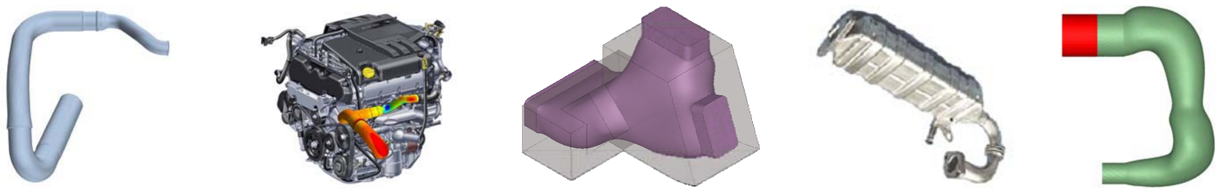

An Efficient Approach for CFD Topology Optimization of interior flows

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Agenda

- Introduction of FE-DESIGN
- Overview of Optimization Concepts
  - Parametric Optimization
  - Topology Optimization
- Application Examples
  - Automotive HVAC Flow Splitter
  - Intercooler Intake Hose
  - Exhaust Gas Recirculation Cooler
- Summary

FE-DESIGN –
the optimization company

3rd ANSA & mETA International Conference
September 9-11, 2009, Porto Carras

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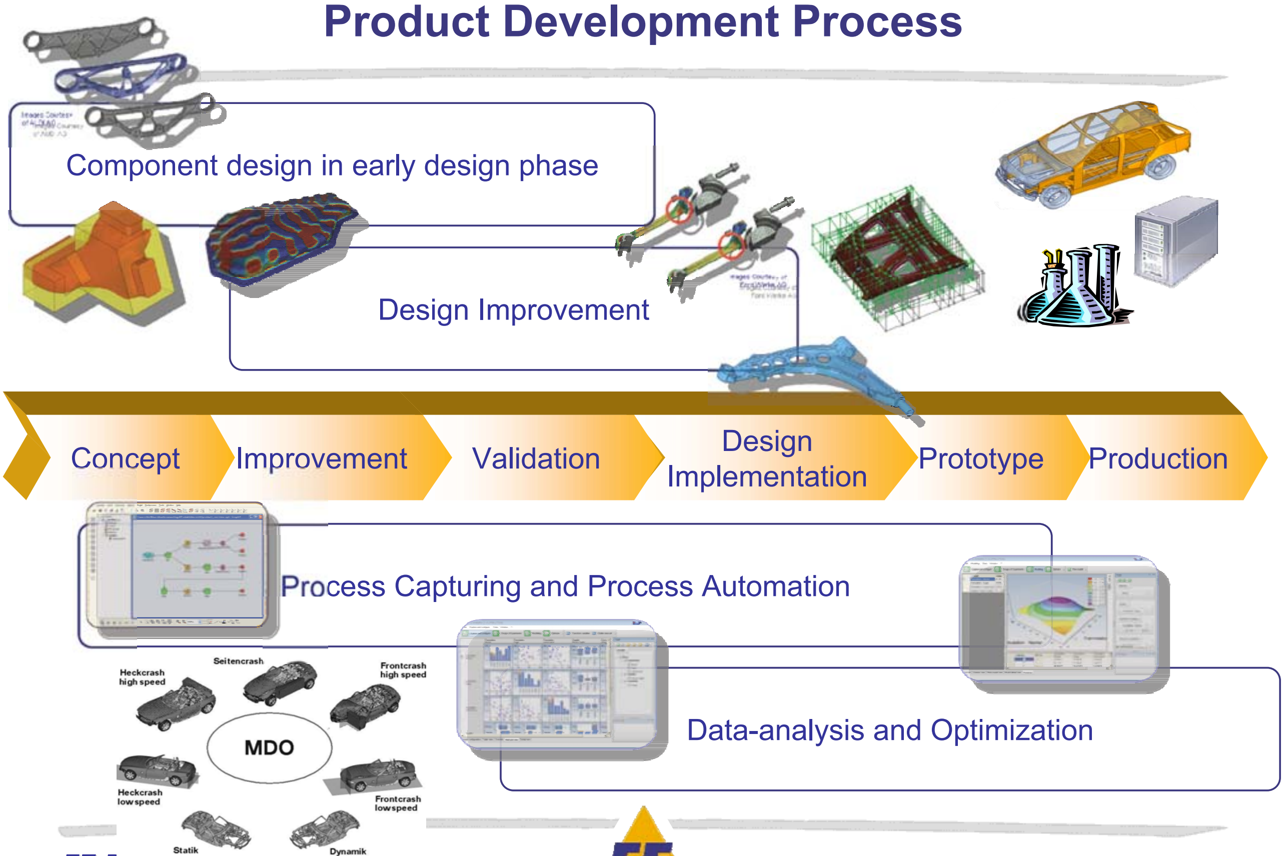
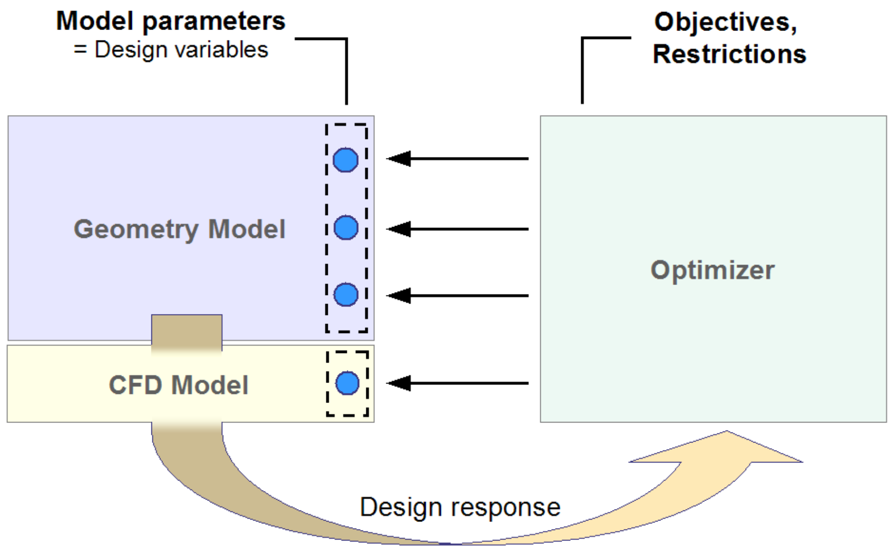
FE-DESIGN customers

Solutions Supporting the Product Development Process

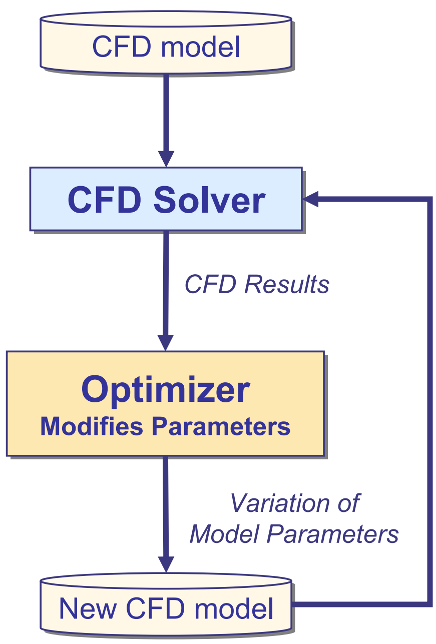


Introduction to Parametric Optimization



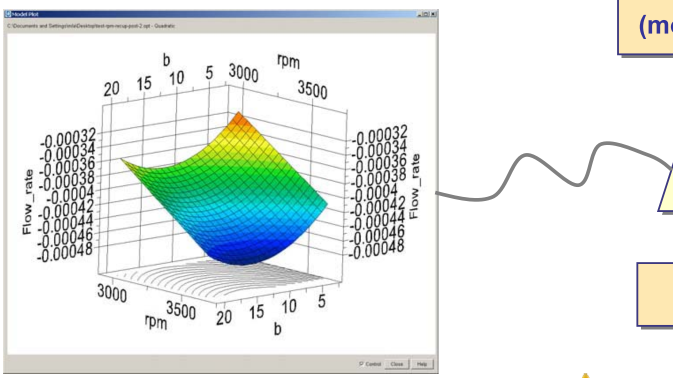
- Restricted solution space
- Comparative high computational effort
- No restrictions with respect to the objective functions

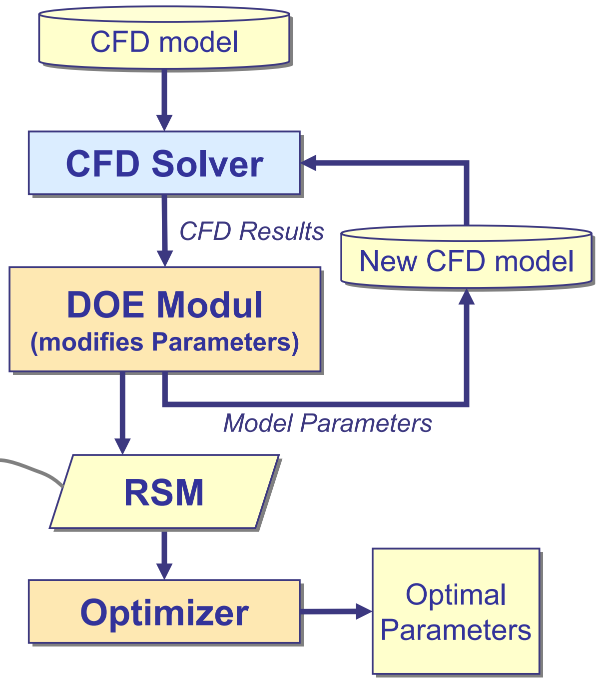
Workflow of Parametric Optimization based on CFD Simulations



Workflow of Parametric Optimization based on Response Surface Models

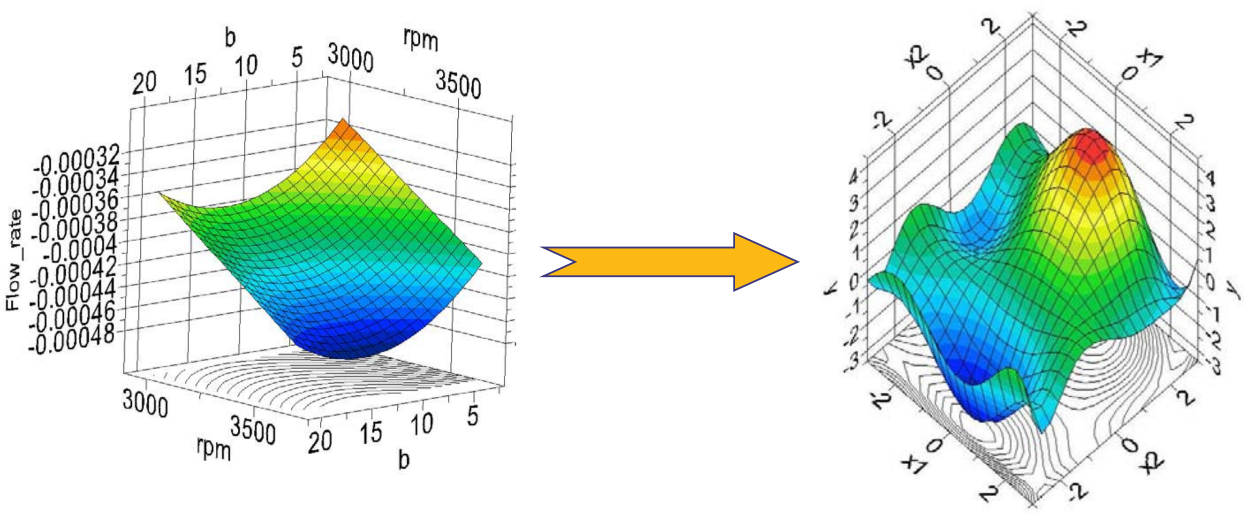
- Alternative:
  - "Design of experiments" (DOE)
  - "Response surface model" (RSM)
  - Optimization based on RSM



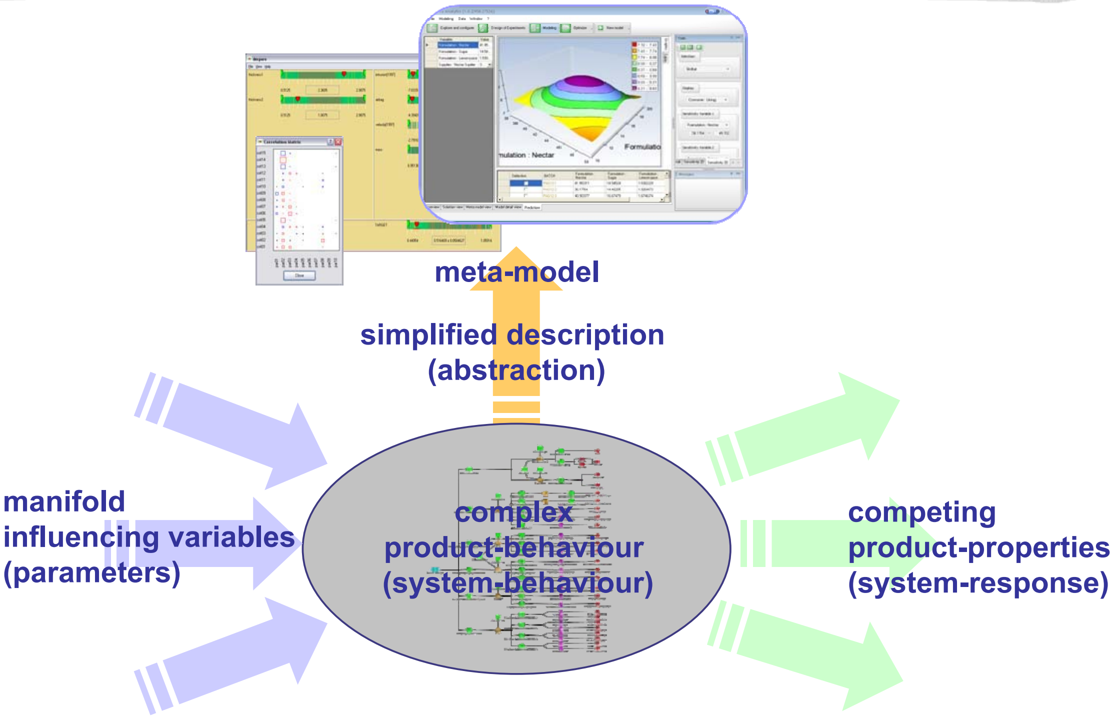


Real Life is Highly Nonlinear

Conventional RSM **Advanced Meta-Models**



Advanced Meta-Models are needed



Meta-Models
Challenges and Opportunities

- **Conventional RSM („Response Surface Model“)**
  - High number of design variables and complex system responses require many simulations
  - Local error estimation of the surrogate model is not supported

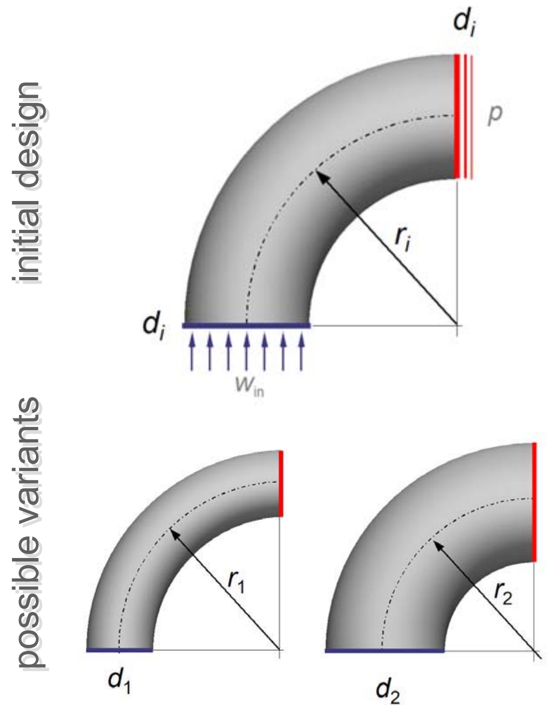
→ Optimization on conventional RSM is expensive and questionable

Meta-Models
Challenges and Opportunities

- **Advanced Meta-Models**
  - Local error estimation gives hints where to refine the model with additional training data
  - Automated model update procedures are supported
  - This assures reliable and verified optimization results
  - Advanced meta-modeling techniques are provided as a one-click solution with an integrated optimization algorithm
  - There is no expert knowledge needed, since the entire process of model selection and generation is completely automated
  - The advanced methods are extremely flexible due to large diversity of integrated model formulations

➔ **Advanced Meta-Models are economically and give a deep insight into product behaviour**

Optimization of CAD-Parameters



- Optimization problem is based on a parameterized Geometry (CAD, Preprocessor, ...)
- Geometric Variation is achieved by reconstruction of an individual geometry based on a given set of parameters
- Geometry parameters are varied automatically within a given range (optional)

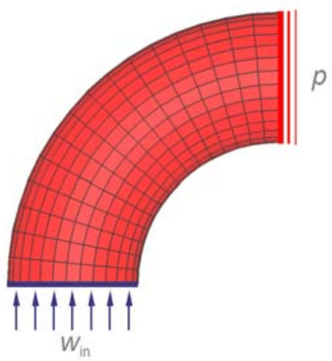
Pros & Cons for Optimization of CAD-Parameters

- **Pros & Cons**
  - Optimization problem has to be parameterized
  - Restricted solution space
  - Identification of relevant influencing variables is not always easy
  - Comparative high computational effort

  - Easy export of optimization results to CAD
  - Many different techniques and algorithms are available
  - No restrictions with respect to the objective function
  - “Straight-forward approach”

Optimization of Morphing-Parameters

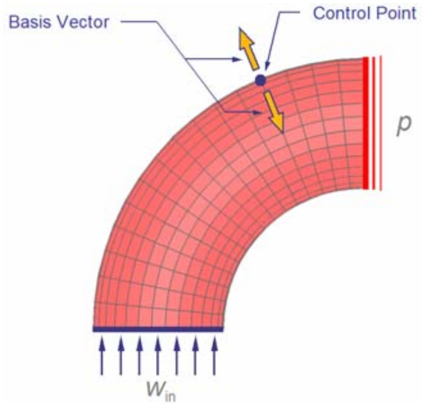
initial design



- Optimization problem is based on a meshed Geometry

Optimization of Morphing-Parameters

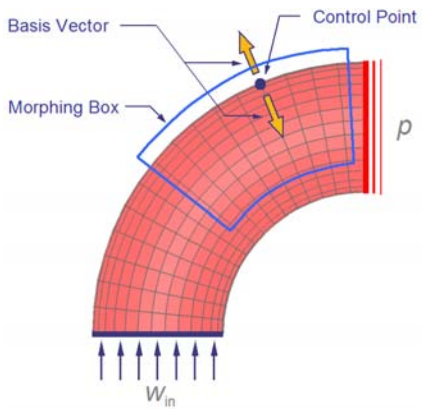
initial design



- Optimization problem is based on a meshed Geometry
- A number of Control Points and Basis Vectors are defined

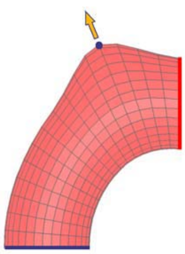
Optimization of Morphing-Parameters

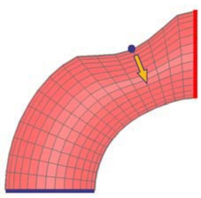
initial design



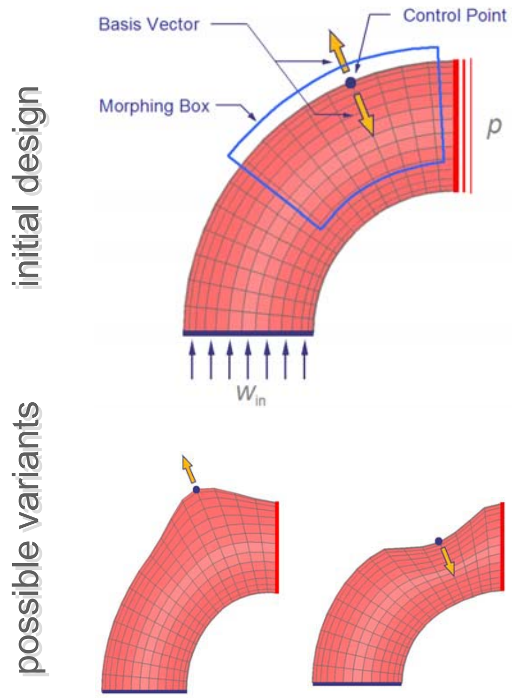
- Optimization problem is based on a meshed Geometry
- A number of Control Points and Basis Vectors are defined
- Geometric Variation is achieved by Mesh deformation within defined Morphing boxes

possible variants

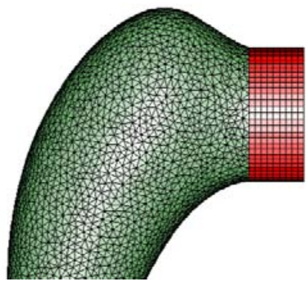




Optimization of Morphing-Parameters



- Optimization problem is based on a meshed Geometry
- A number of Control Points and Basis Vectors are defined
- Geometric Variation is achieved by Mesh deformation within defined Morphing boxes



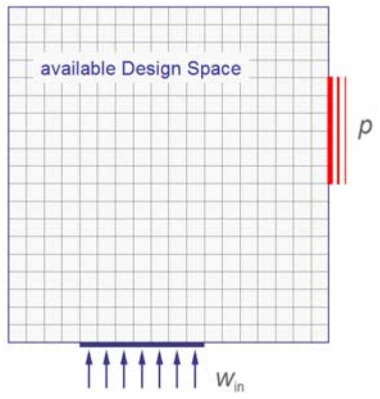
Pros & Cons for Optimization of Morphing-Parameters

- **Pros & Cons**
  - Reconstruction and/or export of optimization results to CAD is not that easy
  - Morphing setup may be difficult, especially if nothing is known about the solution

  - More “creative freedom” compared to CAD-Parameter
  - **Complex Shape deformation possible with few parameters**
  - Larger solution space compared to CAD-Parameters
  - **No restrictions apply with respect to the objective function**
  - “Unconventional” Designs possible (Innovation!)

Nonparametric Topology Optimization

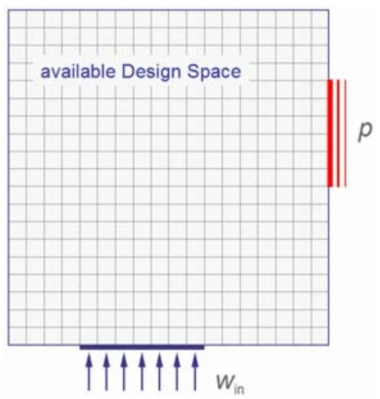
initial design



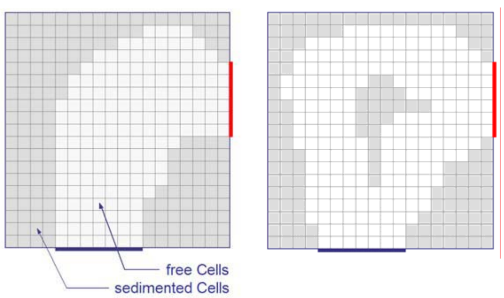
- Optimization problem is based on the (meshed) available Design Space

Introduction: Topology Optimization

initial design

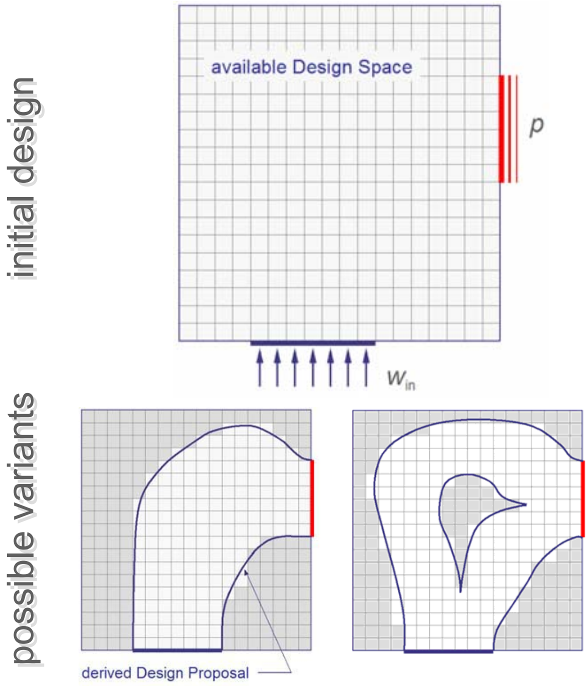


possible variants



- Optimization problem is based on the (meshed) available Design Space
- Geometric Variation is achieved by sedimenting individual cells

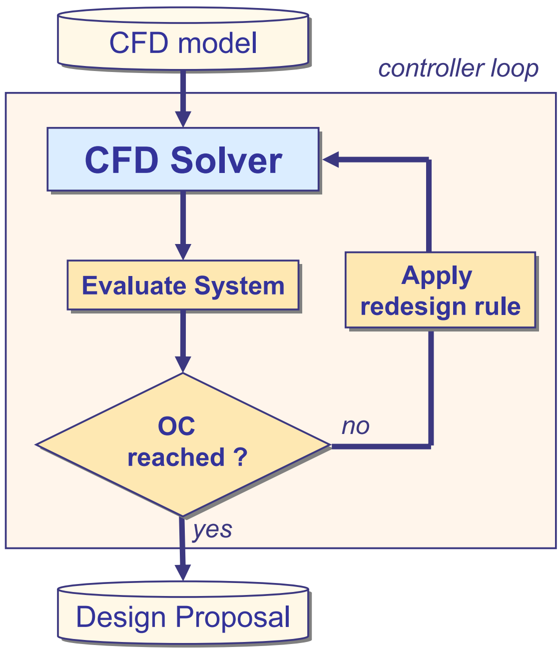
Introduction: Topology Optimization



- Optimization problem is based on the (meshed) available Design Space
- Geometric Variation is achieved by sedimenting individual cells
- An individual design proposal can be derived based on the collectivity of all free (= non-sedimented) cells
- General optimization schemes are not feasible
- **Optimality Criteria** (OC) based schemes

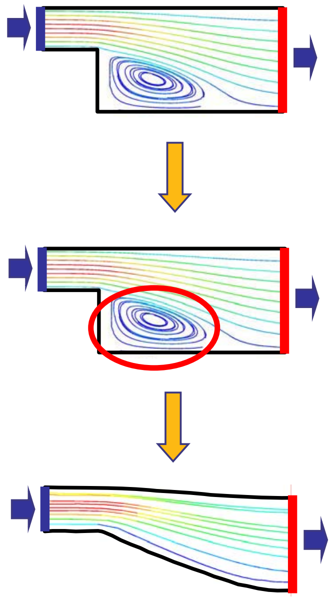
OC-based Topology Optimization

- **O**ptimality **C**riteria methods can be seen as an "empirical approach"
- Consist of "knowledge" about properties of the optimum and a redesign rule (Controller-feedback approach)
- Are widely and successfully used in structural mechanics ("homogenization methods")

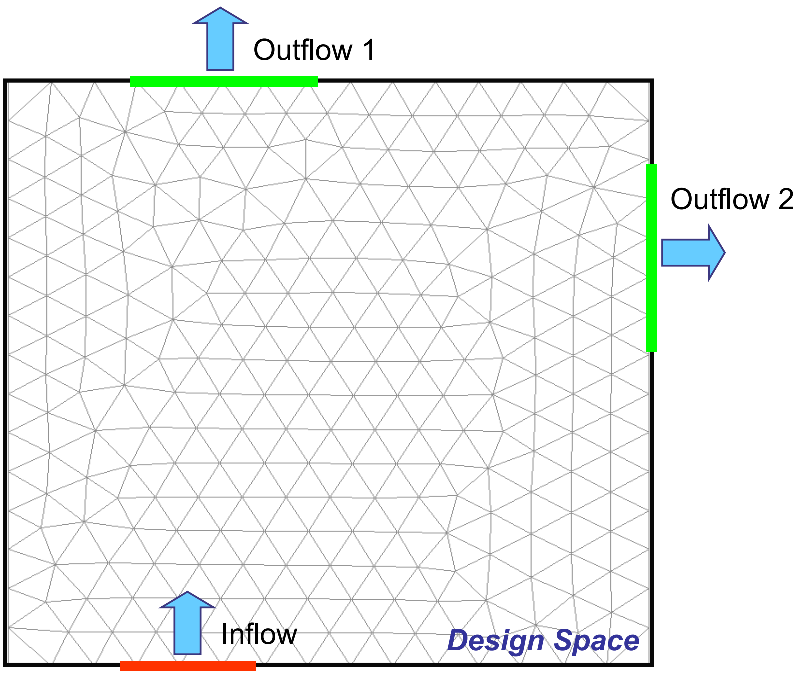


OC-based Topology Optimization: Example

- Example: The Optimality Criterium is to avoid flow recirculation
- Redesign Rule: Elimination of local backflow and recirculation by blocking out of backflow areas
- An achieved consequence is (for many technical flows) a reduction of pressure drop

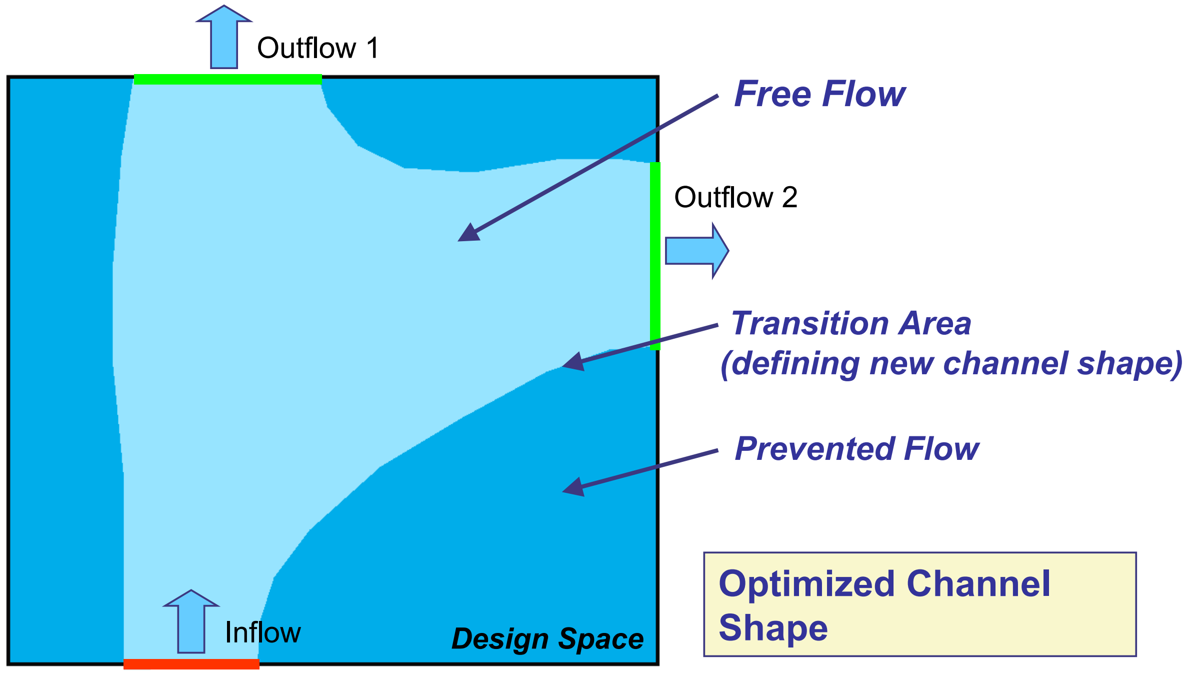


Topology optimization with TOSCA Fluid



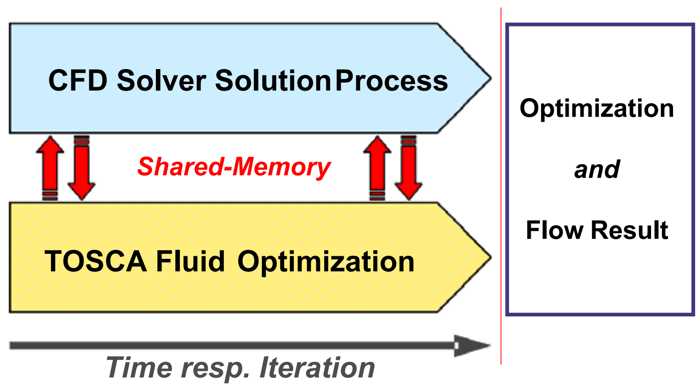
- **Define the Design Space (e.g. CAD)**
- **Meshing as usual**
- **Define your Boundary Conditions**
- **Run the Optimization**

Topology optimization with TOSCA Fluid



Topology optimization with TOSCA Fluid

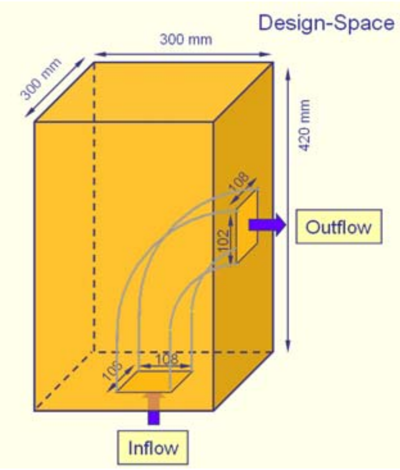
- **Direct run time communication with the CFD solver**
- **Only one single CFD solver-run for complete optimization process**

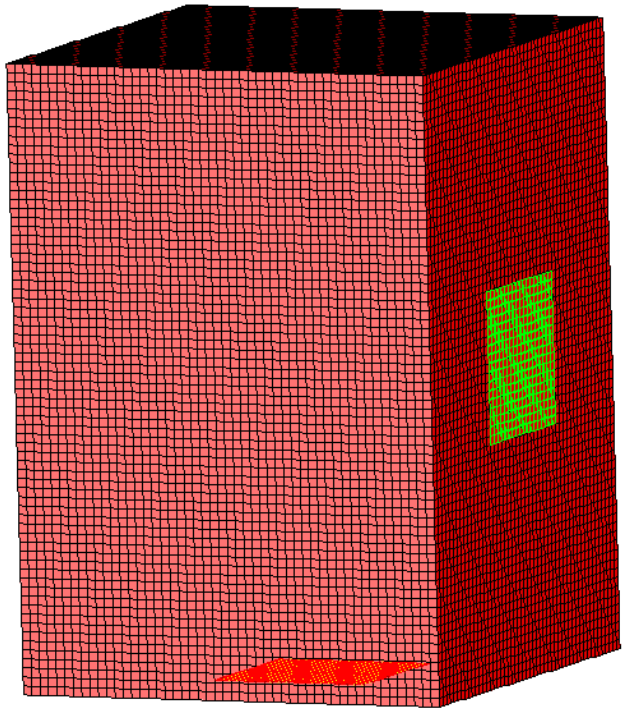


→ suitable for large real world applications

Topology optimization with TOSCA Fluid

Example Animation:
Current optimzation solution during convergence process

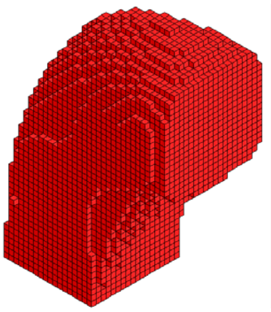


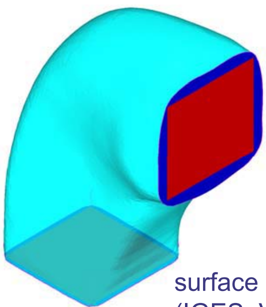


TOSCA Fluid – Process Integration

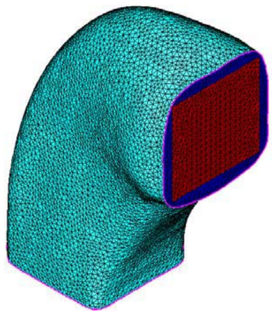
Result smoothing with TOSCA Fluid.smooth:

Topology Optimization	Iso surface calculation, smoothing, data reduction	Derived Verification/ CAD model
TOSCA fluid →	TOSCA smooth →	**Verification/CAD**

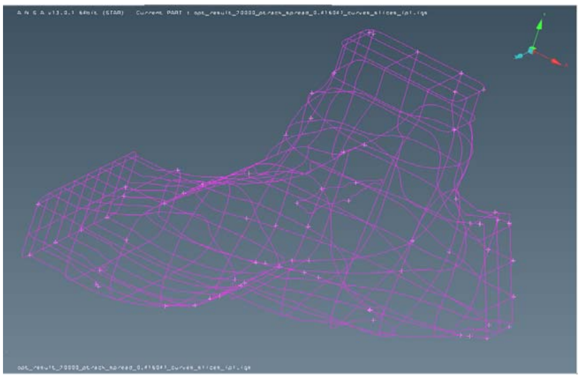




surface model
(IGES, VRML, STL)

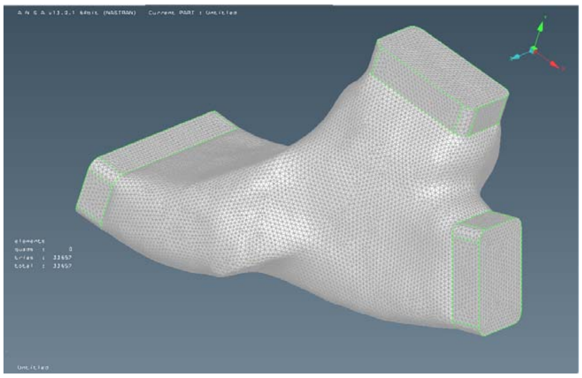


TOSCA Fluid – Process Integration



Result Example for 2D-Cuts („Slices“)

Result Example for 3D-STL-Surface and automatic reconstruction in ANSA



Topology Optimization

- **Pros & Cons**
  - Design-Reconstruction of optimization results is necessary (CAD)
  - Limited number of objective functions
  - Consideration of design space constraints and/or manufacturing restriction is straight forward
  - Easy setup and low modelling effort, no definition of CAD parameters, shape functions, morphing boxes, …
  - Very fast and effective (OC-based)
  - Maximum “freedom” within the design space to find a solution proposal
  - “Unconventional” Designs possible (Innovation!)
  - Optimization can be used as an initial design tool

Agenda

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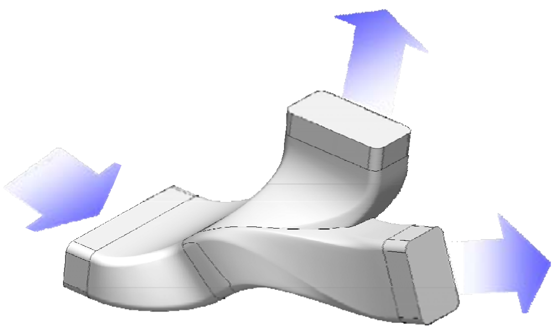
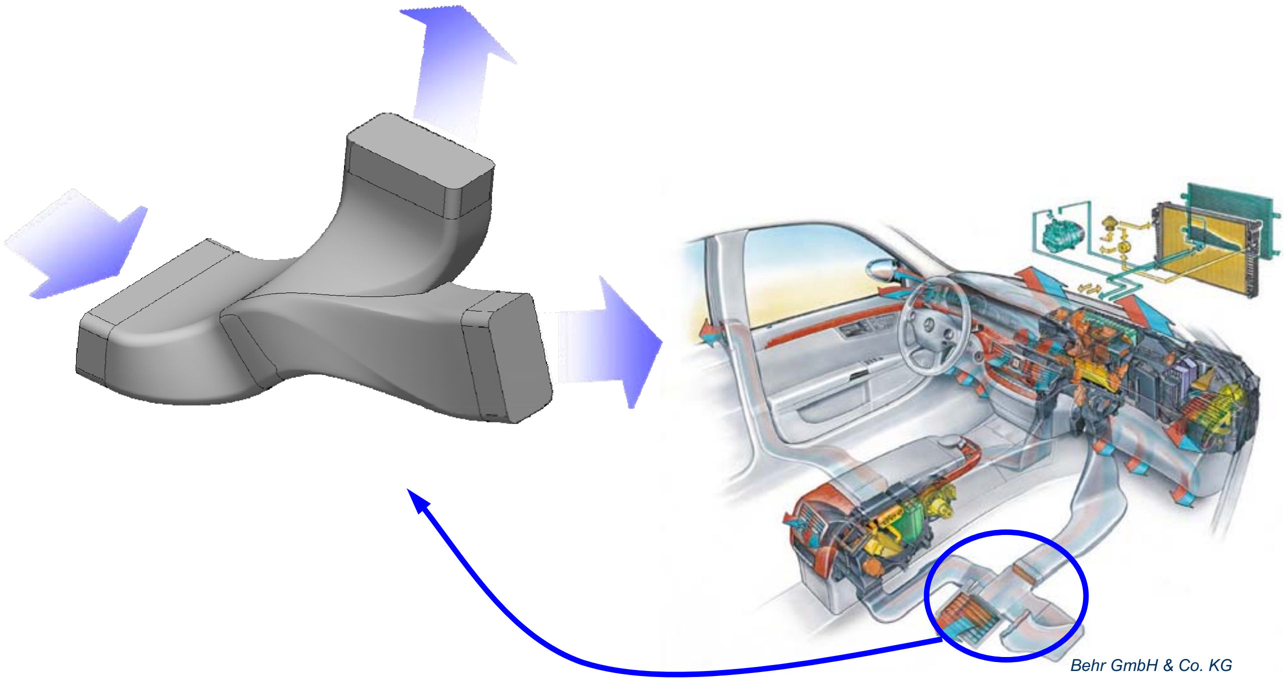
  - Automotive HVAC Flow Splitter
  - Intercooler Intake Hose
  - Exhaust Gas Recirculation Cooler
- Summary

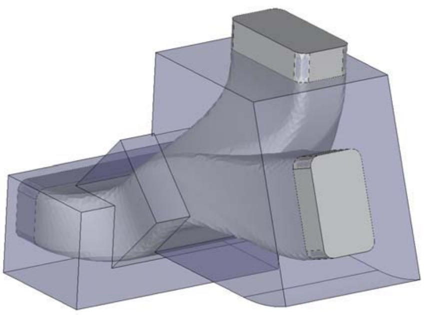
Application Example 1: Automotive HVAC Flow Splitter Manifold



HVAC Flow Splitter Manifold (generic)



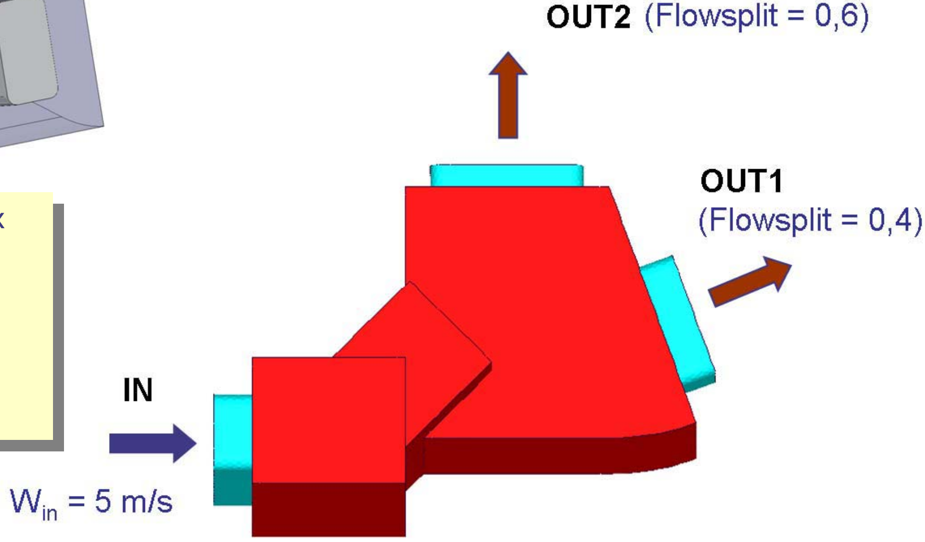
HVAC Flow Splitter
Design Space, physical models and Boundary Cond.



Standard Duct and available Design Space

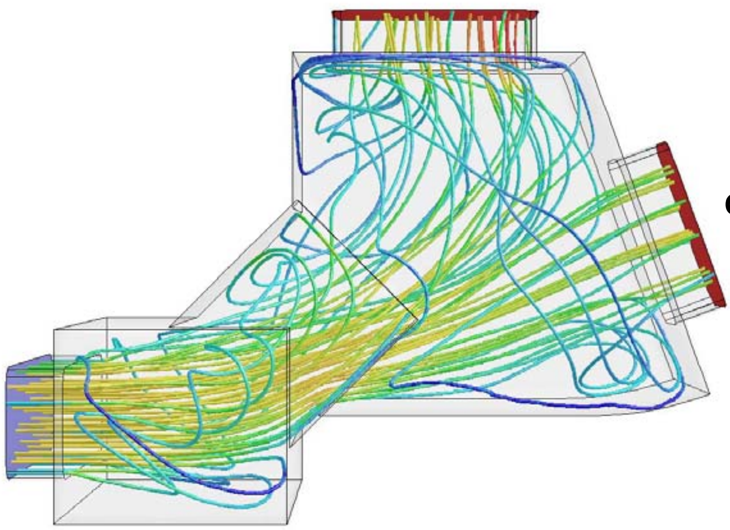
- Objective: Design Proposal with low pressure drop

- Dimensions = (0,2 x 0,14 x 0,12) m^3
- Fluid = AIR
- Objective: Design Proposal with low pressure drop



HVAC Flow Splitter

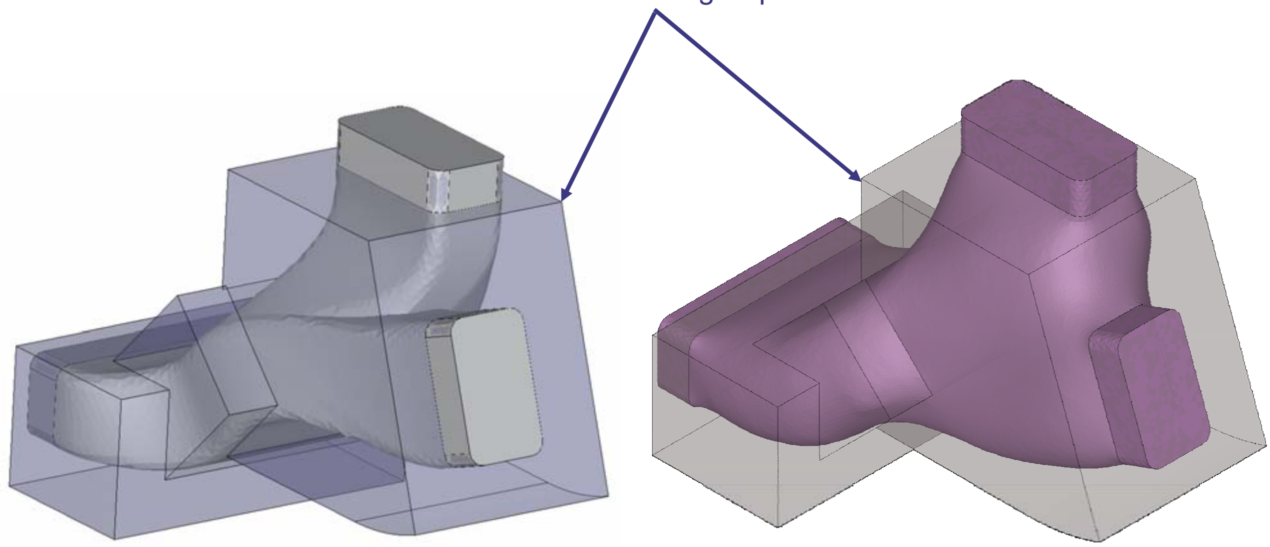
Flow Design Space: Pathline and Pressure Drop at 5 m/s



HVAC Flow Splitter

Results: Optimized Geometry (Design Proposal)

Available Design Space

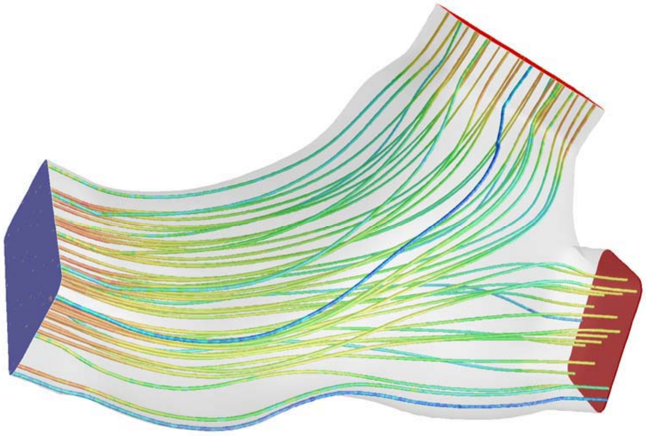


Original Part

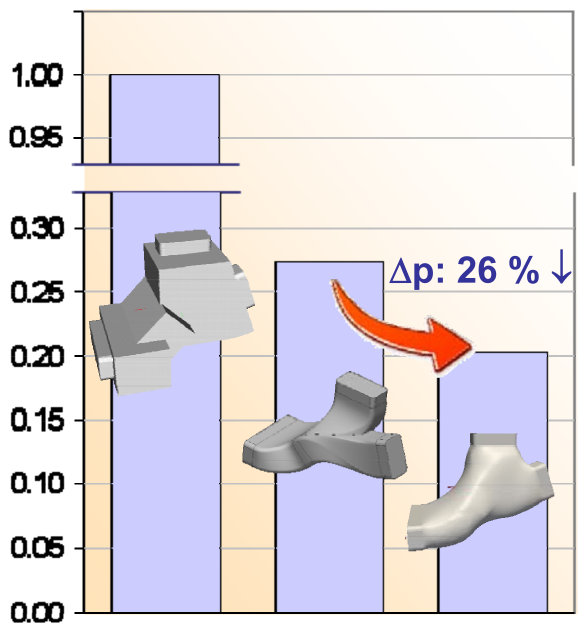
Optimized Design Proposal

HVAC Flow Splitter

Results: Optimized Geometry, Pathline and Pressure Drop at 5 m/s



Pathlines coloured with velocity magnitude

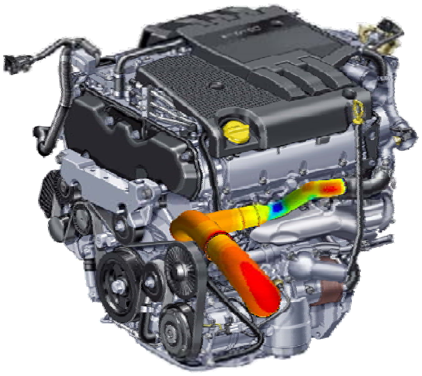


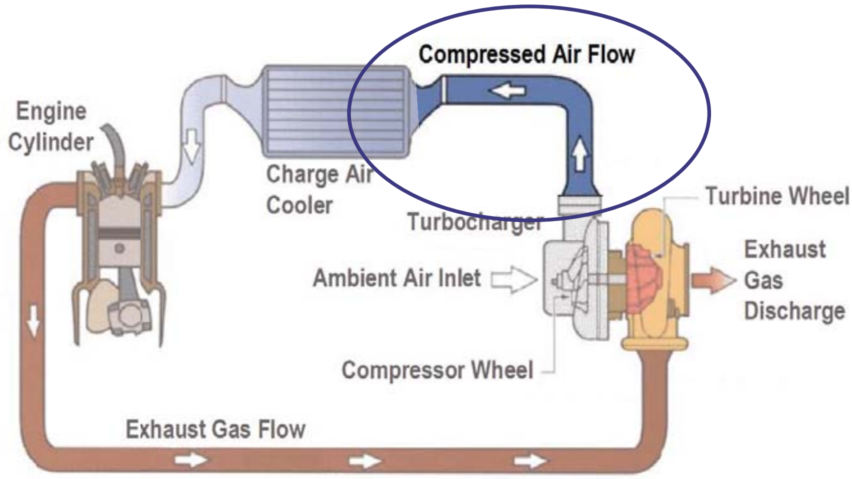
Application Example 2: CFD Topology Optimization of an existing Intercooler Intake Hose

OPEL

GM

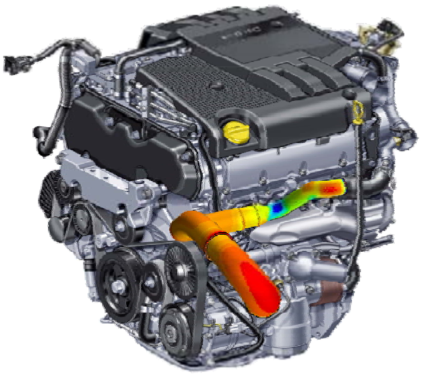
Introduction

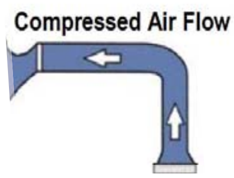


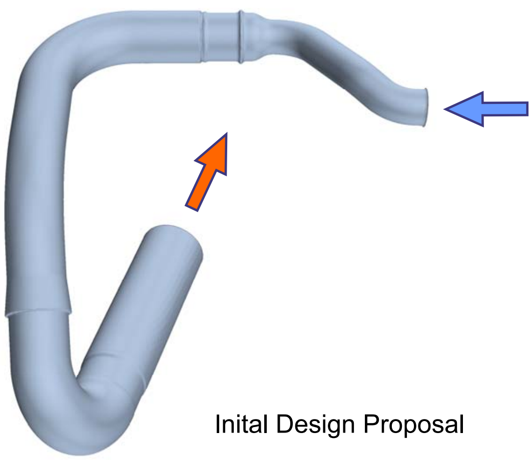


Turbocharger System

Introduction



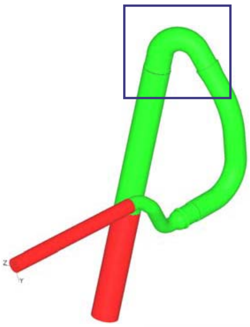


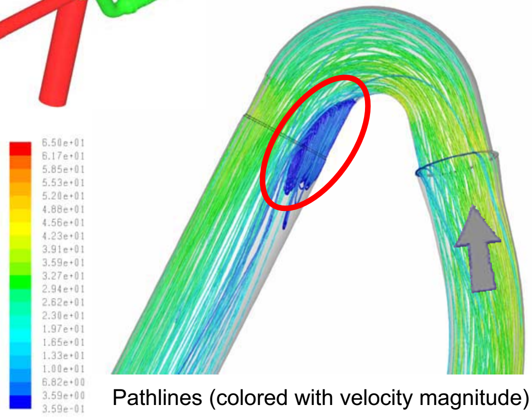


Inital Design Proposal

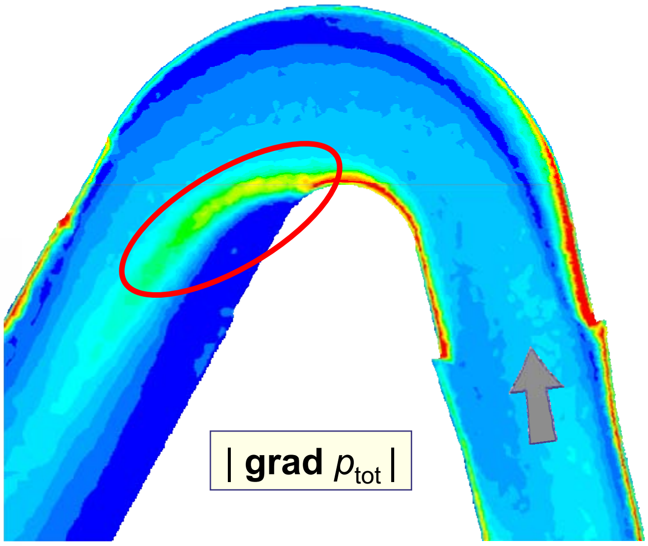
Flow Performance of the Inital Design Proposal (2)

- exemplary local flow separation





Pathlines (colored with velocity magnitude)

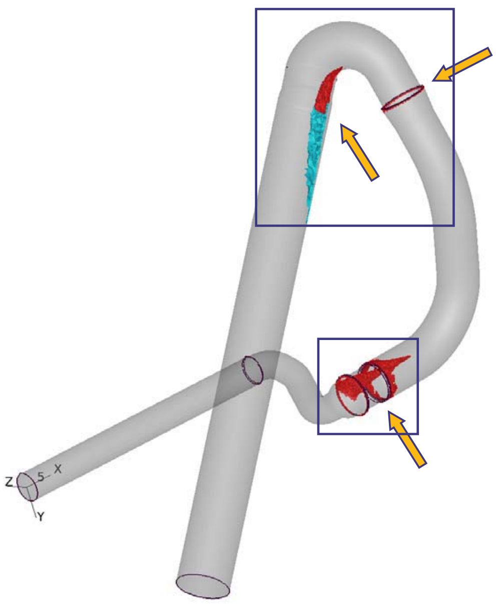


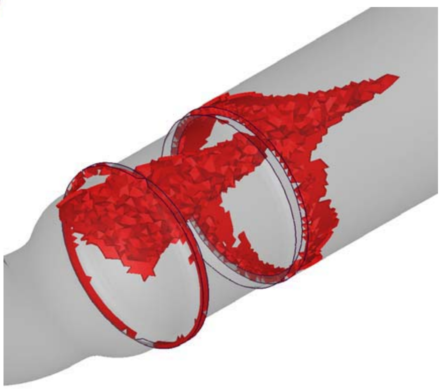
Contours of Total Pressure Gradient (Magnitude), pa/m

→ dissipative flow separation and recirculation zones

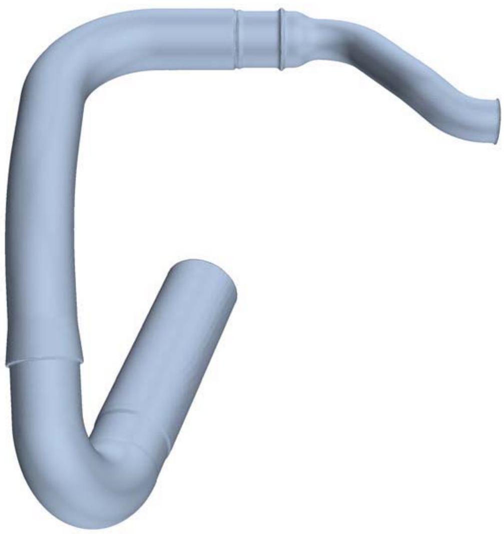
Optimization Results (1)

- Sedimented Zones

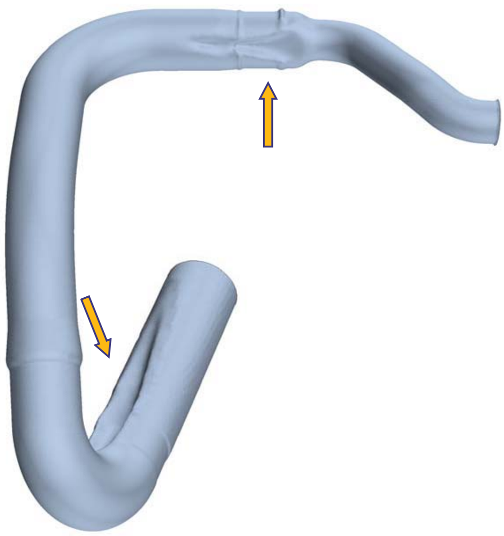




Result Analysis: Geometry



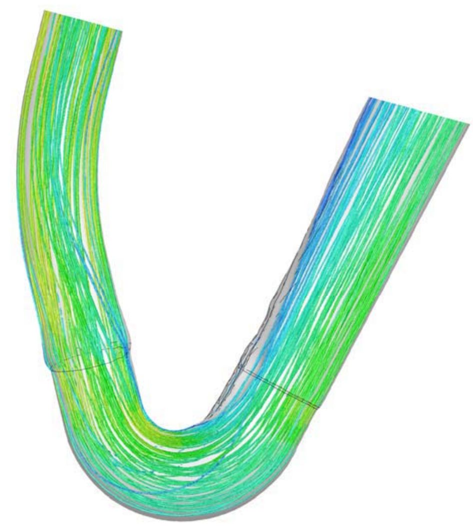
Inital Design



optimized Design

Result Analysis: Pathlines (detail)
(coloured with Velocity Magnitude)

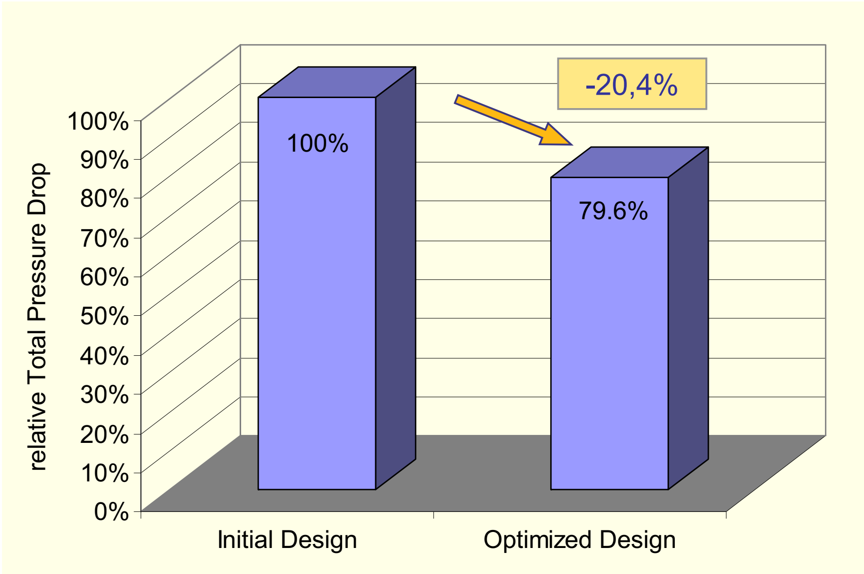
Inital Design



optimized Design

Result Analysis: Total Pressure Drop

- Comparison of the Total Pressure Drop



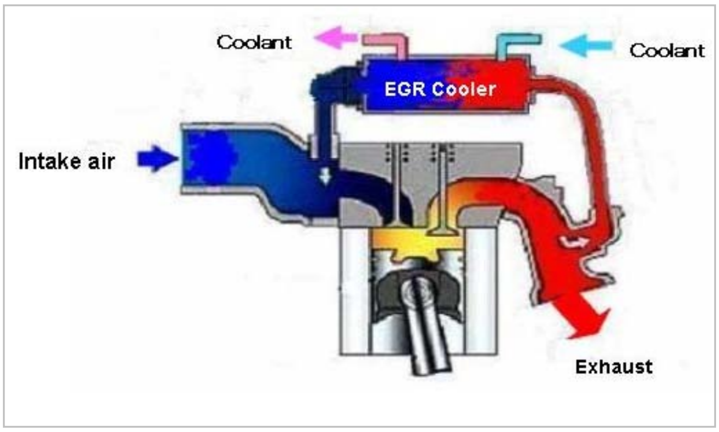
Application Example 3: Exhaust Gas Recirculation Cooler

FE-DESIGN –
the optimization company

3rd ANSA & mETA International Conference
September 9-11, 2009, Porto Carras

EGR Cooler

Exhaust Gas Recirculation Systems → NOx-Abatement for internal combustion engines

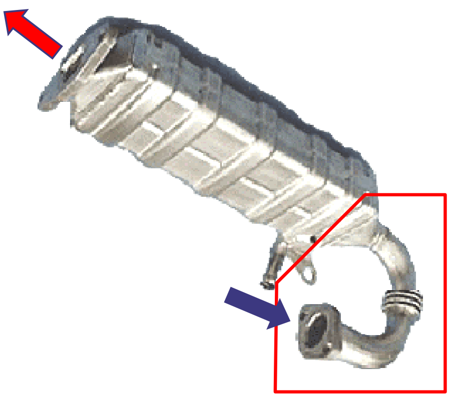


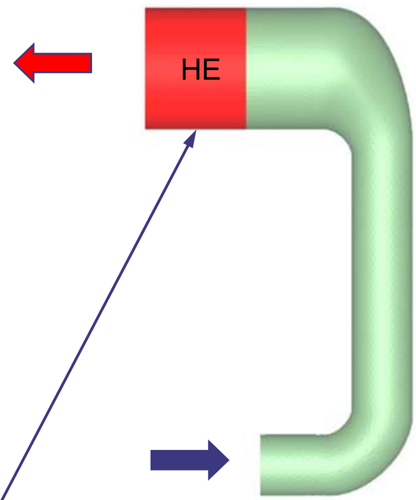
Functional diagramm

Example Assembly

EGR Cooler
existing Design

- Simplified generic model

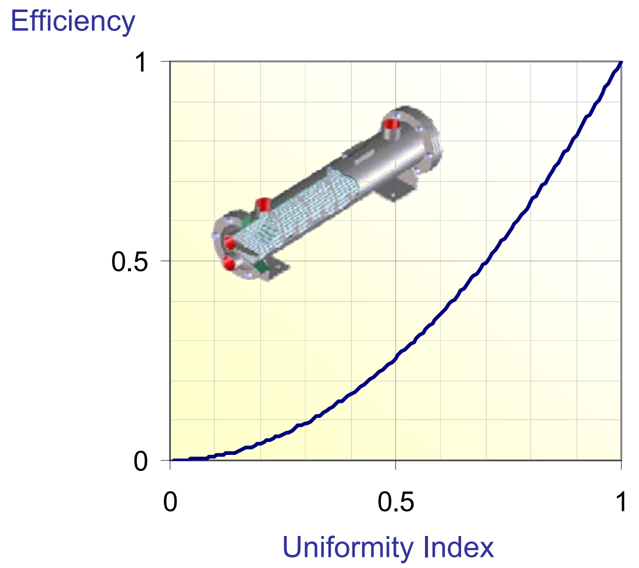


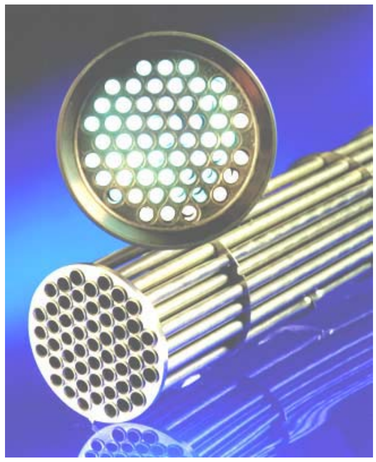


Hydraulic Heat Exchanger model as "porous zone" with preferential flow direction along the main flow axis

Air (w_{in} = 3 m/s)

EGR Cooler
Heat Exchanger Efficiency



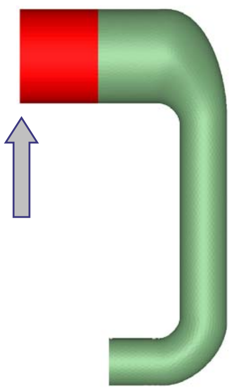


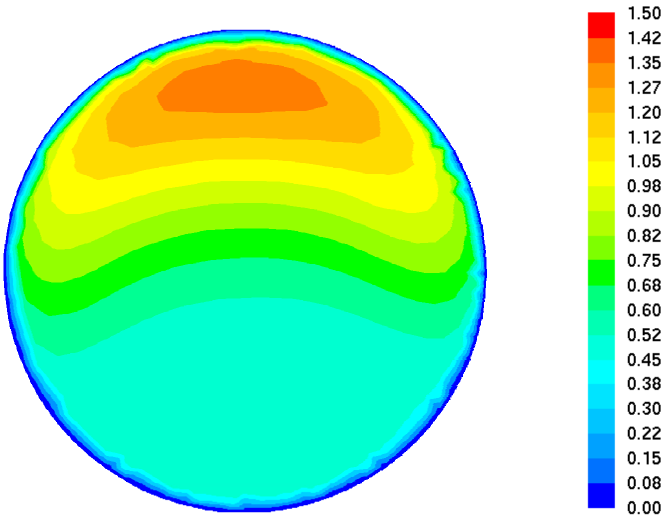
EGR Cooler
Results for existing Designs

- “Standarddesign 1”

Δp_{tot} = 9,5 pa

Uniformity Index = 0,81





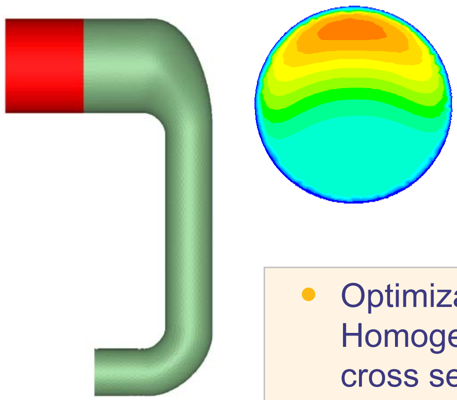
Contours of Normal Velocity Magnitude at Outlet, m/s

EGR Cooler
Results for existing Designs (2)

- "Standarddesign 1"

Δp_{tot} = 9,5 pa

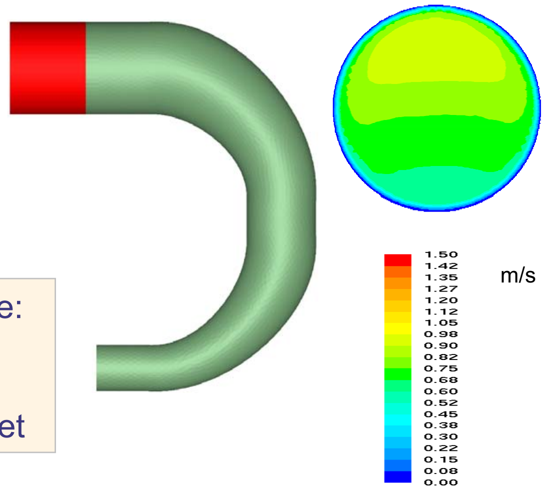
Uniformity Index = 0,81



- "Standarddesign 2"

Δp_{tot} = 6,4 pa

Uniformity Index = 0,93



- Optimization Objective: Homogenization of cross section velocity distribution at the outlet

EGR Cooler
Design Space

- Used Designspace and Model settings

Boundary Conditions:

Inflow = PRESSURE

Outflow = INLET, w_{out} = -3 m/s

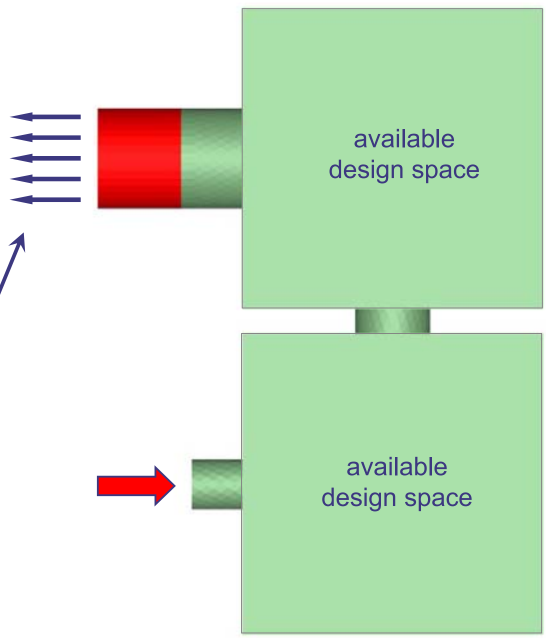
Fluid AIR

Isothermal, turbulent, stationary, incompressibel

η = 1.81 · 10^{-5} kg/(m·s)

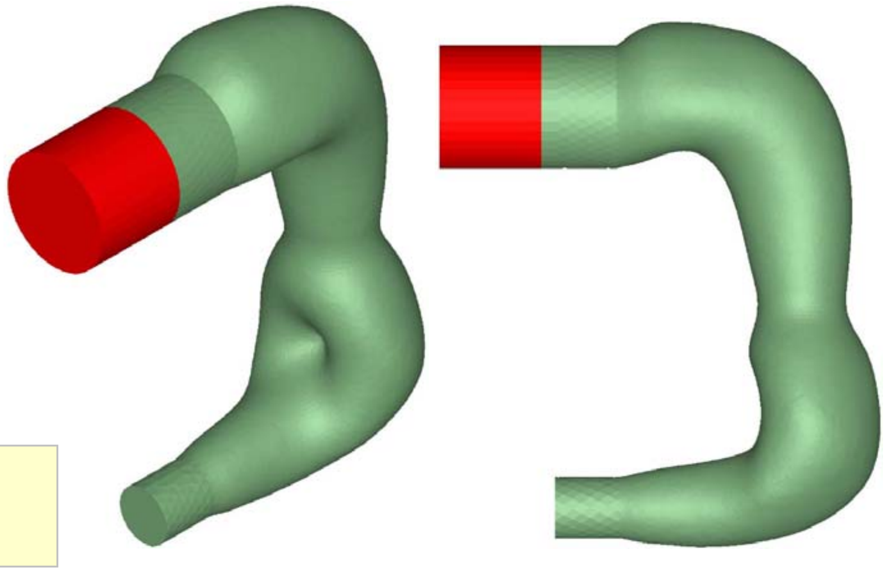
ρ = 1.205 kg/m^3

TOSCA Fluid Version 1.0.0 beta



EGR Cooler
Results: Optimized Design

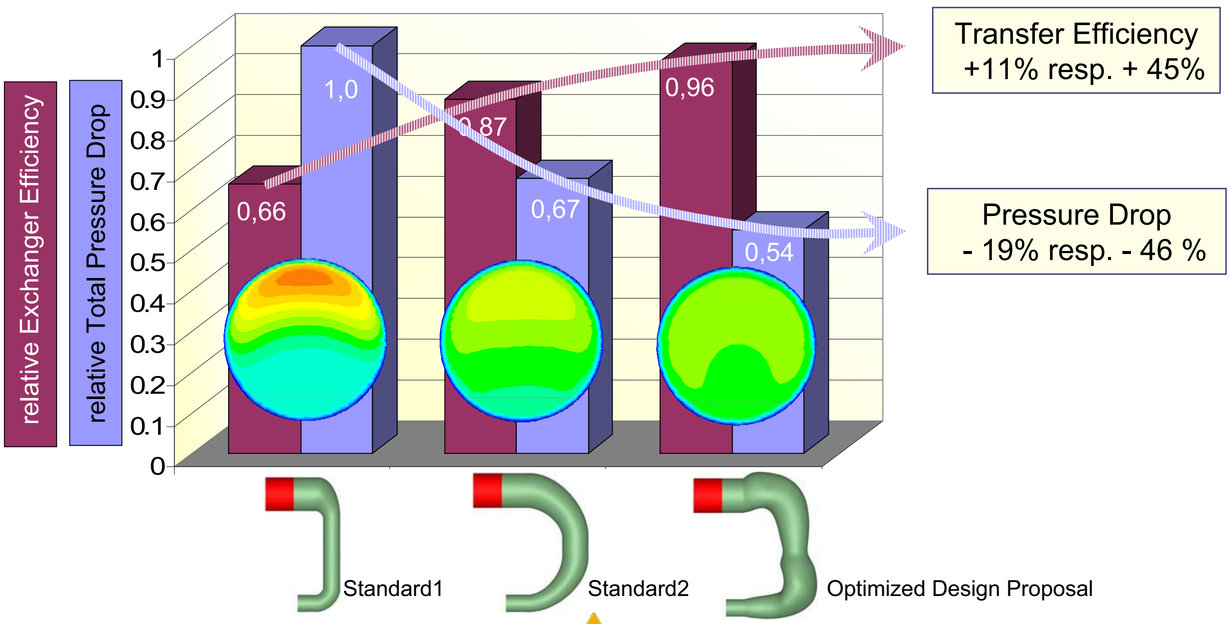
- Extracted New Design Proposal



Tosca Fluid Version 1.0.0 Beta
Backflow Tolerance 0.5
Extraktion: velocity absolute
velocity iso surface 0.25 m/s

EGR Cooler: Comparison of Designs

- Cross sectional velocity uniformity and heat exchanger efficiency



Summary

- Topology Optimization of arbitrary interior flow domains using Optimality Criteria Methods
- Possible Optimization Objectives are
  - Reduction of total pressure drop
  - Homogenization of cross section velocity distribution
  - and more…
- Only one single CFD solver-run for a complete optimization process is needed
- Significantly faster than automatic parametric Optimization
- Giant solution space $\rightarrow$ Innovation!
- Actual available for **STAR-CD** and **ANSYS FLUENT**
- "Initial Design Tool" to find modified Design proposals with reduced energy dissipation by backflow elimination
- Gives good proposals for subsequent fine tuning e.g. via parametric morphing