# SIMULATION AND OPTIMIZATION OF COMPRESSOR FOR $CO_2$ AND $CO_2$ - $CH_4$ MIXTURES IN SUPERCRITICAL CONDITIONS

**Prof. Dr. Jurandir Itizo Yanagihara**
Dept. of Mechanical Engineering
University of São Paulo, Brazil

Research Centre for Gas Innovation
cleaner energy for a sustainable future

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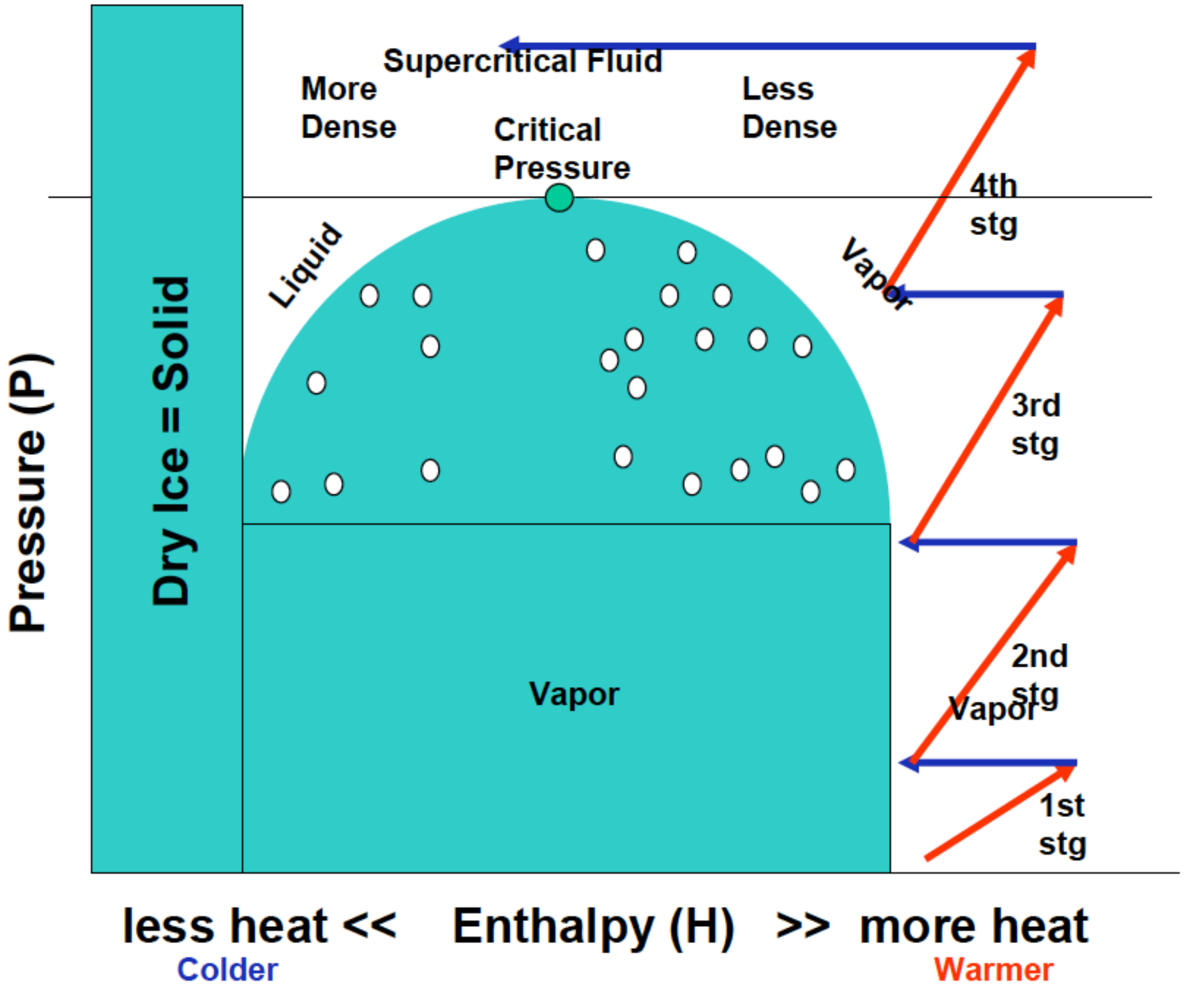
# Research Team

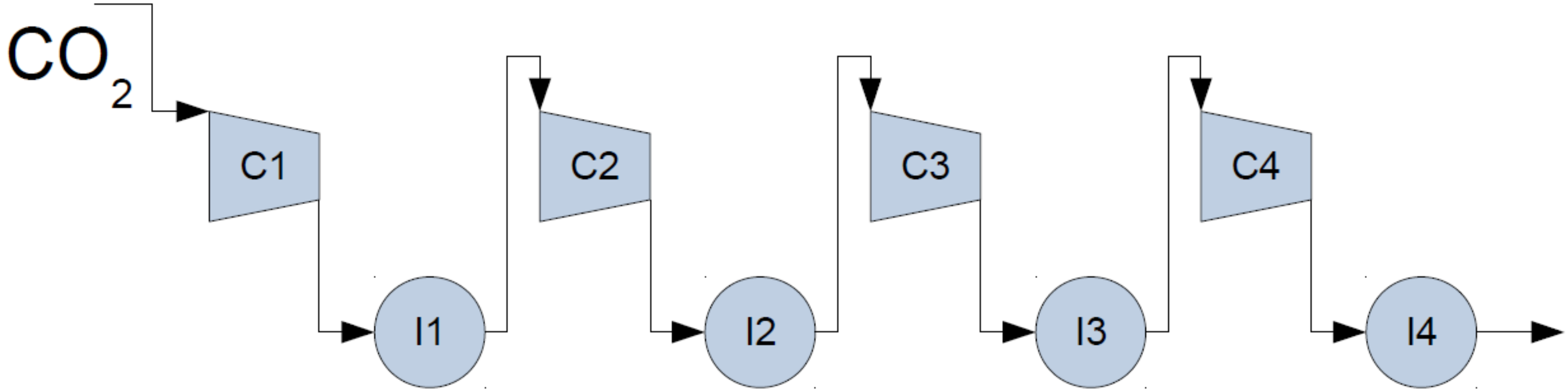
- **Faculties:** Jurandir Itizo Yanagihara - PI (EPUSP), Emilio Carlos Nelli Silva (EPUSP), Fabio Saltara (EPUSP), Sergio Frascino Muller de Almeida (EPUSP), Paulo Eduardo Batista de Mello (FEI), Leandro Oliveira Salviano (UNESP), Daniel Jonas Dezan (UFABC)
- **Doctoral Students:** Carlos Massaiti Okubo Junior, Luis Fernando Garcia Rodriguez
- **Master Students:** Julia Silva de Matos, Bruno Jose Nagy Antonio, Kayo Henrique Rodrigues

# Compression of Supercritical CO2



# Thermodynamic Analysis

- **Objectives**
  - **Estimate total power requirement as a function of the number of stages**
  - **Determine the number of stages (actually, a decision)**
  - **Determine inlet conditions in each stage**
    - **This is a requirement to proceed with rotor geometry definition and its CFD simulation for further optimization**



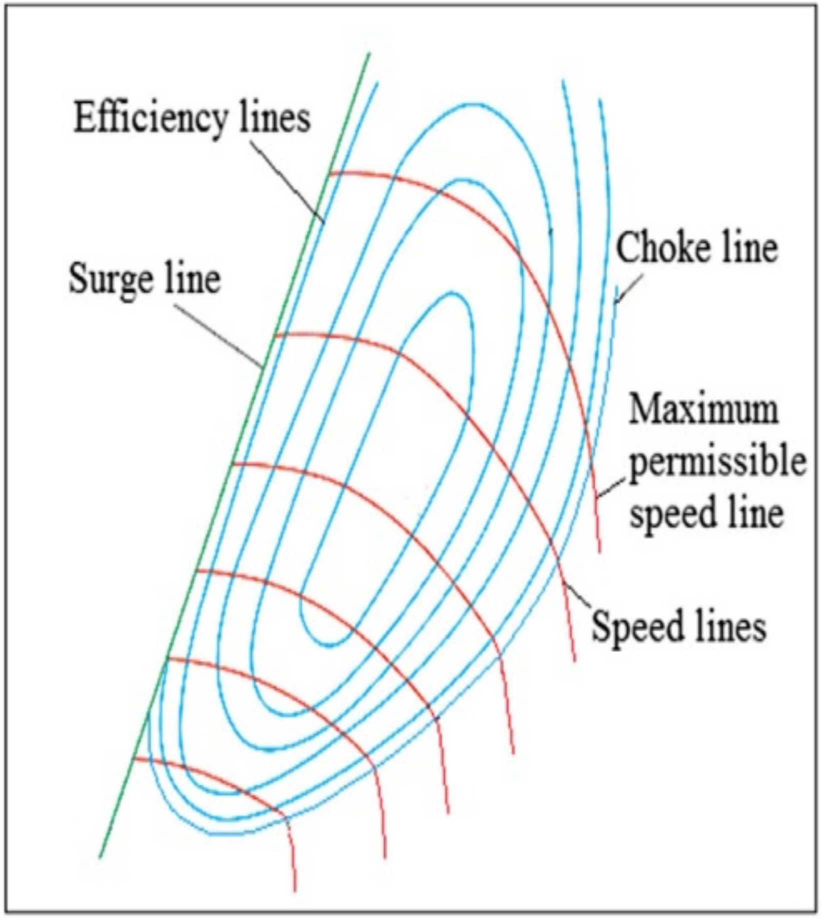
# Thermodynamic Analysis

- **Implementation**
  - **Console application written in C# uses Coolprop to evaluate properties**
  - **Optimization using Matlab**
- **Minimum power: four stages**

| Fluid | rp1 | rp2 | rp3 | rp4 | $W_{TOTAL}$ (kW) |
|---|---|---|---|---|---|
| Pure $CH_4$ | 3.5566 | 2.9894 | 2.5719 | 2.3940 | 49388 |
| Pure $CO_2$ | 4.0318 | 2.9538 | 2.0274 | 2.6980 | 14684 |
| **70% $CO_2$** | **3.8284** | **3.0479** | **2.5264** | **2.2130** | **20340** |

# 1 D Analysis - Mean Line Method

- The Mean Line Method continues to be the best method for a first approach on centrifugal compressors design.
- A Mean Line code was implemented on MATLAB® software.
- The code is able to predict the centrifugal compressor performance faster than a CFD code with good accuracy.



Non-dimensional mass (or volume) flow rate

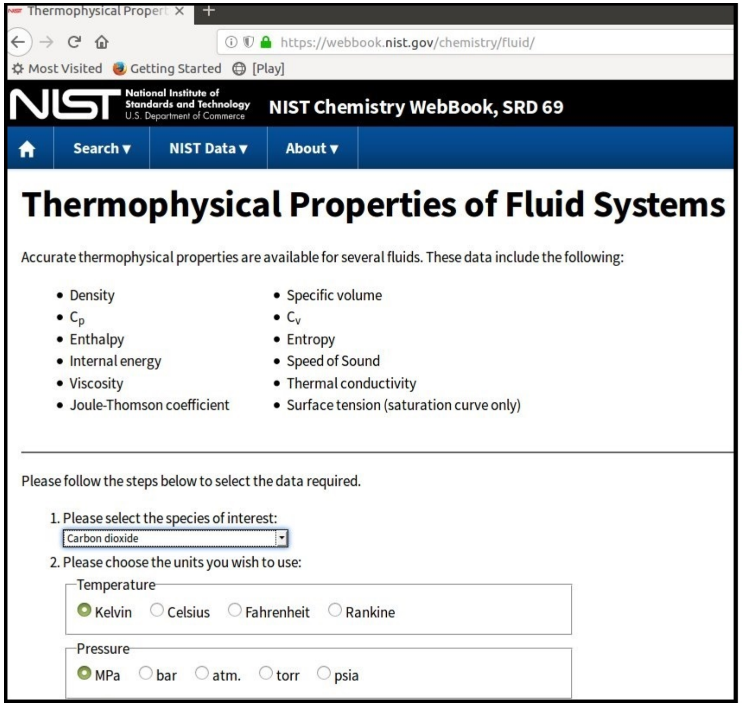
# 1 D Analysis - Mean Line Method

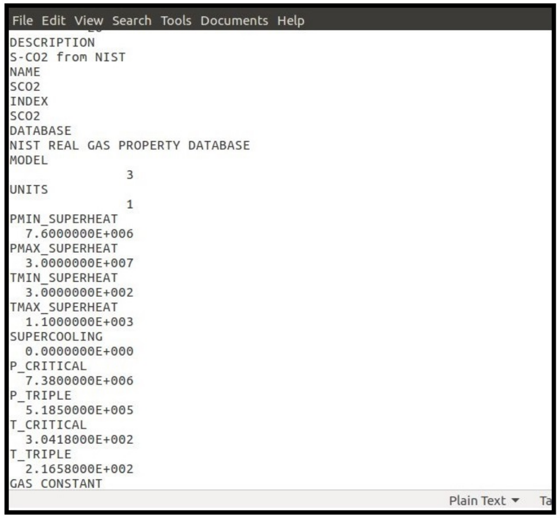
The code was validated with experimental data for Air and Supercritical Carbon Dioxide (S-CO2)

| Air | | | |
|---|---|---|---|
| | Experimental Data | Mean Line Code | Relative Error % |
| Rotor Efficiency [-] | 0,880 | 0,880 | 0,00 |
| Pressure Ratio [-] | 2,176 | 2,081 | 4,37 |

| Supercritical Carbon Dioxide | | | |
|---|---|---|---|
| | Experimental Data | Mean Line Code | Relative Error % |
| Outlet Temperature [K] | 378,9 | 376,93 | 0,52 |
| Outlet Pressure [kPa] | 24000 | 23540 | 1,92 |
| Pressure Ratio [-] | 2,5 | 2,48 | 0,80 |

# Thermodynamic Properties of S-CO2

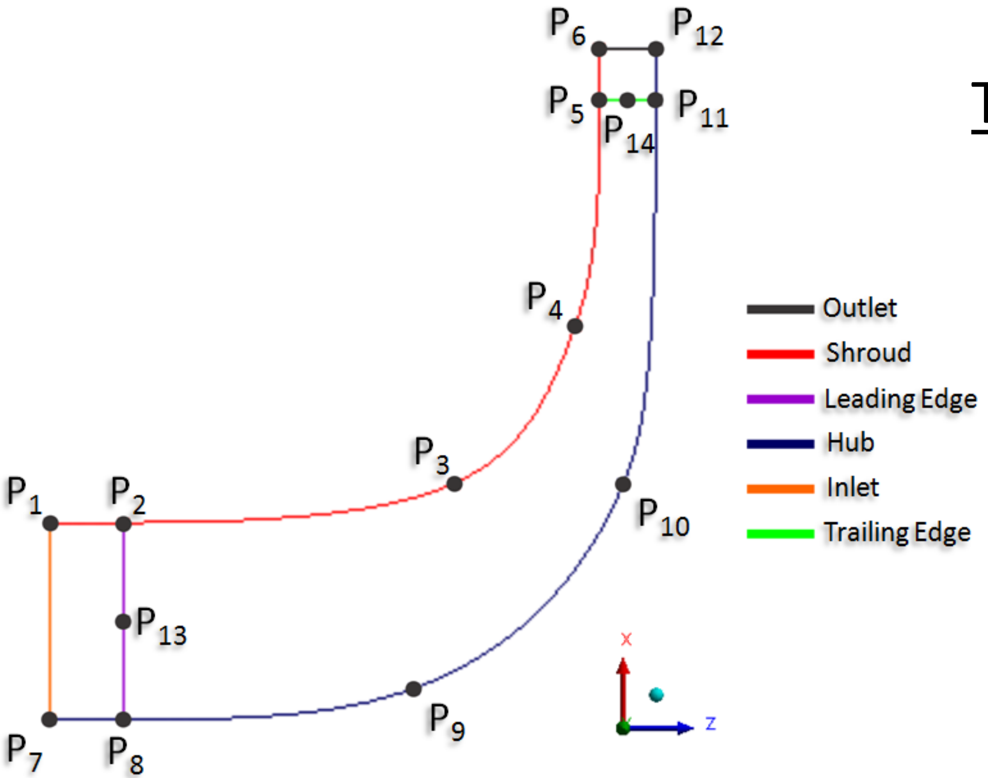


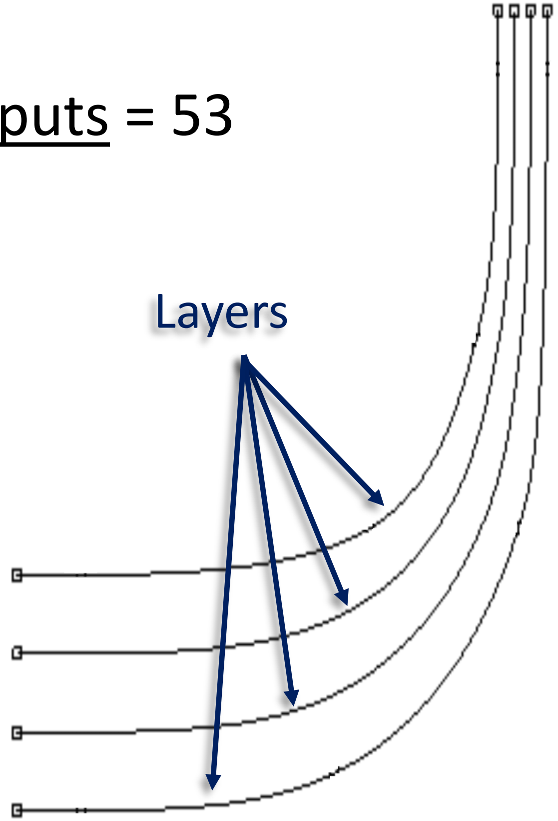

- Properties can be downloaded from NIST Website
- Converted through Matlab application to a RGP (Real Gas Properties) text file that can be used in ANSYS CFX

# Blade Parametric Modeling for FVM

- **Geometry Input Variables:**



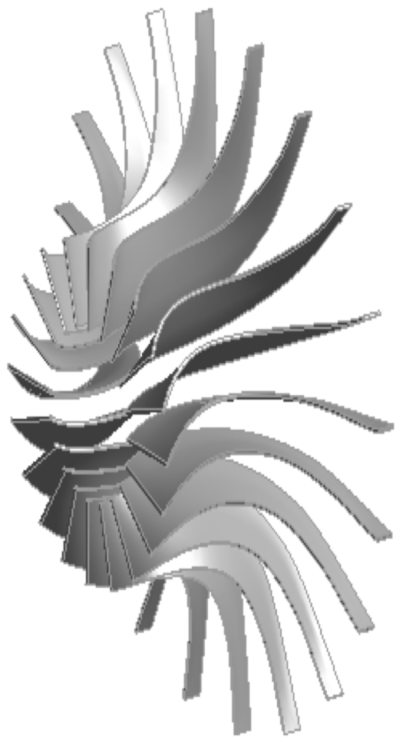

Total Inputs = 53

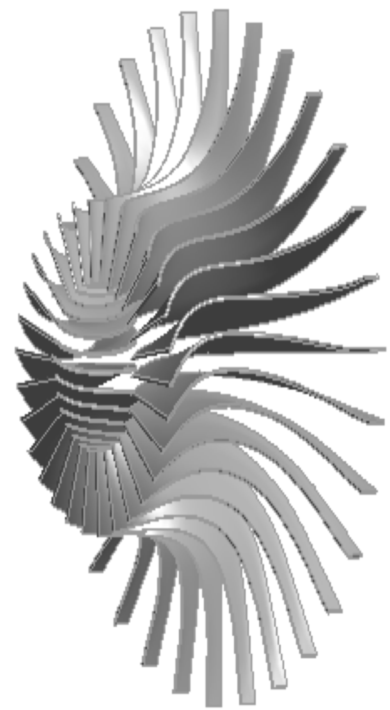


# Centrifugal Compressor Modeling for FVM

- **Geometry Input Variables:**

Brenes, 2014 *



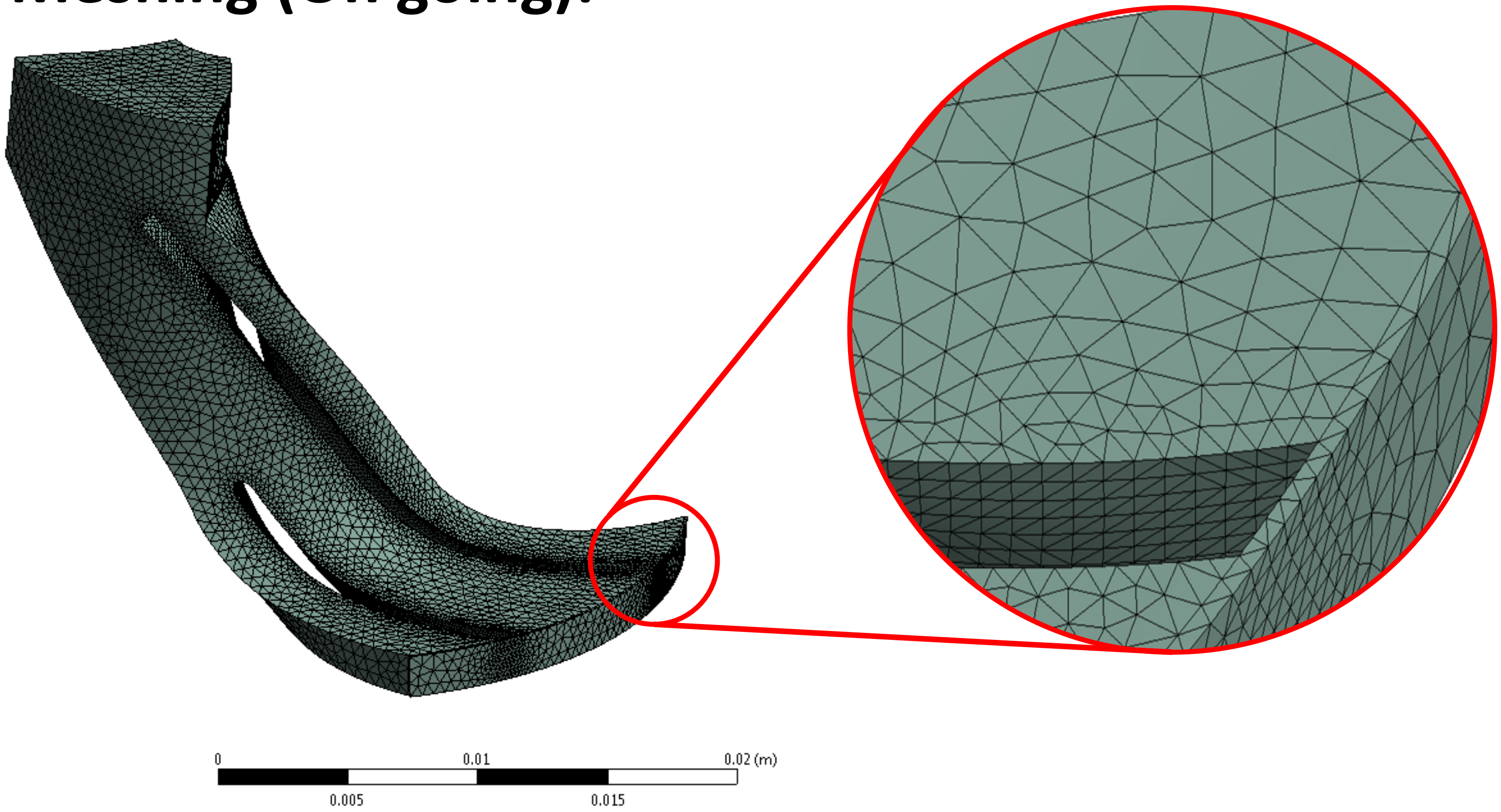


Current Project

* Brenes, B.M., 2014. Design of supercritical carbon dioxide centrifugal compressors. University of Seville, Spain.

# Centrifugal Compressor Modeling for FVM

- **Meshing (On going):**



# FVM Simulation and Parametric Optimization

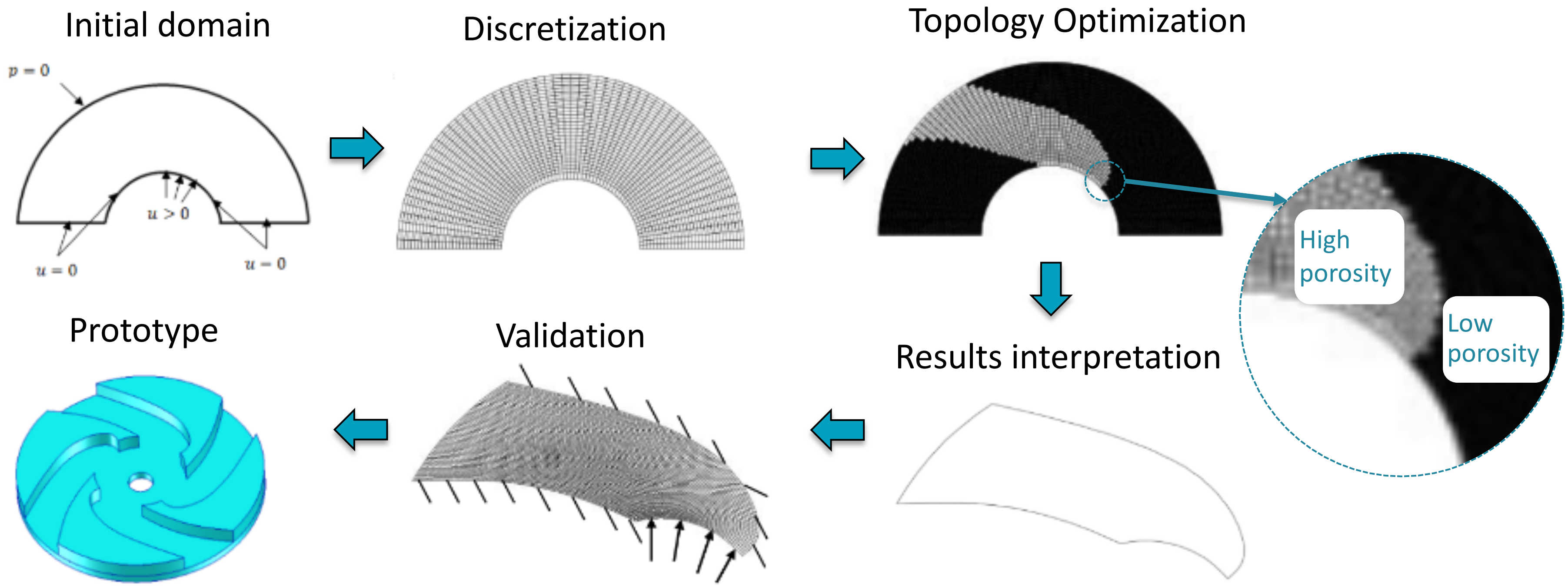
Next Steps:

- Coupling of 1D Software and ModeFrontier for 1D Optimization
- Implementation of Blade Parametric Modeling in the Vista CCD Software
- FVM software validation (turbulence model, meshing, S-$CO_2$ properties) using experimental data from the Sandia S-$CO_2$ Compressor

# Topology Optimization

Determine material distribution in a design domain such that an objective function is extremized and constraints are fulfilled

Ex: rotating channel (aiming rotor design)



# Topology Optimization

- Work is being developed in OpenFOAM
- Currently using Continuous Adjoint Method (sensitivities calculation)
- Optimization problem definition:

$$Minimize\quad Energy\ dissipation\ /Pressure\ drop\ /Other\ functions$$

$$\text{Subject to}\begin{cases} Navier\ Stokes + porosity\ field\ (design\ variables\ for\ TopOpt) \\ Volume\ constraint \\ Design\ variable\ constraint\ (0 \leq \rho_{des} \leq 1) \end{cases}$$

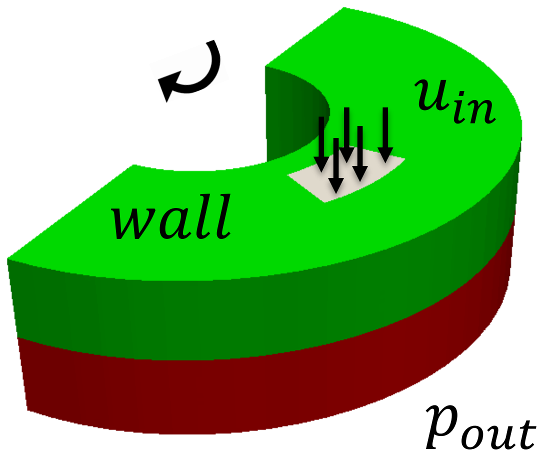
Porosity field represented by $\alpha\boldsymbol{u}$ in Navier Stokes equations

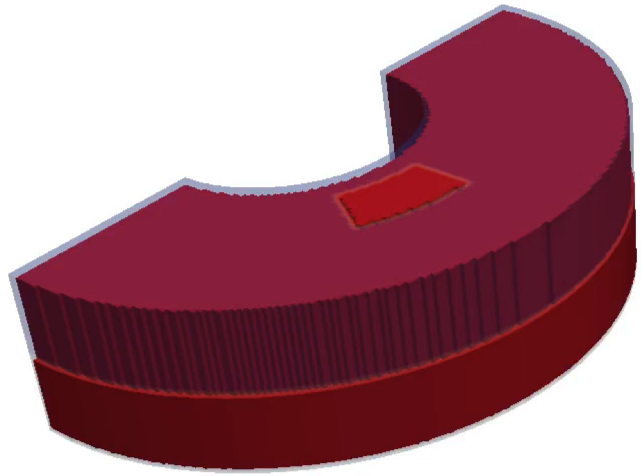
$\alpha = f(\rho_{des})$ ➪ Porosity field controlled by $\rho_{des}$

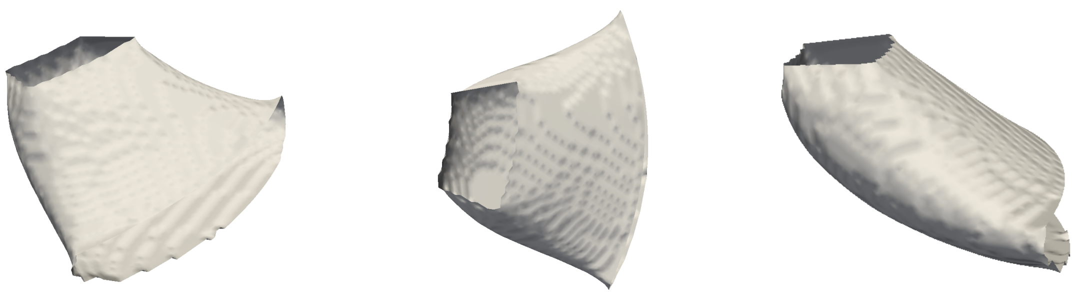
# Topology Optimization

- Example: design of a rotating channel minimizing energy dissipation (incompressible + without turbulence models)

$$u_{in} = 1\, m/s$$
$$p_{out} = 0$$
$$\nu = 1\, m^2/s$$
$$\frac{\int \rho d\Omega}{\int d\Omega} = 20\%$$
$$\omega = 1000\, rpm$$





# Topology Optimization

Next steps

- Cases with turbulence models are being studied, but improvements are necessary
- Assessment of Discrete Adjoint Method (sensitivities calculation)
- Optimize compressible flow cases

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