Energy Conversion Department

Numerical Modelling of Energy Conversion Processes in Flows

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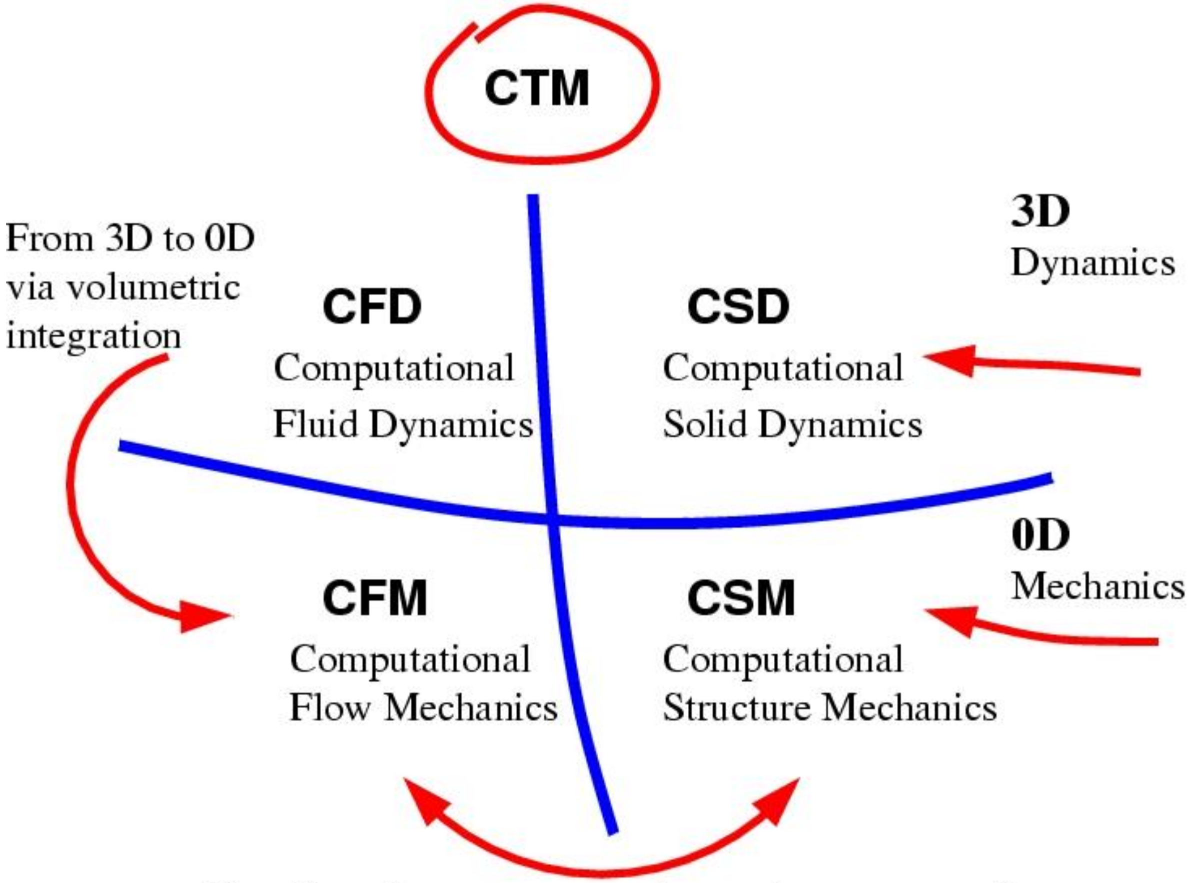
Recent activities

- Basics of sustainable energy conversion processes
- Numerical modelling of pro-ecological and electrochemical fuel combustion (SOFC)
- Lean/oxy-combustion

Future activities

- Micro- and nanoflows
- Clean coal technology
- Innovated hybrid cycles with CO2 sequestration

Computational Thermomechanics of Continuum



CTM

From 3D to 0D
via volumetric
integration

CFD
Computational
Fluid Dynamics

CSD
Computational
Solid Dynamics

3D
Dynamics

CFM
Computational
Flow Mechanics

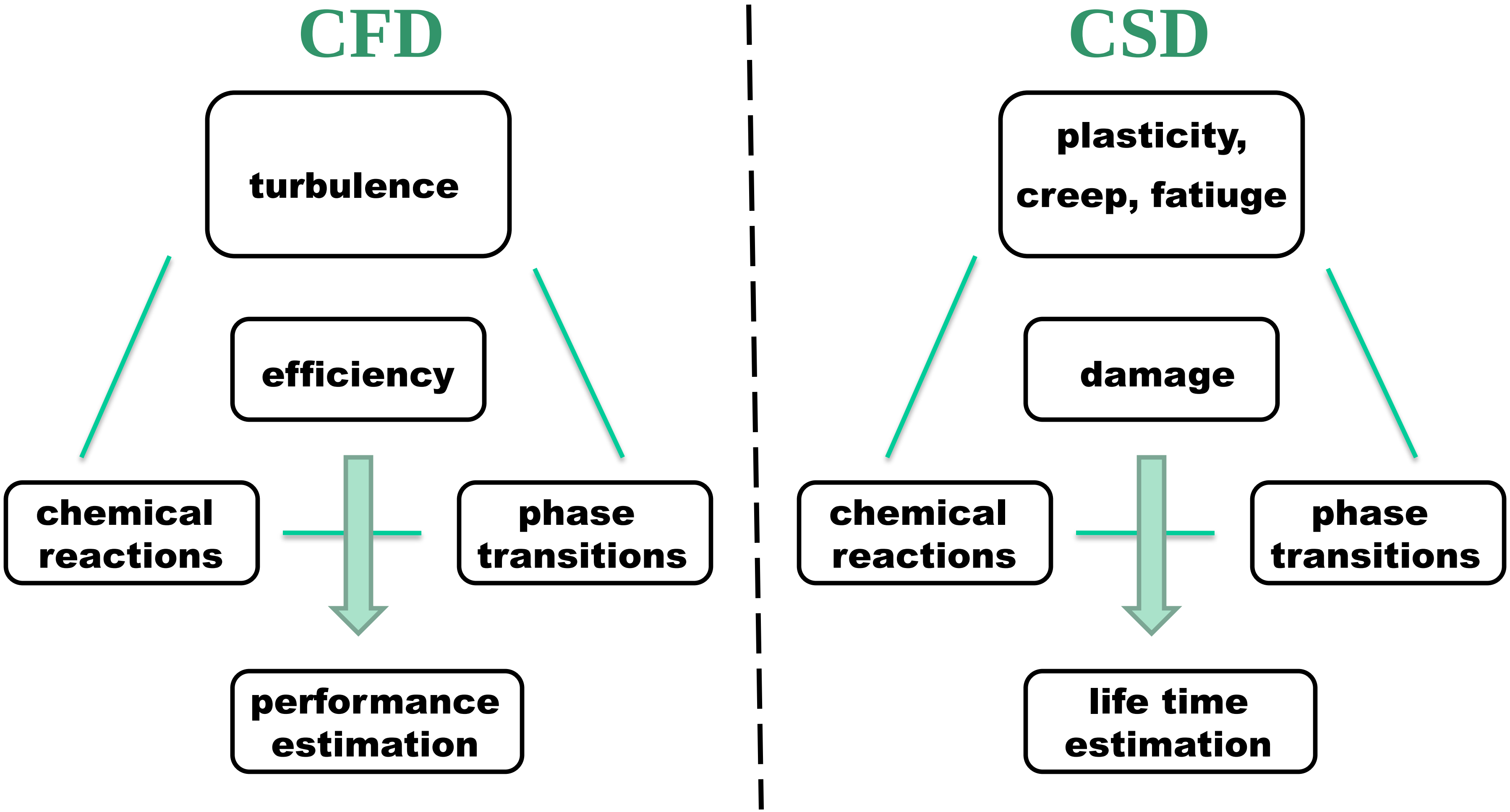
CSM
Computational
Structure Mechanics

0D
Mechanics

Coupling via mass, momentum and energy equations

Energy Conversion Department IMP

- numerical modeling of the combustion chamber related problems (gas turbines, boilers)
- chemical and electrochemical reaction modeling (solid oxide fuel cells)
- parametrical „0D" analysis of hybrid heat cycles
- implementation of own mathematical models and closures to standard CFD and CSD codes
- coupling between CFD and CSD via temperature and chemical species distribution (FSI)



CFD

turbulence

efficiency

chemical reactions

phase transitions

performance estimation

CSD

plasticity,

creep, fatiuge

damage

chemical reactions

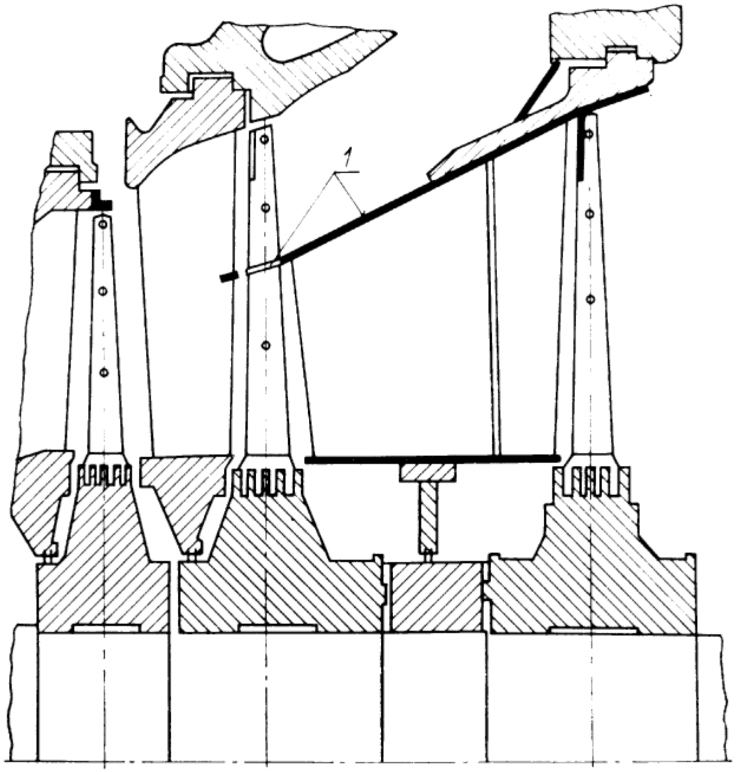
phase transitions

life time estimation

Examples of recent numerical modelling

1. **Spontaneous condensation in turbulent flow (low pressure part of 200MW turbine)**
2. **Natural gas combustion in silo-combustor gas turbine**
3. **Bitumen oxidization in industrial reactor**

1. The problem of two-phase flow in steam turbine



Huge volumetric flow rate of steam creates difficulties in designing the low pressure part of condensation turbine of large output.

In the past a technological constraints leads to the Baumann stage concept with separation of steam flow onto two paths with one stage only for external path and two stages for internal path.

Model of steam condensation - theory

- balance of mass ρ:

$$\partial_t(\rho) + \mathrm{div}(\rho\,\mathbf{v}) = 0$$

- balance of momentum $\rho\mathbf{v}$:

$$\partial_t(\rho\,\mathbf{v}) + \mathrm{div}(\rho\,\mathbf{v}\otimes\mathbf{v} + p\mathbf{I}) = \mathrm{div}(\mathbf{t}^c) + \rho\,\mathbf{b}$$

- balance of energy $e = u(T) + 0.5\mathbf{v}^2$:

$$\partial_t(\rho e) + \mathrm{div}(\rho e\mathbf{v} + p\mathbf{v}) = \mathrm{div}(\mathbf{t}^c\mathbf{v} + \mathbf{q}^c) + \rho\,\mathbf{b}\cdot\mathbf{v}$$

- balance of turbulent kinetic energy k:

$$\partial_t(\rho\,k) + \mathrm{div}(\rho\,k\mathbf{v}) = \mathrm{div}(\mathbf{J}_k) + \rho\,S_k$$

- balance of turbulent kinetic energy dissipation rate ε:

$$\partial_t(\rho\,\varepsilon) + \mathrm{div}(\rho\,\varepsilon\,\mathbf{v}) = \mathrm{div}(\mathbf{J}_\varepsilon) + \rho\,S_\varepsilon$$

- balance of dryness fraction x:

$$\partial_t(\rho\,x) + \mathrm{div}(\rho\,x\,\mathbf{v}) = \mathrm{div}(\mathbf{J}_x) + \rho\,S_x$$

- balance of droplet number a:

$$\partial_t(\rho\,a) + \mathrm{div}(\rho\,a\,\mathbf{v}) = \mathrm{div}(\mathbf{J}_a) + \rho\,S_a$$

Model of steam condensation - theory

Full phenomenological model includes the following constitutive equations:

$$\mathbf{J}_k = (D_{kk})\mathbf{g}_k + (D_{kxo} + D_{kxr})\mathbf{g}_x$$
$$\mathbf{J}_x = (D_{kxo} + D_{kxr})\mathbf{g}_k + (D_{xxo} + D_{xxr})\mathbf{g}_x$$

and

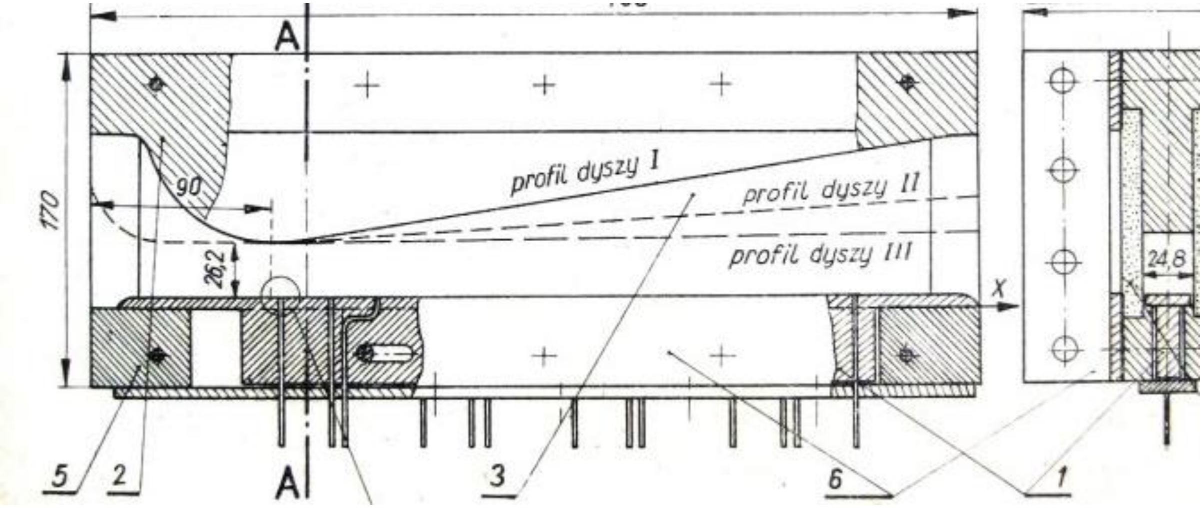
$$\mathbf{J}_\varepsilon = (D_{\varepsilon\varepsilon})\mathbf{g}_\varepsilon + (D_{\varepsilon ao} + D_{\varepsilon ar})\mathbf{g}_a$$
$$\mathbf{J}_a = (D_{a\varepsilon})\mathbf{g}_\varepsilon + (D_{aao} + D_{aar})\mathbf{g}_a$$

The kinematic equations for fluxes description are:

$$\mathbf{g}_k = \mathrm{grad}\,k\ , \quad \mathbf{g}_\varepsilon = \mathrm{grad}\,\varepsilon\,, \quad \mathbf{g}_x = \mathrm{grad}\,x\ , \quad \mathbf{g}_a = \mathrm{grad}\,a$$

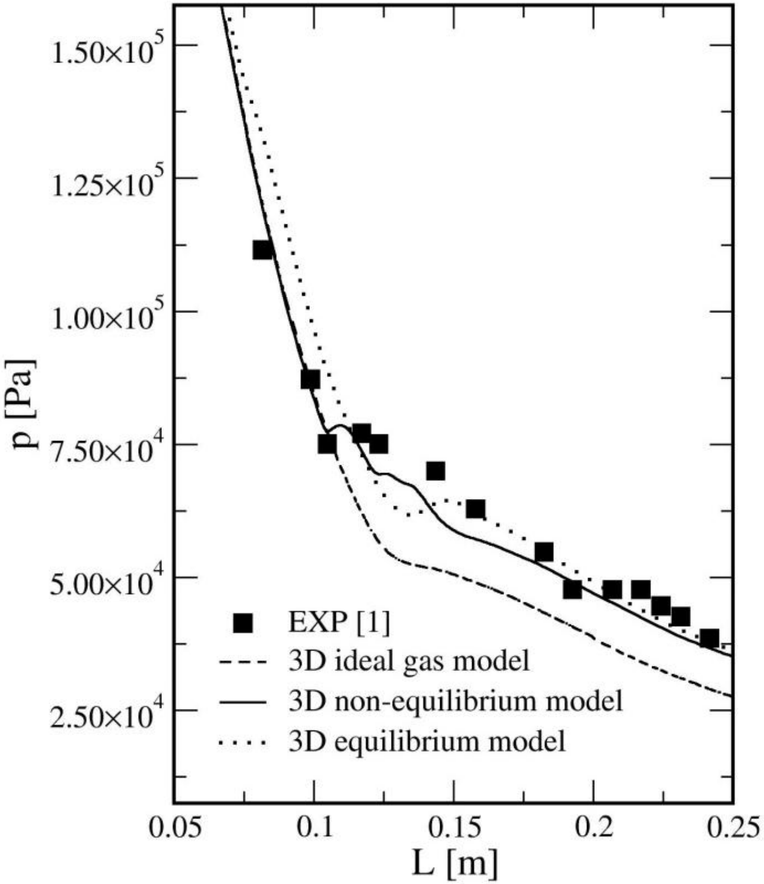
Homogenous source parts responsible for growth and inception of droplets:

$$S_x = 4/3\pi\rho_l I r^{*3} + 4\pi\rho_l\, a\bar{r}^2\dot{\bar{r}}\,,$$



Experiment IMP PAN (R. Puzyrewski, 1972)

de Laval nozzle L=0.5 m
inlet parameters of steam near saturation line



Pressure changes in de Laval nozzle

Numerical analysis of LP part of 200 MW turbine

- Computations of whole LP part of 200 MW steam turbine with Baumann stage – including exhaust hood,

- Boundary conditions according to measurements at the operating turbine in electro-power station (Błażko, 1989),

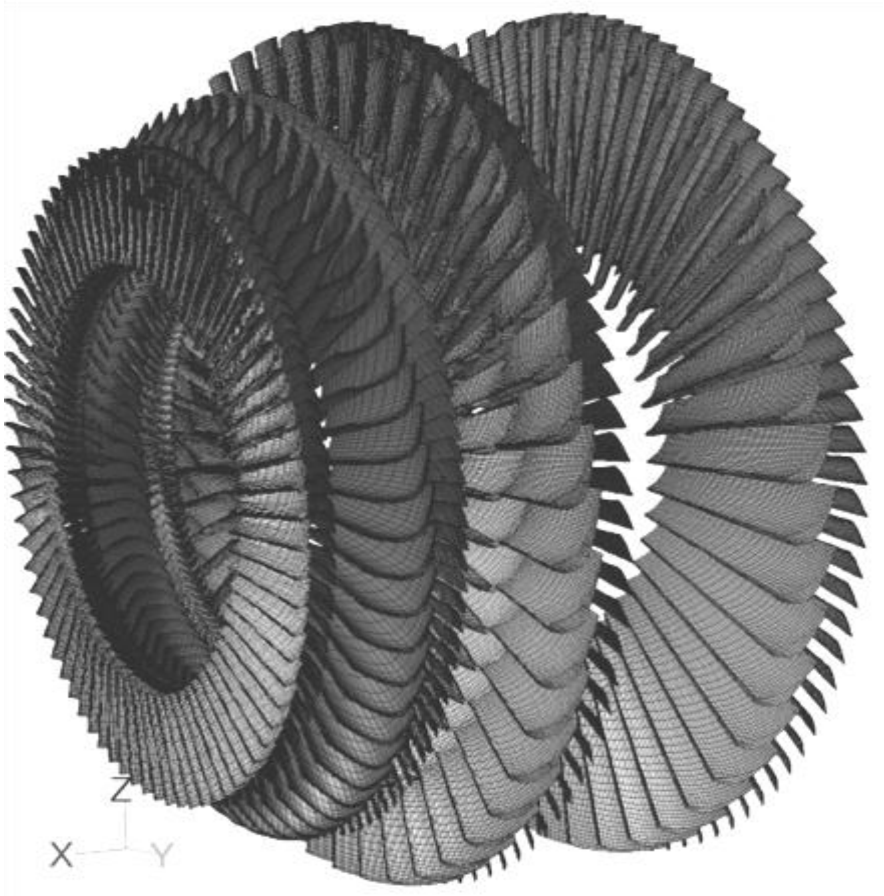
- Two models of steam have been employed: ideal gas (without condensation) and equillibrium model of steam condensation.

Numerical analysis of LP part of 200 MW turbine

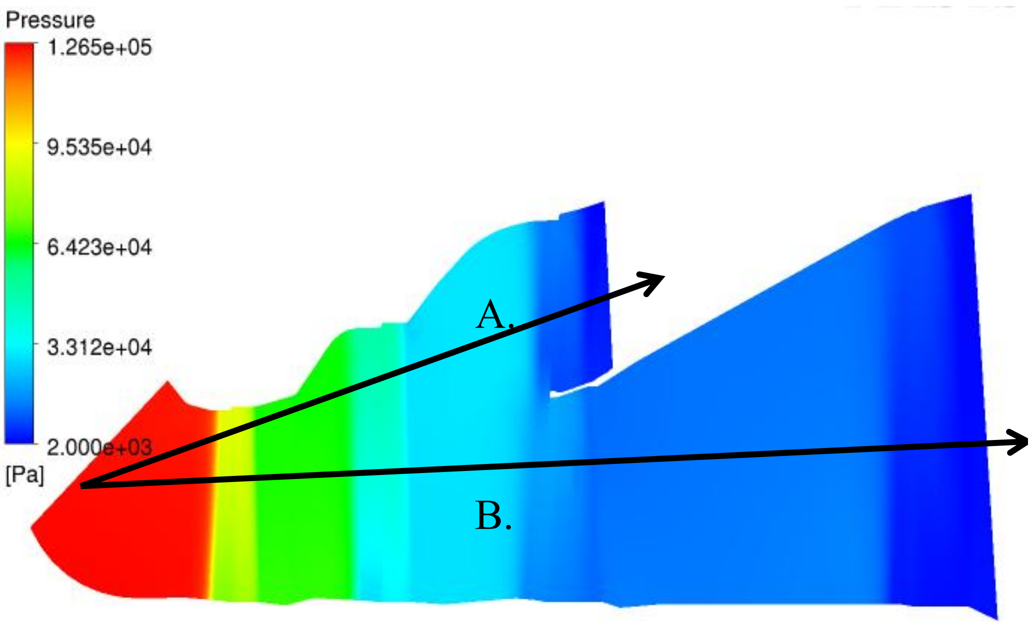
Experimental data
(Błażko, 1989):

p_0 = 1.247 bar
T_0 = 179.2 ˚C
p_2 = 0.023 bar

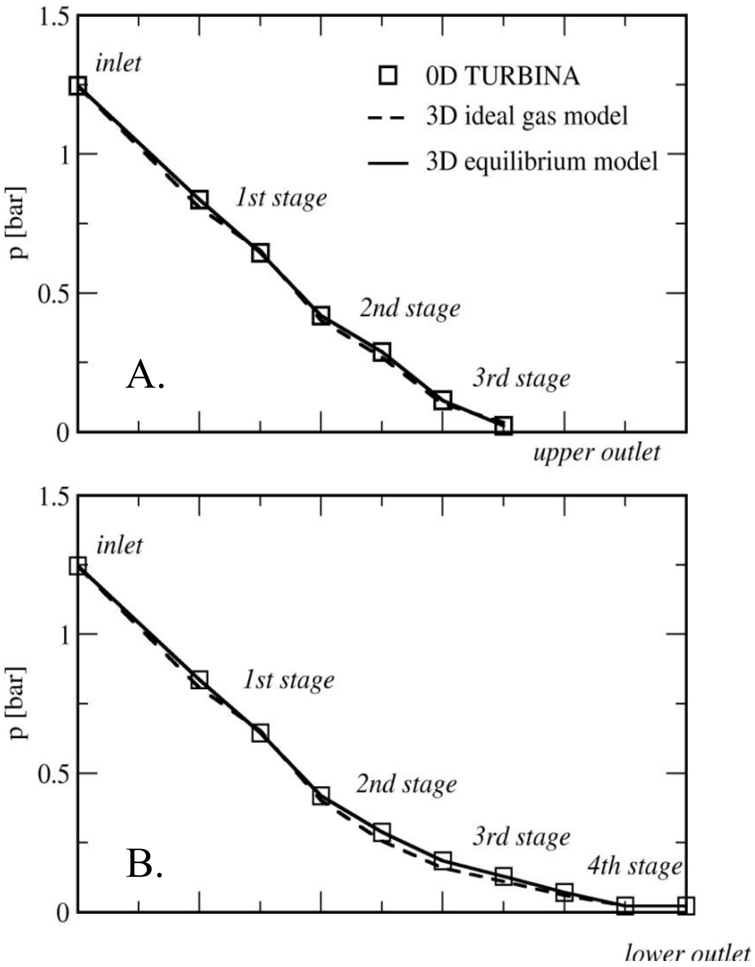
m_{LP} = 65.194 kg/s
$m_{extraction}$ = 4.621 kg/s



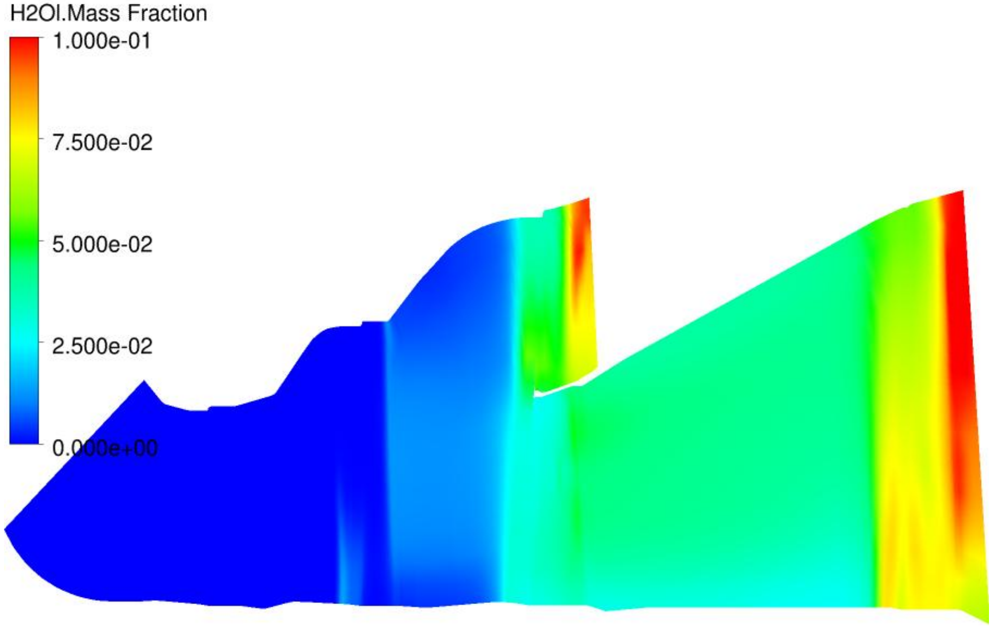
Numerical analysis of LP part of 200 MW turbine



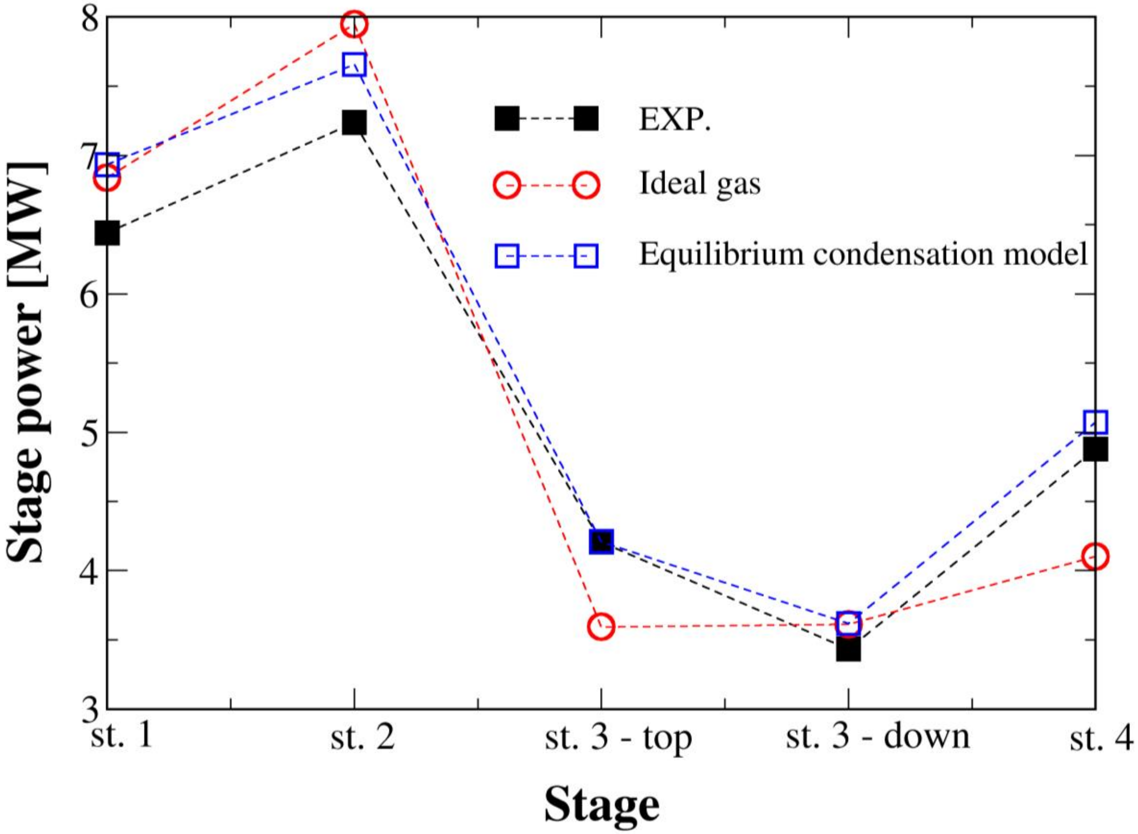
Static pressure distribution during expansion in LP part with Baumann stage



Numerical analysis of LP part of 200 MW turbine



Wetness fraction (1-x) during steam expansion in
LP part with Baumann stage



Prediction of LP stage’s power using different models

Thank You for attention