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Axial turbine modelling and experimental results

Prague, 7th March 2024

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Content

- Axial turbine modelling
  - Tool for performance prediction
  - Novel method to predict choked flow
  - Validation
- Experimental results
  - ORC scheme and test facility
  - Turbine design
  - Results

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Axial turbine modelling

Mean-line method

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Motivation

- Tool for performance prediction of axial turbines
  - Previously only design-tool
- Off-design performance map
- Improve mean-line method
  - Off-design loss model (incidence losses)
  - Model flow angles (deviation model)
  - Improved method for choked state calculation

Method

- Mean-line formulation:
  - Mass and energy conservation
  - Library of thermophysical properties (CoolProp)
  - Loss model (Benner, Sjolander & Moustapha)
    - Incidence losses
  - Deviation model (Aungier)
    - Deviation of flow angle from blade angle

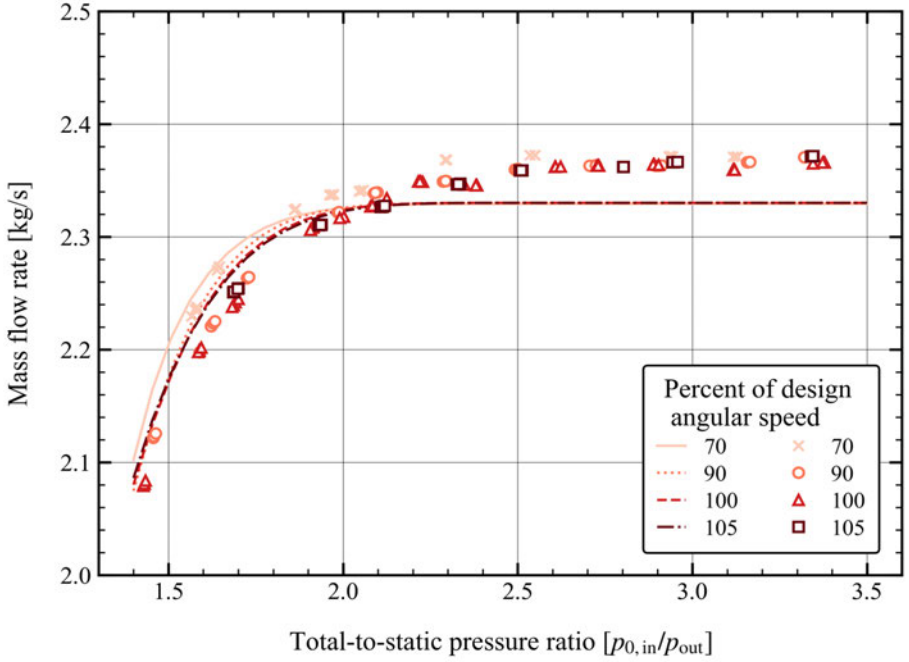
Choked state calculation

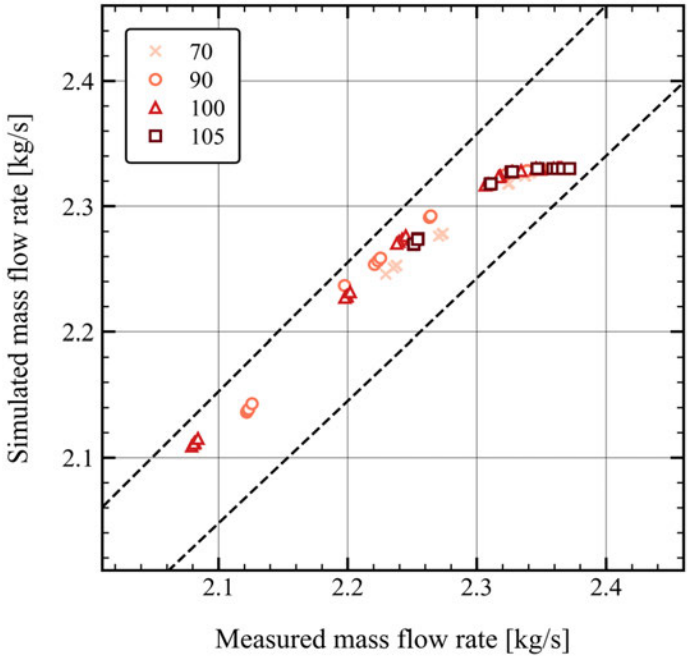
- Previous work either:
  - Assumes mach = 1 at throat for choked calculation
  - Or adopt complex methodology to find maximum mass flux
- Novel method:
  - Maximize mass flow rate at throat through method of Lagrange multipliers
  - Enable calculation of critical state while considering losses
  - Enable equation oriented approach
    - Fewer equation evaluations
    - All equations solved simultaneously
    - Easily integrated with optimization

Validation cases

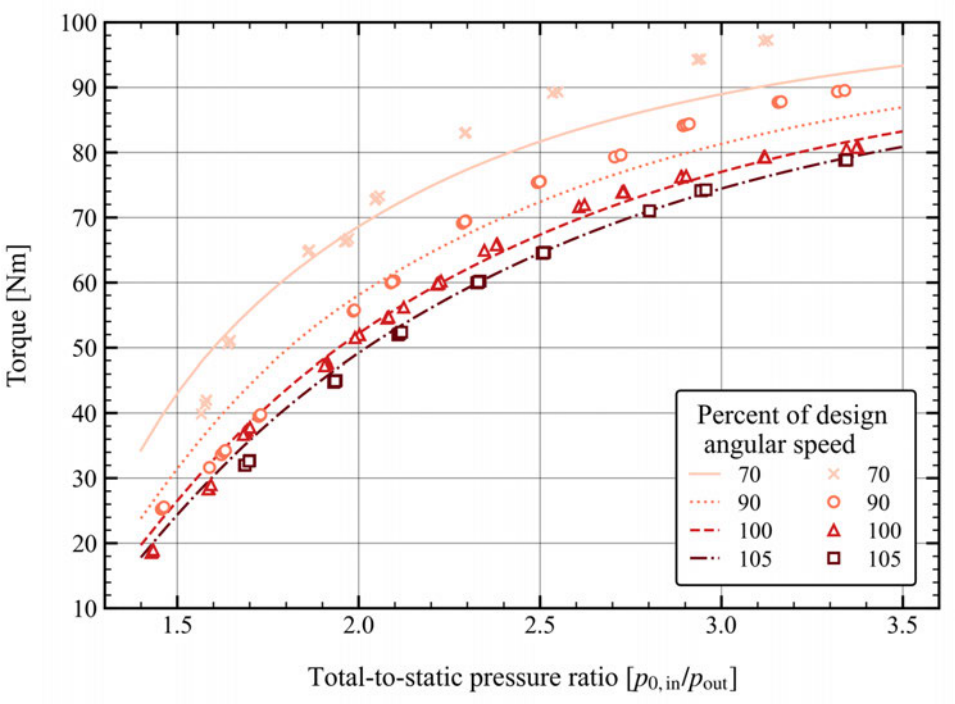
1. Choked stator
   - Mass flow rate
   - Torque
2. Choked rotor
   - Mass flow rate
   - Torque

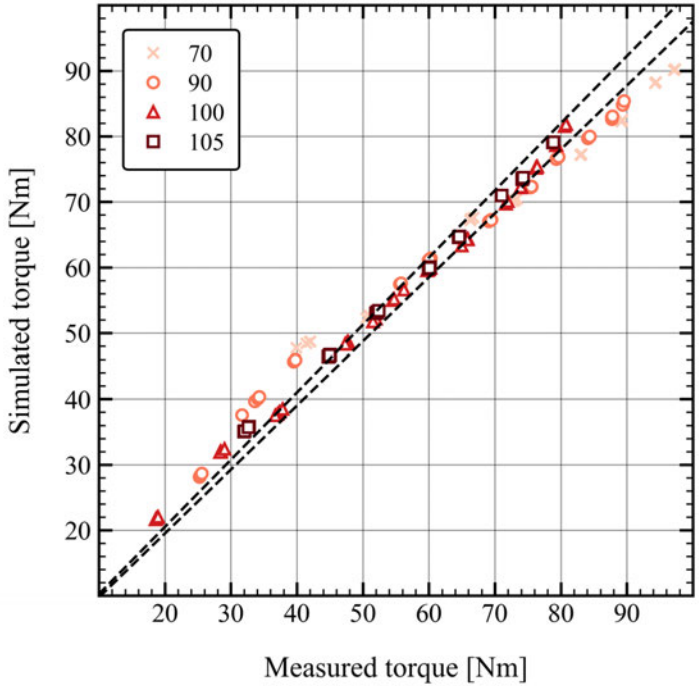
1. Choked stator: mass flow rate



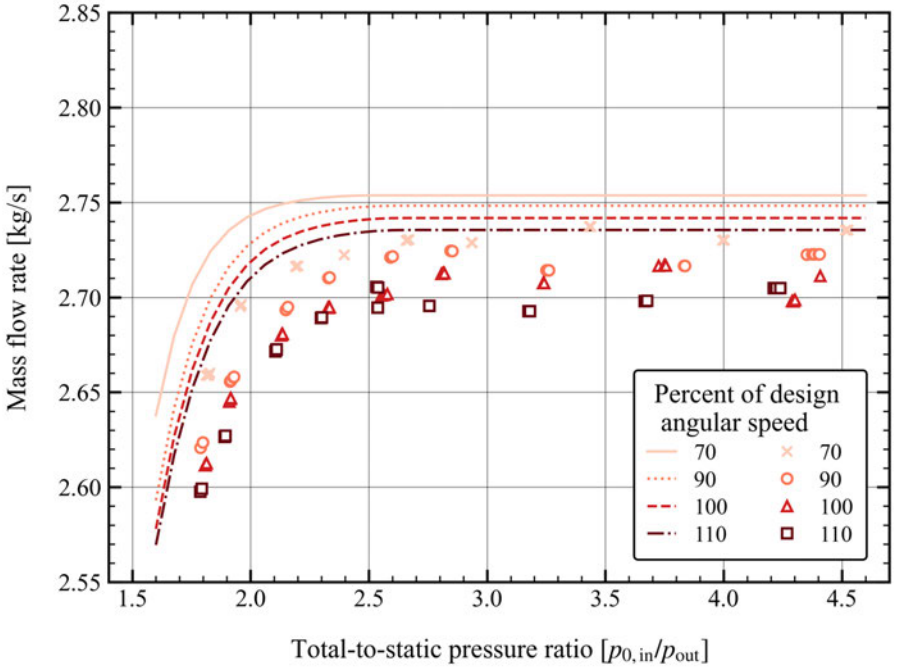


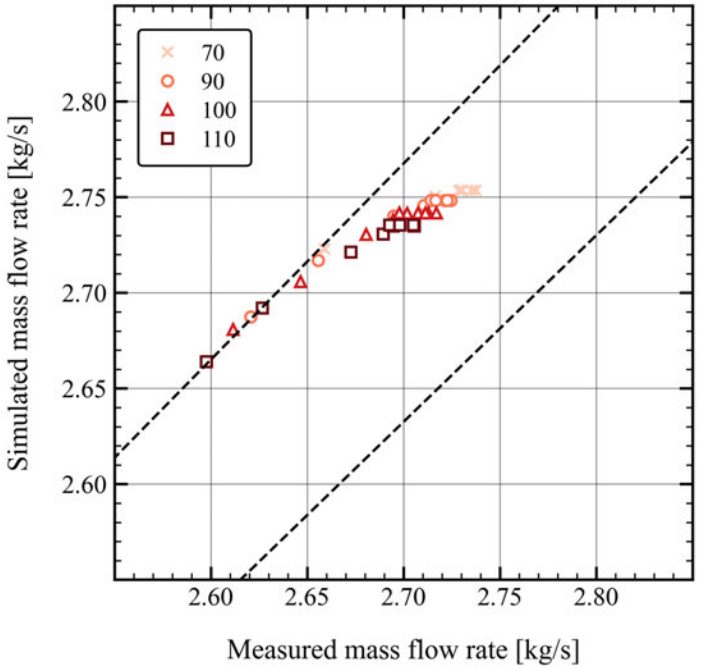
1. Choked stator: torque



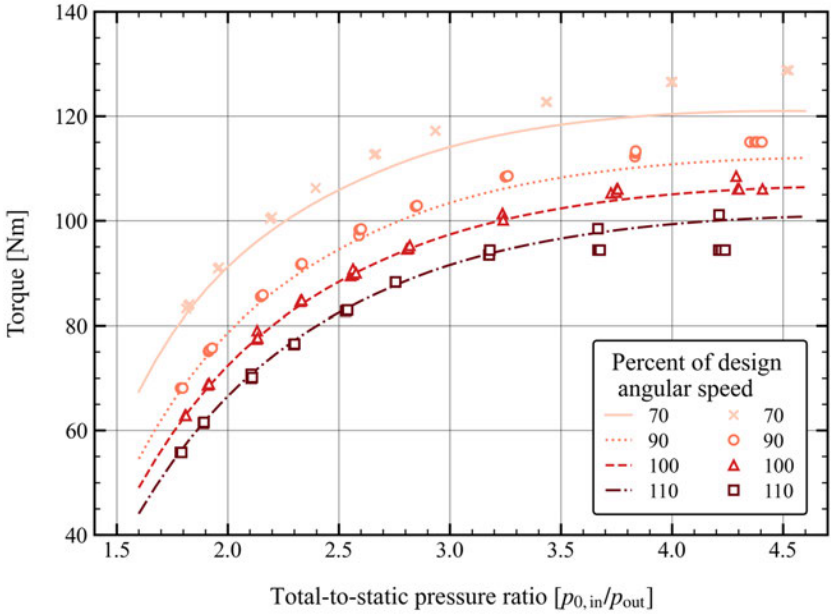


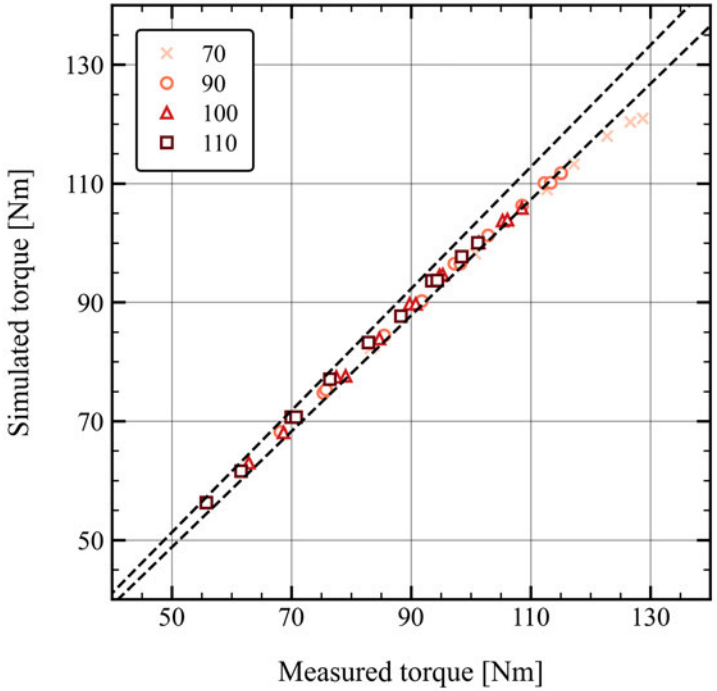
2. Choked rotor: mass flow rate





2. Choked rotor: torque





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Experimental results

EXPAND test rig

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Introduction ORC turbine cycle

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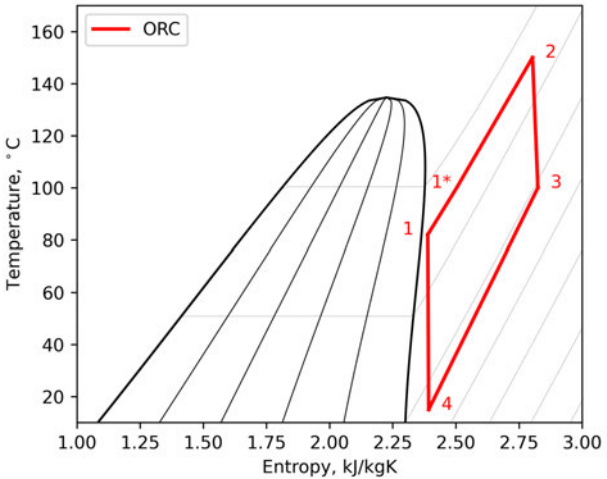
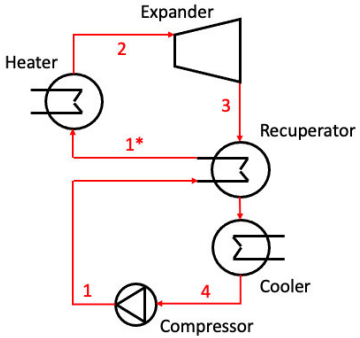
Experimental test facility

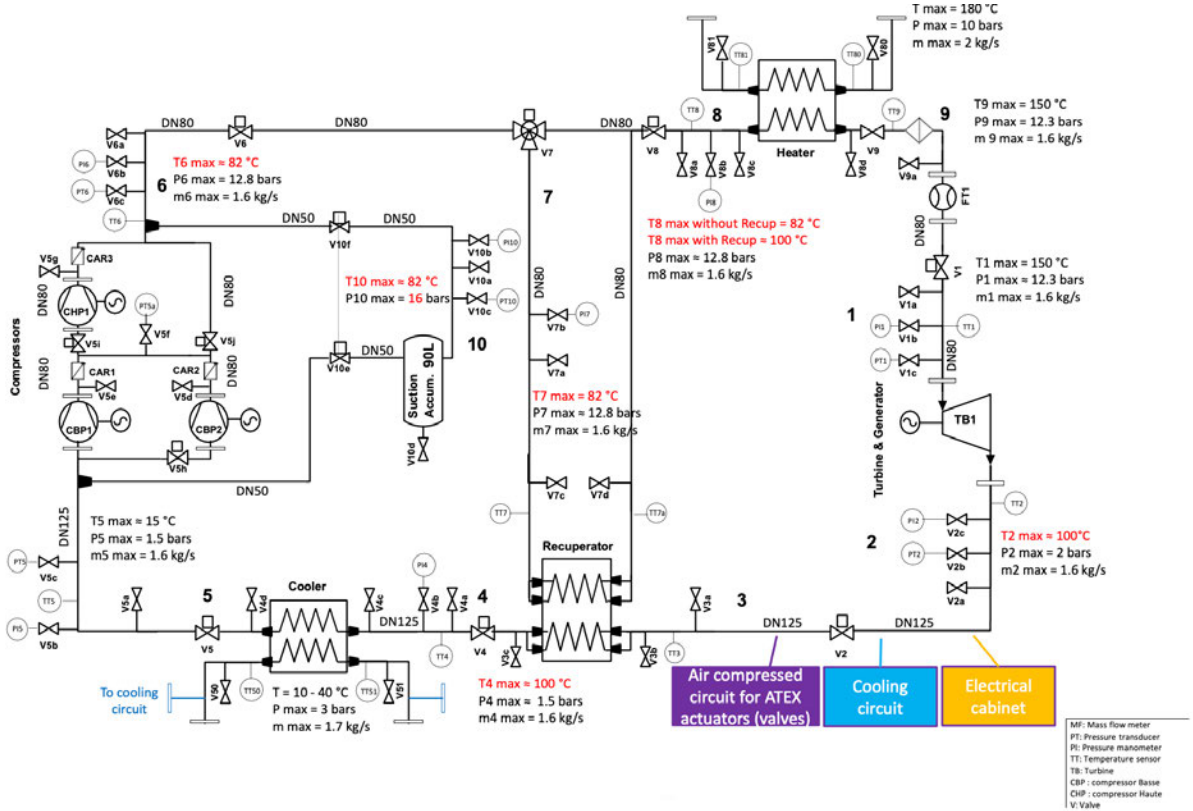
Fundamentals





Working fluid: Isobutane

P&ID of the test rig facility



Source: Enogia

ORC turbine design

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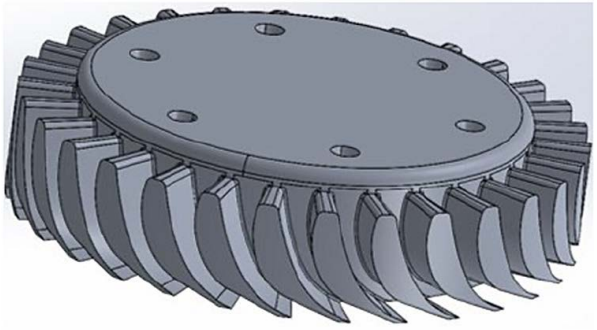
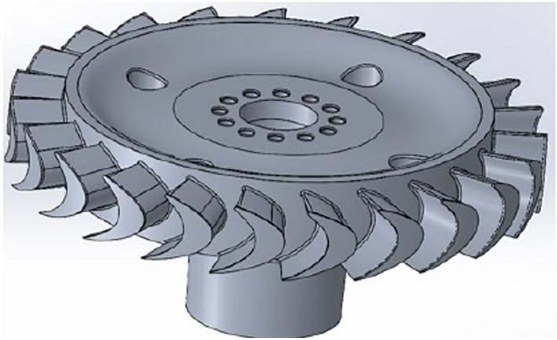


CAD stator blades



CAD rotor blades

Experimental sample of the rotor blades

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Results

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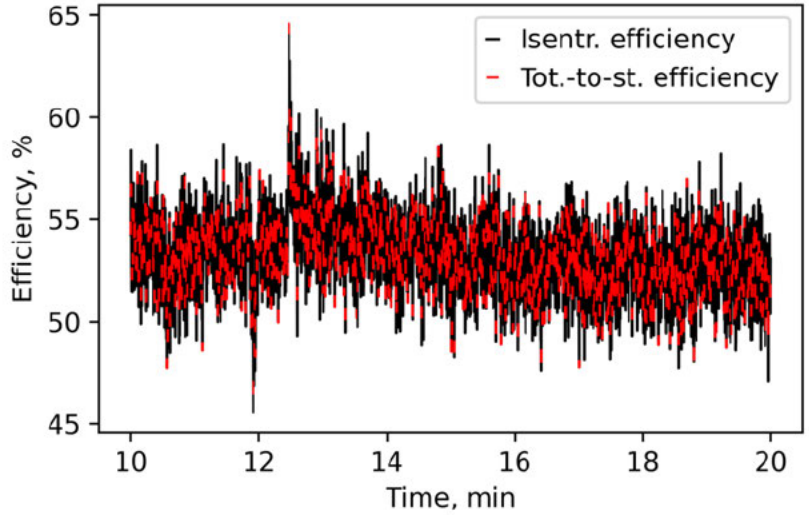
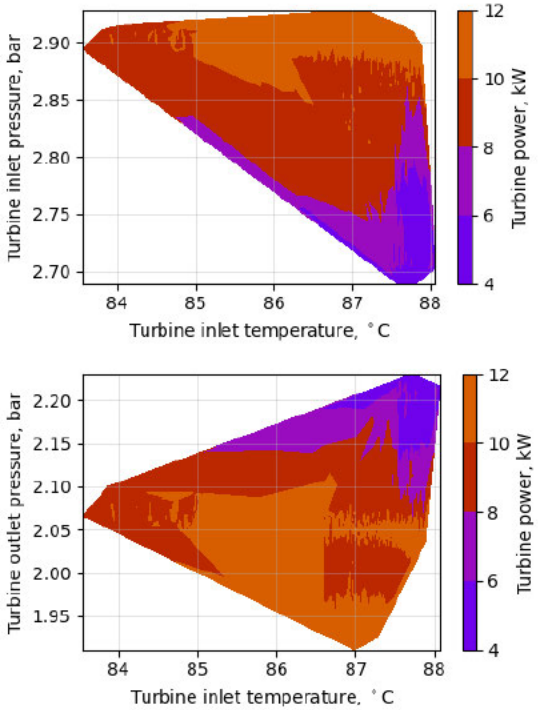
Turbine efficiency

Time slot 10-20 min



Turbine characteristics



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Results

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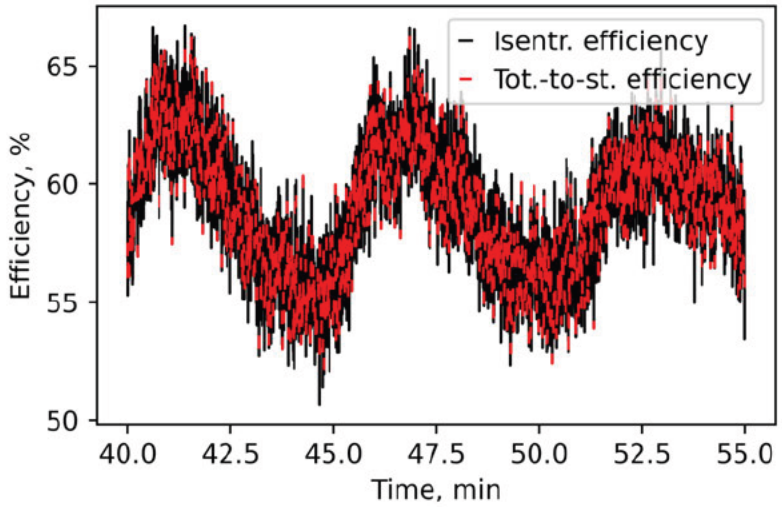
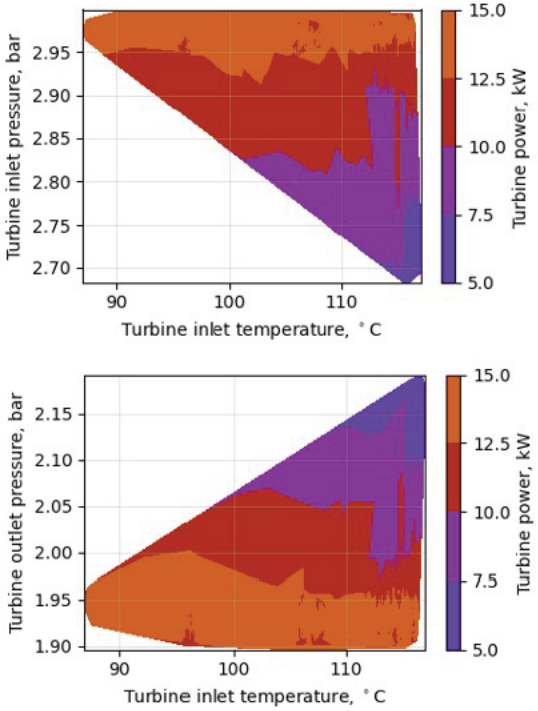
Turbine efficiency

Time slot 40-55 min



Turbine characteristics



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Thanks for the attention

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Additional slides

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Role of losses in nozzle flow

$$(1 - Ma^2)\frac{dv}{v} = -\frac{dA}{A} + \frac{1}{2}\gamma Ma^2\left[C_f\left(\frac{P_w}{A}\right)dx\right]$$

- Friction shifts the location of Ma = 1 downstream of throat
- Choked flow can only be attained if Ma = 1 exist downstream of throat

Role of loss coefficient

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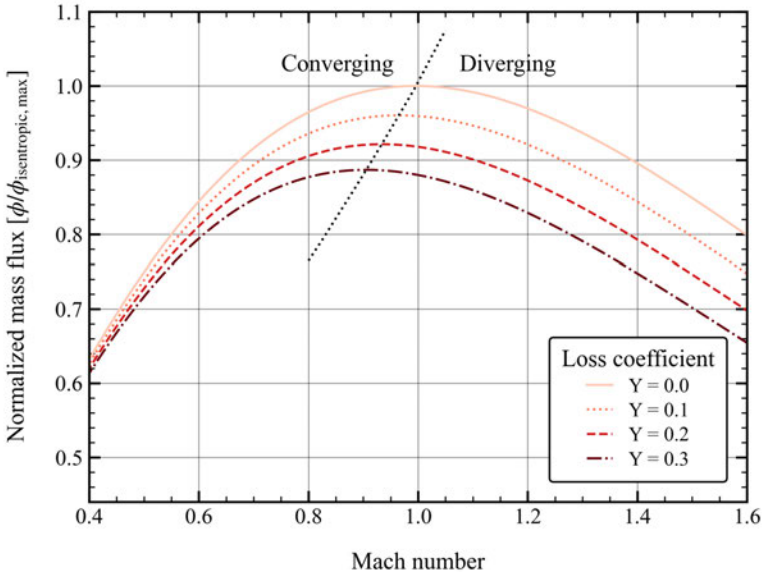
Effect of loss coefficient:



Effect of critical condition: