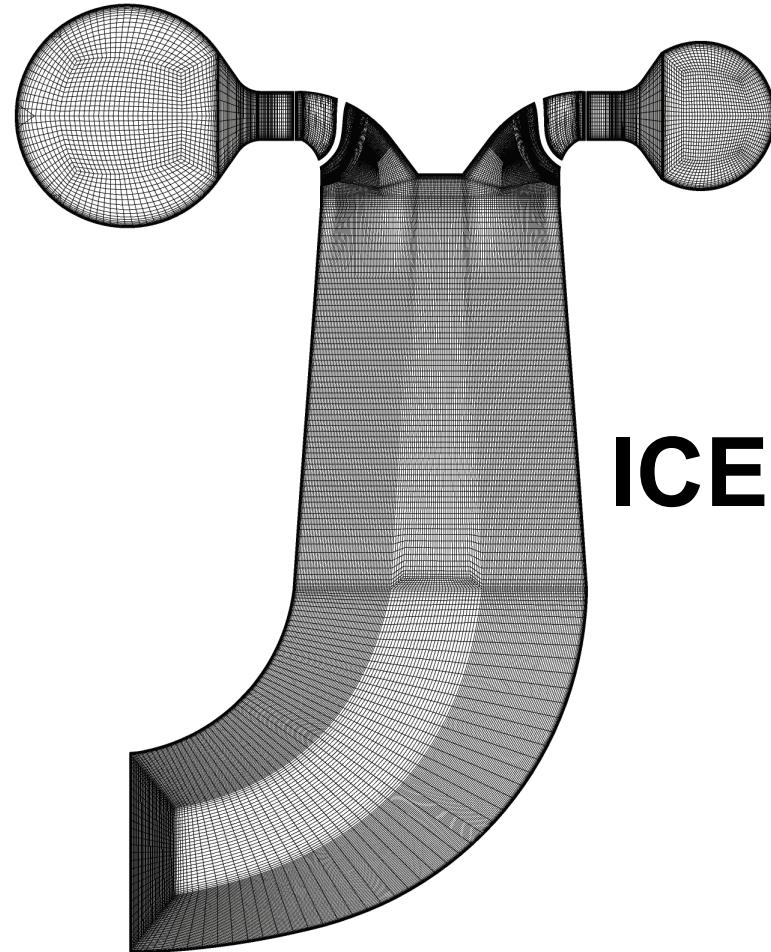
By default: $F_V = 50$, $F_C = 0.01$, $r_{nuc} = 5^{-4}$, $R_B = 2^{-6} m$

$$P_{vap} (T=20^\circ C) = 2300 \text{ Pa}$$



Structured mesh with hexahedra

Part	Number of nodes
Spiral Case	1.69E+06
Stay Vane + Guide Vane	3.17E+06
Runner	2.63E+06
DraftTube	3.10E+06
Total	10.6E+06



ICEM

NUMERICAL SET UP

ANSYS CFX 15.0

Time Scheme

Equation	Scheme
Momentum	Backward Second Order
Turbulence	Backward First Order
Gas Volume Fraction	Backward First Order

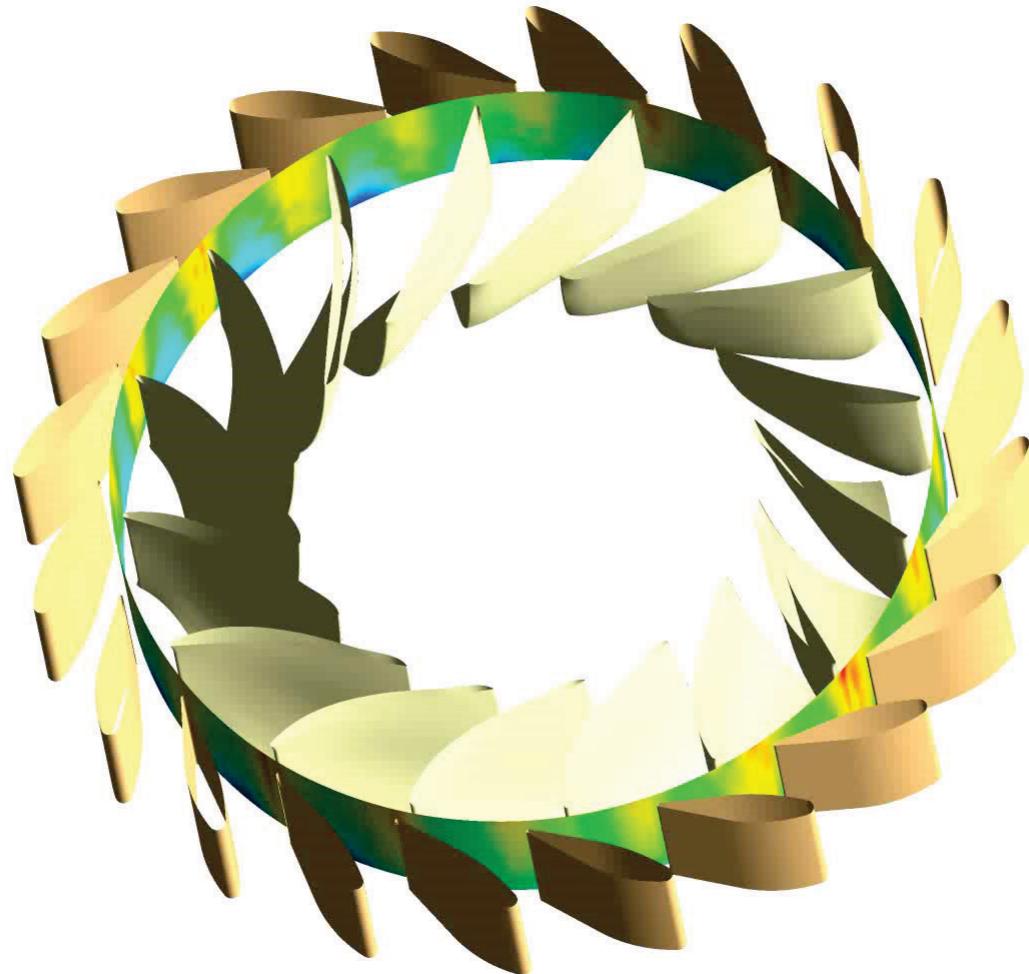
Advection Scheme

Equation	Scheme
Momentum	TVD Scheme
Turbulence	Upwind First Order
Gas Volume Fraction	TVD Scheme

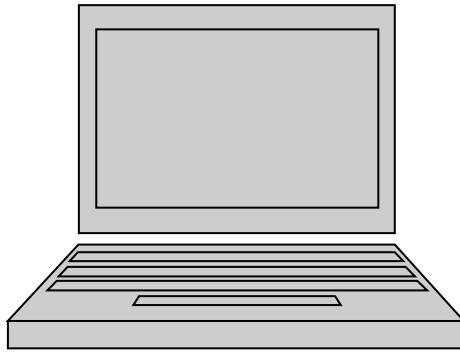
Boundary conditions

Boundary	Condition
Inlet	Discharge
Outlet	Opening Pressure
Wall	No slip condition
Rotating wall	Rotation speed
Interface	Transient rotor/stator

ROTOR/STATOR INTERFACE



COMPUTATIONAL RESSOURCES



- CPU ressources: 2 CPU with 10 cores => 20 cores.
- Memory allocated: from 30 to 60 Gb.
- Computational time: 20 days.
- Storage: 100 Gb
- Message passing : MPICH

GLOBAL RESULTS WITHOUT CAVITATION

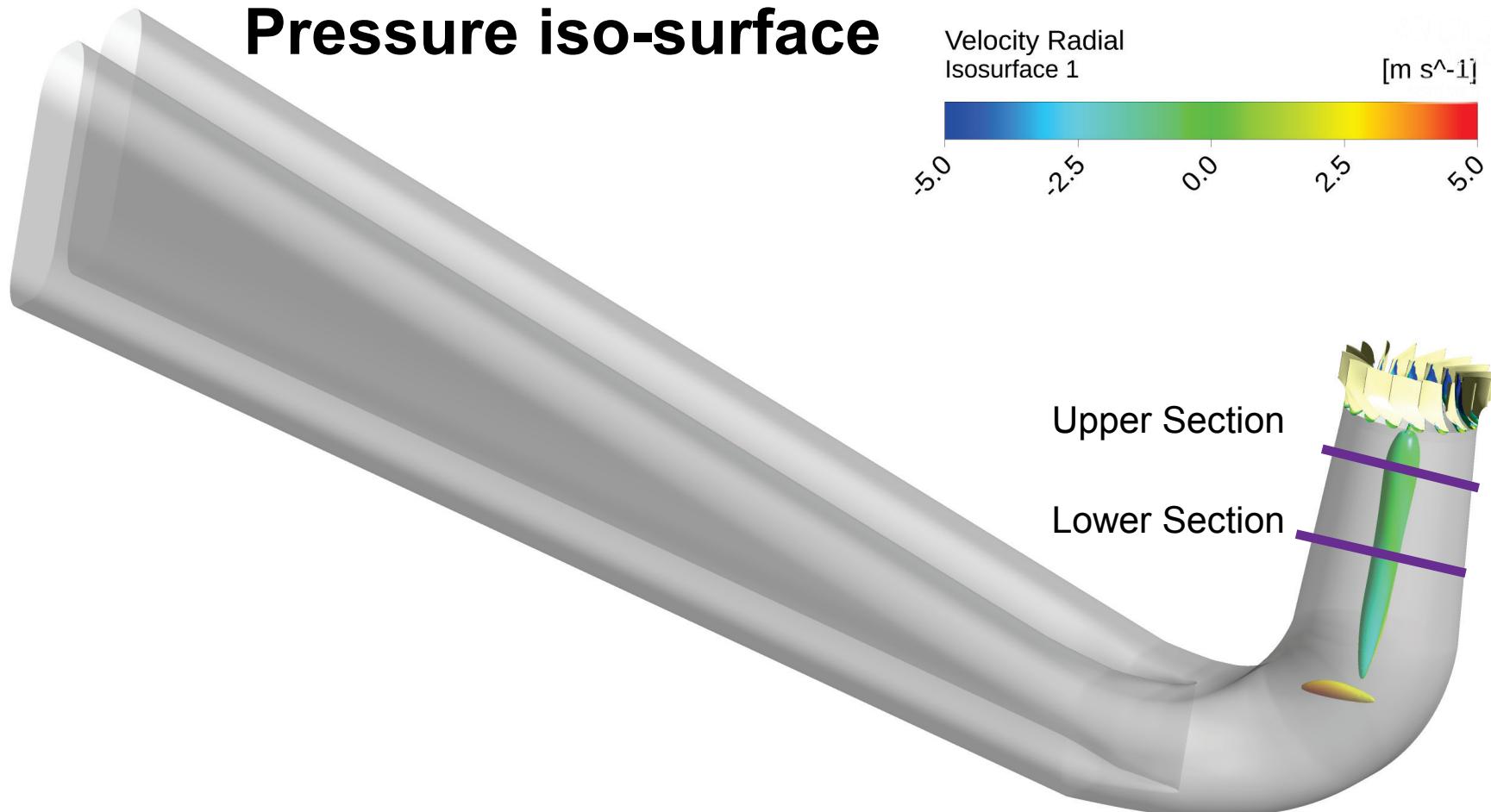
$\Delta t = 10^{-3} \text{ s} \Leftrightarrow 4.8^\circ \text{ of revolution per time step}$

Simulation time duration: $t = 4 \text{ s}$

Parameters	Experiment	Computation
Head (m)	26,8	26,2
Torque (N.m)	1411	1411
Specific Energy (J/kg)	263	257
Efficiency (-)	0,87	0,90
Ned (-)	0,288	0,291
Qed (-)	0,259	0,262

VORTEX ROPE WITHOUT CAVITATION

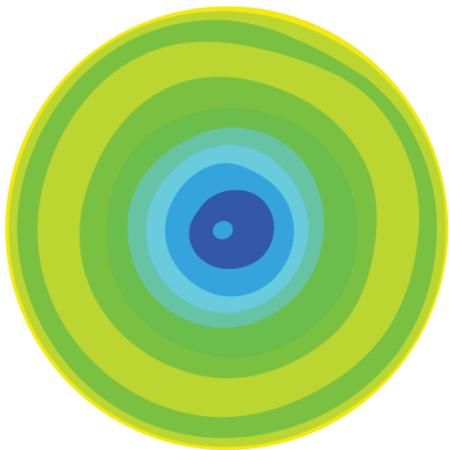
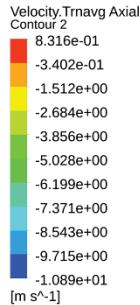
Pressure iso-surface



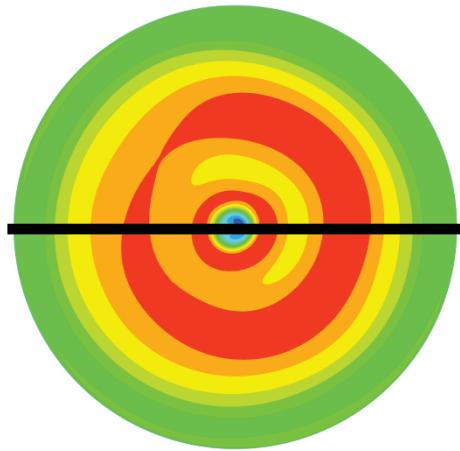
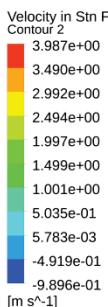
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VELOCITY FIELDS WITHOUT CAVITATION

Upper Section



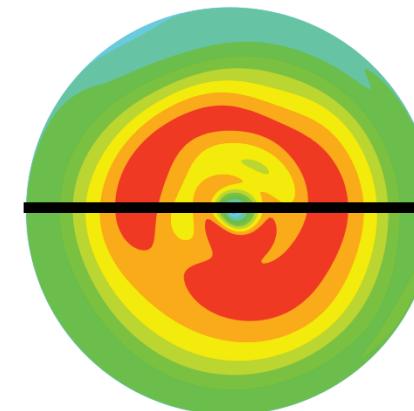
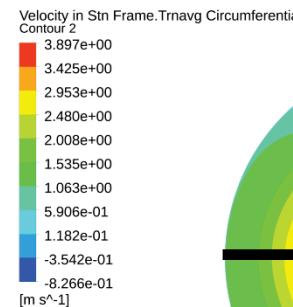
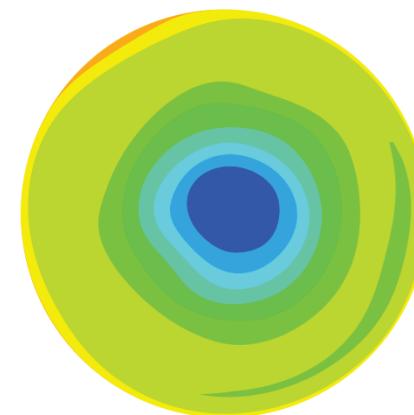
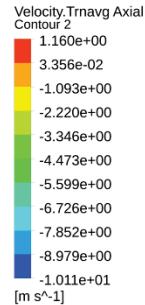
Mean
Axial
Velocity



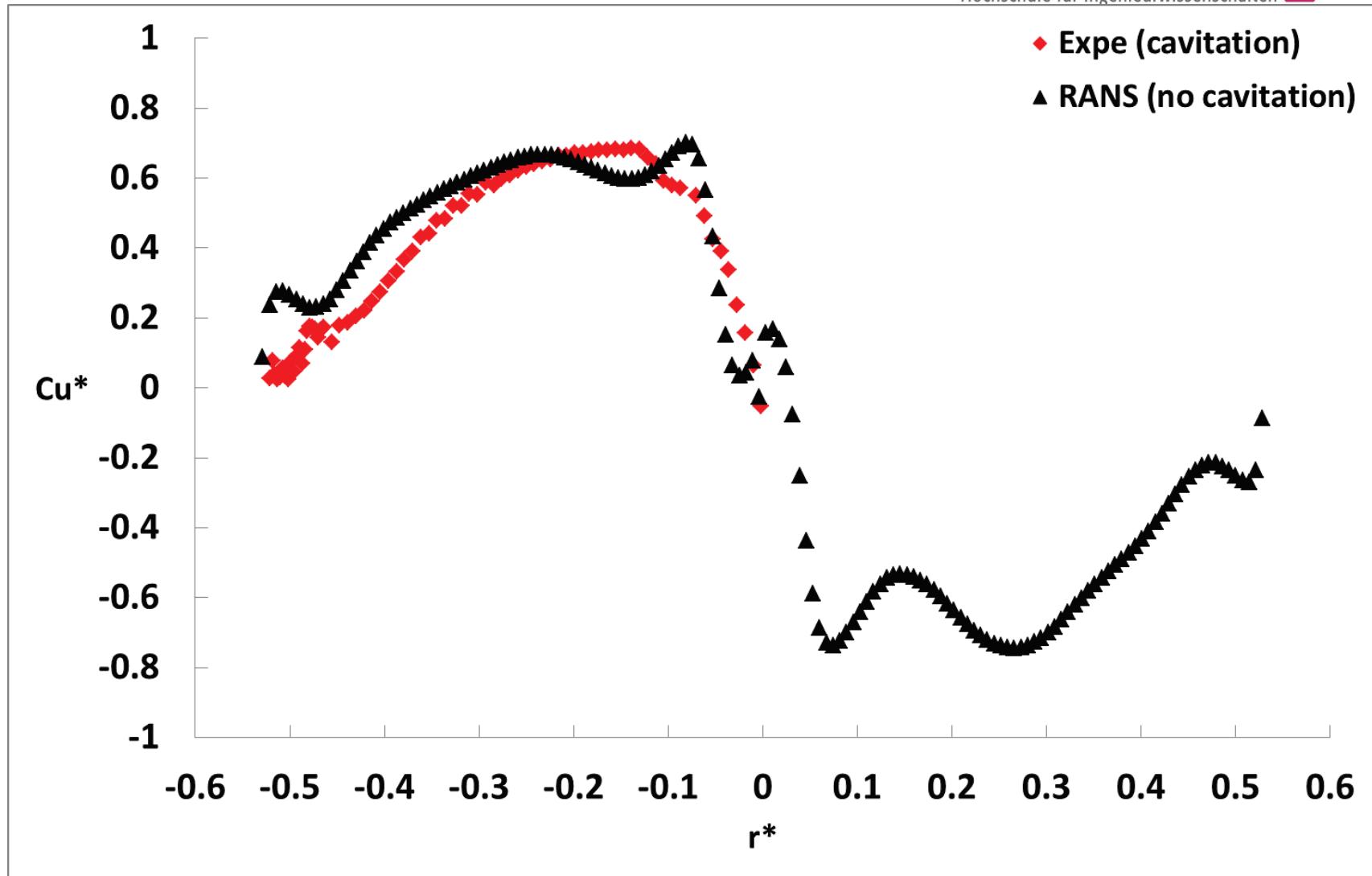
Mean
Tangential
Velocity



Lower Section π

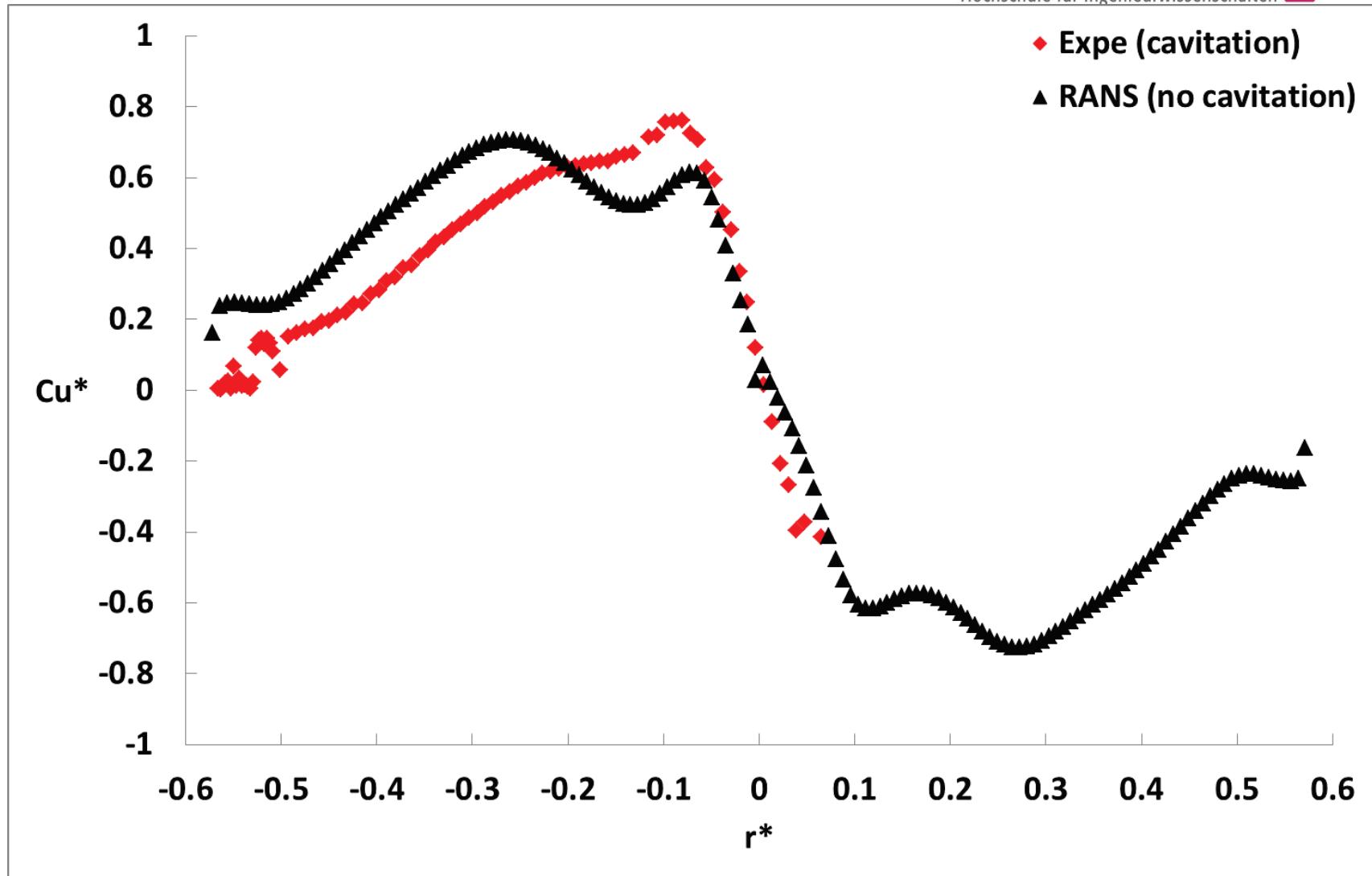


UPPER SECTION: TANGENTIAL VELOCITY

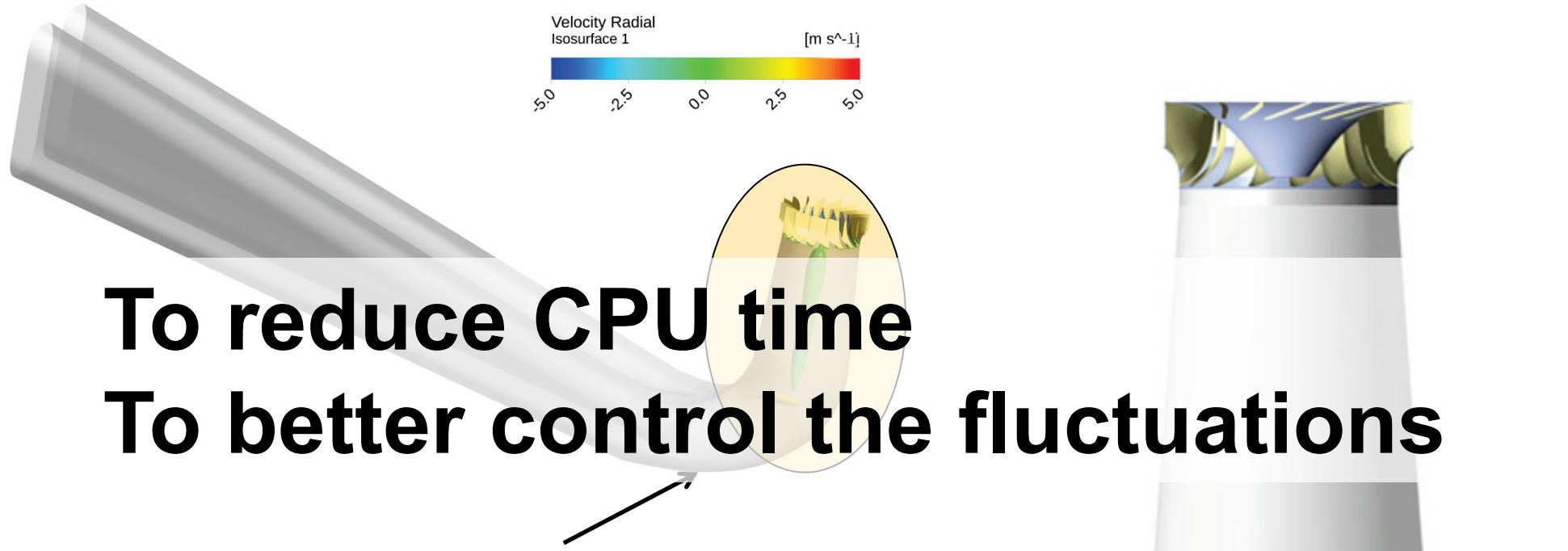


LOWER SECTION : TANGENTIAL VELOCITY Hes-SO // VALAIS WALLIS

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Hochschule für Ingenieurwissenschaften π



REDUCED DOMAIN: MOTIVATION

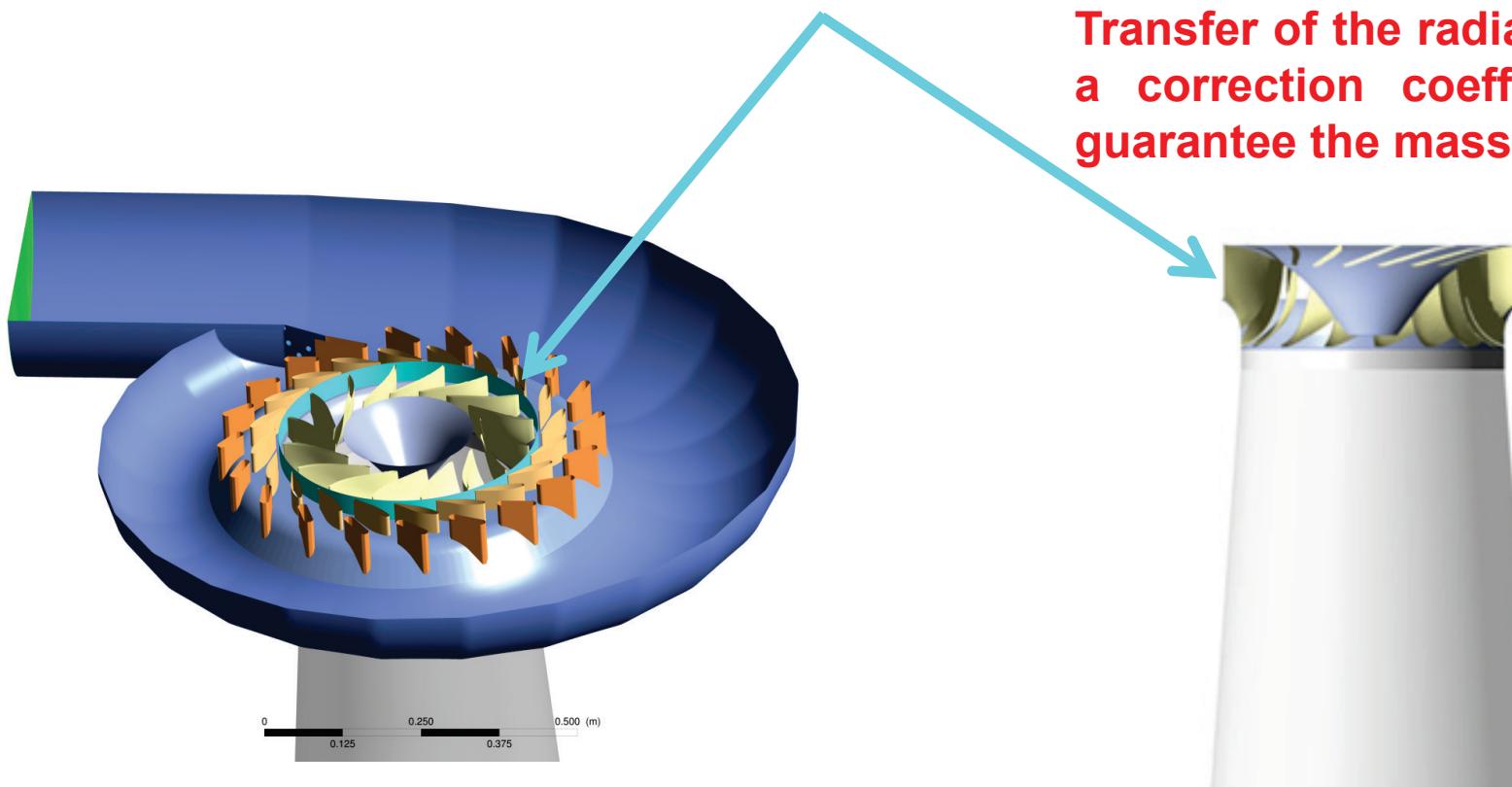


Pressure surge due to the elbow

Pressure surge controlled by the boundary condition

REDUCED DOMAIN: METHODOLOGY

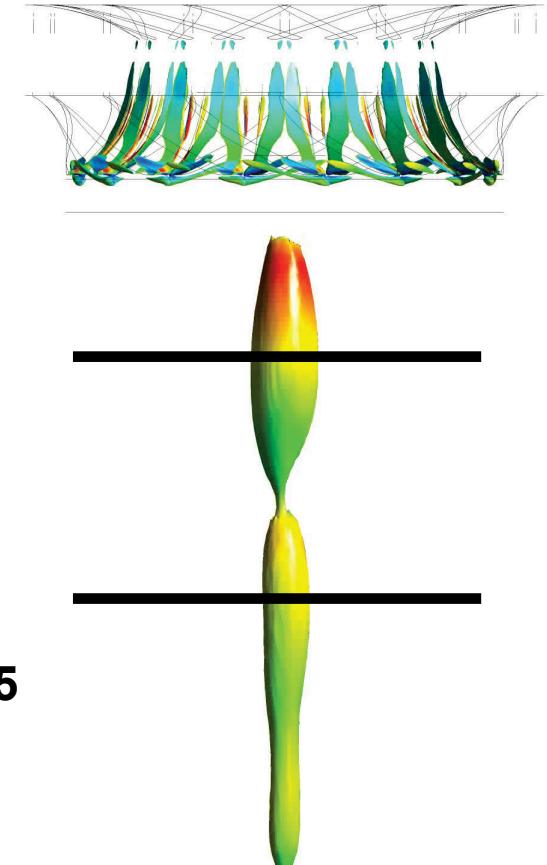
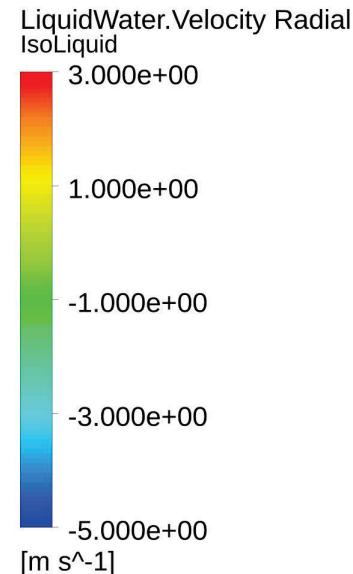
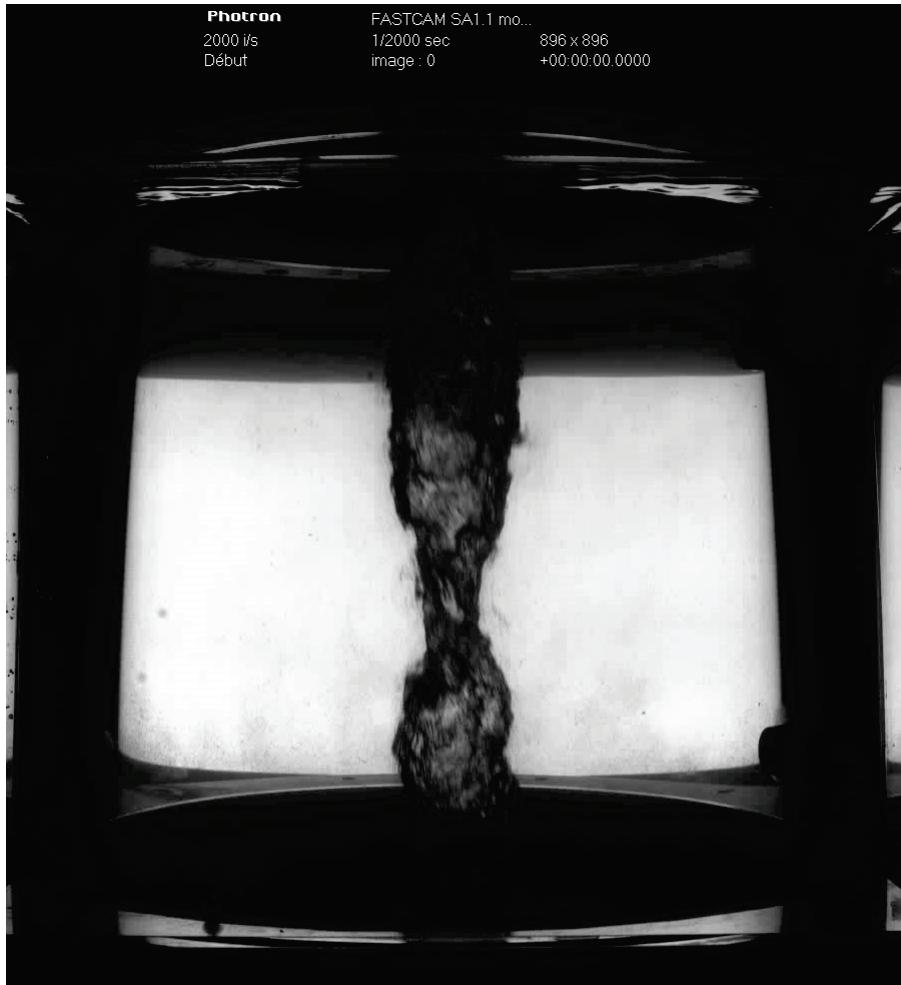
Guide Vanes/Runner interface



Full domain

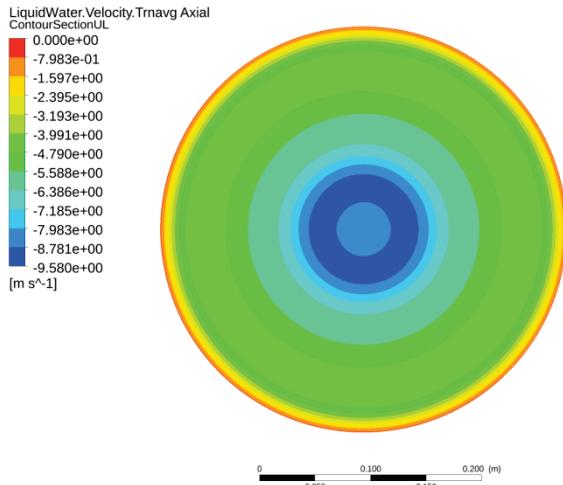
Reduced domain
Runner + Straight part of the Draft Tube

CAVITATING VORTEX ROPE

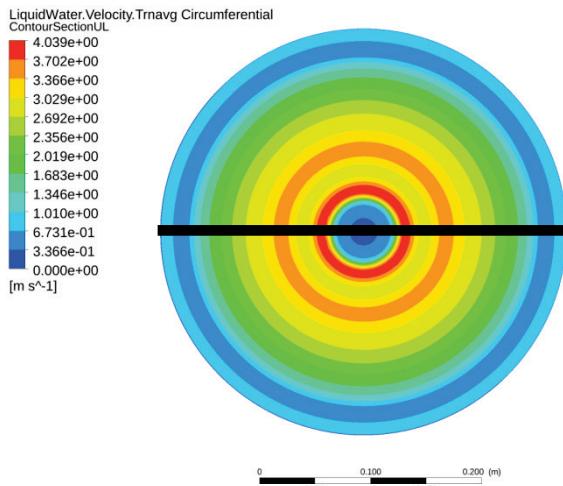


VELOCITY FIELD WITH CAVITATION

Upper Section



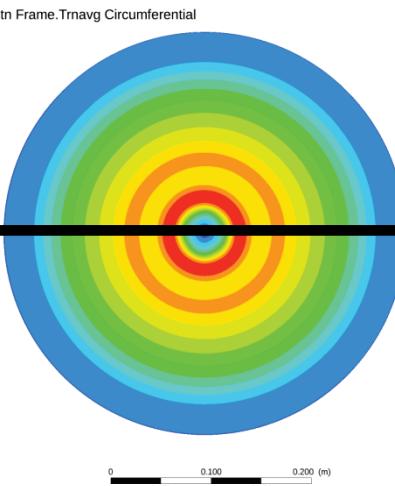
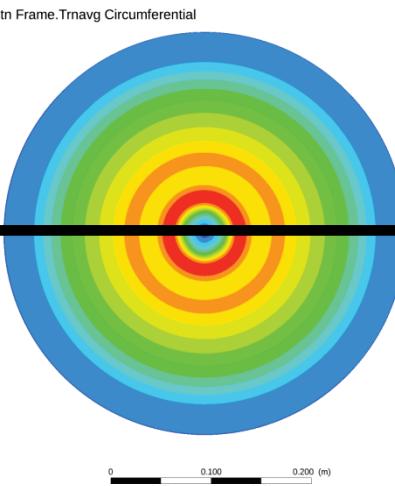
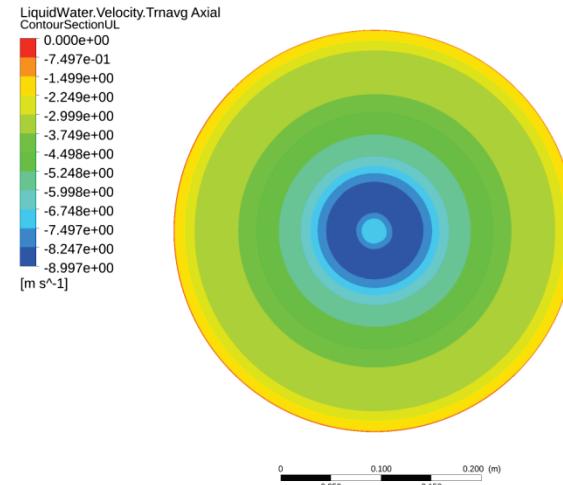
Mean
Axial
Velocity



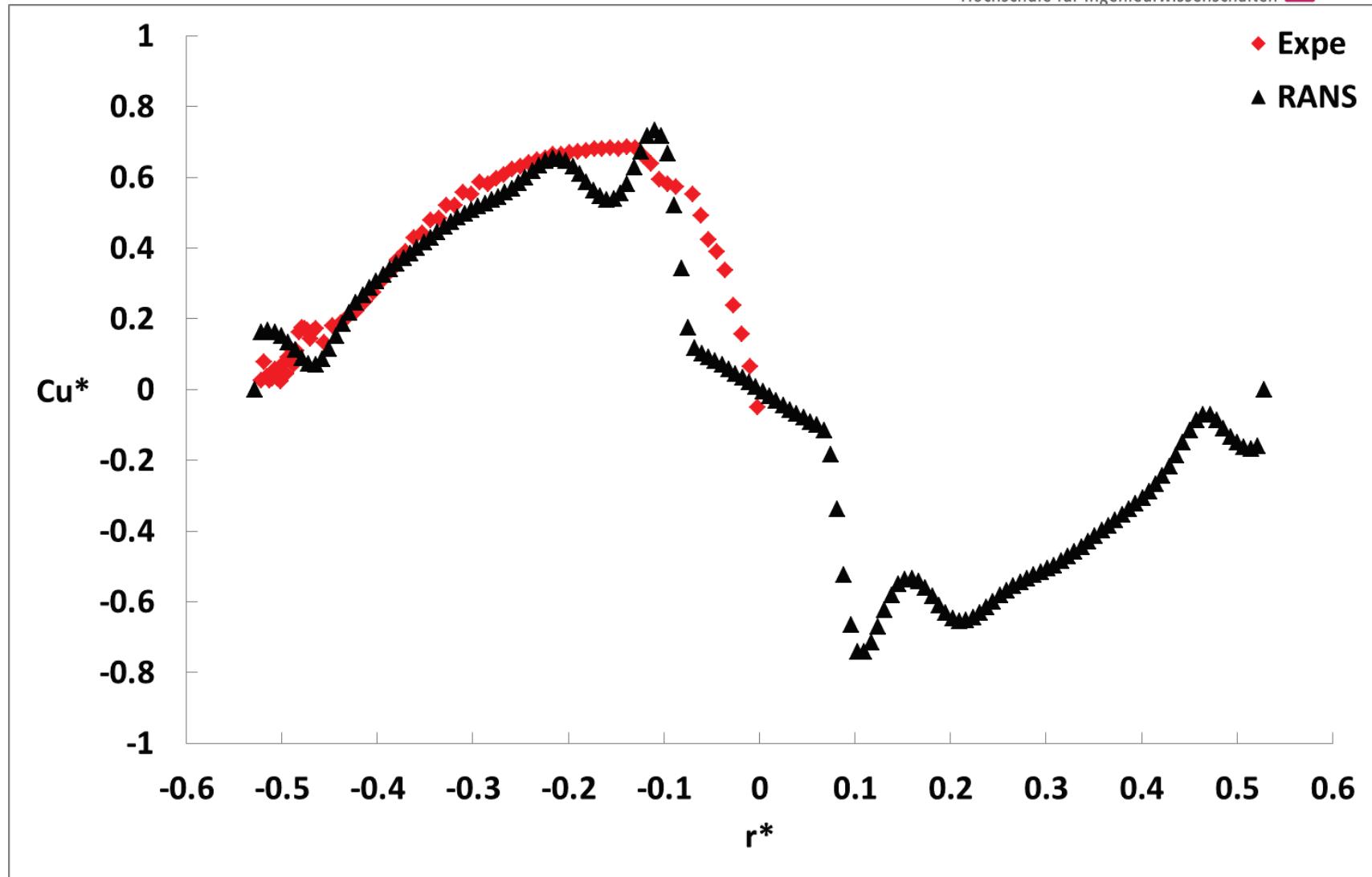
Mean
Tangential
Velocity



Lower Section π

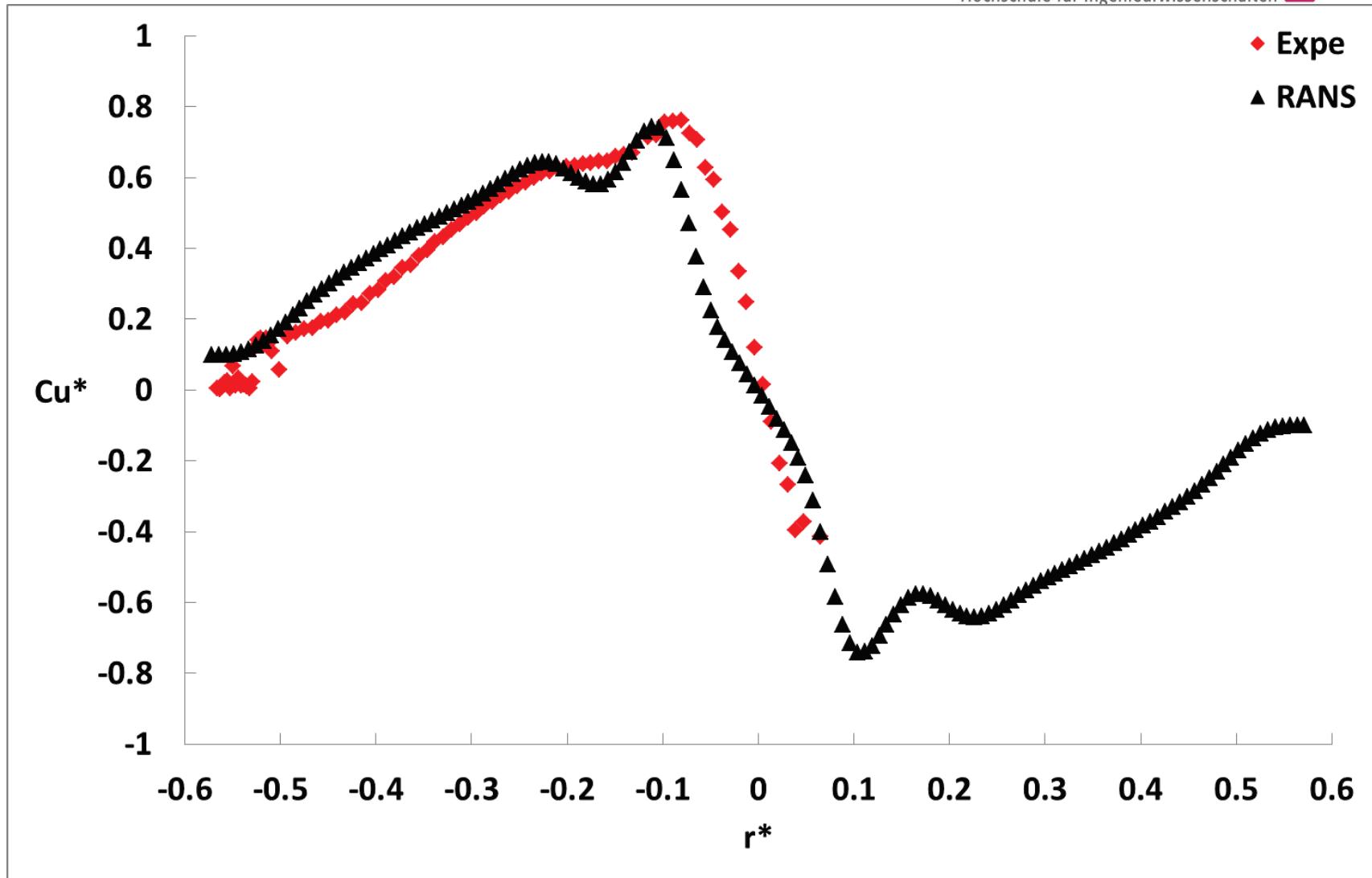


UPPER SECTION: TANGENTIAL VELOCITY



LOWER SECTION: TANGENTIAL VELOCITY Hes-SO // VALAIS WALLIS

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Achievement

- ✓ **Full domain:** CFD results are in agreement with the experiment.
- ✓ **Reduced domain:** Cavitating rope is captured accurately compared to the experiment.

Ongoing work Methodology has been already tested on a 2D case

- To compute the flow with an excitation pressure at the outlet of the reduced domain.
- To provide the correct inputs to the 1D model.

THANK YOU FOR YOUR ATTENTION

