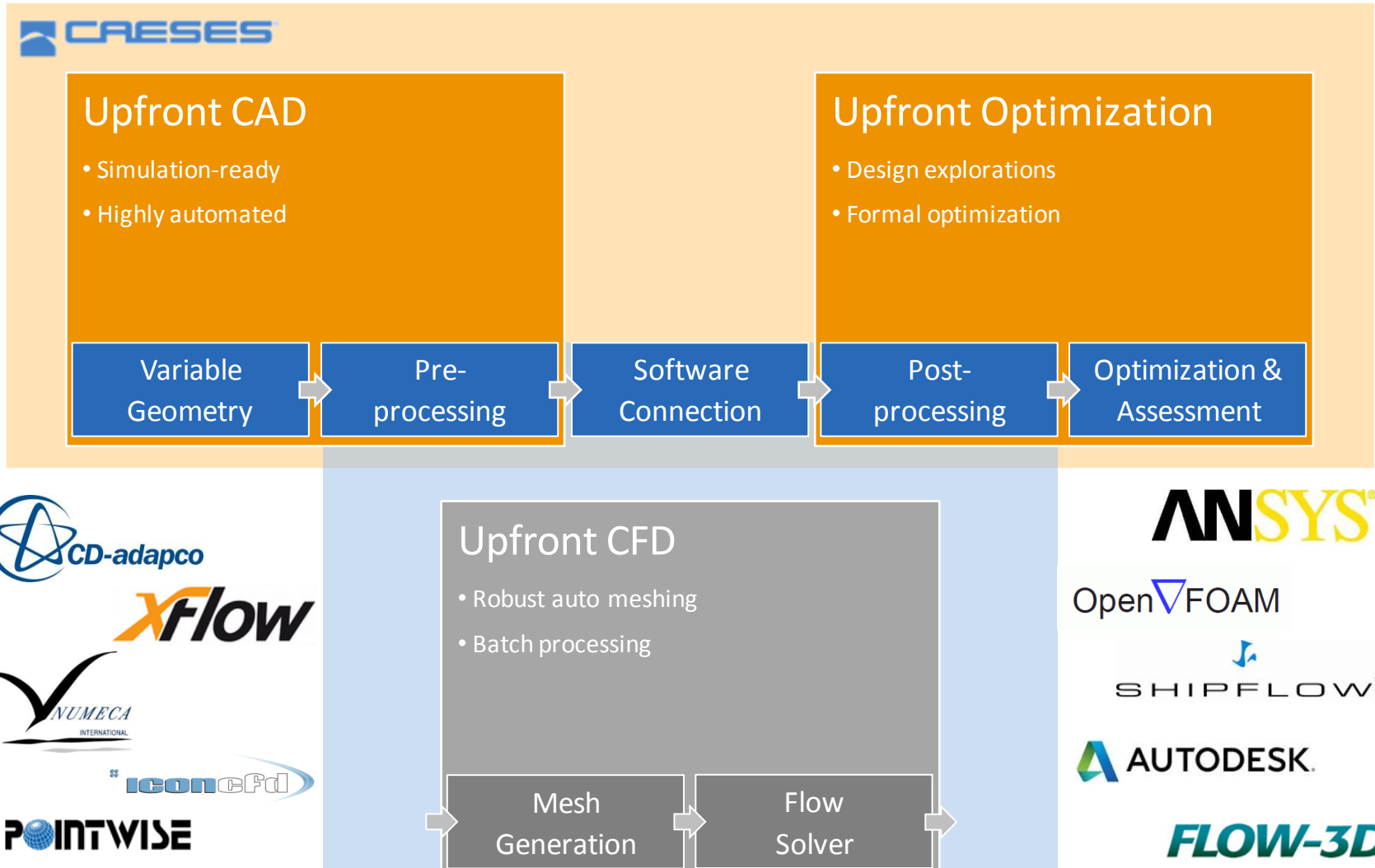




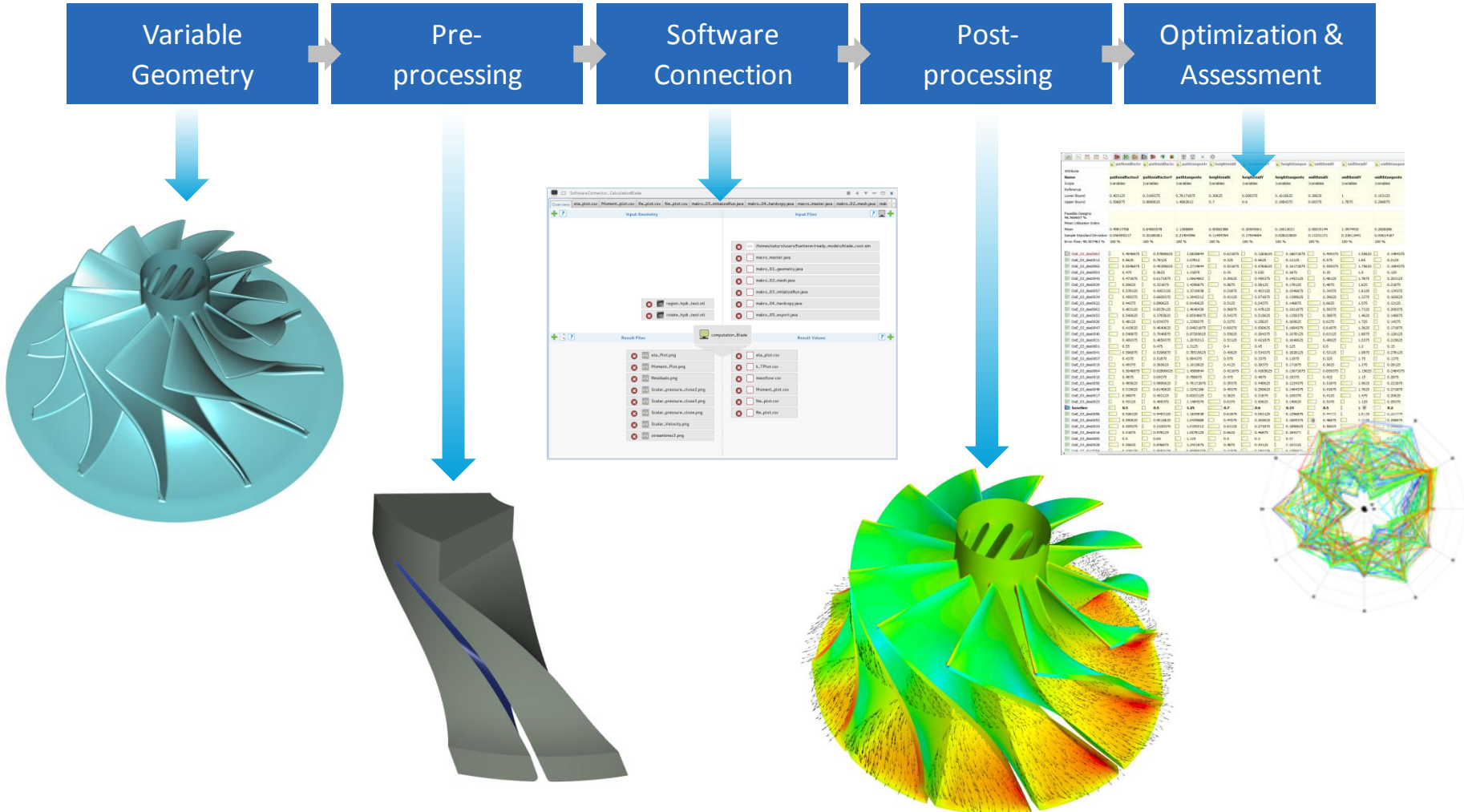
Automatic Design Exploration And Optimization Using **CAESES** and **OpenFoam**



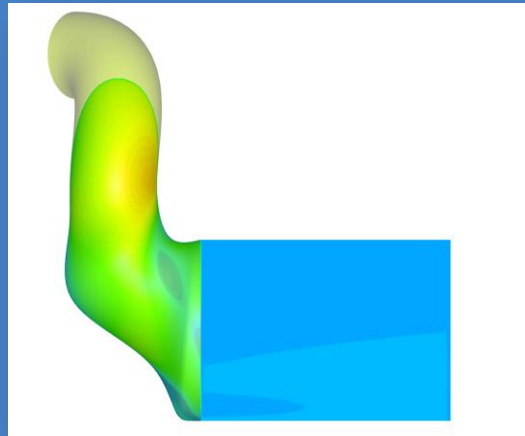
CAESES | Upfront CAE System Empowering Simulation



Process Workflow: Setting up the Automation Chain



**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

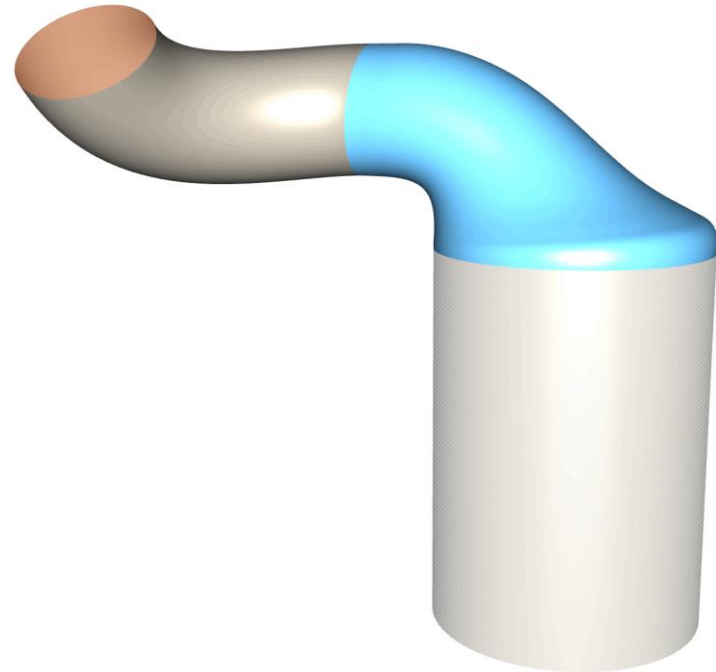
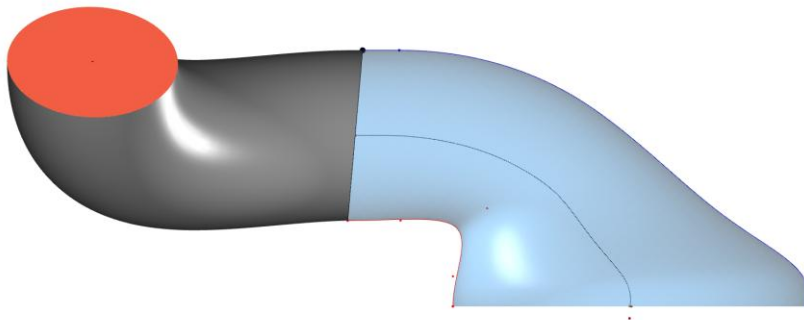


Catalytic converter for Mercedes-Benz M-Class
Source:
<http://www.autoteiledirekt.de/vegaz-2322336.html>



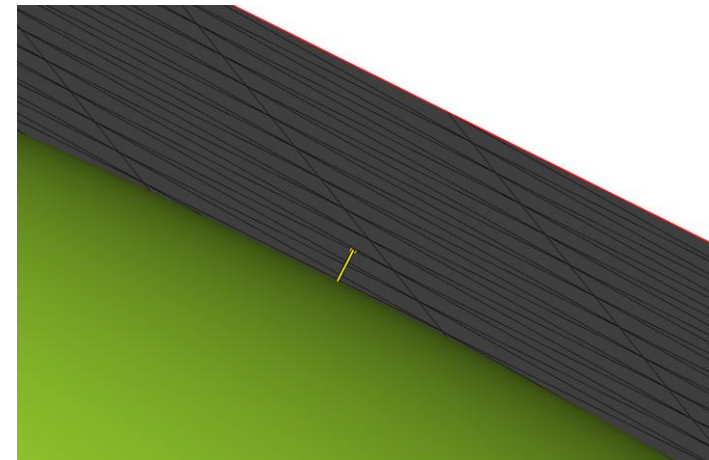
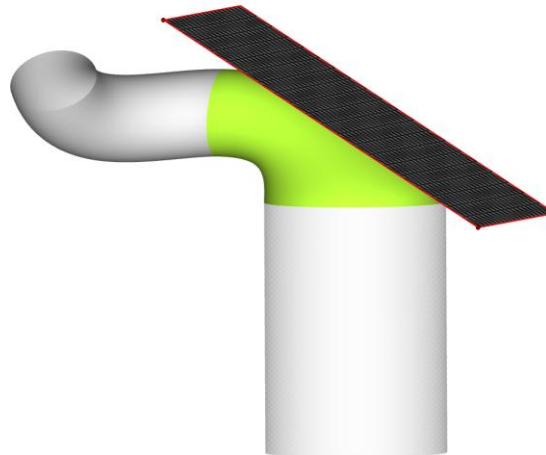
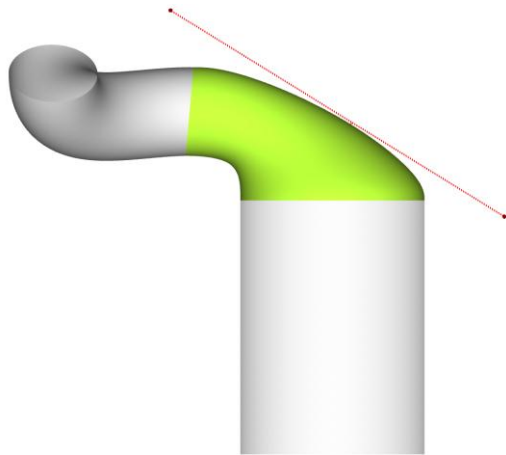
Catalytic Converter – full parametric modeling in CAESSES

- 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



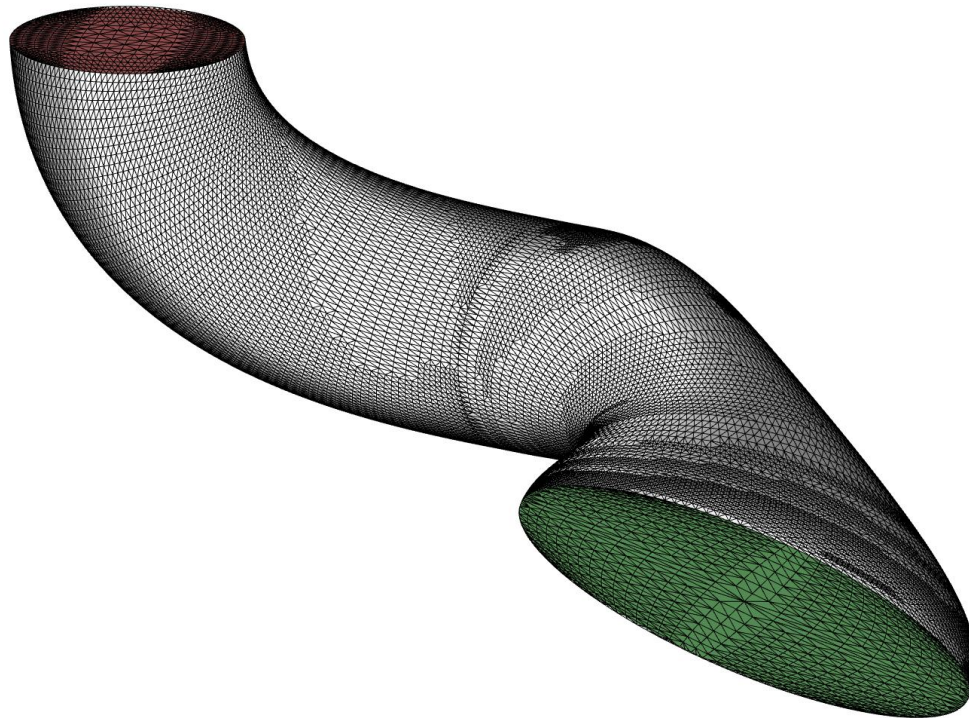
Catalytic Converter – considering space constraints

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



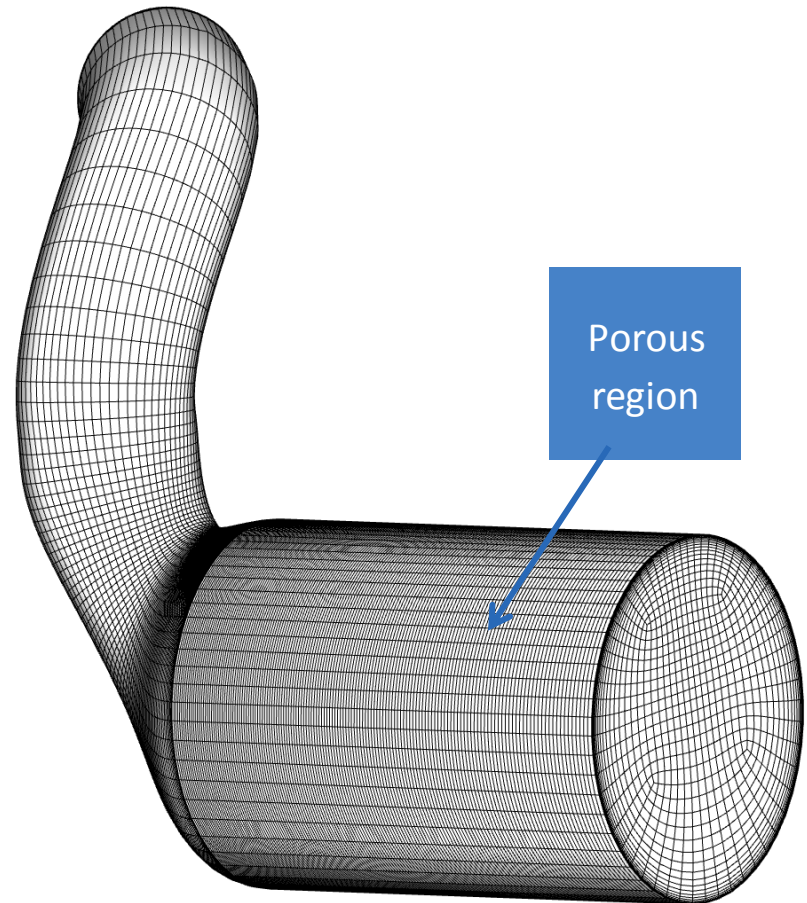
Catalytic Converter – pre-processing

- 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

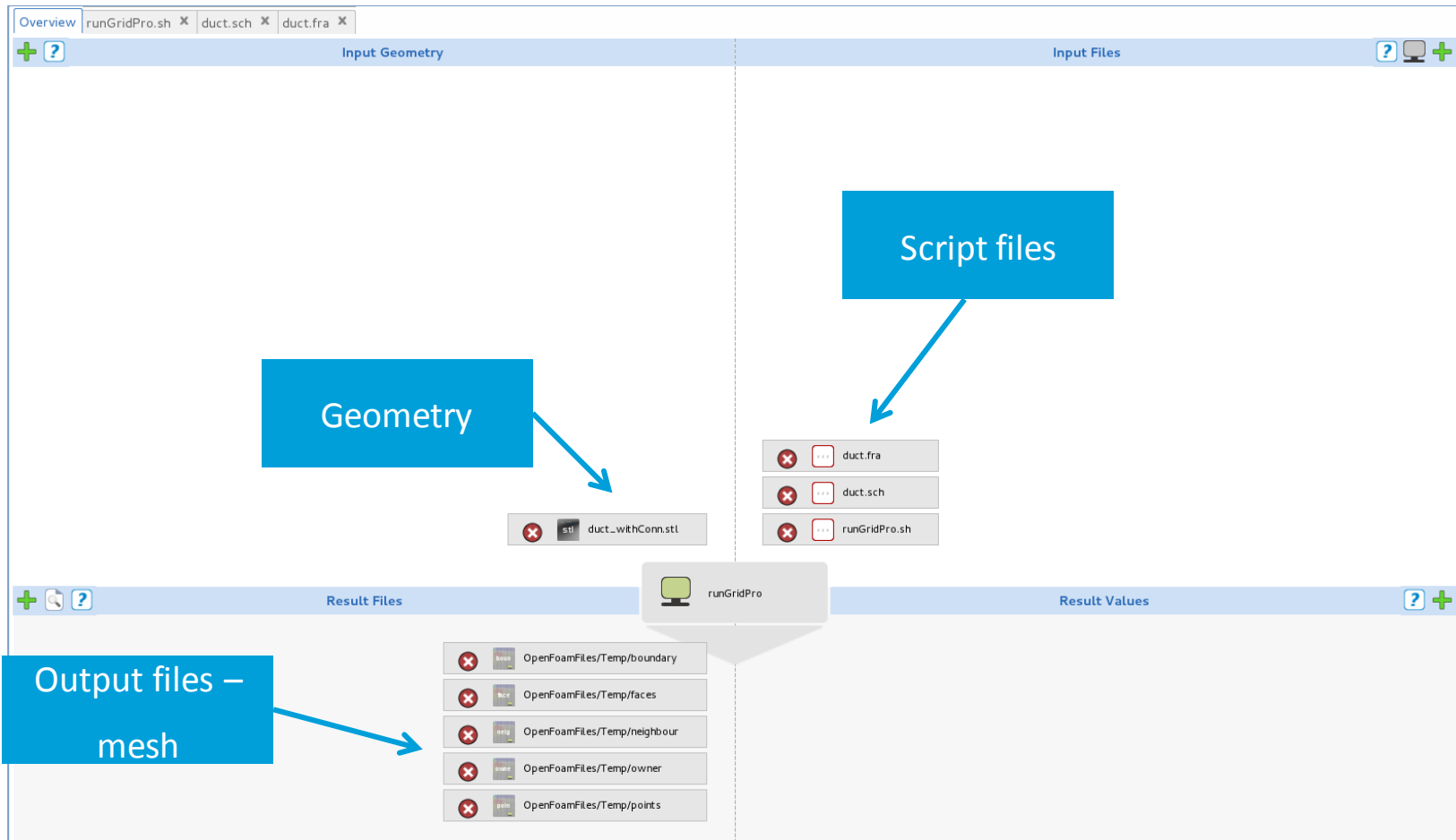


Catalytic Converter – GridPro and OpenFoam setups

- 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 ($\mu(T)$ by southerland eq.)
 - Porous medium (Darcy-Forchheimer)
 - $T_{in}=963K$
 - $M_{in}=0.18kg/s$
 - $P_{out}=1.35bar$
 - $A=8.451/m$; $B=5.251/m^2$
 - OpenFOAM commands are written into a shell script



Catalytic Converter – Coupling CAESES and GridPro



Catalytic Converter – Coupling CAESES and OpenFOAM

Input Files

- constant/thermophysicalProperties
- OpenFoamFiles/Temp/boundary
- OpenFoamFiles/Temp/faces
- OpenFoamFiles/Temp/neighbor
- OpenFoamFiles/Temp/owner
- OpenFoamFiles/Temp/points
- probes.txt
- residuals.txt
- runOF
- system/controlDict
- system/createPatchDict
- system/decomposeParDict
- system/extrudeMeshDict
- system/fvSchemes
- system/fvSolution
- system/probesDict
- system/sampleDict
- system/topoSetDict
- system/topoSetDict2
- system/topoSetDict3
- uniformityIndex.txt
- O/alphat
- O/epsilon
- O/k
- O/mut
- O/p
- O/T
- O/U
- O/yPlus
- constant/porosityProperties
- constant/RASProperties

Result Files

- probes.png
- residuals.png
- uniformityIndex.png
- VTK/OperFoam02_1000.vtk
- checkMesh.log
- p_in.dat
- postProcessing/swakExpression_UniformityIndex0/UniformityIndex
- p_out.dat

Mesh files from GridPro (pointing to OpenFoamFiles/Temp/...)

Script files (pointing to runOF)

Output files:
-Gnuplot images
-vtk file

Output:
-uniformity index
-pressure

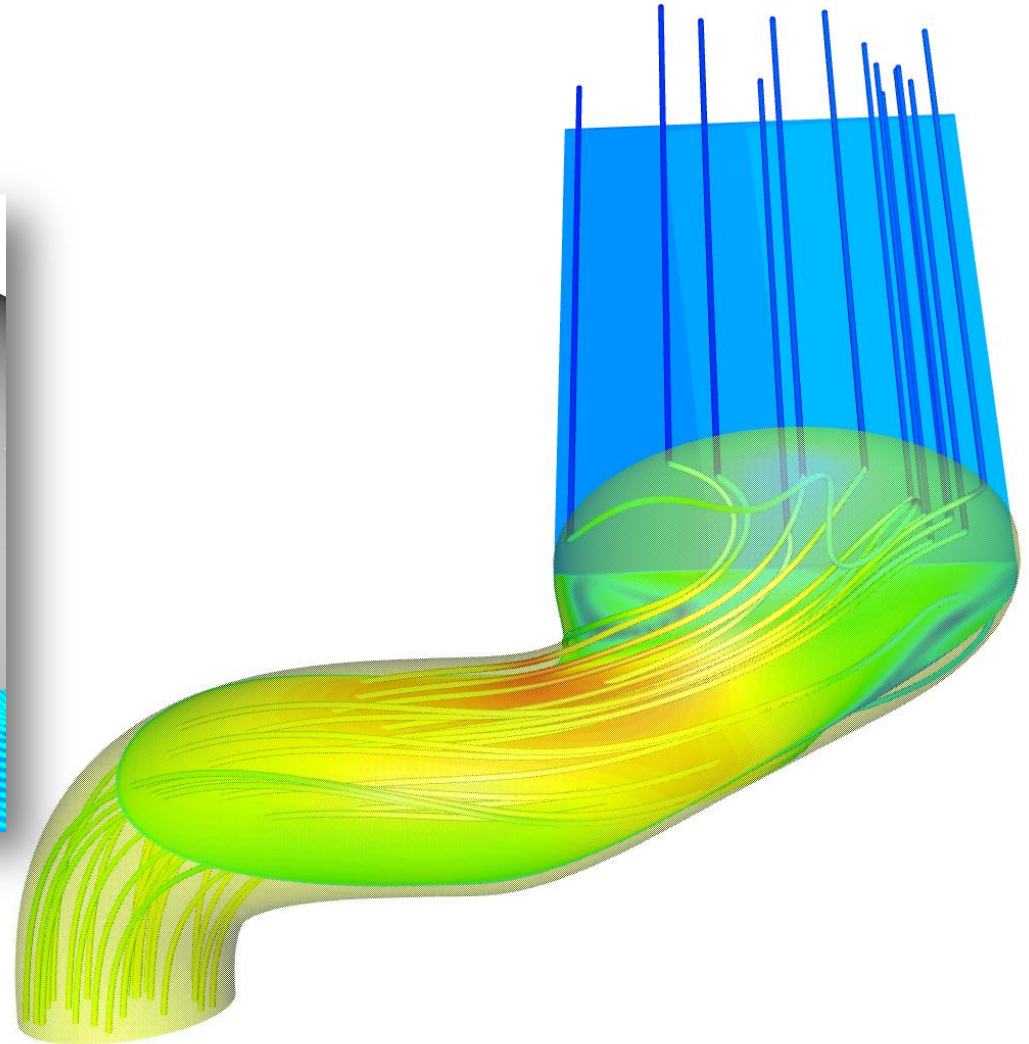
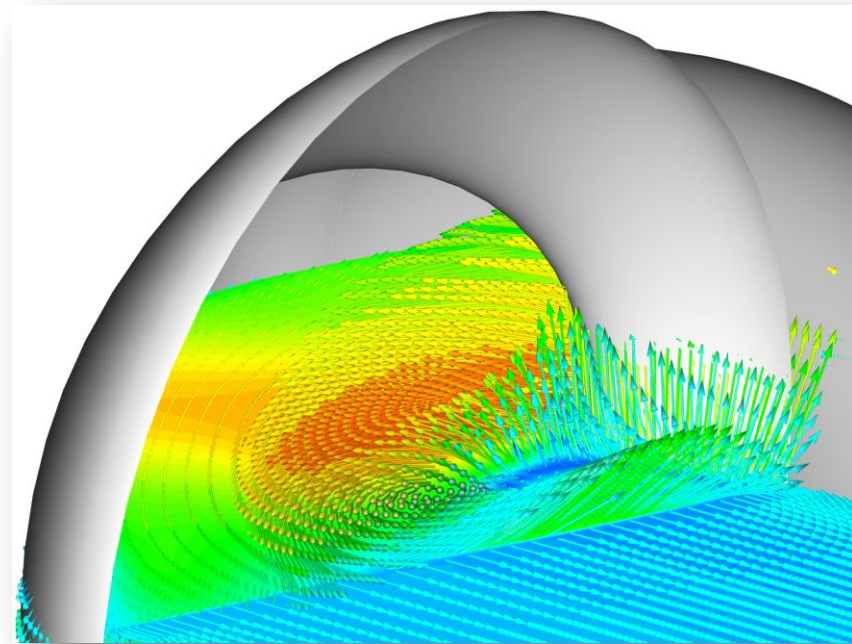
Results Preview Table:

Iteration	Value	Type
440	0.95925	
441	0.95928	
442	0.95928	
443	0.95928	
444	0.95929	
445	0.95917	
446	0.95917	
447	0.95910	
448	0.95904	
449	0.95902	
450	0.95899	
451	0.95891	
452	0.95887	
453	0.95883	
454	0.95880	
455	0.95880	
456	0.95879	
457	0.95873	
458	0.95870	
459	0.95867	
460	0.95867	
461	0.95860	
462	0.95857	
463	0.95853	
464	0.95850	
465	0.95846	
466	0.95843	
467	0.95839	
468	0.95834	
469	0.95832	
470	0.95829	
471	0.95826	
472	0.95823	
473	0.95820	
474	0.95817	
475	0.95815	
476	0.95812	
477	0.95810	
478	0.95808	
479	0.95807	
480	0.95805	
481	0.95803	
482	0.95802	
483	0.95801	
484	0.95800	
485	0.95799	
486	0.95798	
487	0.95797	
488	0.95794	
489	0.95791	
490	0.95791	
491	0.95790	
492	0.95790	
493	0.95790	
494	0.95790	
495	0.95790	
496	0.95790	
497	0.95790	
498	0.95790	
499	0.95790	
500	0.95784	



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

The screenshot shows the Dakota optimization software interface for a project named 'Dakota_maximization'. The interface is divided into several sections:

- General:** Method is set to 'MOGA Global Optimization Efficient'. Iterations are 10, and Solutions Considered are 3. The 'Use Result Pool for Initial Surrogate Model' checkbox is checked. Initial Samples are 20.
- Design Pre/Postprocessing:** Screenshots are set to 'pics04'.
- Run Pre/Postprocessing:** (Empty section)
- Design Variables:** A table with 8 rows and 6 columns: Design Variable, Lower, Value, Upper, Active, and a status column. All variables are currently inactive (marked with 'X' in the Active column).
- Evaluations:** A table with 2 rows and 3 columns: Evaluation, Objective, and a status column. The first evaluation, 'eval_uniformityIndex', is marked as failed (marked with 'X' in the Objective column).
- Constraints:** A table with 2 rows and 3 columns: Constraint, Considered, and a status column. The first constraint, 'spaceConstraint', is marked as failed (marked with 'X' in the Considered column).

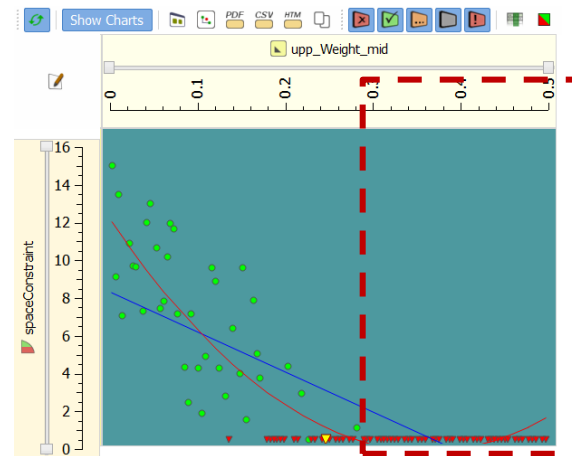
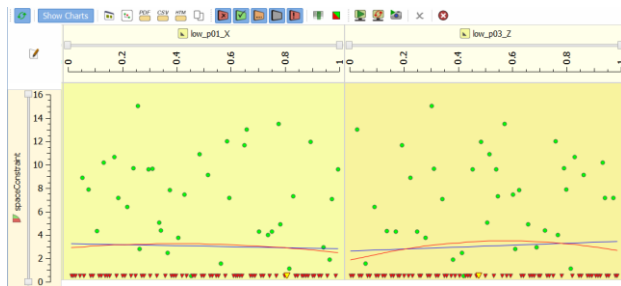
Design Variable	Lower	Value	Upper	Active	
1 diamRatio_mid	0	0.5	1	X	X
2 low_p01_X	0	1	1	X	X
3 low_p03_Z	0	1	1	X	X
4 upp_p01_X	0.1	0.2	1	X	X
5 upp_p02_Z	0.1	0.4	1	X	X
6 low_Weight_mid	0	1	1	X	X
7 upp_Weight_mid	0	0.24	0.25	X	X
8					

Evaluation	Objective	
1 eval_uniformityIndex	X	X
2		

Constraint	Considered	
1 spaceConstraint	X	X
2		

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



FSober: DOE_ForDesignSpace_1

DOE_ForDesignSpace_1

General

Variants: 100

Sequence Start Index: 0

Design Pre/Postprocessing

Screenshots: pics04

Run Pre/Postprocessing

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	0.5	✗	✗
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

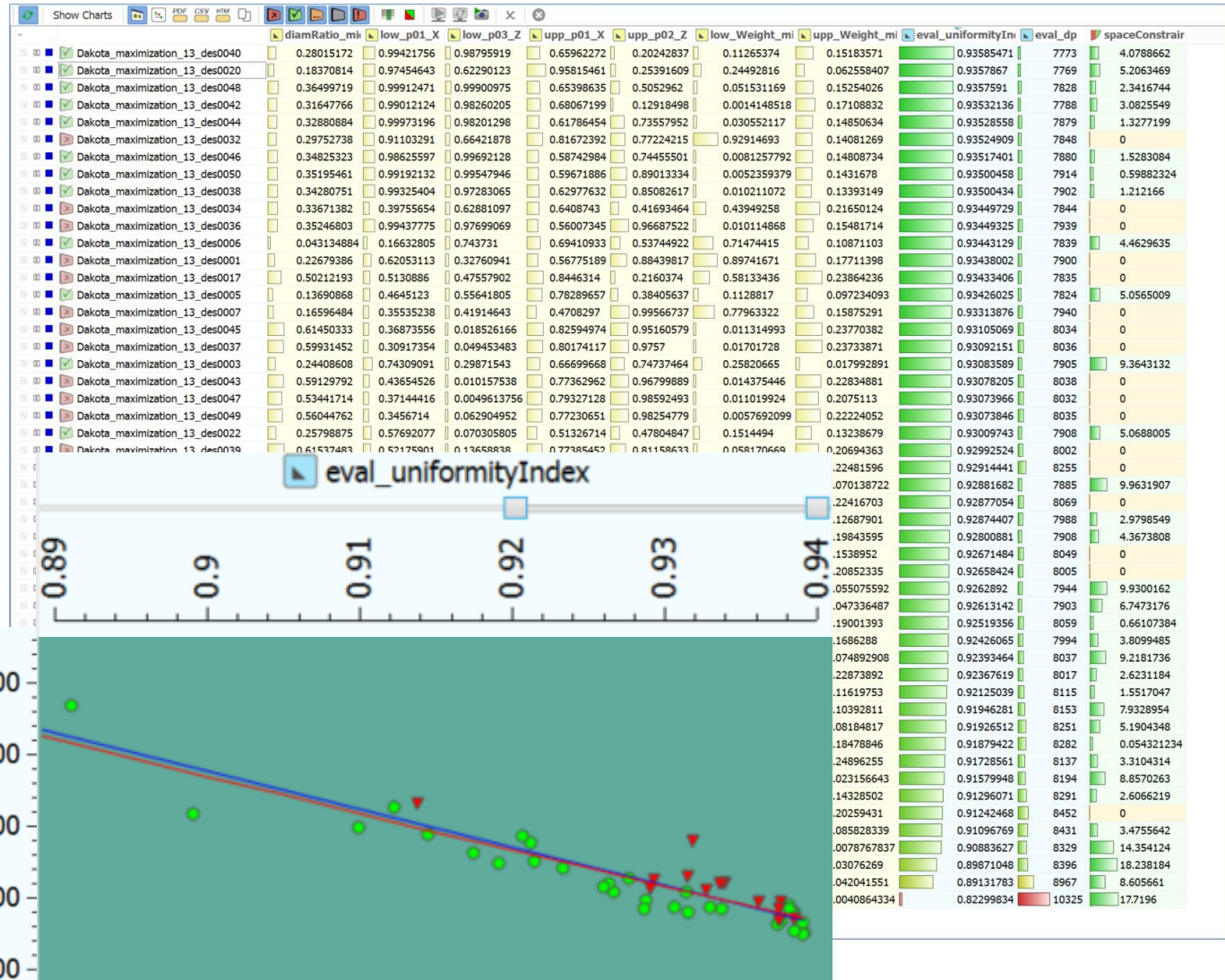
The screenshot shows the FDakota software interface for a Dakota_maximization optimization. The window title is 'FDakota: Dakota_maximization'. The main area is divided into several sections:

- General:** Method is set to 'MOGA Global Optimization Efficient'. Iterations are 10, and Solutions Considered are 3. The 'Use Result Pool for Initial Surrogate Model' checkbox is checked. Initial Samples are 20.
- Design Pre/Postprocessing:** Screenshots are set to 'pics04'.
- Run Pre/Postprocessing:** (Empty section)
- Design Variables:** A table with 8 rows and 6 columns: Design Variable, Lower, Value, Upper, Active, and a status column with a red 'X' icon. All variables are active and have a red 'X' in the status column.
- Evaluations:** A table with 2 rows and 3 columns: Evaluation, Objective, and a status column with a red 'X' icon. The first evaluation is 'eval_uniformityIndex' and is active.
- Constraints:** A table with 2 rows and 3 columns: Constraint, Considered, and a status column with a red 'X' icon. The first constraint is 'spaceConstraint' and is active.

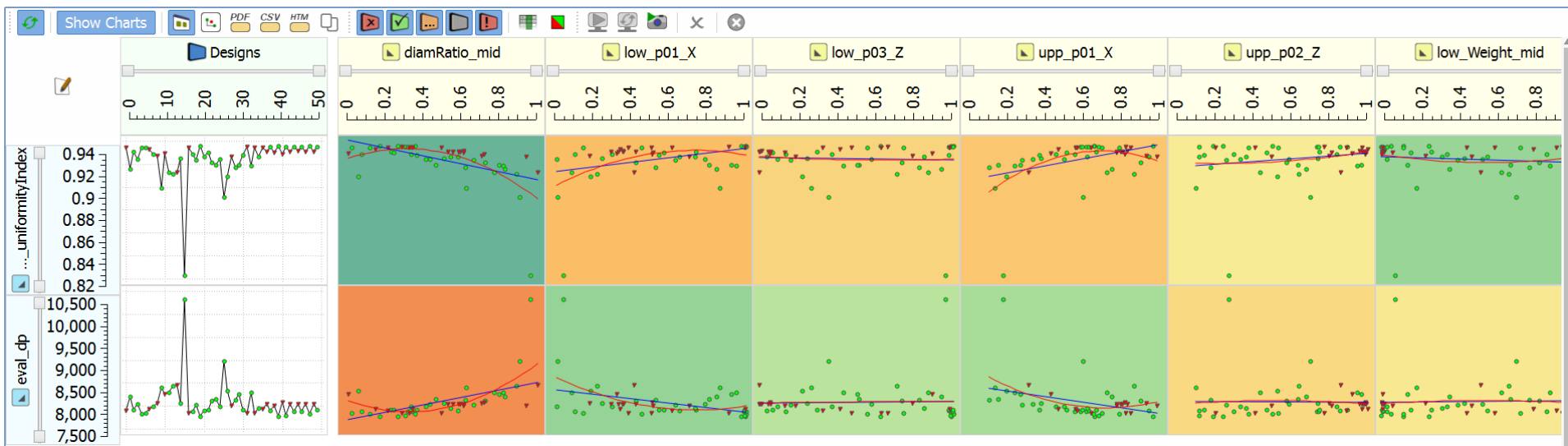


Catalytic Converter – Result evaluation

- 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

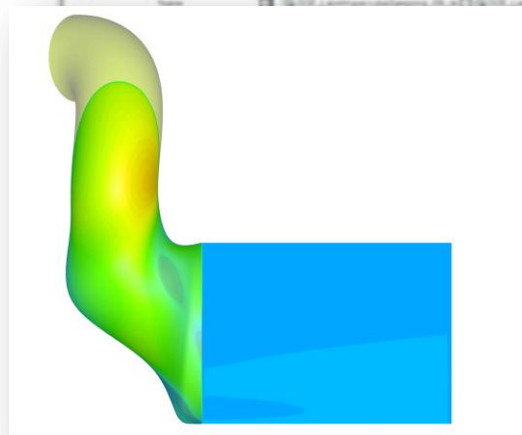
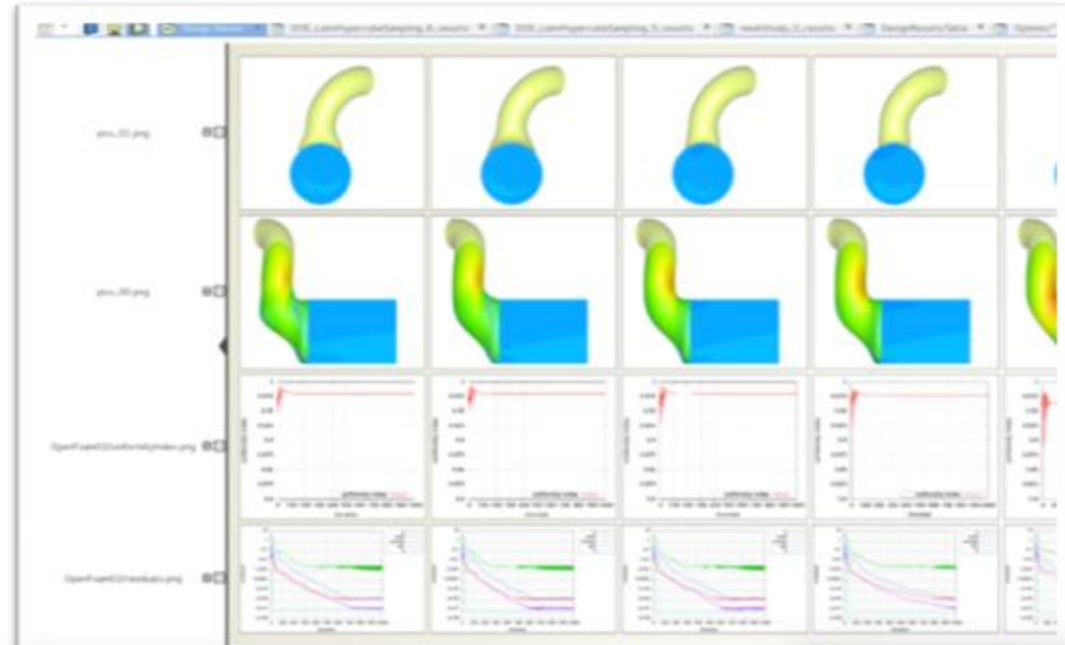


- Charts give a good overview, which design variables have the largest impact on the objective
- First 35 designs with LHS to create a surrogate model
- Reached nearly the maximum uniformity index with the first evaluated design of the surrogate model

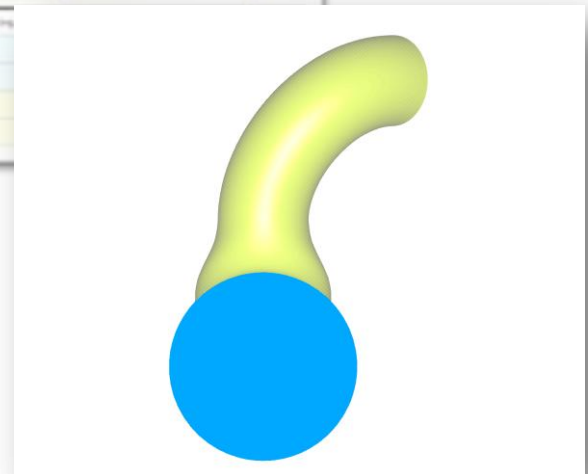


Catalytic Converter – Comparing Designs

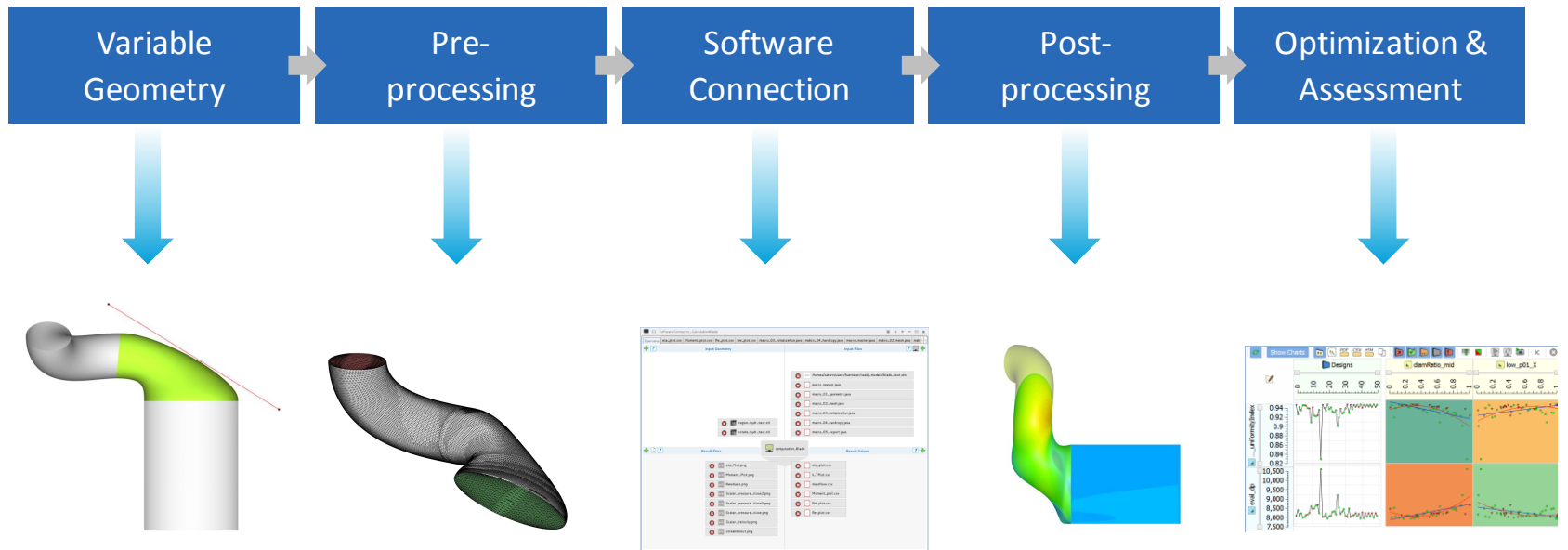
- Design viewer to compare the designs
- Understand the effects of the design variables on the flow field
- Include residuals and other plots, to make sure that the design has converge
- Create animations



0.019	0.76
4.75e+02	4.8e+02
0.235	0.466
0.756	0.933



Conclusion



- Variable geometry
- Including space constraints

- High quality STL with specific boundary patches

- Grid Pro
- OpenFoam
- Gnuplot

- Visualizing flow field

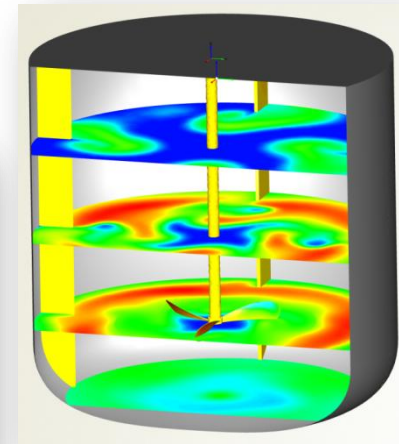
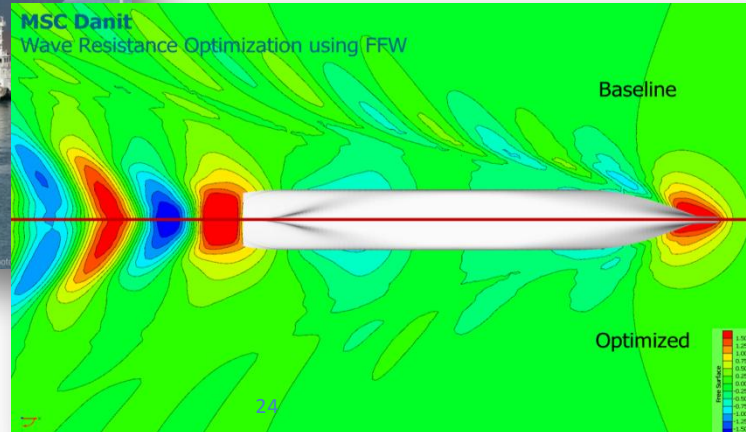
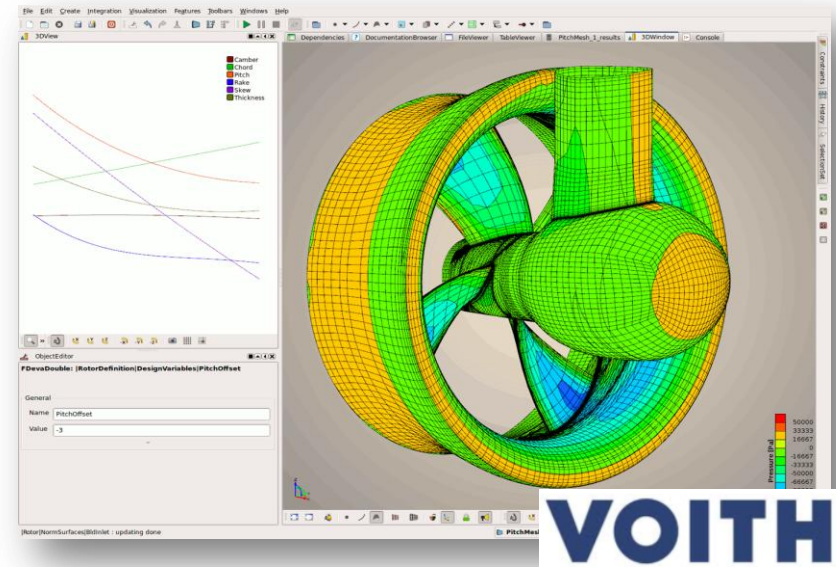
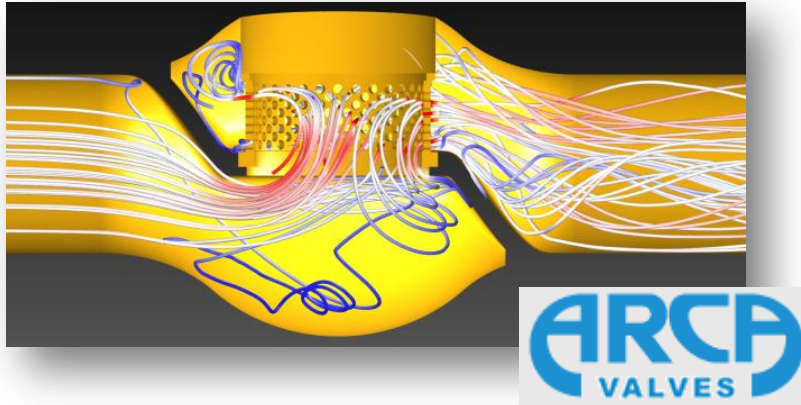
- Optimization using Dakota Algorithms
- Analyzing results



Further examples



Further Examples



CAESES, Your Upfront CAE System for Shape Optimization

Design • Solve • Optimize

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