Design of radial turbomachinery for supercritical CO_2 systems using theoretical and numerical CFD methodologies

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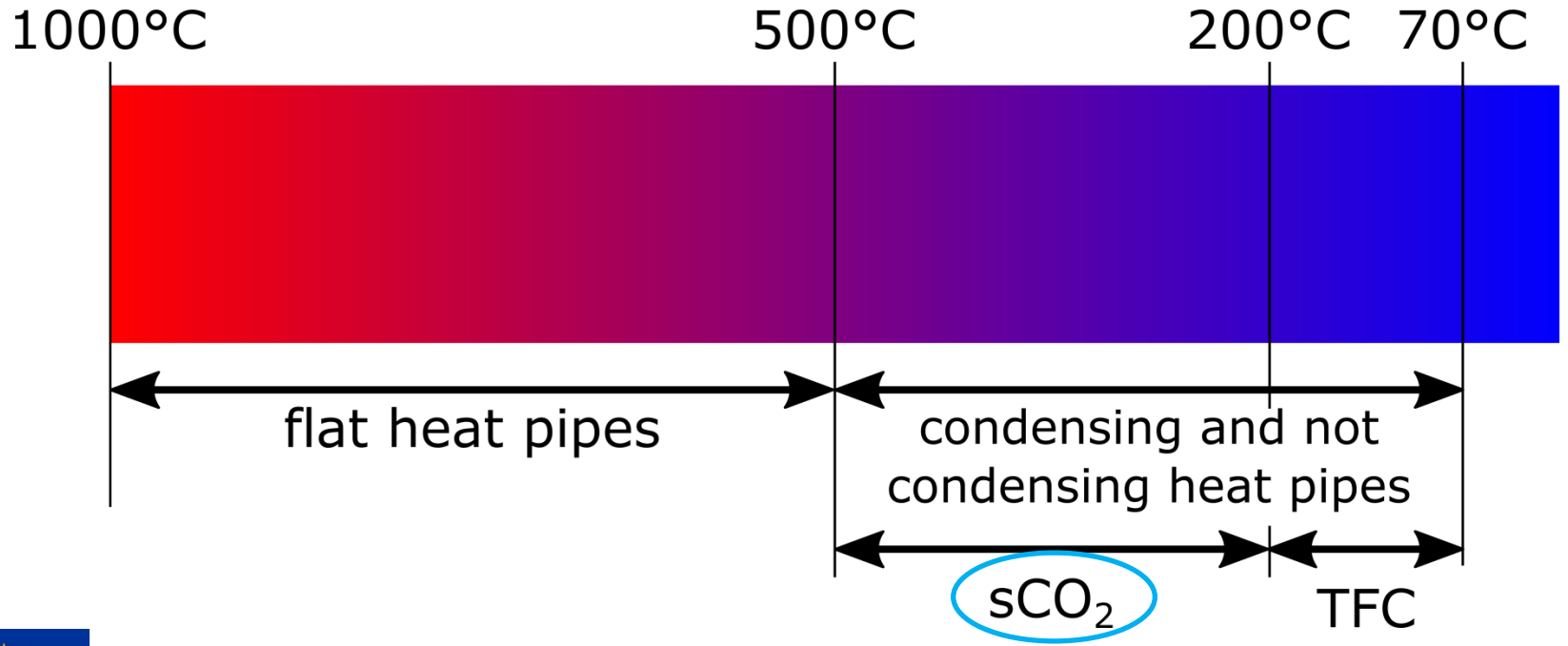
Windsor, 20/04/2017

I-ThERM Project aim is to…

Investigate, design, build and demonstrate innovative plug and play waste heat recovery solutions to facilitate optimum utilisation of energy in selected applications with high replicability and energy recovery potential in the temperature range 70 ℃ – 1000 ℃



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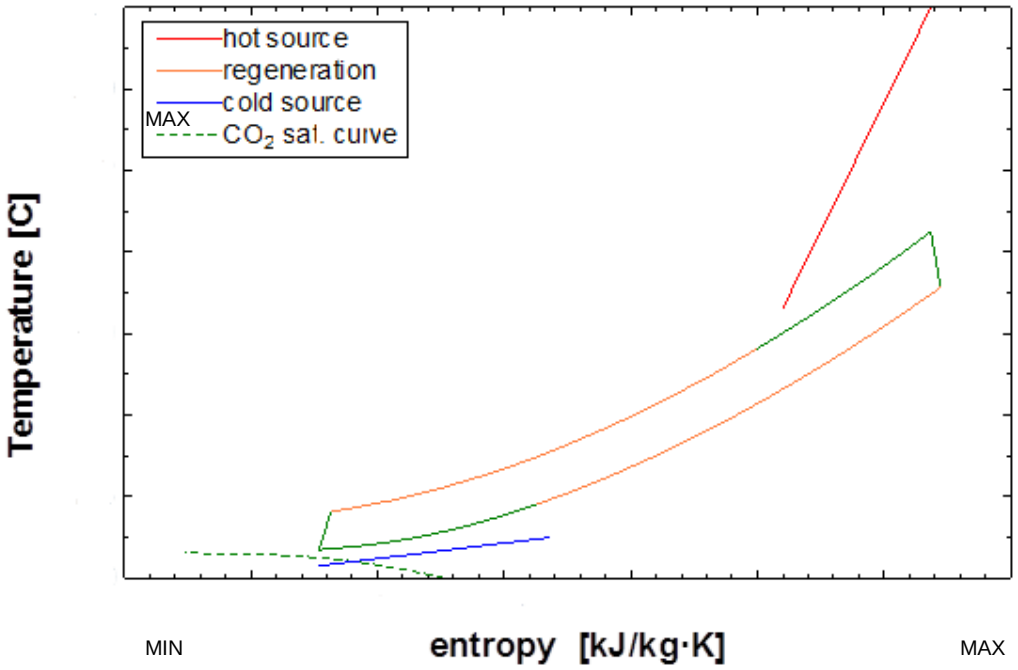
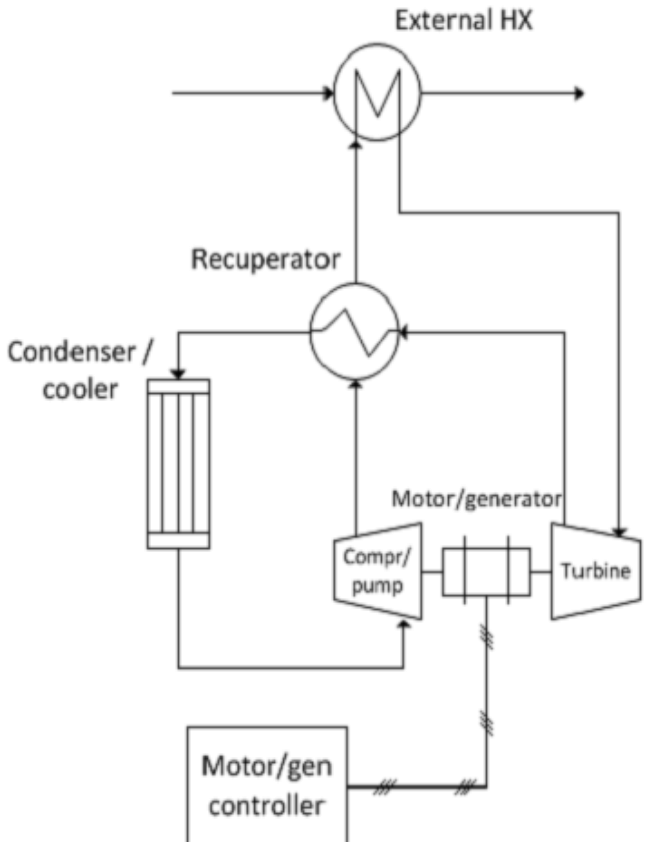
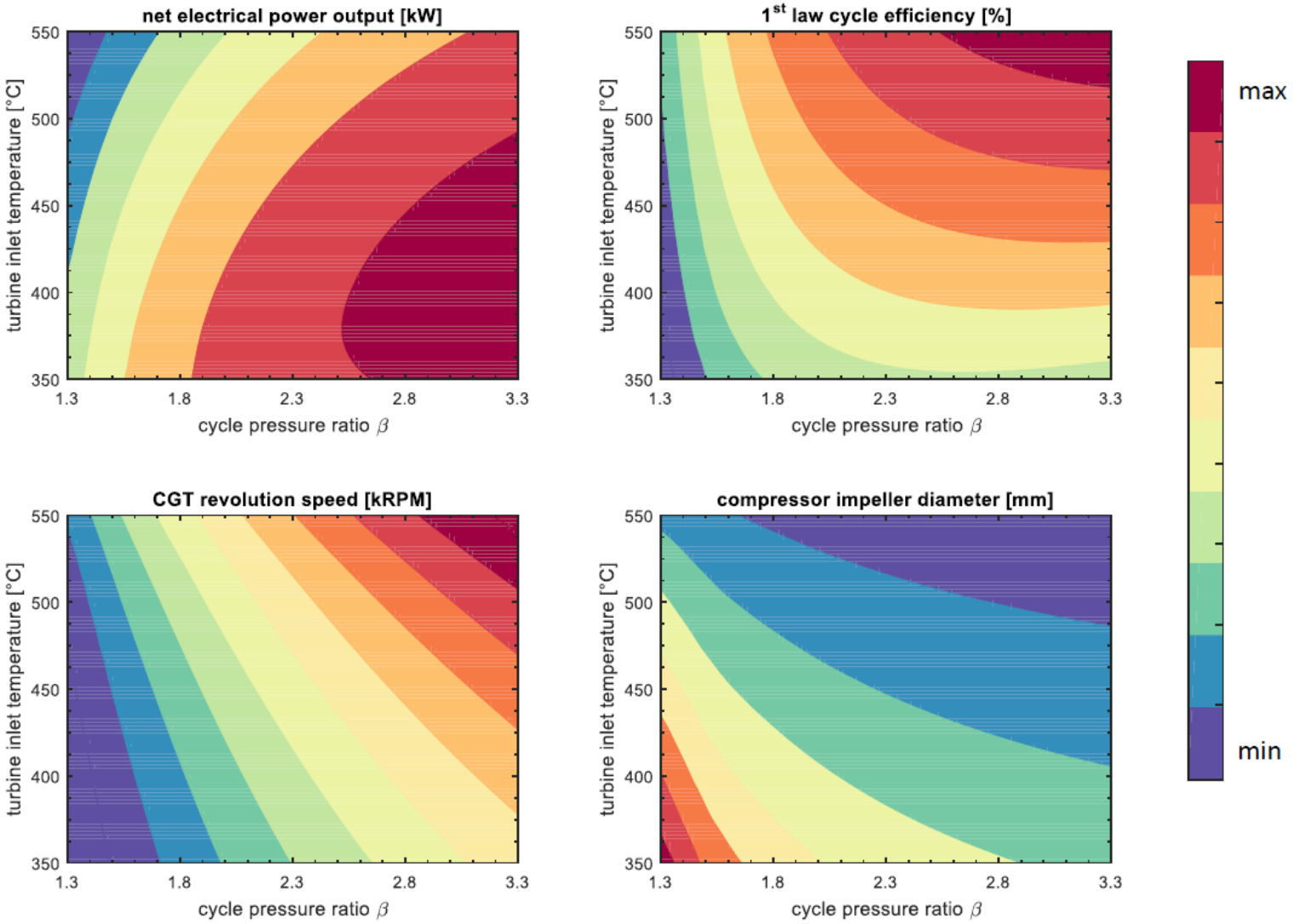
Outline

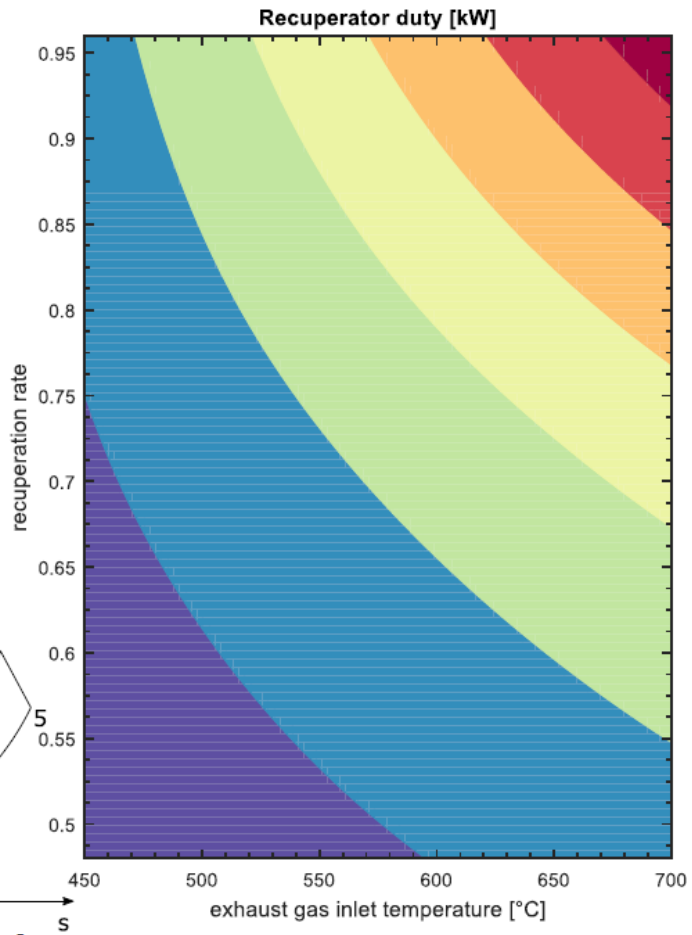
- Reference thermodynamic cycle
- Preliminary turbomachinery design
- CAD
- Simulation CFD
- Turbine Design
- Results and discussion

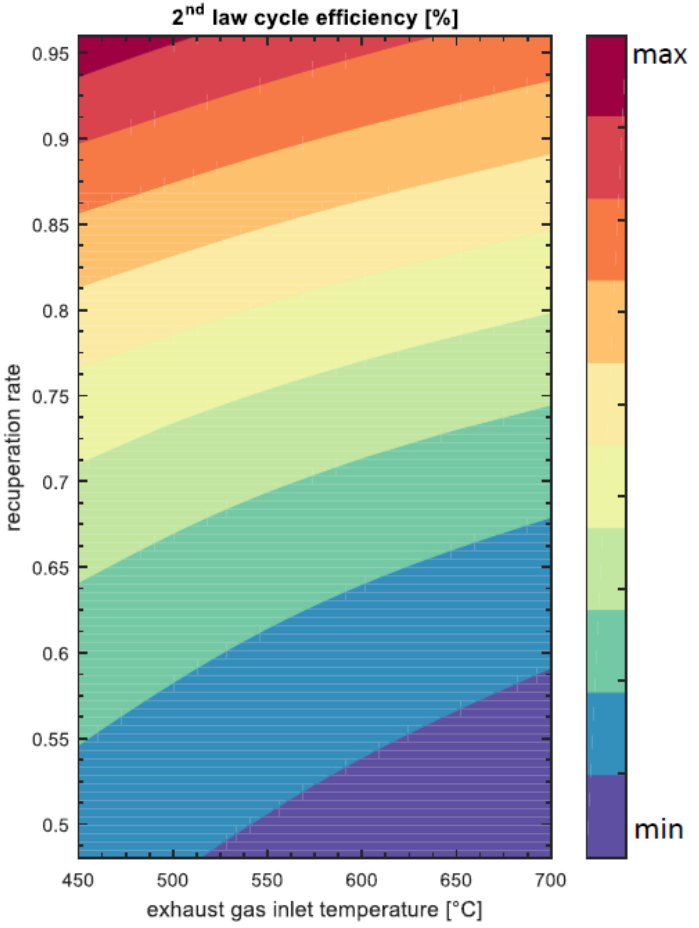
Thermodynamic cycle

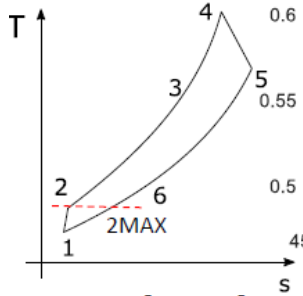




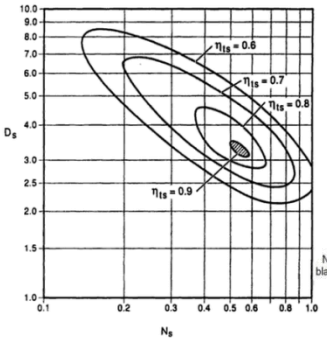

net electrical power output [kW]
1st law cycle efficiency [%]
CGT revolution speed [kRPM]
compressor impeller diameter [mm]
turbine inlet temperature [°C]
cycle pressure ratio β
550
500
450
400
350
1.3
1.8
2.3
2.8
3.3
max
min



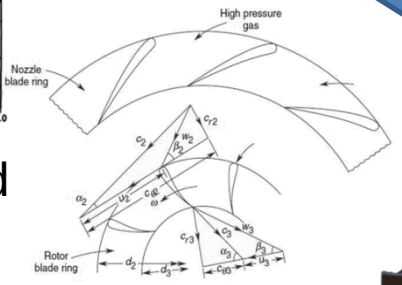




$$R = \frac{h_5 - h_6}{h_5 - h_{2MAX}}$$

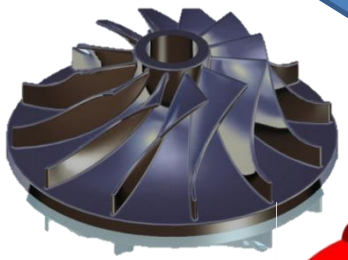


Specific speed and diameter

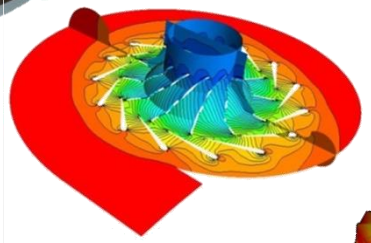


Velocity triangles

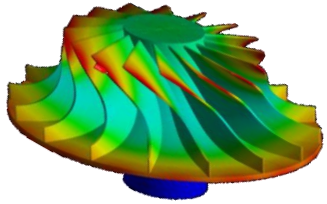
Turbomachinery Design



CAD



CFD



FEA

- Balje's charts available for air and water turbo machines
- Loss correlations available for air
- Need of coupling CFD tools with thermo-physical properties of CO_2 (dll libraries or look-up tables)
- Need of importing thermomechanical properties in FEA tools if custom materials are employed

Balje Equations

$$N_s = \frac{N \cdot Q_3^{1/2}}{H_{ad}^{3/4}}$$

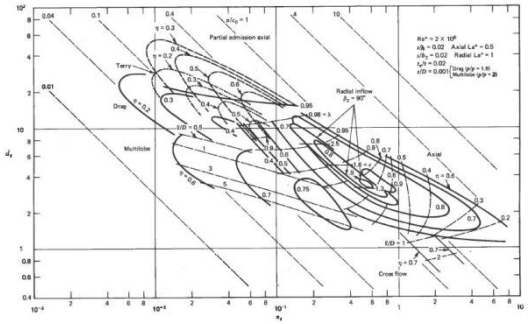
$$D_s = \frac{D \cdot H_{ad}^{1/4}}{Q_3^{1/2}}$$

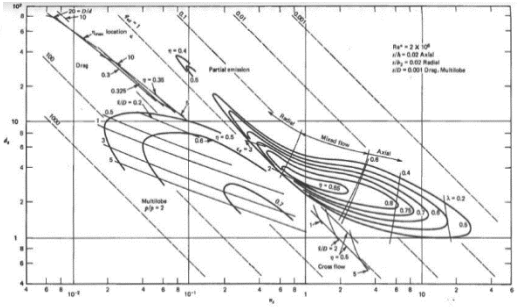
N = Rotational Speed (rpm)

Q_3 = Rotor Flow Rate (ft^3/sec)

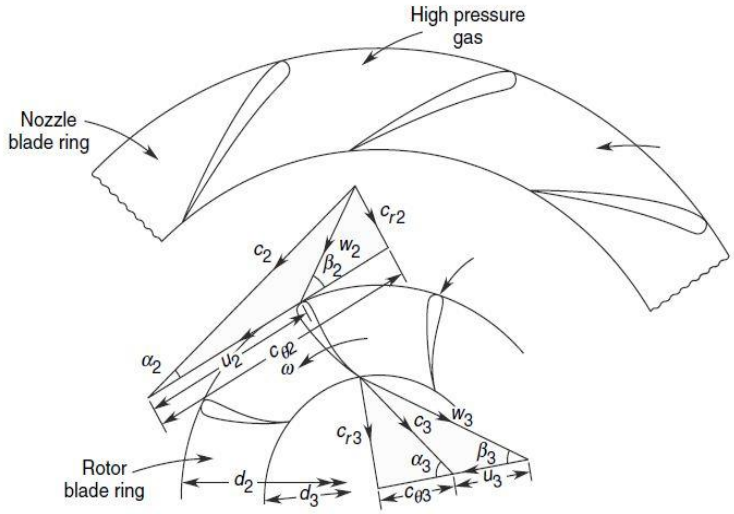
H_{ad} = Adiabatic Head (ft)

D = Diameter (ft)

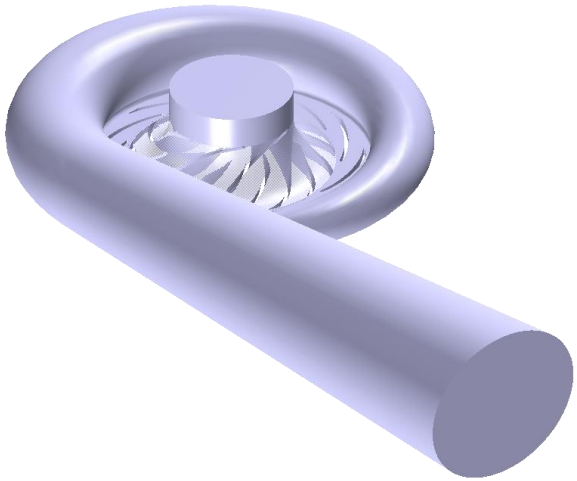


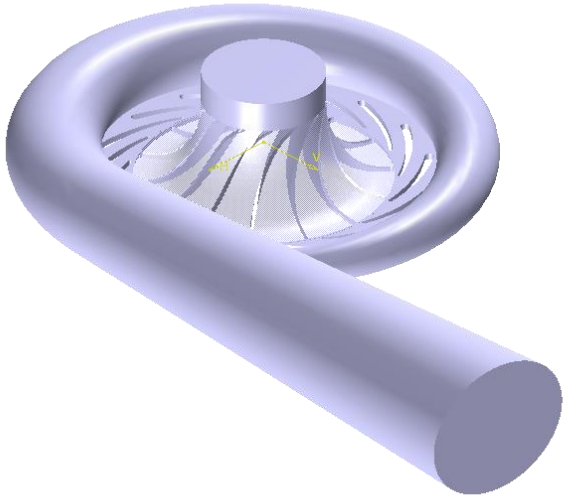


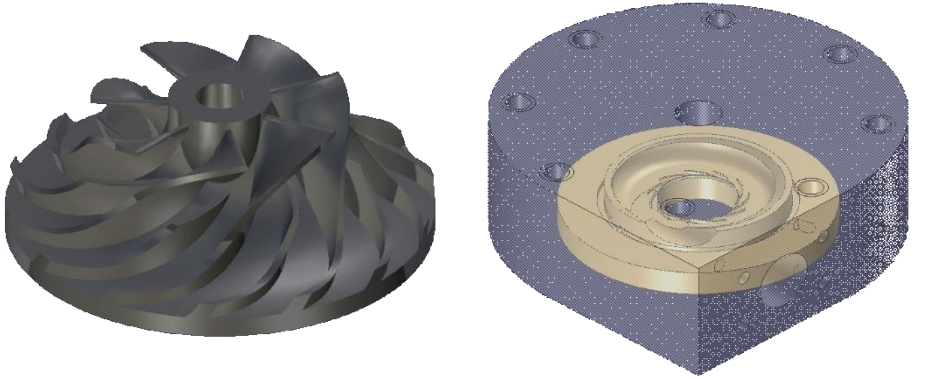
Velocity Diagram



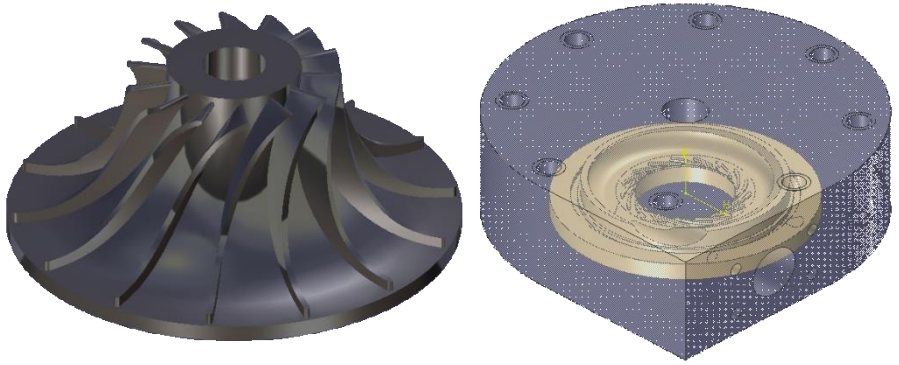
Computer Aided Design







Compressor



Turbine

CFD simulations setup

- Flow type

  3D Steady Compressible Flow

- Solver

  coupled flow

- Turbulence model

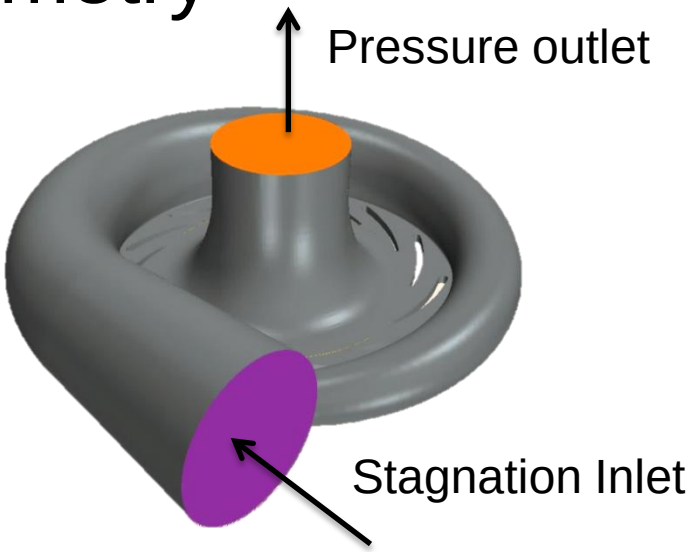
  RANS, K-Epsilon, All Wally+

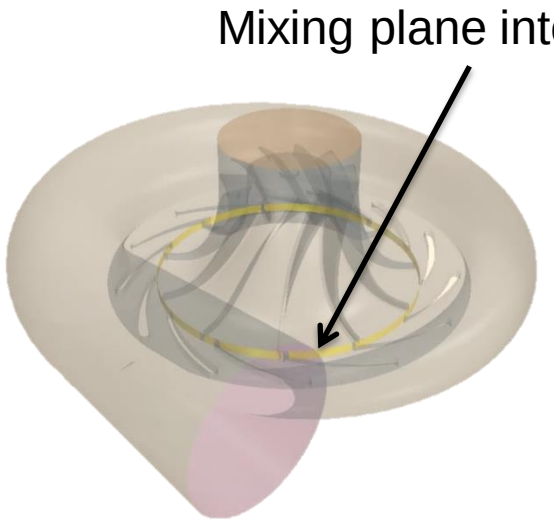
- Equation state

  Peng-Robinson

Turbine CFD – boundary conditions

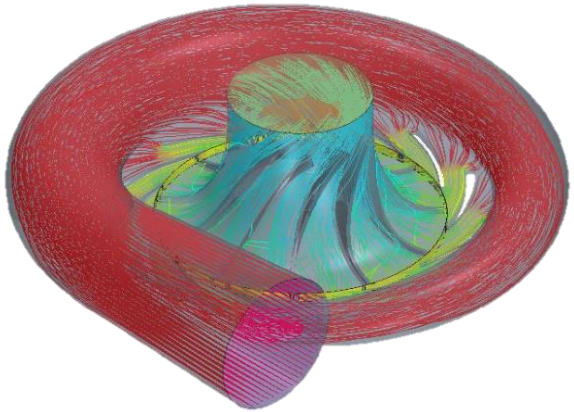
Geometry



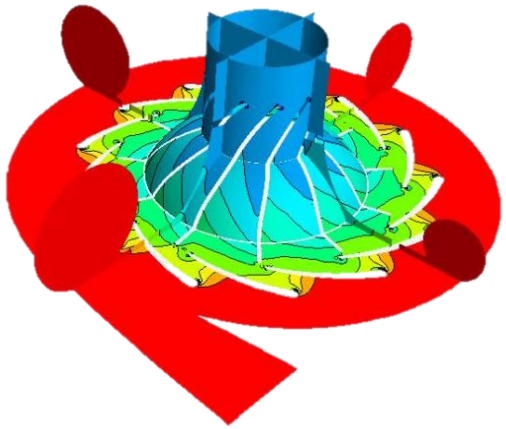


2 domains : 1 considered Stationary (Volute+Nozzel)
1 considered in Rotation (Wheel)

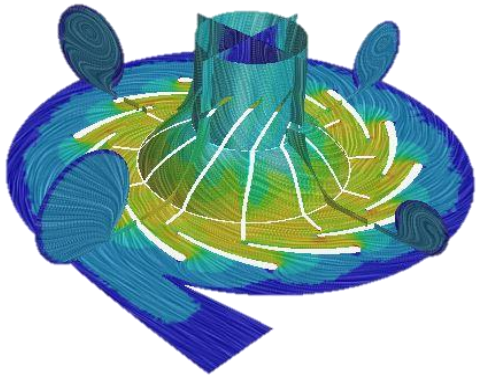
Turbine CFD - Results



Streamlines



Pressure Field

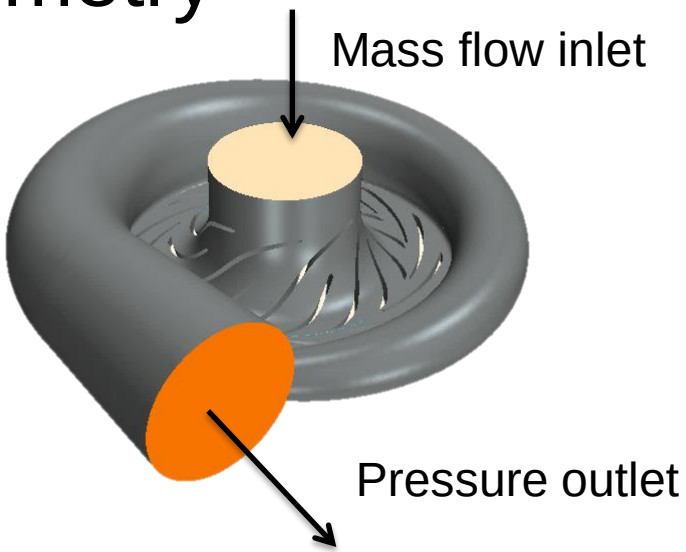


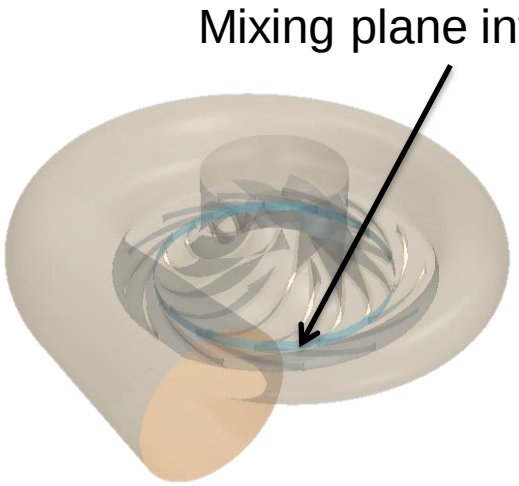
Velocity field

Isentropic efficiency: 70%

Compressor CFD – boundary conditions

Geometry





2 domains : 1 considered Stationary (Volute+Nozzel)
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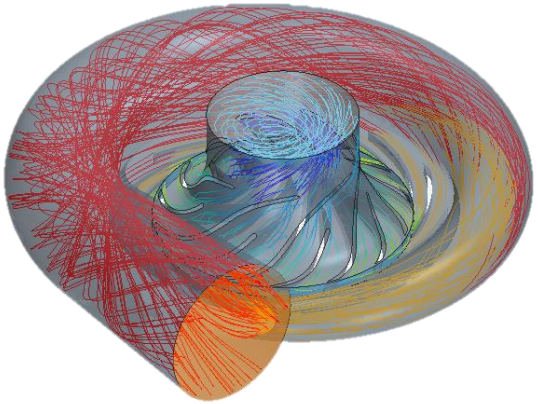
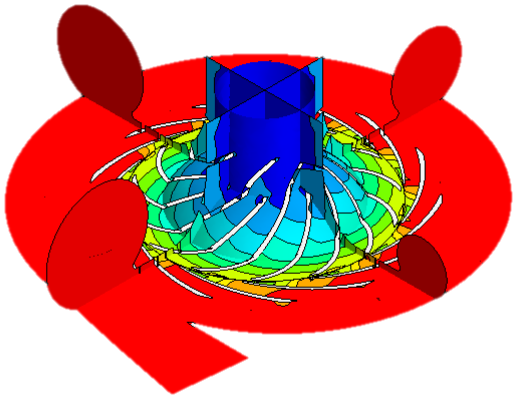
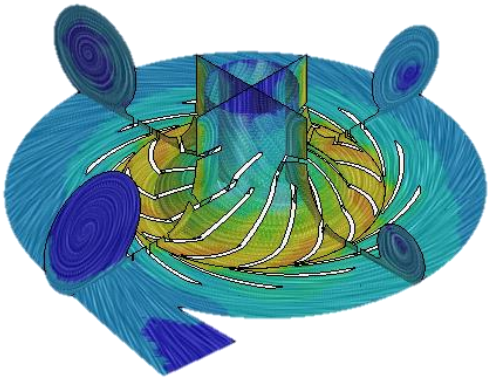
Compressor CFD - Results



Streamlines



Pressure Field

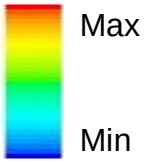


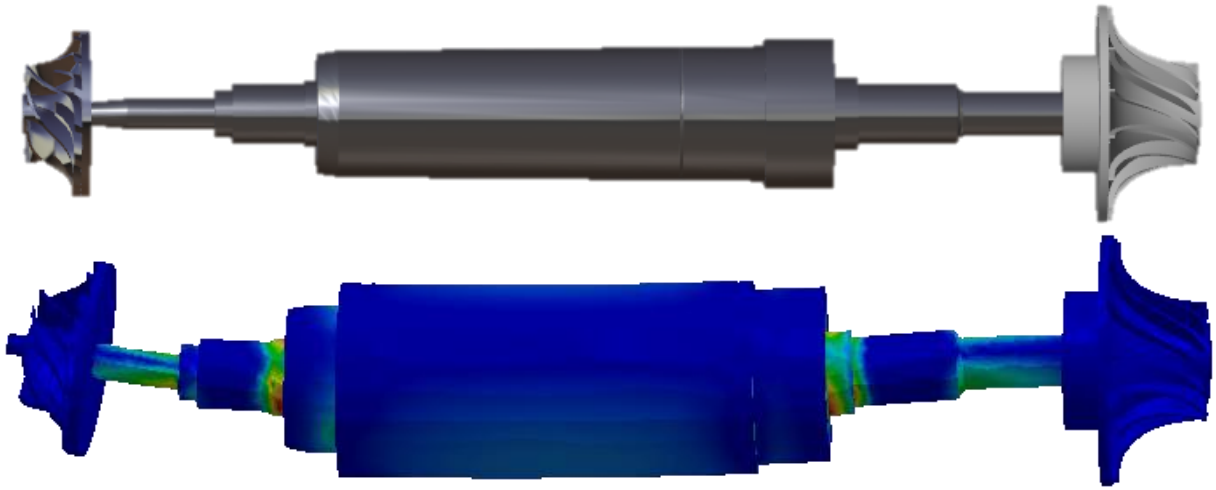
Velocity field

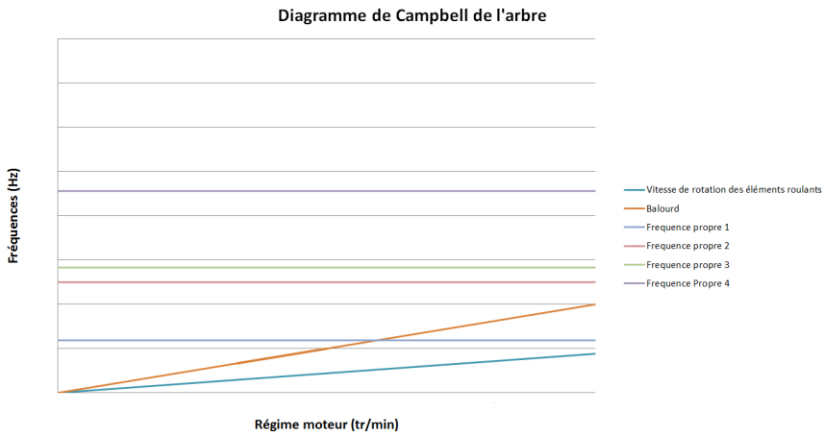
Isentropic efficiency: 76%

Rotordynamic analysis

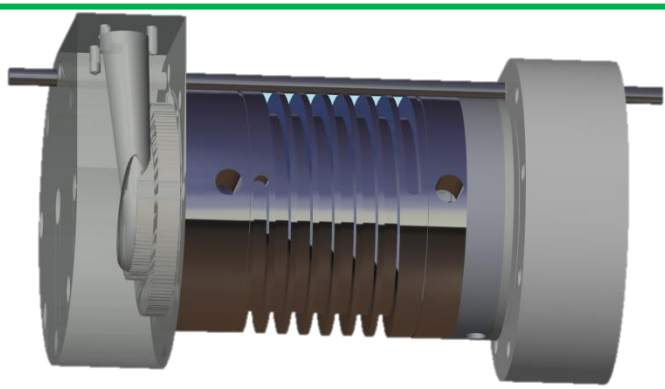
Results

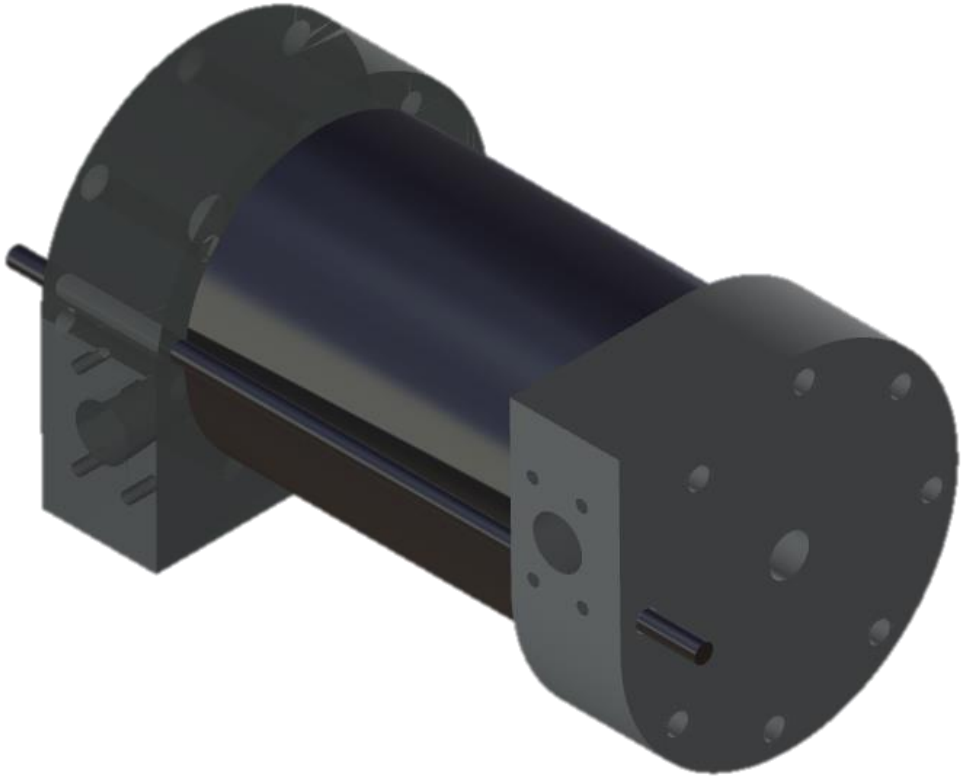


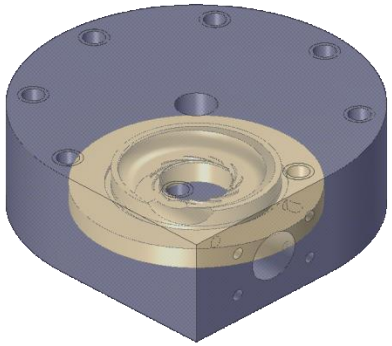


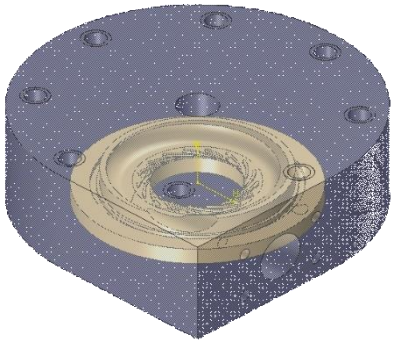


CGT assembly









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