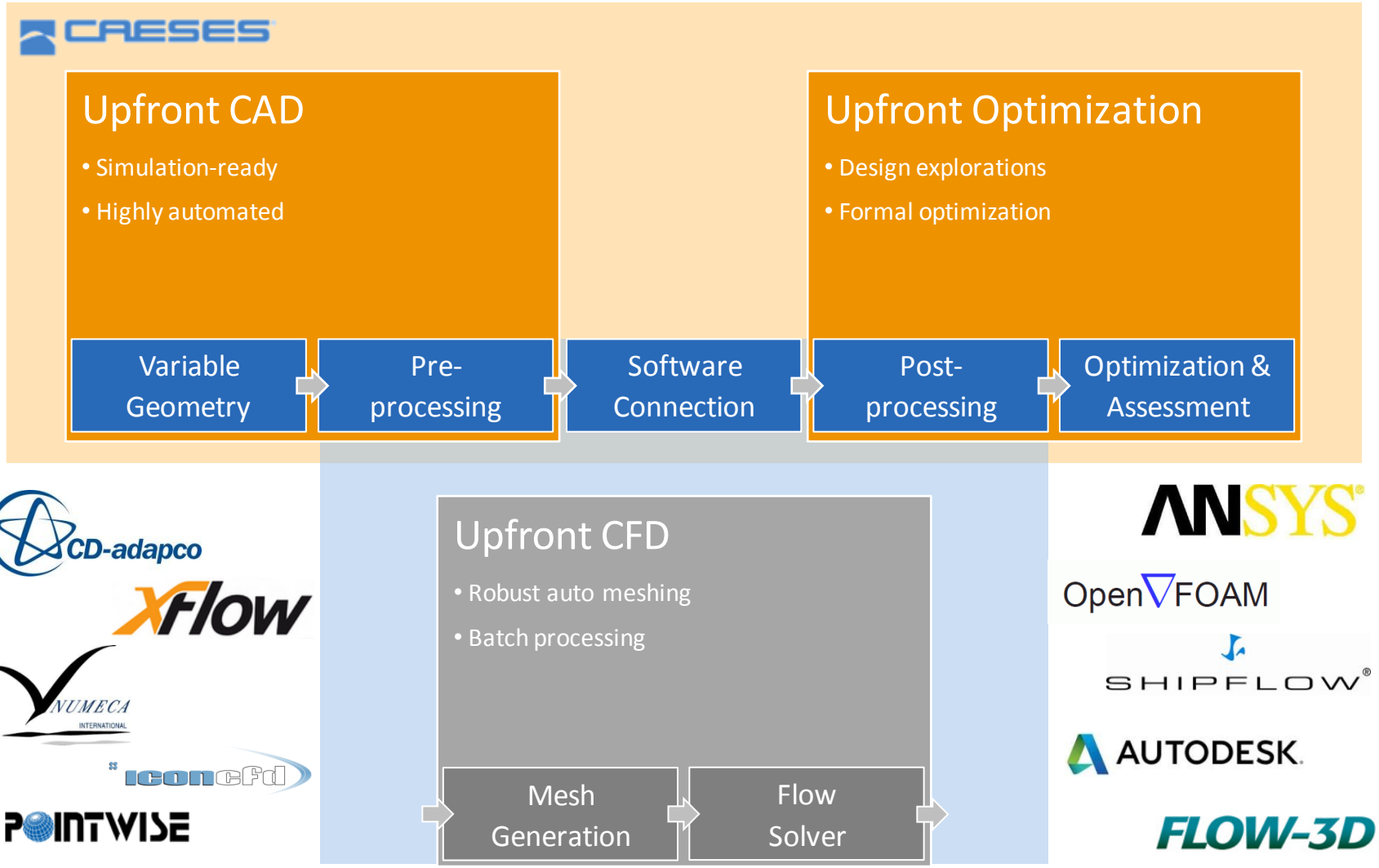
Automatic Design Exploration And Optimization Using **CAESES** and **OpenFoam**

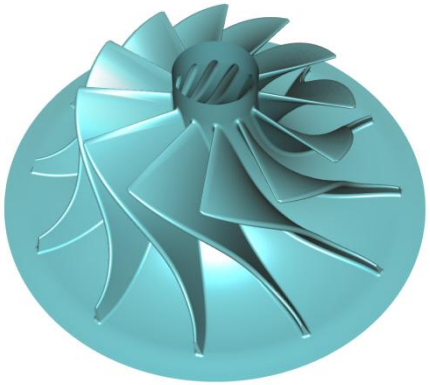
CAESES®

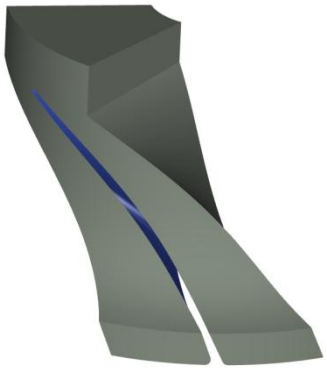
CAESES | Upfront CAE System Empowering Simulation

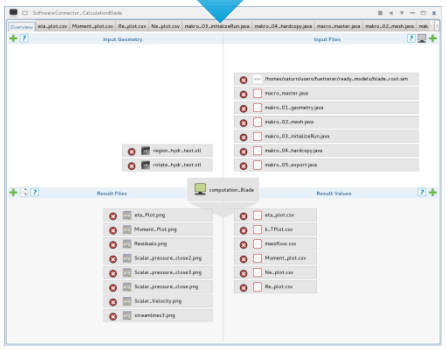


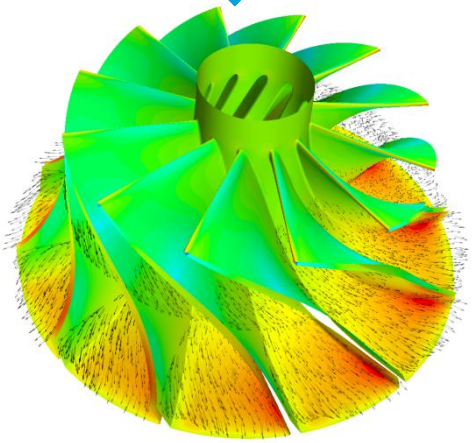
Process Workflow: Setting up the Automation Chain

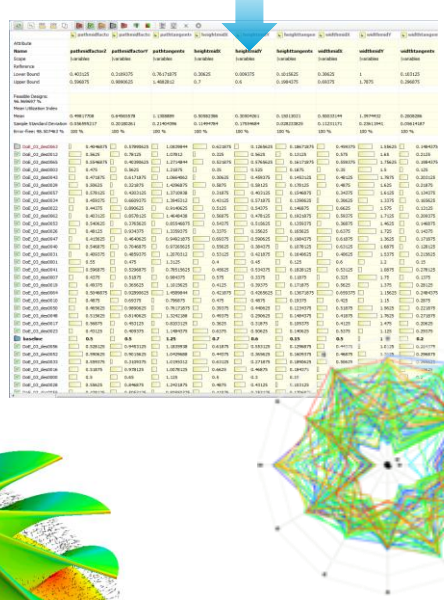
Variable Geometry → Pre-processing → Software Connection → Post-processing → Optimization & Assessment



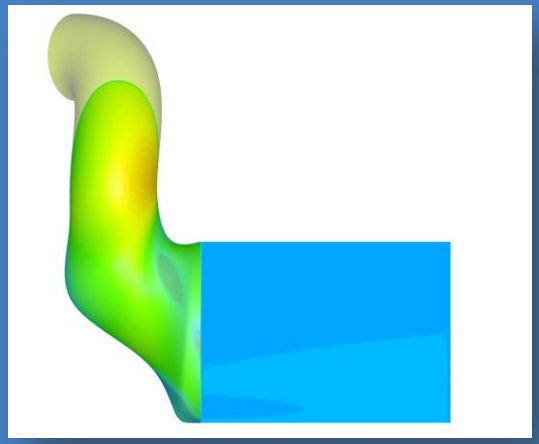








Example:
Optimization of the flow uniformity in a car exhaust catalytic converter



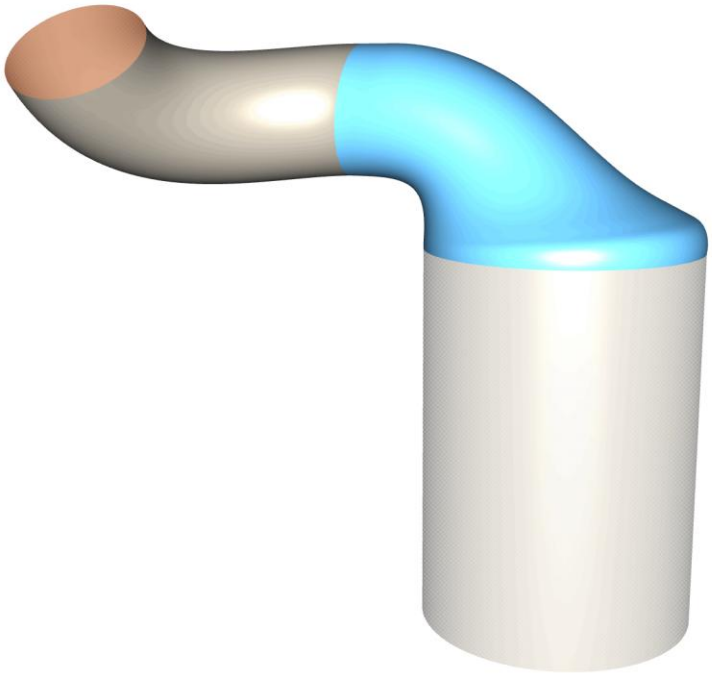
Catalytic Converter - overview

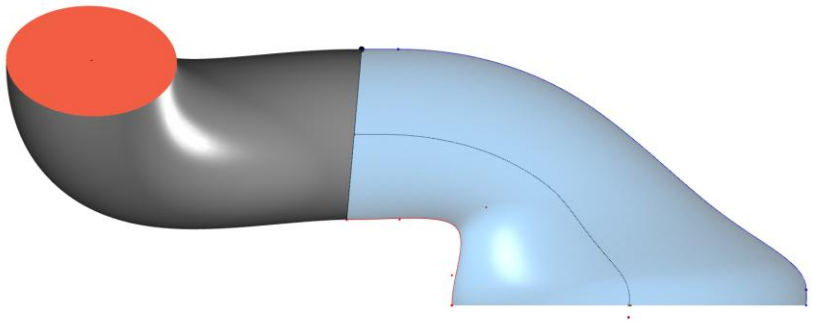
- Problem discription:
  - Often the pipe before the catalytic converter is bended due to space constraints
  - This leads to an non uniform flow distribution
  - This can lead to higher emissions
- Problem solved by:
  - Using CAESES as a parametric modeling and optimization platform
  - Using GridPro for high quality structured and automated meshing
  - Using OpenFOAM for CFD calculations

Catalytic converter for Mercedes-Benz M-Class
Source:
http://www.autoteiledirekt.de/vegaz-2322336.html

Catalytic Converter – full parametric modeling in CAESES

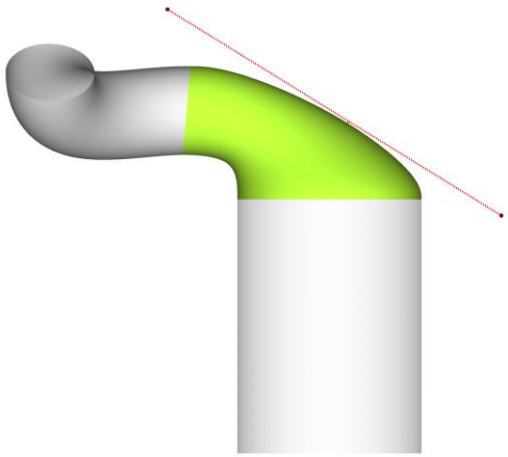
- Modeling approach:
  - Using meta surface technique for creating a smart parametric model
  - Highly flexible with low number of design variables
  - Ellipse swept along two paths, to create inlet section
  - 7 design variables are used

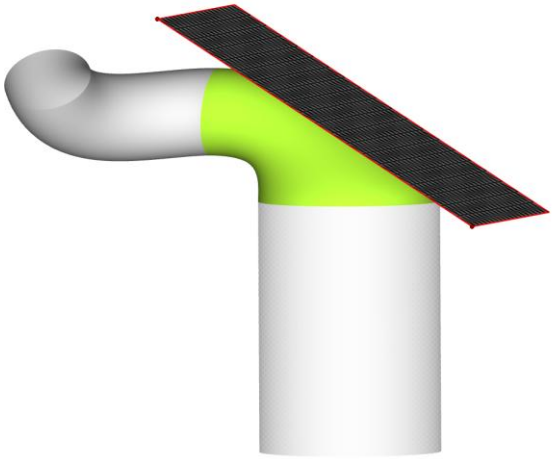


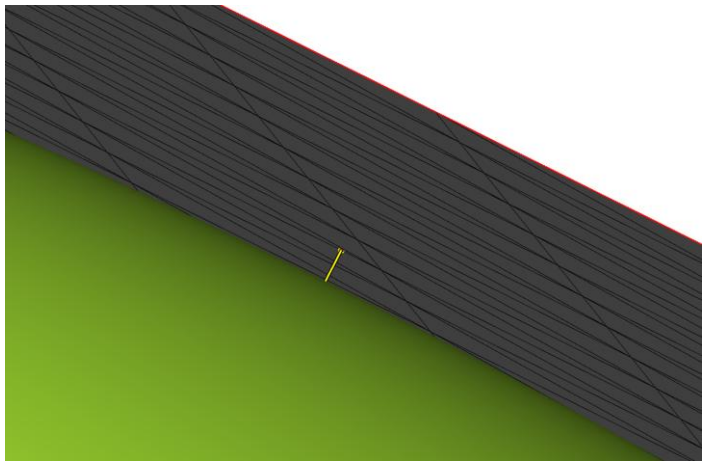


Catalytic Converter – considering space constraints

- Considering constraints
  - Creating plane
  - Creating a “shortest distance line” between two discretized surfaces (called TriMesh in CAESES)
  - Measuring length
  - Length should not be smaller then x

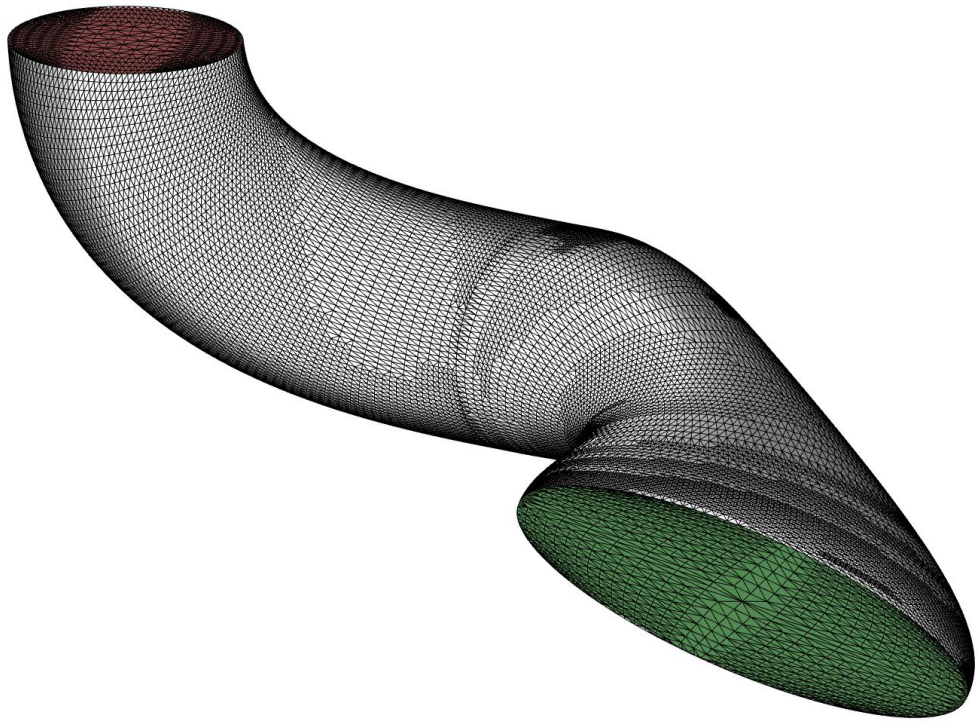






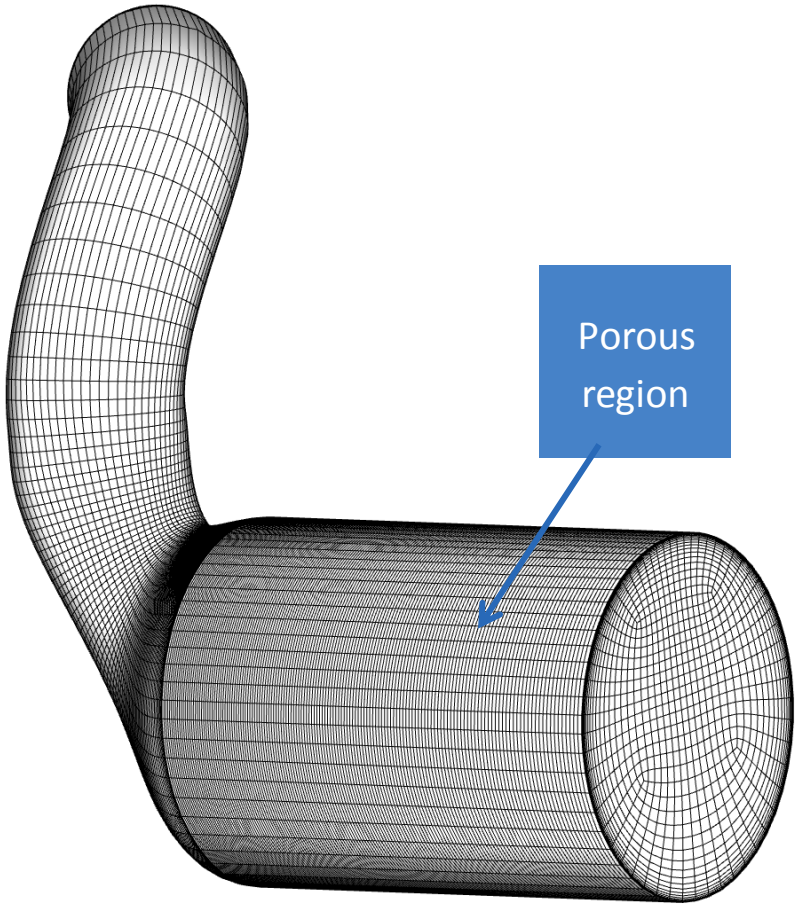
Catalytic Converter – pre-processing

- Creating watertight stl mesh, with applied colors
- One stl patch for color
- Boundaries can be named
- Refinement of stl mesh can be adjusted
- For GridPro we created on stl for each boundary

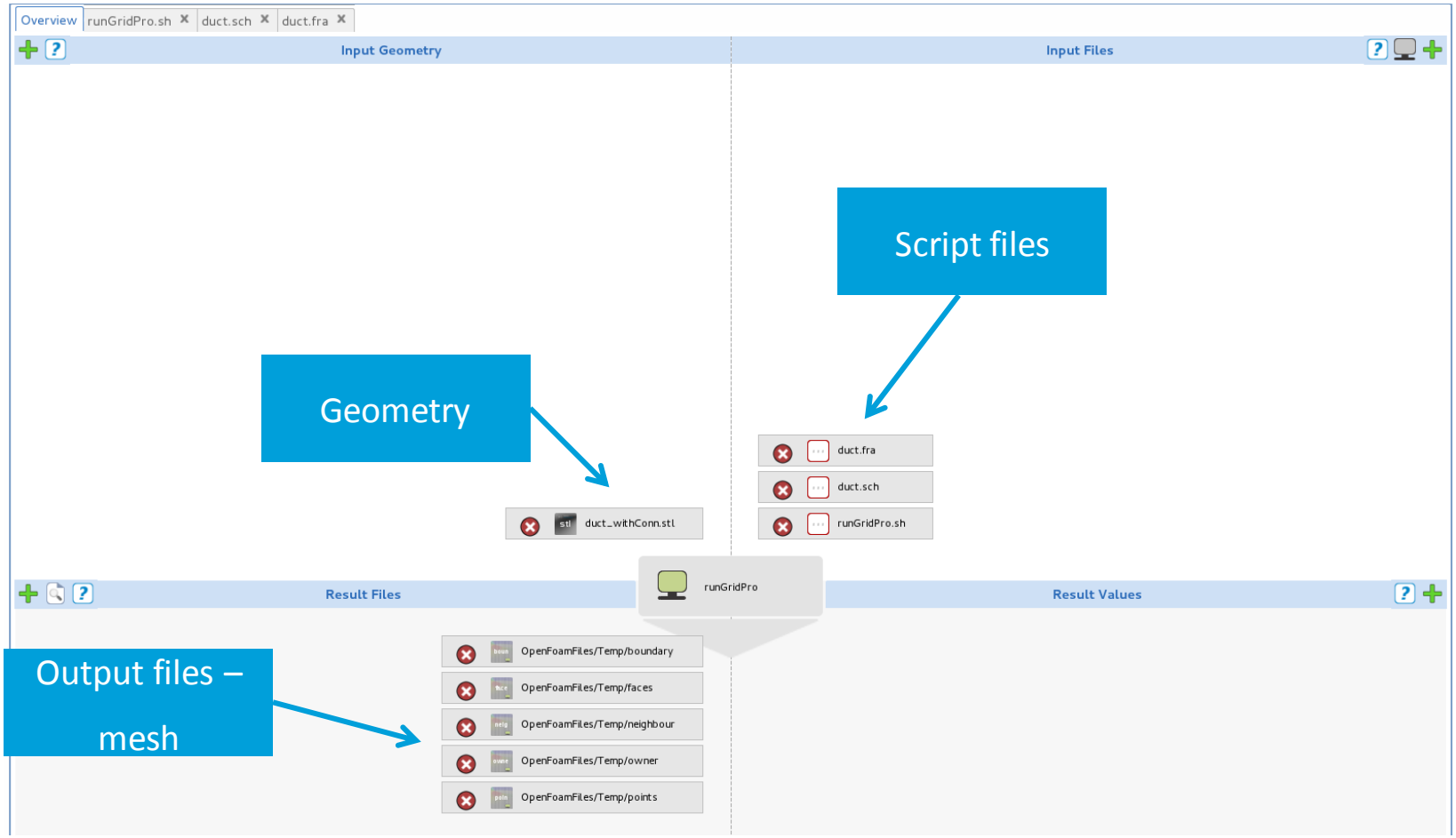


Catalytic Converter – GridPro and OpenFoam setups

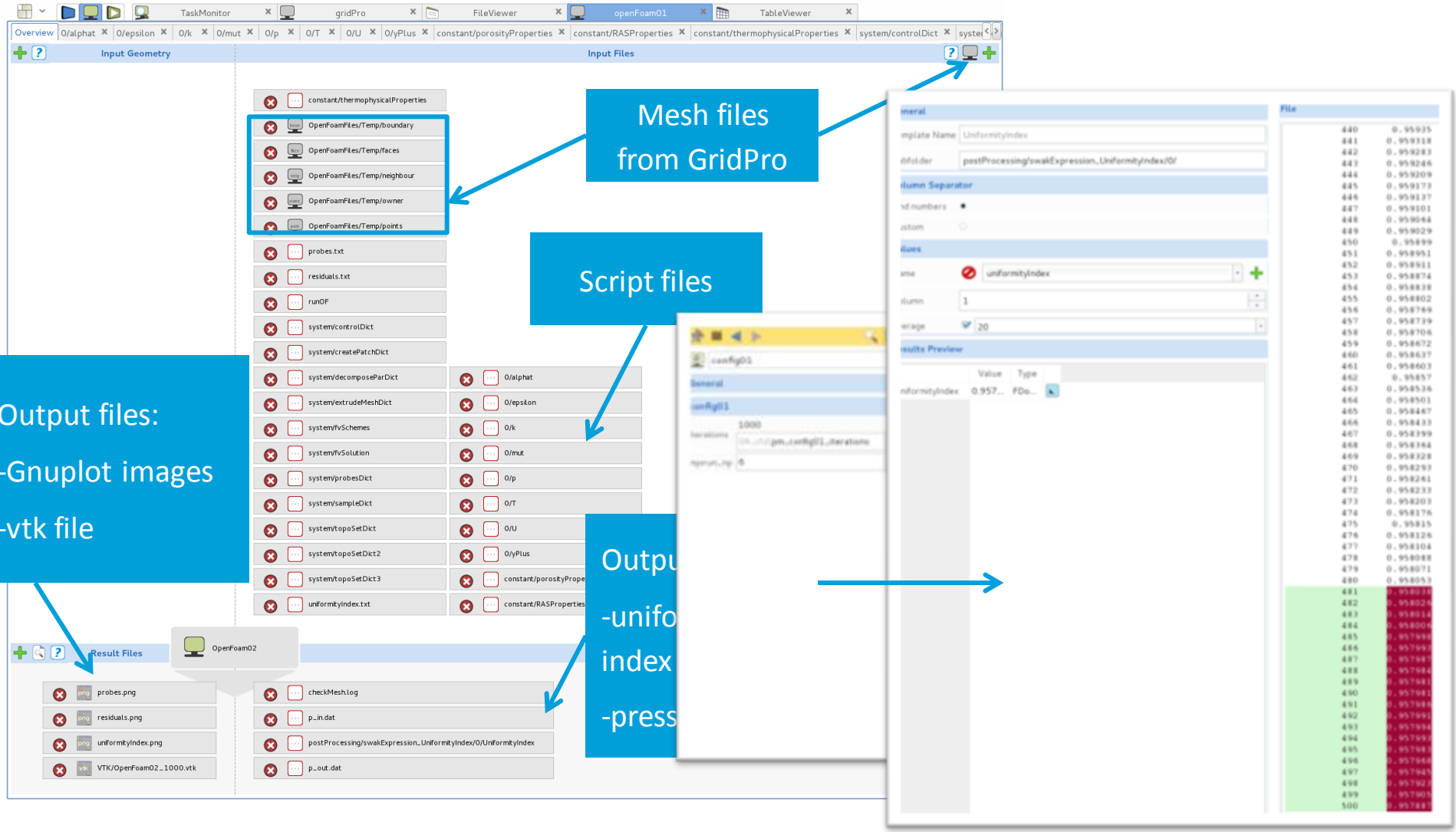
- GridPro:
  - Key benefit: flow aligned structured mesh, which can adopt automatically to changed geometry
  - Output mesh can be converted to OpenFOAM format
  - GridPro commands are written into a shell script
- OpenFOAM
  - Compressible gas (μ(T) by southerland eq.)
  - Porous medium (Darcy-Forchheimer)
  - T_{in}=963K
  - M_{in}=0.18kg/s
  - P_{out}=1.35bar
  - A=8.451/m; B=5.251/m2
  - OpenFOAM commands are written into a shell script



Catalytic Converter – Coupling CAESES and GridPro

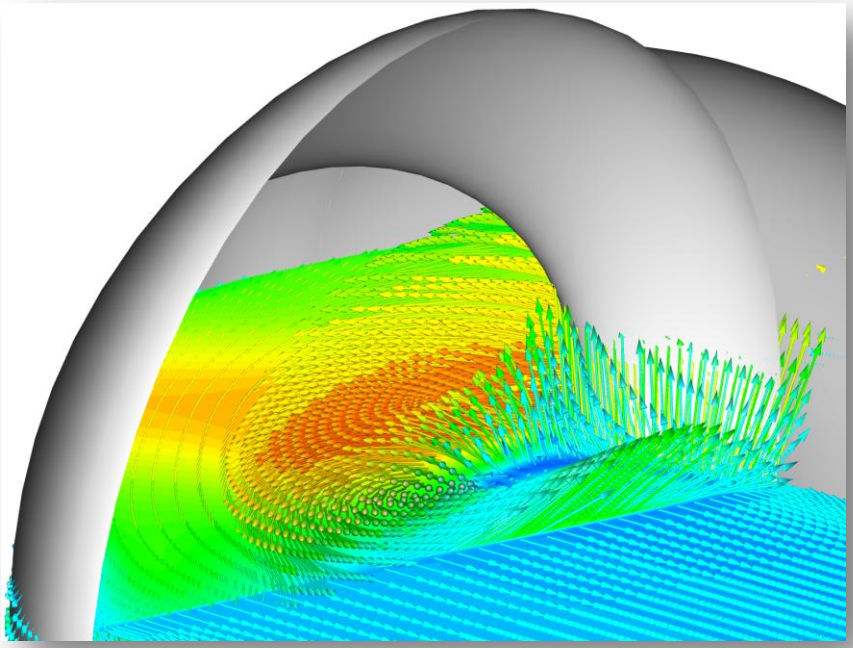


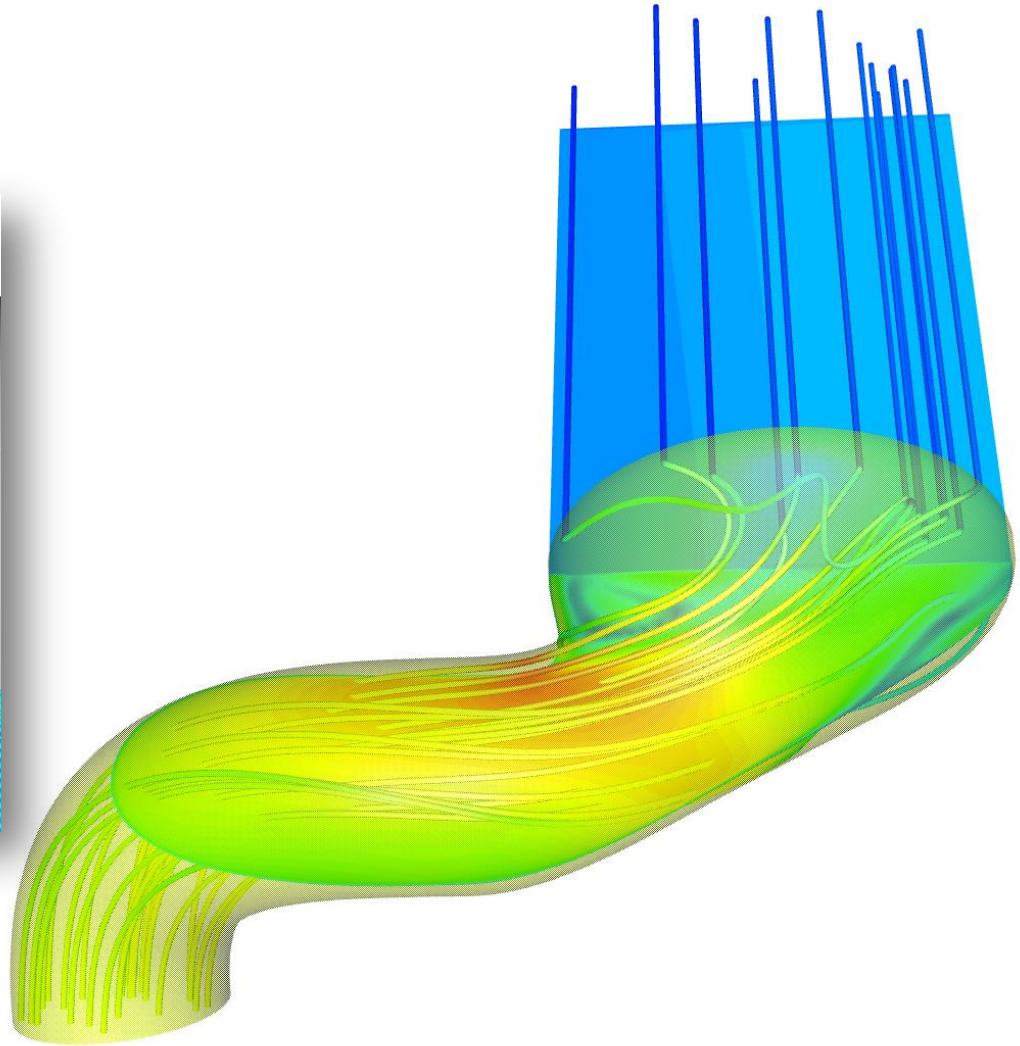
Catalytic Converter – Coupling CAESES and OpenFOAM



Catalytic Converter – post-processing

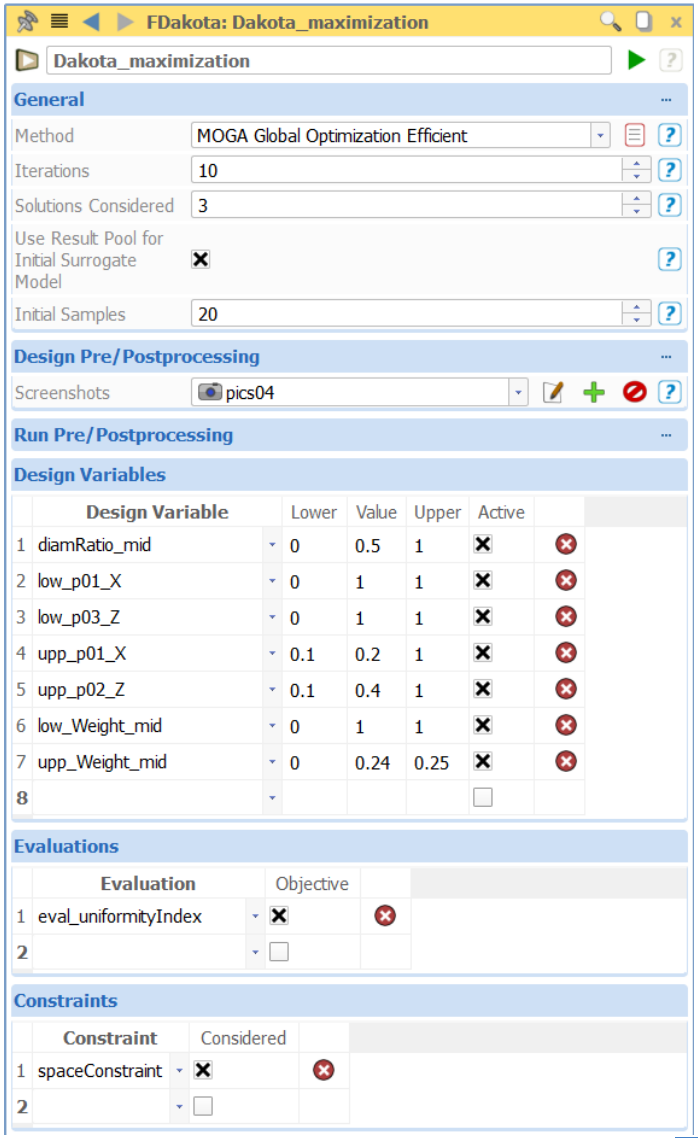
- Using VTK format to import and visualize the solution





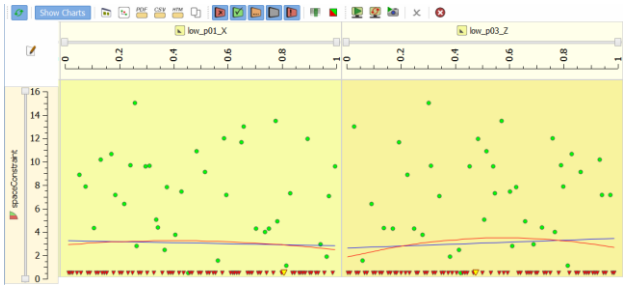
Catalytic Converter – Optimization Strategy

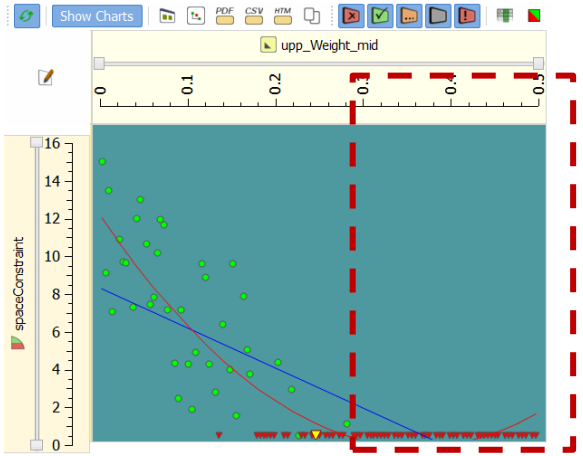
- Know your design space!
- Run Design of Experiments to get a design space with mostly feasible designs, which not violate the space constraint
- Run an optimization with CFD

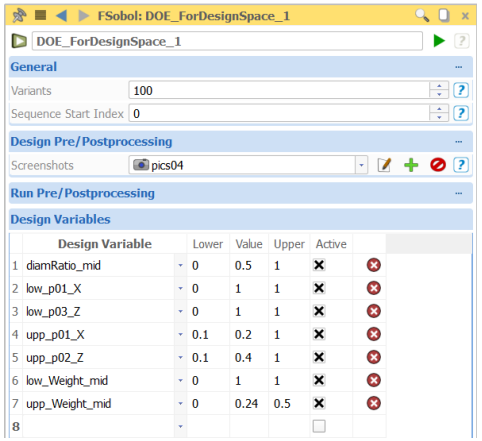


Catalytic Converter – Exploring design space

- Ranges of the design variables are unknown with respect to the space constraint
- -> creating Design of Experiment (DOE) to explore the influence of each design variable on the constraint
  - 38% feasible designs







	Design Variable	Lower	Value	Upper	Active
1	diamRatio_mid	0	0.5	1	✓
2	low_p01_X	0	1	1	✓
3	low_p03_Z	0	1	1	✓
4	upp_p01_X	0.1	0.2	1	✓
5	upp_p02_Z	0.1	0.4	1	✓
6	low_Weight_mid	0	1	1	✓
7	upp_Weight_mid	0	0.24	0.5	✓
8					

- -> adjusting range and do a second DOE
  - 78% feasible designs
- **Ready for CFD!**

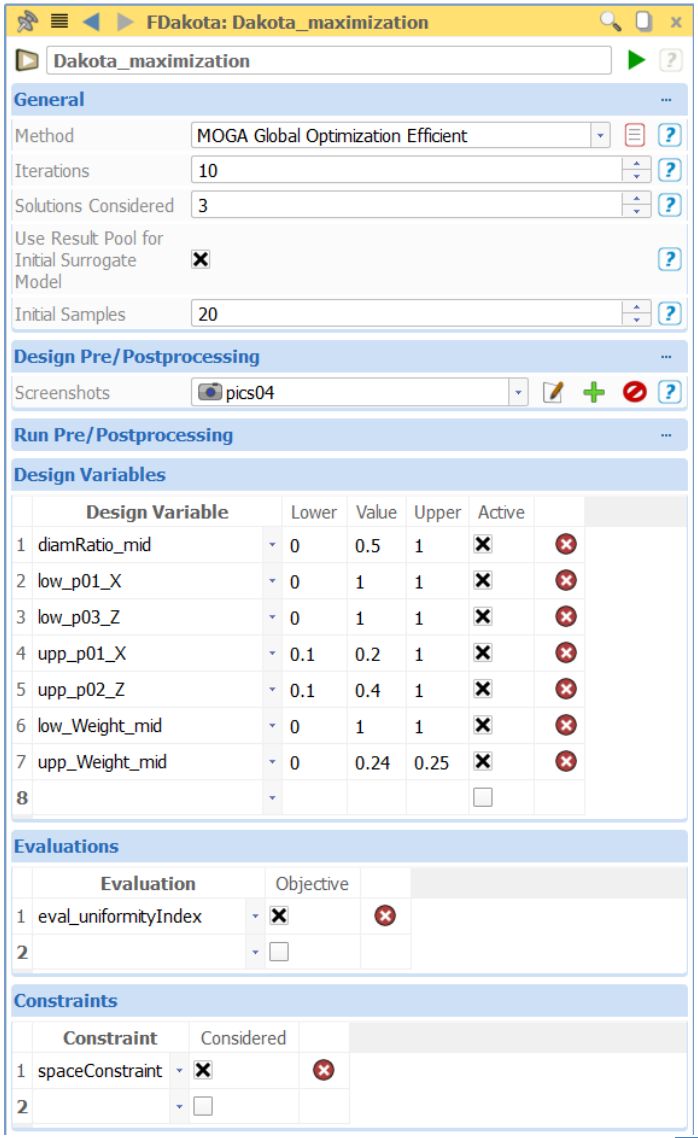
Design Variables

	Design Variable	Lower	Value	Upper	Active
1	diamRatio_mid	0	0.5	1	✓
2	low_p01_X	0	1	1	✓
3	low_p03_Z	0	1	1	✓
4	upp_p01_X	0.1	0.2	1	✓
5	upp_p02_Z	0.1	0.4	1	✓
6	low_Weight_mid	0	1	1	✓
7	upp_Weight_mid	0	0.24	0.25	✓
8					

Catalytic Converter – Optimization

- CAESES includes different design engines for:
  - Design exploration (eg. Sobol, LHS)
  - Optimization algorithms (eg. Tsearch, NSGA-II, MOSA)
  - Connection to Dakota

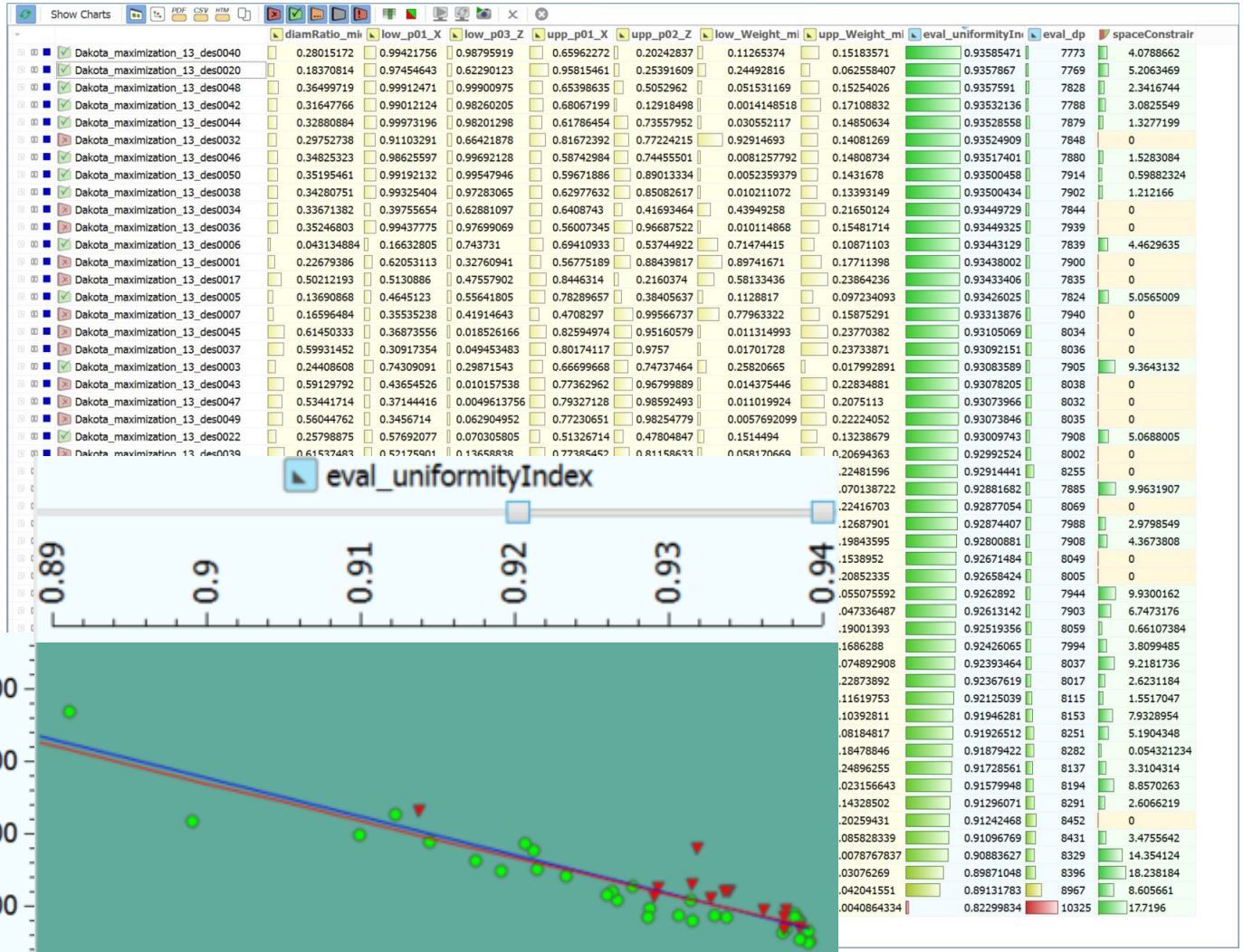
- In this example we used:
  - Single Objective Global Optimization based on a surrogate model (response surface) provided by Dakota



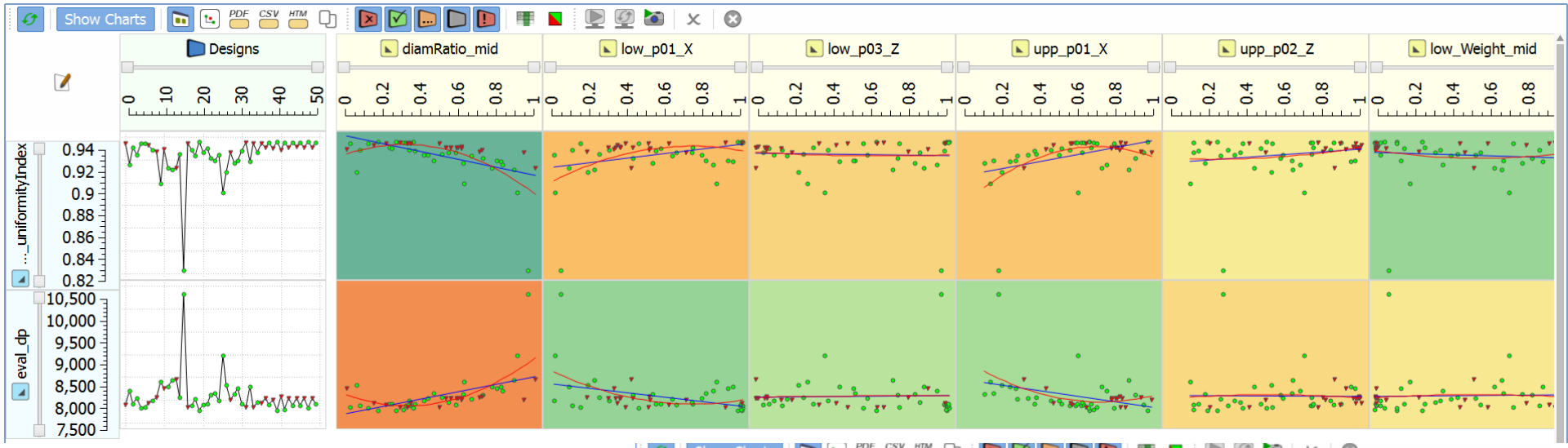
Catalytic Converter – Result evaluation

- Uniformity index varies from 82.2%-93.6%
- Many designs with similar uniformity index
- Small changes in uniformity index, have positive influence on pressure drop

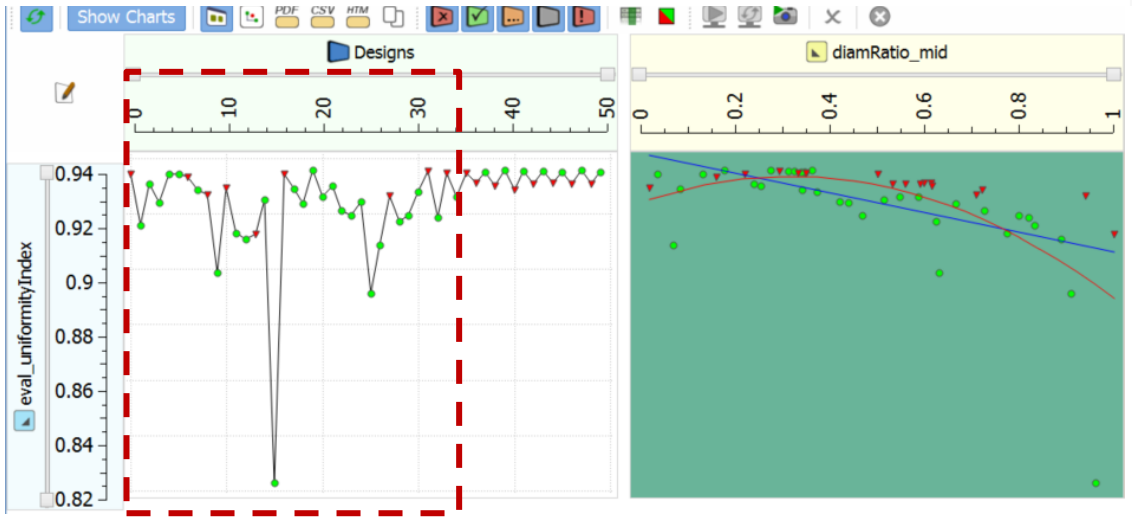
-> No multi objective optimization necessary



Catalytic Converter – Analyzing Charts

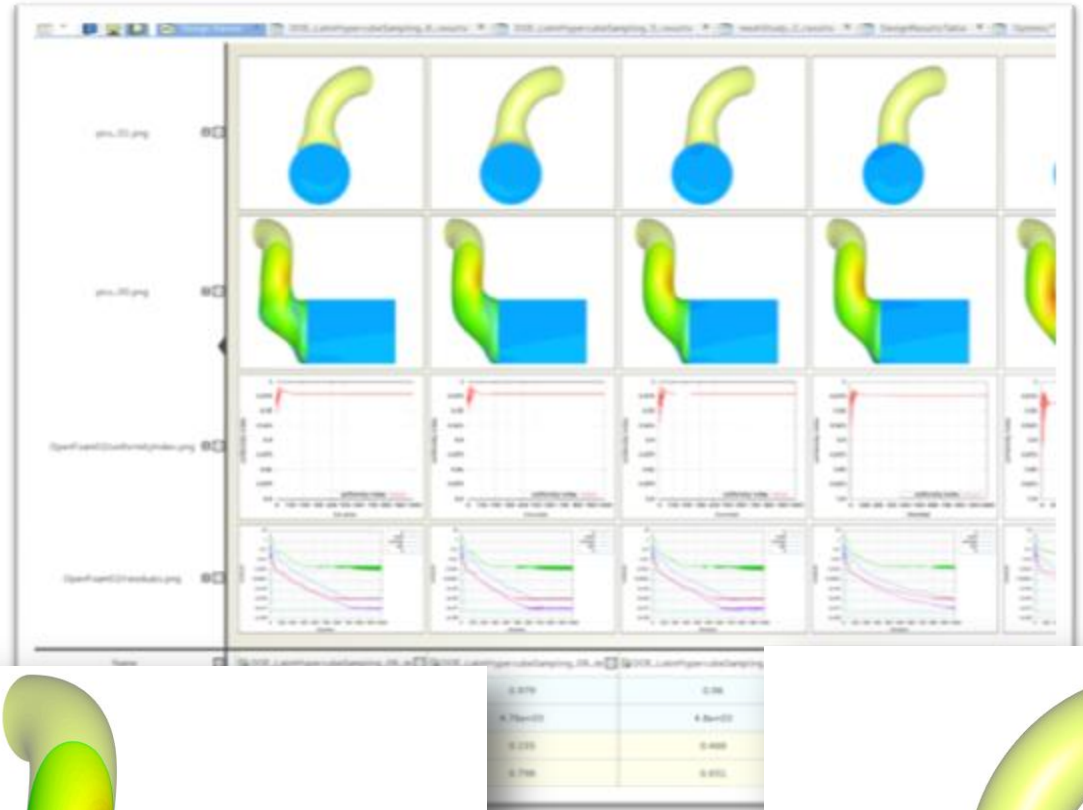


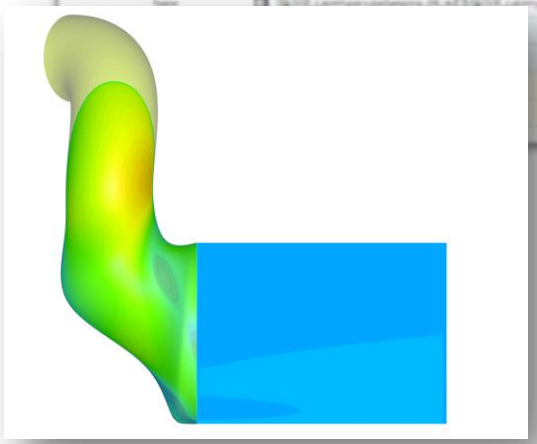
- Charts give a good overview, which design variables have the largest impact on the objective
- First 35 designs with LHS to create a surrogate model
- Reached nearly the maximum uniformity index with the first evaluated design of the surrogate model

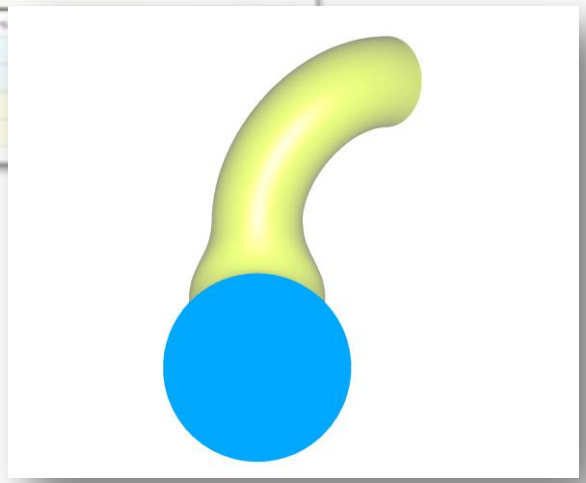


Catalytic Converter – Comparing Designs

- Design viewer to compare the designs
- Understand the effects of the design variables on the flow field
- Include residuals and other plots, to make sure that the design has converge
- Create animations

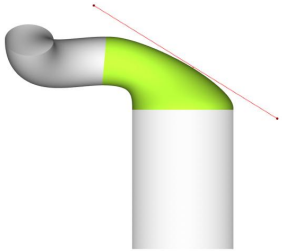




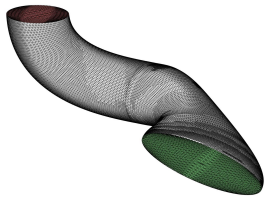


Conclusion

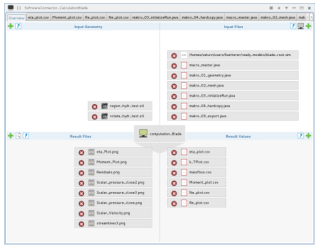
Variable Geometry → Pre-processing → Software Connection → Post-processing → Optimization & Assessment



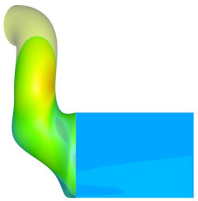
- Variable geometry
- Including space constraints



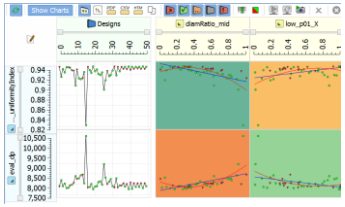
- High quality STL with specific boundary patches



- Grid Pro
- OpenFoam
- Gnuplot



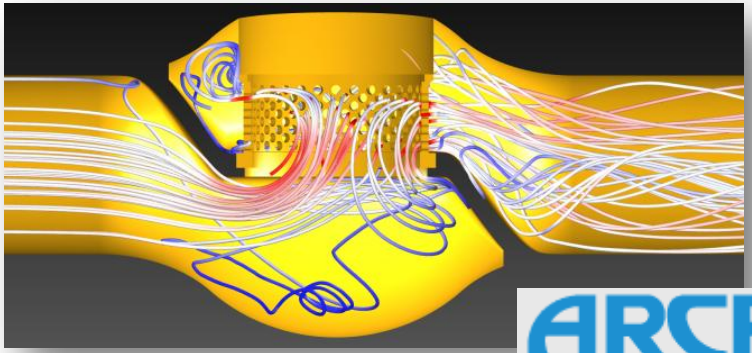
- Visualizing flow field

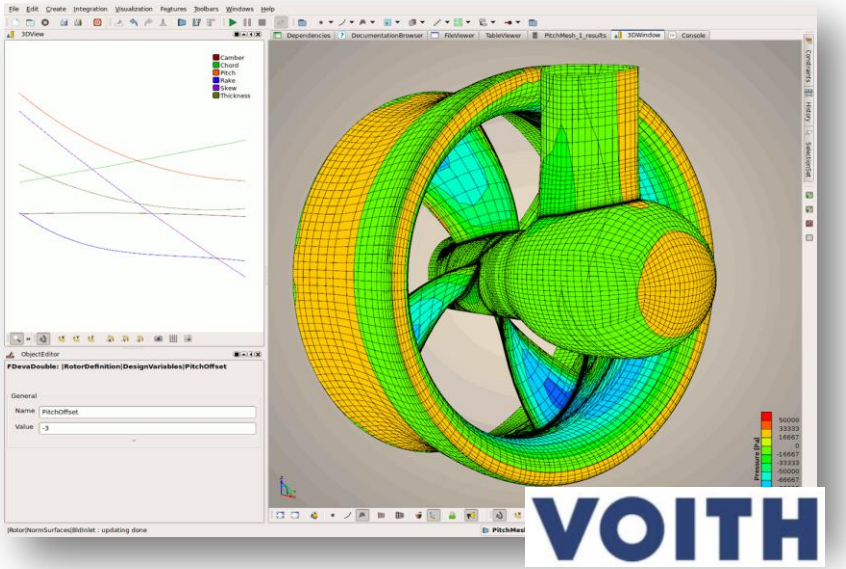


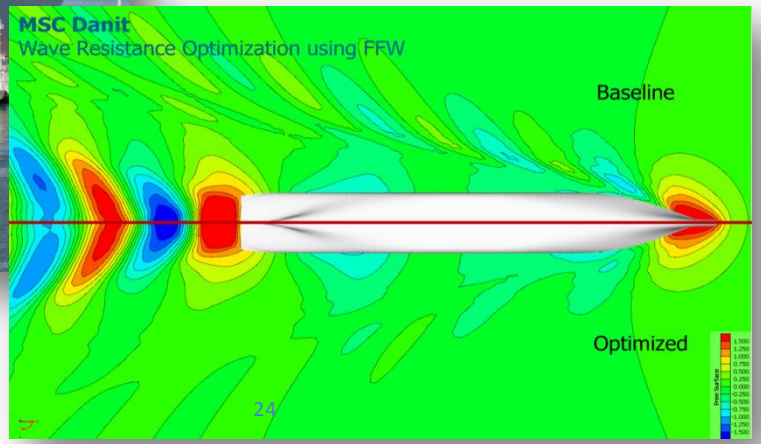
- Optimization using Dakota Alogorithms
- Analyzing results

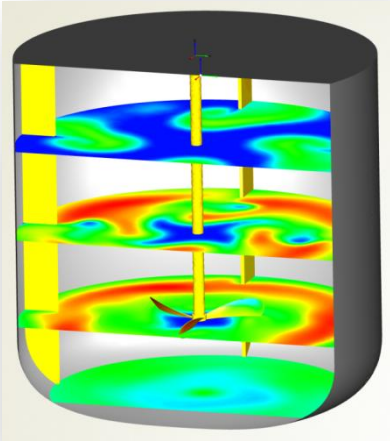
Further examples

Further Examples









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Carsten Fütterer

fuetterer@friendship-systems.de
+49-331-96766-0

www.caeses.com

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