31st Workshop on Turbomachinery

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TECHNISCHE UNIVERSITÄT DRESDEN

EFFICIENCY OPTIMISATION OF TURBINE FLOW SYSTEMS USING MODERN OPTIMISATION TECHNIQUES

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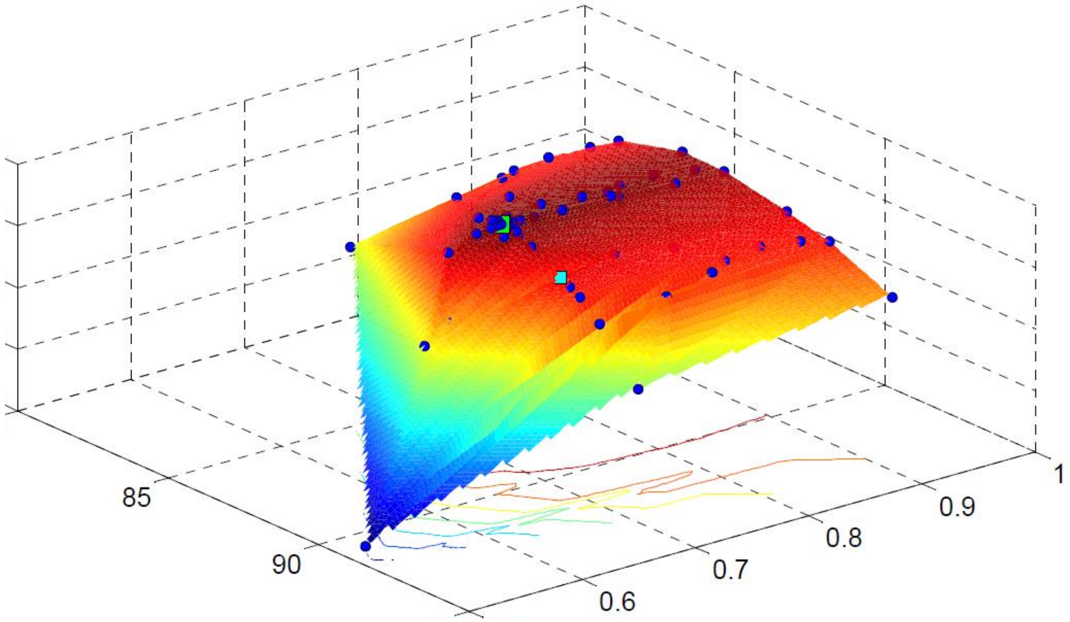
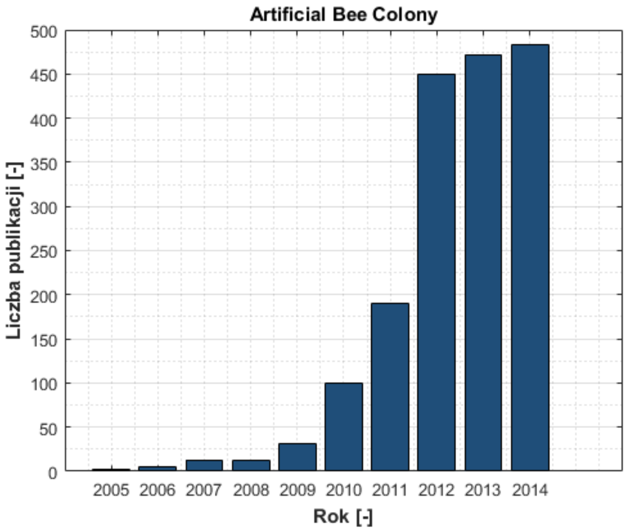
Optimisation

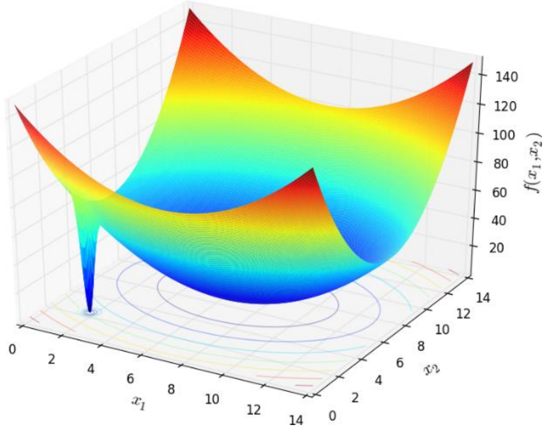
- Optimisation allows us to improve efficiency of the machines
- Procedure for finding maximum/minimum of objective function
- Objective function, penalty function, boundaries
- Methods of optmisation – wide range
- Reduction of flow losses:
  - profile loss
  - boundary loss
  - exit kinetic energy losses

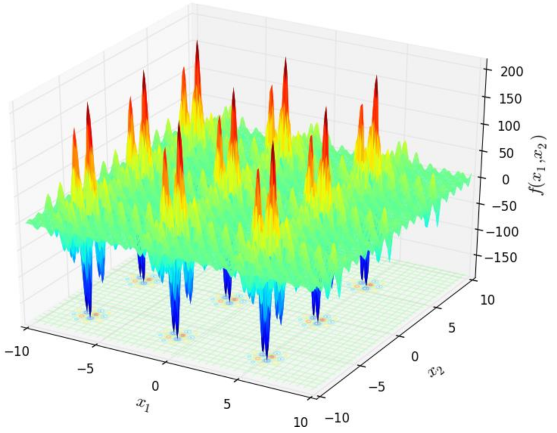


Methods of optimisation

- Deterministic Methods: Nelder-Mead, Hooke-Jeevesa.
- Stochastic methods: Swarm intelligence, Genetic methods.







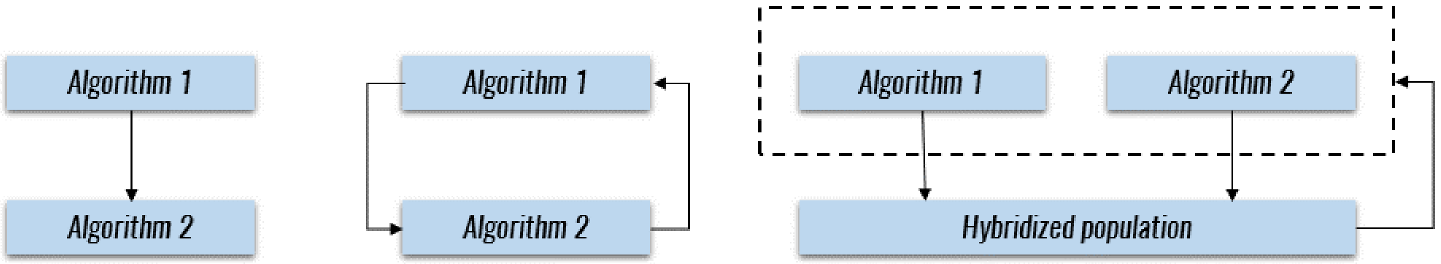
- Hybrid methods:

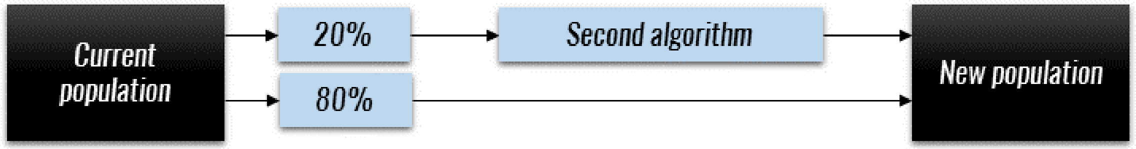
Bat algorithm
Cuckoo Search
Glowworm swar optimization
Grey wolf optimizer
Spider Monkey Optimization

\+ Nelder Mead
Hooke-Jeeves

Hybrid algorithms

- Collectively and cooperatively solving a predefined problem
- Collaborative Hybrids: multi-stage, sequential, paralel structures
- Integrative Hybrids: full manipulation, partial manipulation
- Chalanges: namin convention, complexity, computational speed





Hybrid algorithms

- A NEW METAHEURISTIC BAT-INSPIRED ALGORITHM - Xin-She Yang, Nature Inspired Cooperative Strategies for Optimization (NISCO 2010), (Eds. J. R. Gonzalez et al.), Studies in Computational Intelligence, Springer Berlin,284, Springer, 65-74 (2010)
- A SIMPLEX METHOD FOR FUNCTION MINIMIZATION - Nelder, J.A. and Mead, R. , Comput. J., 7, pp. 308 – 313

1. Initialize the bat population x
2. Define pulse frequency
3. Initialize pulse rates (r) and loudness (A)
4. While (t < Max number of iterations

   Generate new solutions by adjusting frequency and updating velocitiec and locations

   - If rand > r

   Select a solution among the best solutions. Generate a local solution around the best solution.

   - End if

   Generate a new solution by flying randomly

   - If rand < A and f(x_new < x_new_previous)

   Accept the new solution.

   - Elseif

   Neldera – Mead Method

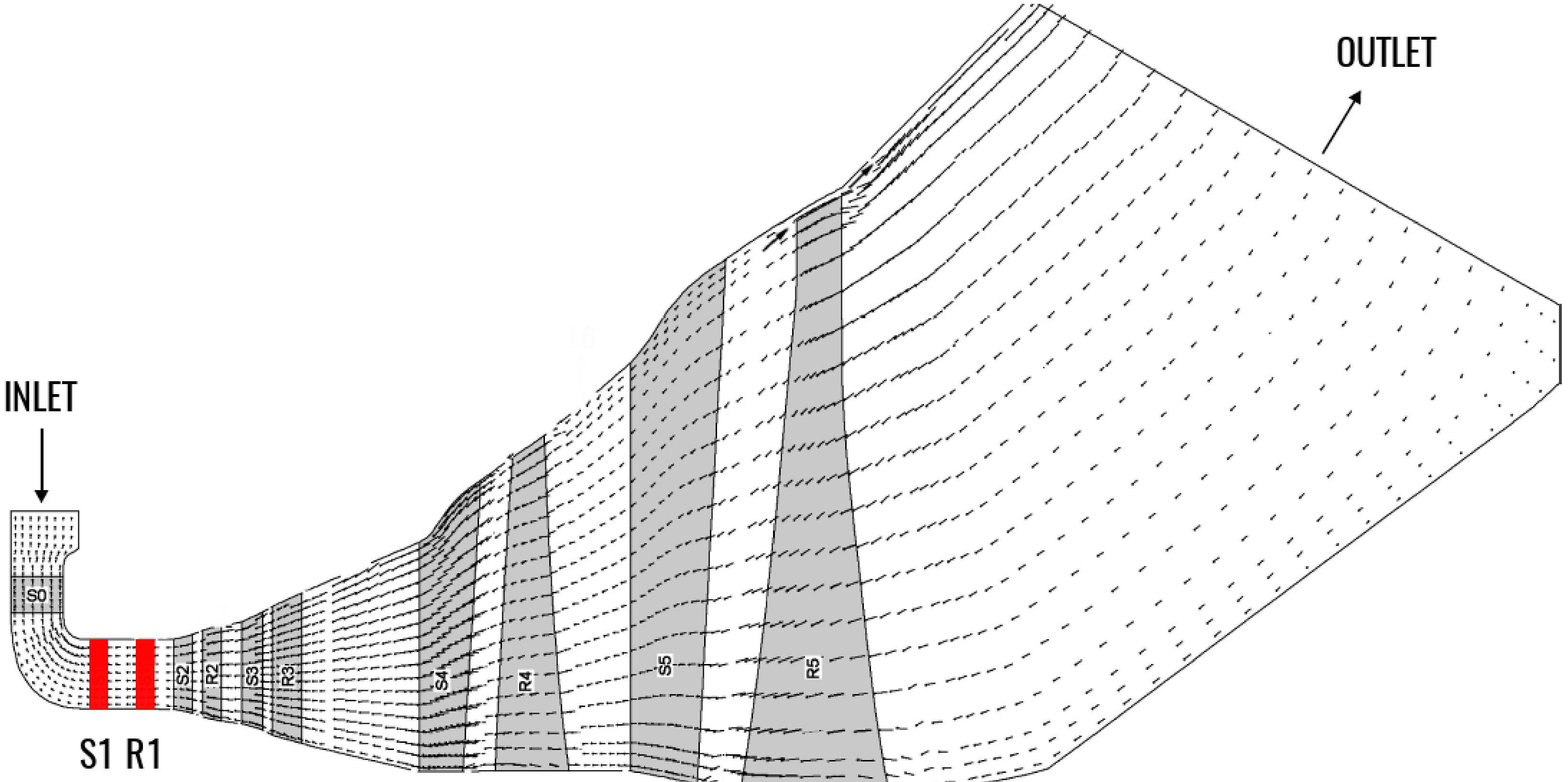
   - End if

   Rank the bats and find current best

5. End while

Case study – axial turbine

- LP part of steam axial turbine
- Number of stator blades - 202
- Number of rotor blades - 227
- Design parameters:
    - Rotational speed – 3000 rpm
    - Inlet pressure – 514 kPa
    - Inlet temperature – 537 K
    - Outlet pressure – 9 kPa
    - Mass flow – 135 kg/s
    - Working fluid - water



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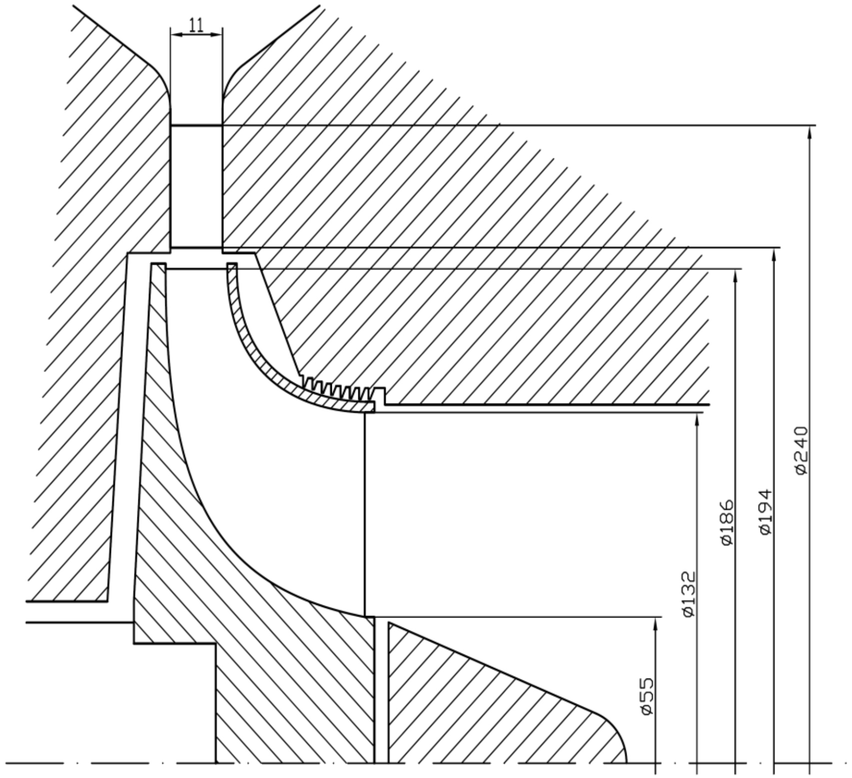
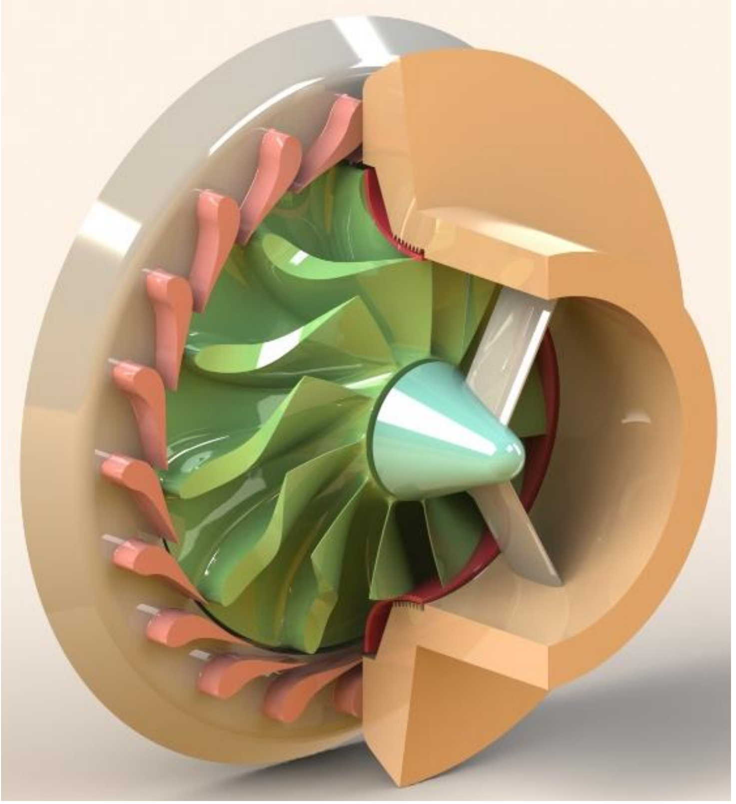
Case study – radial-axial turbine

- 1 stage, axial-radial air turbine
- Number of stator blades - 20
- Number of rotor blades - 11
- Design parameters:
    - Rotational speed – 44000 rpm
    - Inlet pressure – 701 kPa
    - Inlet temperature – 476.95 K
    - Outlet pressure – 101 kPa
    - Mass flow – 1.48 kg/s
    - Working fluid - air





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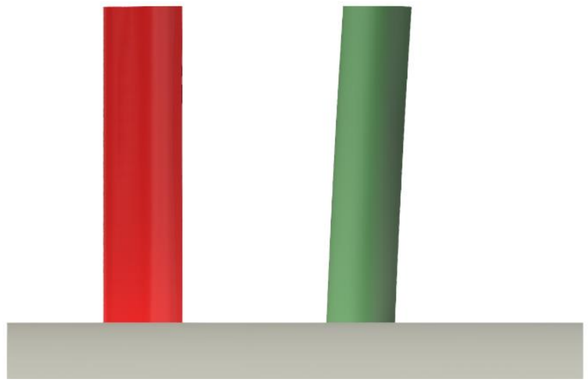
Parametrization – axial turbine

- Parametrization is a **key to success** of optimisation
- B-spline function with control point at the medium height of blade and blade tip
- 12 changing points (6 stator, 6 rotor)

2



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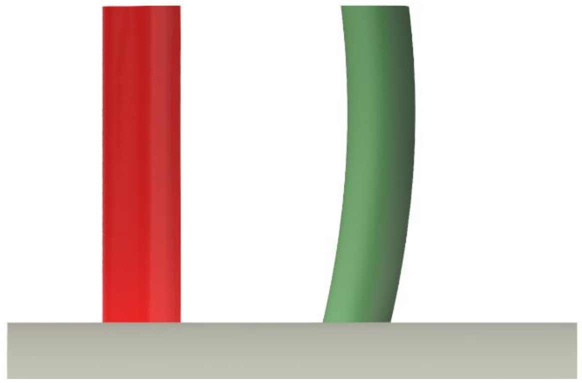

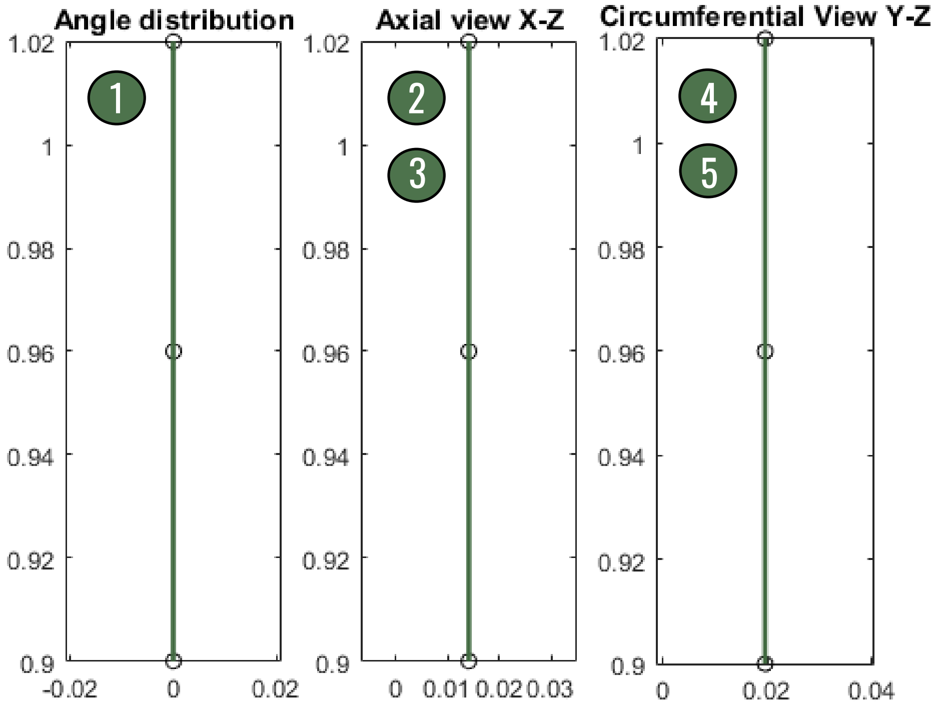

1. Blade twist angle
2. Blade simple axial lean
3. Blade compound axial lean
4. Blade simple circumferential lean
5. Blade compound circumferential lean

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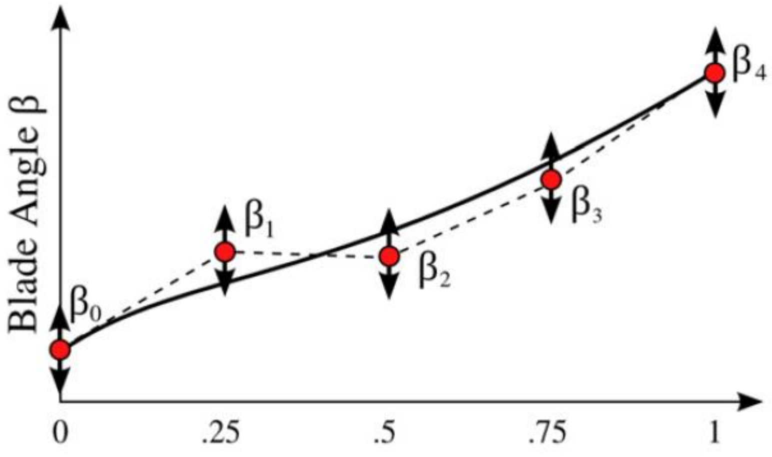
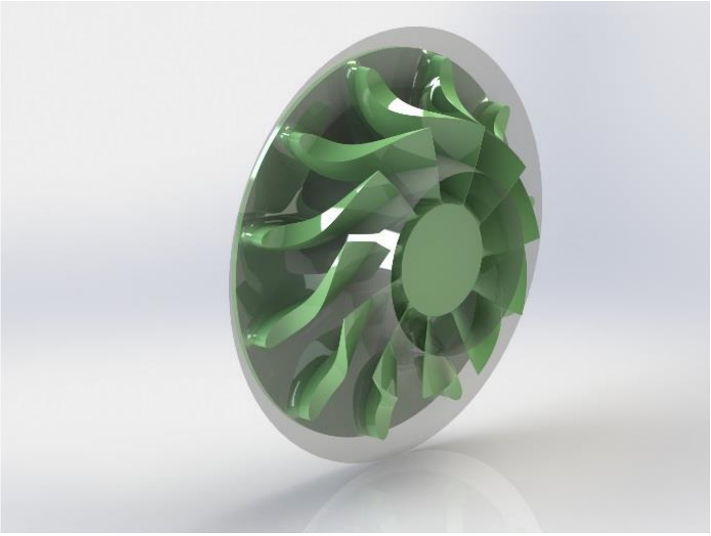
Parametrization – radial-axial turbine

- The blade camber line at the hub, the medium height of blade and blade tip is defined by the blade angle β
- The β – distribution is parametrized by a Bezier curve with five control points, one each at leading and trailing edge
- 15 changing points





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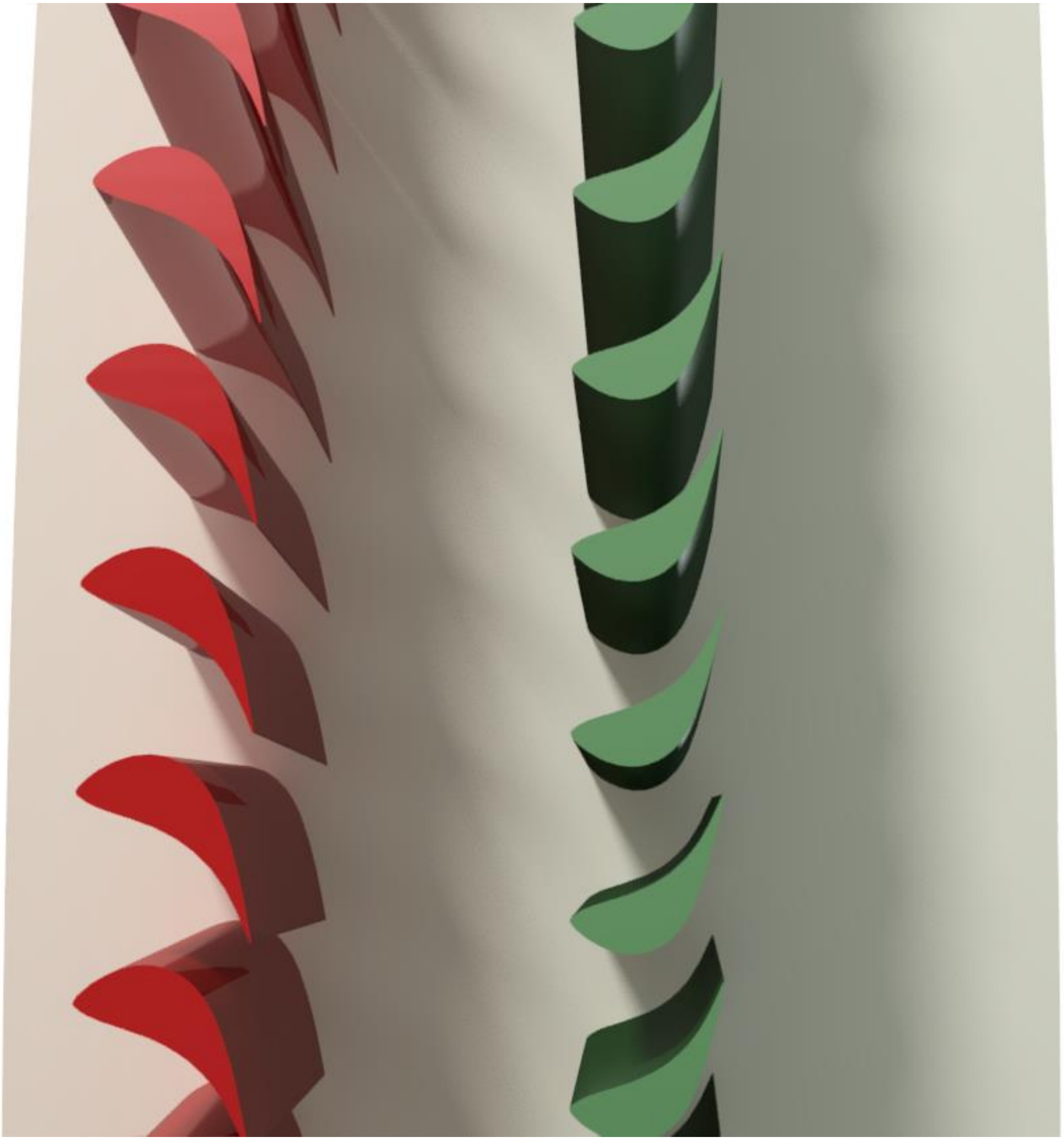
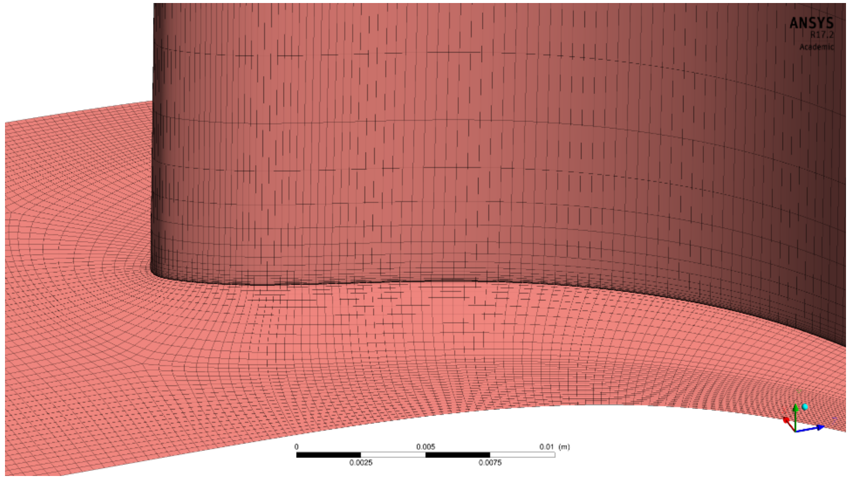
Methodology

- RANS (Reynolds-averaged Navier-Stokes) stationary simulations in ANSYS CFX
- k-ω SST turbulence model
- Periodicity conditions
- ANSYS Turbogrid software is used for meshing
- Boundary conditions:
  - inlet – total pressure , total temperature
  - outlet – static pressure
  - other – rotational speed

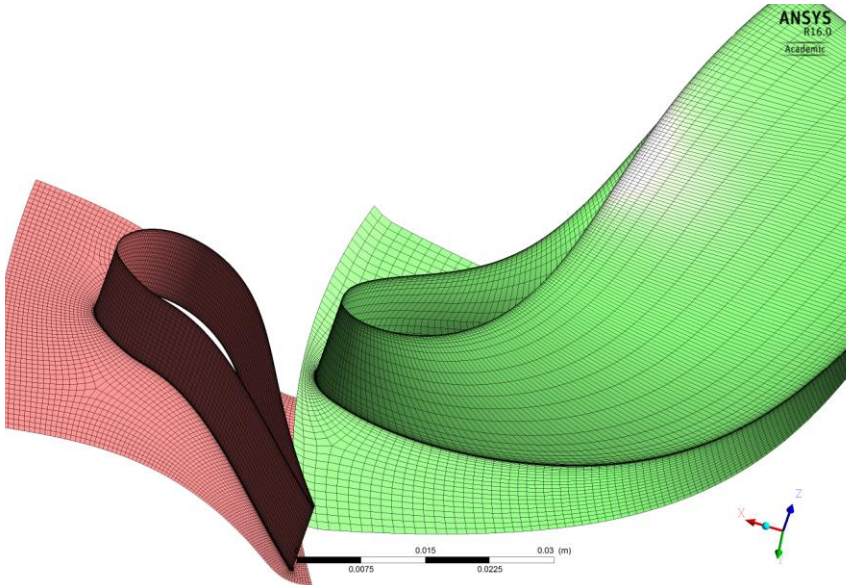


Discretization

- Topology definition – Single Round Round Symmetric
- Mesh limits:
  - Maximum face angle - 165°
  - Minimum face angle - 15°
  - Maximum volume ratio - 20
  - Edge length ratio – 1000
- Number of elements:
  - Optimisation task – 0.5 mln
  - Verification task – 2 mln – 20mln

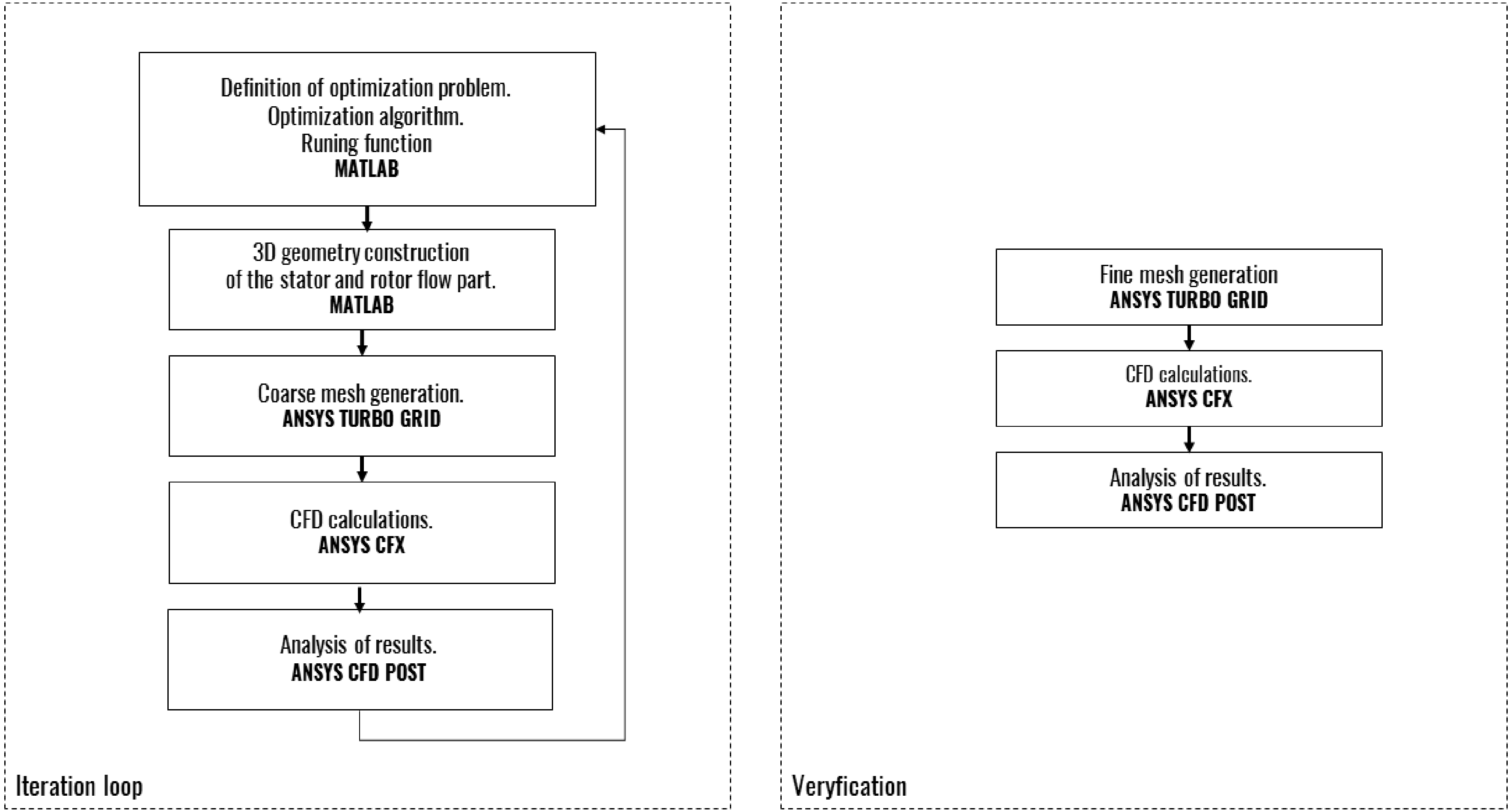


Mesh – 2 mln elements in stage



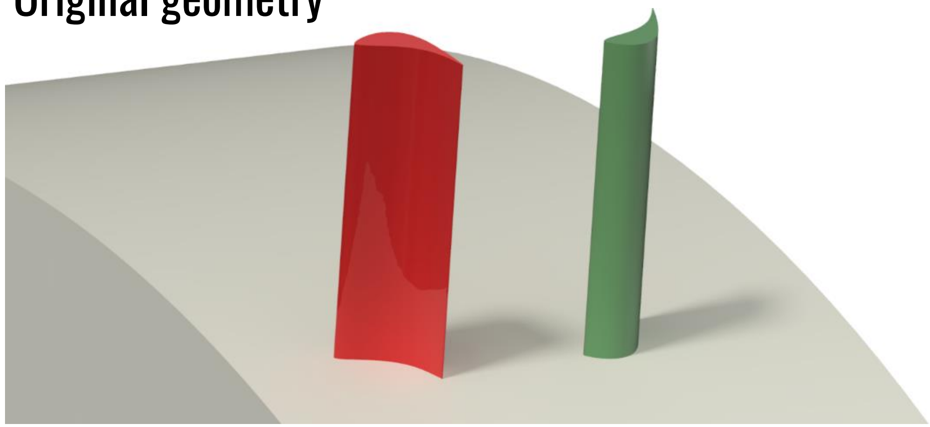
Mesh – 0.5 mln elements in stage

Scheme of optimization & verification

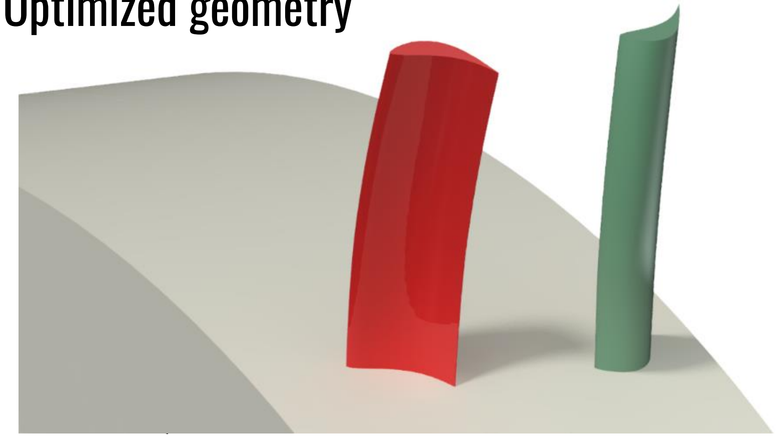


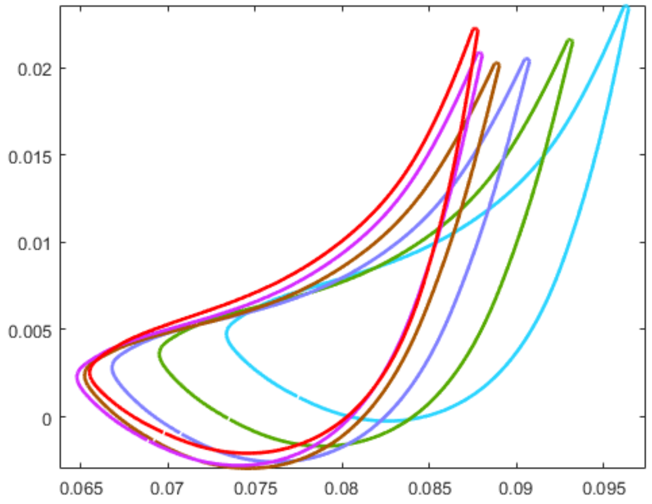
Results – axial turbine

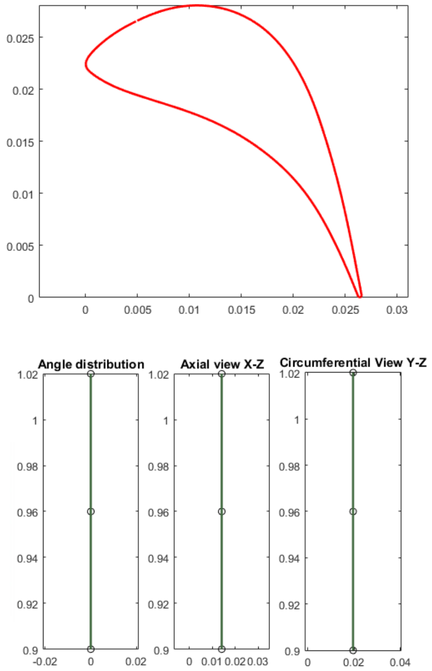
Original geometry

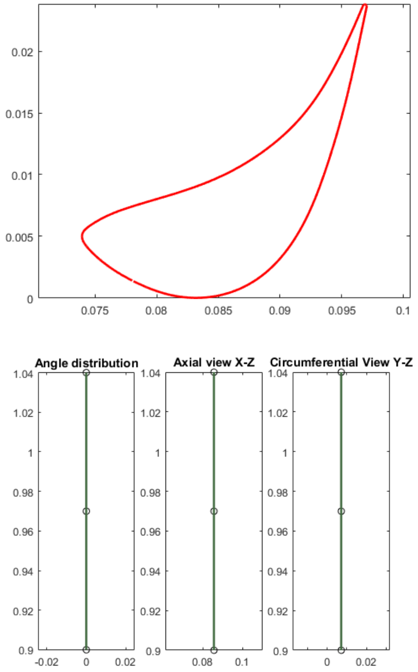


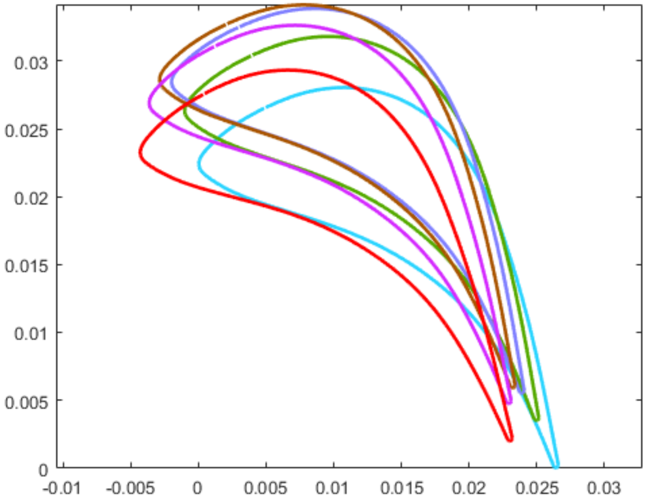
Optimized geometry

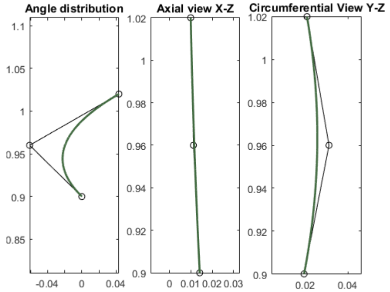


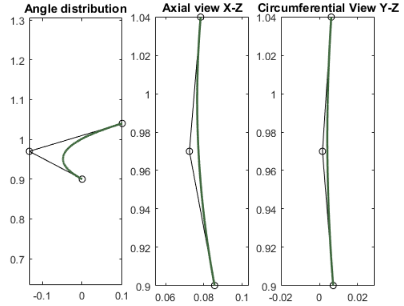












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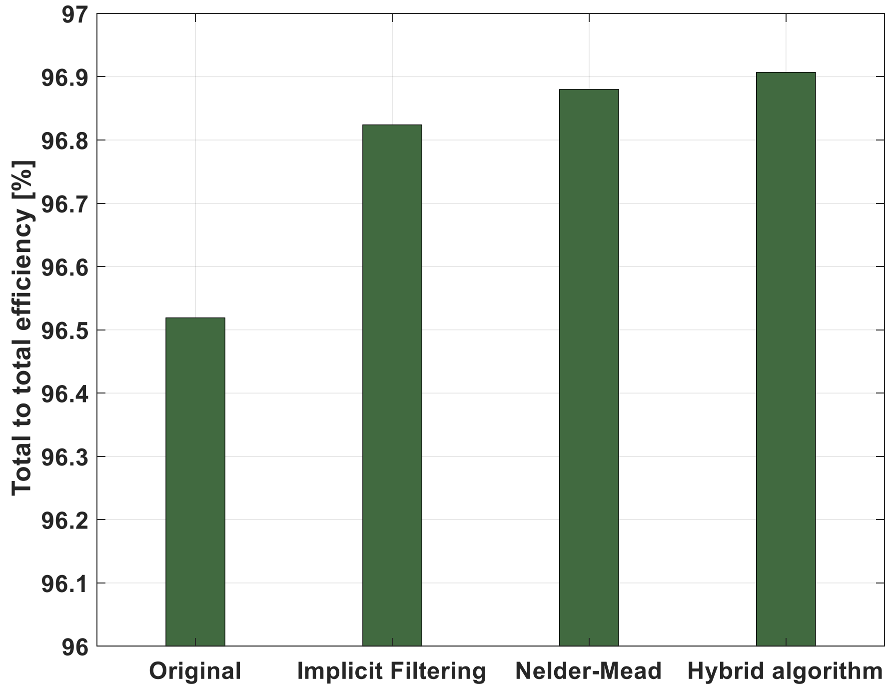
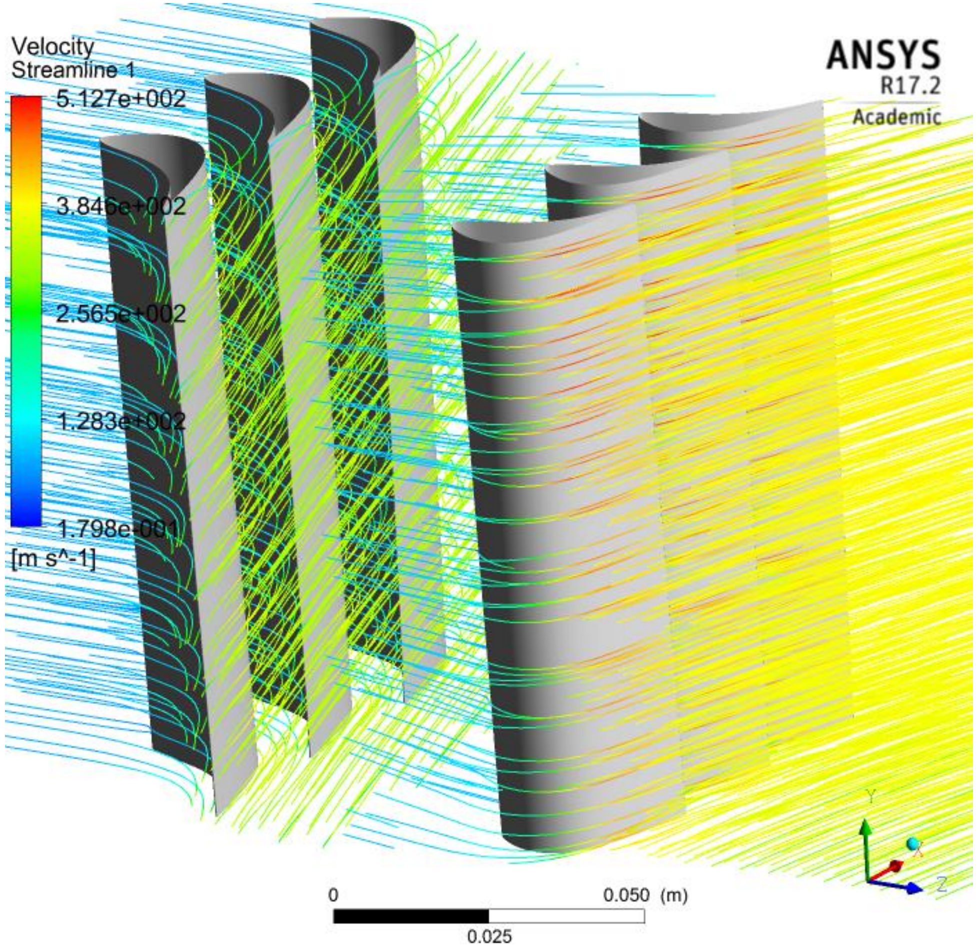
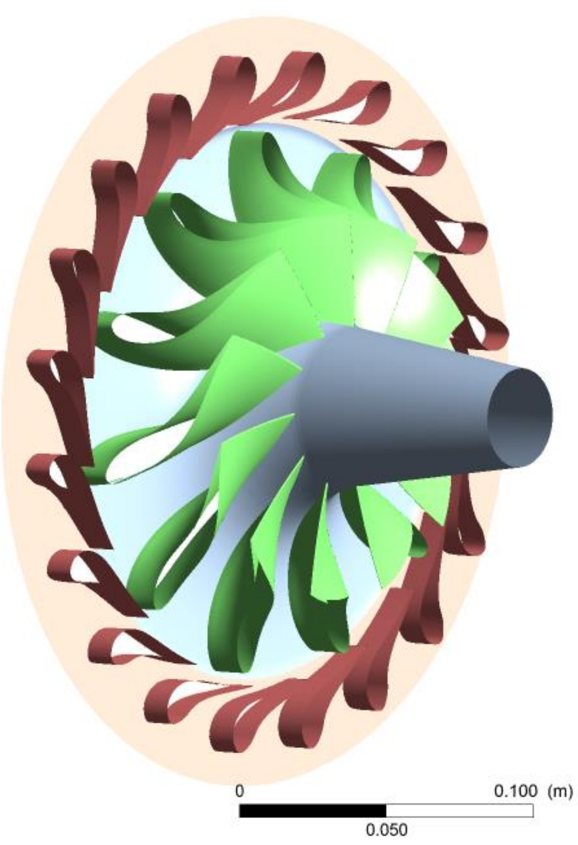
Results – axial turbine



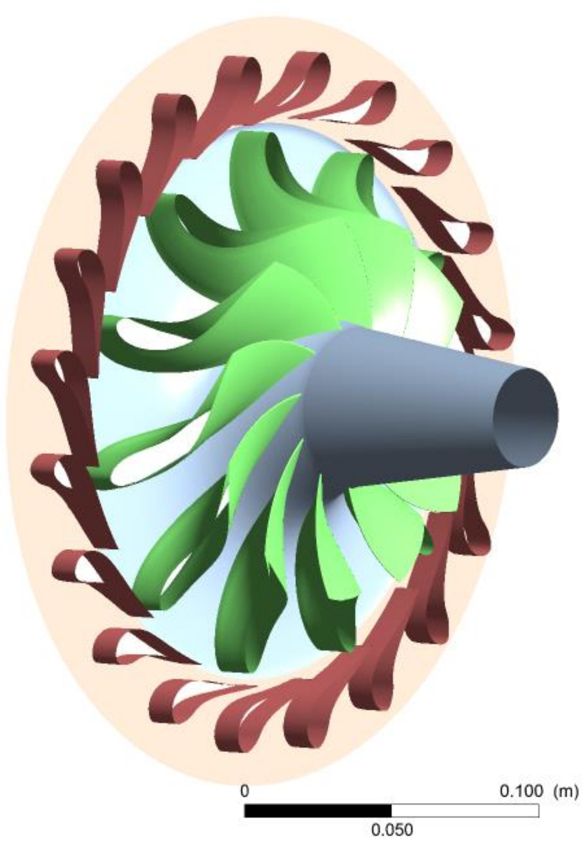
Comparison of total to total efficiency of orginal and optimized geometries



Results – radial-axial turbine



Original



Optimized

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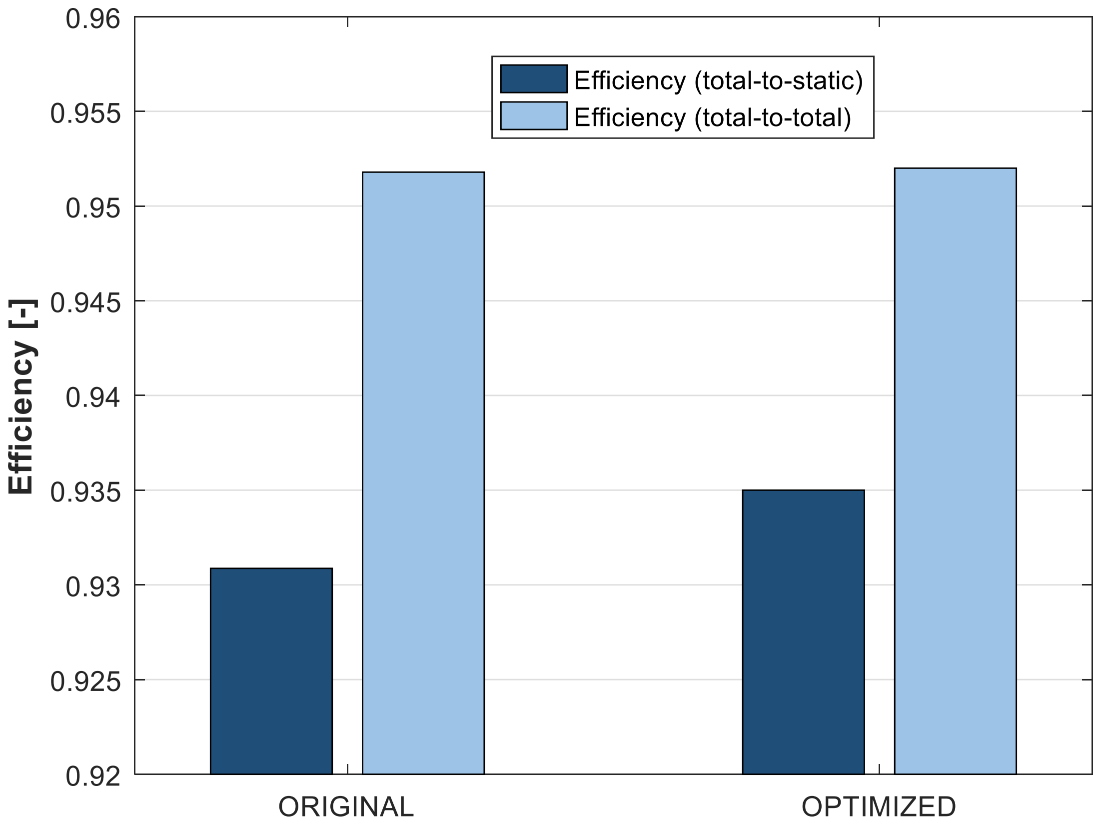

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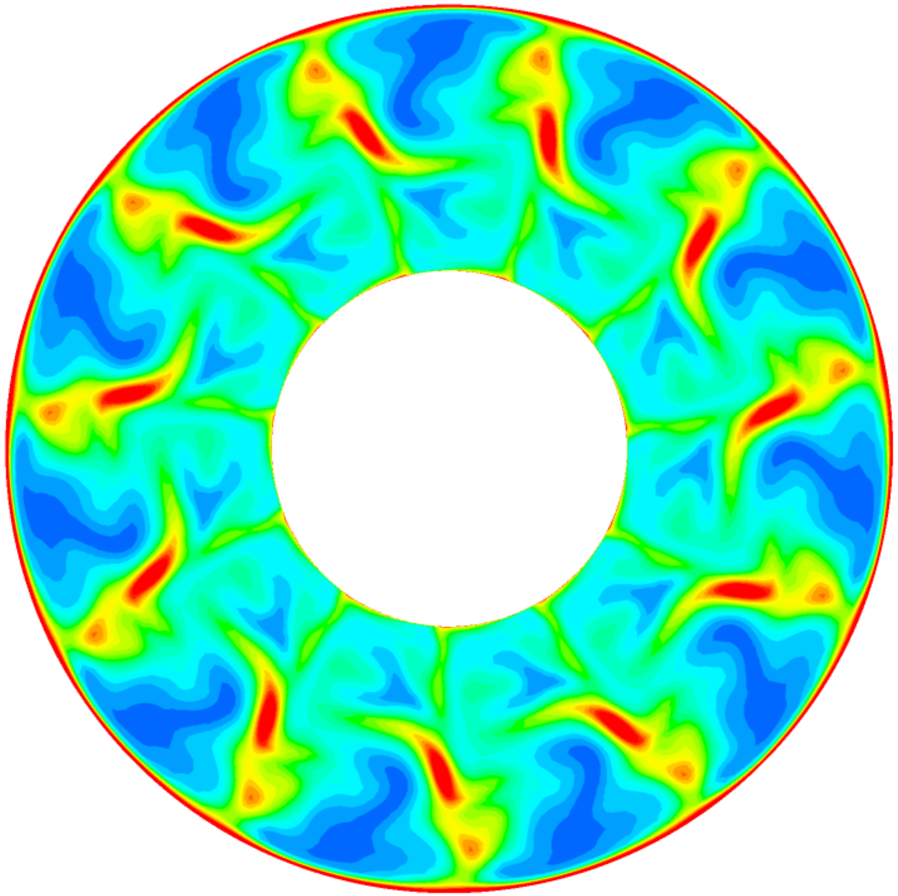
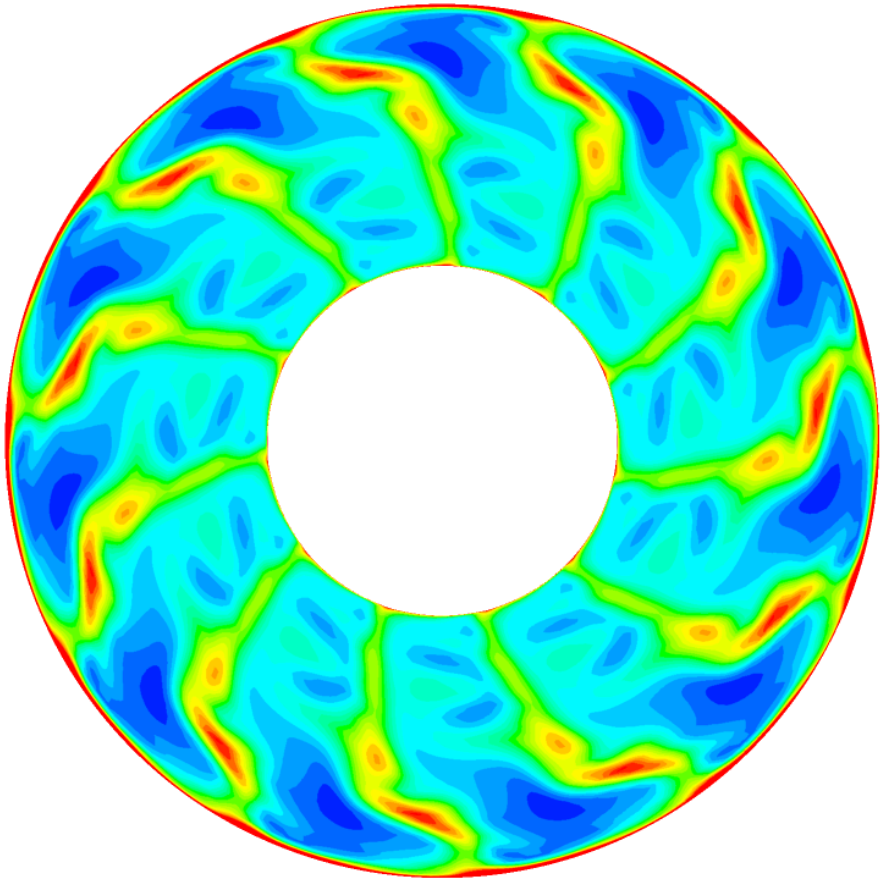


Original



Optimized

Conclusion

- The results show an improvement of objective function
- The hybrid algorythm are suitable for turbine optimization
- Finding the global minimum is very difficult and time-consuming
- The algorithm needs some changes to avoid unnecessary calculation of objective function
- Future studies should take into account new parametrization:
  - number of blades
  - meridional contour
- New algorithms will be implemented

Thank you!

Acknowledgements

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