# OpenFOAM for CFD in water power and for international collaboration

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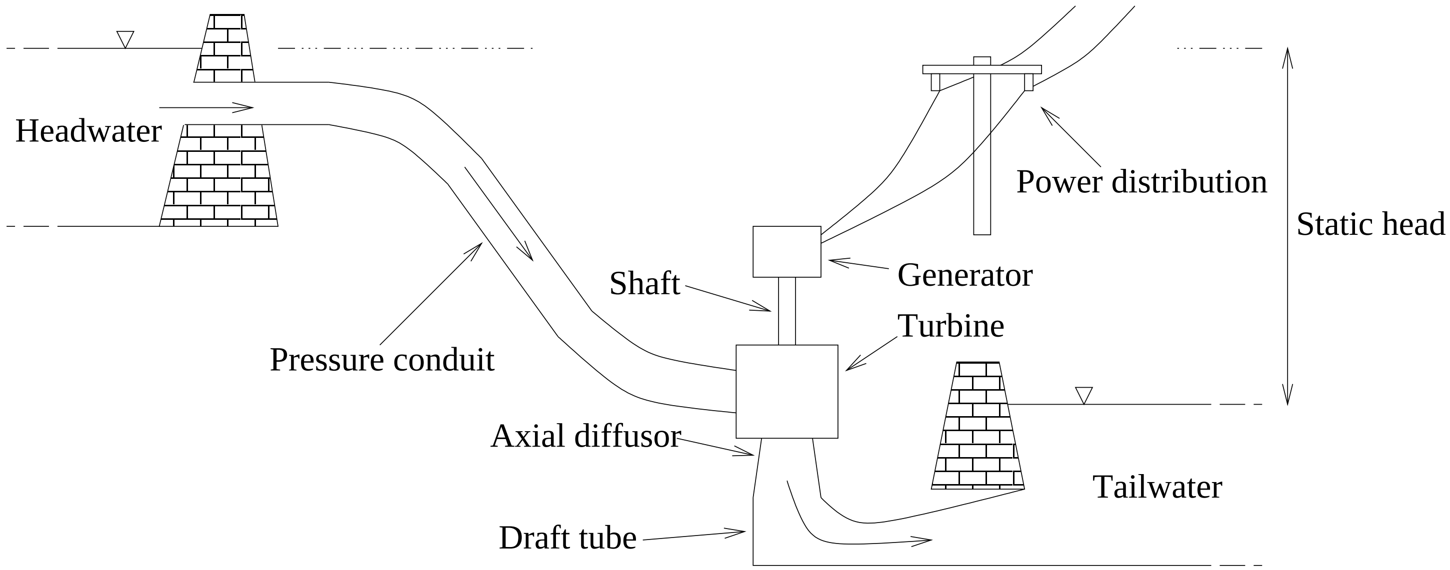
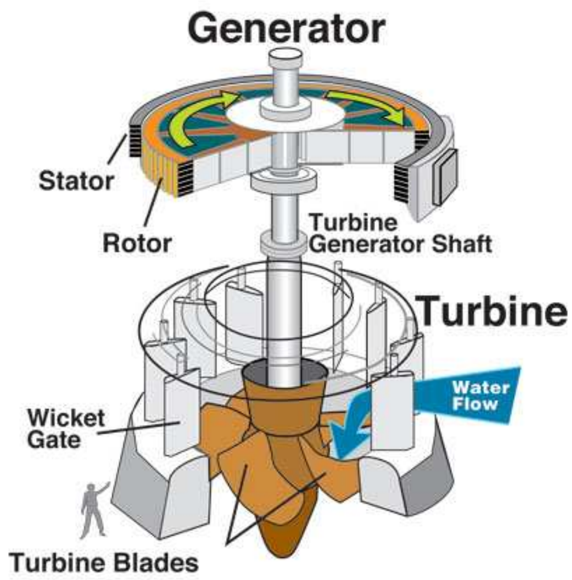
**Outline of the presentation:**

- OpenFOAM for CFD in water power
  - Overview of flow in Hydro Power Stations
  - OpenFOAM results from inlet to outlet and generator (real geometries and academic test-cases)
  - Validation against measurements
  - Comparisons with results from CFX-5/10 and Fluent
- OpenFOAM for international collaboration
  - The OpenFOAM Turbomachinery Working Group
  - The OpenFOAM Wiki
  - The OpenFOAM-extend project at SourceForge
  - The OpenFOAM Workshop / Working Group Day

# Overview of Fluid Dynamics in Hydro Power Stations



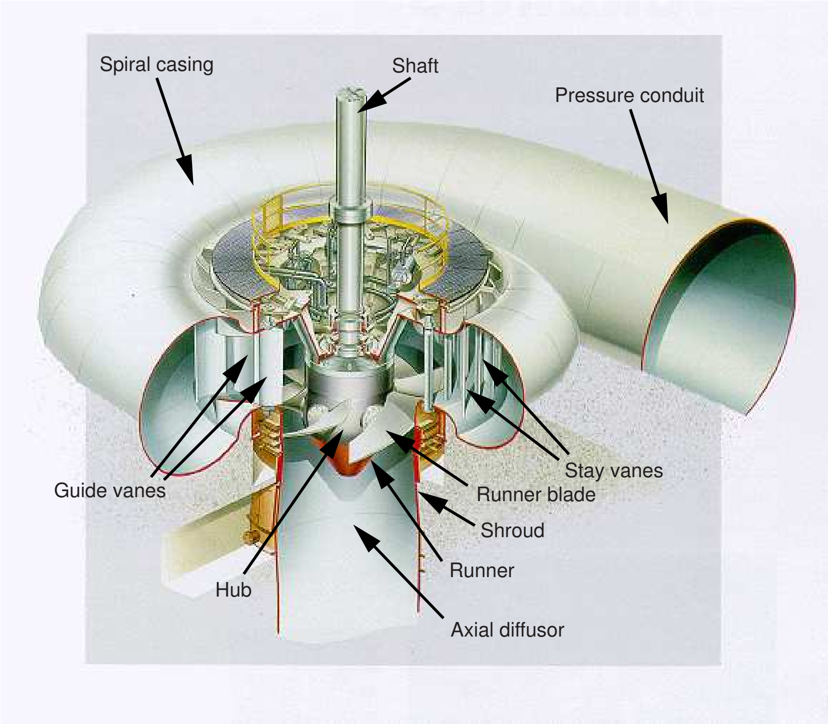



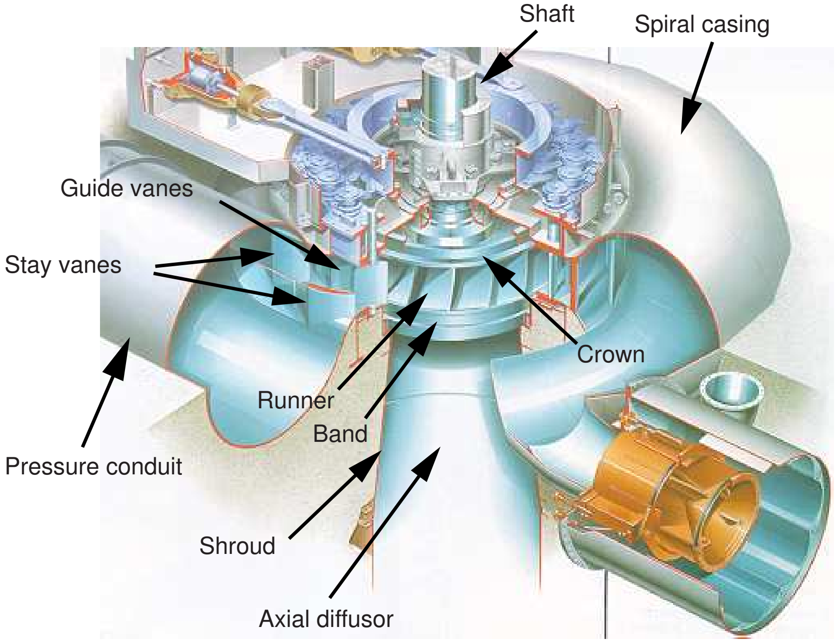

Source: Wikipedia

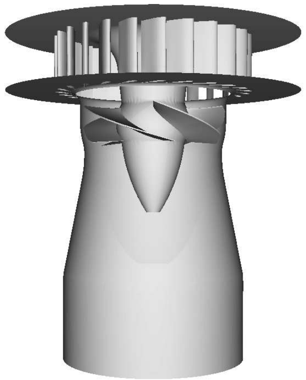
**Some important flow features:**
(Red text discussed more later)

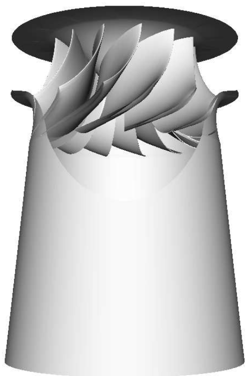
- Intake losses – vortices, wakes, friction
- Pressure conduit – friction, secondary flow, pressure transients
- Wicket gate and runner – separation, wakes, clearance flow, cavitation, secondary flow, rotor-stator interaction
- Draft tube and outlet – separation, unsteadiness, secondary flow
- Bearings – friction, cavitation, dynamics
- Generator – convective cooling, friction
- Spillways – erosion of dams and river
- Fish friendliness – guide the fish to safe passages

# Kaplan and Francis runners – the most common types in Sweden



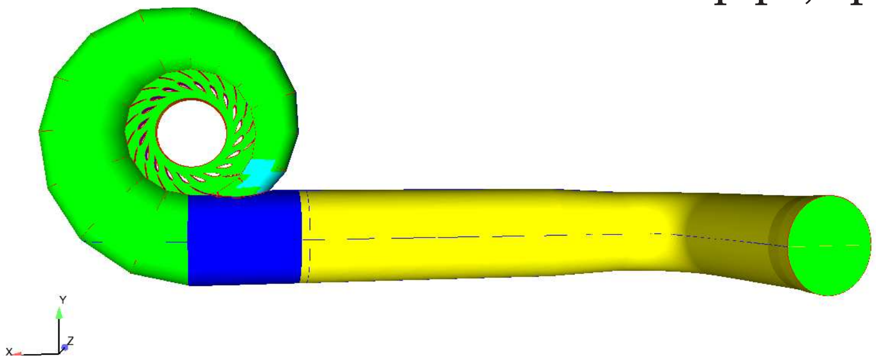



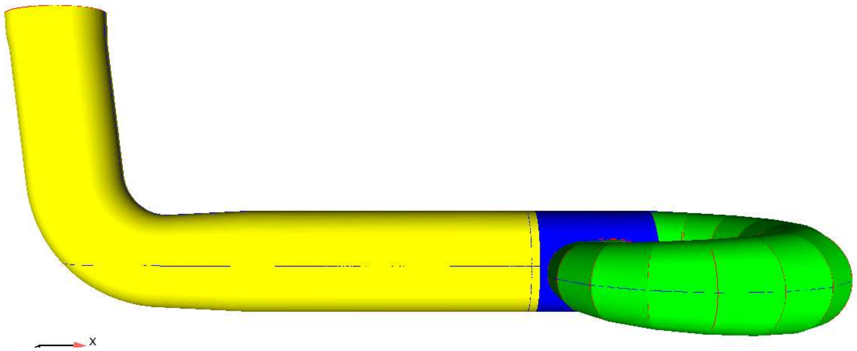



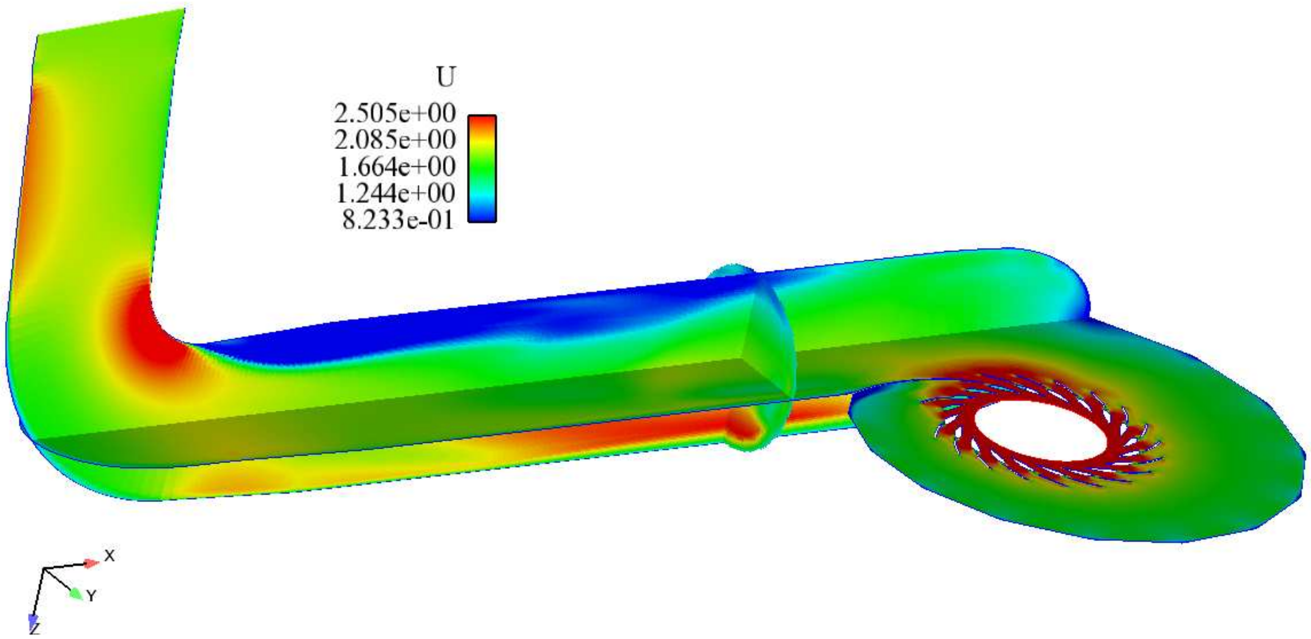


# Pressure conduit – Secondary flow

Olivier Petit, under my supervision
Here: the inlet pipe, spiral casing and distributor.

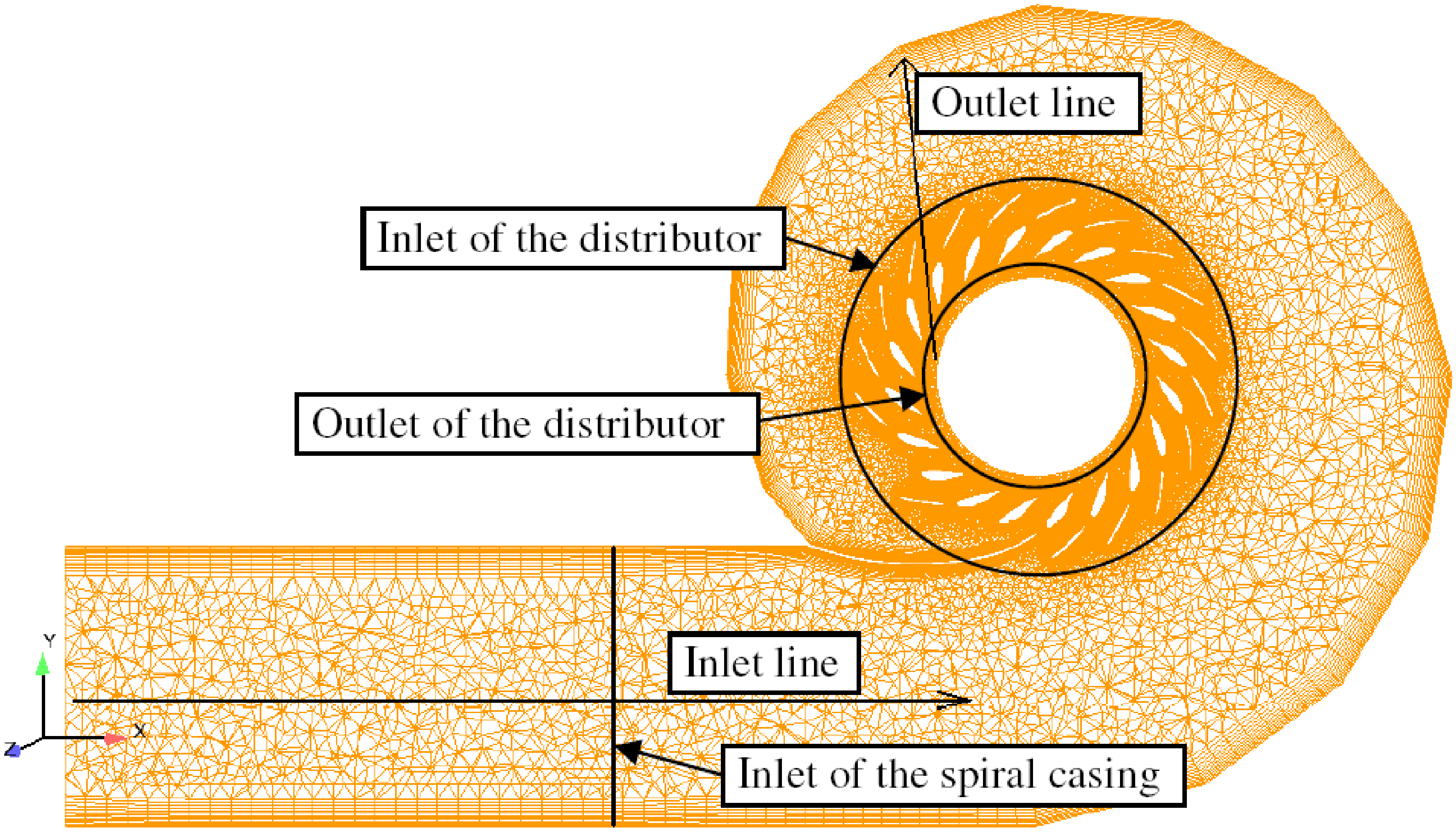


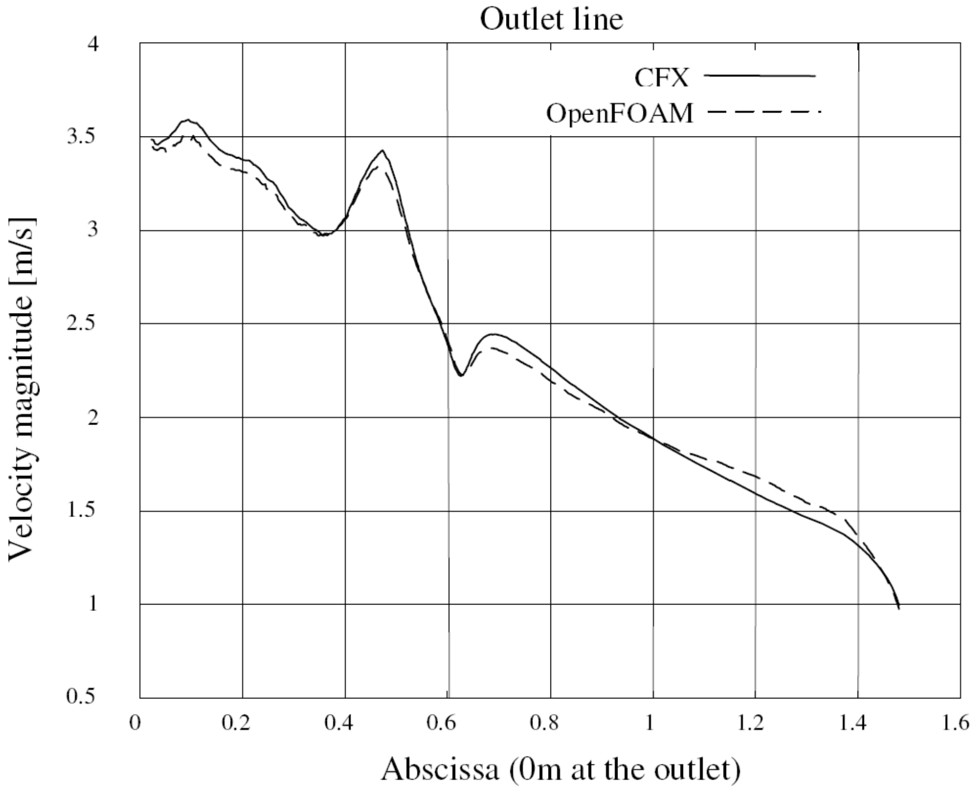
# U9 spiral casing, OpenFOAM vs. CFX-10

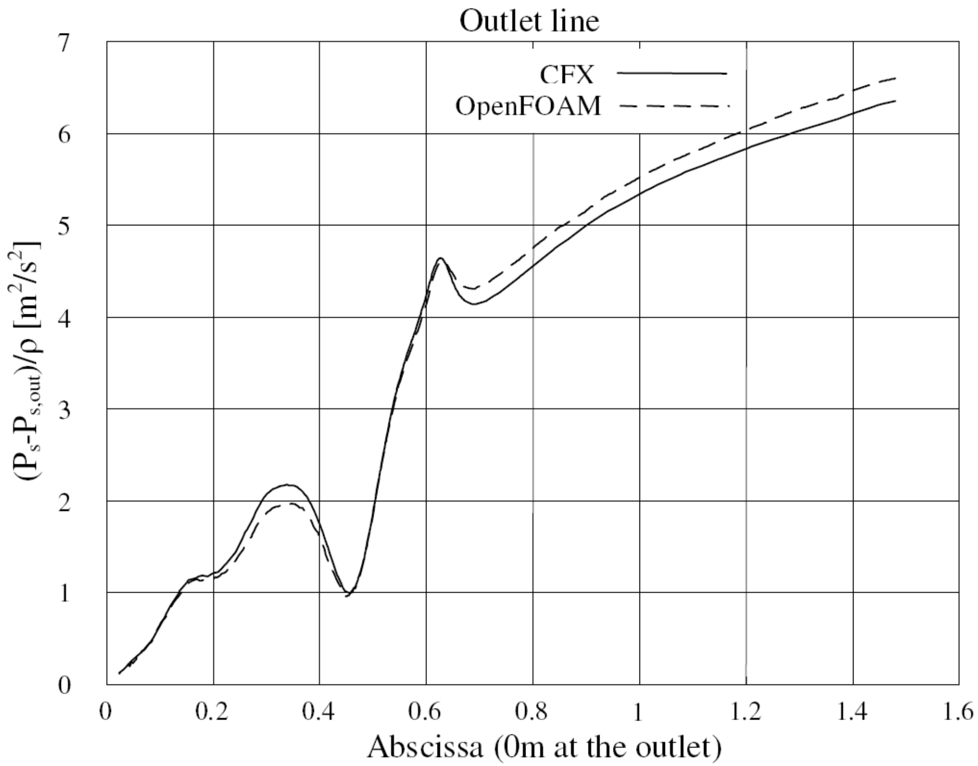
We will have a look at results along the 'outlet line':



# U9 spiral casing, OpenFOAM vs. CFX-10

Velocity magnitude (left) and static pressure (right) at the 'outlet line'

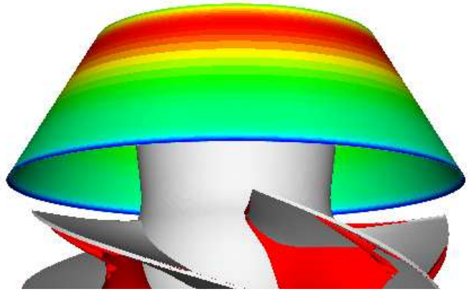


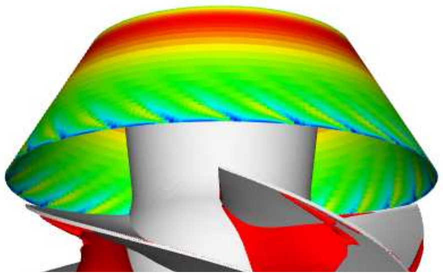
# Wicket gate and runner – Rotor-stator interaction

Simulations by Håkan Nilsson & Martin Karlsson, LTU

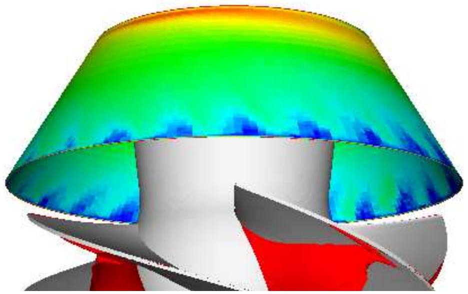
Axi-symmetric

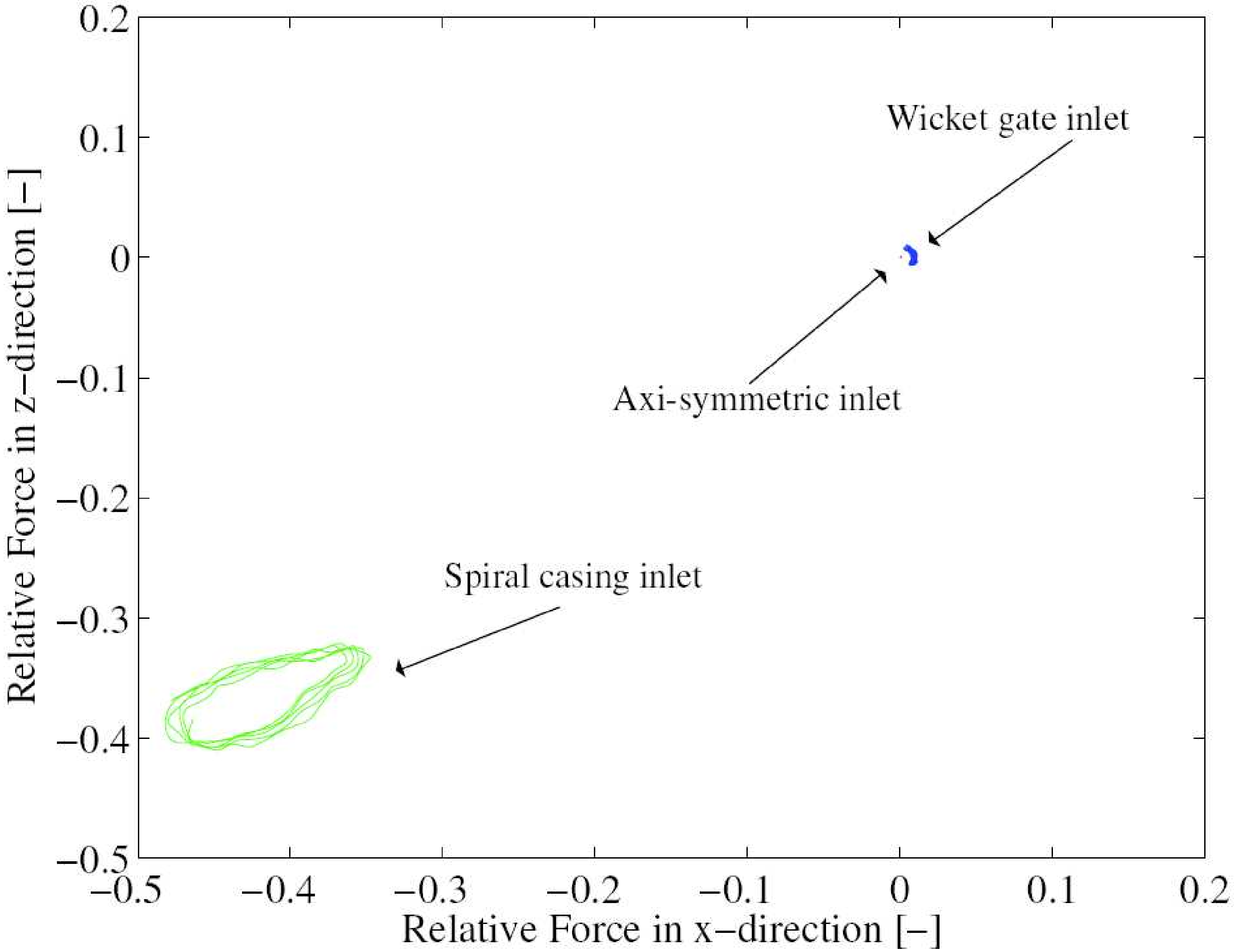


Guide vanes



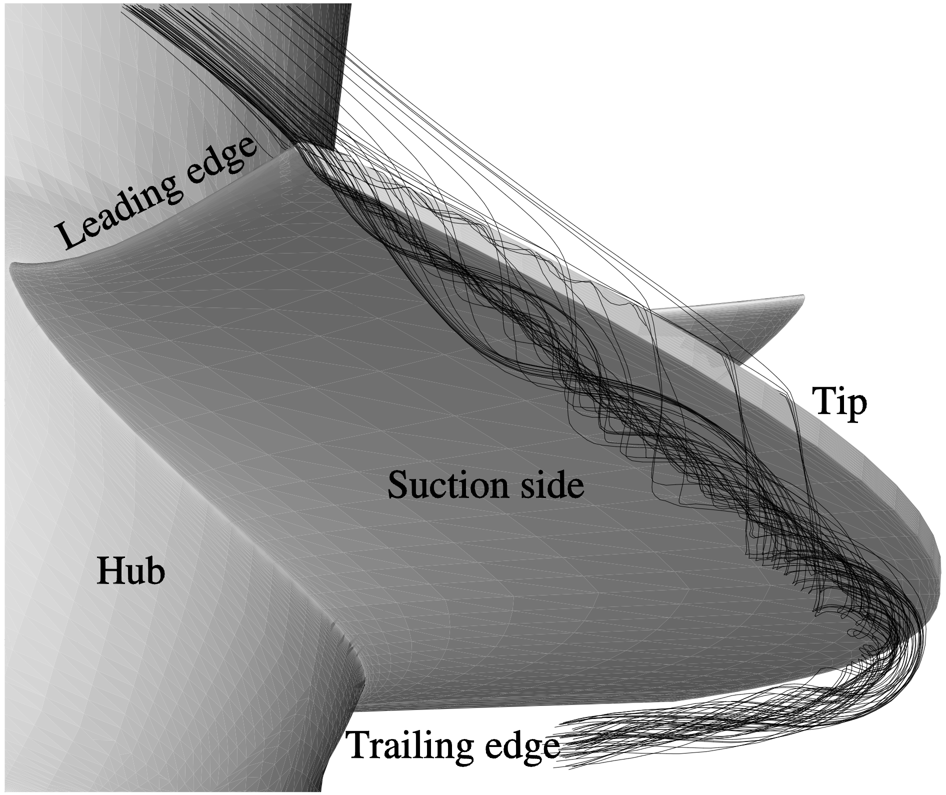
Spiral casing

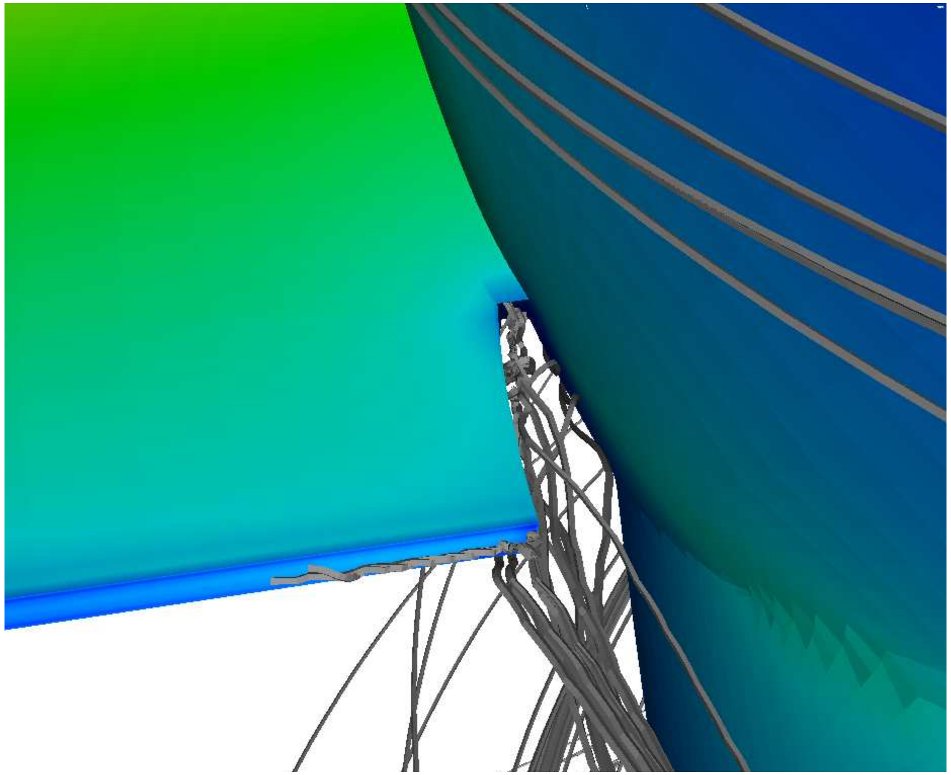




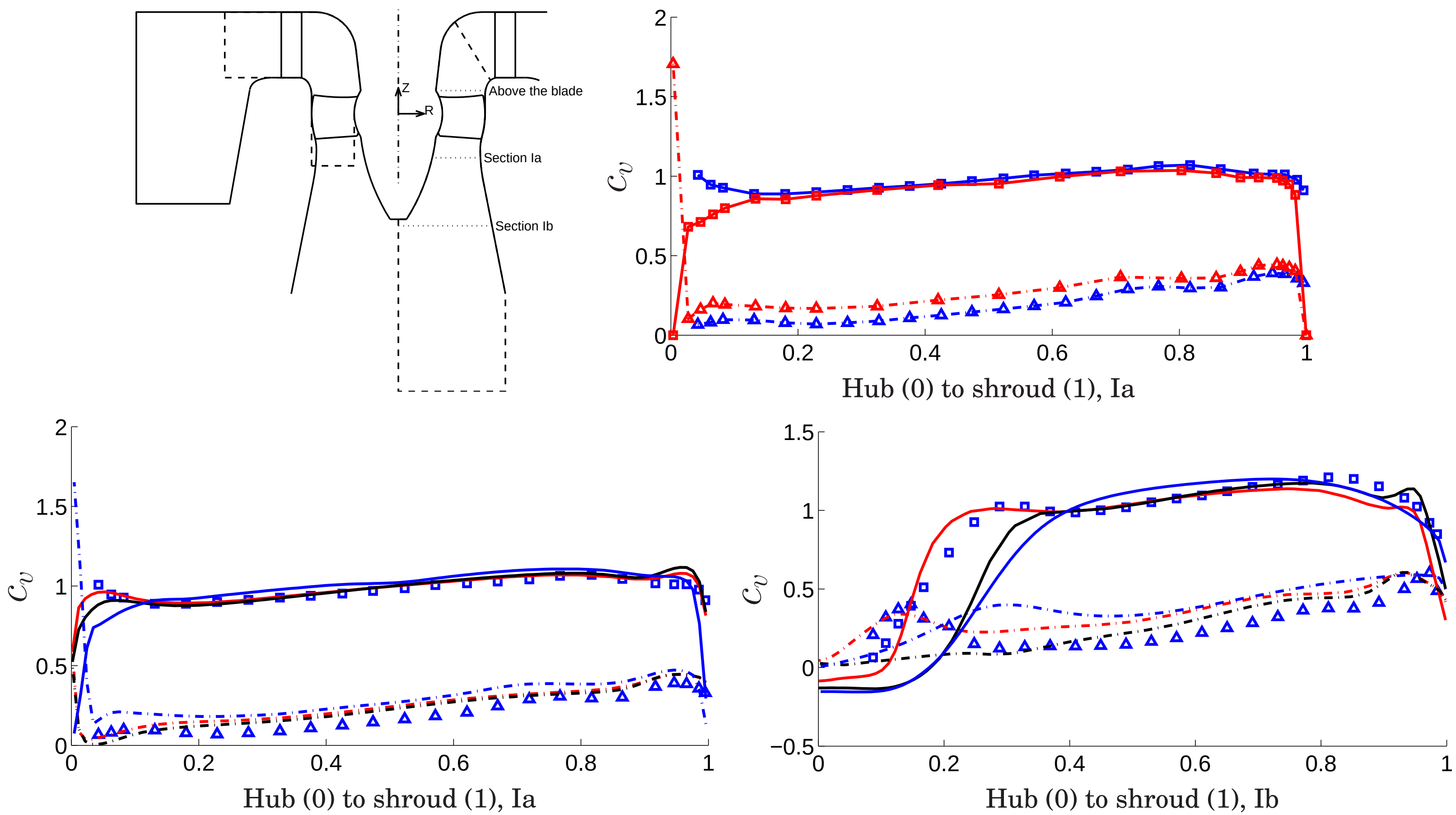
# Wicket gate and runner – Clearances

Kaplan runner tip and hub clearances
Simulations by Håkan Nilsson



# Runner – Validation of OpenFOAM in the Hölleforsen runner (velocity profiles at cross-sections Ia and Ib)



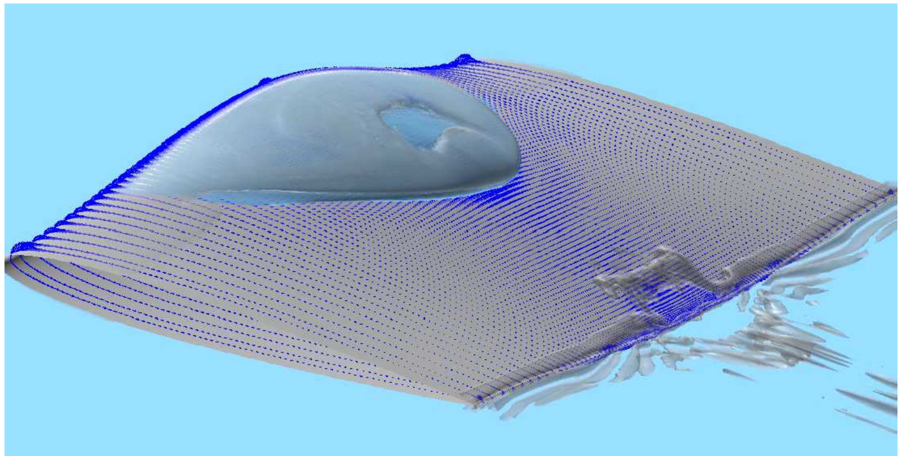

Squares: measured axial velocity. Triangles: measured tangential velocity. In (a) the colors correspond to two different measurements. In (b) and (c): Blue curve: quasi-steady draft tube, Black curve: runner without hub clearance, Red curve: runner with hub clearance.

# Wicket gate and runner – Cavitation

Cavitation occurs where the static pressure is low, and when the static pressure increases the cavitation implodes, causing erosion
(Collaboration with Naval Architecture and LTH - Aurelia Vallier, co-supervised by me)

Source: tripatlas.com/Water_turbine

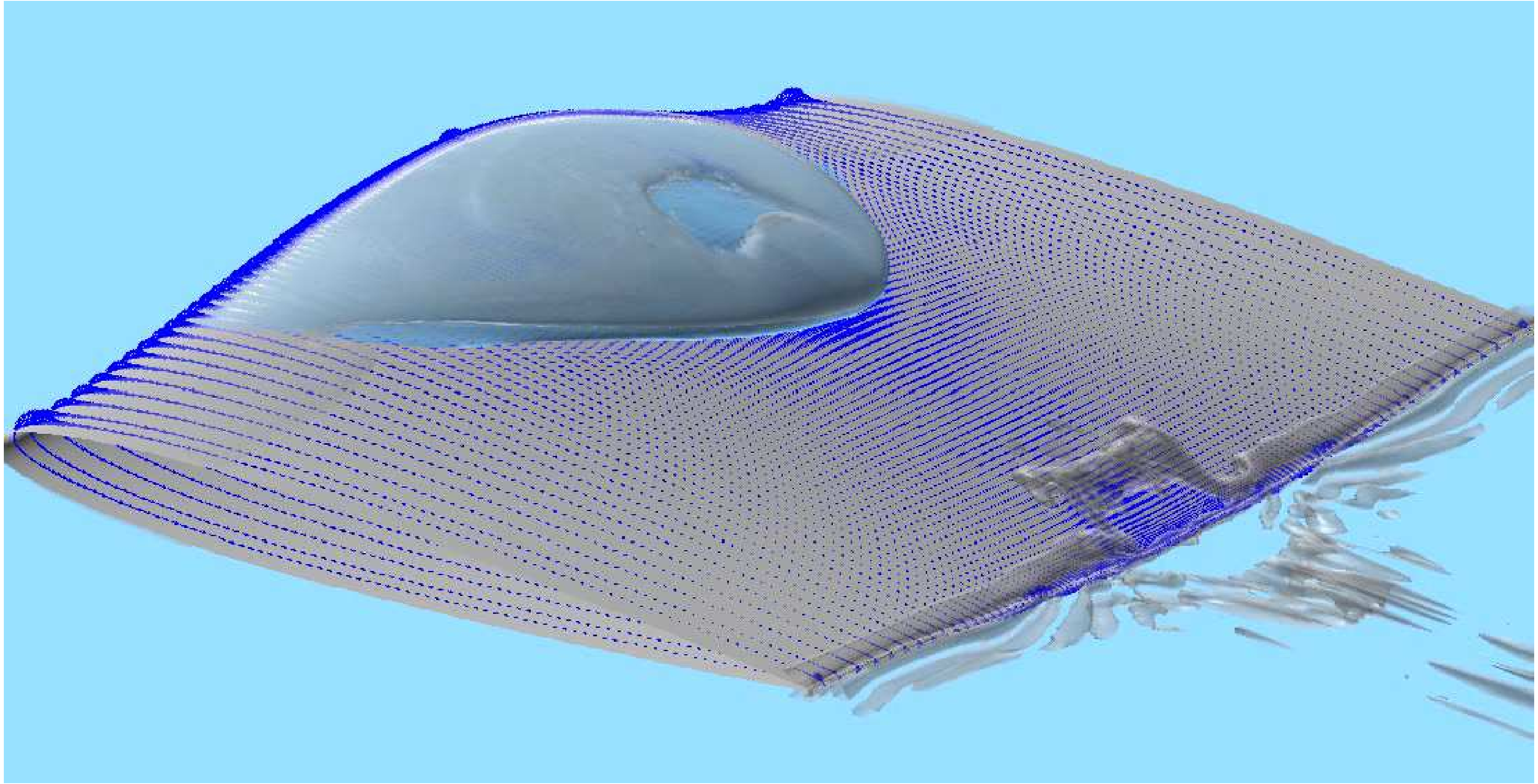

Source: Mikael Grekula, Naval Architecture, Chalmers



Source: Tobias Huuva, Naval Architecture, Chalmers

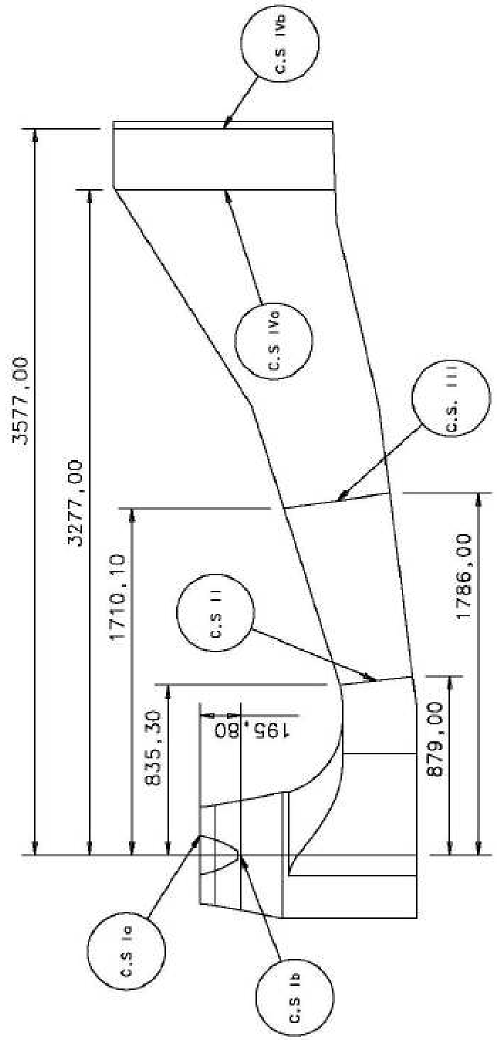
# Cavitation movie, courtesy of Tobias Huuva

We will see a sheet cavity form, re-entrant jets breaking off a part of the sheet, hair-pin vortices, and cavitation shedding. The snapshot shows the re-entrant jet breaking the cavity.

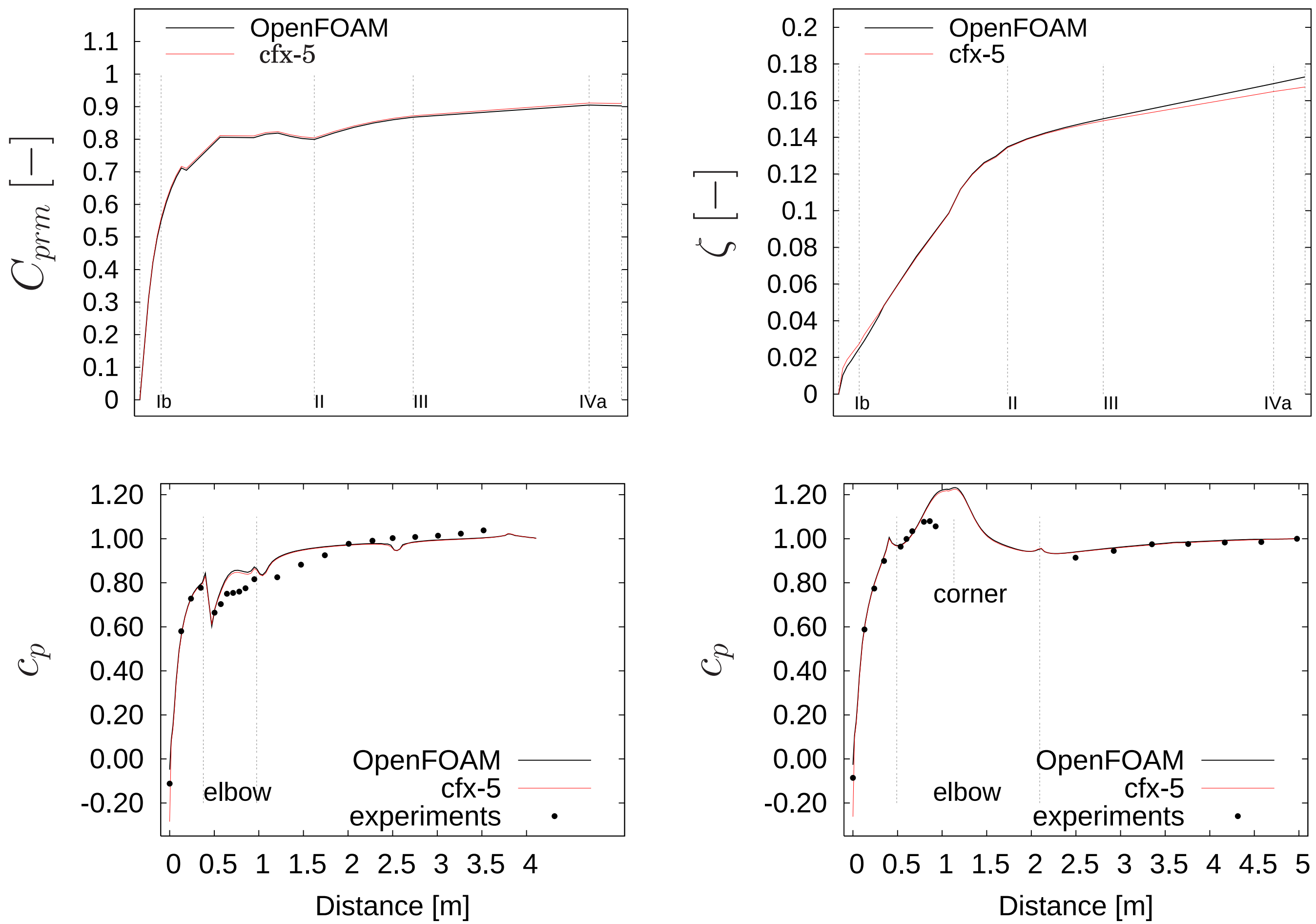


The blue iso-surface is $\gamma = 0.5$ and the gray iso-surface is at a constant vorticity.

# Draft tube – Validation in the Hölleforsen draft tube (development of engineering quantities in the flow direction)



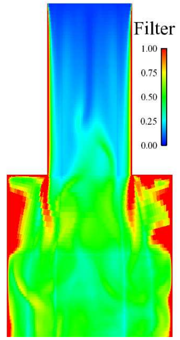

## Quasi-steady draft tube computation



# The Dellenback Combustor (resembling a draft tube)

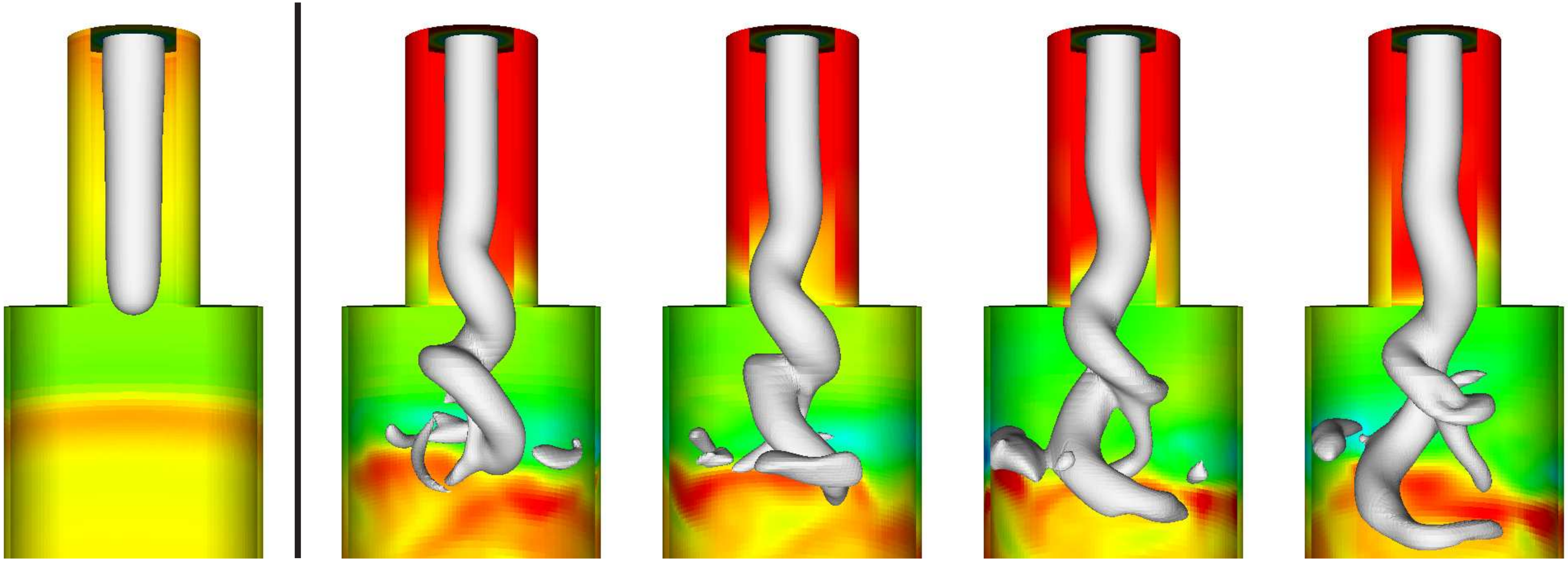
kOmegaSSTF = Filtered kOmegaSST
Developed by Dr. Walter Gyllenram
Upper limit to the modelled length scale:

$$\Delta_f = \alpha \max\left\{ \left|\vec{U}\right| \delta t, \Delta^{1/3} \right\}, \qquad \alpha = 3 \quad (\alpha > 1)$$



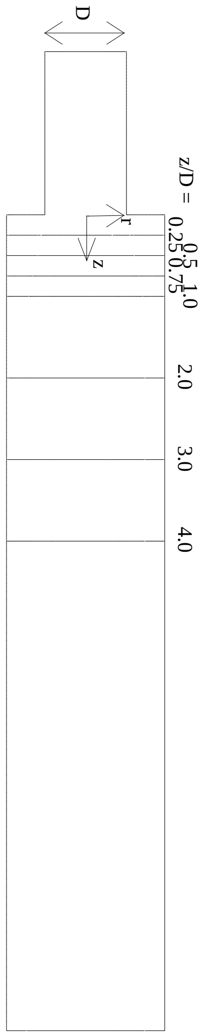

**Static pressure iso-surfaces**

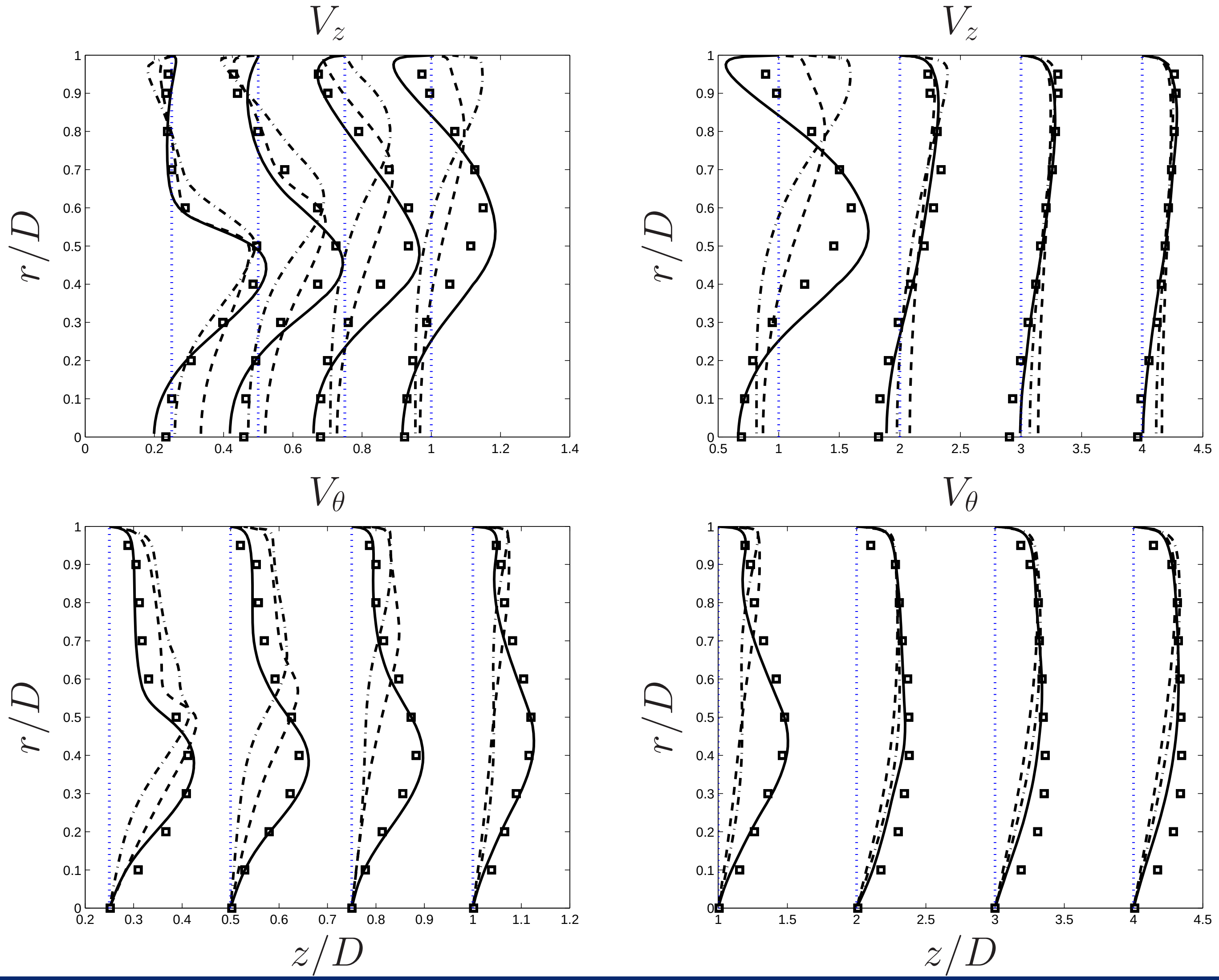
**kOmegaSST** **kOmegaSSTF – one revolution of the vortex rope**



# Combustor velocity profiles

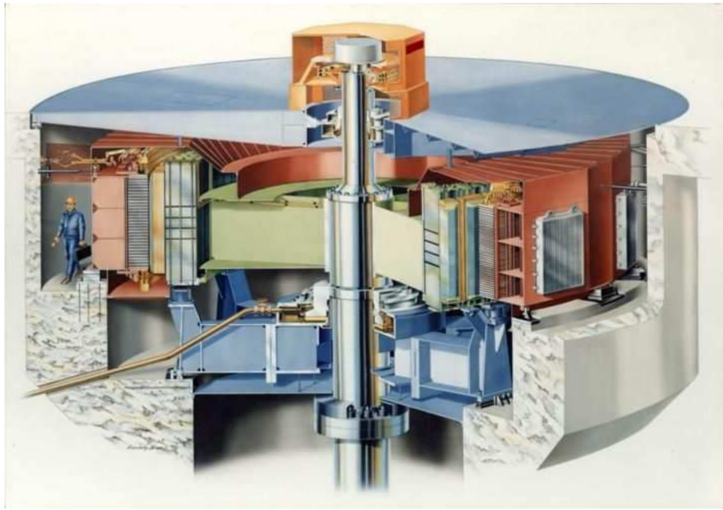
Combustor velocity profiles of kOmegaSSTF (solid), kOmegaSST (dashed) and Fluent $k-\omega$ SST (dashed-dotted). Markers from measurements.

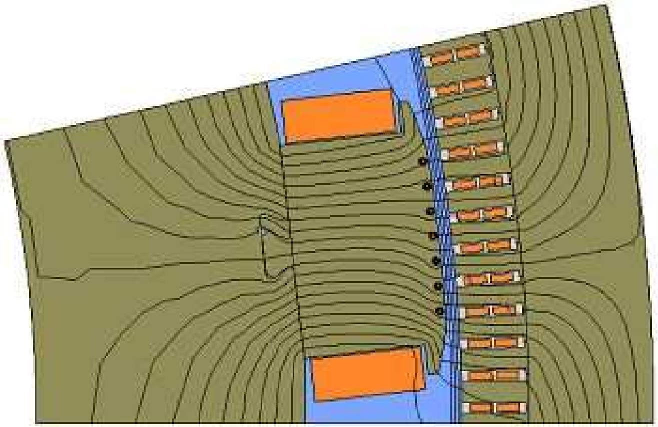
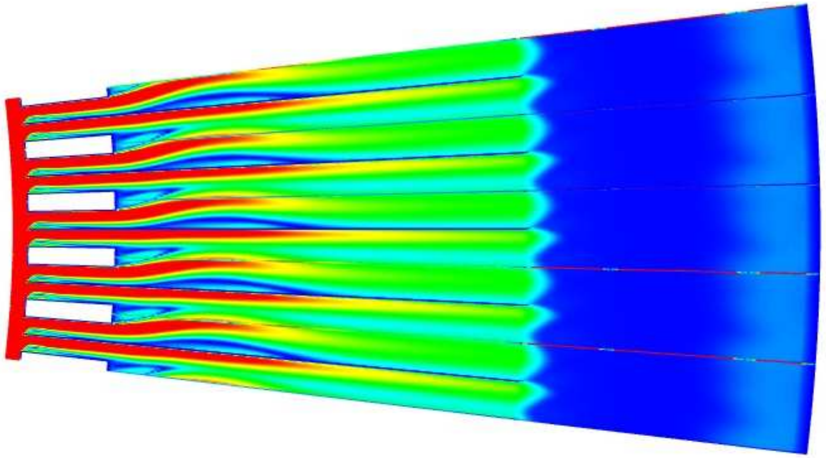


# Generators – Convective cooling

Pirooz Moradnia, under my supervision



Some of the pictures from: http://www.el.angstrom.uu.se/frameset.html?/forskningsprojekt/vattenkraft.html

# Summary – special needs for CFD in Hydro Power Stations

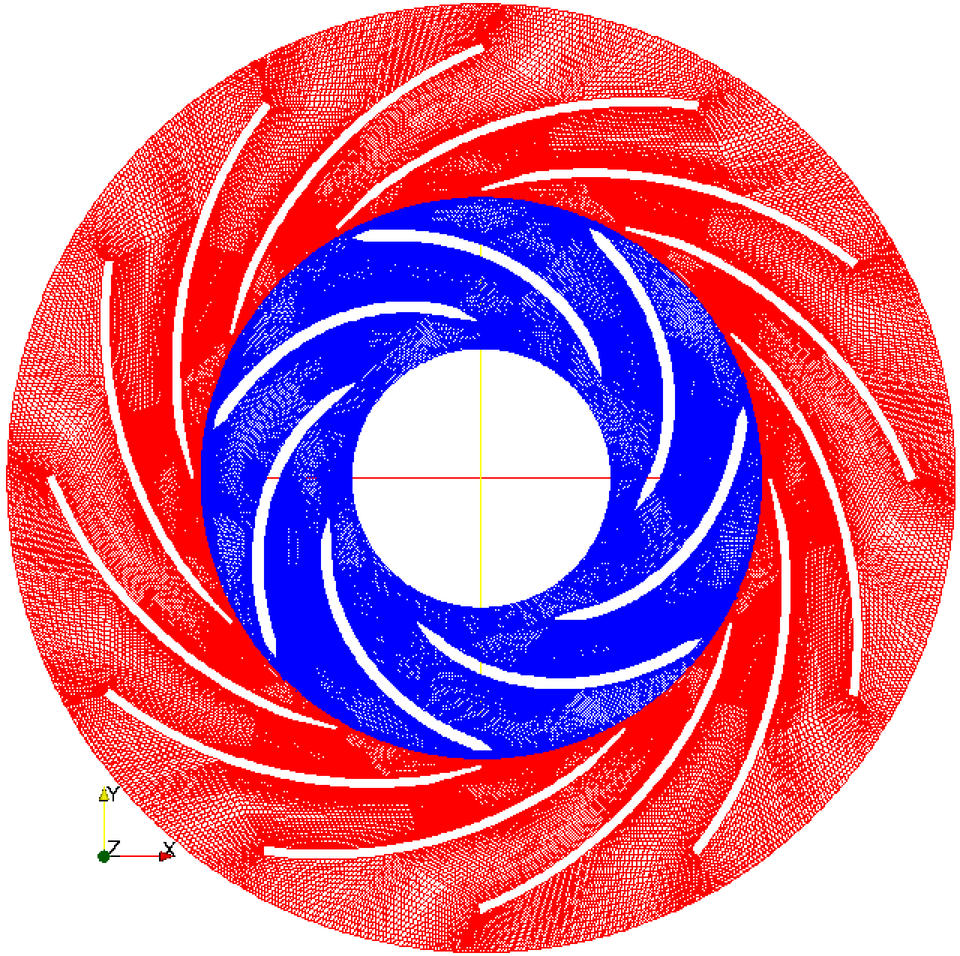
- Rotating coordinate systems / multiple frames of reference
- Sliding grid / mixing plane / GGI
- Rotational periodic boundaries (conformal / non-conformal)
- Unsteady turbulence modeling in coarse grids and large time steps
- Wall treatment in coarse grids and unsteady flow
- High-order discretization schemes and automatic mesh refinement for coarse and skew grids
- Cavitation, free surfaces / two phase methods
- Solvers that perform well in coarse and skew grids
- Fine resolution in large domains (parallel computations)
- Moving mesh (rotor dynamics)
- A cheap, powerful and accurate CFD tool for industry / academia, research / development / teaching, and global collaborations – OpenFOAM

# OpenFOAM for international collaboration

- This part is based on web pages:
  - The OpenFOAM Wiki
    `http://openfoamwiki.net`
  - The OpenFOAM Turbomachinery Working Group
    `http://openfoamwiki.net/index.php/Sig_Turbomachinery`
  - The OpenFOAM-extend project at SourceForge
    `http://openfoam-extend.wiki.sourceforge.net/`
  - The OpenFOAM Workshop / Working Group Day
    `http://www.openfoamworkshop.org`

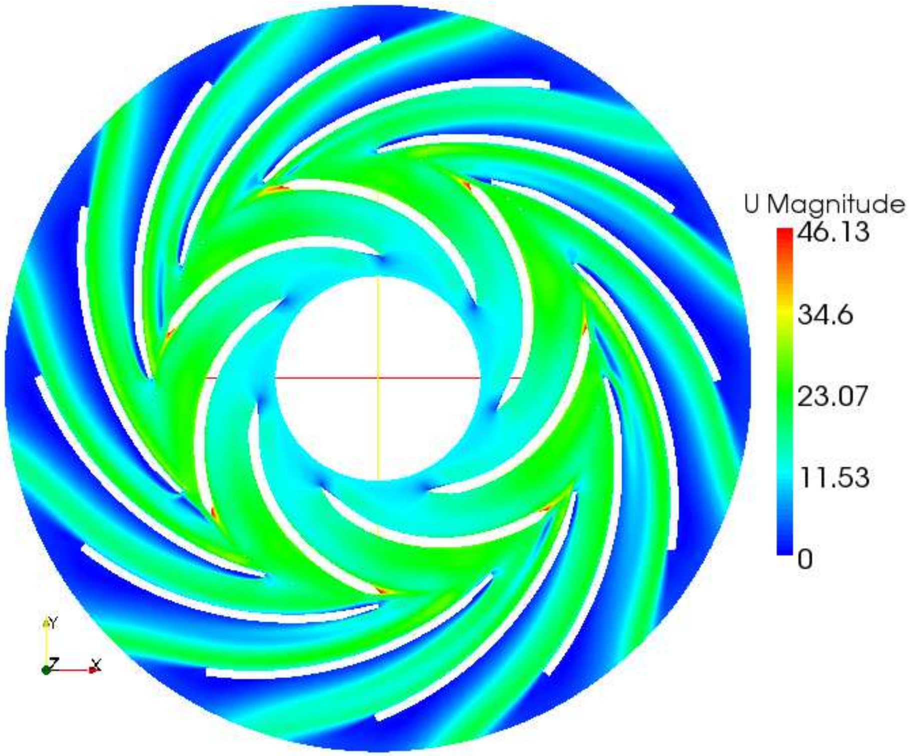
# The ERCOFTAC Centrifugal Pump

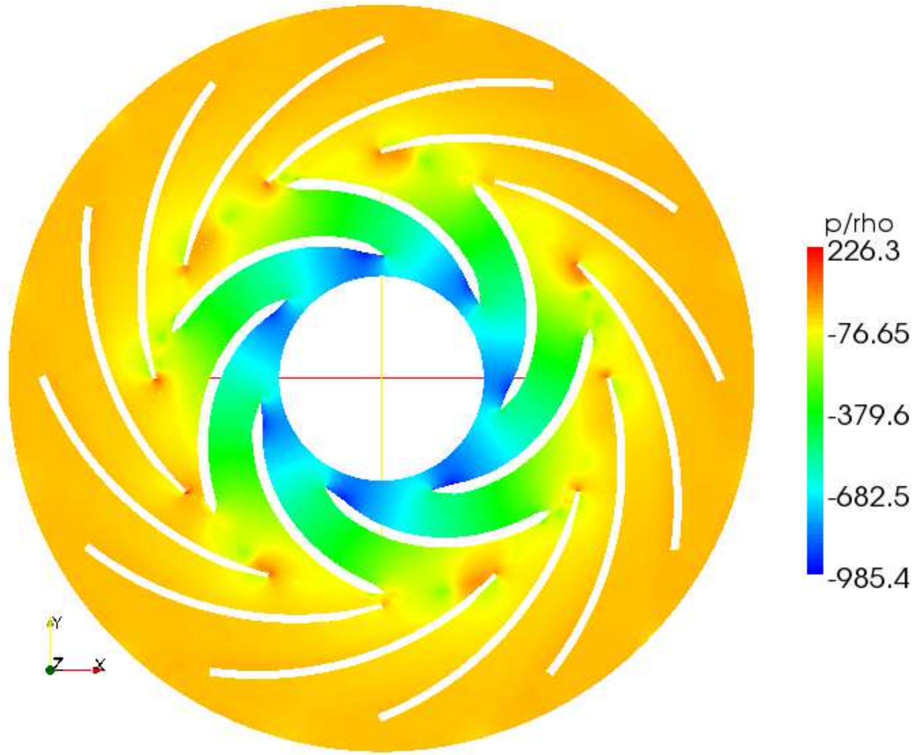
The 2D mesh, impeller blade (blue, rotating) and diffuser blade (red, fixed) regions.



# The ERCOFTAC Centrifugal Pump

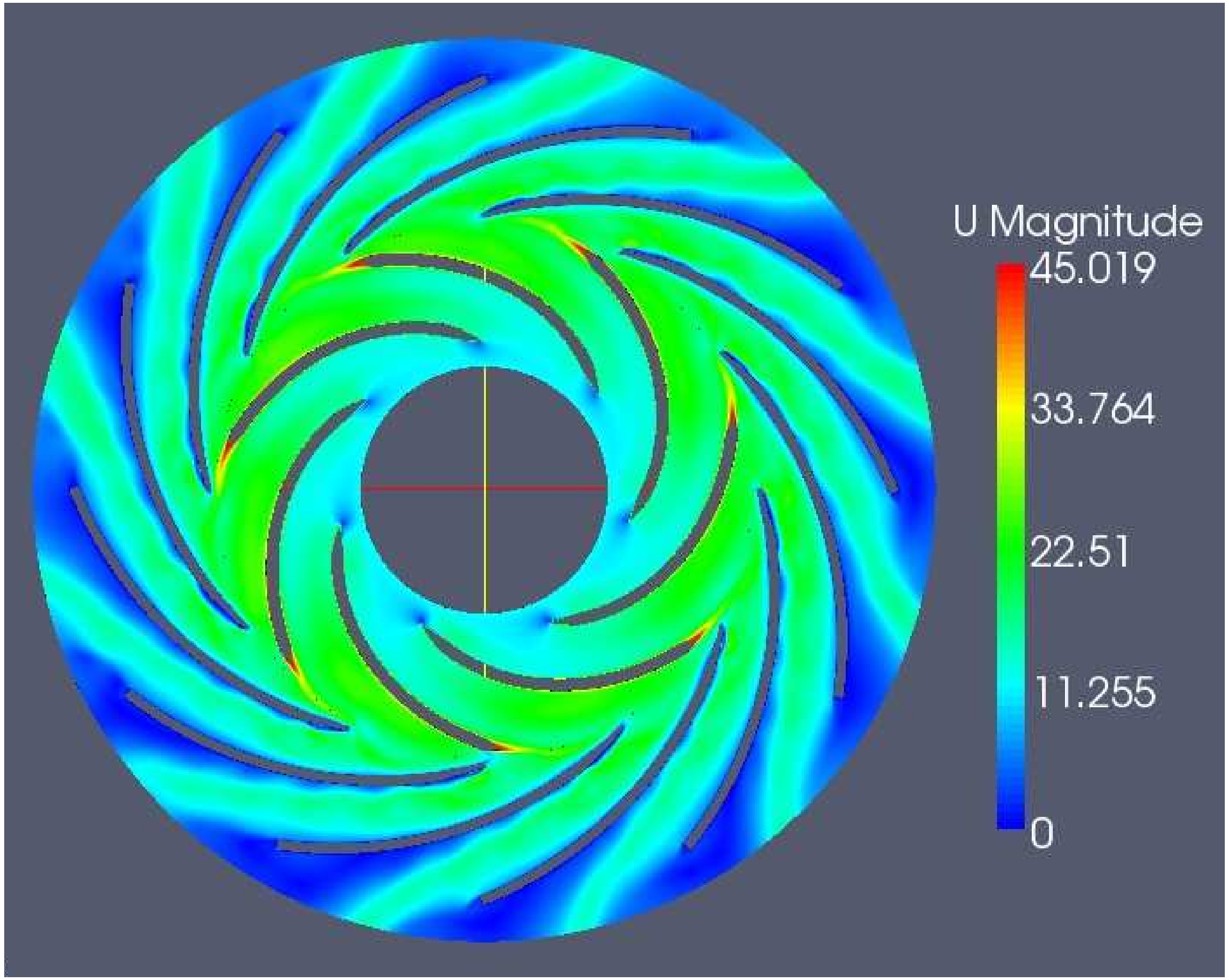
These are 'frozen rotor' results with `MRFSimpleFoam` and `Ggi/stitchMesh` (no difference)
MRF = Multiple Reference Frames



# The ERCOFTAC Centrifugal Pump

These are 'sliding mesh' results with `turbDyMFoam` and `Ggi`



# Thank you for your attention!

Learn more about OpenFOAM at the homepage of my course *'CFD with OpenSource Software'*:
`http://www.tfd.chalmers.se/~hani/kurser/OS_CFD_2008/`
Send me an e-mail if you want updates (`hani@chalmers.se`).

**Acknowledgements**

Professor Hrvoje Jasak is greatly acknowledged.

**Håkan Nilsson is partly financed by SVC** (www.svc.nu):
Swedish Energy Agency, ELFORSK, Svenska Kraftnät, [1]
Chalmers, LTU, KTH, UU

[1]Companies involved: CarlBro, E.ON Vattenkraft Sverige, Fortum Generation, Jämtkraft, Jönköping Energi, Mälarenergi, Skellefteå Kraft, Sollefteåforsens, Statoil Lubricants, Sweco VBB, Sweco Energuide, SweMin, Tekniska Verken i Linköping, Vattenfall Research and Development, Vattenfall Vattenkraft, VG Power, Öresundskraft, Waplans and Andritz Inepar Hydro