IMP PAN GDAŃSK
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TURBINE
DEPARTMENT

OPTIMISATION OF AXIAL TURBINE FOR A SMALL SCALE WASTE HEAT RECOVERY ORC SYSTEM

13th sdewes Conference Palermo 2018

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TURBINE DEPARTMENT – CENTRE OF HEAT AND POWER ENGINEERING

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Plan of presentation

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3. Case study
4. Parametrization
5. Methodology
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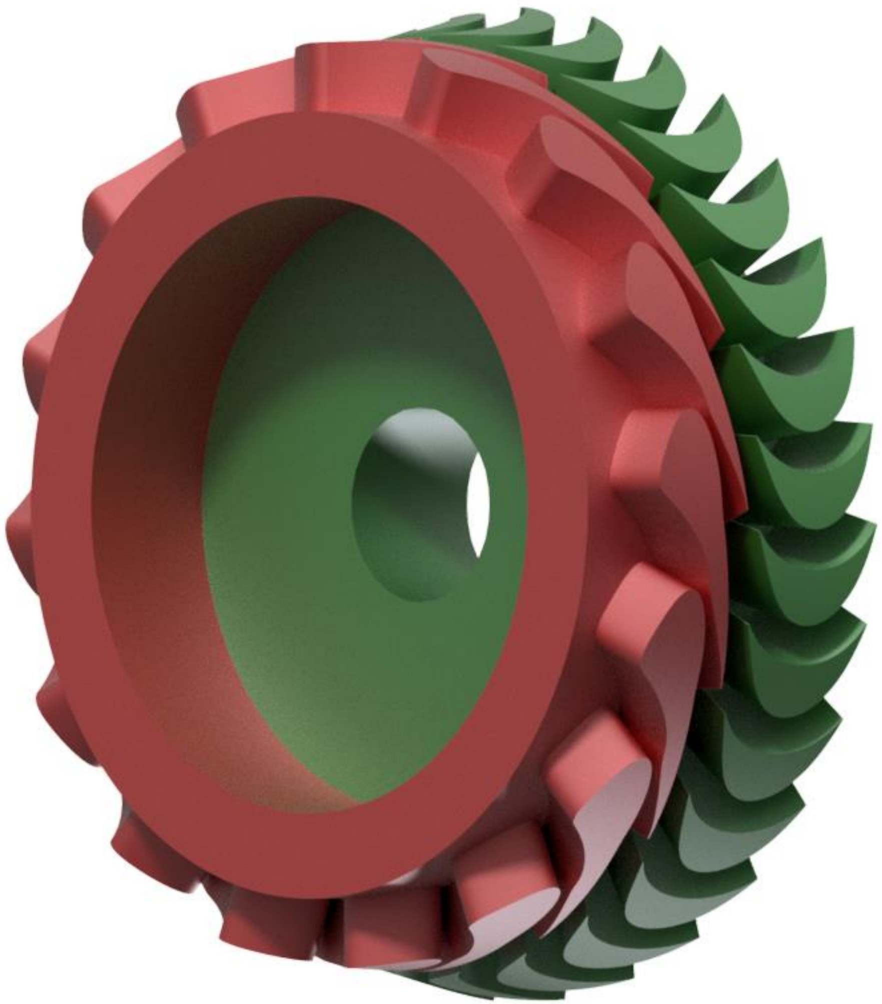
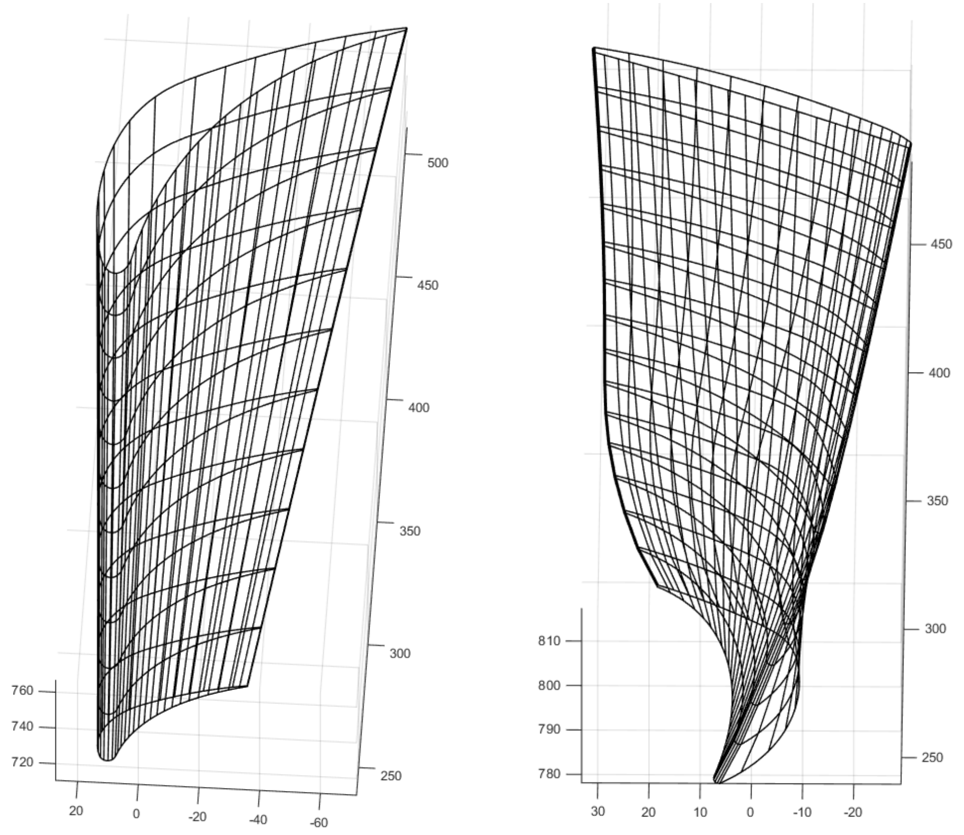


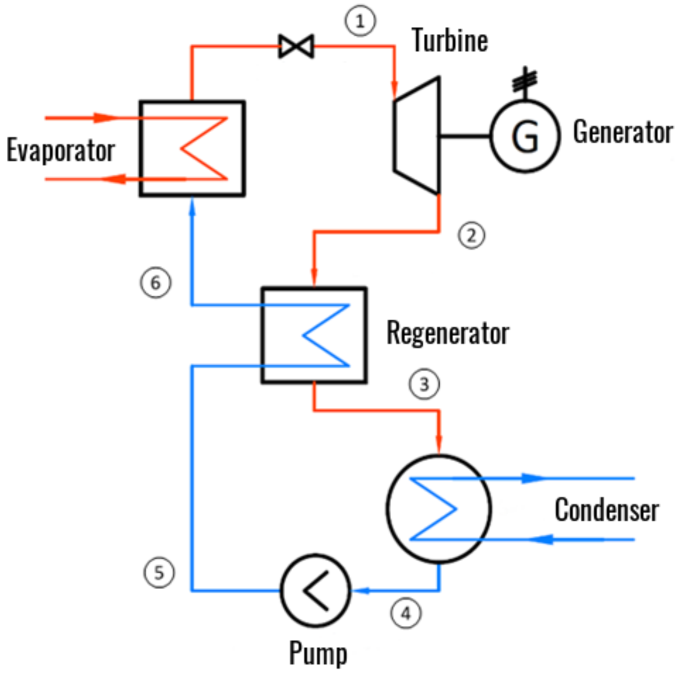
Introduction

Selecting the best solution of a given problem with respect to the given criteria. Finding the extreme of a given function (or functions) in the given design variables domain.

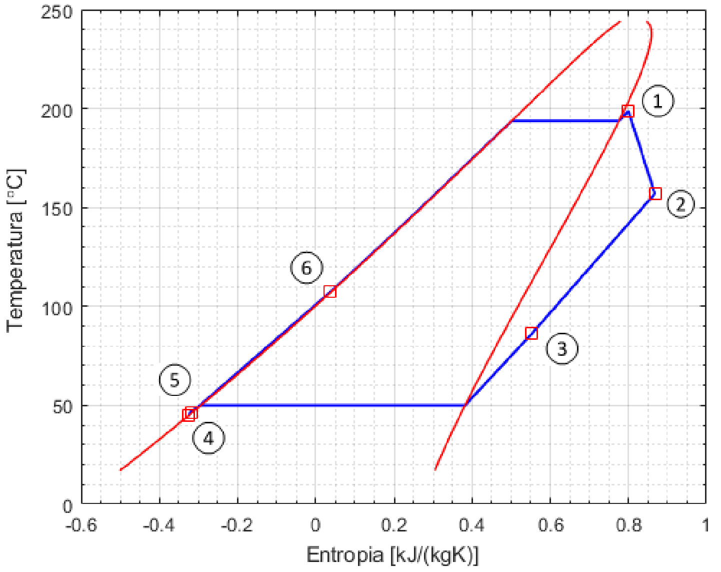
- Optimisation allows us to improve efficiency of the machines
- Procedure for finding maximum/minimum of objective function
- Objective function, penalty function, boundaries
- Methods of optimisation – wide range
- Reduction of flow losses:
    - profile loss
    - boundary loss
    - exit kinetic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



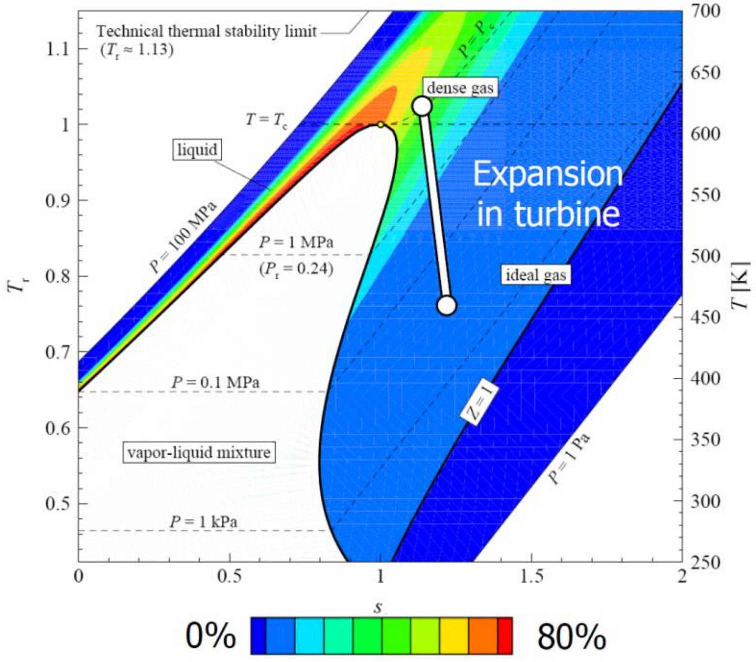
Organic Rankine Cycle



ORC scheme



T-s diagram of an organic fluid

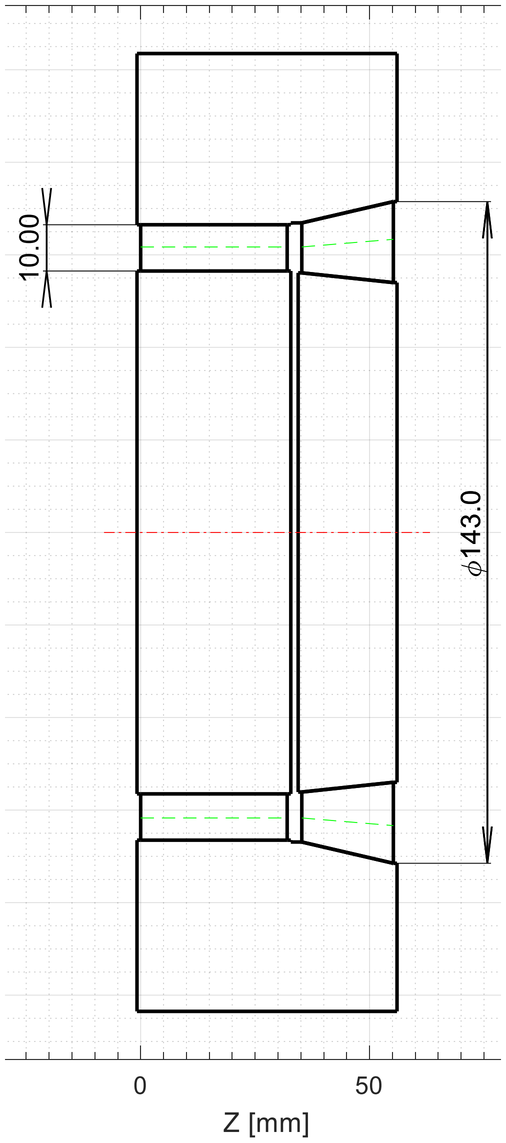


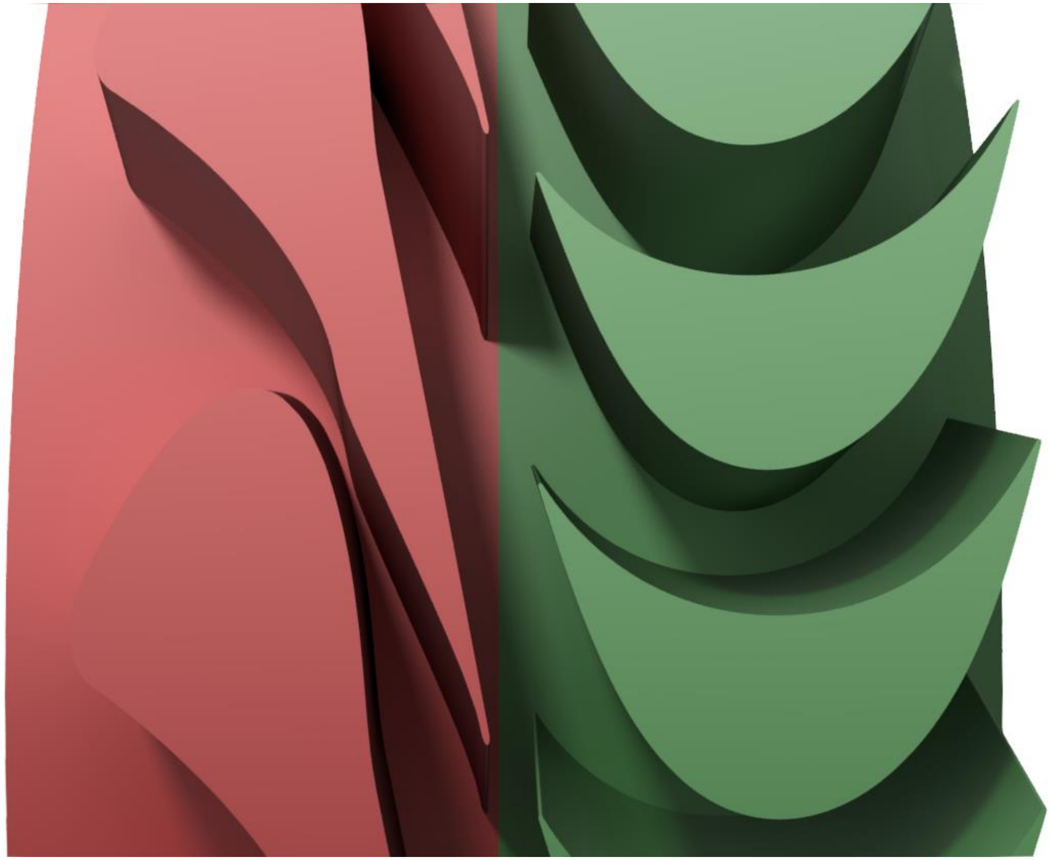
Volumetric deviation from simple ideal gas law in T-s diagram of an organic fluid

Source: J. Harinck, D. Pasquale, R. Pecnik, P. Colonna, Three-Dimensional RANS Simulation of a High-Speed Organic Rankine Cycle Turbine, in: First Int. Semin. ORC Power Syst. ORC 2011, Delft, 2011.

Case study

- One stage axial turbine
- Number of stator blades - 16
- Number of rotor blades - 31
- Design parameters:
  - Rotational speed – 40 000 rpm
  - Inlet pressure – 845 kPa
  - Inlet temperature – 485 K
  - Outlet pressure – 20 kPa
  - Mass flow – 0.3 kg/s
  - Working fluid - Toluen

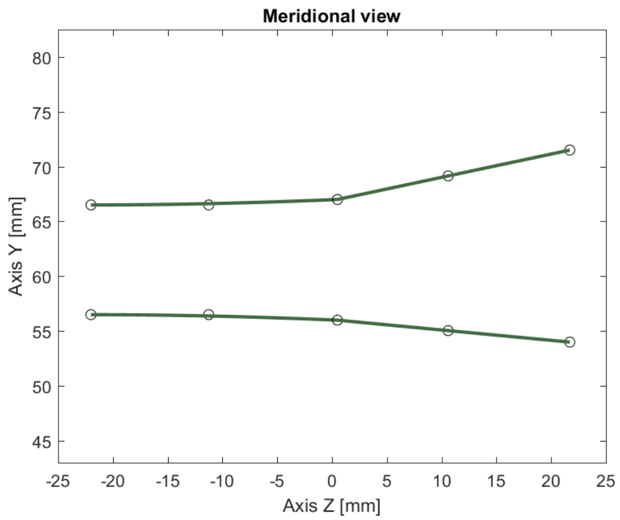


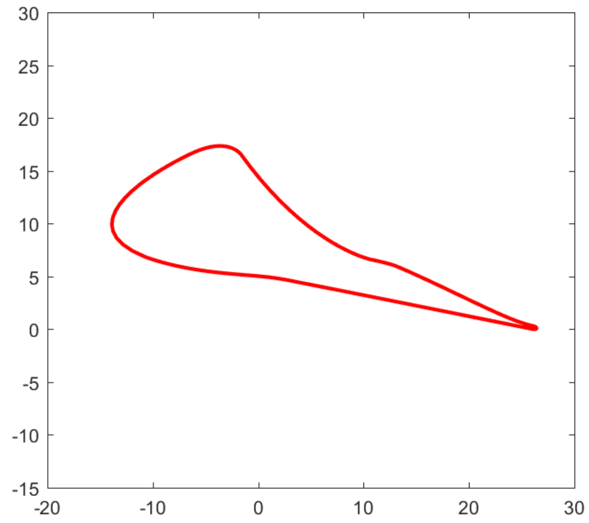


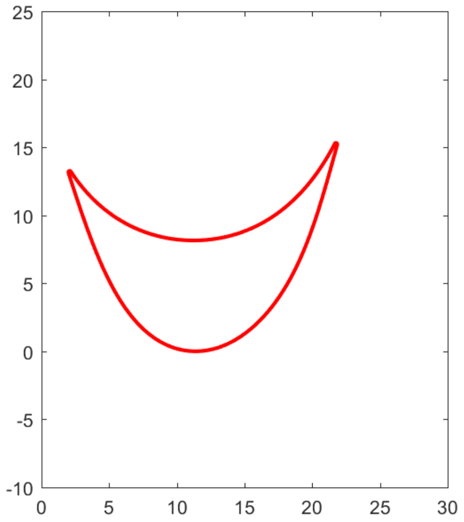
Parametrization

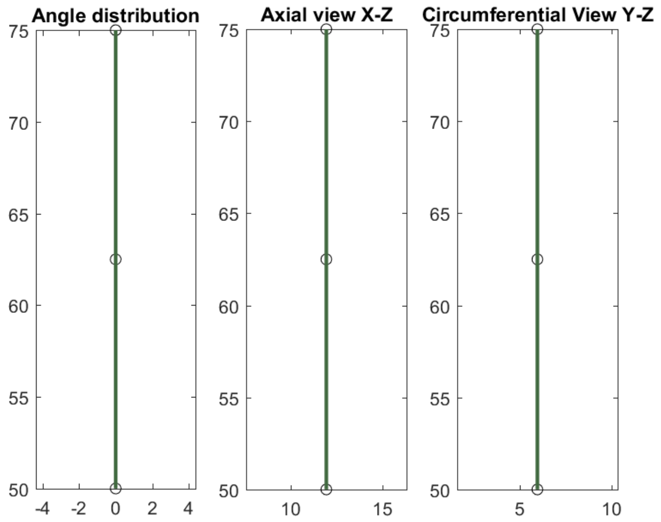
Axial turbine

- Changing nozzle design parameters at the hub and the tip of blade (S)
- Modification of rotor profile shape at the hub and the tip of blade (R)
- Blade twist (R)
- Simple and compound circumferential lean (R)
- Simple and compound axial lean (R)
- Meridional channel modification (S+R)
- 52 changing parameters (S+R)

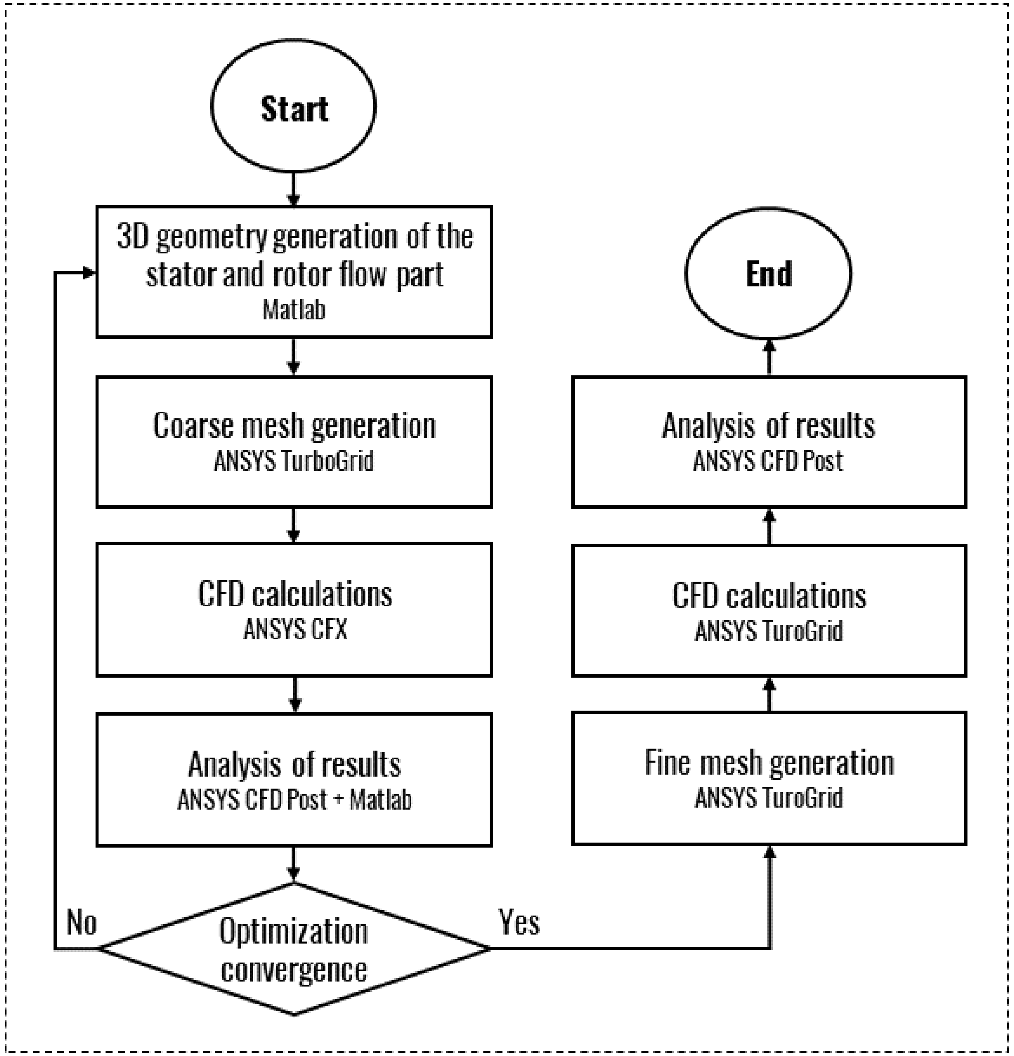






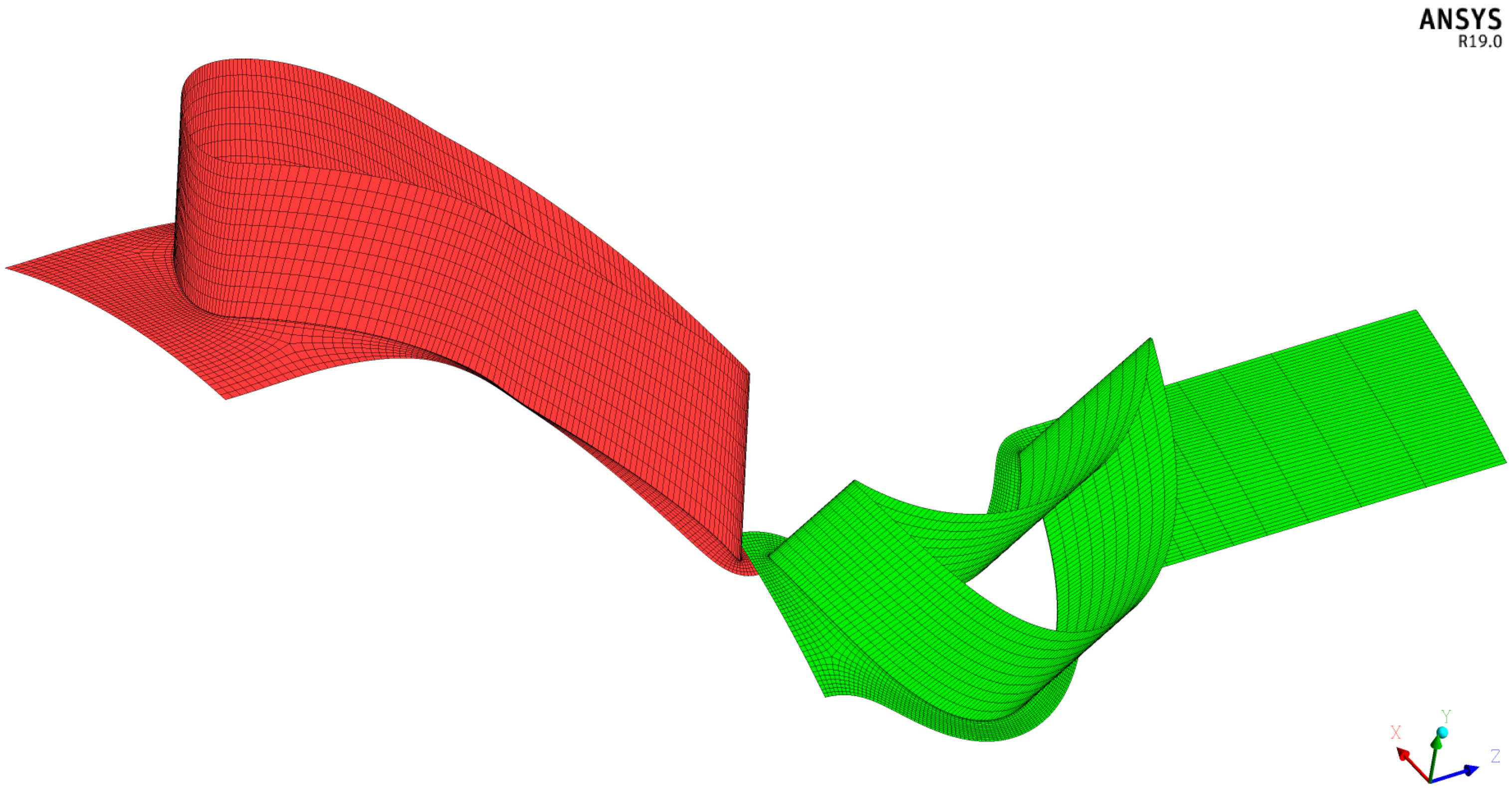


Methodology



- RANS (Reynolds-averaged Navier-Stokes) stationary simulations in ANSYS CFX
- k-ω SST turbulence model
- Periodicity conditions
- Gas model: NIST Refprop library
- Boundary conditions:
  - inlet – total pressure, total temperature
  - outlet – average static pressure
  - other – rotational speed

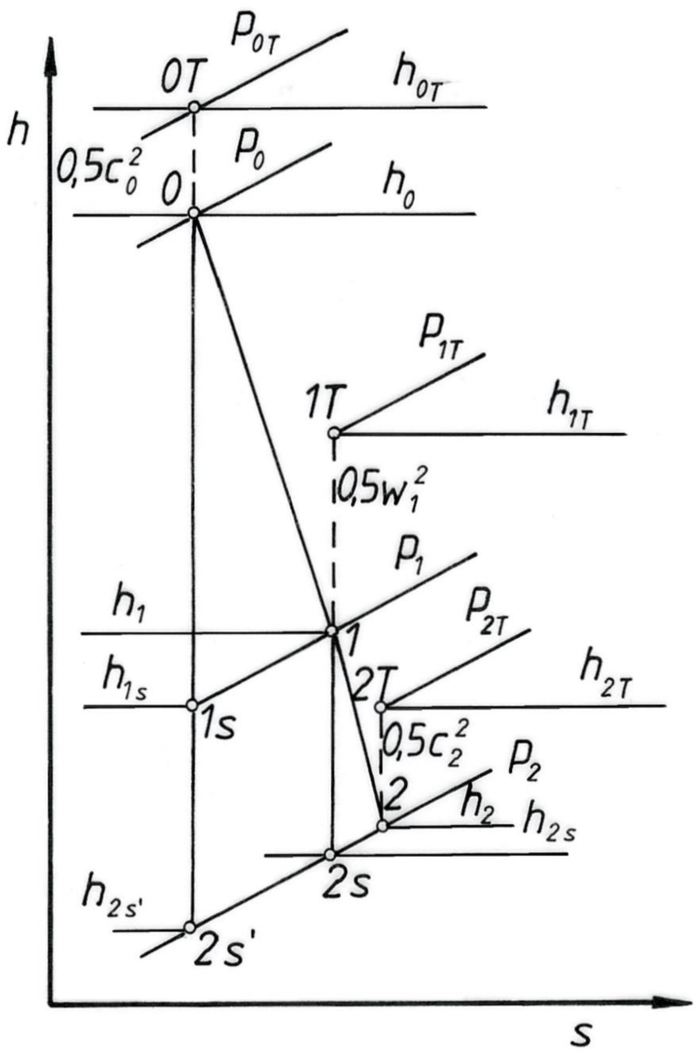
Discretization



- Number of elements in stage:
  - Optimisation < 0.1 mln
  - Verification level 1 from 0.5mln to 10 mln
  - Verification level 2 from 10mln to 30 mln

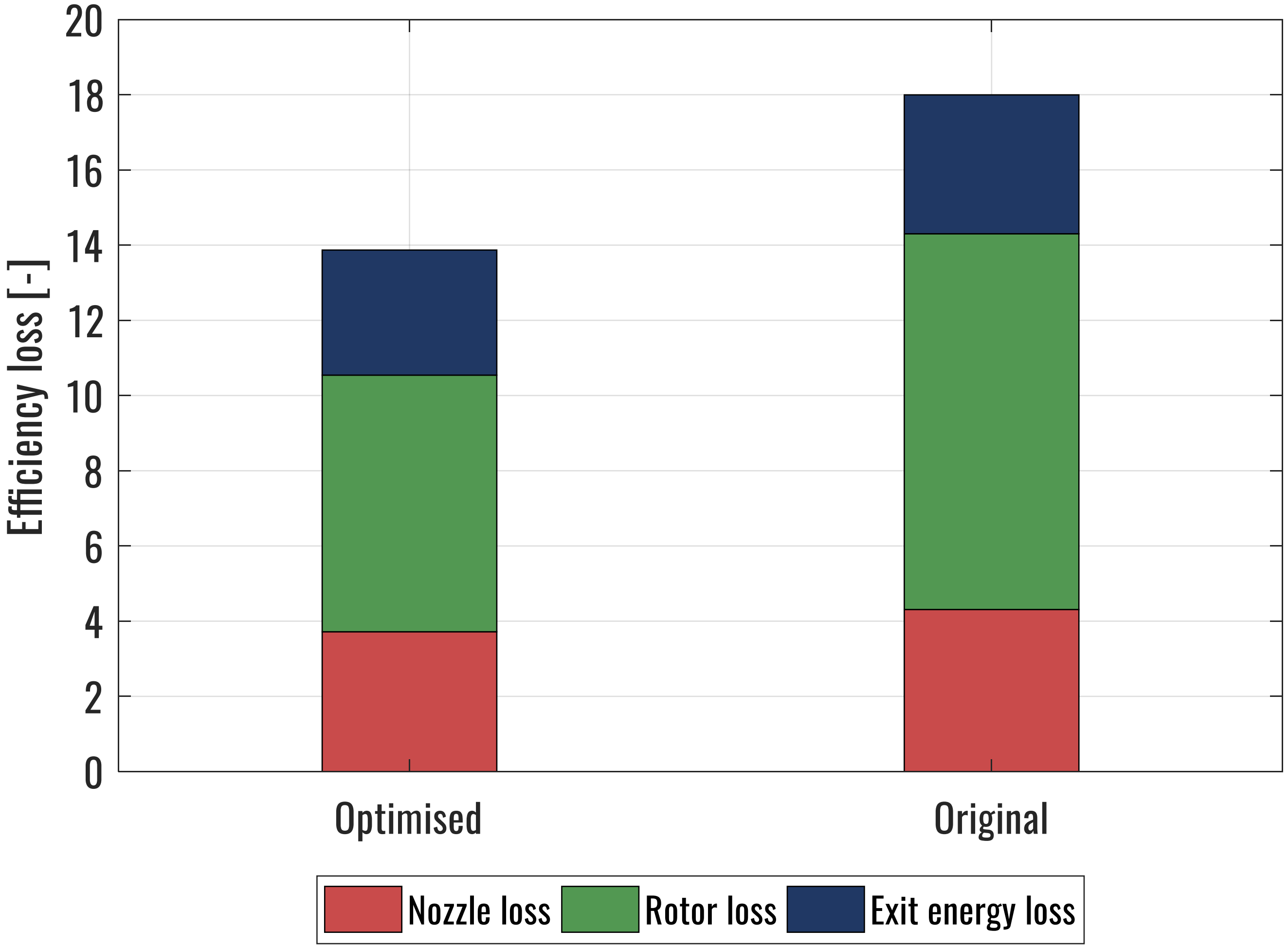
- Mesh limits:
  - Maximum face angle - 165°
  - Minimum face angle - 15°
  - Maximum volume ratio - 20
  - Edge lenth ratio – 500

Objective function



Parameter	
Reaction	$\rho = \frac{h_1 - h_{2s}}{h_{0T} - h_{2s'}}$
Stator loss	$\xi_1 = \frac{h_1 - h_{1s}}{h_{0T} - h_{1s}}$
Rotor loss	$\xi_2 = \frac{h_2 - h_{2s}}{h_{1T} - h_{2s}}$
Stage loss (without exit energy)	$\xi_{12} = \frac{h_2 - h_{2s'}}{h_{0T} - h_{2s'}}$
Stage loss (with exit energy)	$\xi_{12c} = \frac{h_{2T} - h_{2s'}}{h_{0T} - h_{2s'}}$
Total to static isentropic efficiency	$\eta_{TS} = \frac{h_{0T} - h_2}{h_{0T} - h_{2s'}}$
Total to total isentropic efficiency	$\eta_{TT} = \frac{h_{0T} - h_2}{h_{0T} - h_{2s'} - 0.5 \times c_2^2}$

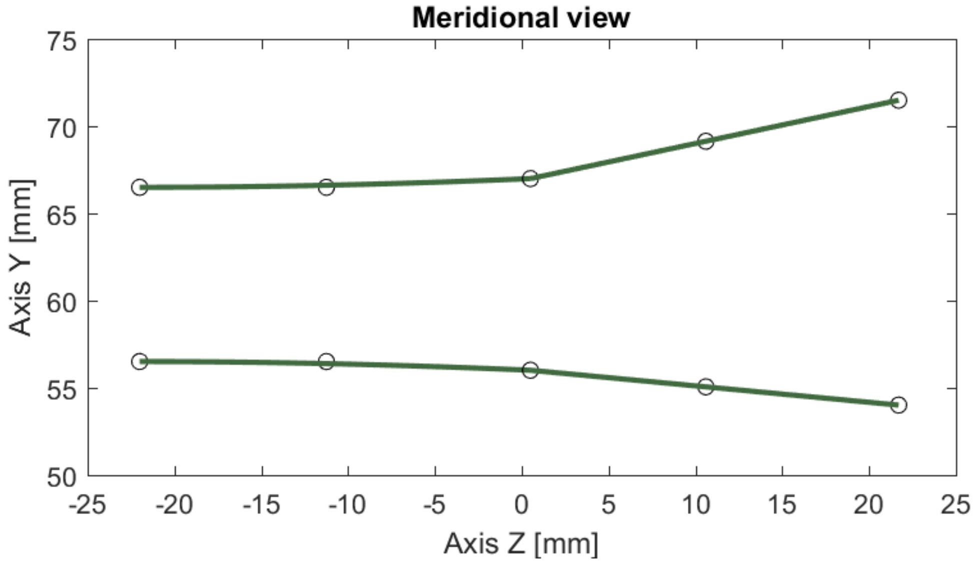
Results



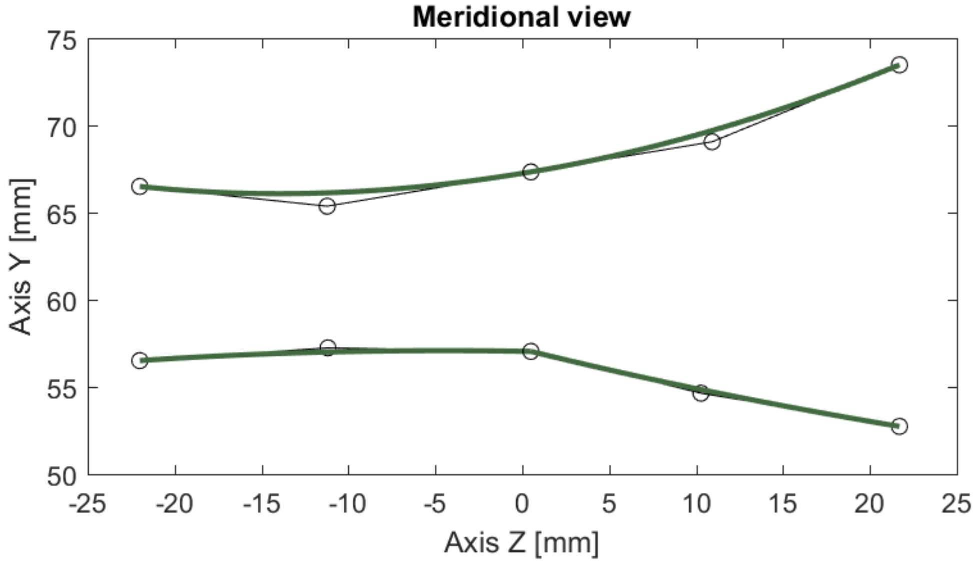
$\eta_T = 82\%$

$\eta_T = 86\%$

Results



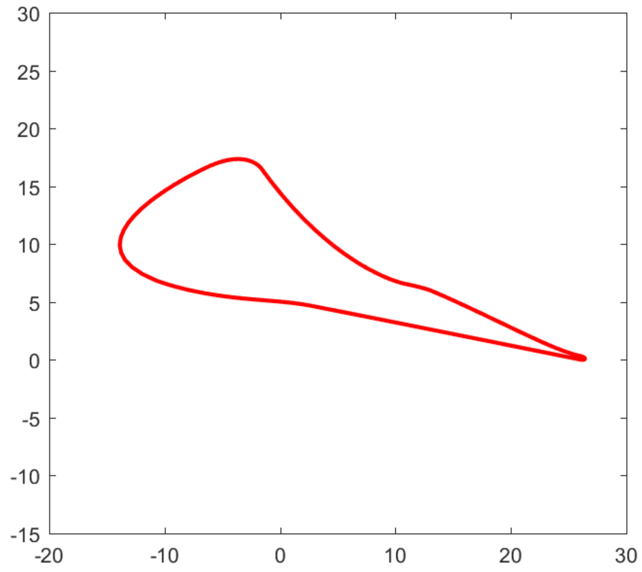
ORIGINAL

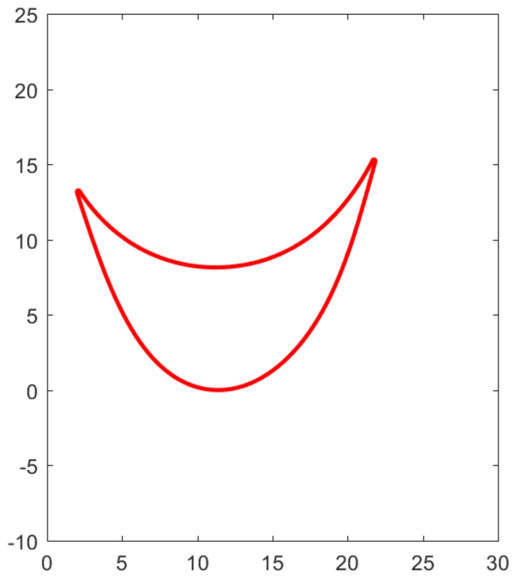


OPTIMISED

Results

ORIGINAL





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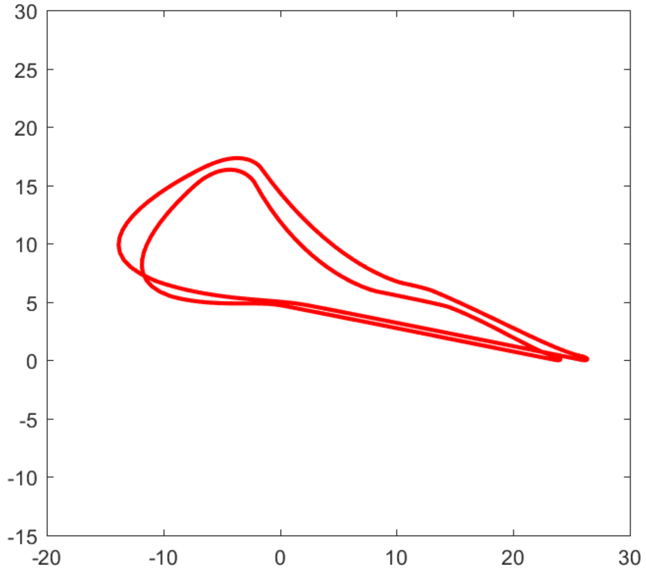
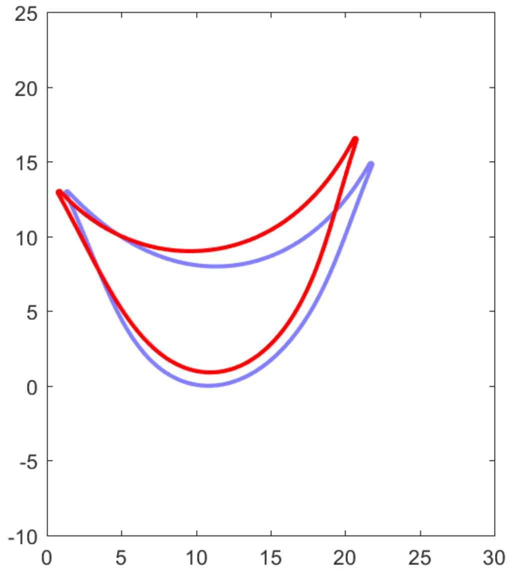
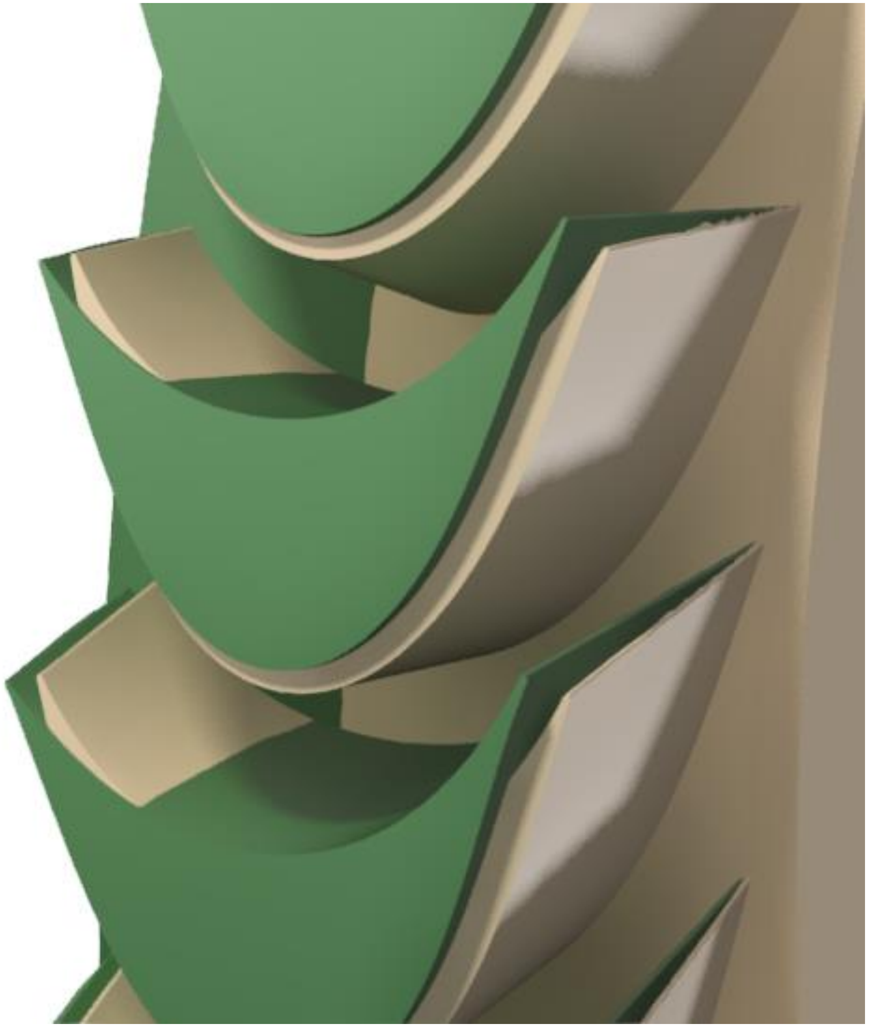
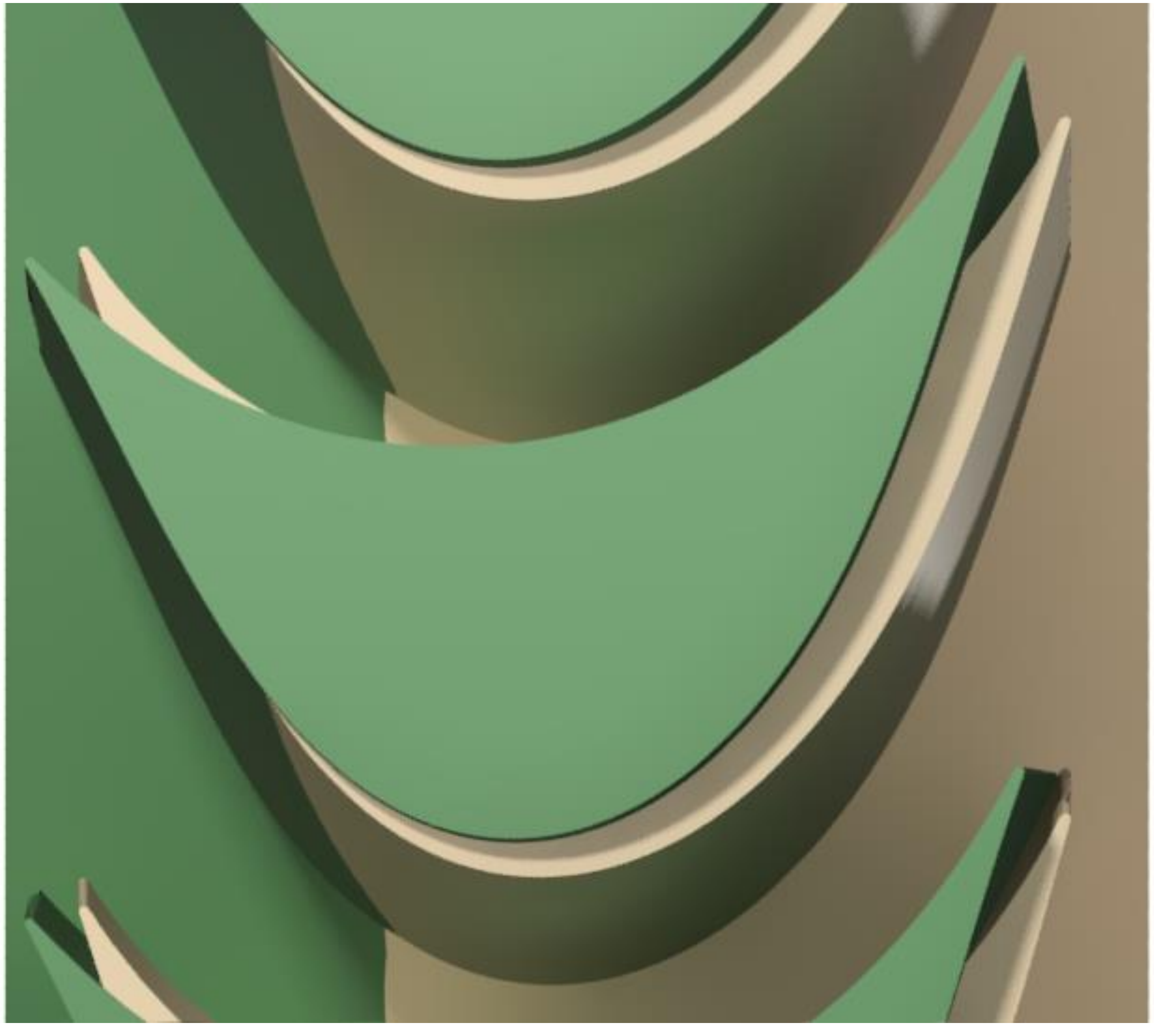




Results

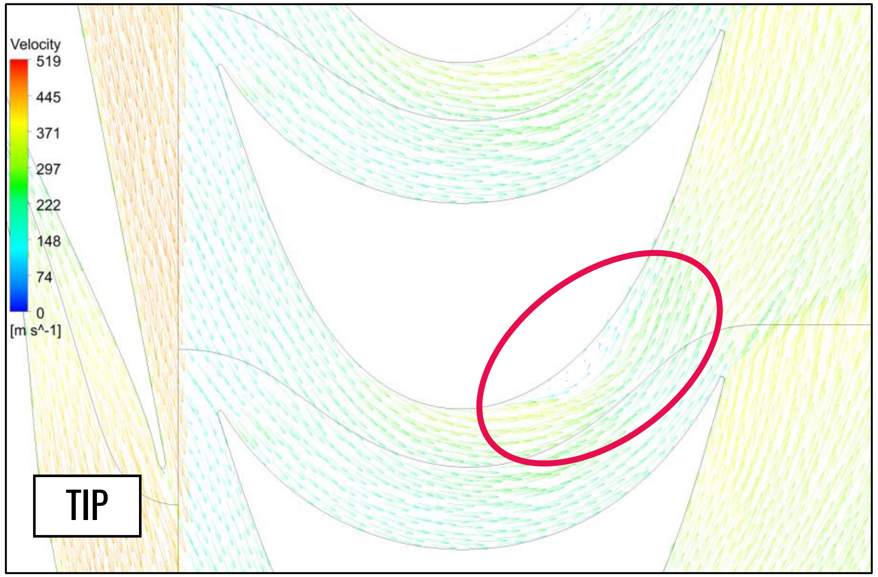


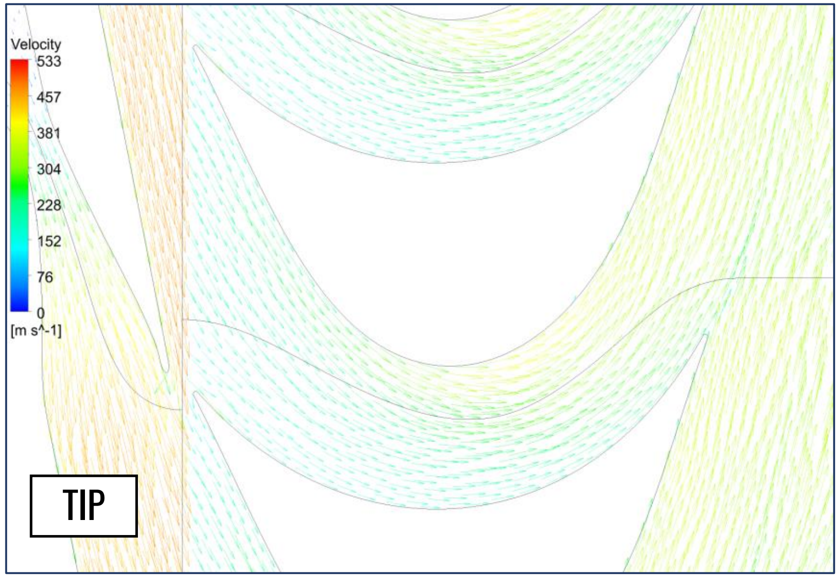


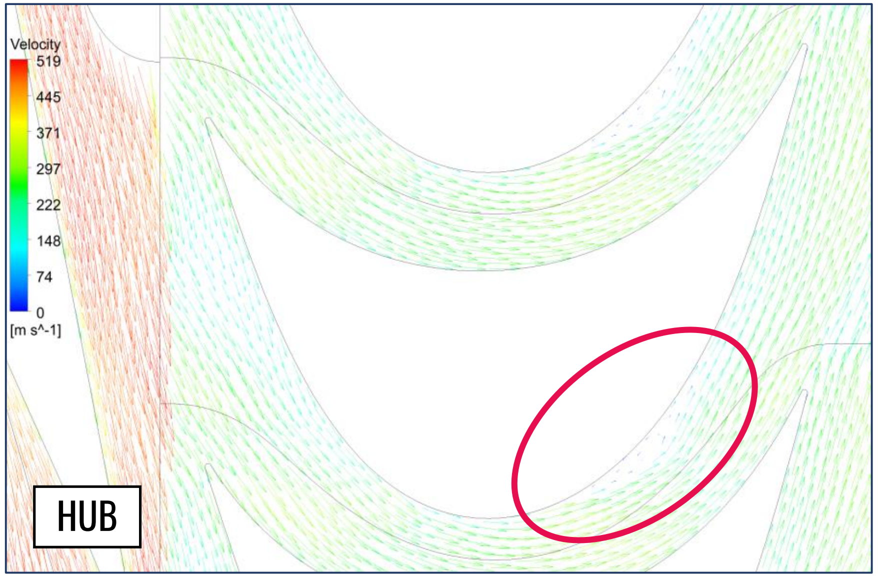
Results

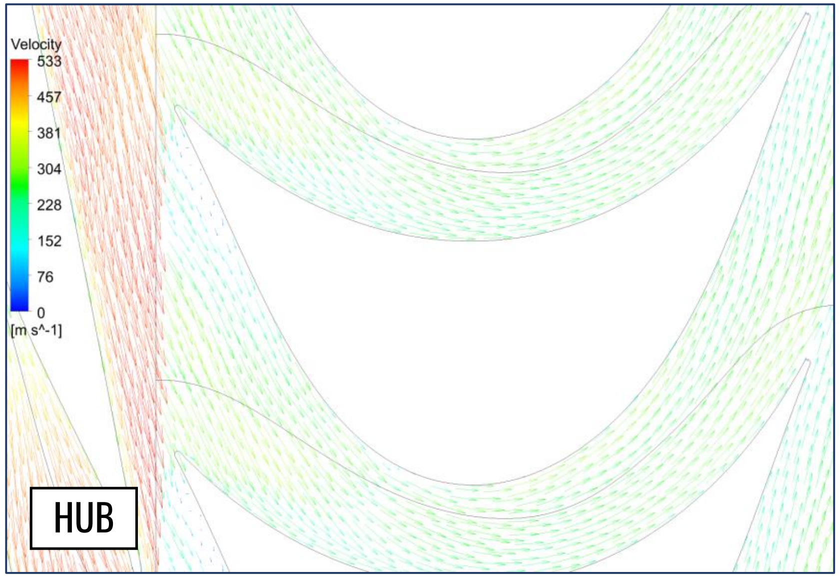
ORIGINAL

OPTIMISED









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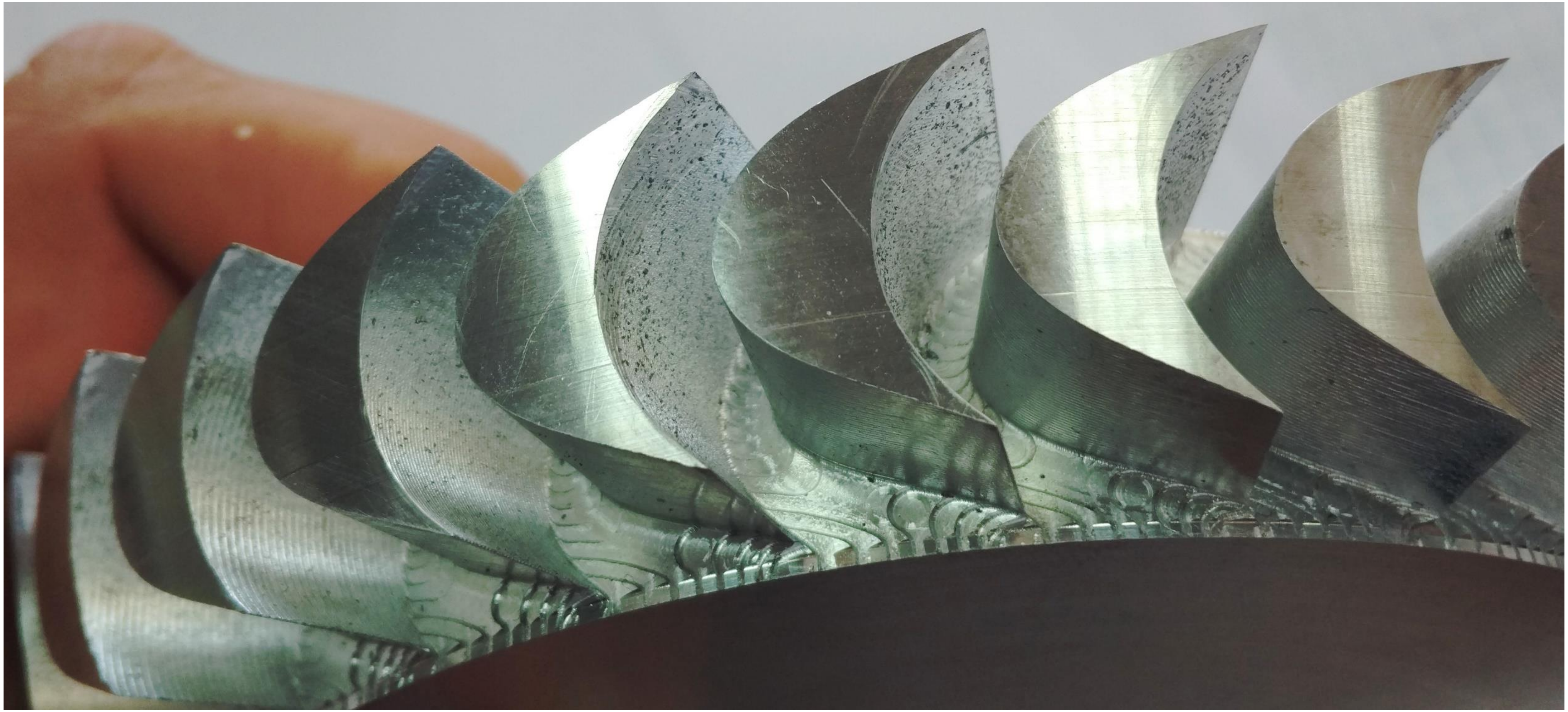

Conclusion

- The results show an improvement of objective function
- The presented method is proper for turbine optimization
- Finding the global minimum is very difficult and time-consuming
- Leakage and mechanical (strength, stress deformation) analysis should be performed
- Future studies should take into account new parametrization (for example – number of blades)

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