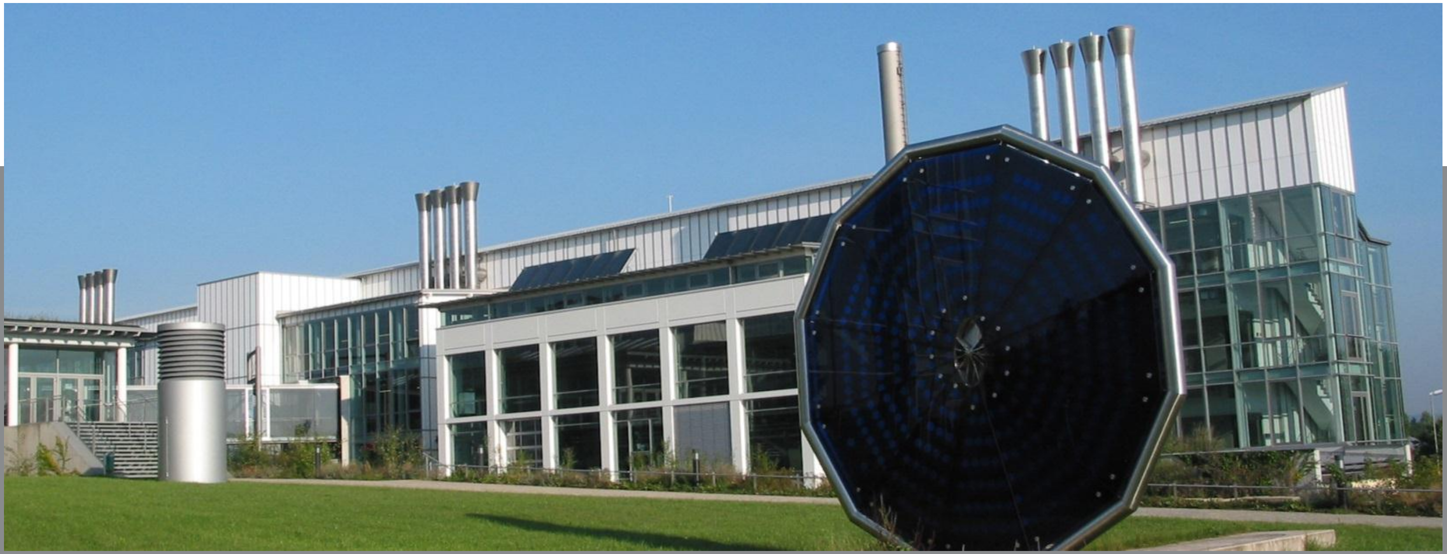

2D UNSTEADY RANS SIMULATIONS OF AN ORGANIC VAPOR PARTIAL ADMISSION TURBINE

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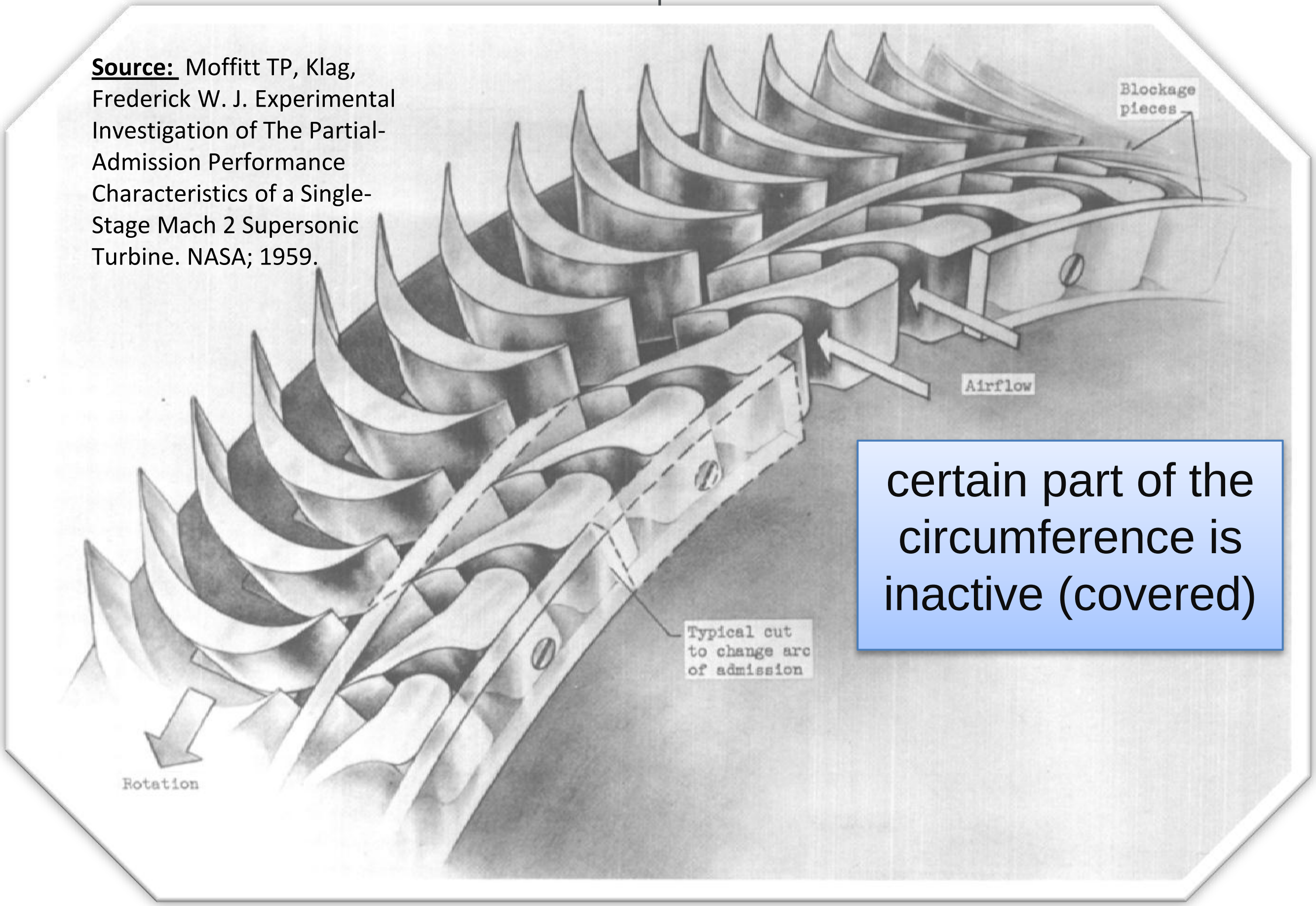
Introduction

Work principle of partial admission

Source: Moffitt TP, Klag, Frederick W. J. Experimental Investigation of The Partial-Admission Performance Characteristics of a Single-Stage Mach 2 Supersonic Turbine. NASA; 1959.



certain part of the circumference is inactive (covered)

Pros & cons of partial admission

Benefits

- in large steam turbines can be applied in control stages
- in small scale machines:
  - increased aspect ratio (reduced secondary losses)
  - reduced tip clearance loss

Drawbacks

- additional losses (pumping, end-sector, expansion)
- unforeseen excitation frequencies
- unsuitable for reaction stages
- difficult to obtain reliable CFD results

CFD applied to partially admitted stages

Why is it needed?

- Lack of really universal correlative relations for losses
- In order to predict the excitation frequencies

Problems:

- Very time consuming
  - Lack of periodicity
  - Strongly unsteady character at the end-sectors
- Large separations (RANS methods can produce significant errors)

Simplification of the flow

Examples

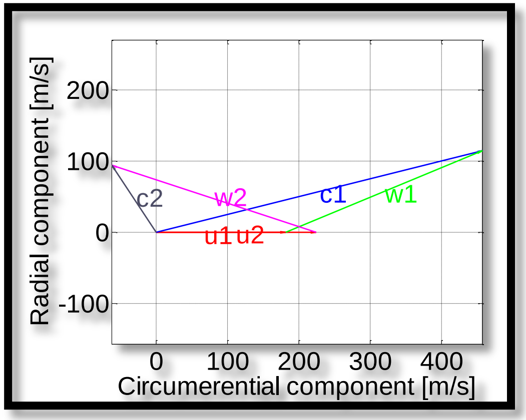
1. Simulating a stage expanded to full admission
   - periodicity condition
   - losses correlation for partial admission
2. Reducing a 3D domain into 2D in blade-to-blade plane
   - symmetry condition
   - losses correlation for the secondary losses
3. Combining the approach from points 1 & 2

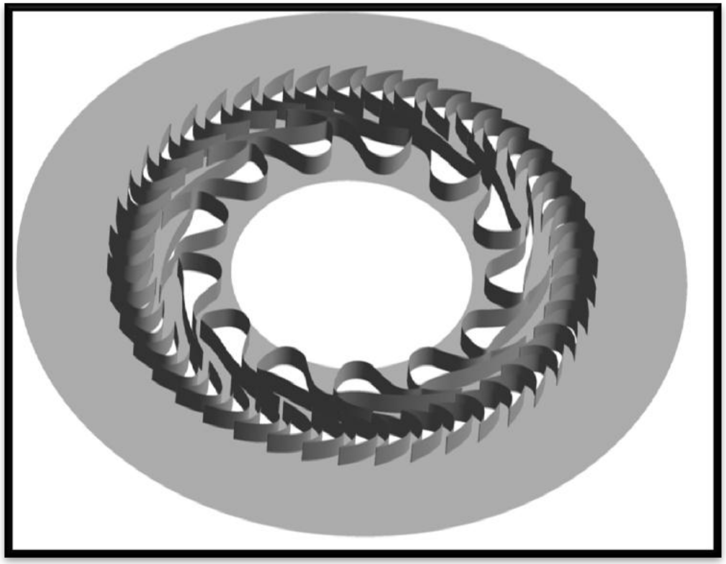
Potential problems with 2D approach

- Flow in partial admission has three-dimensional nature
- Stage must have an appropriate geometry
  - cylindrical hub & shroud surfaces in axial machines
  - hub & shroud surfaces normal to the rotation axis in radial stages

A case study

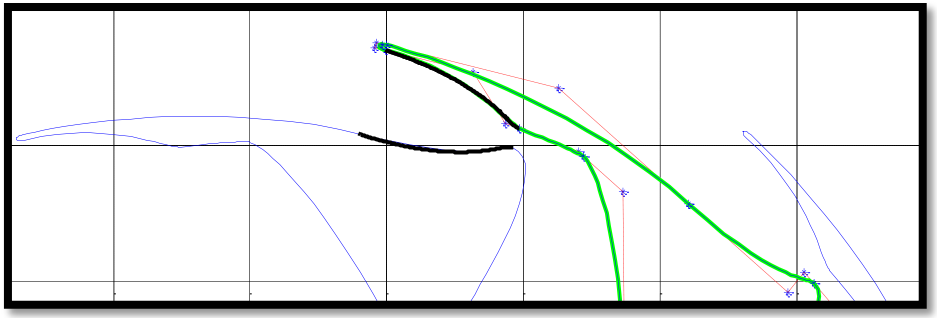
Assumptions
- Cyclopentane as the working fluid
- Expansion ratio about 20
- Centrifugal flow direction, naturally suitable for 2D CFD analysis
- 1D mean line calculations
- Cyclopentane regarded as a real gas (REFPROP)

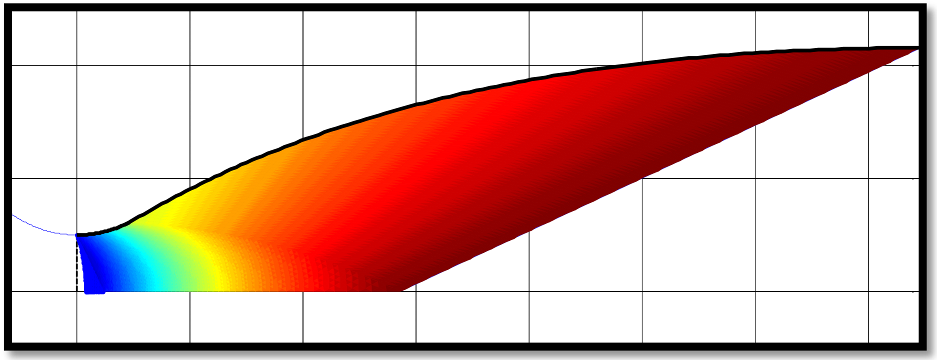


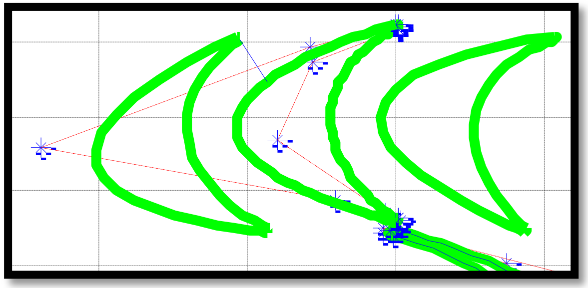


Blade design

- The geometry of the blades generated by means of Bezier curves (suitable for optimization)
- Nozzle divergent part designed in a way to provide the expansion to the design pressure (e.g. by method of characteristics to obtain uniform flow)
- Rotor blade designed to fit the flow angles and to obtain constant channel width (one can also adopt the vortex flow method)





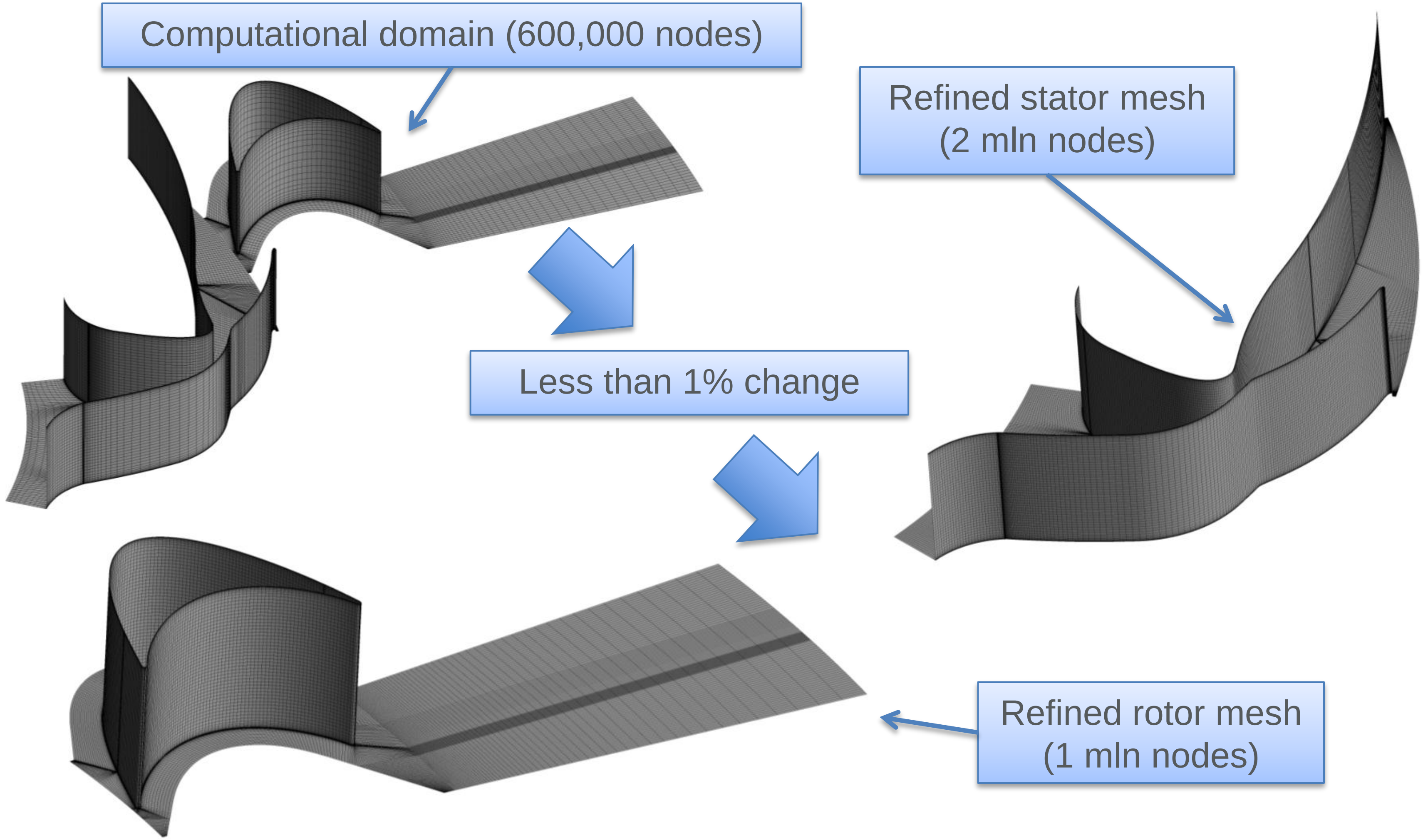


The numerical model

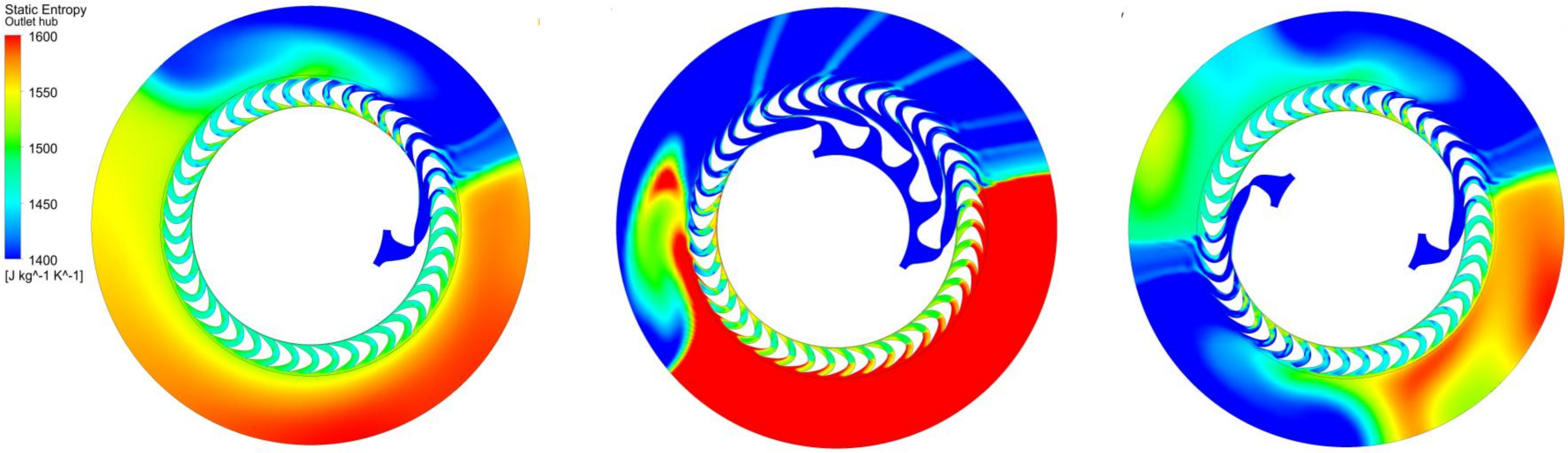
- Commercial CFD code Ansys CFX v. 14.0
- Cyclopentane described as a real gas in form of tabularized data (REFPROP)
- Boundary conditions:
  - inlet total pressure and temperature
  - outlet average static pressure
- SST k-ω turbulence model
- Second order space discretization
- 30 time steps for one rotor blade pass in unsteady simulations

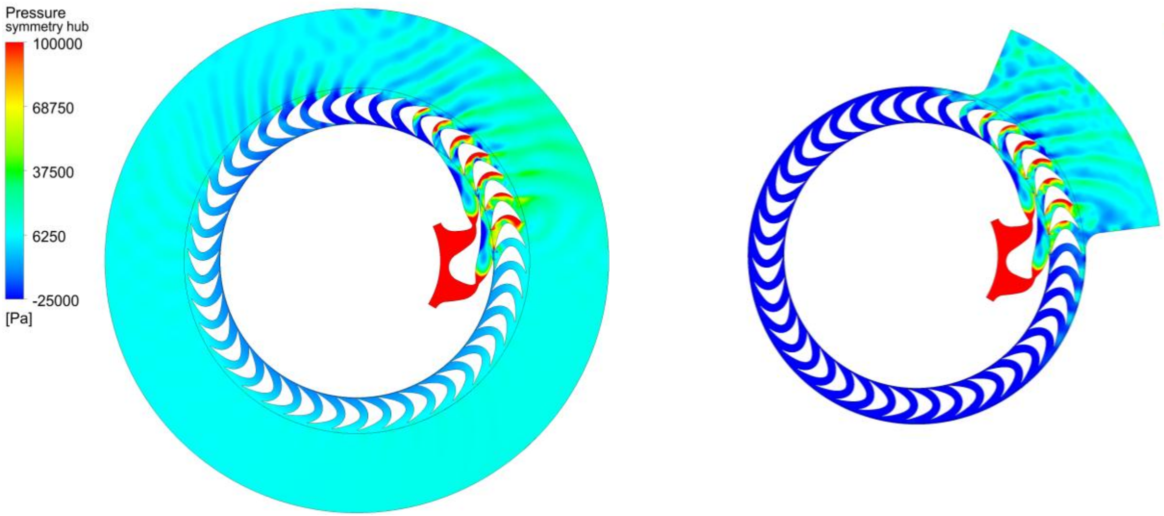
→ **design values**

Mesh of the domain

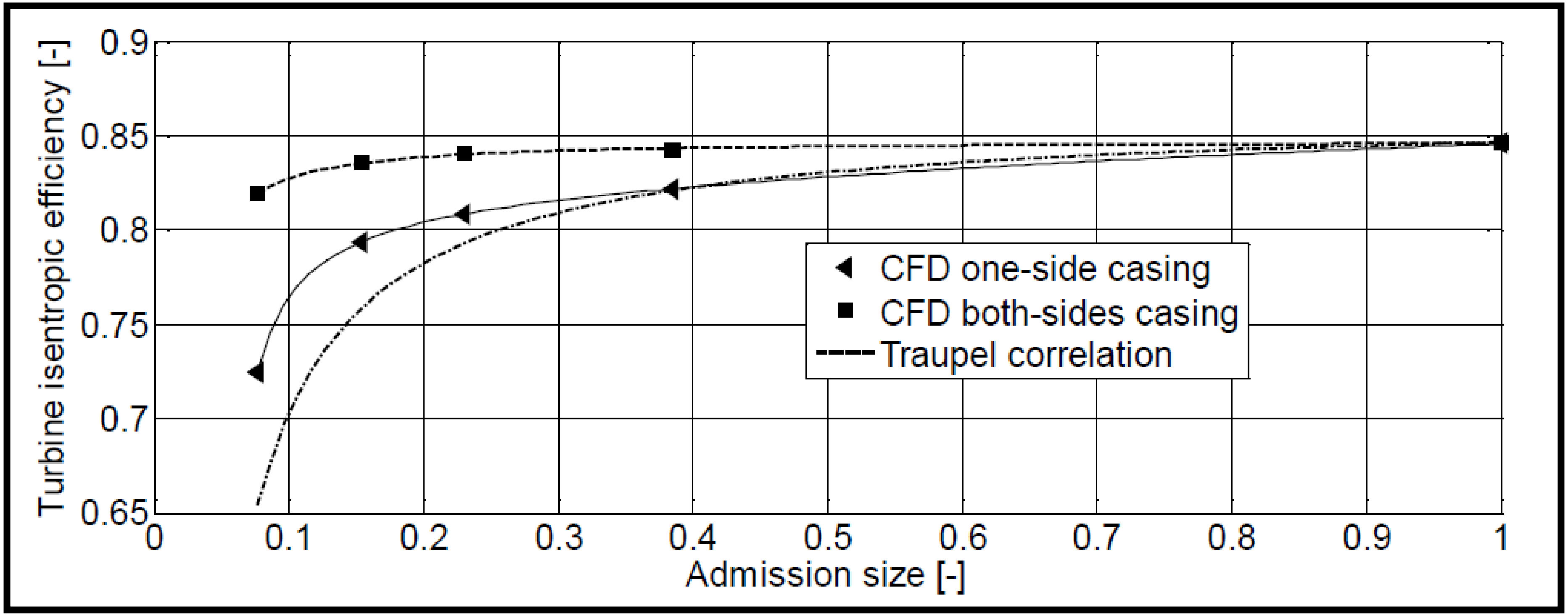


2D unsteady results (different configurations)





Efficiency vs. admission



Loss estimation

Superposition principle

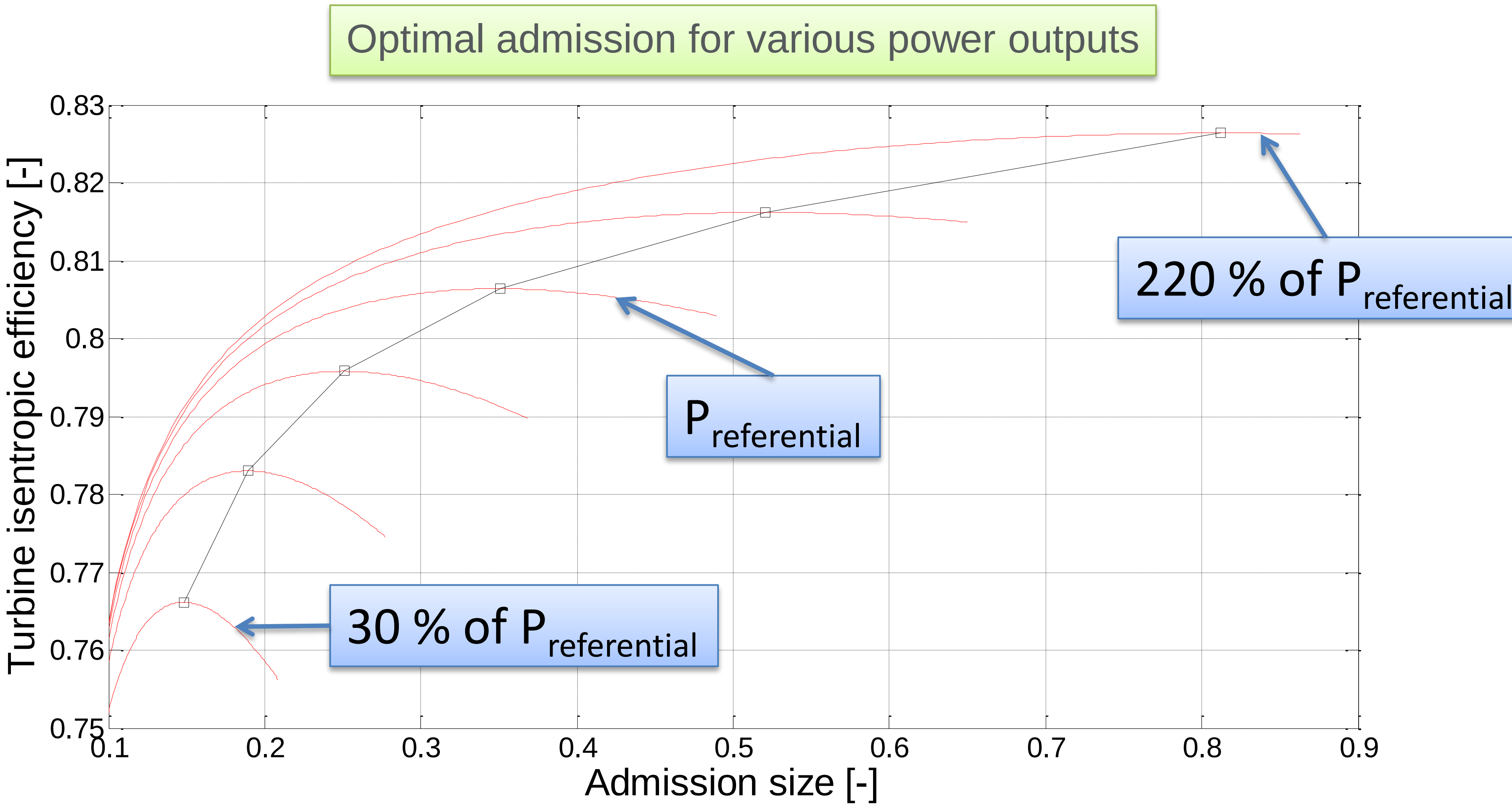
$$\begin{cases} P = P_T - P_P(1-\varepsilon) - P_S & \text{for single sector admission} \\ P = P_T - P_P(1-\varepsilon) - 2P_S & \text{for double sector admission} \end{cases} \Rightarrow \boldsymbol{P_P, P_S}$$

Where:
P – internal power of the partial admission stage
P_T – internal power of the stage expanded to full admission
P_P – pumping power of the whole rotor circumference
P_S – total sector loss for one sector

Conclusion:

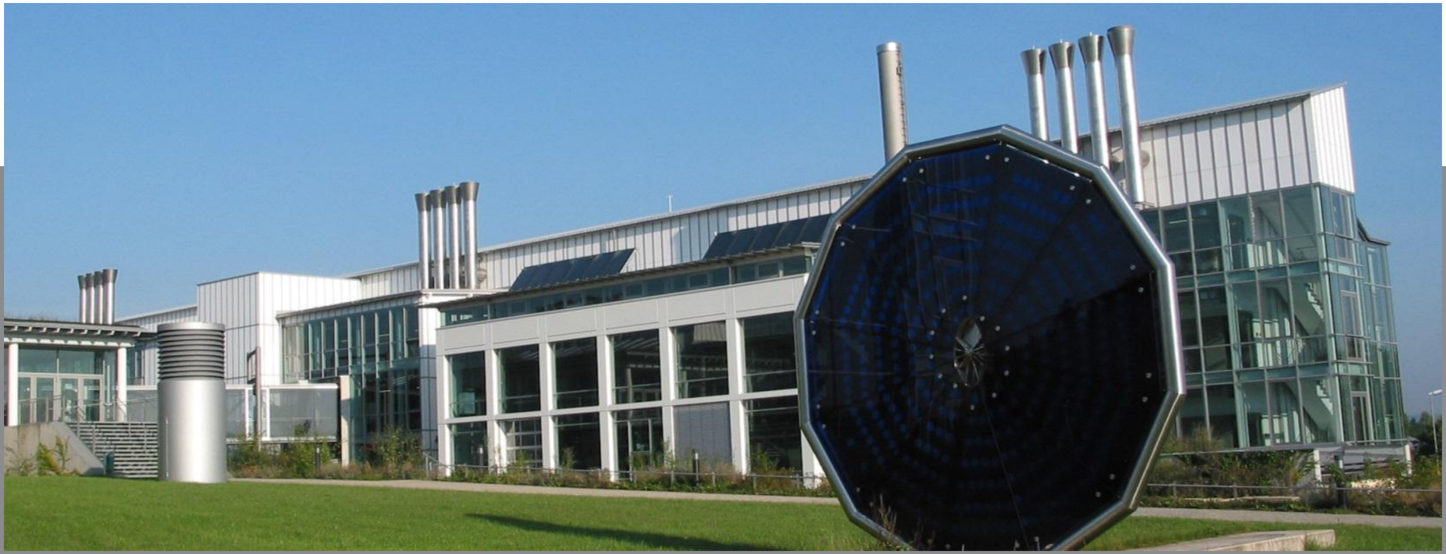
- Casing on both sides reduced not only the pumping loss (by a factor of about 5) but also the end-sector loss by a factor of more than 3!
- The value of the sector loss is comparable with the pumping loss of the whole rotor circumference (not more than 20% difference)

Combining with 3D steady CFD



Conclusions

- Stable 2D blade-to-blade unsteady numerical solutions of flow fields in supersonic turbines working with real gases are possible.
- This approach may be helpful in finding optimal admission sizes.
- The 2D model has obvious limitations and in future should be compared with its 3D equivalent to investigate its reliability.
- Different stage specifications have to be checked such as different blade pitches, different chord sizes and various blade angles.
- The presented design shows a promising performance which in further work will be compared with equivalent centripetal stages.



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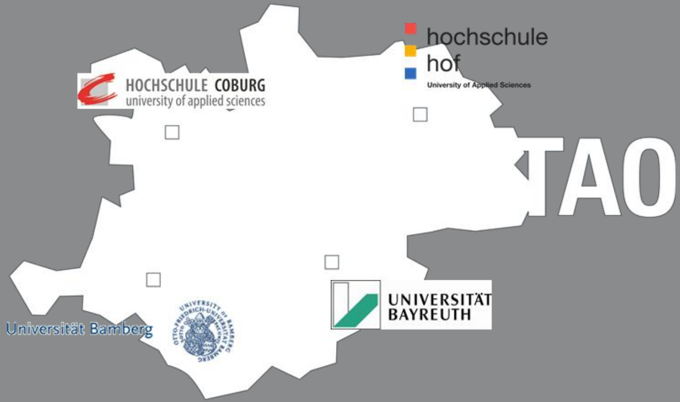

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