A HYBRID APPROACH TO OPTIMISATION OF UNDERWATER COMPRESSED AIR ENERGY STORAGE TURBINE

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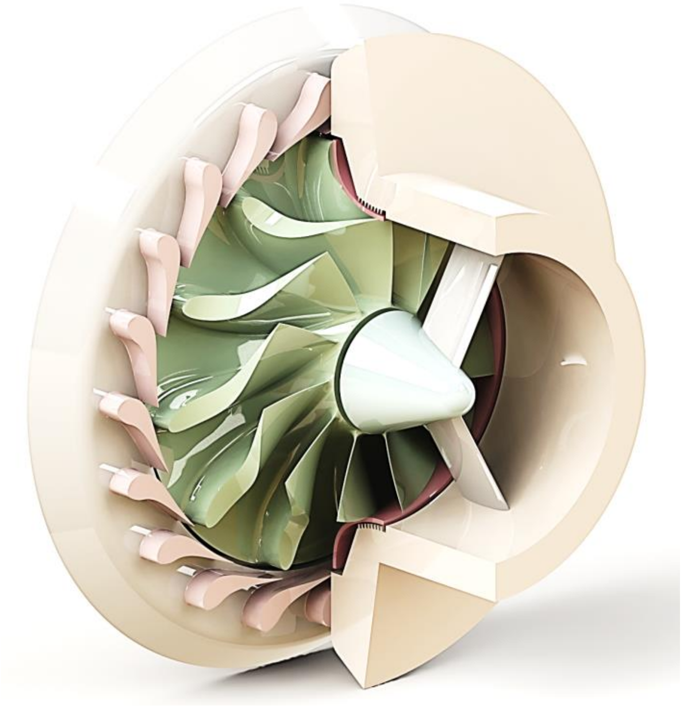
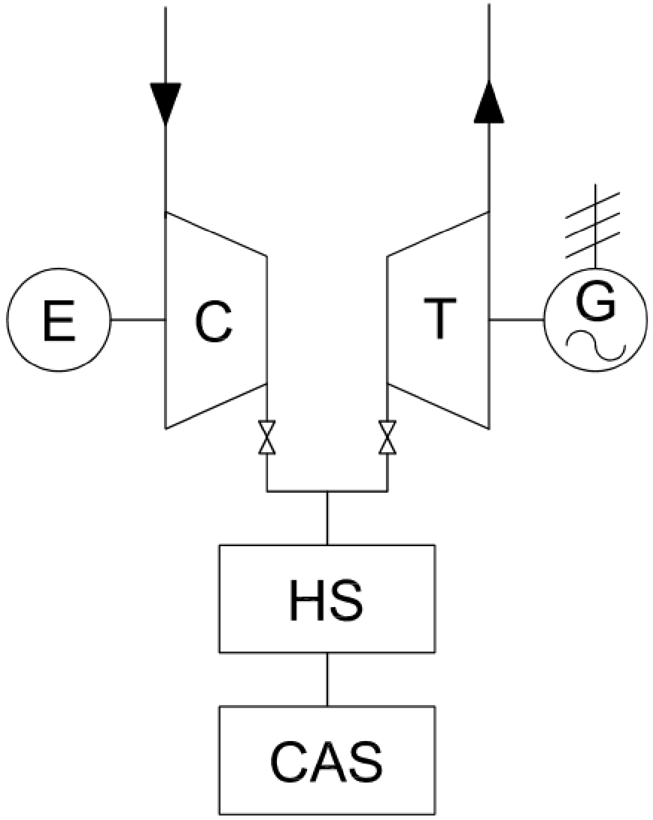


Introduction and Motivation

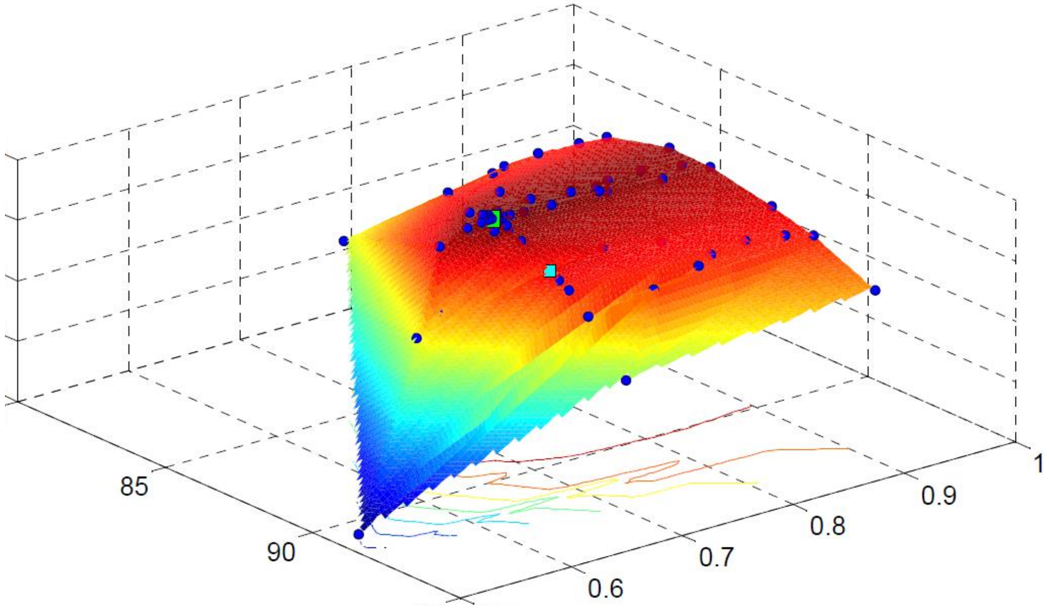
- Pumped-hydro storage systems (PH), Battery, Compressed Air Energy Storage (CAES)
- UWCAES (Underwater Compressed Air Energy Storage)
- Constant pressure, low-cost air storage, easy to expand
- Hydrostor, Canada (Ontario), 6 underwater balloons, 400m^2, 1320 kWh
- Optimisation allows us to improve efficiency of the machines



E - engine T - turbine G - generator
HS - heat storage
CAS - compressed air storage

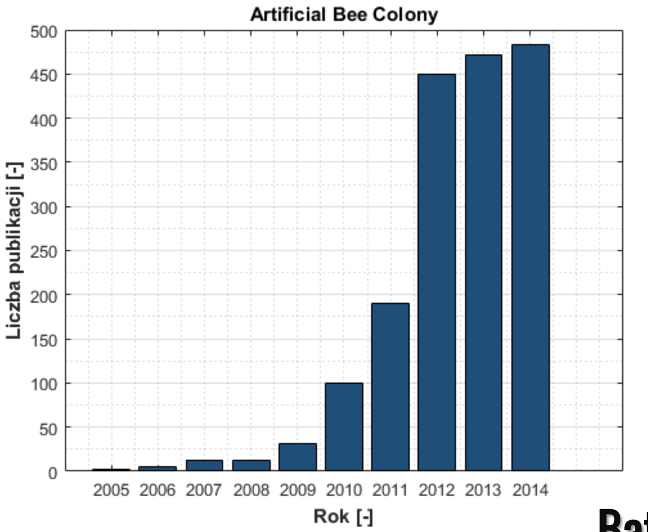
Optimisation

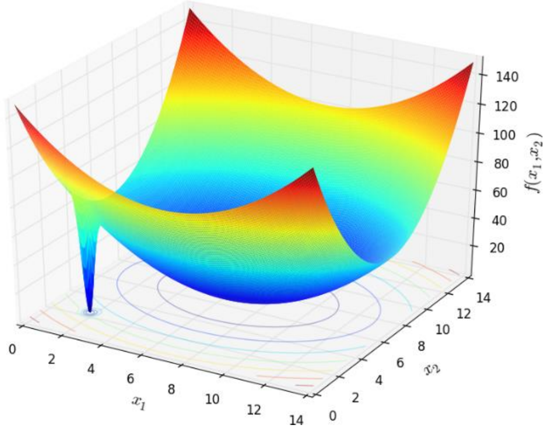
- Procedure for finding maximum/minimum of objective function
- Objective function, penalty function, boundaries
- Methods of optmisation – wide range
- Reduction of flow losses:
  - profile loss
  - boundary loss
  - exit kinetic energy losses

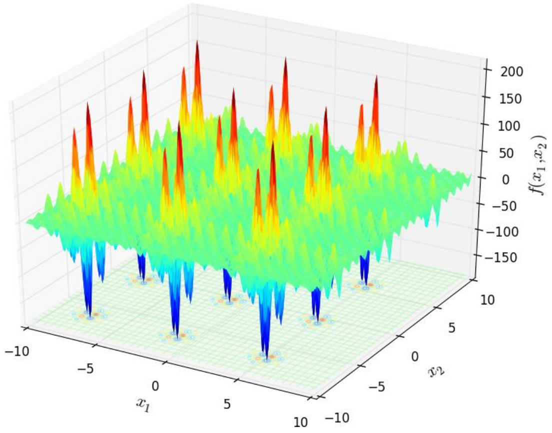


Methods of optimisation

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







- Hybrid methods:

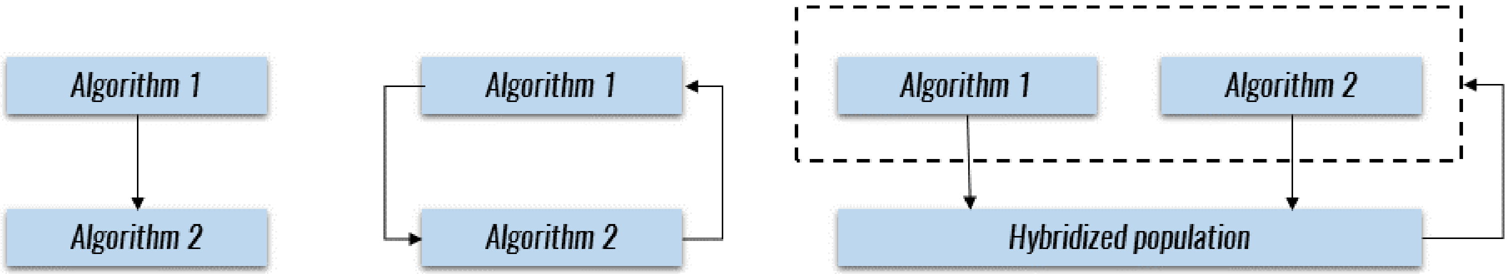
Bat algorithm
Cuckoo Search
Glowworm swar optimization
Grey wolf optimizer
Spider Monkey Optimization

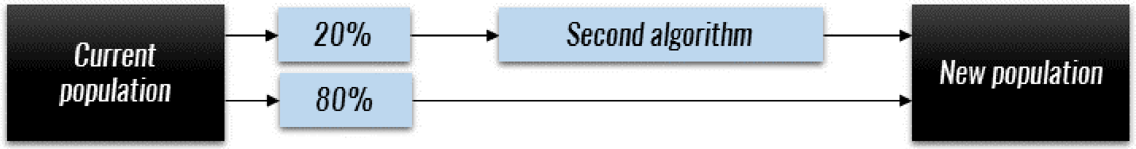
+

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, coputational speed





Hybrid algorithm

- 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

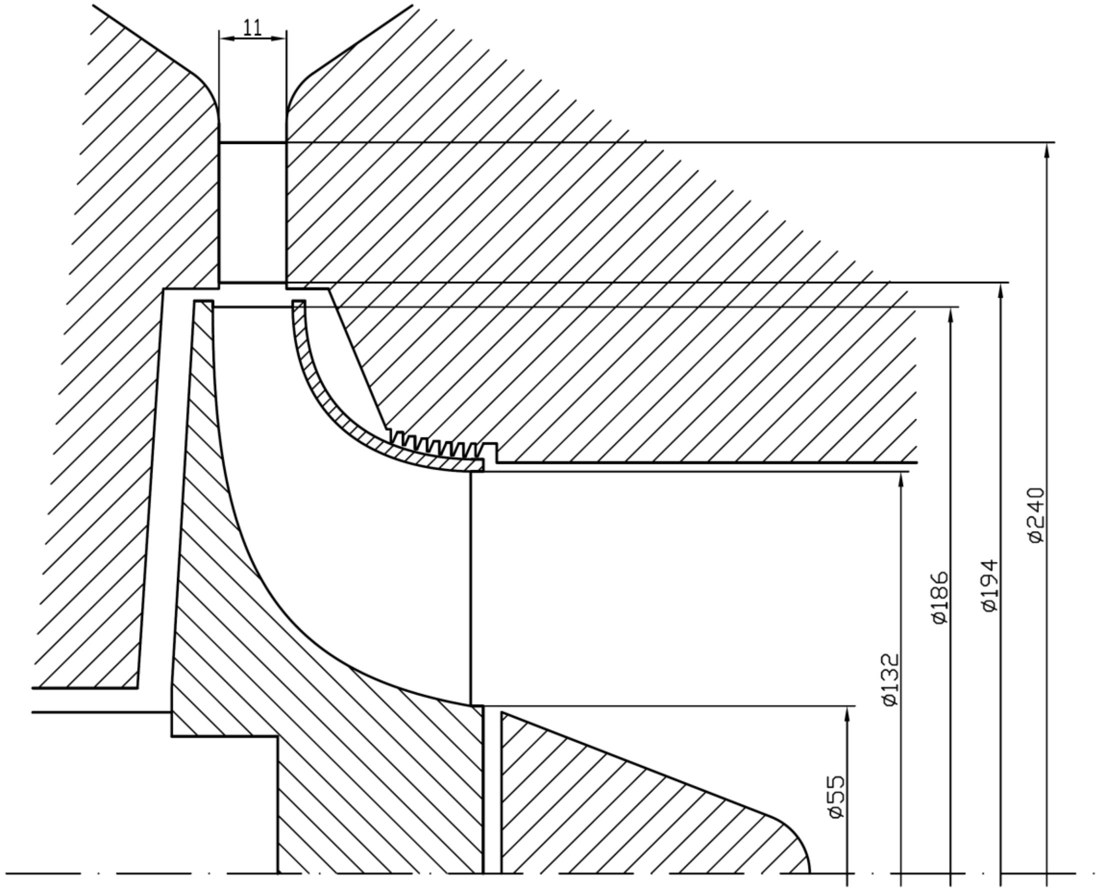
   Rank the bats and find current best

5. End while

Case study

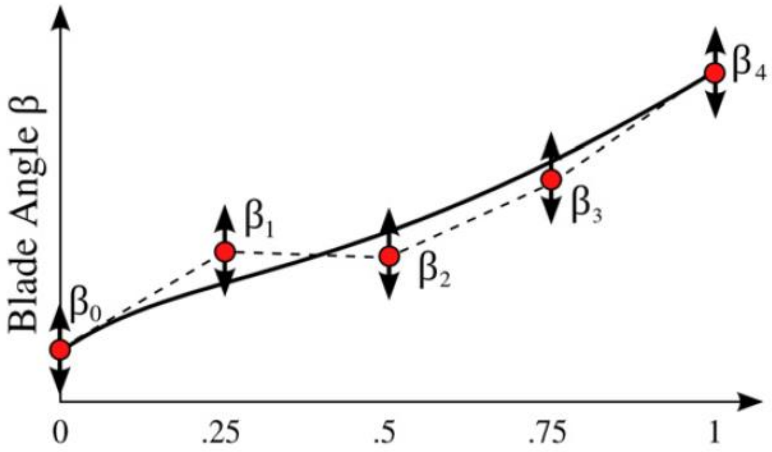
- Radial – axial air turbine, 1 stage
- Number of rotor blades - 11
- Number of stator blades – 20
- Design parameters:

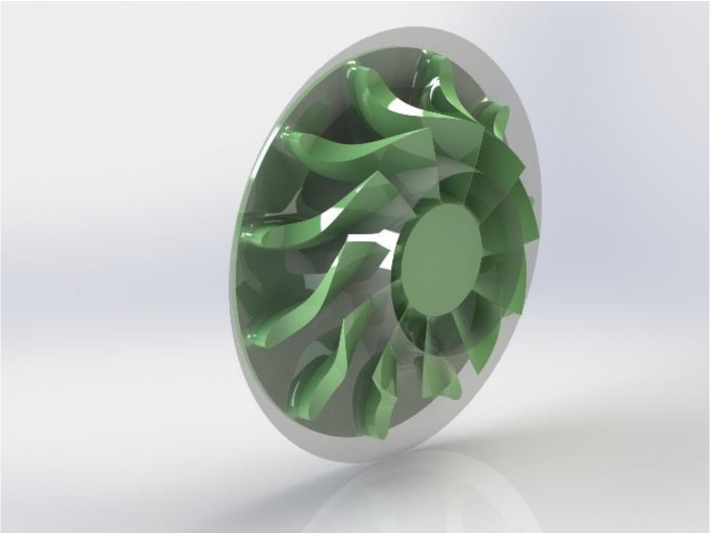
Rotational speed	44000 rpm
Inlet pressure	701.54 kPa
Inlet temperature	476.95 K
Outlet pressure	101.33 kPa
Mass flow	1.48 kg/s
Power	270 kW



Parametrization

- Parametrization is a **key to success** of optimsation
- 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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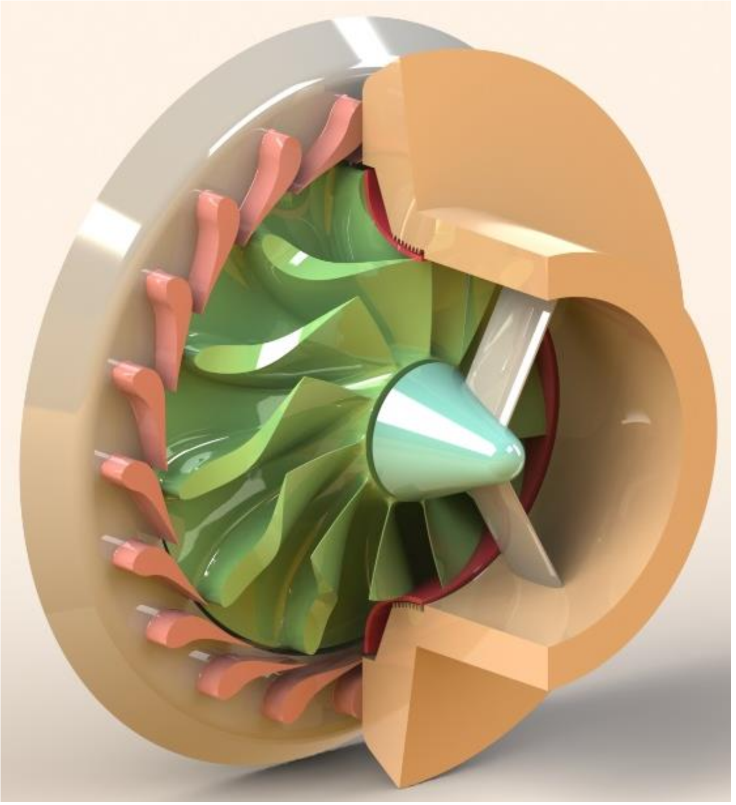
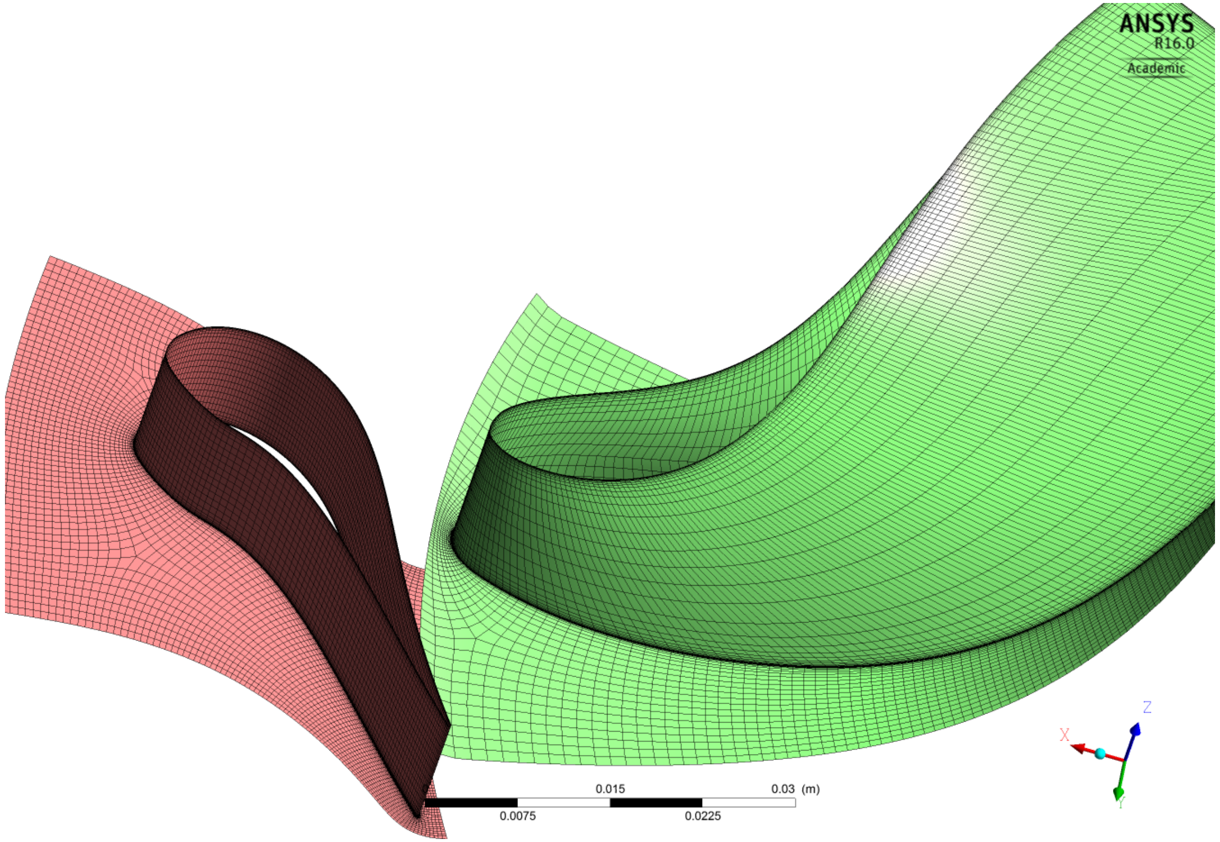
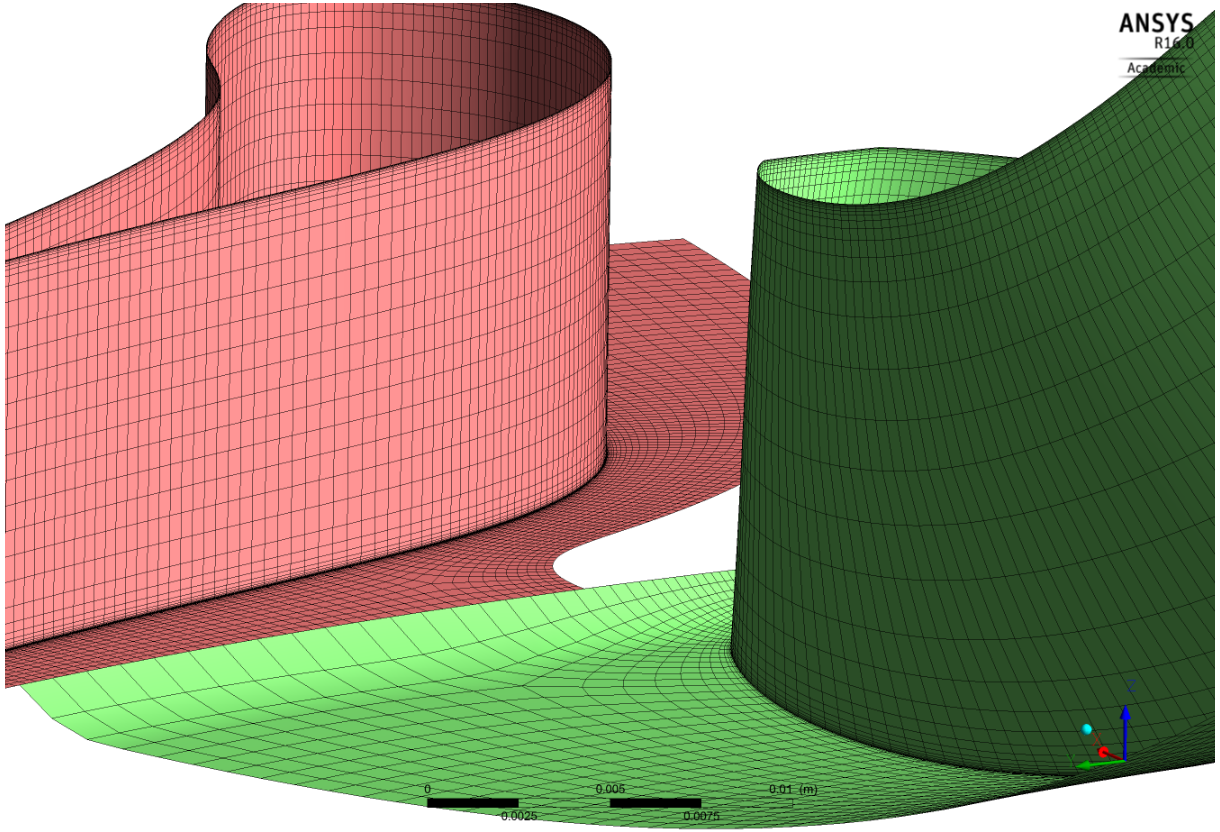
Methodology

- RANS *(Reynolds-averaged Navier-Stokes) stationary* simulations in ANSYS CFX v.16
- *k-ω SST turbulence model*
- Periodicity conditions
- ANSYS Turbogrid v.16 software is used for meshing
- Boundary conditions:
  - inlet – total pressure , total temperature
  - outlet – static pressure
  - other – rotational speed



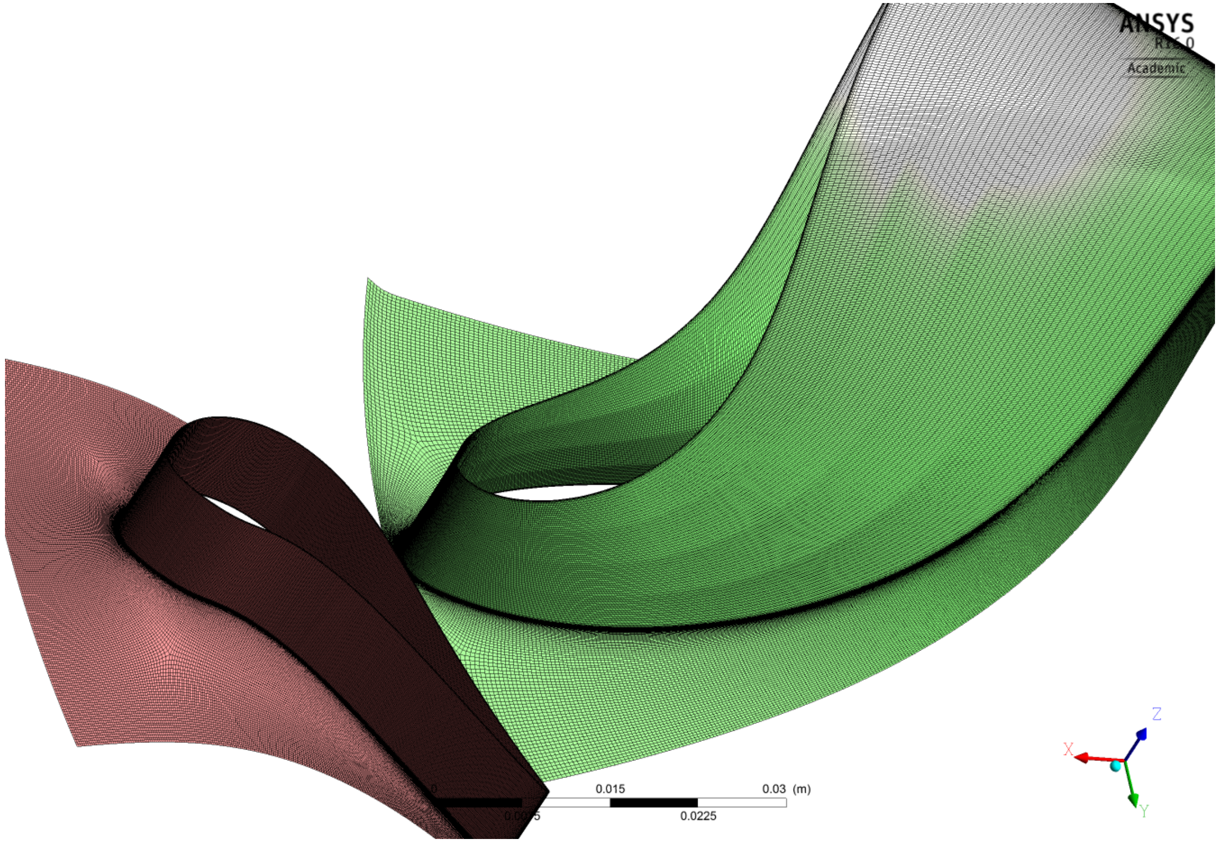
Discretization

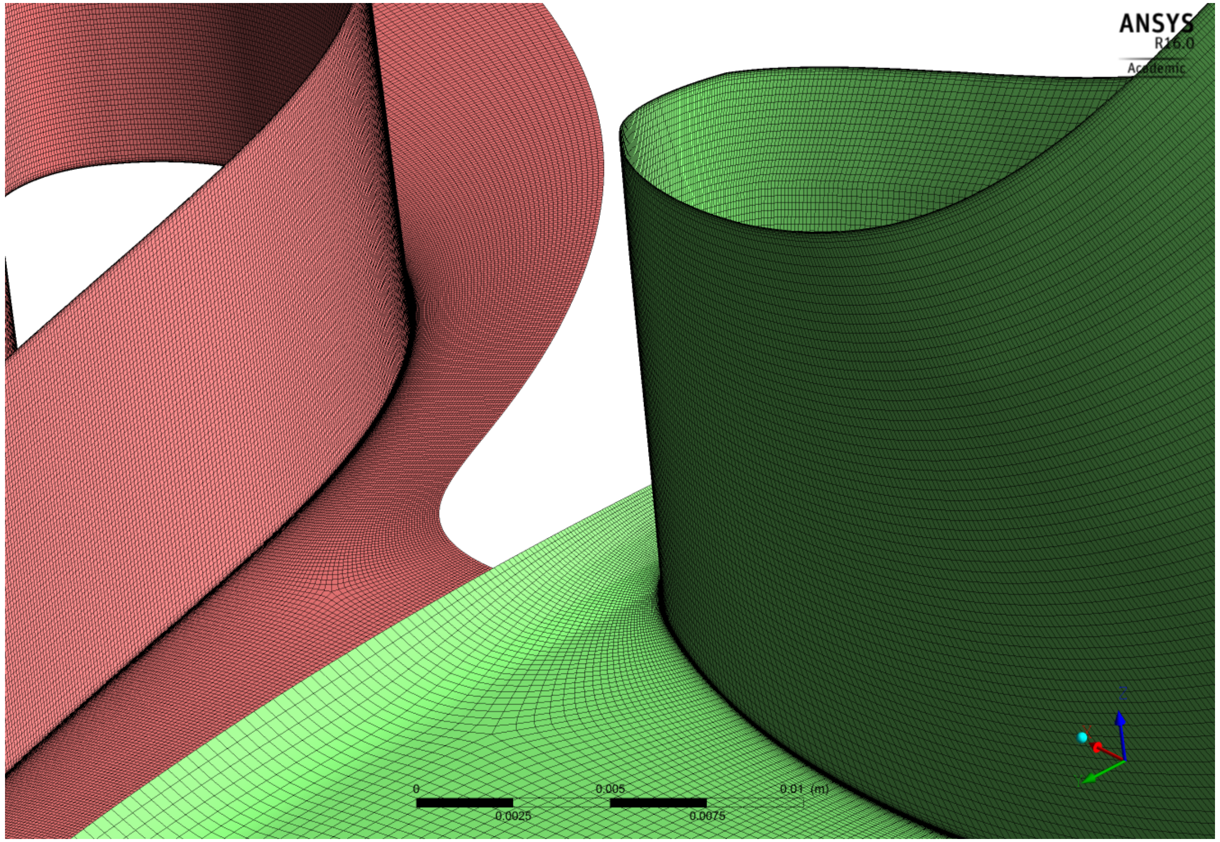




Mesh – 0.6 mln elements in stage

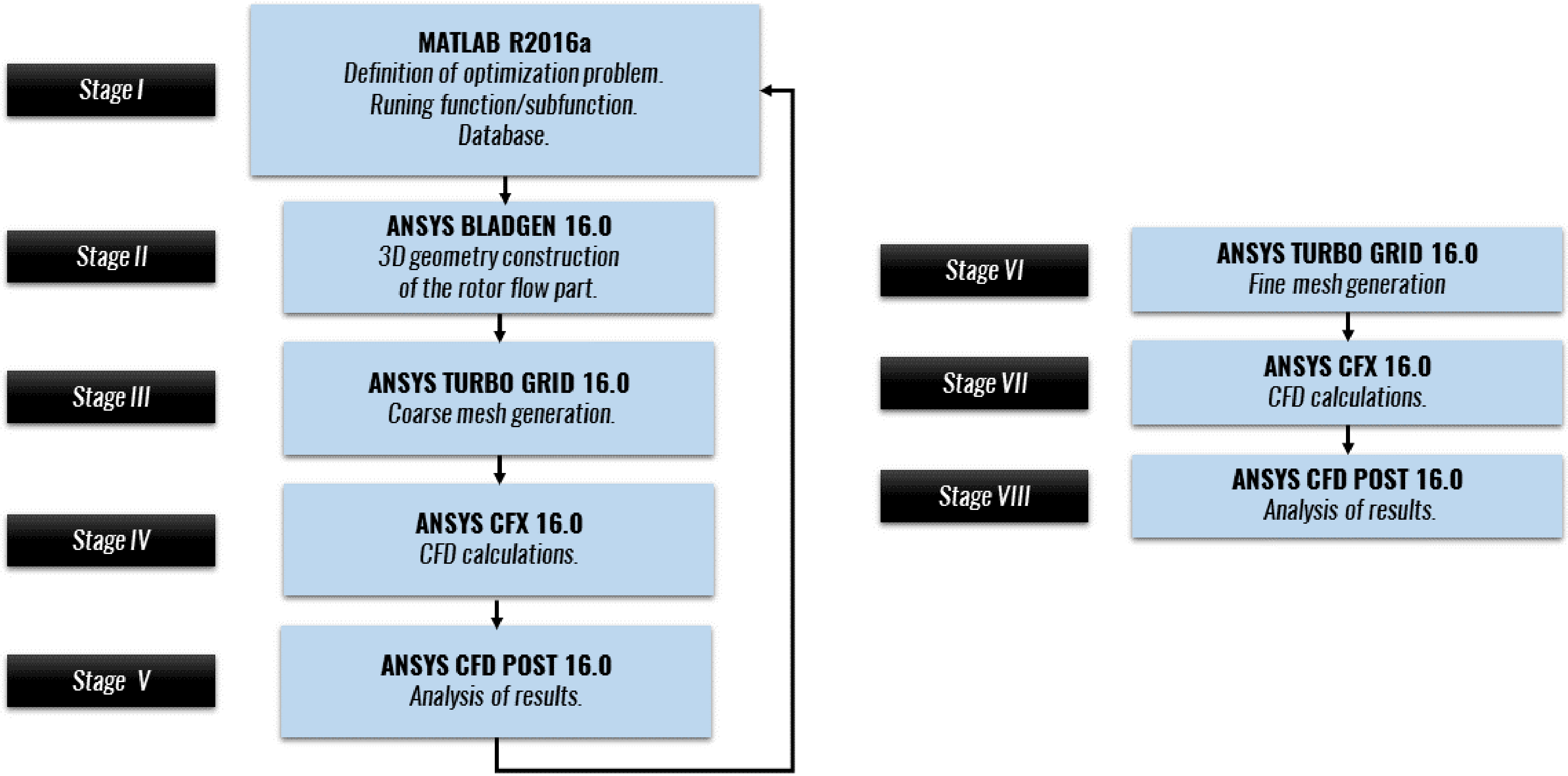
Discretization



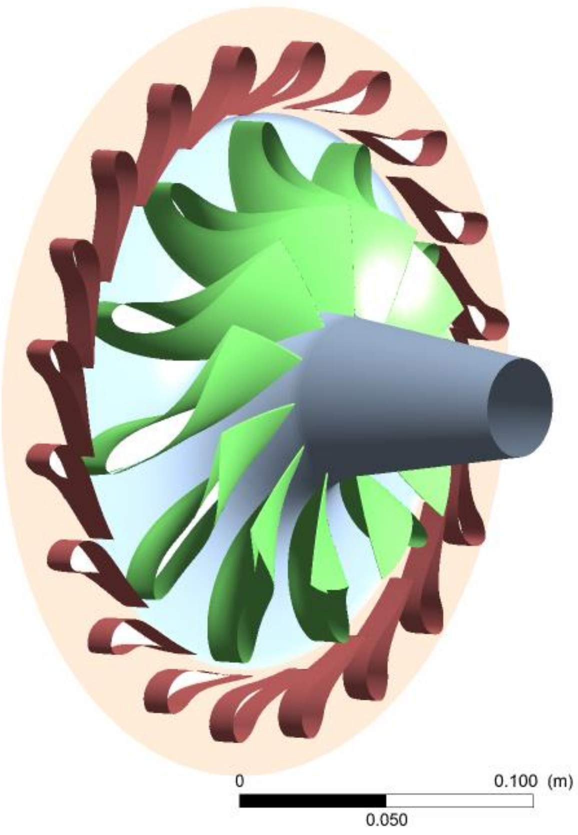


Mesh – 20 mln elements in stage

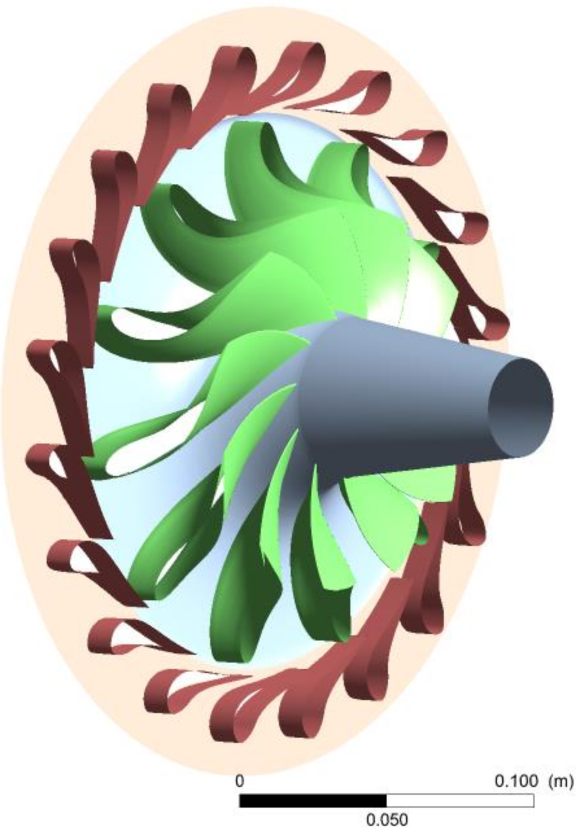
Scheme of optimization & verification



Results



Original



Optimized

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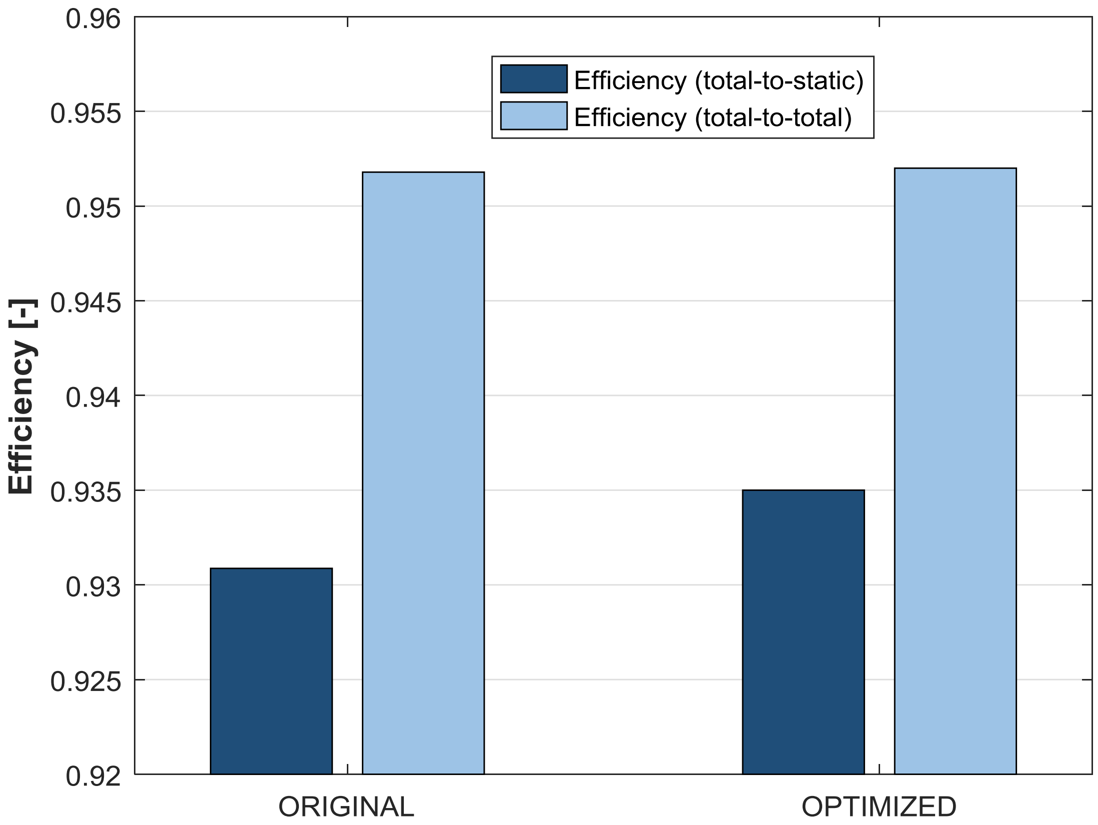
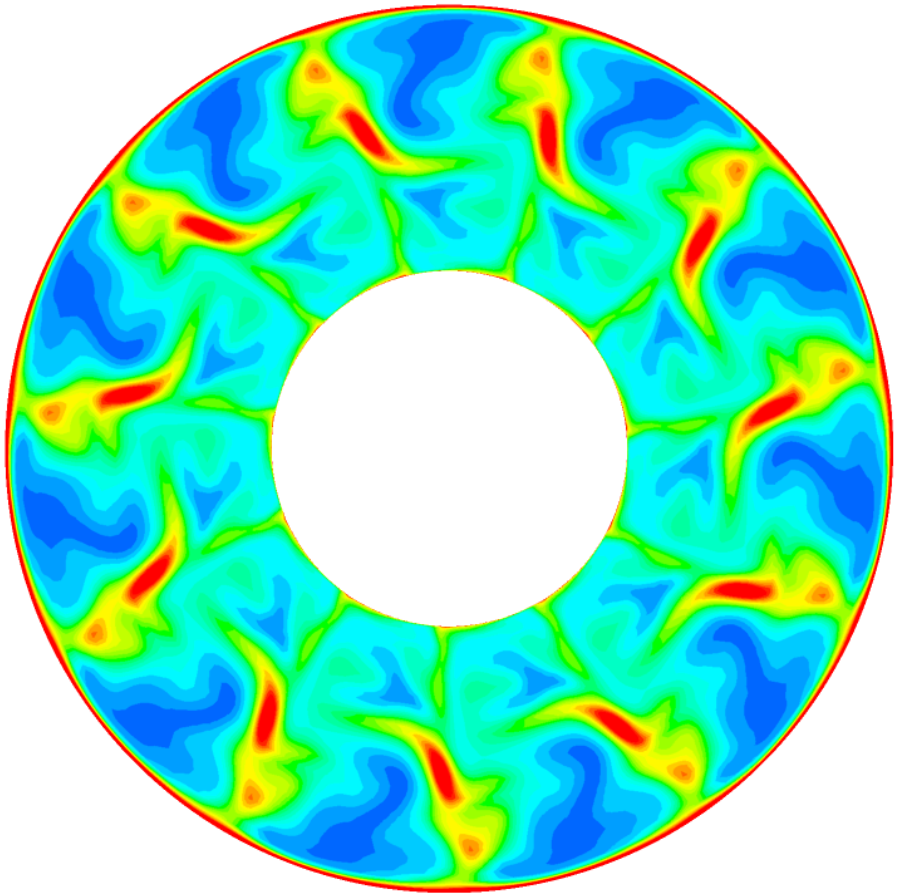
11th Conference of sustainable development of energy, water and environment systems, 4-9.09.2016r.

Results

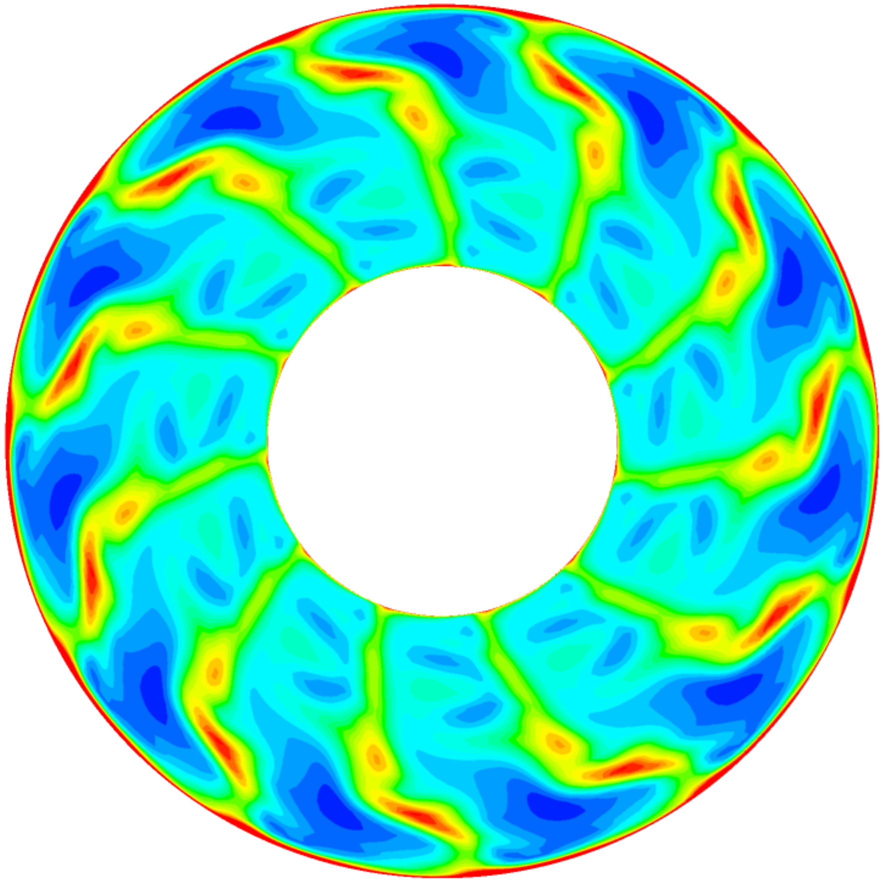


Efficiency (total-to-static)
Efficiency (total-to-total)
Efficiency [-]
0.96
0.955
0.95
0.945
0.94
0.935
0.93
0.925
0.92
ORIGINAL
OPTIMIZED

Results



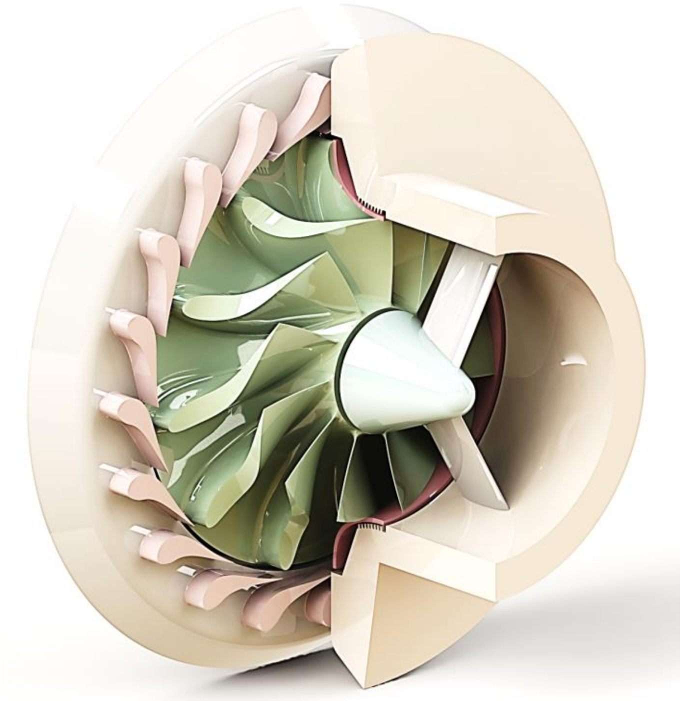
Original



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



Thank you!

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