3rd International Seminar on Non-Ideal Compressible Fluid Dynamics for Propulsion and Power
October 29 – 30

Numerical Investigation of Loss Mechanisms in a Partially Loaded Supersonic ORC Turbine Stage

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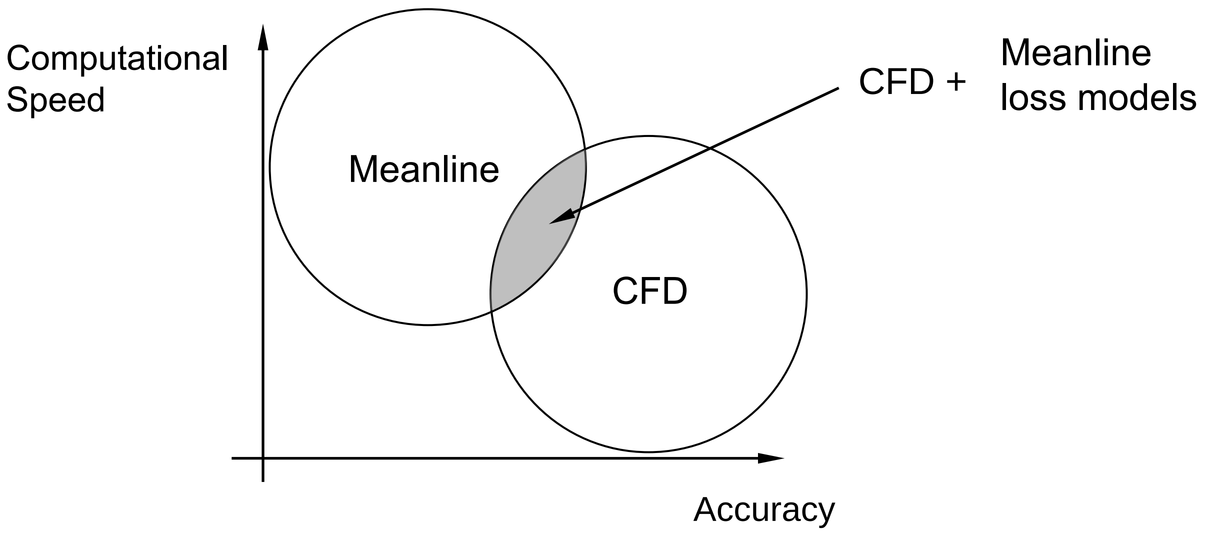
1. Motivation

- Nowadays, the design process of turbomachinery based on Meanline and CFD computations



- Partial admission control can be found in ORC turbines:
  - to decrease end-wall and secondary flow losses [1, 2]
  - to enable an efficient and economical operation at partial load [1]

1. Motivation

- ORC turbine design is challenging due to supersonic flow conditions under non-ideal/real gas behaviour
- The commonly used partial admission loss model by Suter & Traupel [3], which was adopted by Aungier [4], was validated against a subsonic test rig at approximately ideal gas conditions

→ **Question**: Is the partial admission loss model by Aungier [4] appropriate for predictions of real gas flows under supersonic conditions?

Agenda

1. Motivation
2. Methodology
3. Experimental Configuration
4. Numerical Setup
5. Comparison to Experimental Results
6. Aerodynamic Losses in a Partial Admitted ORC Turbine Stage
7. Comparison to Partial Admission Loss Model Results & Conclusion
8. Future Work

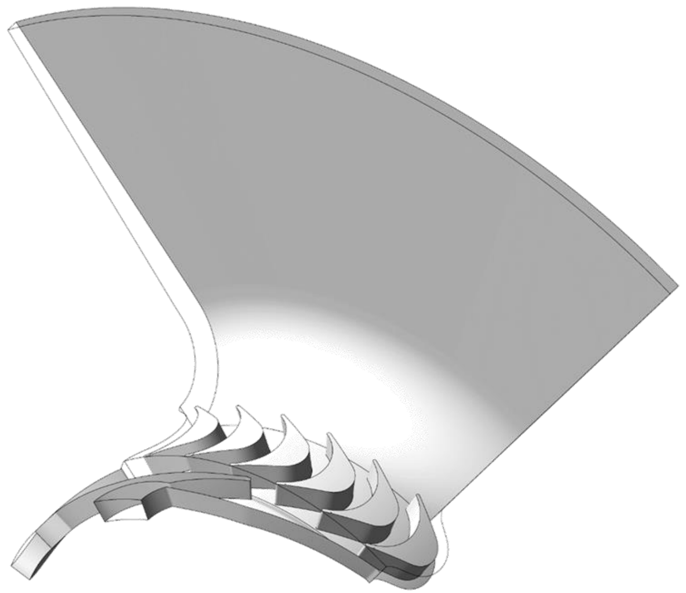
2. Methodology

- Using the in-house CFD solver (Shar-C) optimized for turbomachinery and real-gas applications [5, 6]
- Development of two CFD models of a partially loaded supersonic single-stage ORC turbine:

<u>Configuration 1</u>

Full annulus model

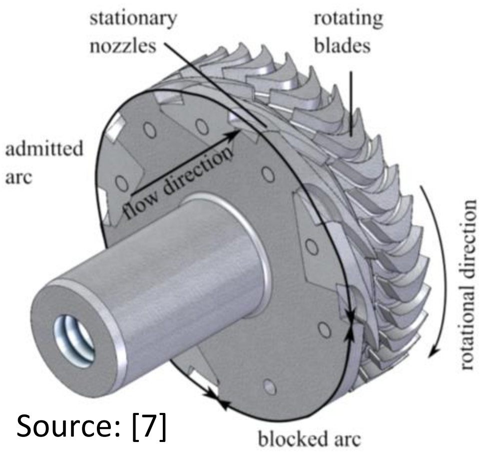
<u>Configuration 2</u>



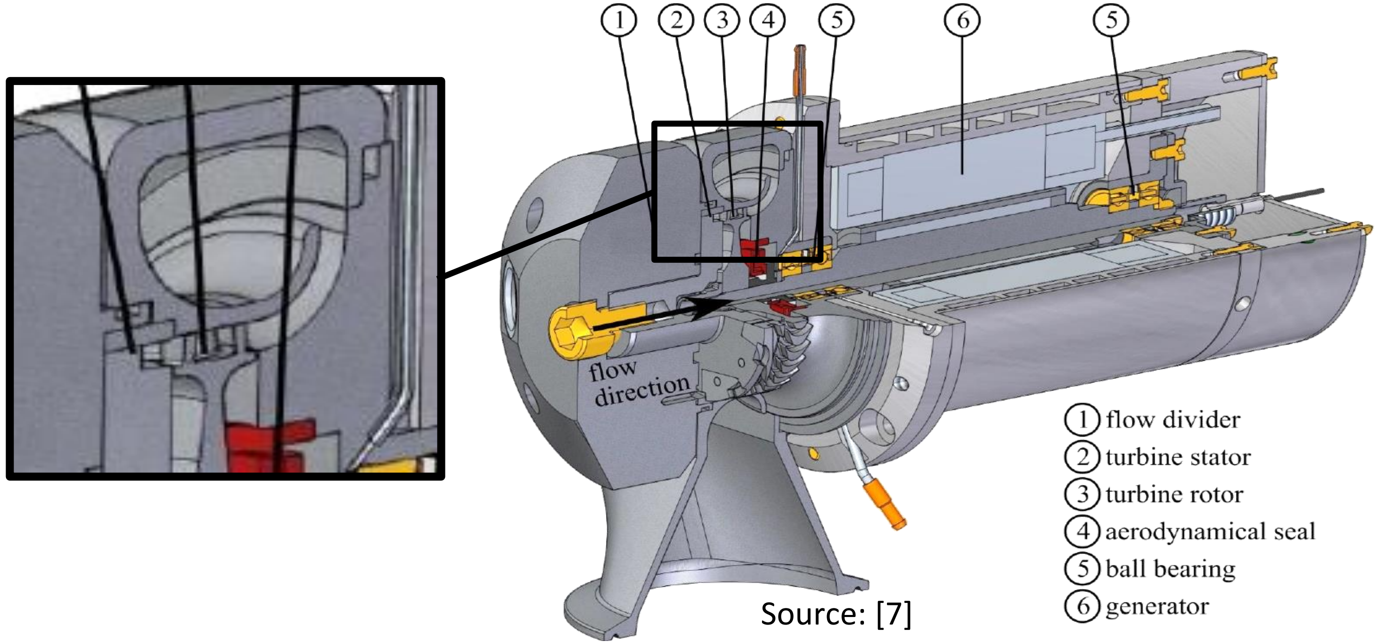
72°-sector model + partial admission loss model by Aungier [4]

3. Experimental Configuration

- ORC turbine generator of the Institute of Turbomachinery and Fluid Dynamics (TFD) of Leibniz University Hannover [1, 7]
- Designed for energy recovery for a 12.8 l diesel engine



Source: [7]



Source: [7]

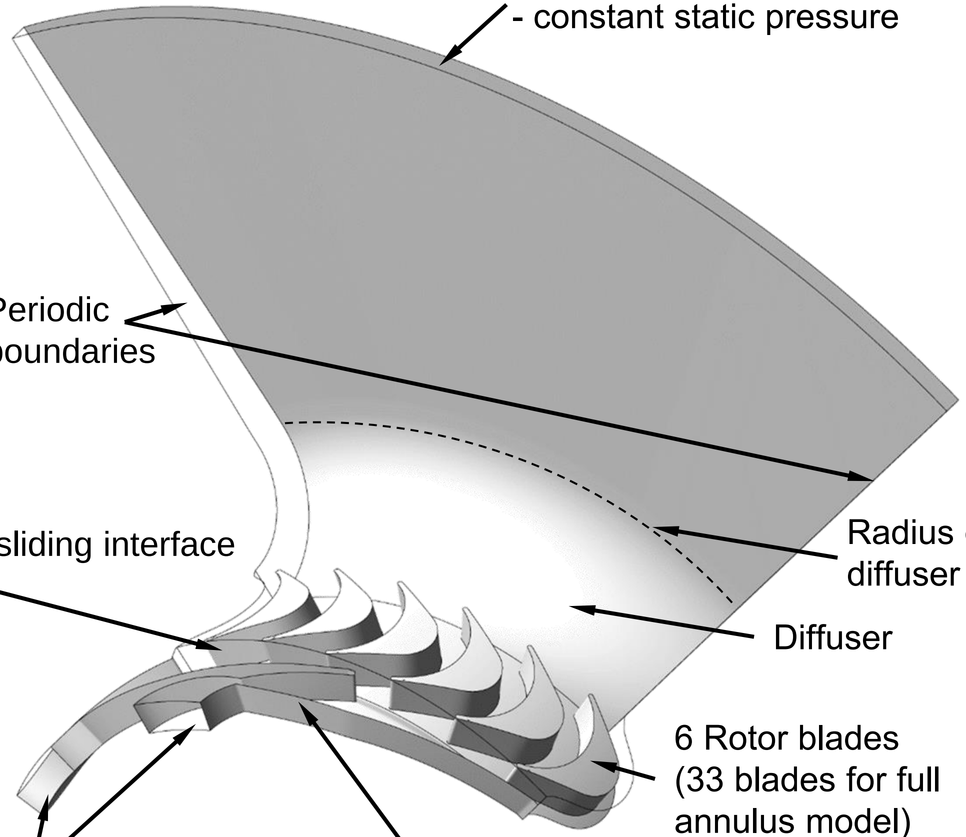
- 33 rotor blades and 8 stator passages
- Maximum degree of partial admission is 80 % (8 opened stator passages)
- Ethanol/water-mixture (95 % / 5 % mass fraction) as working fluid

4. Numerical Setup

- CFD RANS steady state simulations
- Spalart–Allmaras turbulence model [8]
- Peng-Robinson EoS [9]
- Gas-mixture model of Chung *et. al* [10]
- No wall function model → $y^+ \approx 1$
- Block structured mesh
- Mesh independence study resulted in:
  - 4.3 million nodes for 72°-sector model
  - 20.5 million nodes for full annulus model

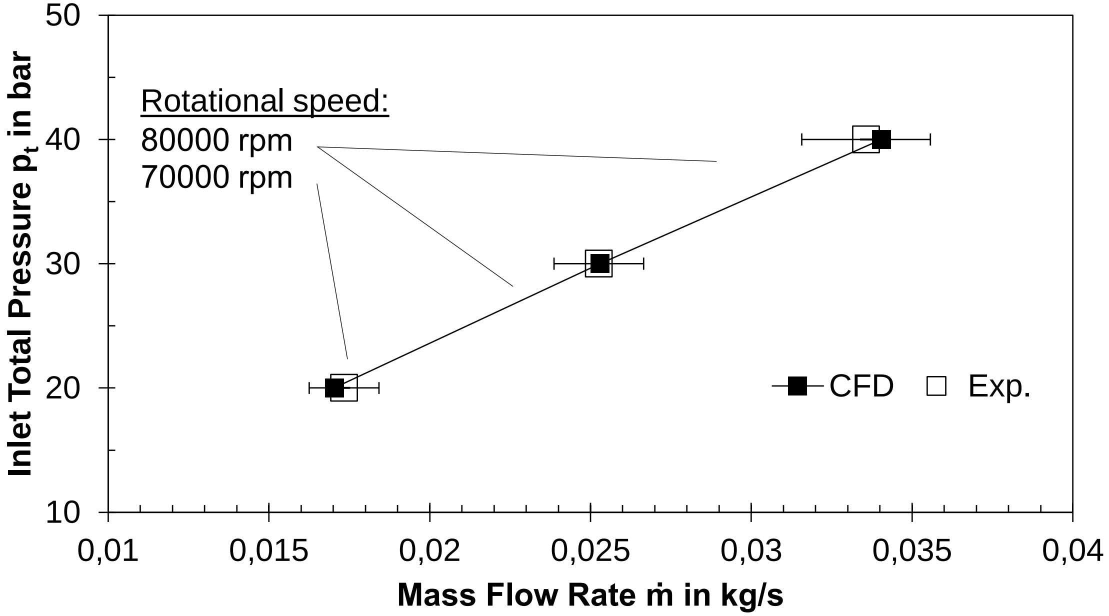
Full annulus model

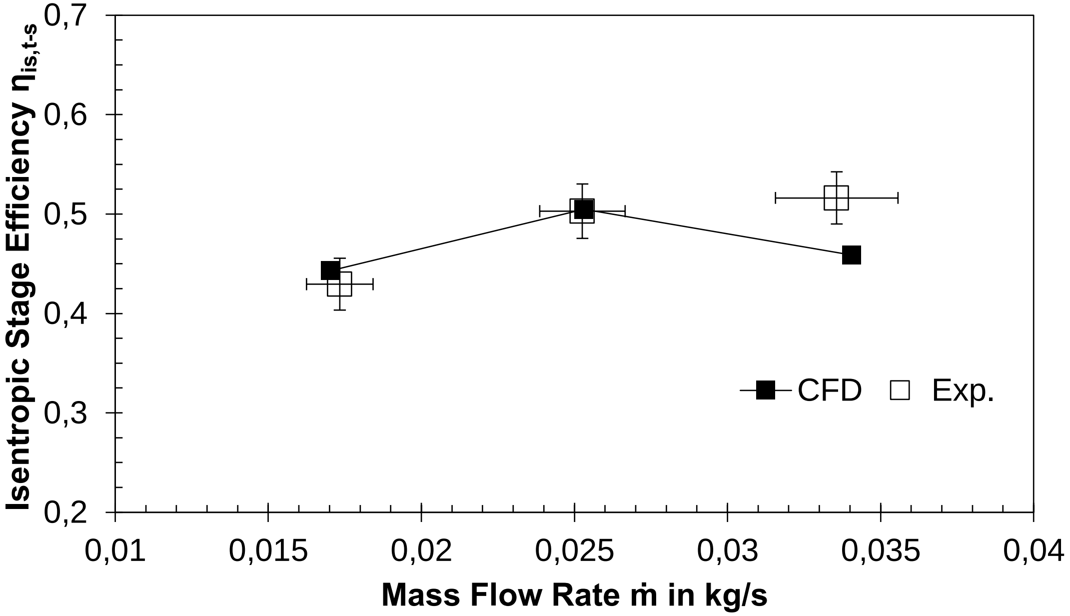
72°-sector model



5. Comparison to Experimental Results

- Degree of partial admission of 20 % (2 opened stator passages)



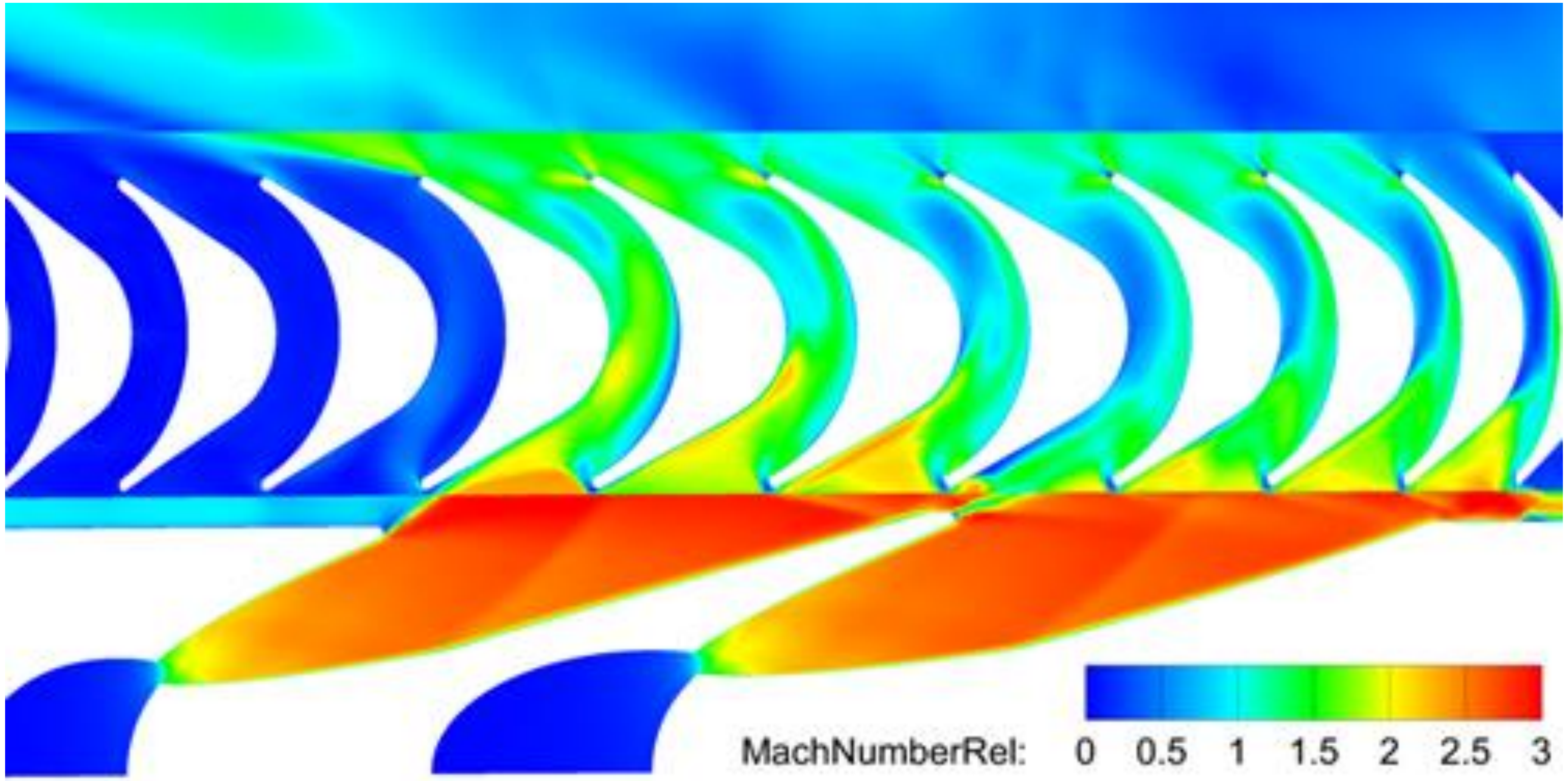


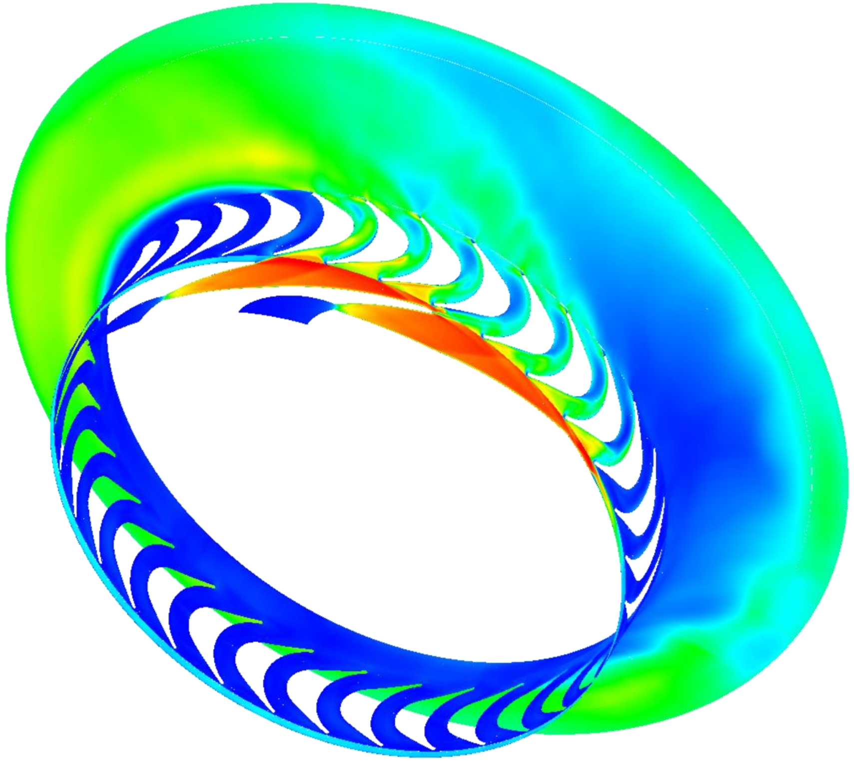
- Calculated mass flow rates are in very good agreement to experimental data

- Predicted efficiency levels within the measurement uncertainty at 1. and 2. operating point
- Underprediction at 3. operating point, was also observed by [1] → highly unsteady flow regime and boundary conditions affected by relatively high degree of uncertainty

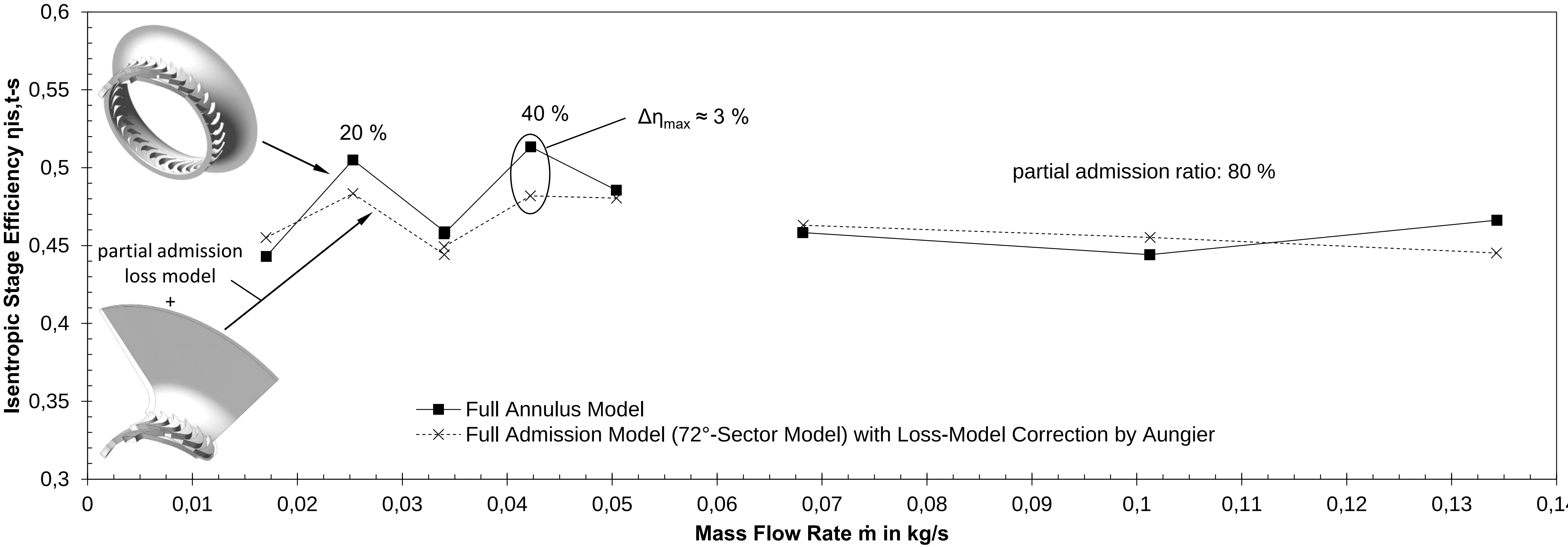
6. Aerodynamic Losses in a Partial Admitted ORC Turbine Stage

- Contour plots of relative Mach number at mid-span for the operating point with a degree of partial admission of 20 % and a total inlet pressure of 30 bar





7. Comparison to Partial Admission Loss Model Results & Conclusion



- Differences between performance curves of the full annulus model and the 72°-sector model (adapted by the partial admission loss model) are 1.252 ppt on average and approx. 3 ppt in maximum

→ **Answer:** This finding suggests that the partial admission loss model by Aungier [4] is generally appropriate for predictions of real gas flow under supersonic conditions investigated in this work!

8. Future Work

- Unsteady effects will be taken into account
  → Transient simulations are running

- The applicability of further empirical loss models under highly non-ideal gas conditions will be investigated

Any questions?

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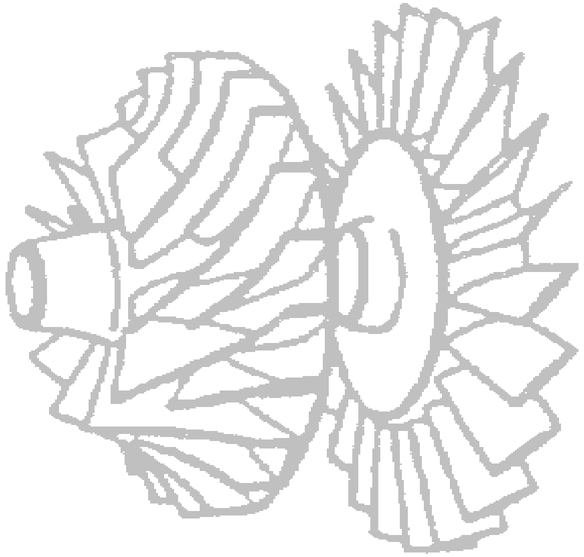

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