CFD Analysis in Pumps

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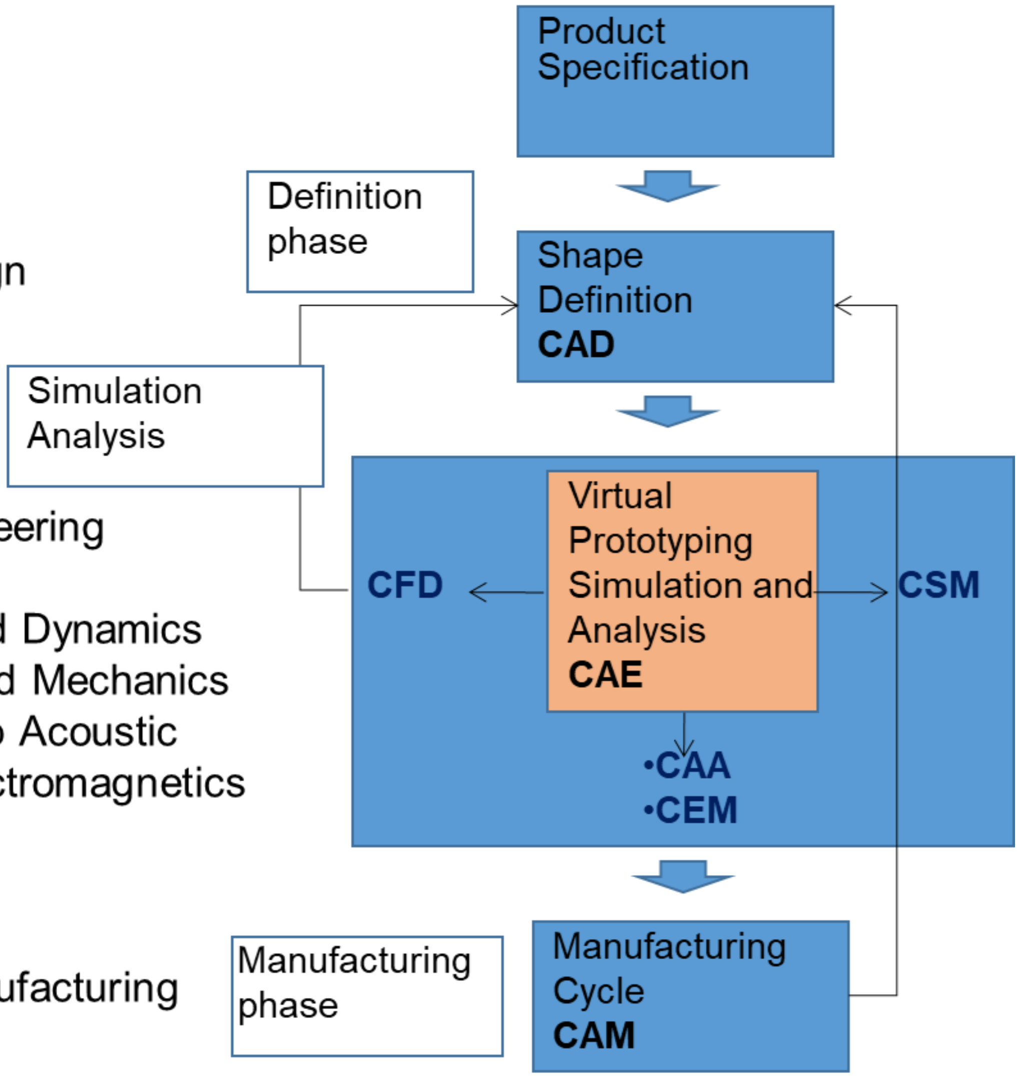
- **Virtual Prototyping**

  - CAD – Computer Assisted Design

  - CAE – Computer Assisted Egineering

    - CFD – Computational Fluid Dynamics
    - CSM – Computational Solid Mechanics
    - CAA – Computational Aero Acoustic
    - CEM – Computational Electromagnetics

  - CAM – Computer Assisted Manufacturing



What are basic questions of the CFD ?

- accuracy of the results

- Basic equation of fluid dynamics,
- Turbulence modelling,
- Basic discretization techniques, Grid generation
- The analysis and resolution of numerical schemes

- analysis time

- Complexity of application,
- Computer performance.

Basic equations

- **Navier – Stokes equations**

$$\rho \frac{\partial u_j}{\partial t} + \rho u_k \frac{\partial u_j}{\partial x_k} = -\frac{\partial p}{\partial x_j} + \mu \frac{\partial^2 u_j}{\partial^2 x_i} + \rho f_i$$

$$\frac{\partial \rho}{\partial t} + \rho \frac{\partial u_k}{\partial x_k} = 0$$

Basic equations

- **Reynolds averaged equations**

$$\rho \frac{\partial \overline{u_j}}{\partial t} + \rho u_k \frac{\partial \overline{u_j}}{\partial x_k} = -\frac{\partial p}{\partial x_j} + \mu_t \frac{\partial^2 \overline{u_j}}{\partial^2 x_i} + \rho f_i$$

Turbulence models

- RANS – Reynolds Averaged N-S
- URANS – Unsteady RANS
- SRS - Scale-Resolving Simulation

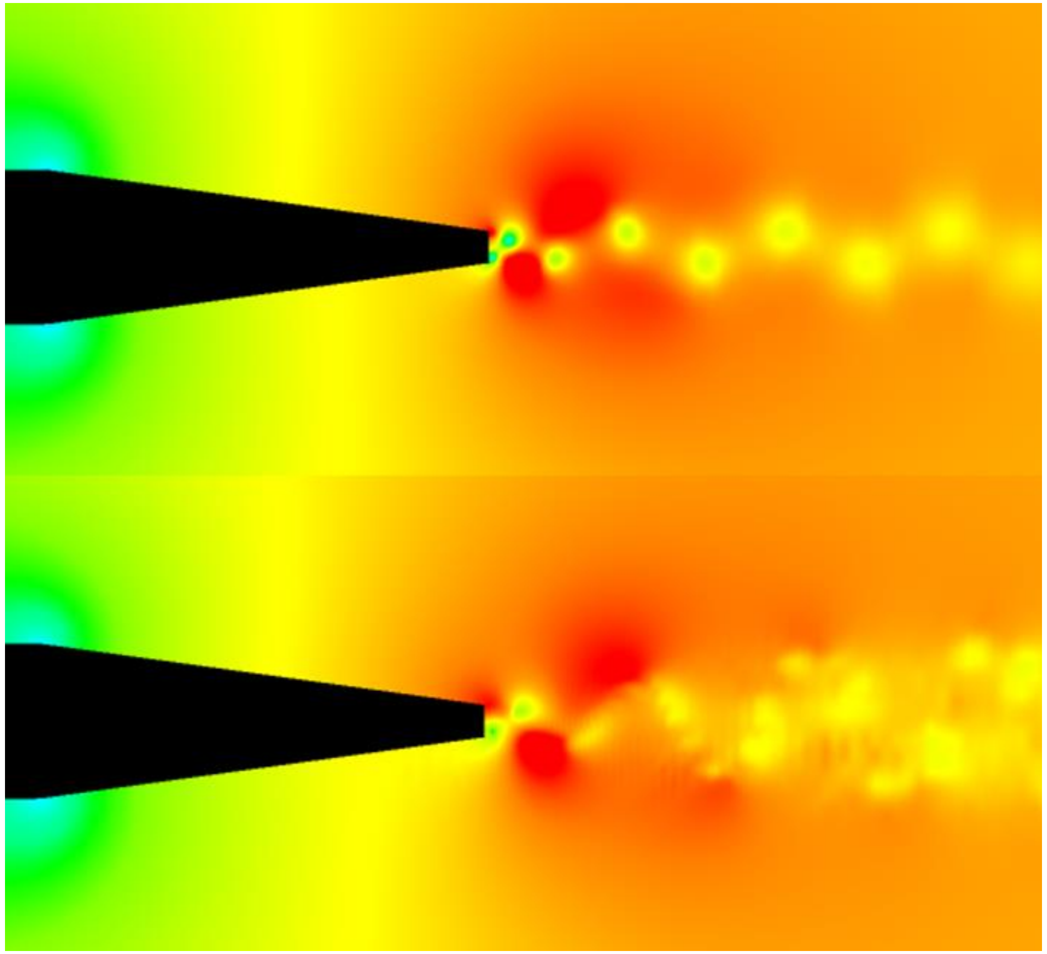
Turbulence models

- Scale-Resolving Simulation (SRS)

- SRS refers to all turbulence models, which resolve at least a portion of the turbulence spectrum in at least a part of the domain
    - Scale-Adaptive Simulation (SAS)
    - Hybrid RANS-LES Methods (DES …)
    - Embedded and Zonal LES (ELES)
    - Modelled LES (WMLES)
    - Large Eddy Simulation (LES)

Direct Numerical Simulation (DNS) – extremely expensive

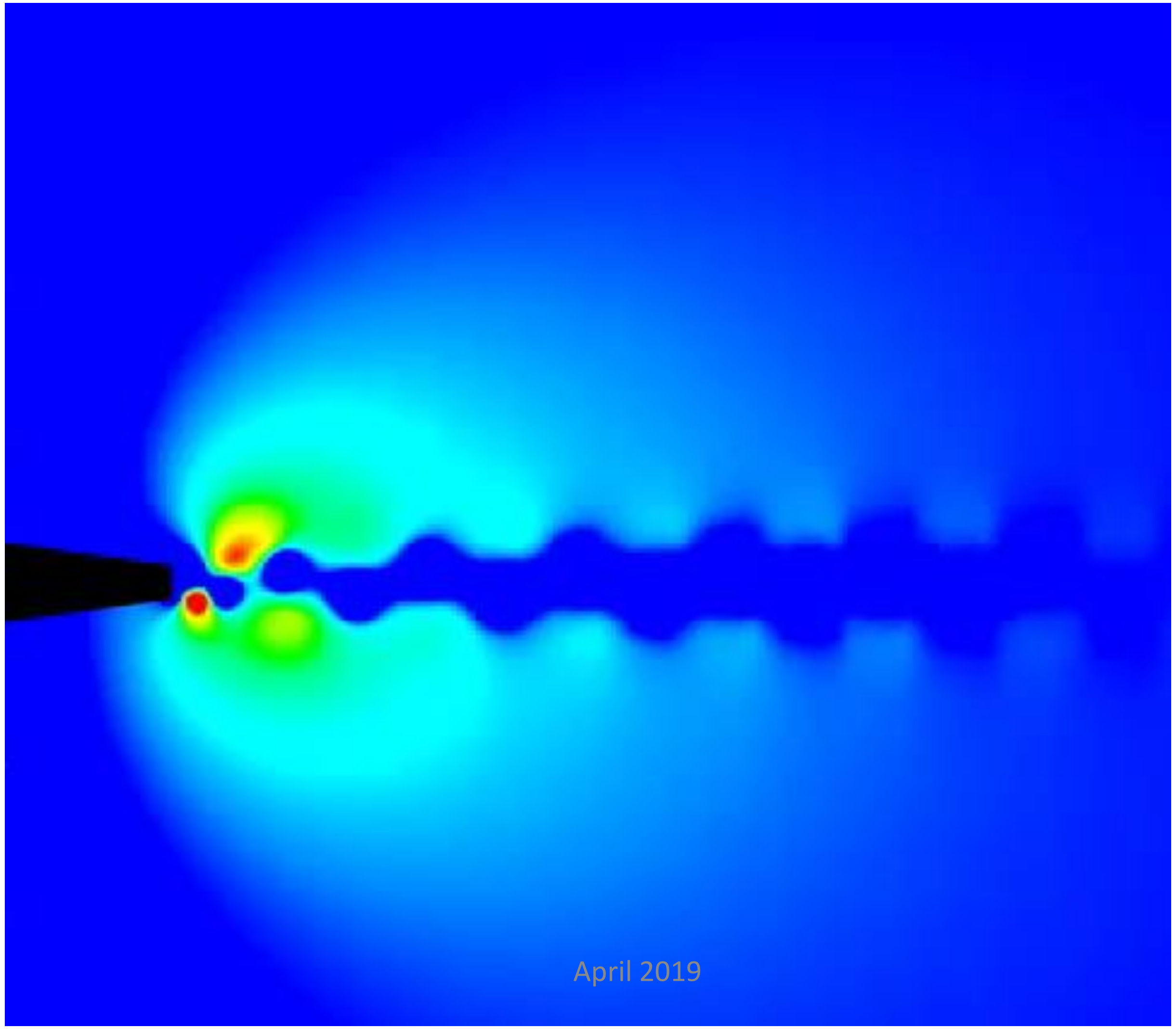
Turbulence models



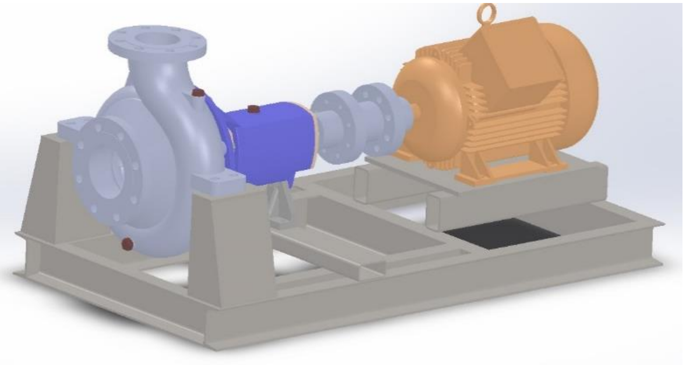
RANS

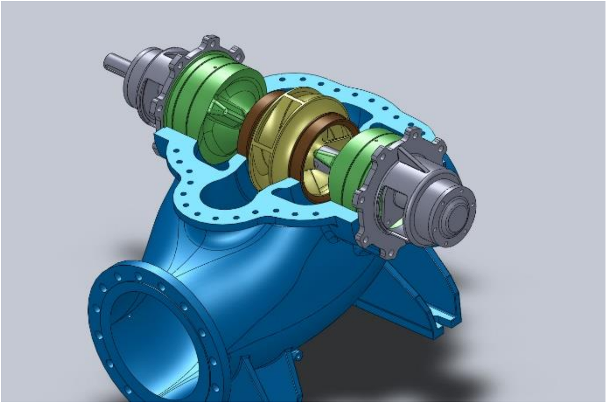
SRS

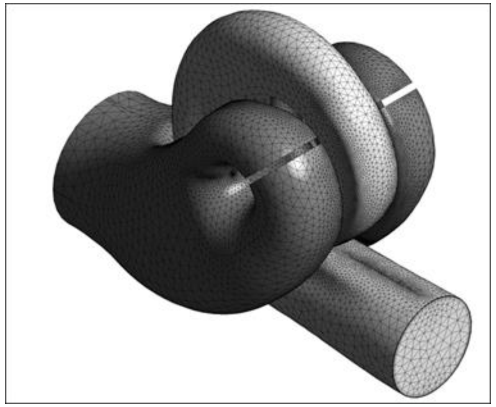
Turbulence models

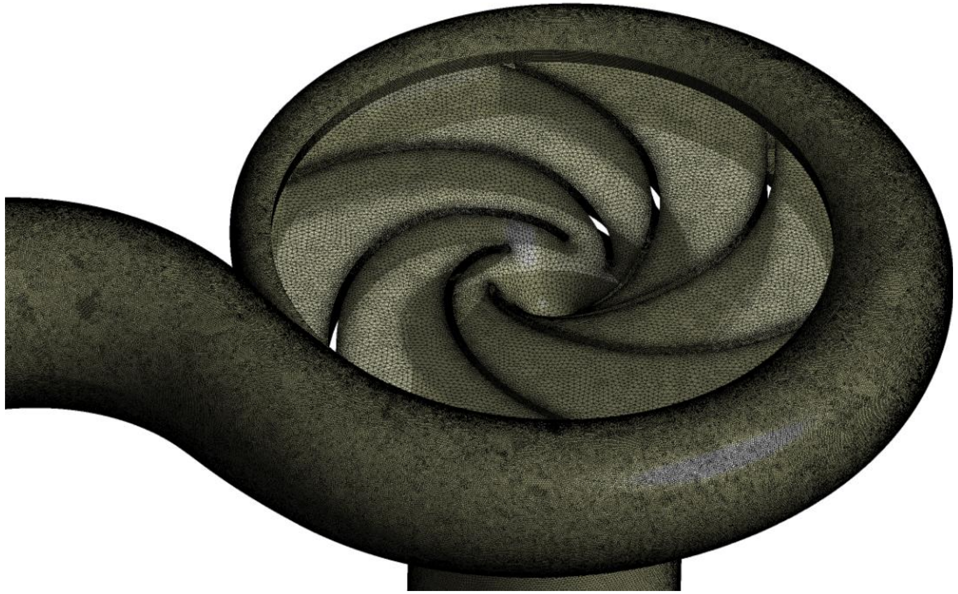


Computational grid

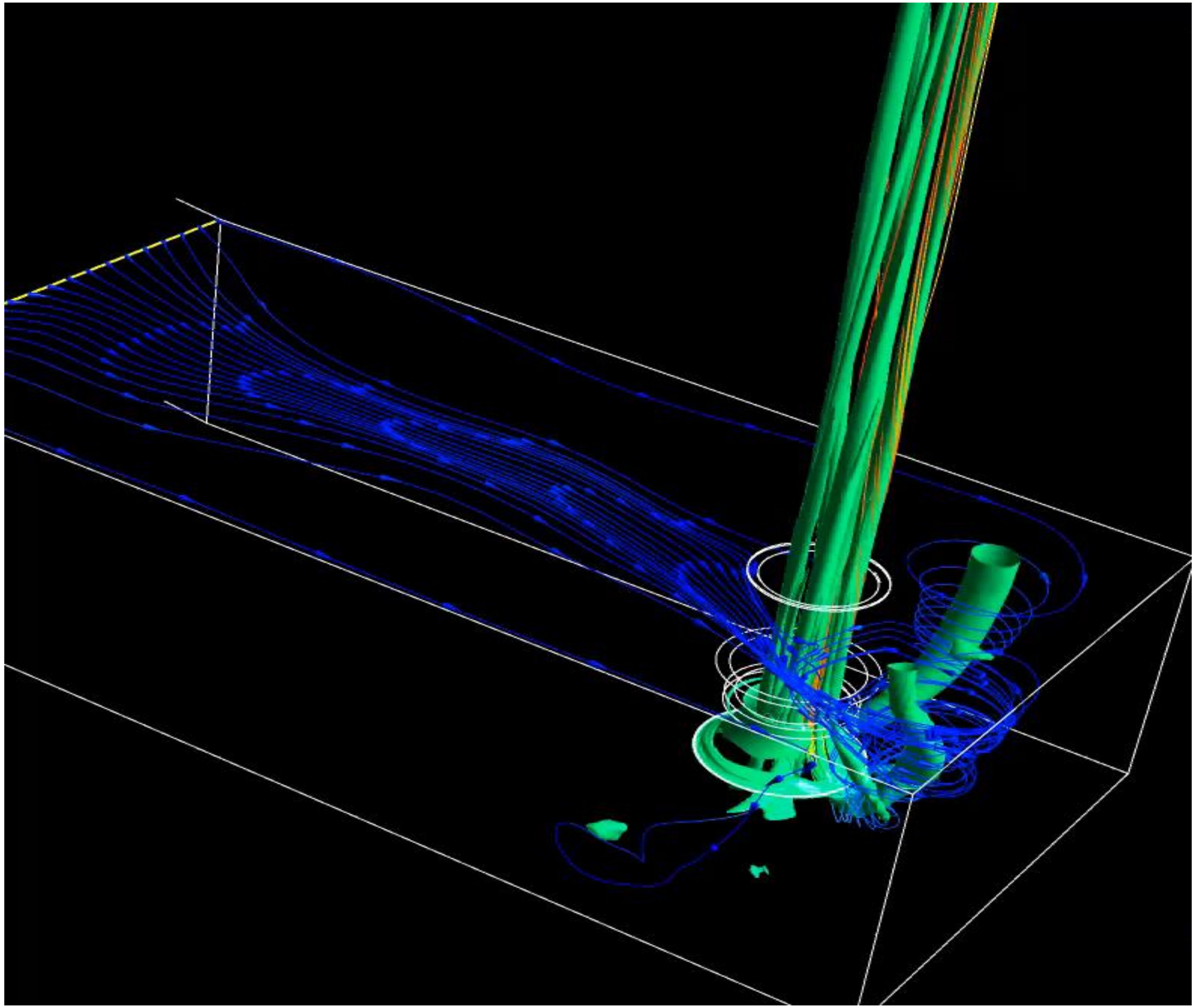






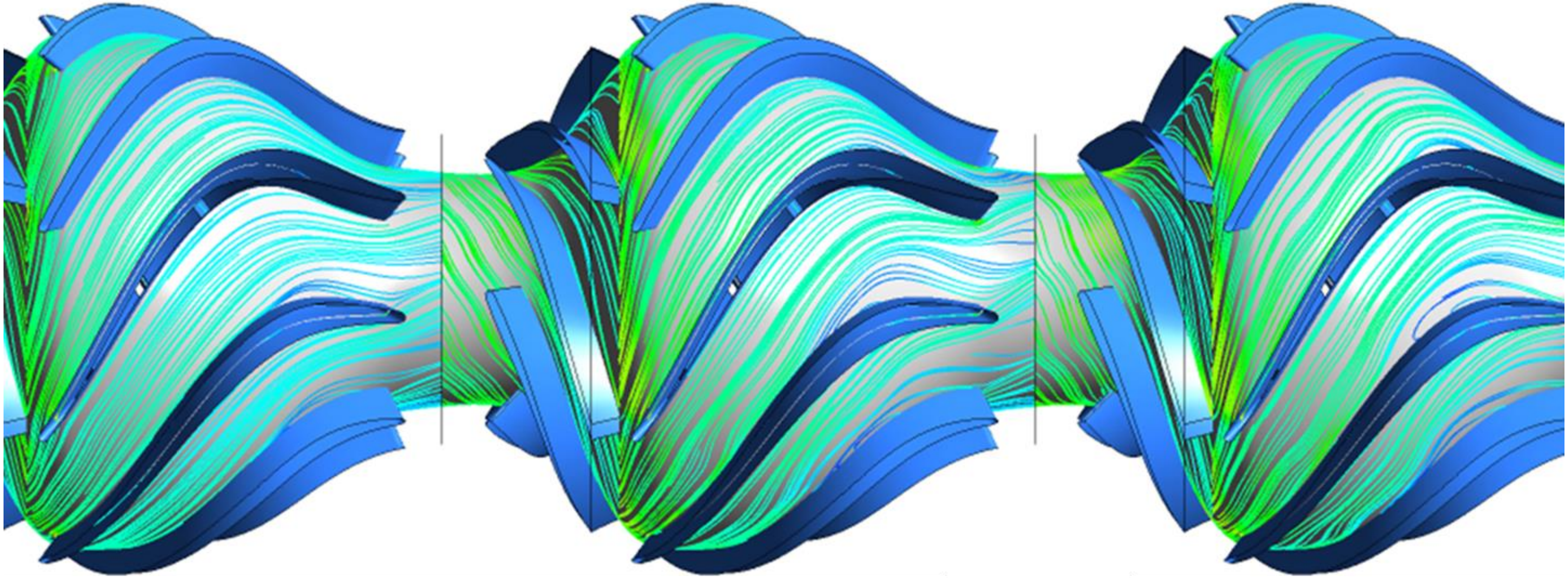


Pump sump

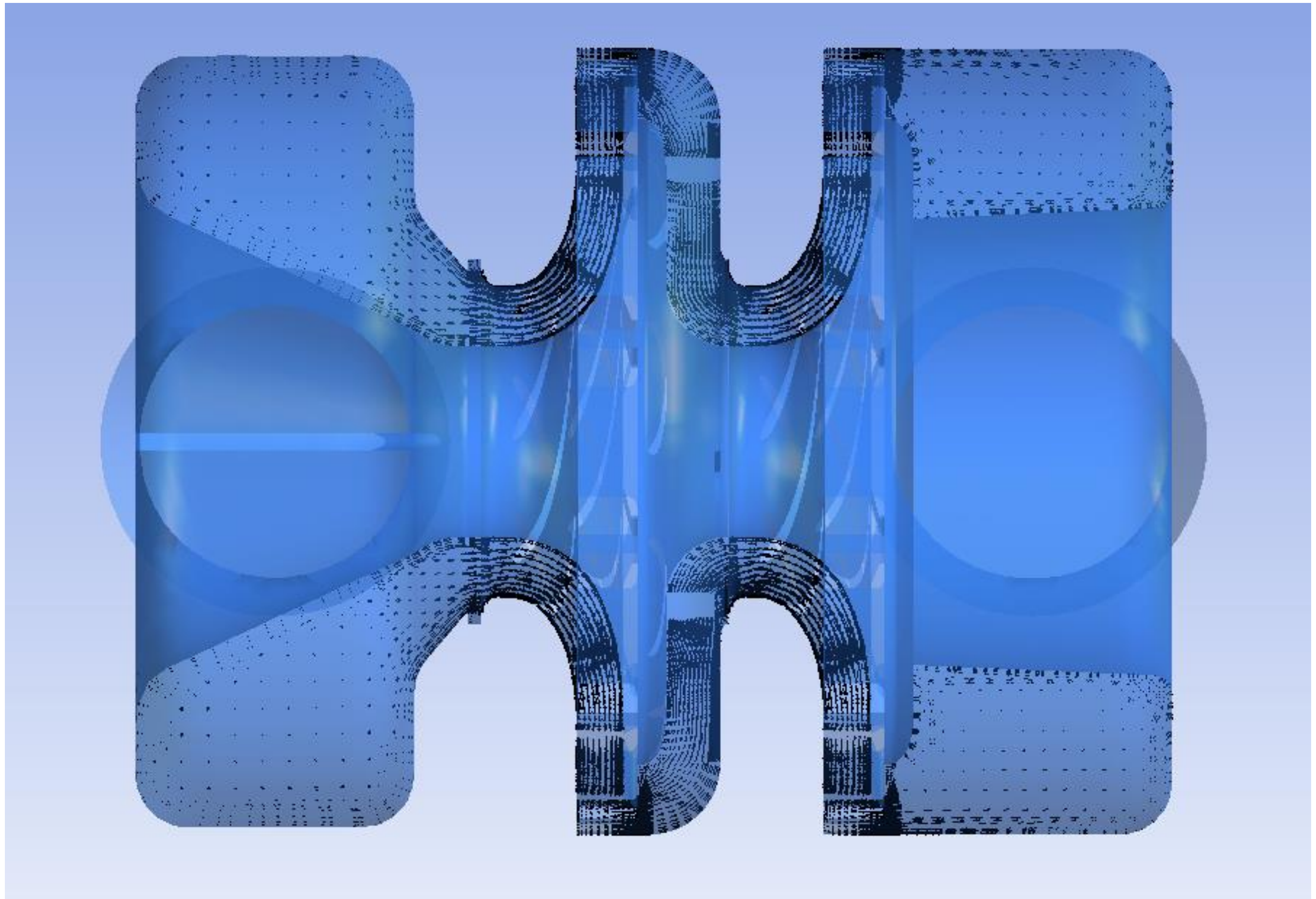


Reversible pump turbine

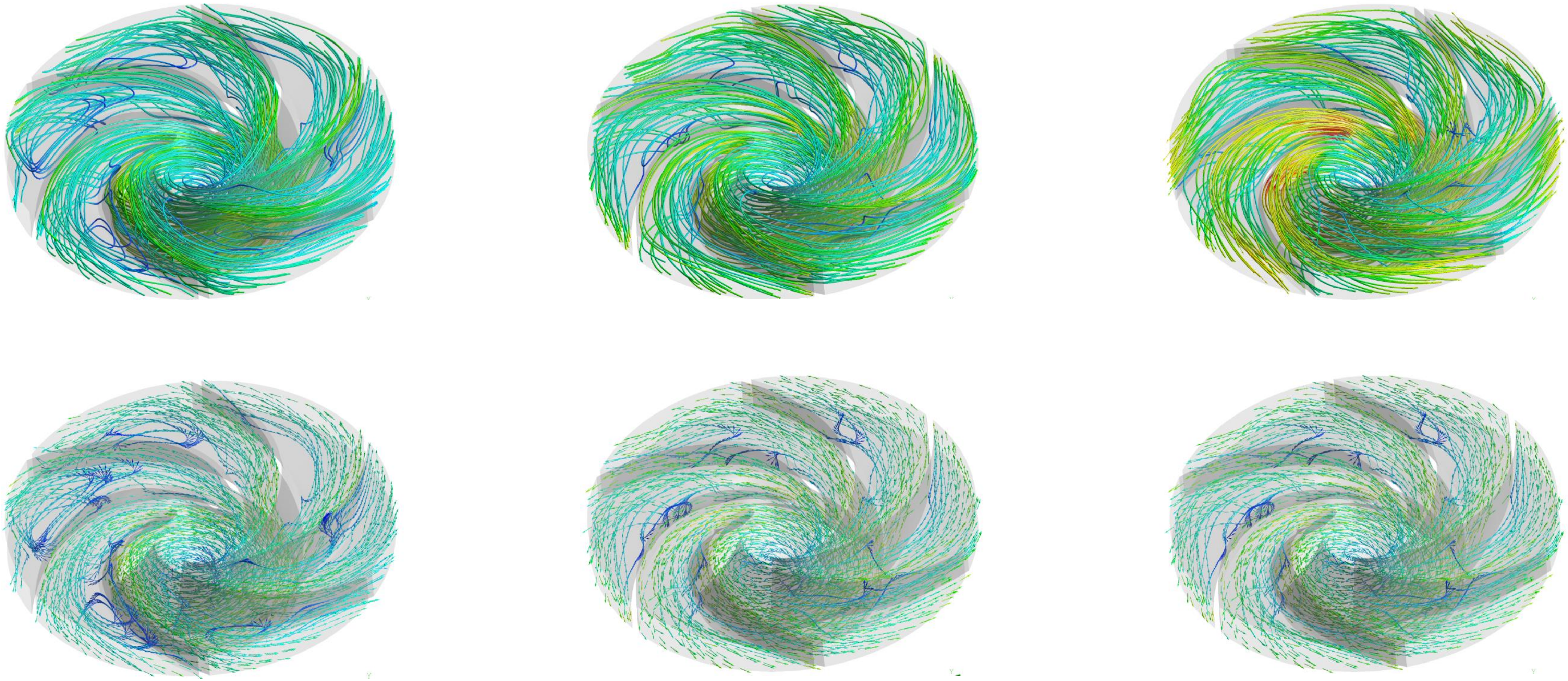
Multi stage pump – stream lines



Multi stage pump

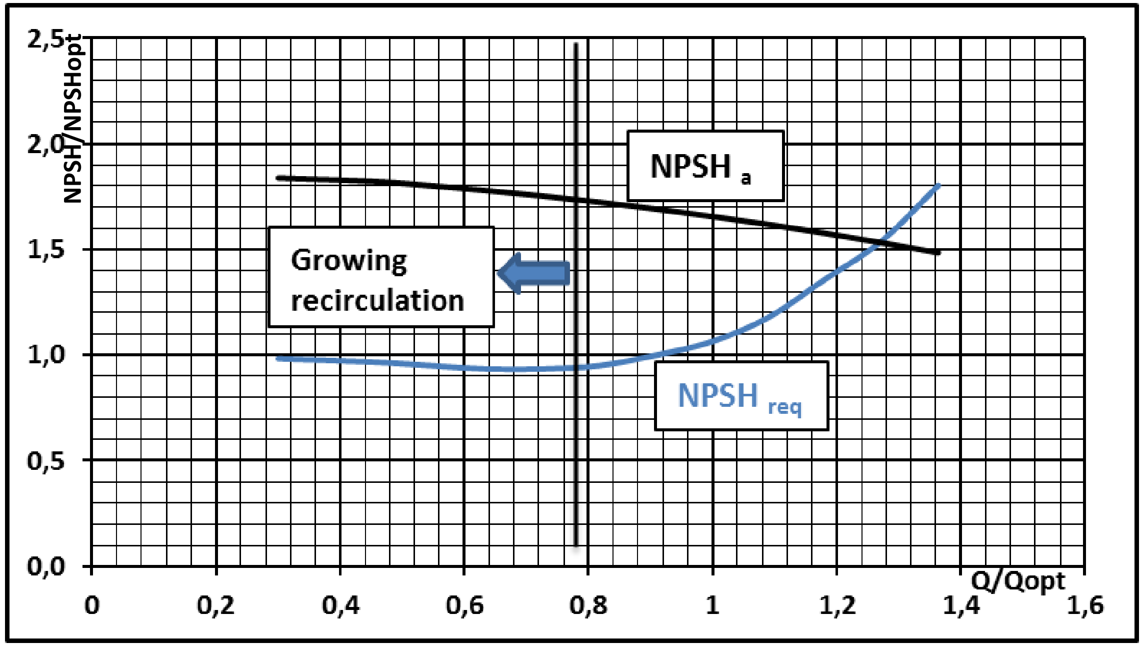


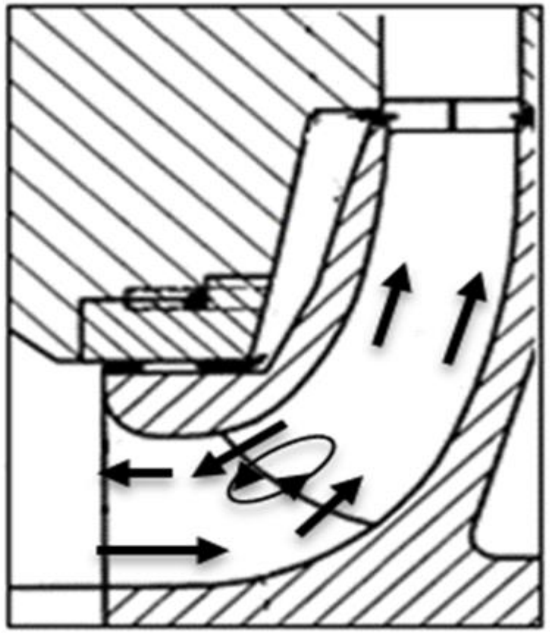
FLOW DISTRIBUTION FOR THREE OPERATING POINTS



Inlet recirculation

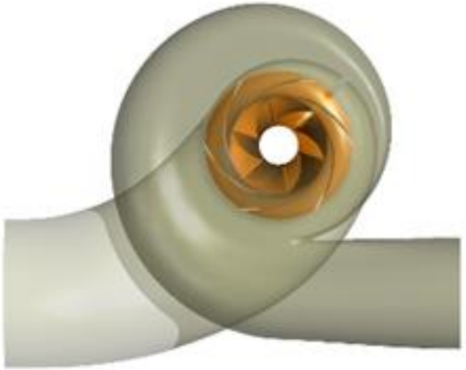
- **Dimensionless Q-NPSH characteristic of the existing pump**

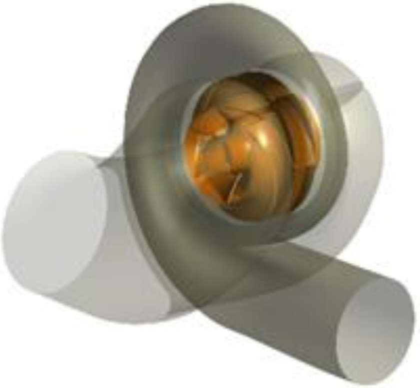
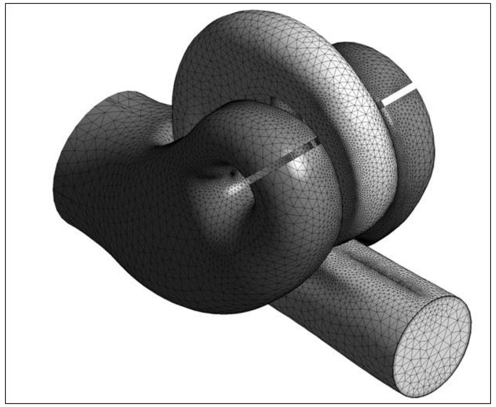




Geometry of optimised pump

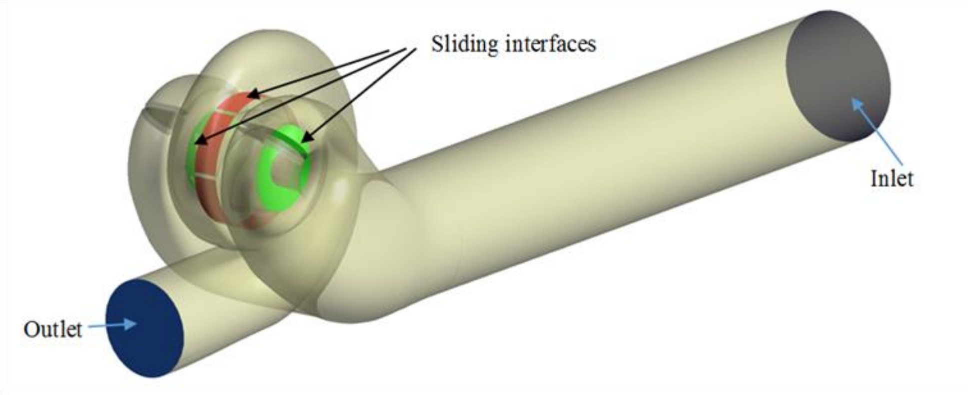
- Geometry and computational grid



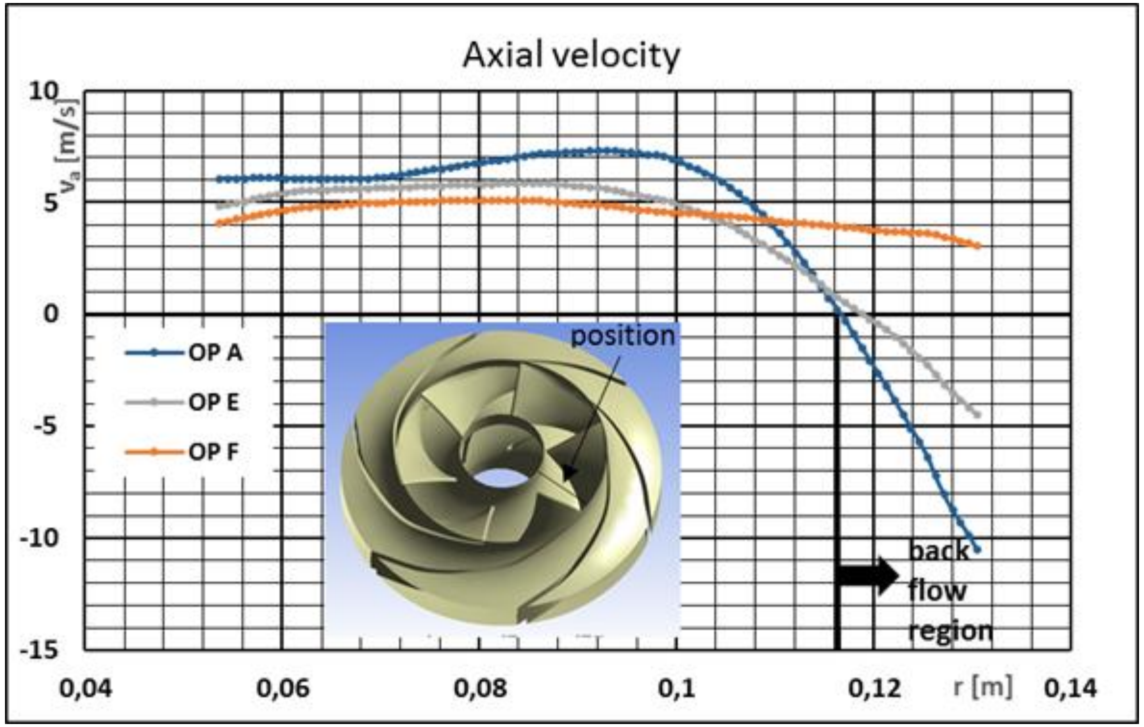
Operating points

Operating point	Flow rate Q/Q_{opt}
A	0.26
B	0.33
C	0.46
D	0.56
E	0.62
F	0.65



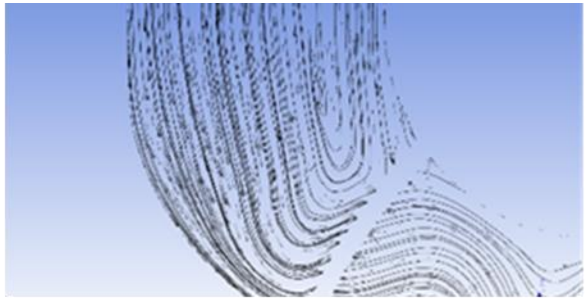
Impeller inlet flow conditions

- Inlet axial velocity distribution between hub and shroud

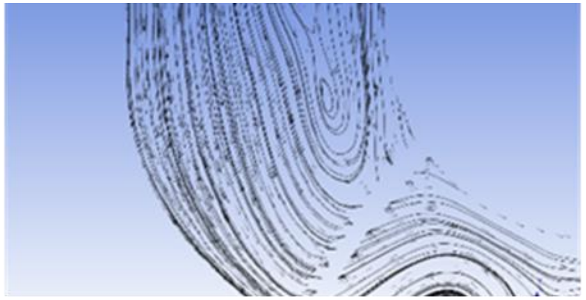


Inlet recirculation

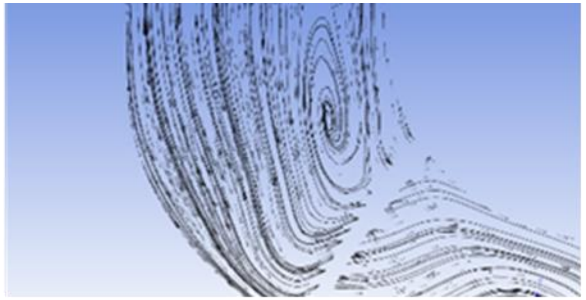
- Inlet vortex at vertical cross section for six operating points



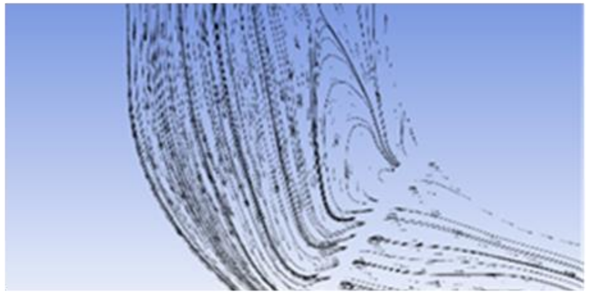
A



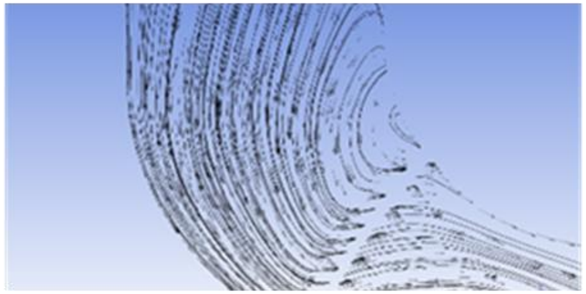
B



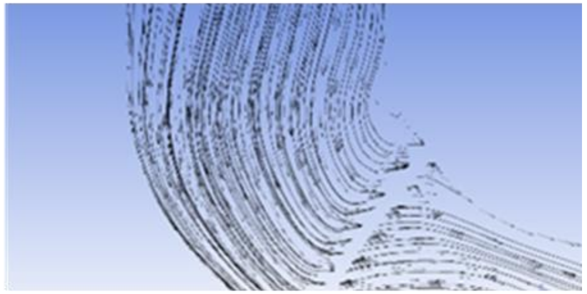
C



D



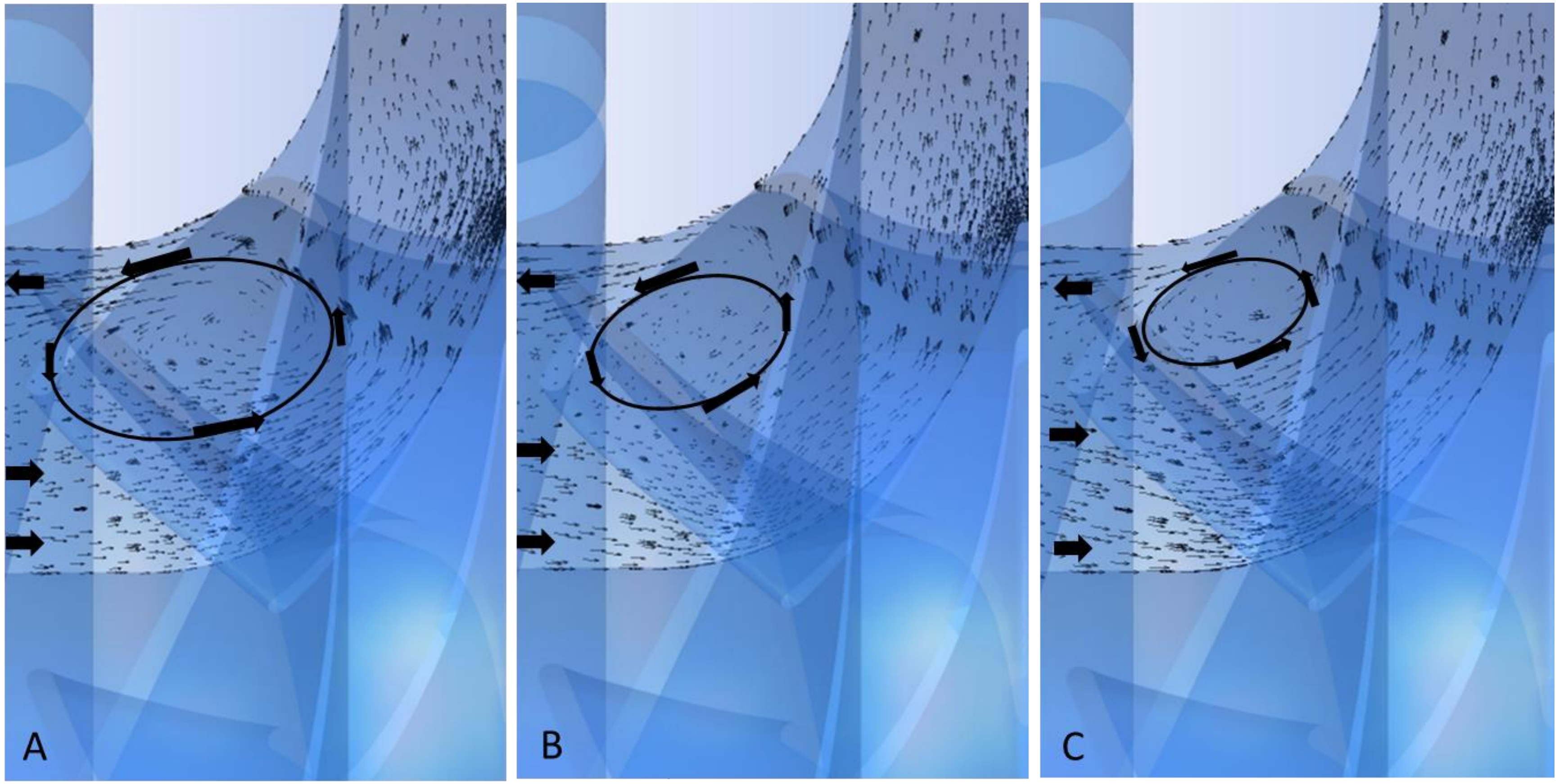
E



F

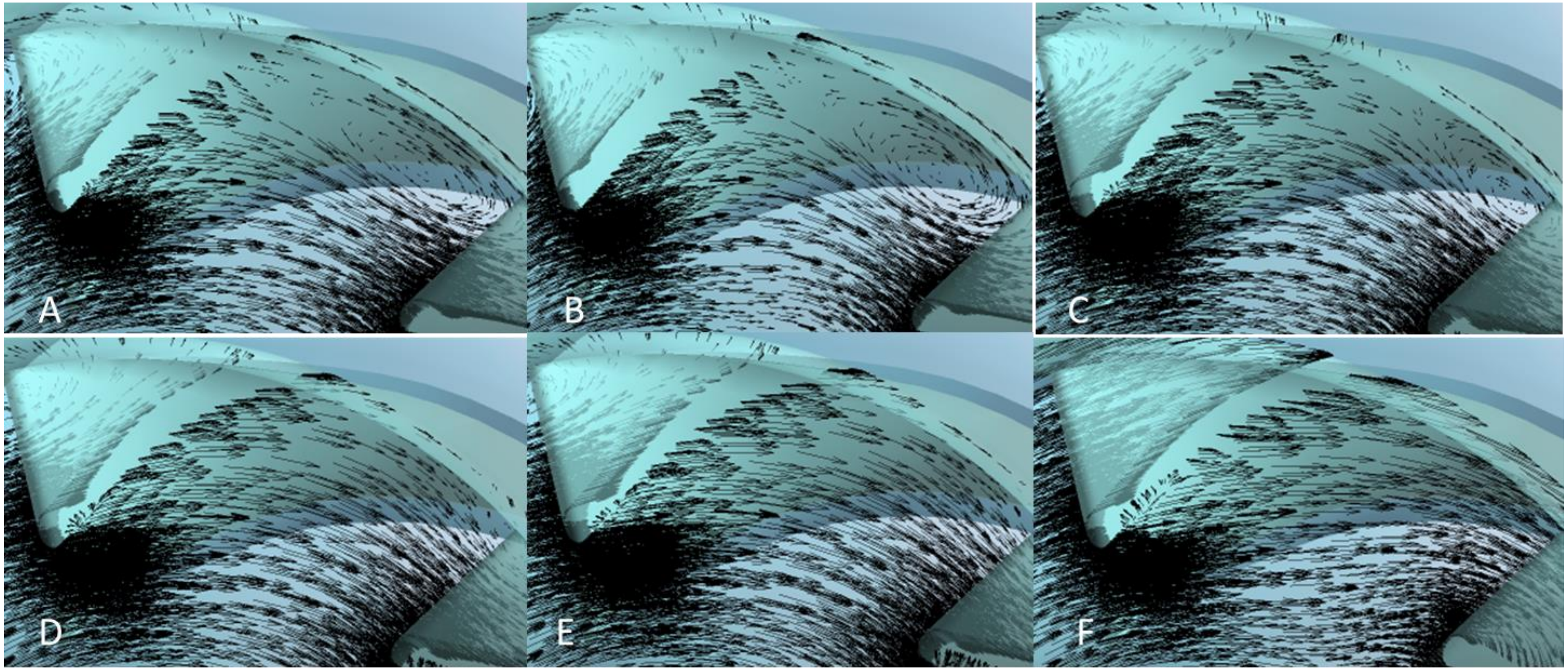
Inlet velocity

- **Recirculation at the inlet – velocity vectors**



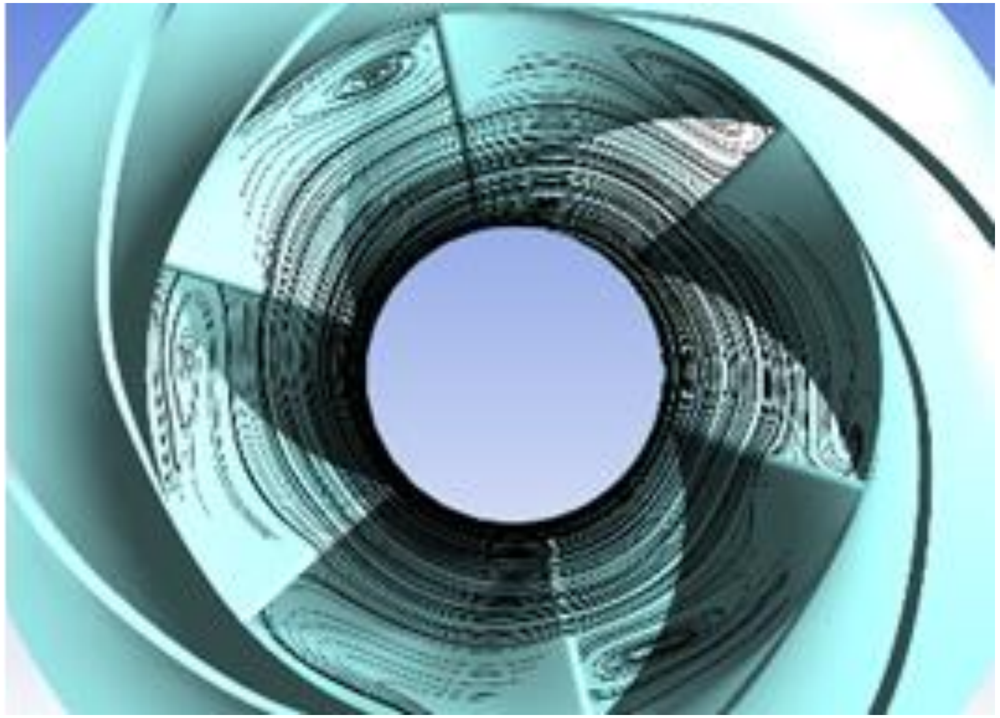
Vortices between impeller blades

- **Recirculation between impeller blades – velocity vectors**

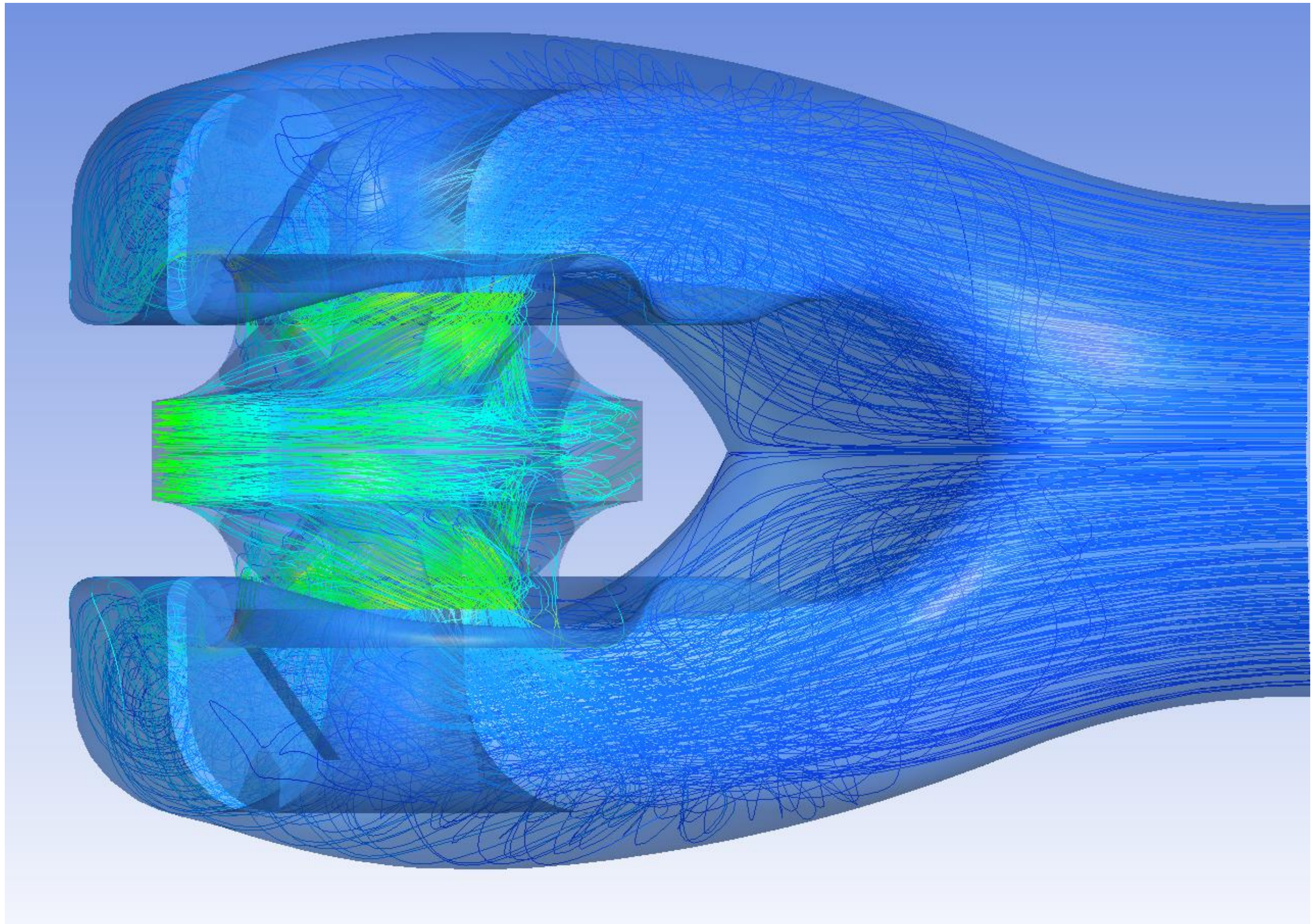


Vortices between impeller blades

- Recirculation between impeller blades

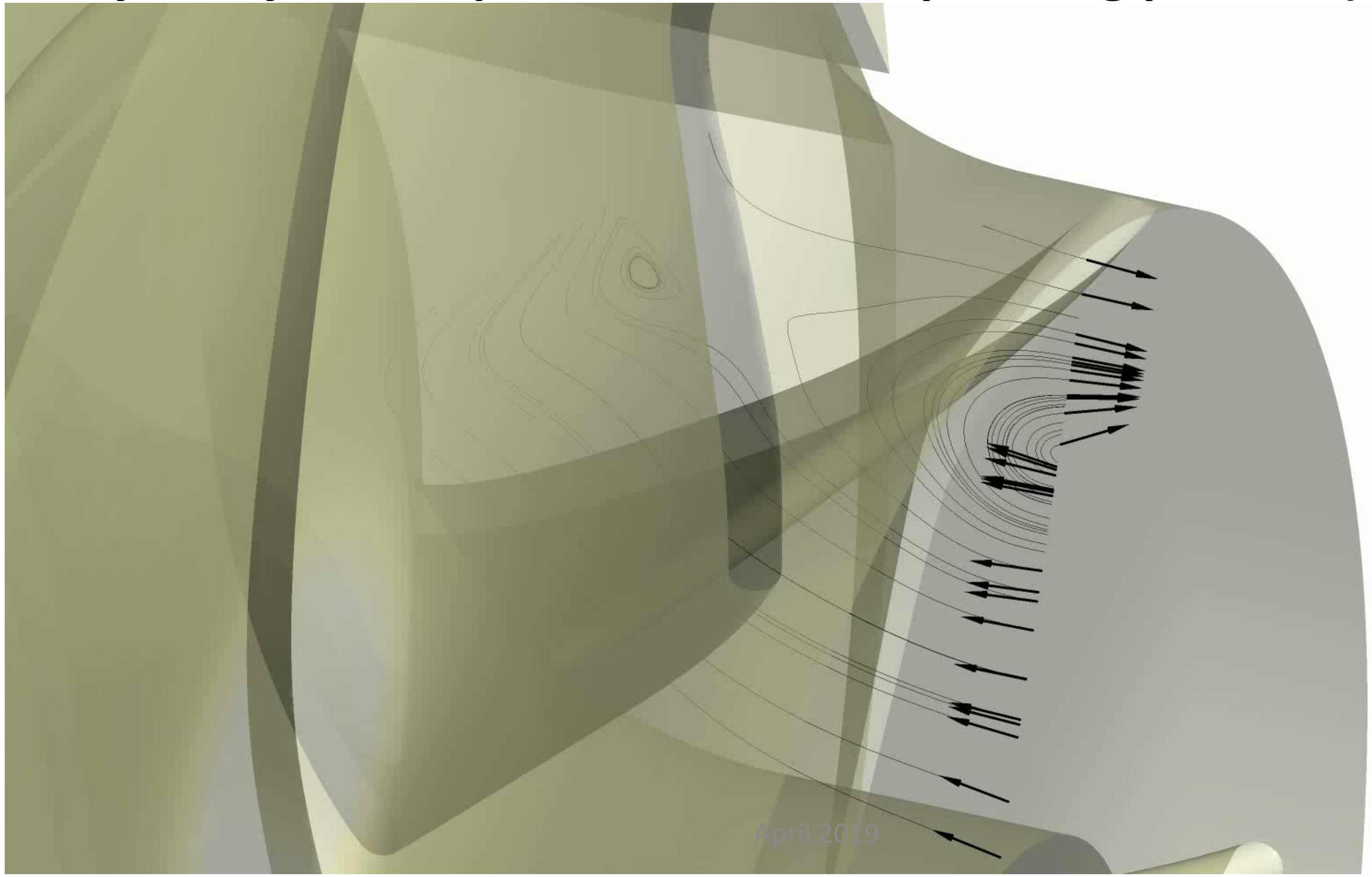


Flow inside the computational domain



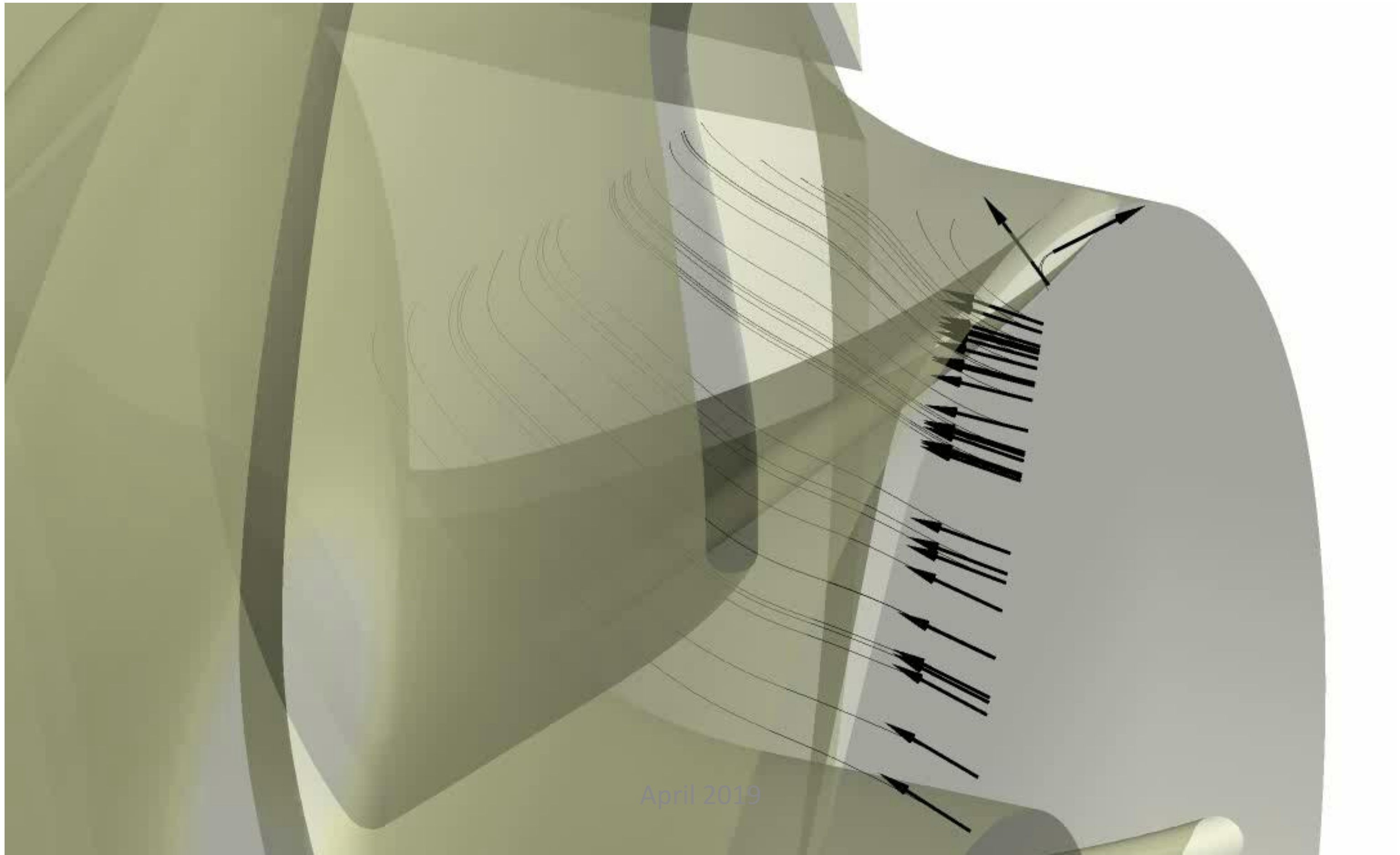
Inlet flow animation

- unsteady analysis – impeller inflow for operating point A (local unsteadiness)



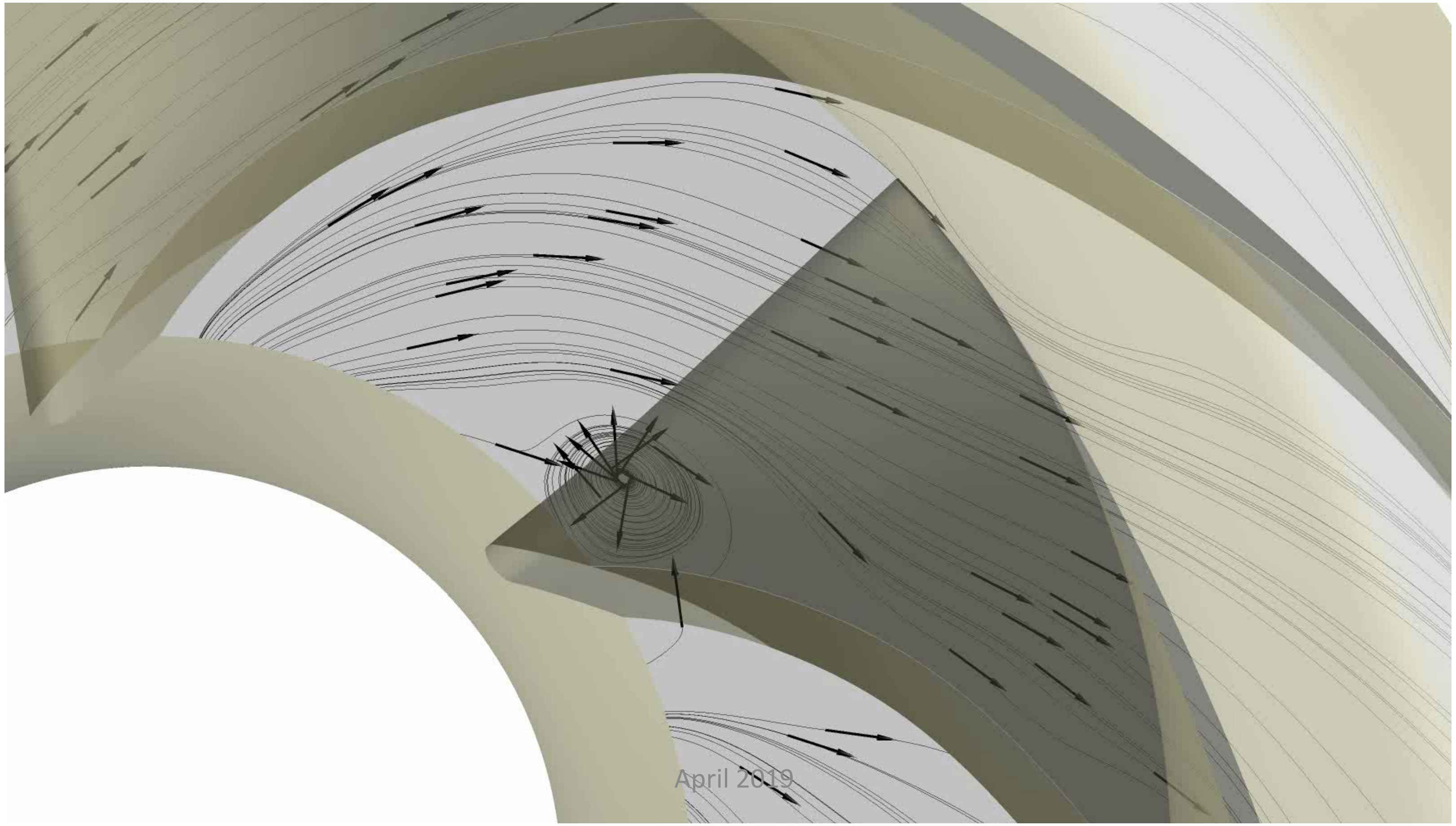
Inlet flow animation

- unsteady analysis – impeller inflow for operating point E (negligible unsteadiness)



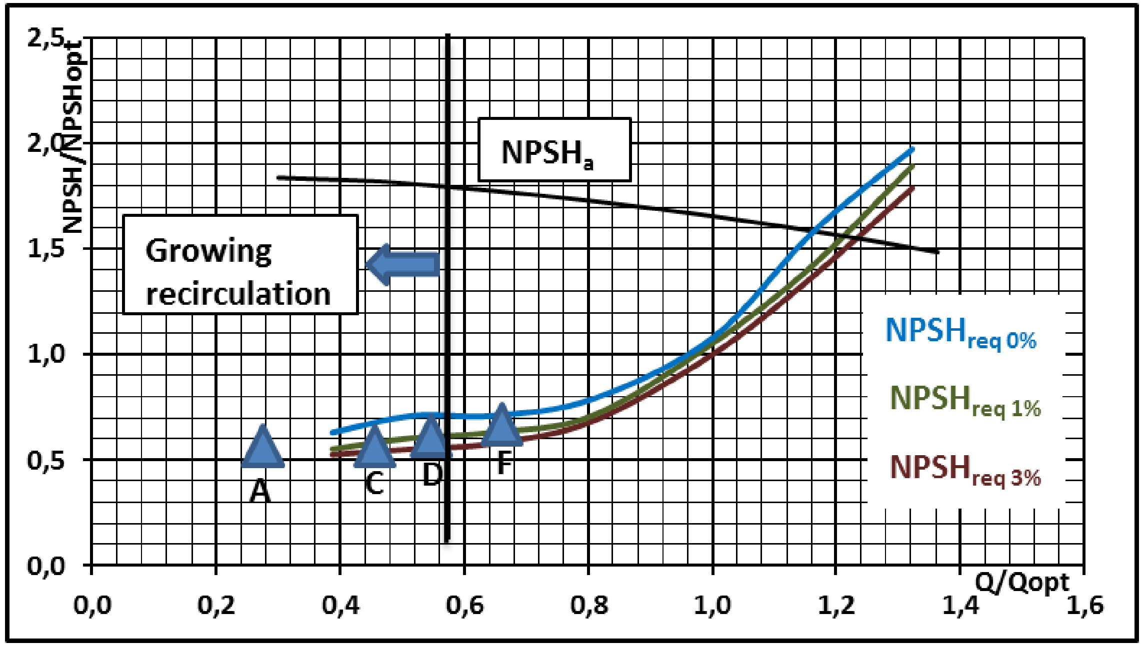
Flow animation

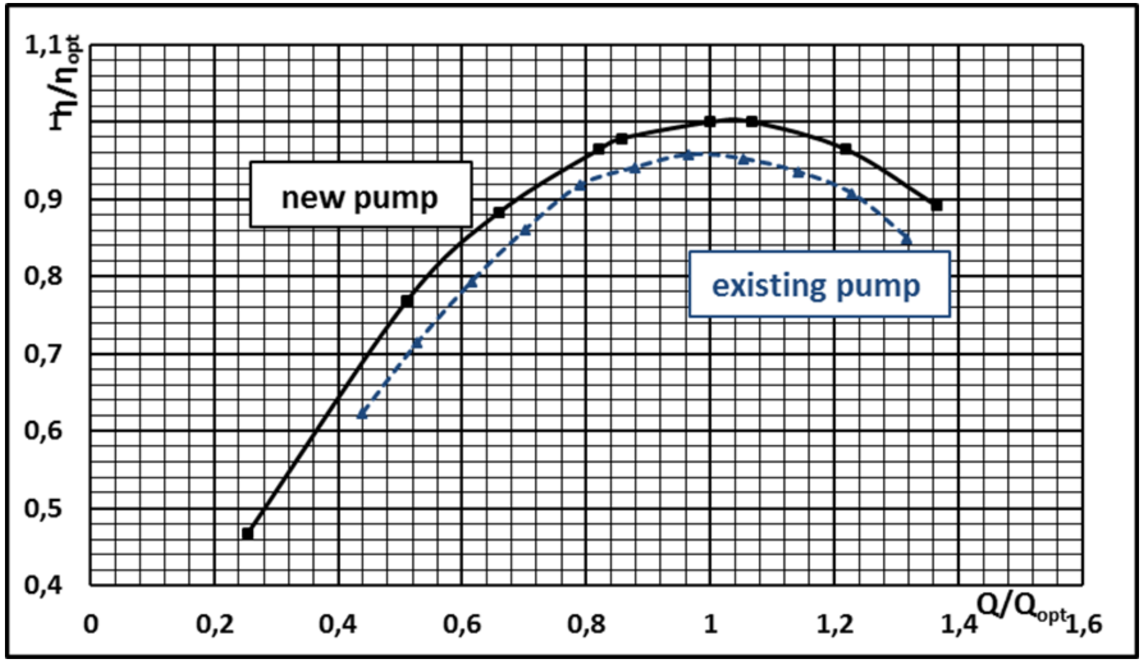
- unsteady analysis



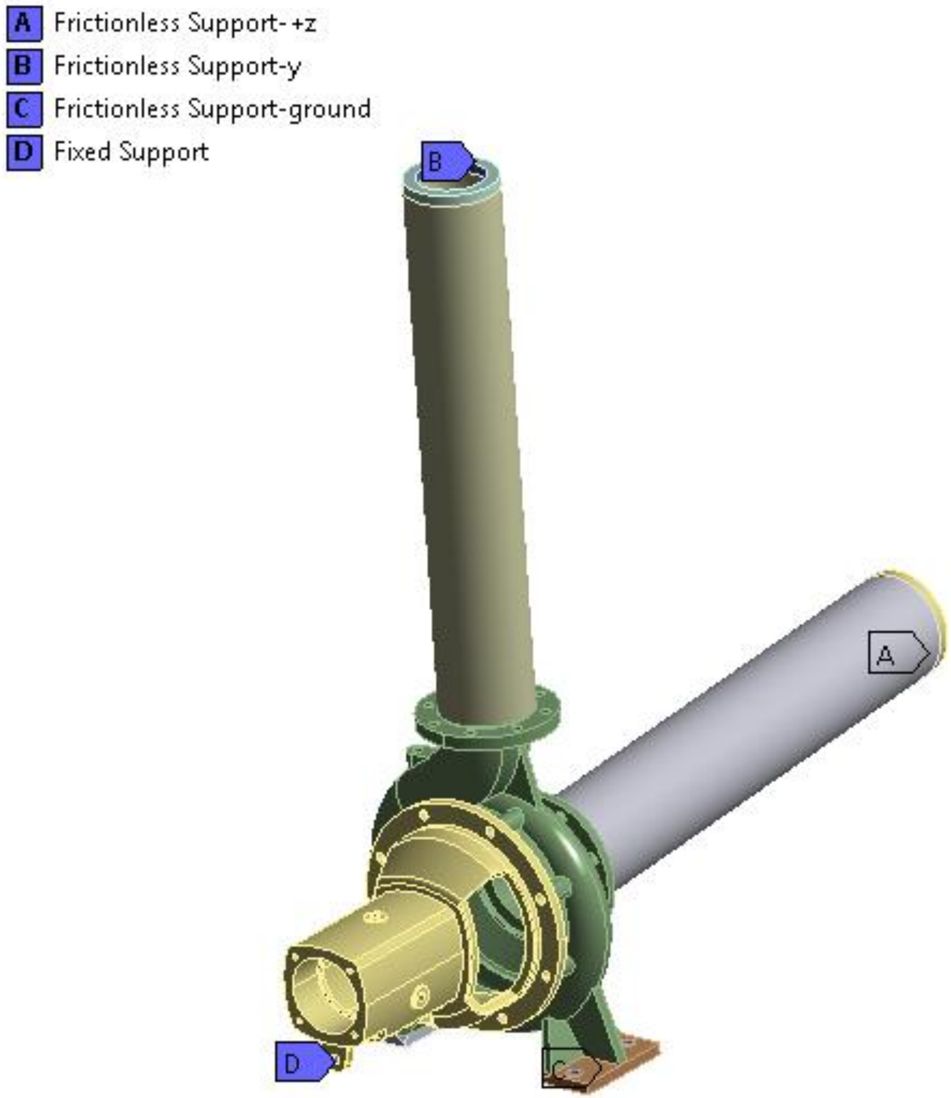
NPSH

- **Dimensionless NPSH characteristic of the optimised pump**





NUMERICAL MODEL



Loading conditions:

Pressure: 10 MPa

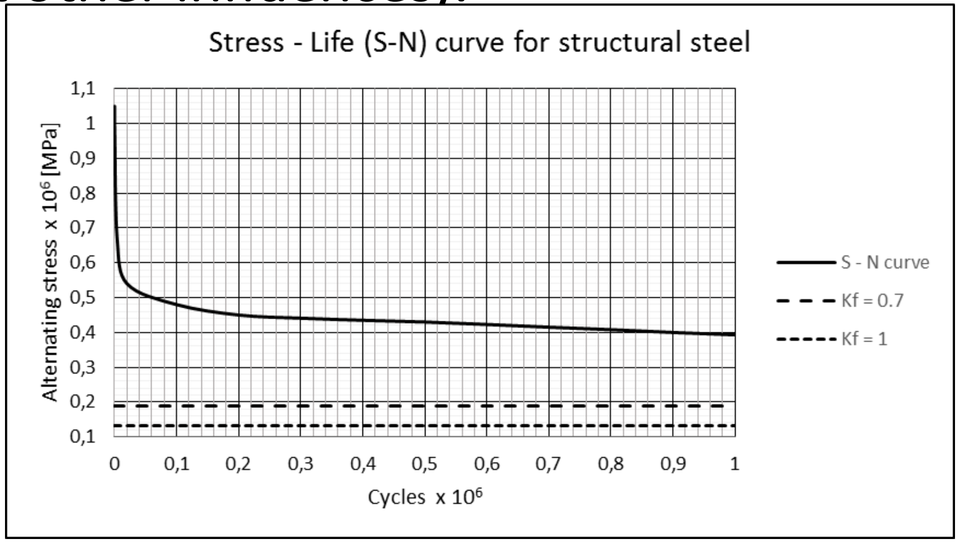
Temperature: 400 °C (50 °C/h)

Material properties:

Young‘s modulus: 200 GPa

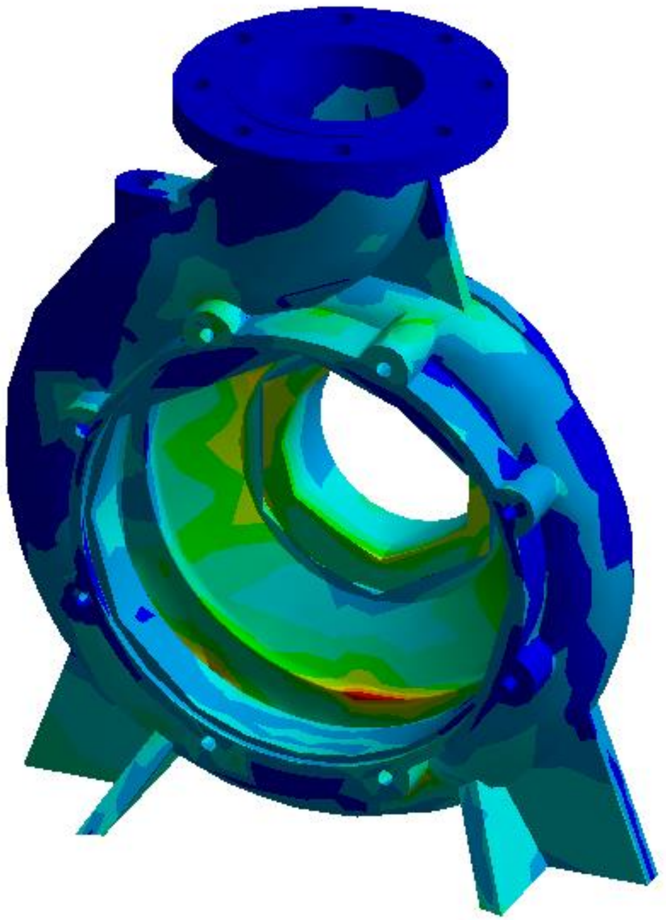
Poisson‘s ratio: 0.3

S-N curve for mean stress equal to 0 MPa (without other influences):



Fatigue calculation: R = 0 and using of Goodman theory

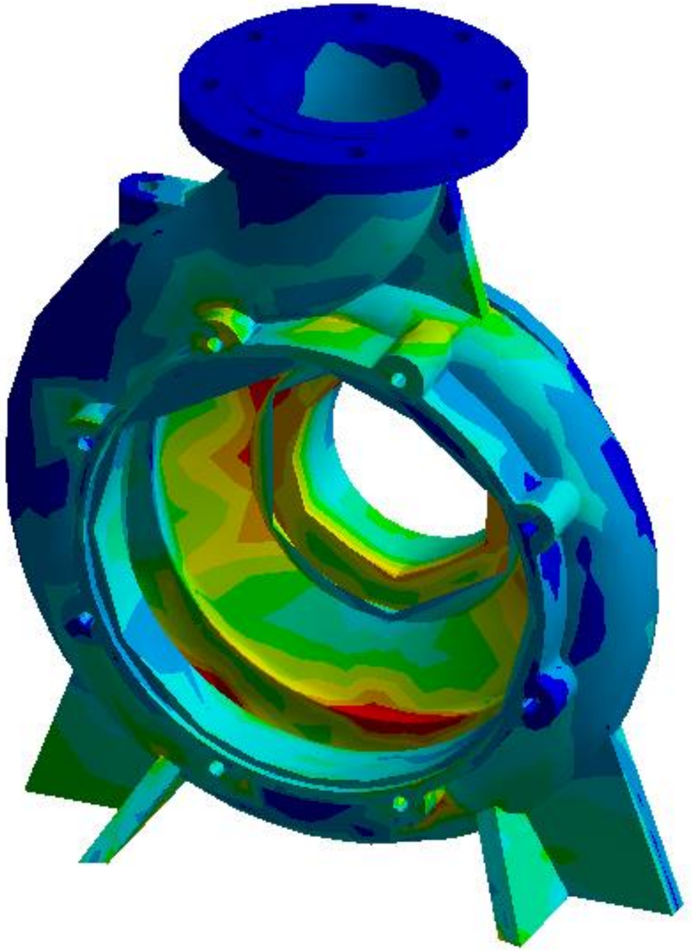
RESULTS – ALTERNATING STRESS



$K_f = 1$

Alternating stress from S-N curve for Infinity-Life Design: 393 MPa

RESULTS – ALTERNATING STRESS



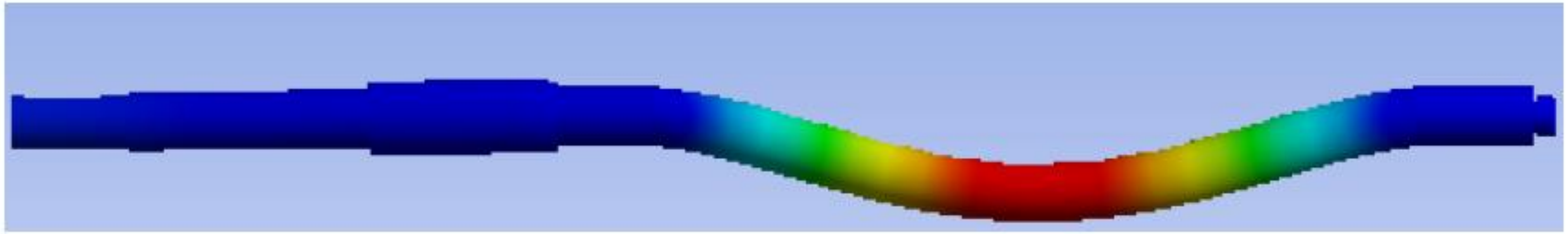
$K_f = 0.7$

Alternating stress from S-N curve for Infinity-Life Design: 393 MPa

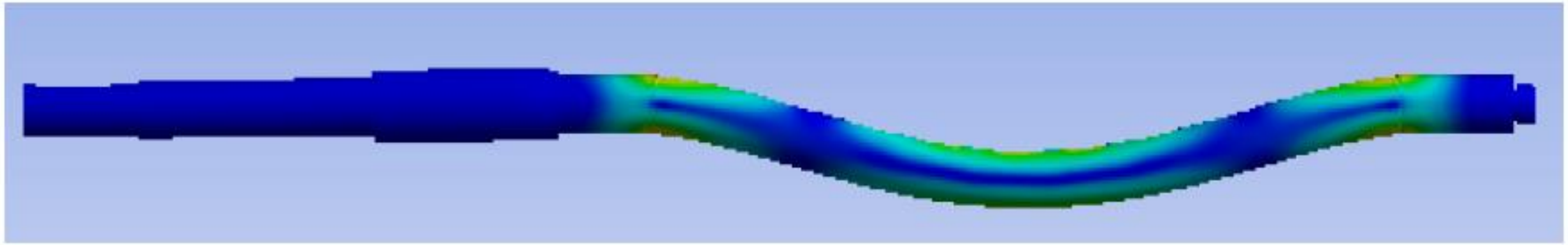
Stress analysis

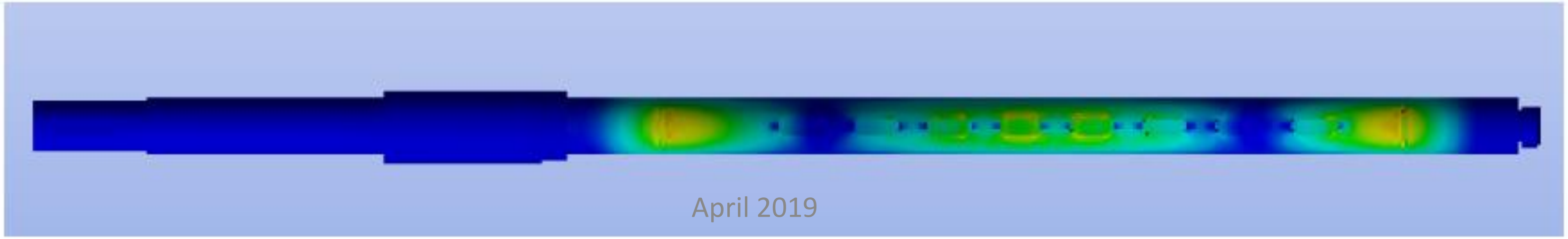
Results

a. Deformations – max 0.05722 mm (red colour)

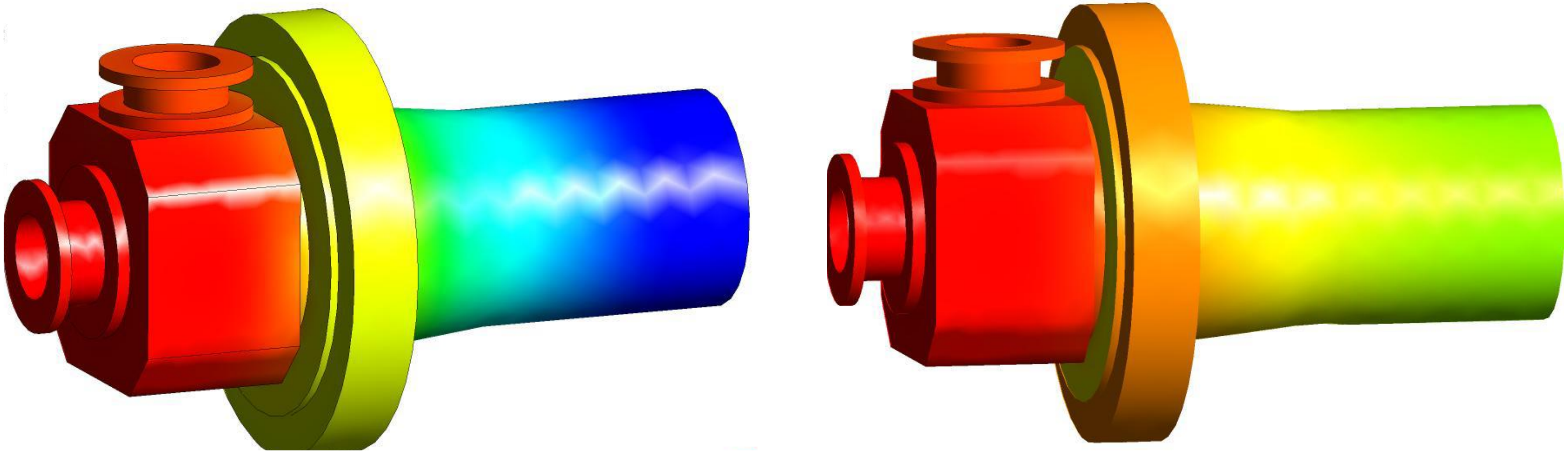


b. Stresses – max 17.813 MPa (Equivalent von-Mises stresses)

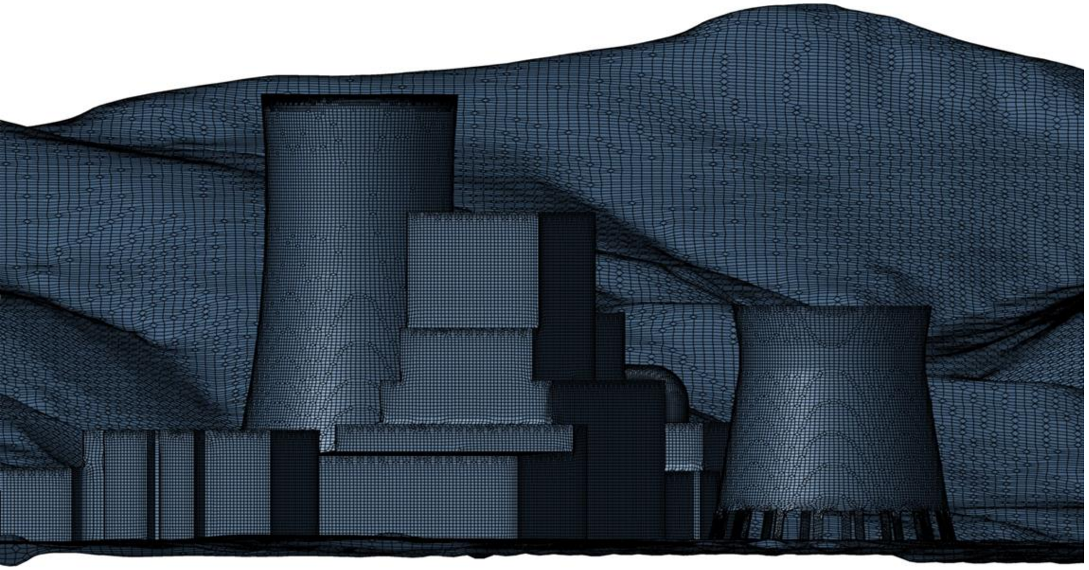


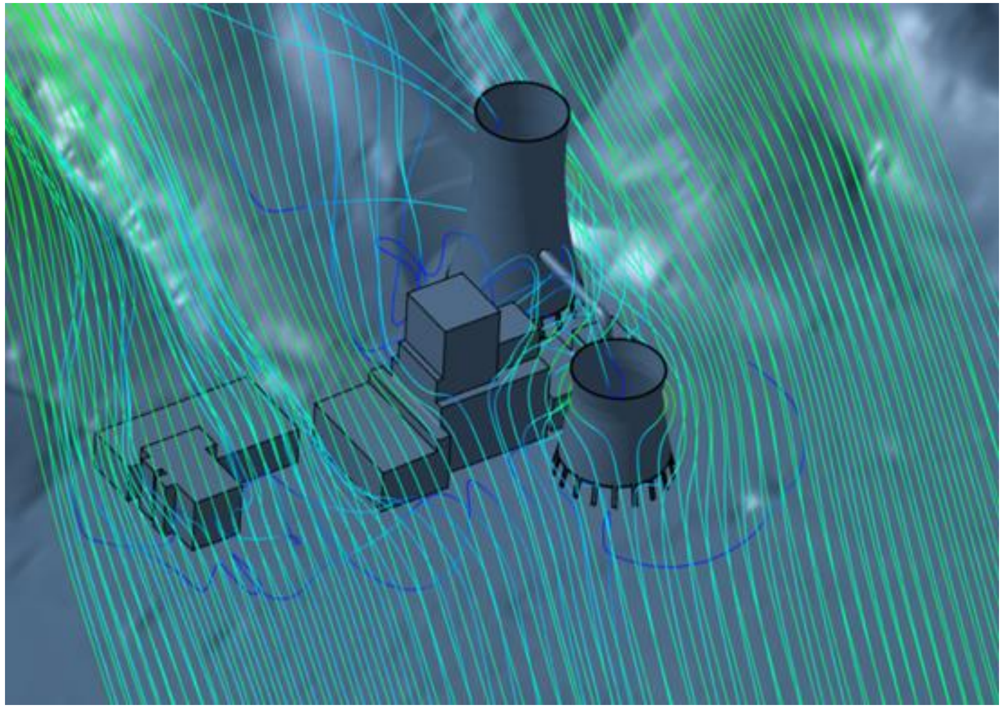


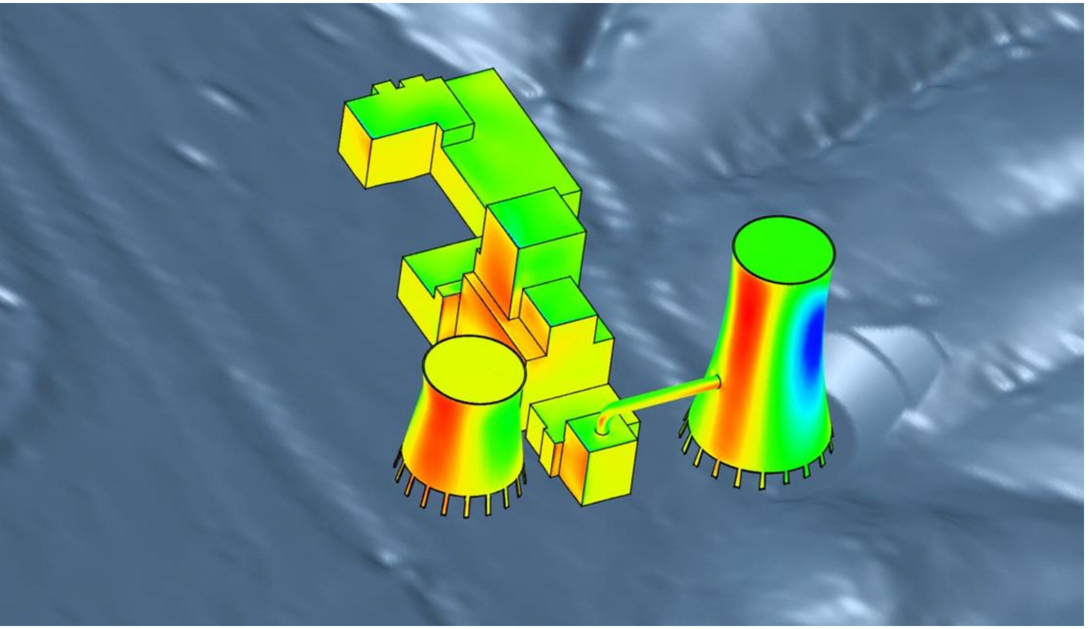
Heat Transfer

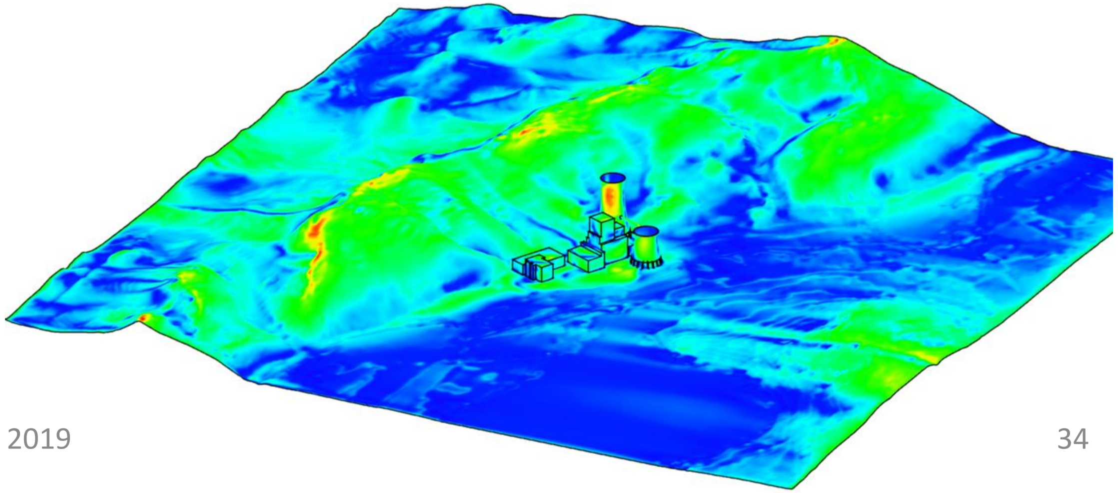


Cooling tower – flow analysis around buildings









Conclusions

- Computation is now firmly established as the third pillar of science alongside theory and experiment.
- CFD is very powerful tool for energetic, cavitation and dynamic analysis of all types of centrifugal pumps.
- Reliable results can be obtained by experienced engineer or researcher.
- CFD can replace a lot of experimental work.
- For some special applications a high performance computing facilities is necessary.
- There are many scientific problems which stretch the limits of the largest supercomputers in the world.