PROJECT 39 - DEVELOPMENT OF GAS SUPERSONIC SEPARATORS - OPTIMISATION, NUMERICAL SIMULATION AND EXPERIMENTS

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Research Centre for Gas Innovation

cleaner energy for a sustainable future

V WORKSHOP INTERNO RCGI

21 e 22 de agosto de 2018

Outline

- Introduction
- WCCM Presentation: Comparison between numerical approaches to simulate a supersonic nozzle
- Parametric Optimization (second throat)
- Shape Optimization

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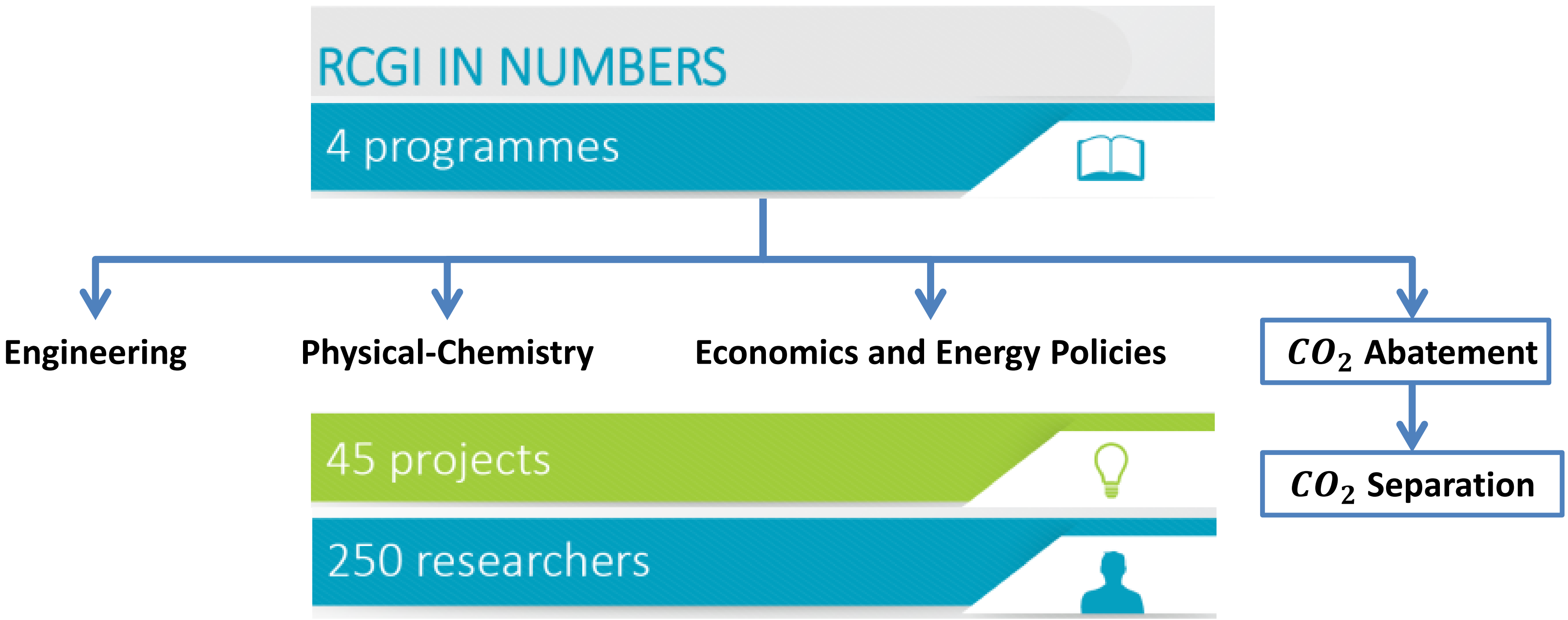
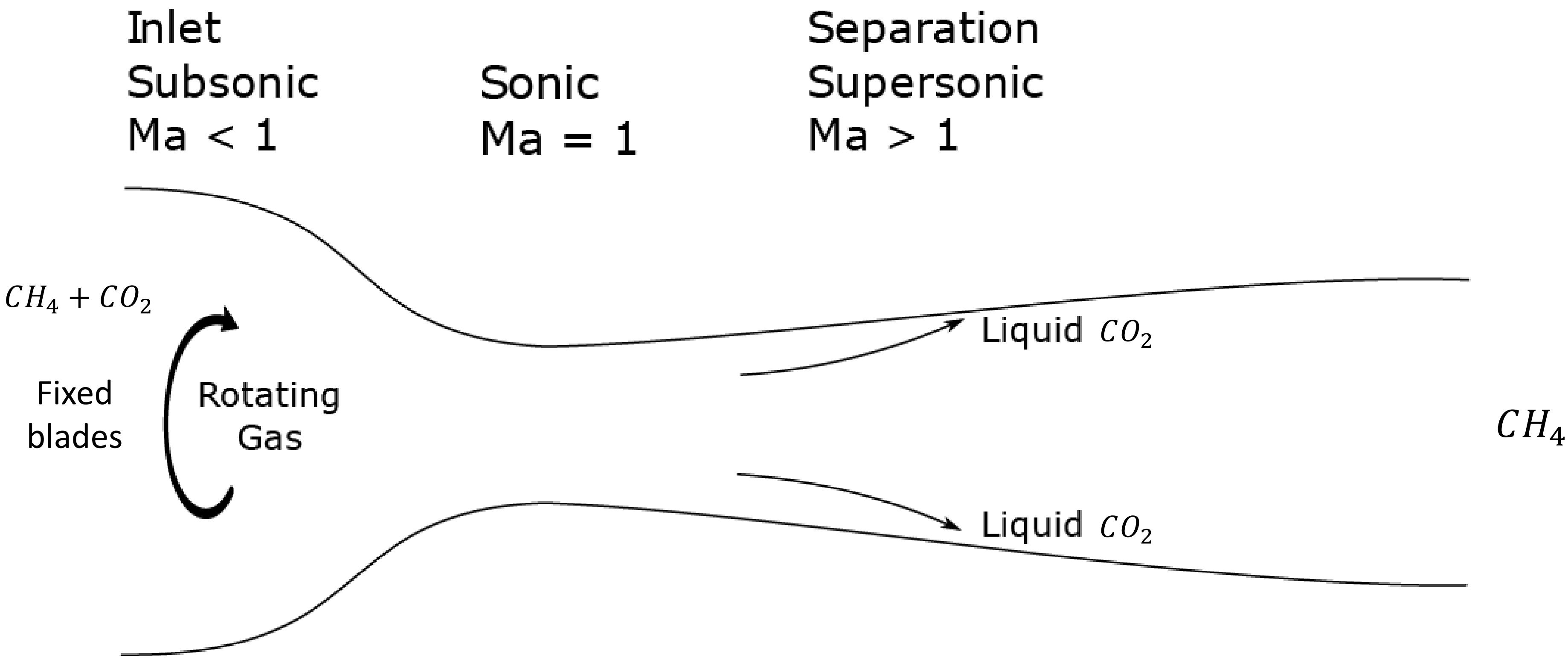
Project 39: Development of gas supersonic separators - optimization, numerical simulation and experiments



Supersonic Separator



Uses the cooling properties of a converging-diverging nozzle with the principles of centrifugal separation

Advantages: Compact, no moving parts, no extra chemical products

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Comparison between numerical approaches to simulate a supersonic nozzle

- **13th World Congress on Computational Mechanics, July 22-27, New York-USA**

- **Objective:** Use different numerical approaches for the same test case and compare the results (i.e. shock position, Stagnation Temperature conservation)

Computer codes

ANSYS FLUENT	SU2 The Open-Source CFD Code	NEKTAR++	FEniCS project
Commercial	Open source	Open source	Open source
Finite Volume Method	Finite Volume Method	Finite Element Method	Finite Element Method
Multiphysics models	Designed for compressible fluids	High-order methods (DNS)	Variational formulation
Benchmark	Adjoints equations		

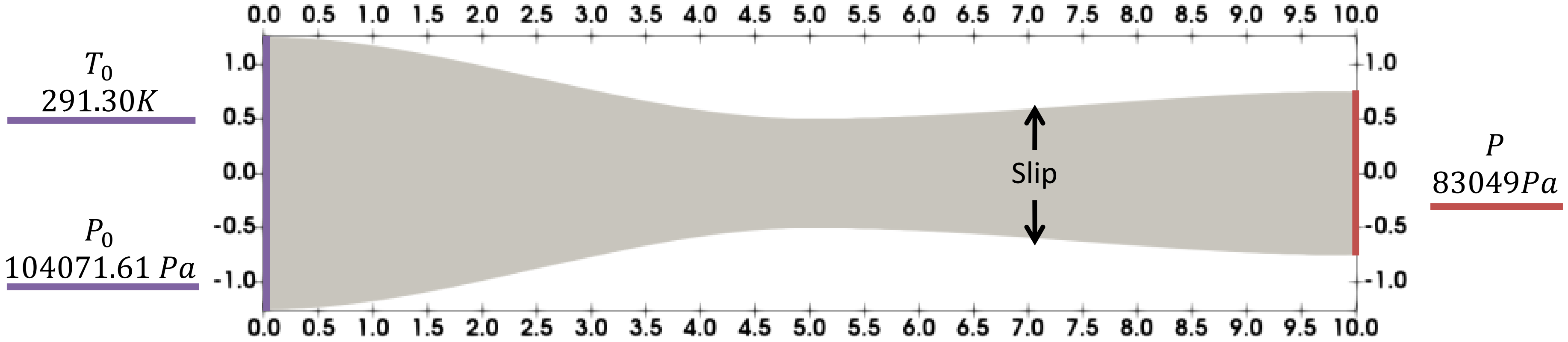
Main Hypothesis

- Inviscid (2D Compressible Euler equations)
- Perfect Gas
- No phase change
- Single component

Geometry and boundary conditions

$$Area(x) = 2.5 + 3\left(\frac{x}{5} - 1.5\right)\left(\frac{x}{5}\right)^2 \quad for\ x \leq 5$$

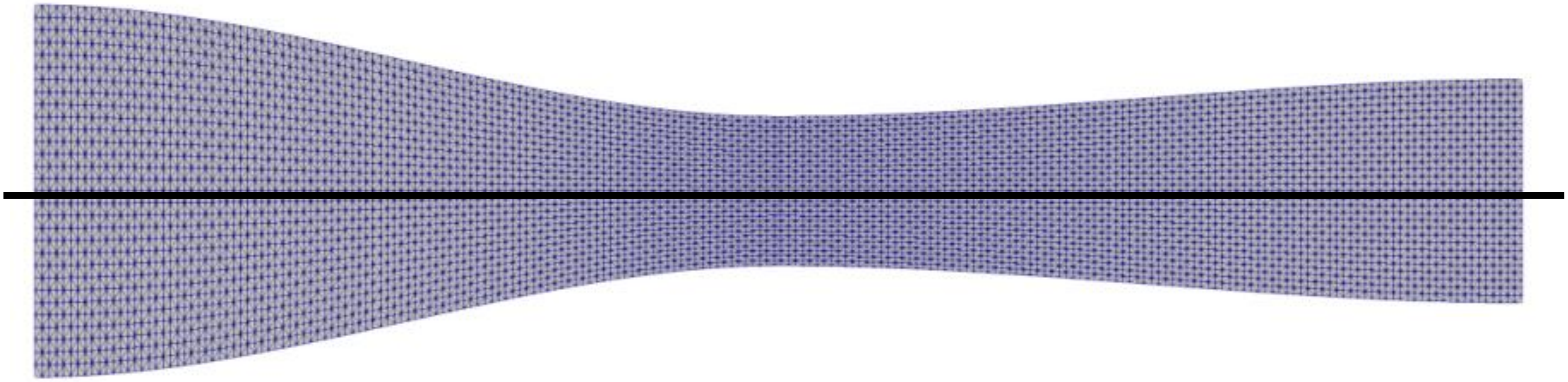
$$Area(x) = 3.5 - \frac{x}{5}\left[6 - 4.5\left(\frac{x}{5}\right) + \left(\frac{x}{5}\right)^2\right] \quad for\ x > 5$$



Arina R., Numerical simulation of near-critical fluids, *Applied Numerical Mathematics*, Volume 51, Issue 4, 2004, Pages 409-426, ISSN 0168-9274, https://doi.org/10.1016/j.apnum.2004.06.002.

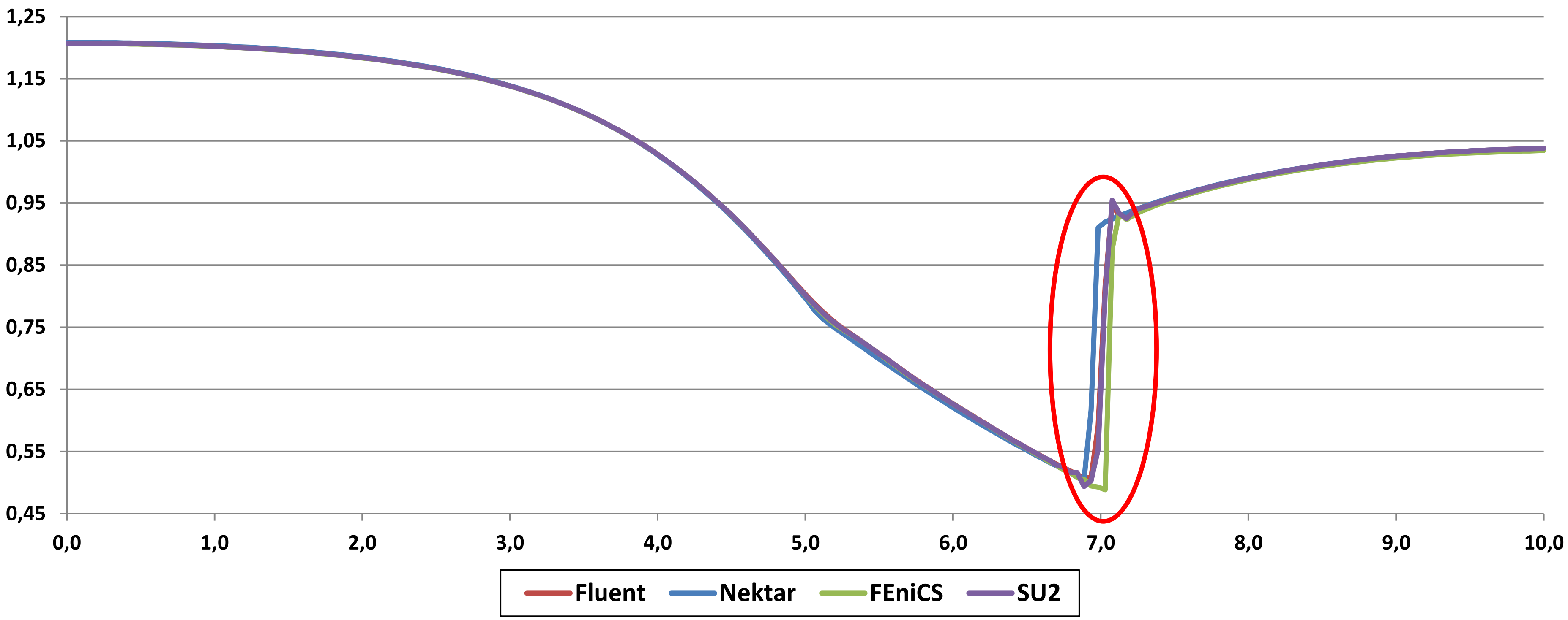
Mesh

12600 elements

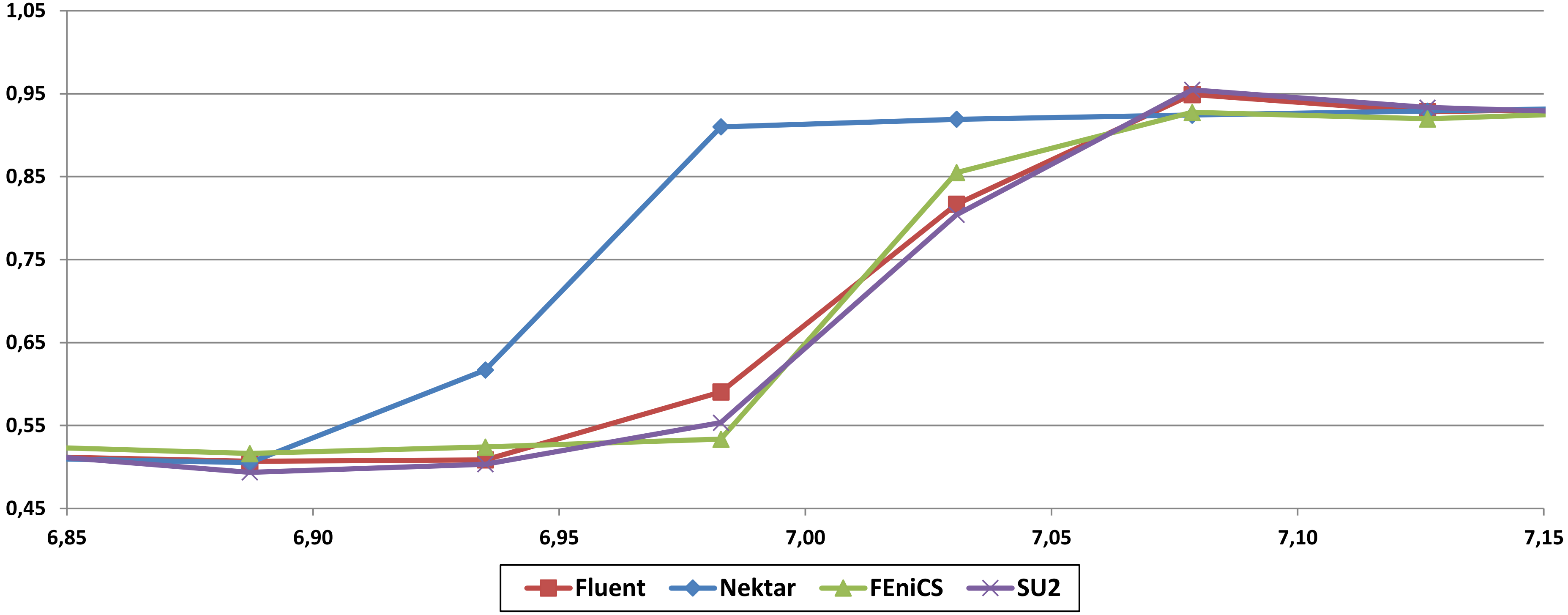


Results compared at the center line of the geometry (y=0)

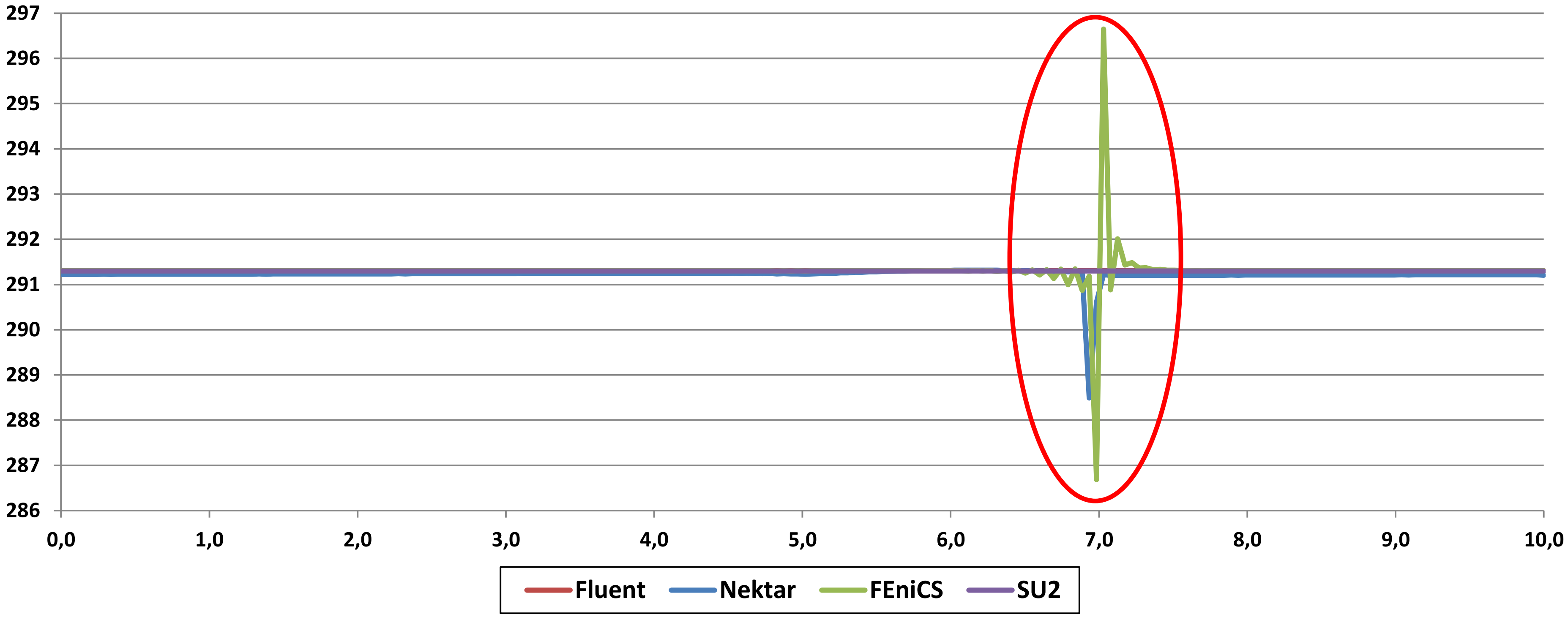
Comparison - Density $[kg/m^3]$



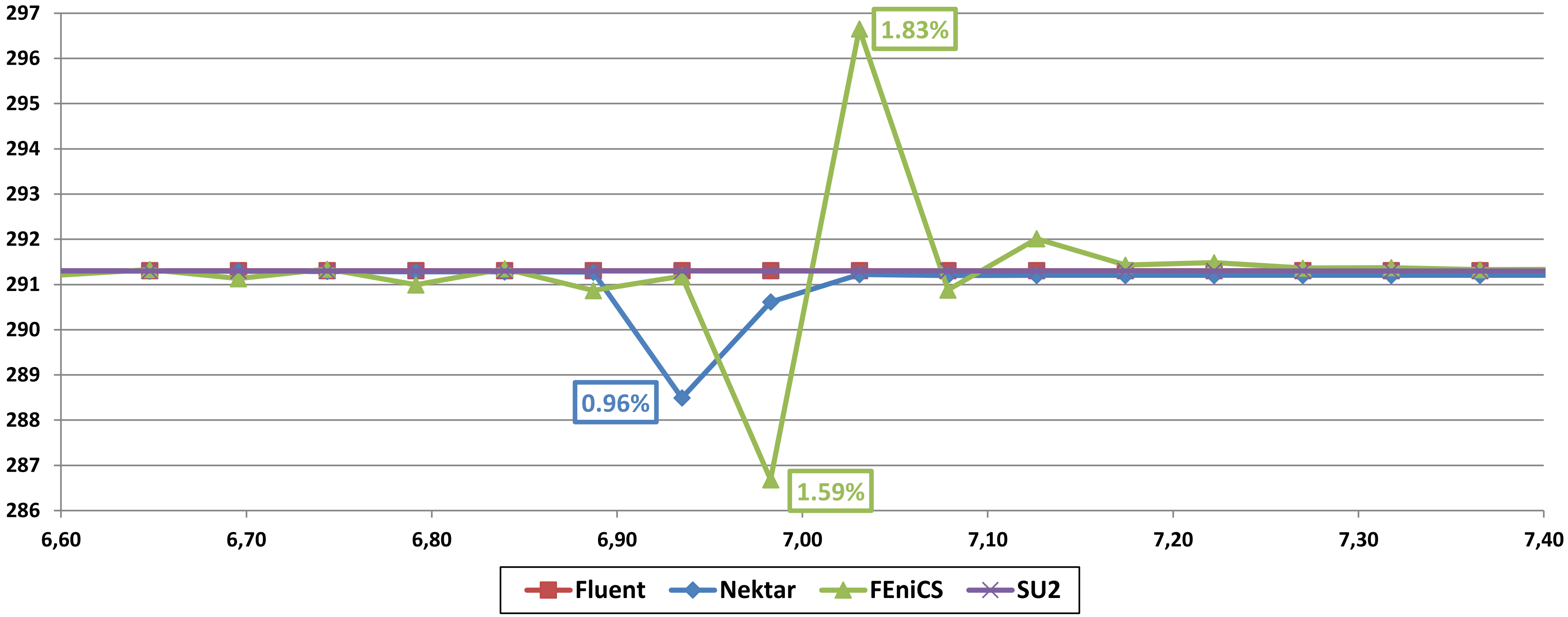
Comparison - Density $[kg/m^3]$- (zoom)



Comparison –Stagnation Temperature $[K]$



Comparison –Stagnation Temperature $[K]$



Conclusion of comparison

- Shock position:
  - All numerical approaches predicted the shock near 7.0
  - Nektar predicted the shock upstream

- Total Temperature conservation:
  - FVM (Fluent and SU2) - no oscillations
  - FEM (Nektar and FEniCS) - oscillations near shock

- Cannot discard any of the computer programs (yet)
  - Can improve the results with some tuning (using different methods and schemes)

- Still needs experimental tests to validate the solvers (for this particular case)

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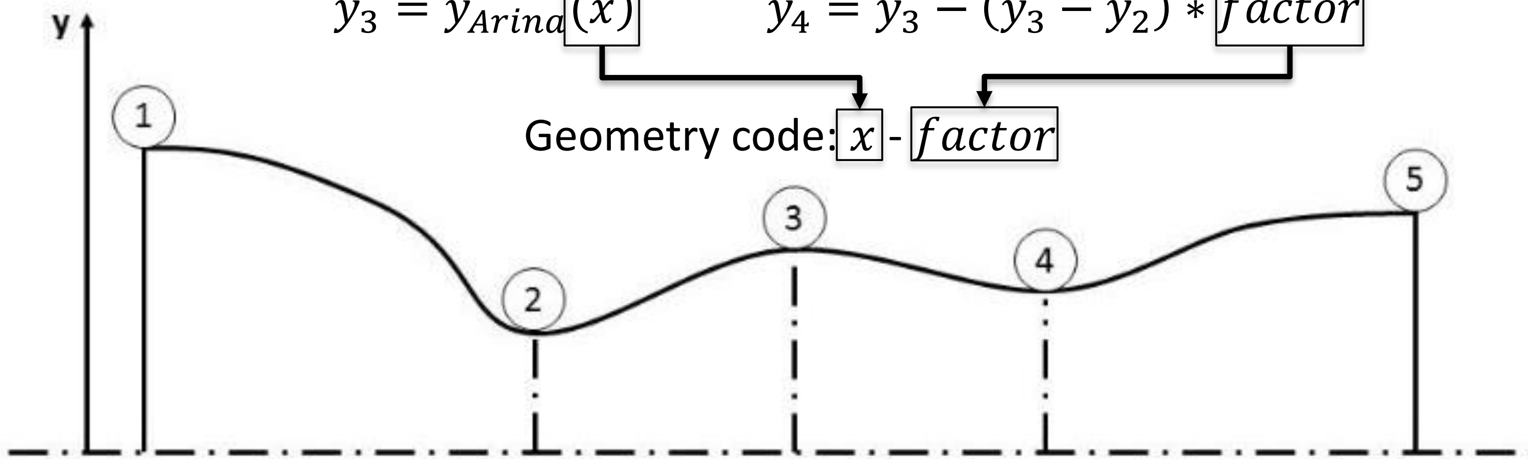
CFD flow modeling

- Fluent
- Turbulence model: $k\epsilon - RNG$;
- Equation of state: Ideal gas;
- Main assumptions of the flow:
  - Adiabatic flow;
  - No chemical reactions;
  - Gases flowing in equilibrium;

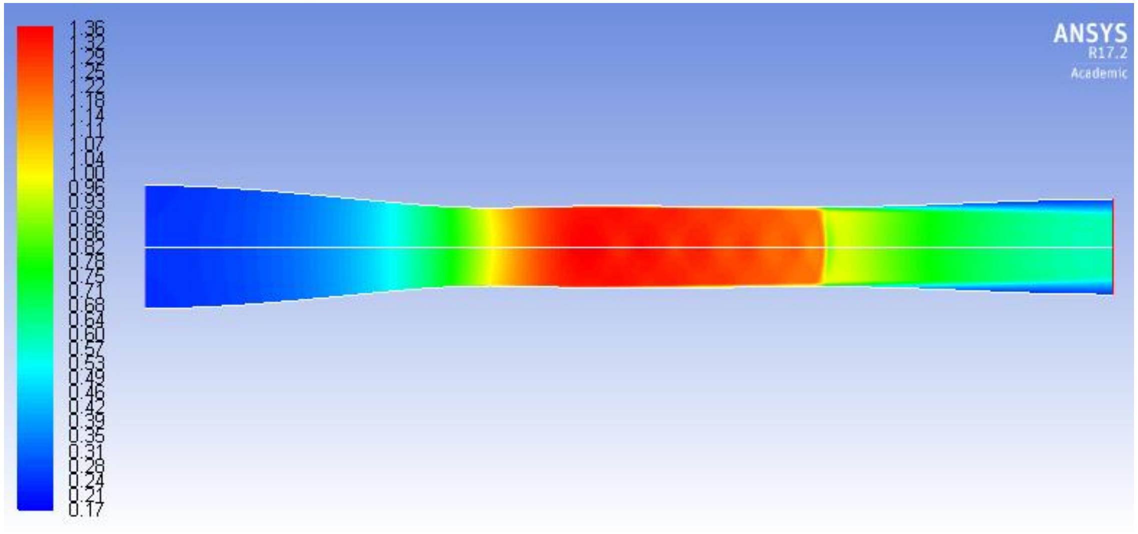
Second throat – Geometry definition

$y_3 = y_{Arina}(x)$ $y_4 = y_3 - (y_3 - y_2) * factor$

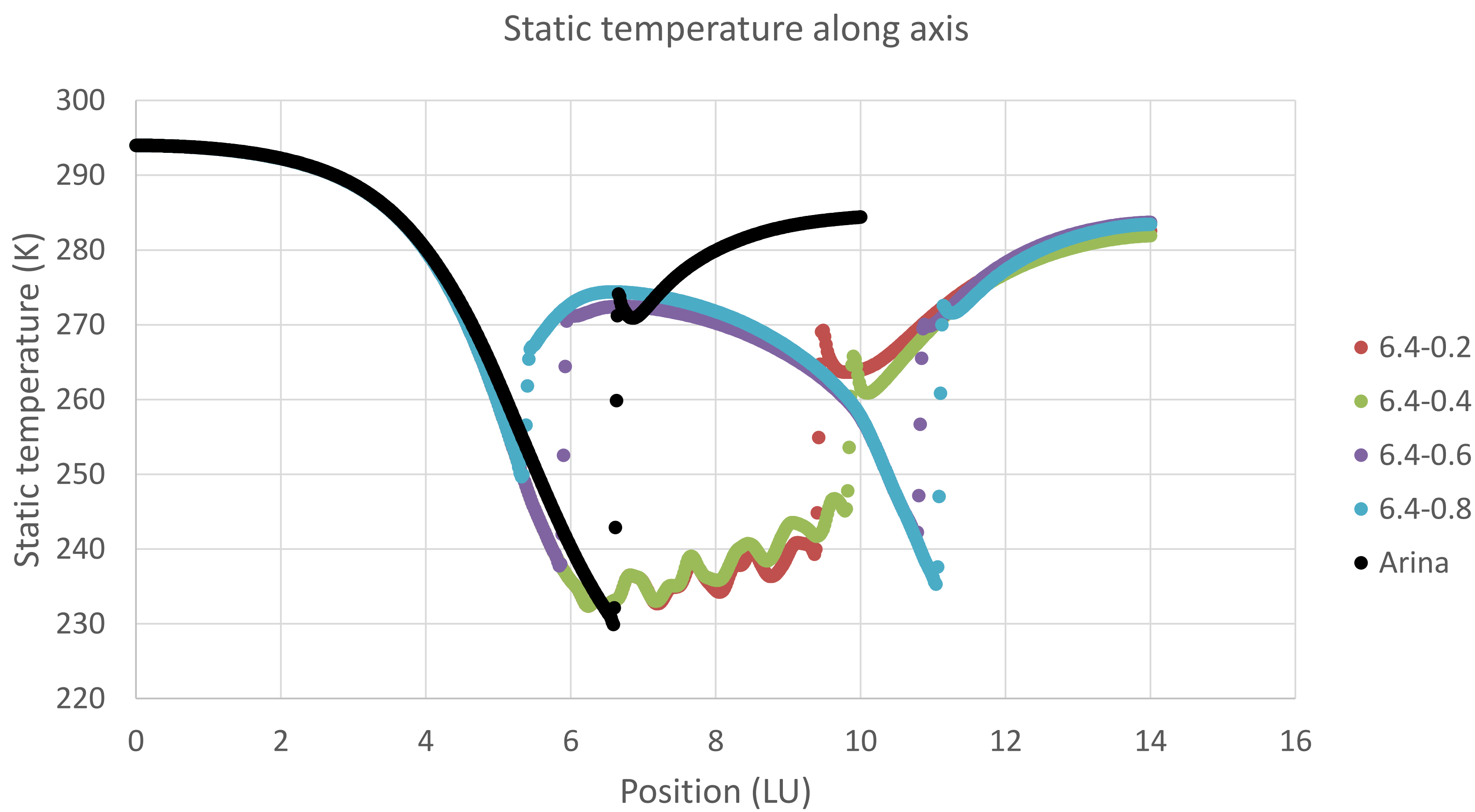
Geometry code: x - $factor$



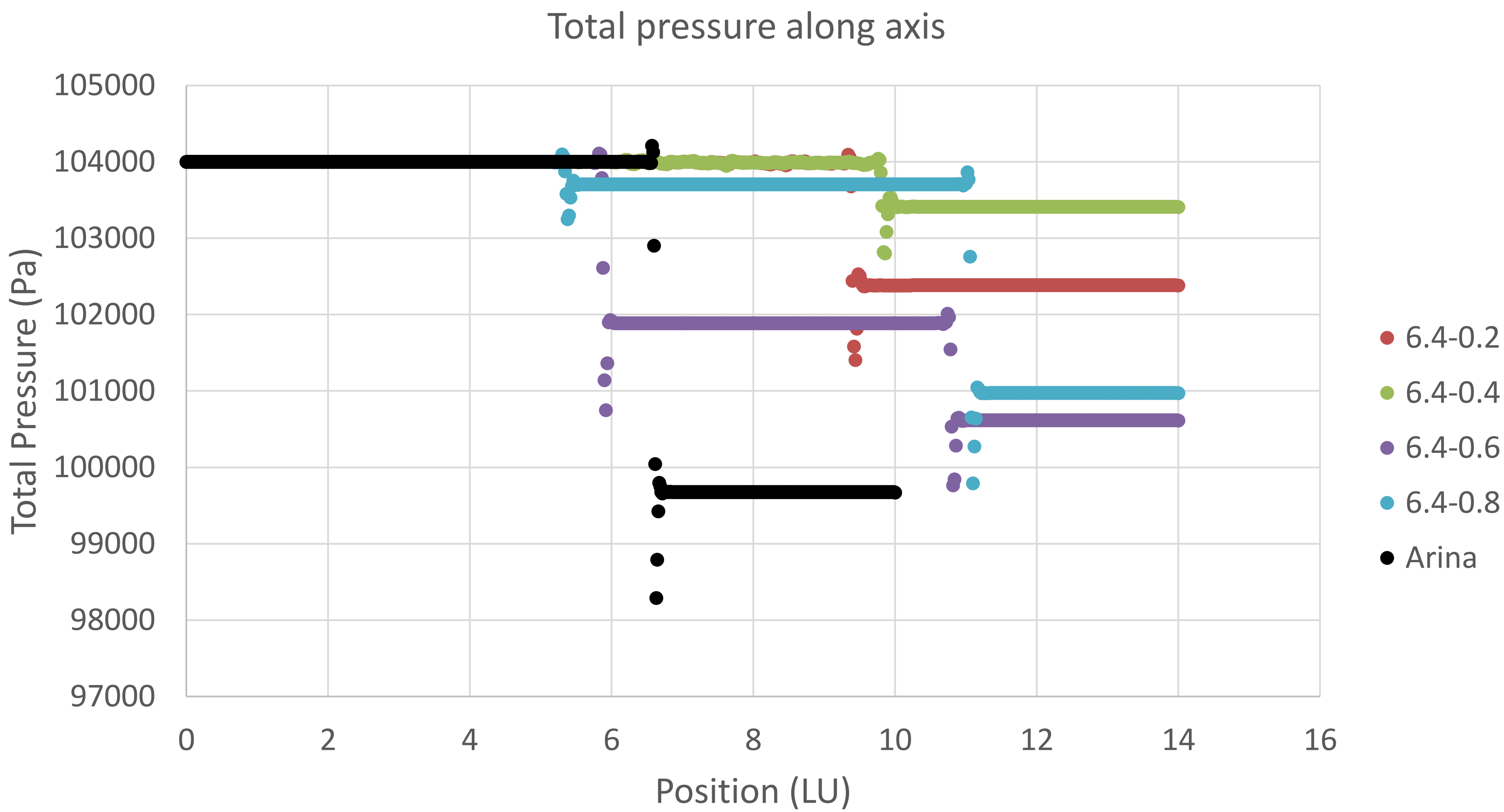
Mach number field in 6.4-0.4 geometry



Second throat – Static temperature



Second throat – Total pressure



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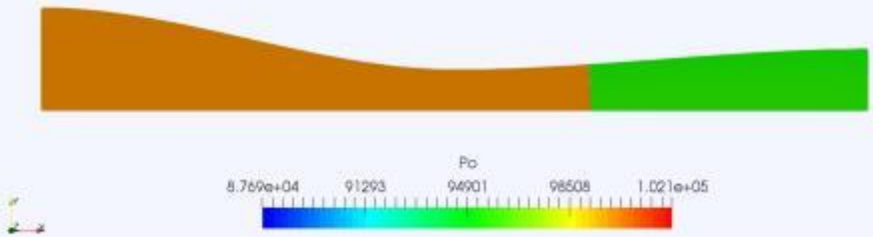
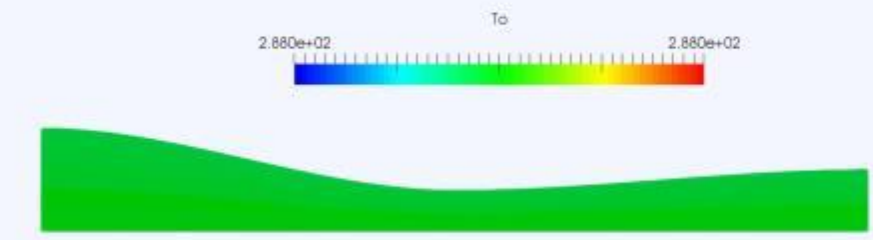
CH_4 as an Ideal Gas: Stagnation properties

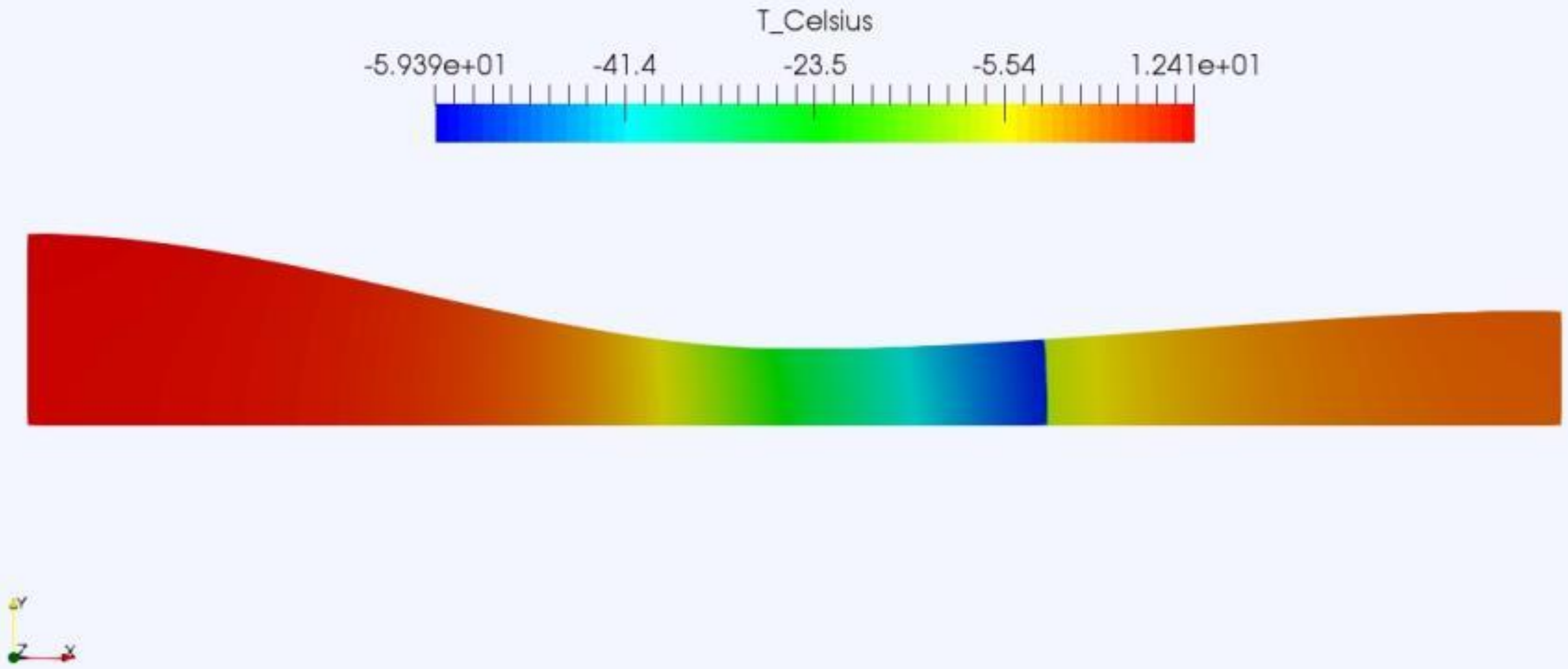
Stagnation pressure [Pa]





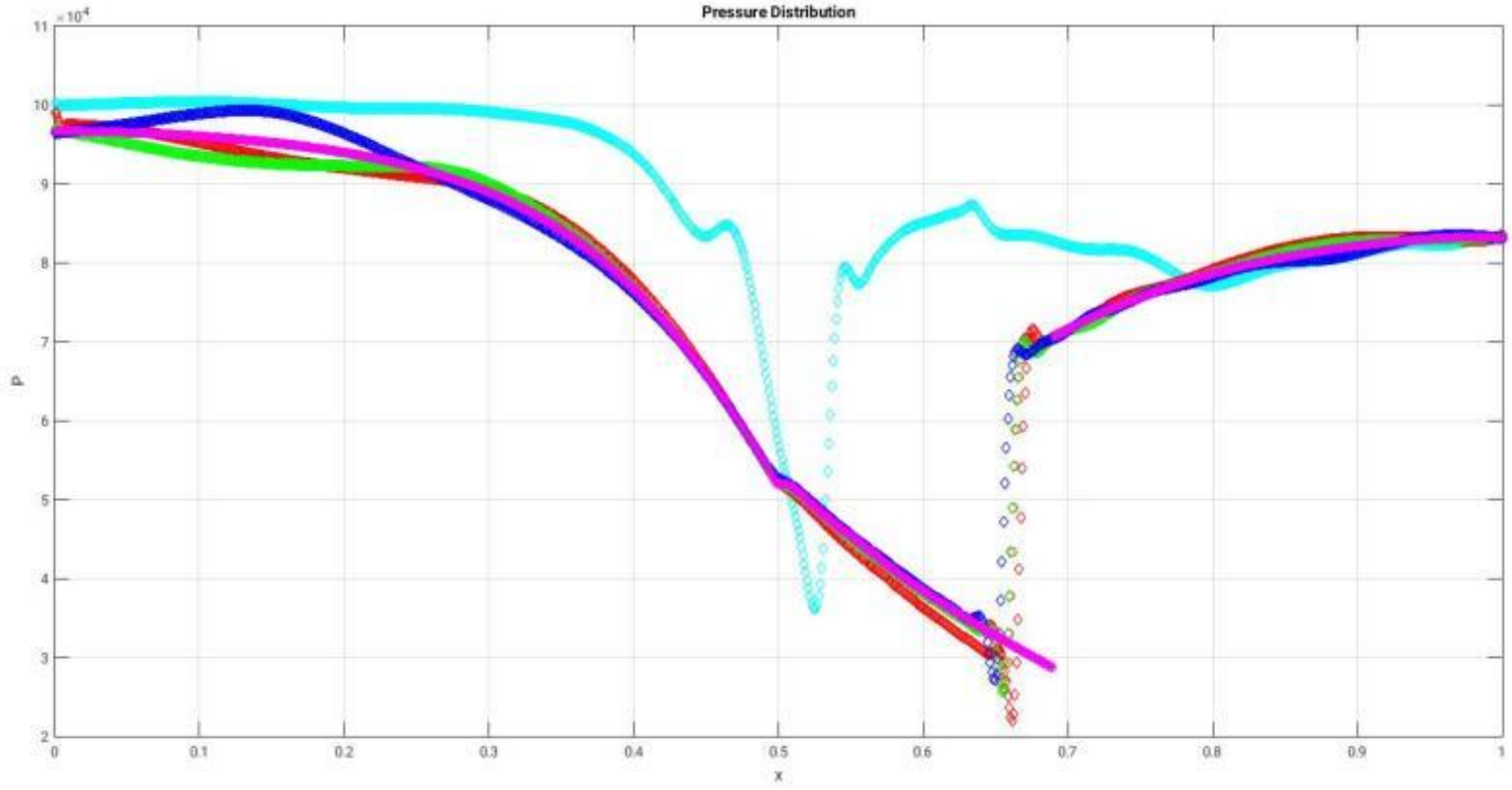
Stagnation temperature [K]

CH_4 as an ideal gas: Temperature distribution [Celsius]



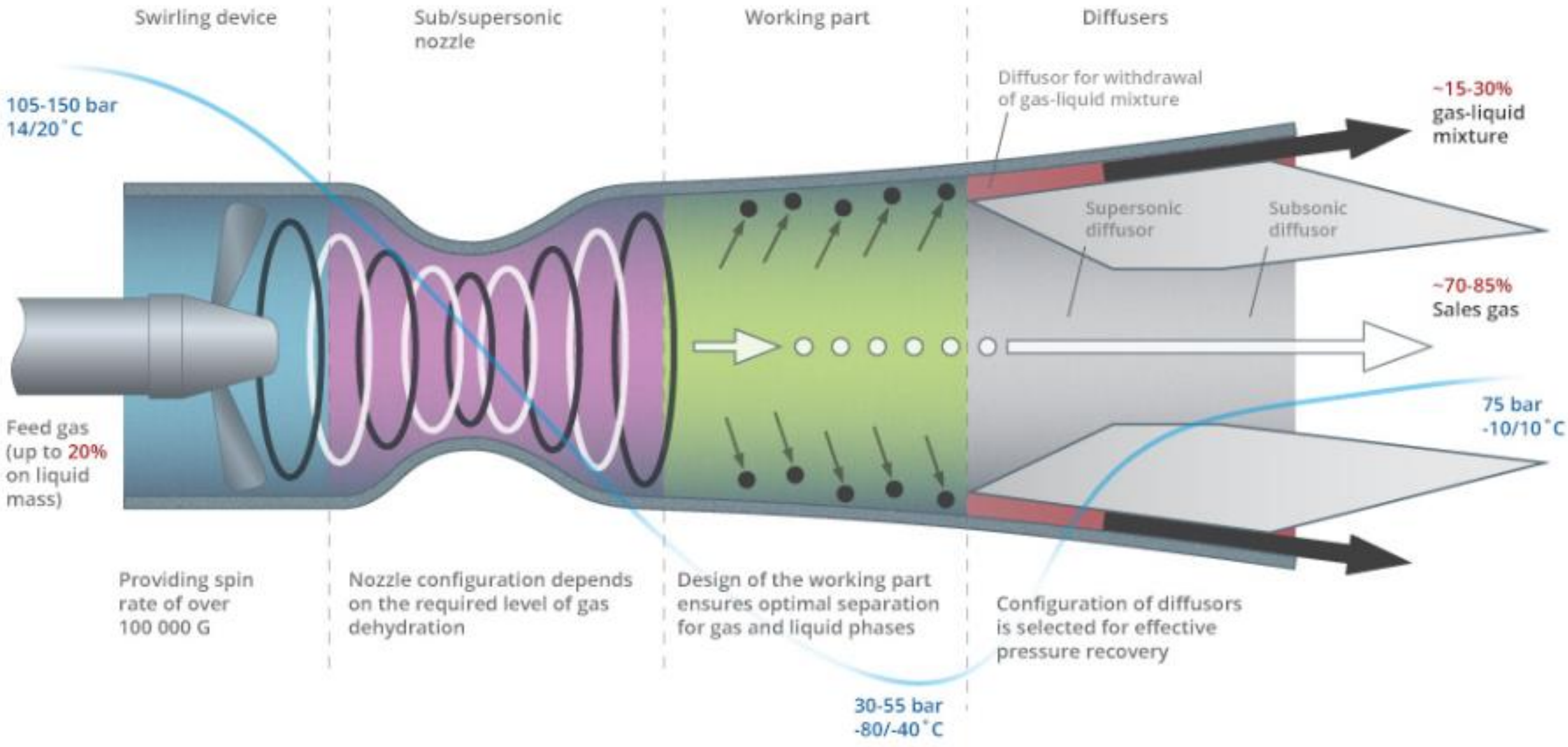
CH_4 as an ideal gas: Pressure distribution at several Optimization Cycles

Method: Hicks-Henne bump functions



Next Steps

- Use different computer codes: OpenFOAM, Comsol, CFD++
- Study the influence of the collector
- Study Turbulence models
- Study shape optimization
- Study real gas effects
- Implement topology optimization



Swirling device
Sub/supersonic nozzle
Working part
Diffusers
105-150 bar
14/20˚C
Diffusor for withdrawal of gas-liquid mixture
~15-30%
gas-liquid mixture
Supersonic diffusor
Subsonic diffusor
~70-85%
Sales gas
75 bar
-10/10˚C
Feed gas (up to 20% on liquid mass)
Providing spin rate of over 100 000 G
Nozzle configuration depends on the required level of gas dehydration
Design of the working part ensures optimal separation for gas and liquid phases
Configuration of diffusors is selected for effective pressure recovery
30-55 bar
-80/-40˚C

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