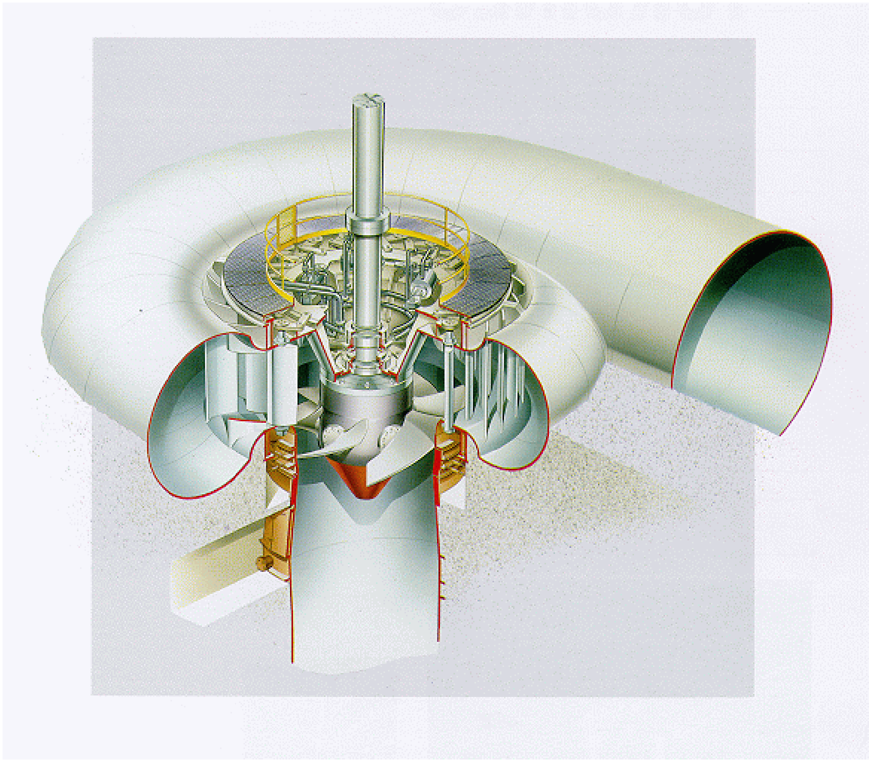
A Numerical Investigation of the Turbulent Flow in a Kaplan Water Turbine Runner



http://www.tfd.chalmers.se/~ lada/projects/proind.html

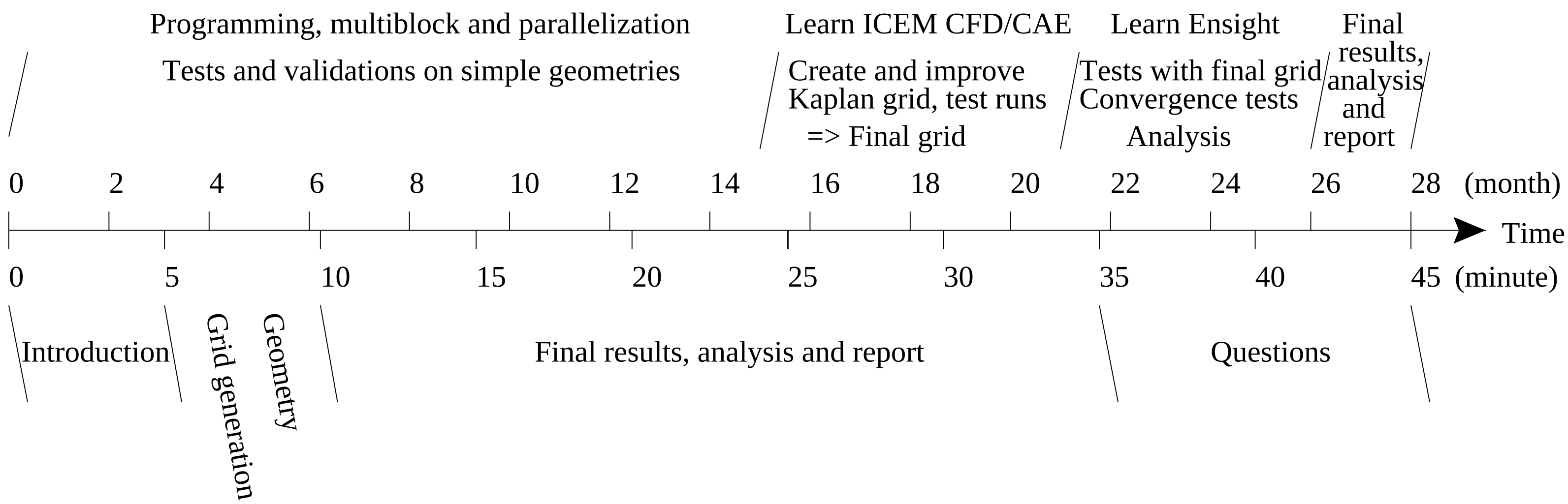
Project

- Started 1st of may 1997 as a part of the Swedish Hydraulic Turbine Research Programme, financed by a collaboration between the Swedish power industry via ELFORSK (Swedish Electrical Utilities Research and Development Company), the Swedish National Energy Administration and Kvaerner Turbin AB
- Title: A Numerical Investigation of the Turbulent Flow in a Kaplan Water Turbine Runner
- Supervisor: Professor Lars Davidson, CHALMERS

- Implementation of a parallel multiblock CFD solver for complex domains
- Runner calculations including tip clearance (licentiate thesis)
- Transient turbulent wakes after guide vanes (doctor thesis)

Outline of project and presentation

Outline of project

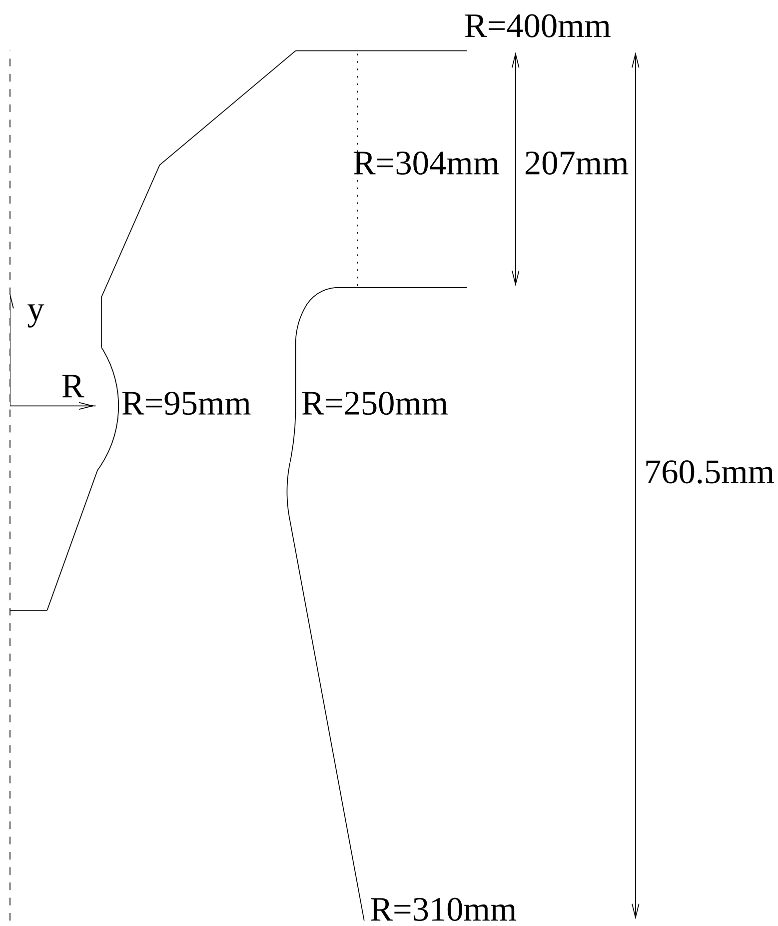


Outline of presentation

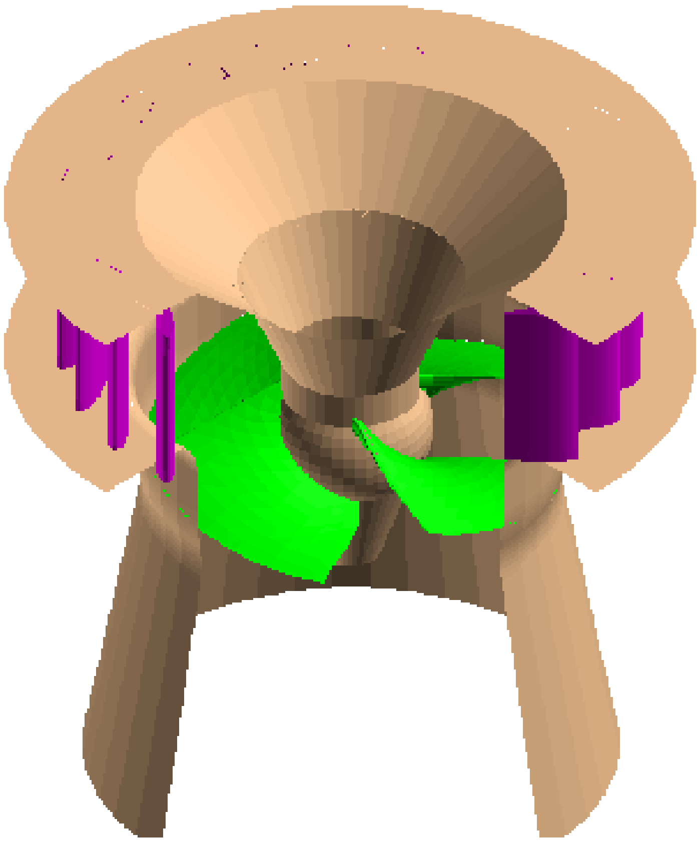
Method

- Finite volume method
  Boundary fitted coordinates
  Collocated, structured grid
  Rhie and Chow interpolation
  SIMPLEC (Pressure-velocity coupling)
- Parallel multiblock solver
  Conformal blocks
  Dirichlet-Dirichlet block coupling
  Parallel solver using message passing (PVM or MPI)
- Turbulence model
  Wilcox -88 standard k-ω

Definition of the casing

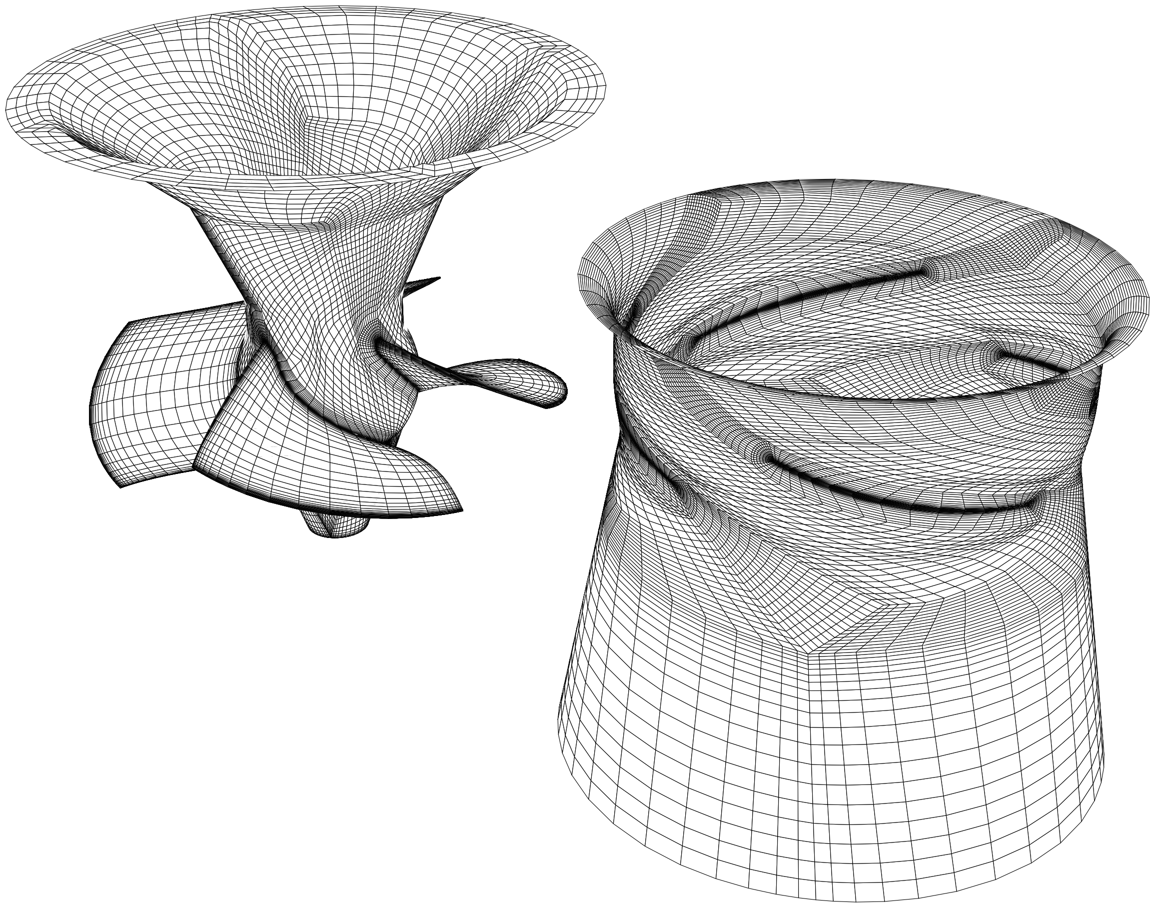


A Kaplan water turbine geometry, generated in ICEM CFD/CAE



(Some of it is excluded in order to show the interior parts)

Surface grid



Test cases supplied by Kvaerner Turbin AB

A Kaplan test rig with four runner blades and 24 guide vanes

D = 0.5m (Runner diameter)

α = 0 (Runner blade angle)

H =1m (Head)

Case	N_{11}	Q_{11}	γ	η
k15	160.1	1.195	35.1	92.40
k138	150.0	1.136	33.3	92.62
k150	145.0	1.115	33.0	92.56
k123	140.0	1.084	31.9	92.26

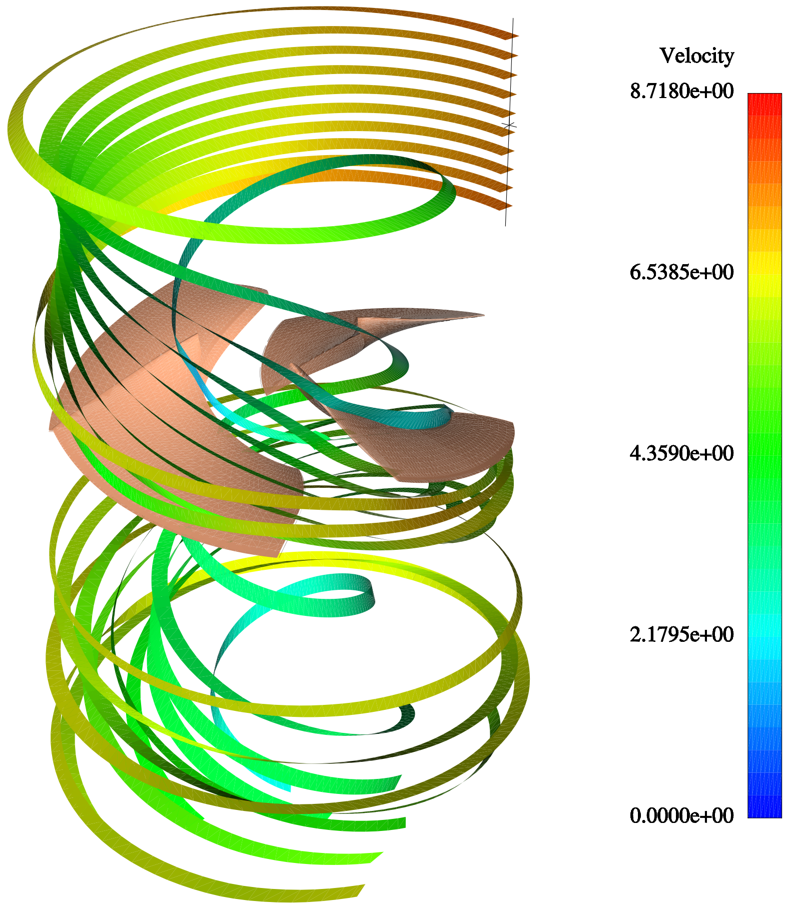
$N_{11} = \frac{ND}{\sqrt{H}}$ (unit speed)

$Q_{11} = \frac{Q}{D^2\sqrt{H}}$ (unit flow)

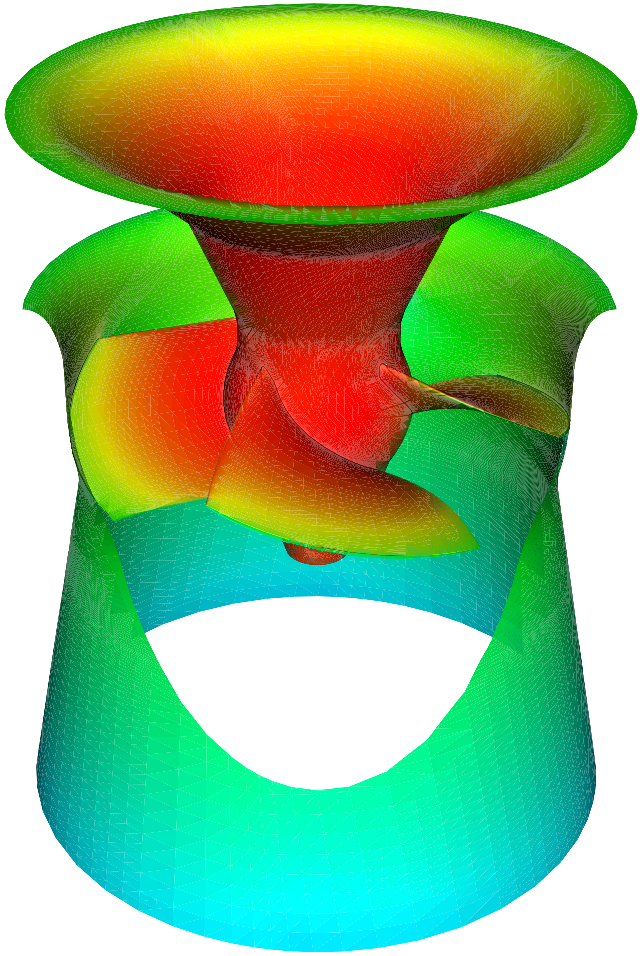
γ = guide vane angle

η = efficiency

Stream ribbons from inlet to outlet



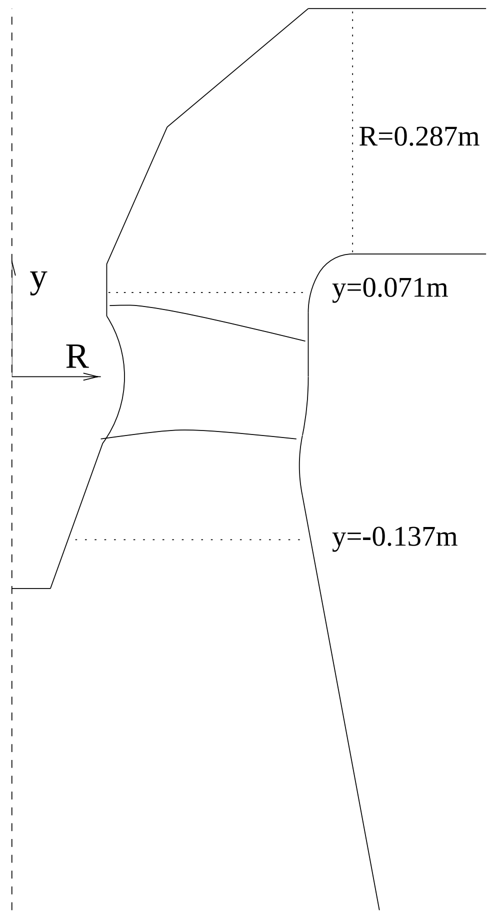
Surface pressure distribution



Flow details

- Circumferentially averaged absolute velocity
- Runner blade static pressure distribution
- Tip clearance mass flow
- Tip clearance relative velocity

The positions of the circumferential averaging



Tip clearance mass flow

Case	k15	k138	k150	k123
$\dot{m}_{tip}$	$2.15 \cdot 10^{-4}$	$2.12 \cdot 10^{-4}$	$2.12 \cdot 10^{-4}$	$2.08 \cdot 10^{-4}$
$\dot{m}_{tip}/\dot{m}_{tot}$	$2.88 \cdot 10^{-3}$	$2.98 \cdot 10^{-3}$	$3.04 \cdot 10^{-3}$	$3.08 \cdot 10^{-3}$

Visualization of tip clearance effects

Simple visualization

- Vector / contour / isosurface / streamline plot

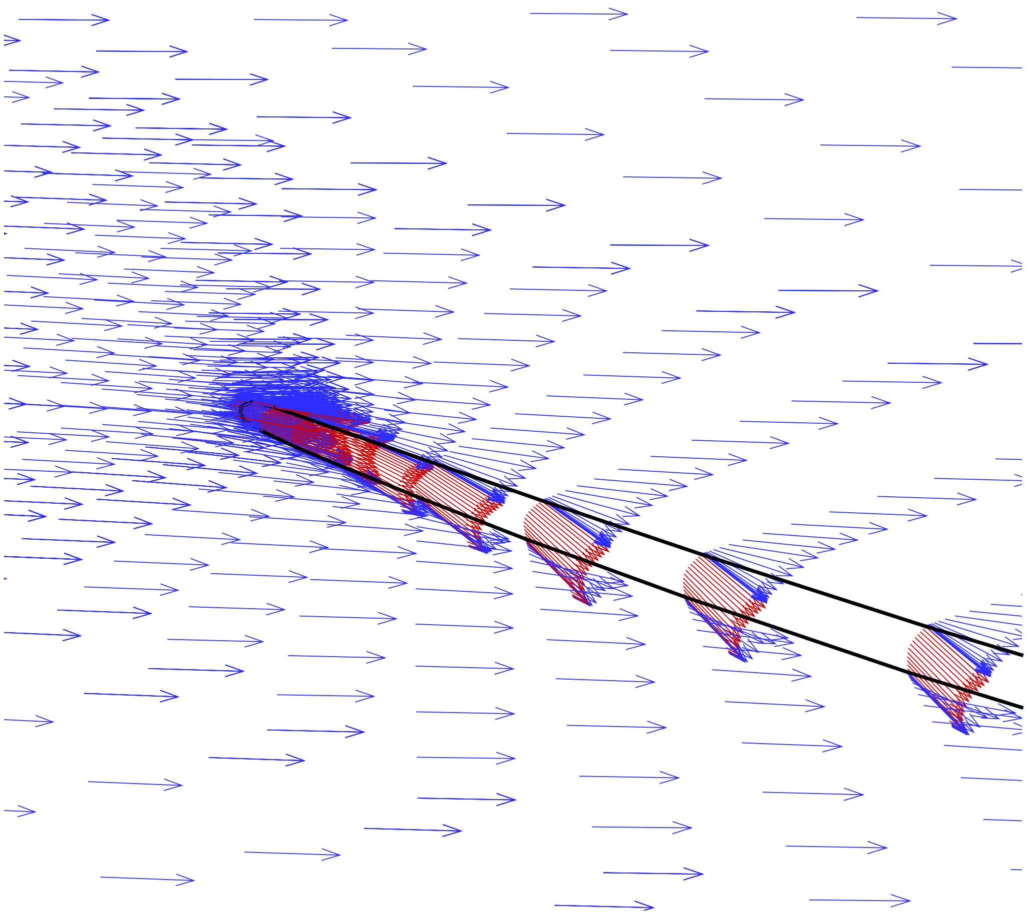
Advanced visualization, for vortex identification

- λ_2 method
  Def.: Pressure minimum, discarding unsteady straining and viscous effects.
  $-\frac{1}{\rho}p_{,ij} = \Omega_{ik}\Omega_{kj} + S_{ik}S_{kj}$
  $\Rightarrow$ a vortex core is a region with two negative eigenvalues of $\vec{S}^2 + \vec{\Omega}^2$.

- Normalized helicity
  Def.: $H_n = \frac{\vec{\xi}\cdot\vec{u}}{|\vec{\xi}||\vec{u}|}$, $-1 \leq H_n \leq 1$
  Where $\vec{\xi}$ is the absolute vorticity and $\vec{u}$ is the relative velocity.

- Absolute streamwise vorticity
  Def.: $\xi_s = \frac{\vec{\xi}\cdot\vec{u}}{2\Omega|\vec{u}|}$

Tip clearance flow in center of tip clearance, leading edge



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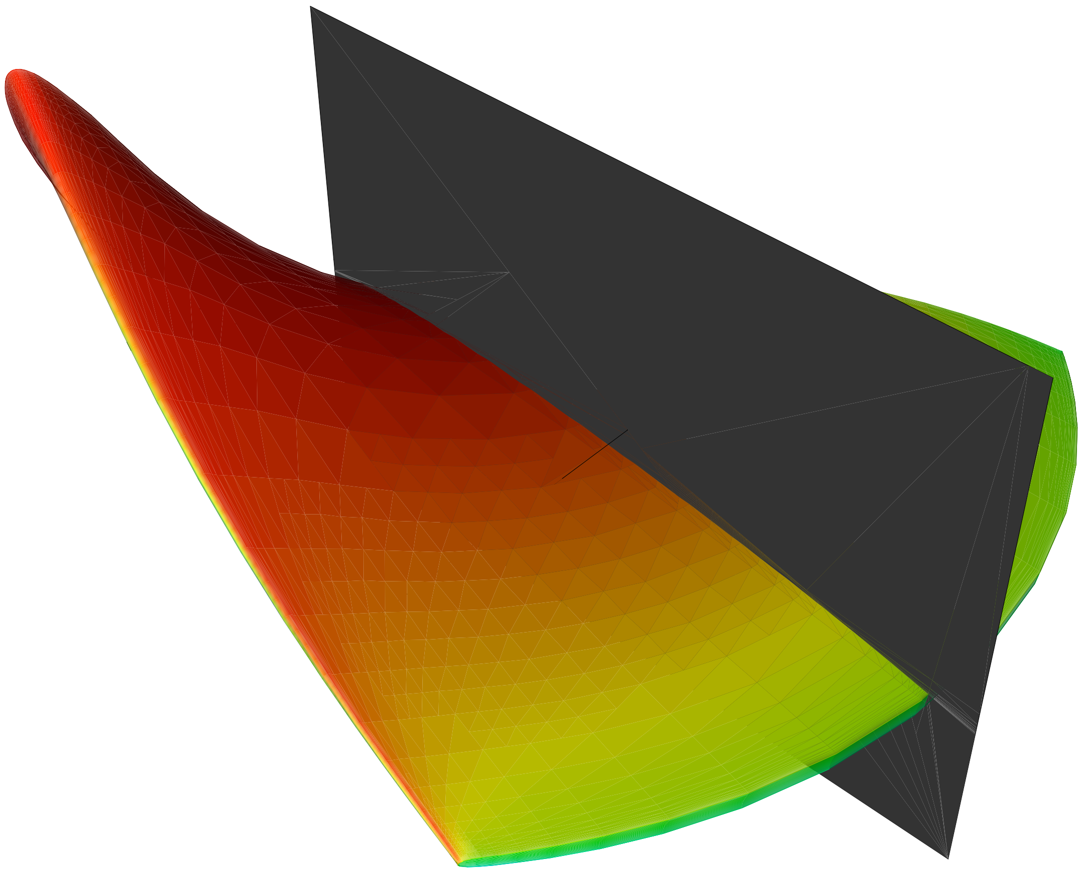
Meridional cut plane



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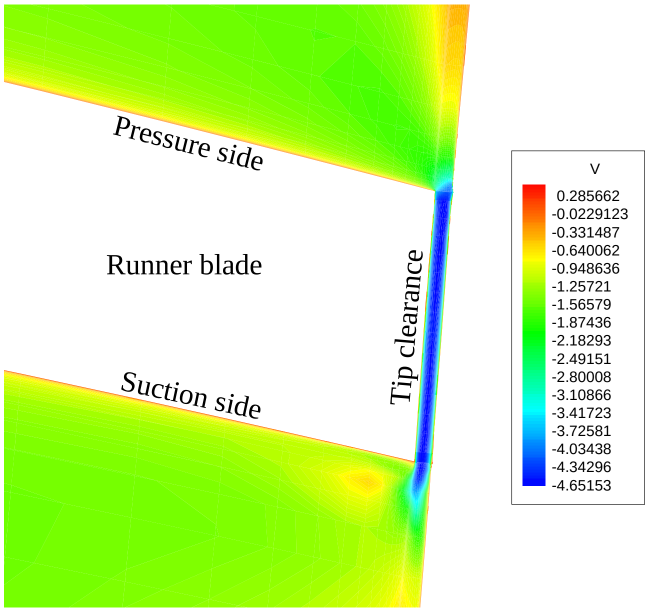
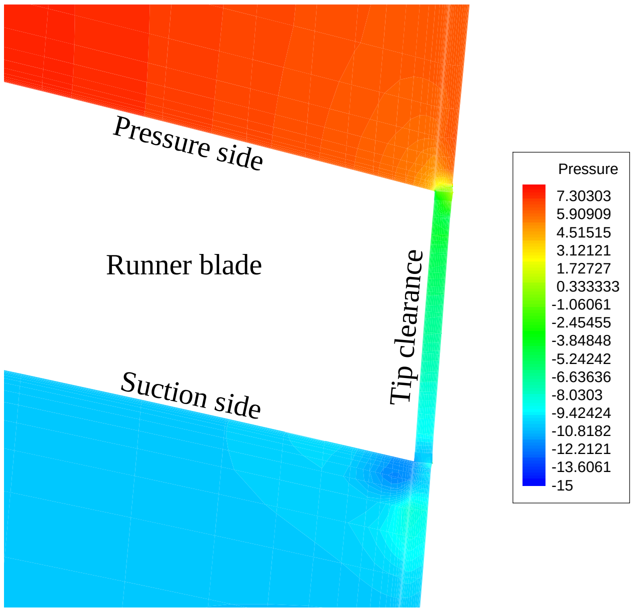
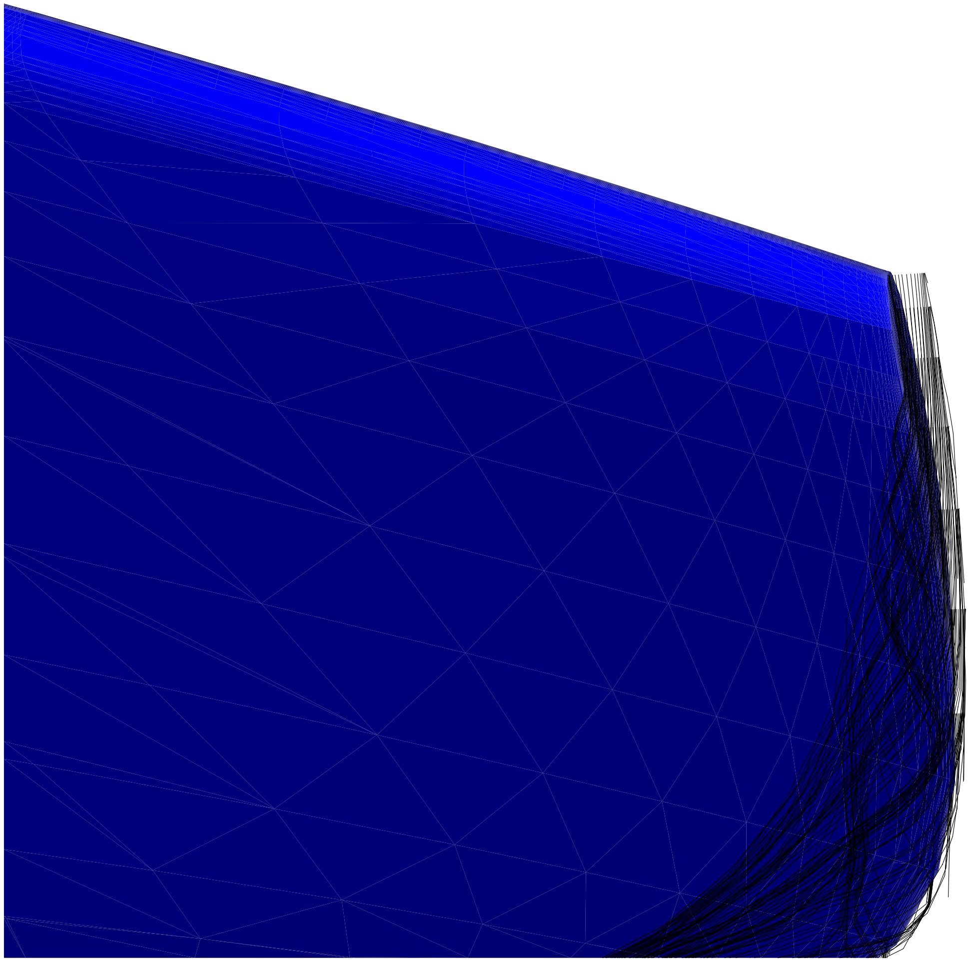
Axial velocity and static pressure in a meridional plane through the center of the blade

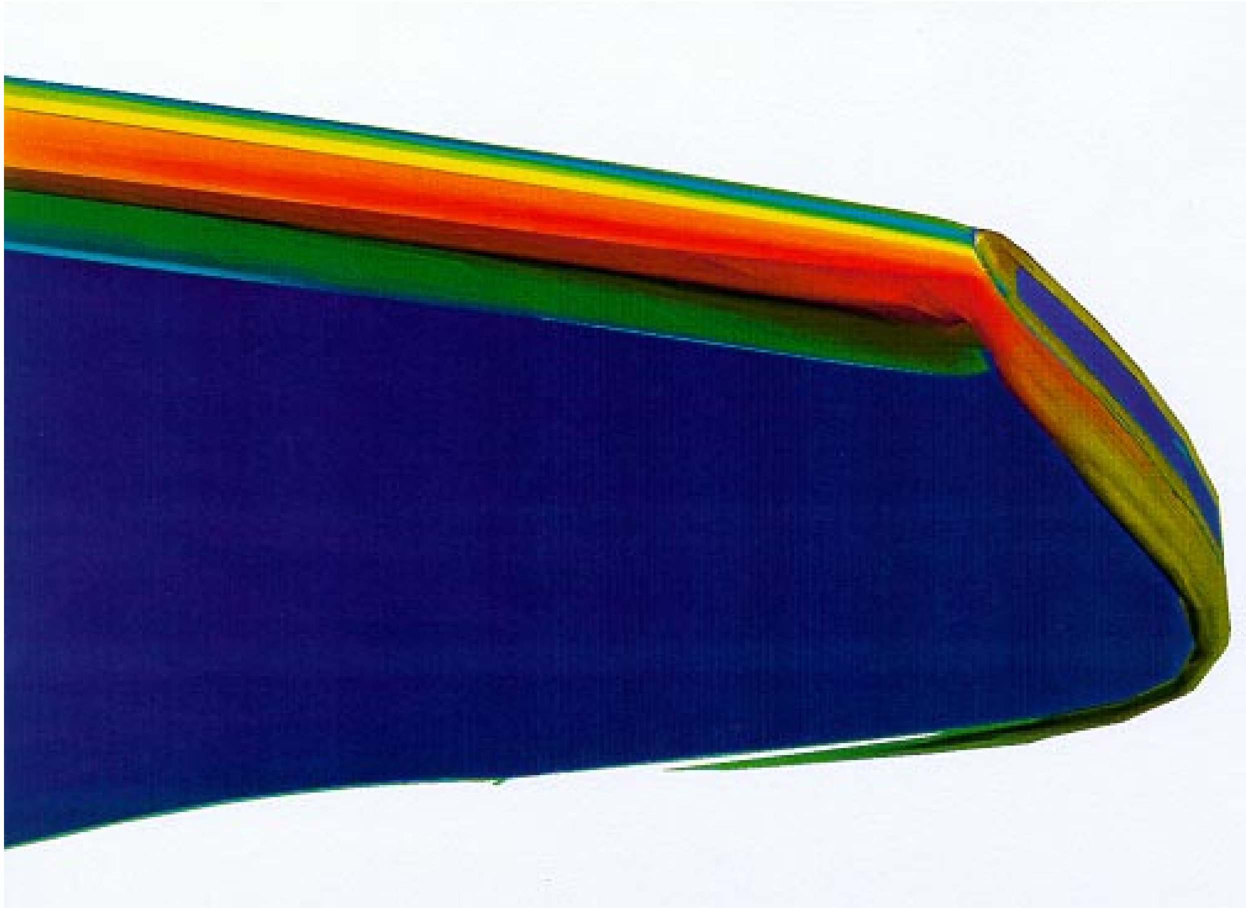




Tip flow streamlines

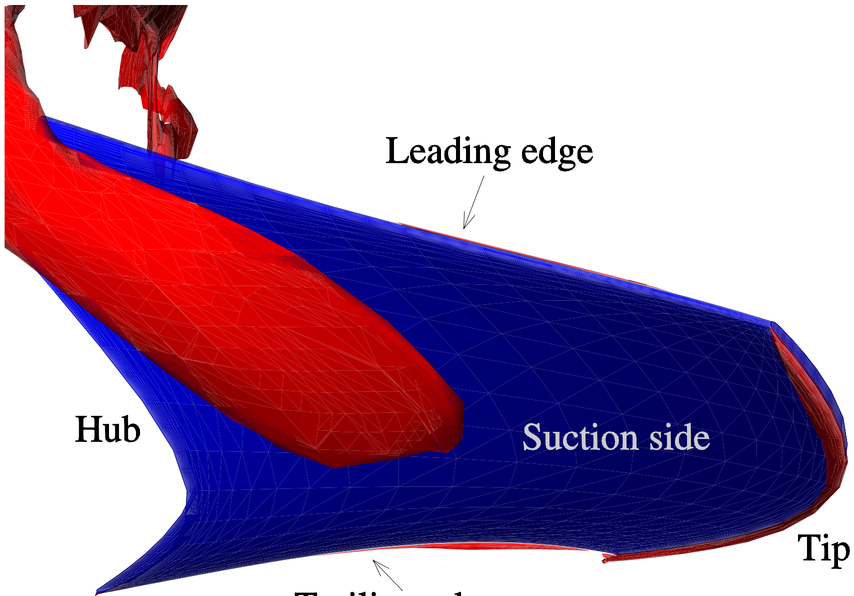


The λ_2 method

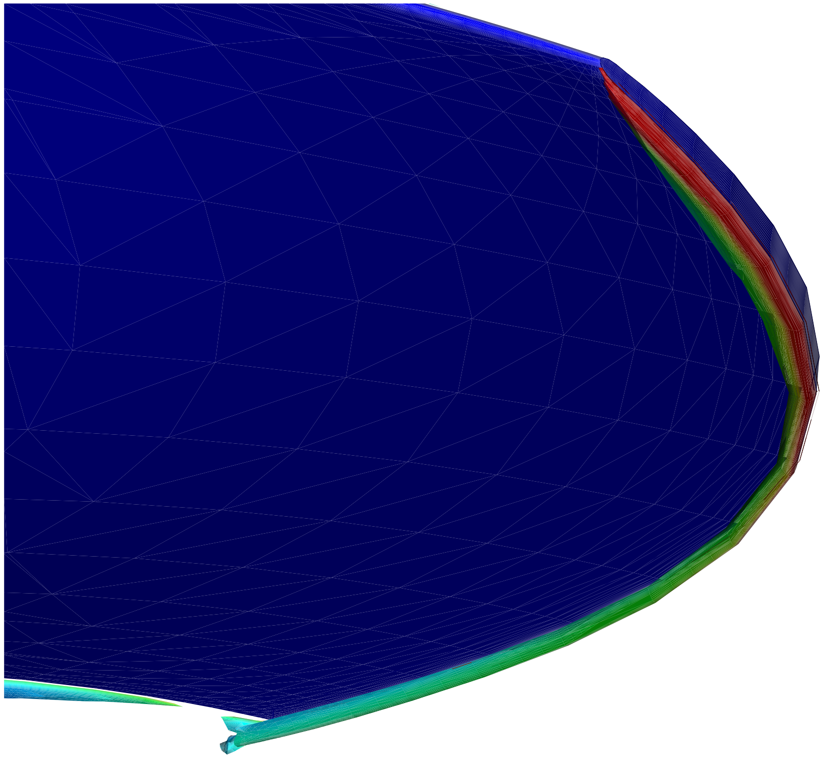


Colored by velocity (Blue = 0 m/s, Red = 8 m/s)

Normalized helicity ($H_n = \frac{\vec{\xi} \cdot \vec{u}}{|\vec{\xi}||\vec{u}|} = 0.8$)

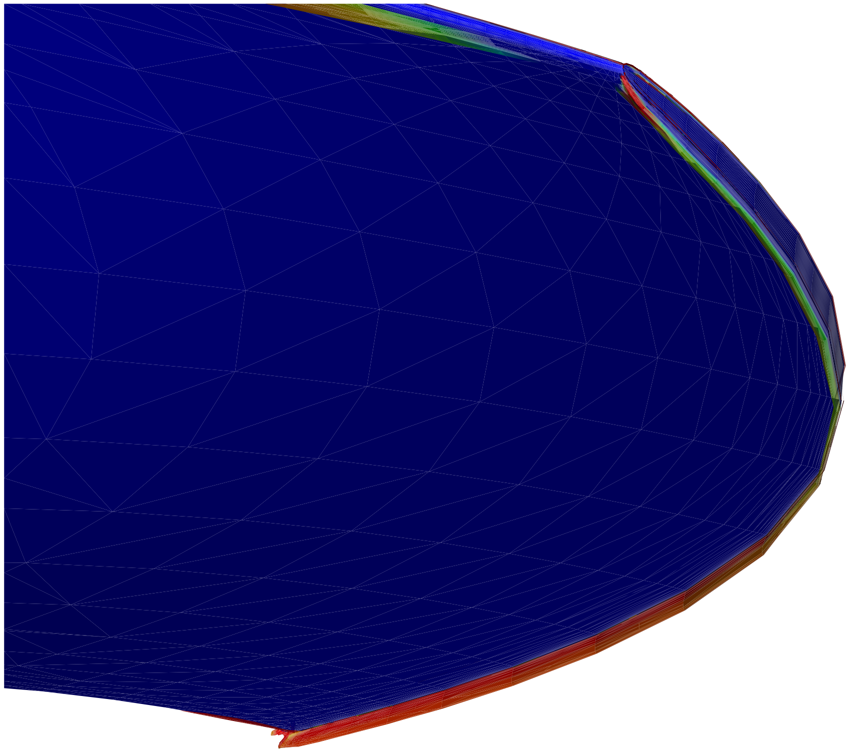


Normalized helicity ($H_n = \frac{\vec{\xi} \cdot \vec{u}}{|\vec{\xi}||\vec{u}|} = 0.8$)



Colored by absolute streamwise vorticity,
$\xi_s = \frac{\vec{\xi} \cdot \vec{u}}{2\Omega|\vec{u}|}$, (Blue = 0, Red = 30)

Absolute streamwise vorticity ($\xi_s = \frac{\vec{\xi}\cdot\vec{u}}{2\Omega|\vec{u}|} = 30$)

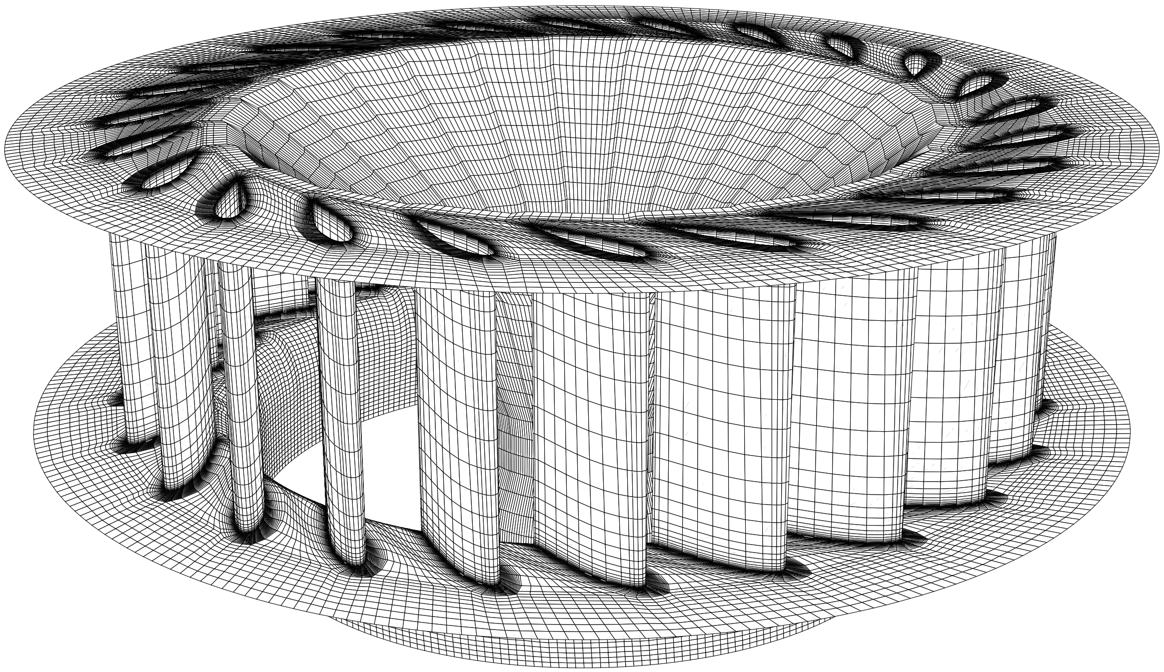


Colored by λ_2 (Blue = $-5 \cdot 10^6$, Red =0)

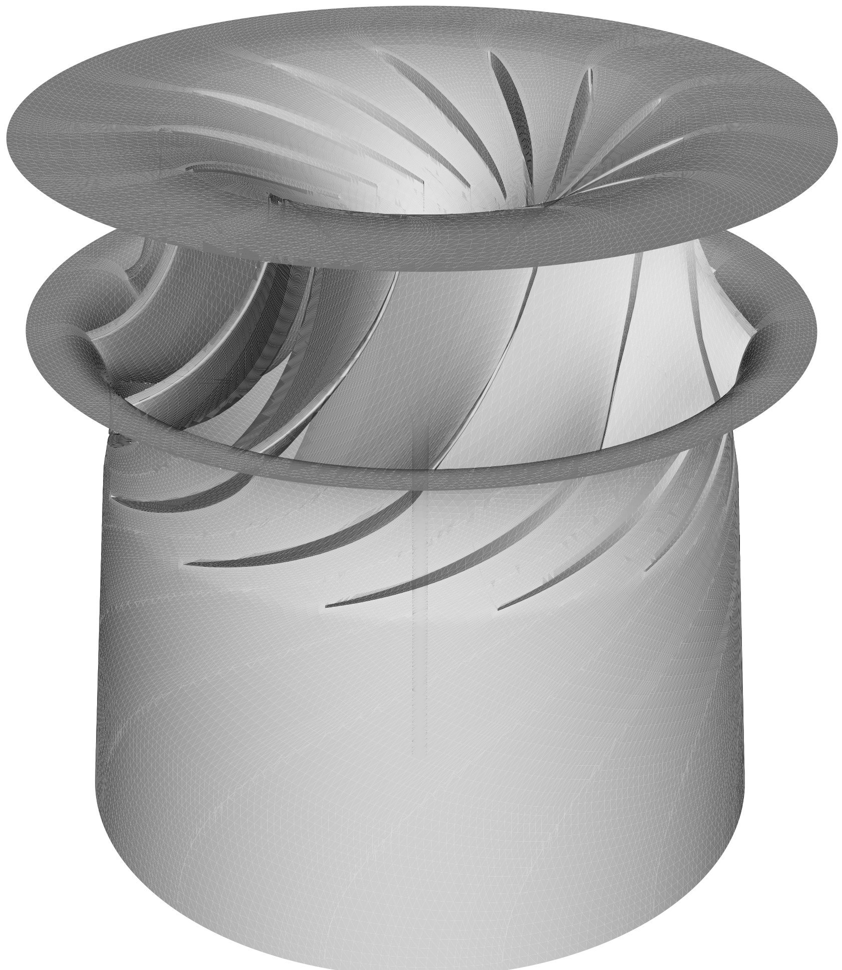
Future work

- Improve boundary conditions
- Include guide vanes (circumferential averaging / transient)
- Transient calculations
- Measurement comparison
- Verification of the code against the GAMM Francis turbine
- Further analysis of the results

Distributor surface grid



The GAMM Francis water turbine geometry



Discussion

- An efficient and general parallel multiblock CFD code was developed
- Flow features captured by the calculations:
  The leading edge blade loading increases when N_{11} decreases
  The axial tip clearance flow increases with decreasing N_{11}
- Further analysis of the results is needed
- Comparison with experiments is needed
- Advanced vortex identification methods are needed
- Grid generation is very important for convergence and accuracy, but also very time consuming