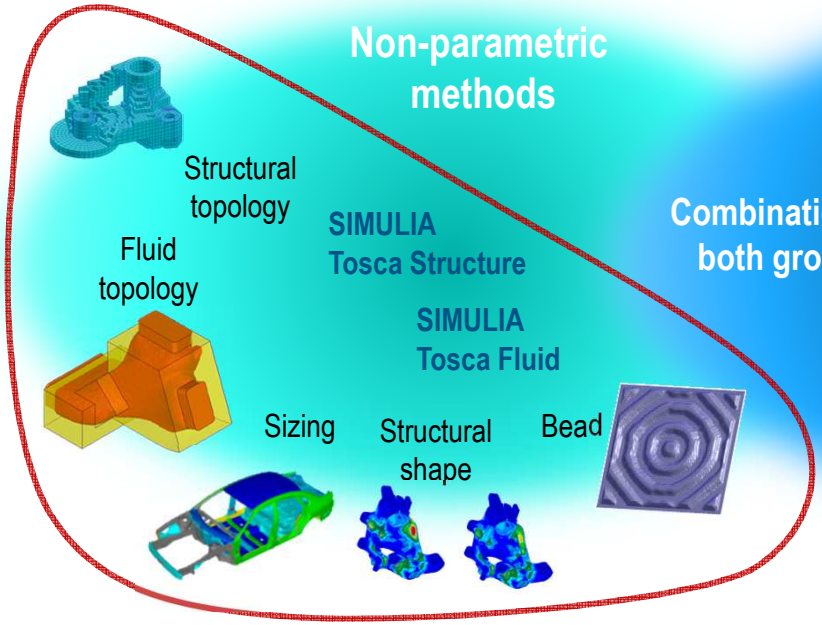
Optimization techniques with SIMULIA Tosca

Georgi CHAKMAKOV
SIMULIA Bulgaria

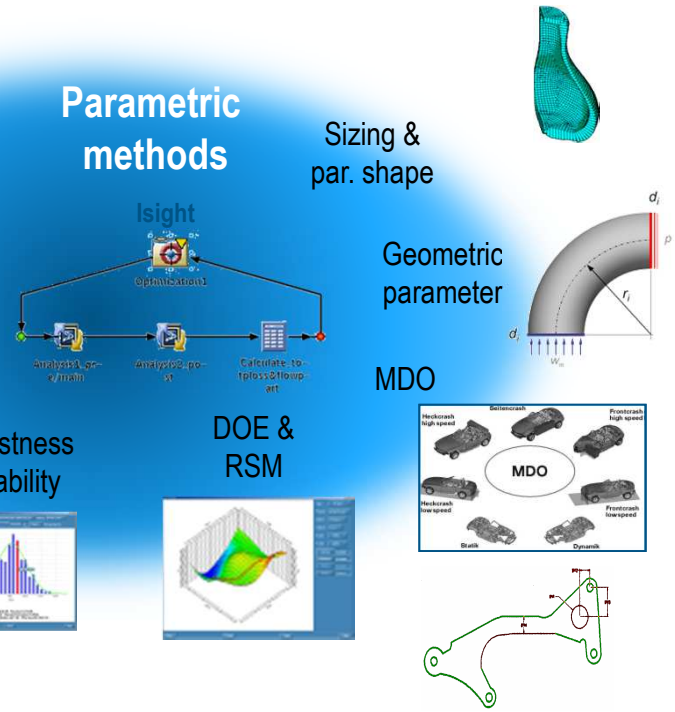
Optimization with SIMULIA Tosca

Introduction

A rough Classification into two Groups of Optimization Methods

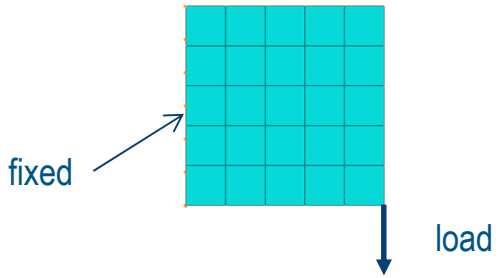


Combination of both groups

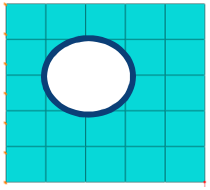


Both groups have their strengths → The feasible method depends on the given optimization task

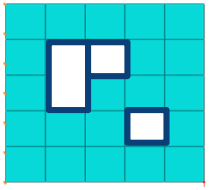
Parametric vs. non-parametric optimization



- Isight
  - Size, shape and location of the cutout is unknown and it is constrained by parameters



- Tosca
  - Size, shape and location of the cutout is unknown, and thus, non-parametric optimization

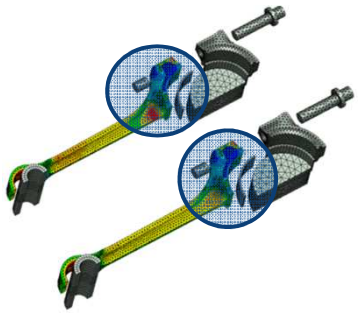


SIMULIA Tosca product line

Tosca Structure.topology

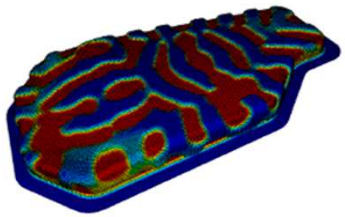
- Find the design with maximum stiffness or minimum weight

Tosca Structure.shape



- Reduce local stresses and increase durability

Tosca Structure.bead

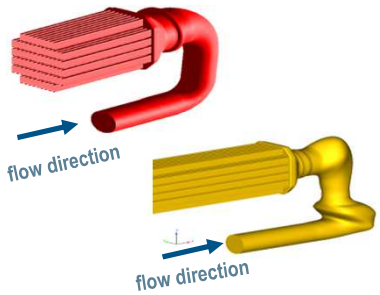


- Increase stiffness or eigenfrequency of sheet metal structures

Tosca Structure.sizing

- Best static and dynamic behavior of sheet metal components

Tosca Fluid.topology



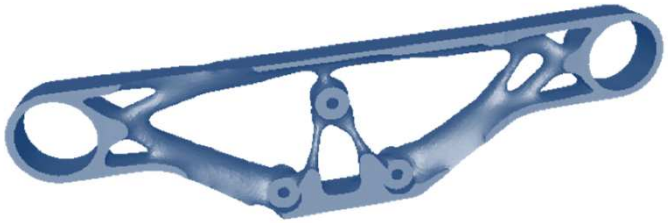
- Topology optimization of channel flow to reduce pressure drop

Images courtesy of AUDI AG

Images courtesy of Ford Werke AG

Topology Optimization

SIMULIA Tosca Structure.topology



Topology optimization approach

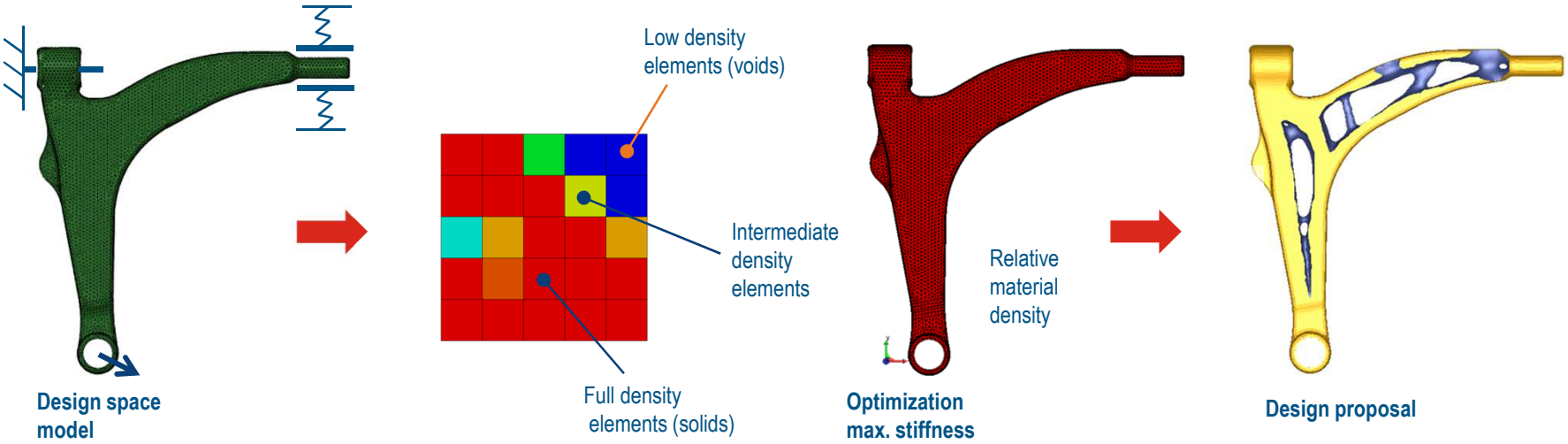
Process

- Change density of elements within design space considering:

Objective function	**Constraints**	**DV constraints**
Minimize/maximize quantity	Physical bounds	Manufacturing, symmetry

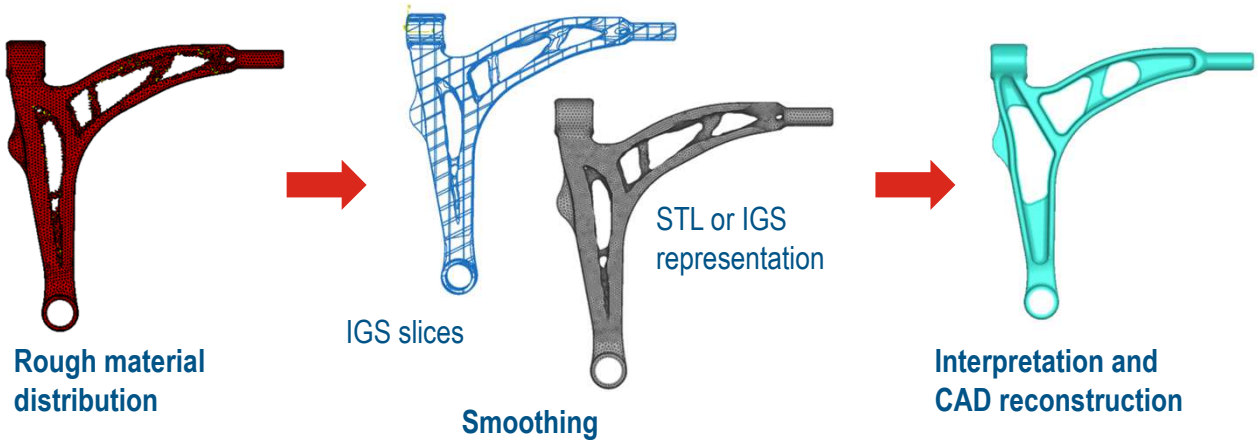
Result

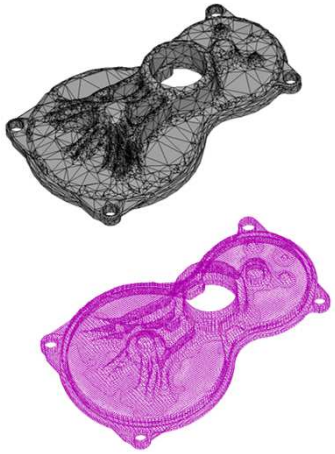
- Optimal material distribution for given optimization problem



Results transfer and generation of new CAD model

- Export smoothed surface model in CAD-readable format (STL or IGS)
- Generate slices from smoothed results and export as IGS splines to be imported in CAD systems for the generation of new CAD design
- Reduction of the facets possible
- Guidelines for efficient CAD reconstruction using CATIA native functionalities



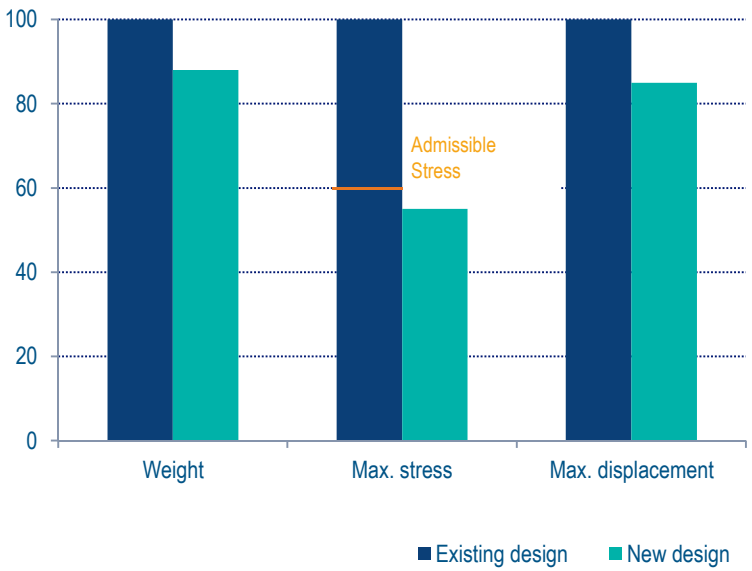


Topology optimization of a transverse link at AUDI

Courtesy of AUDI AG

Comparison

Existing design – new design



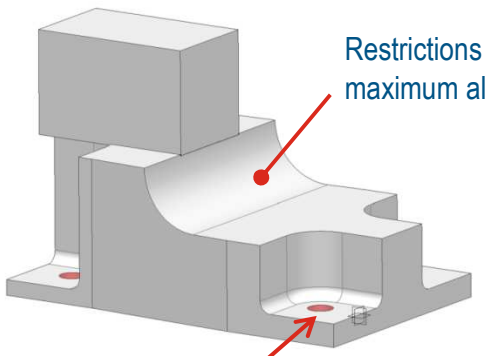
Result

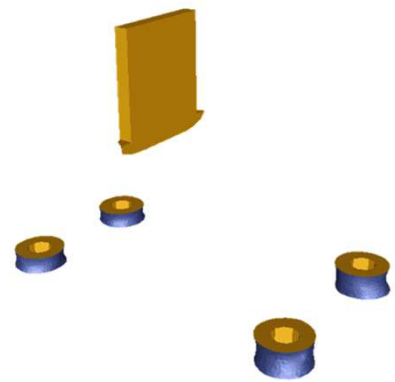
- Speed-up of the development process
- 45% stress reduction, 10% weight reduction
- The 1st prototype passed all mechanical tests!

(Image ATZ MTZ extra)

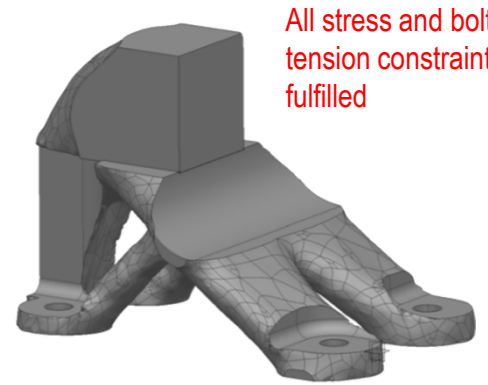
Optimization and Additive Manufacturing

- TOSCA is a powerful topology optimization tool for producing design concepts that often can't be manufactured using traditional techniques.
- Those designs are driven by the ***functional requirements*** of the part.
- Additive Manufacturing makes topology optimization results ***accessible*** for production.





Optimization for maximum stiffness



Final weight 210g ➔ 30% weight reduction compared to an existing design

Shape Optimization

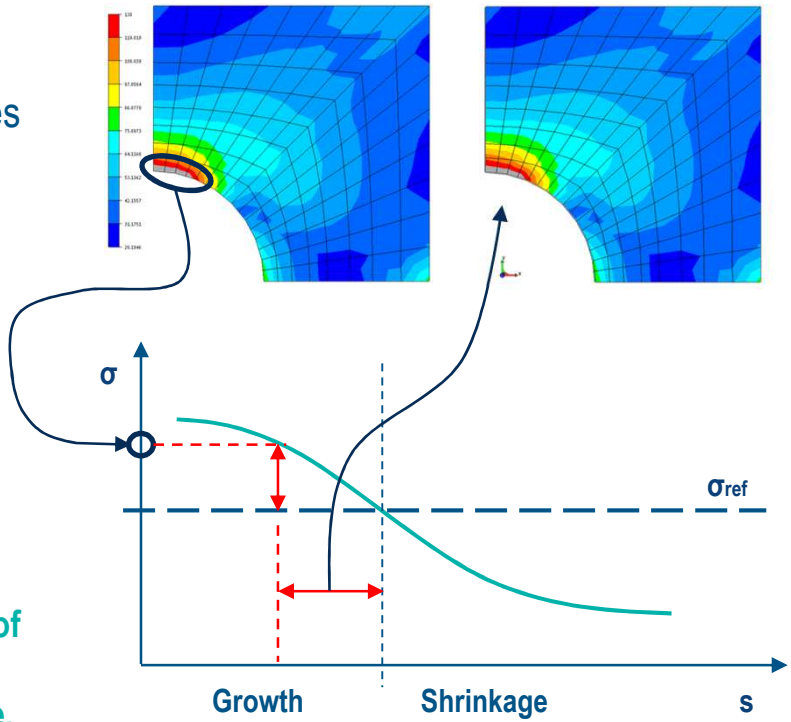
SIMULIA Tosca Structure.shape

SIMULIA Tosca Structure.shape

Functionality

- Shape optimization by homogenization of the stresses
- Controller algorithm update rule:
  - Node stress > reference value
    → Growth in order to reduce stress
  - Node stress < reference value
    → Shrinkage in order to increase stress
  - Result: homogeneous stress distribution to the level of the reference value
  - Very fast convergence

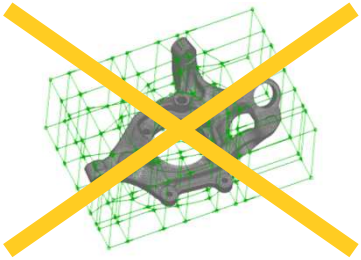
Homogeneous stress distribution results in a minimization of the stress peaks in the design area but can also result in a further mass reduction at a later product development stage.

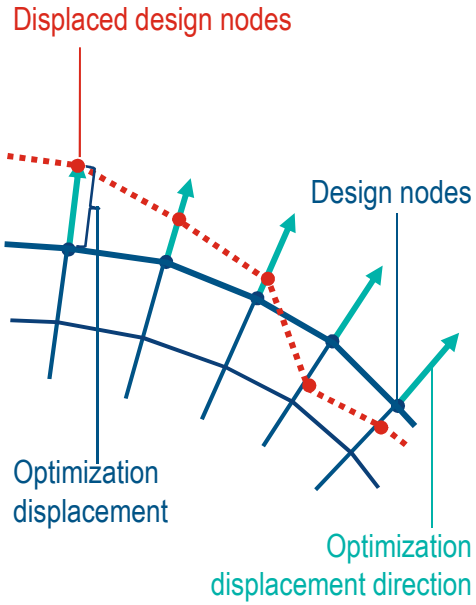


SIMULIA Tosca Structure.shape

Non-parametric approach

- All optimization definitions directly on the FEA mesh
- Node group of surface nodes (design nodes)
  - Node position can be modified
  - Optimization displacement is calculated during optimization
  - No shape basis vectors and/or morphing required
- Design variables are the displacement values of the design nodes
  - Positive:
    node “grows” out of the structure
  - Negative:
    node “shrinks” into the structure

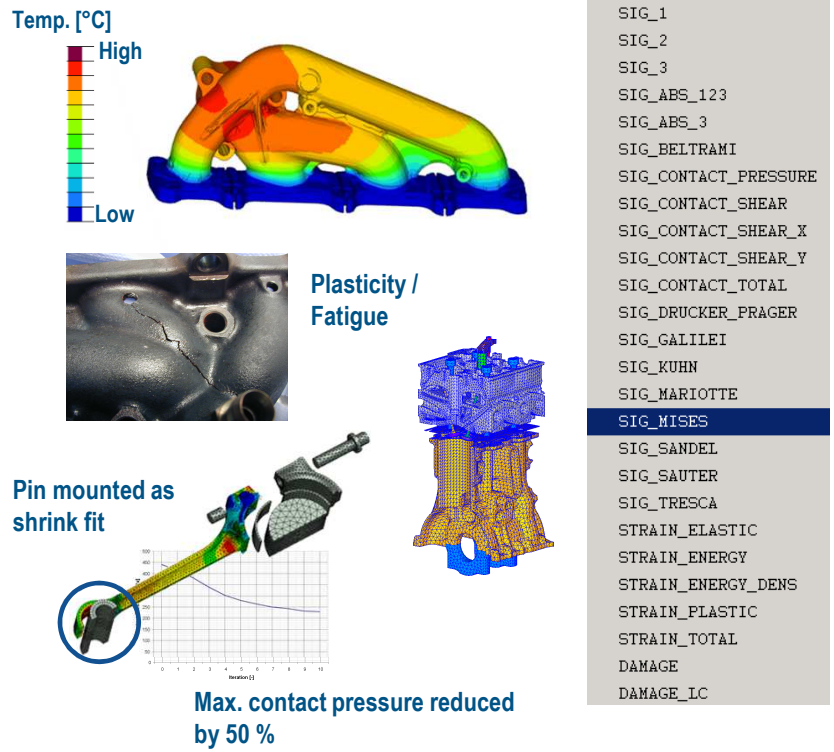




Courtesy of Daimler

Some Possible Objectives

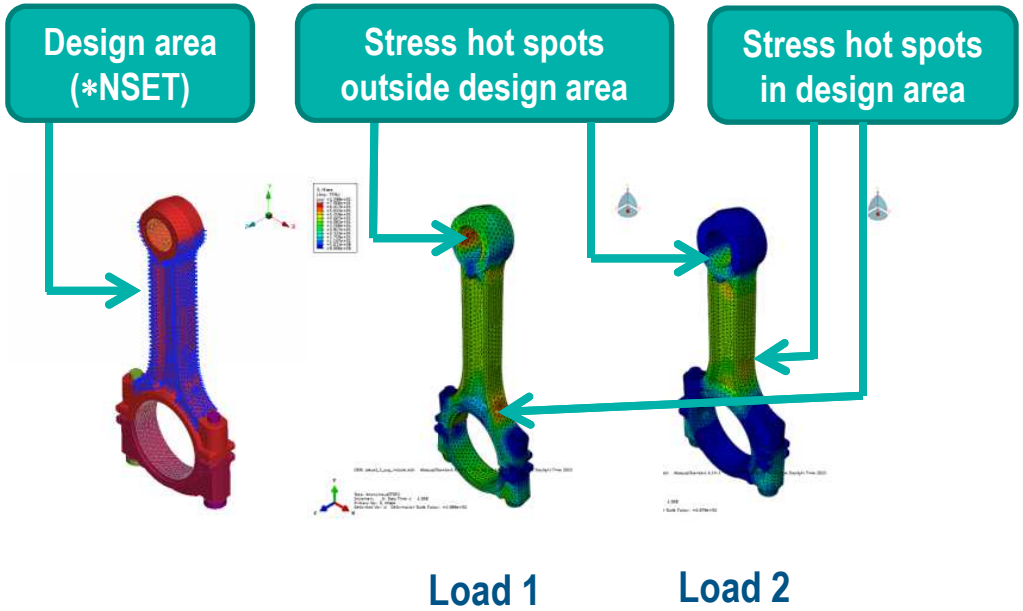
- Finite element solver result:
  - Different stress criteria
  - Nodal strain density
  - Nodal plastic strains
  - Different strain criteria
  - Nodal contact pressure
  - Maximizing the first natural frequency
- Fatigue results:
  - Damage
  - Safety Factor
- **Generally: stress or strain related responses**



New sensitivity based algorithm

General shape optimization

- Free choice of design responses (DRESP) in objective function and constraint
- Optimize for stresses outside the design area (DV)
- New implementation of manufacturing constraint
- To be released



Optimization of thermo-mechanically loaded components

***Load History/Workflow* for**

sequentially coupled transient nonlinear Analysis + Fatigue

1.) THERMAL ANALYSIS

Transient Temperature Field e.g. from CFD simulation

2.) STRUCTURAL ANALYSIS

Step 1: Assembly (Press Fits)

Step 2: Bolt Forces

Step 3: Temperature Loading: Heat Up
Step 4: Temperature Loadung: Cool Down } Cycle 1

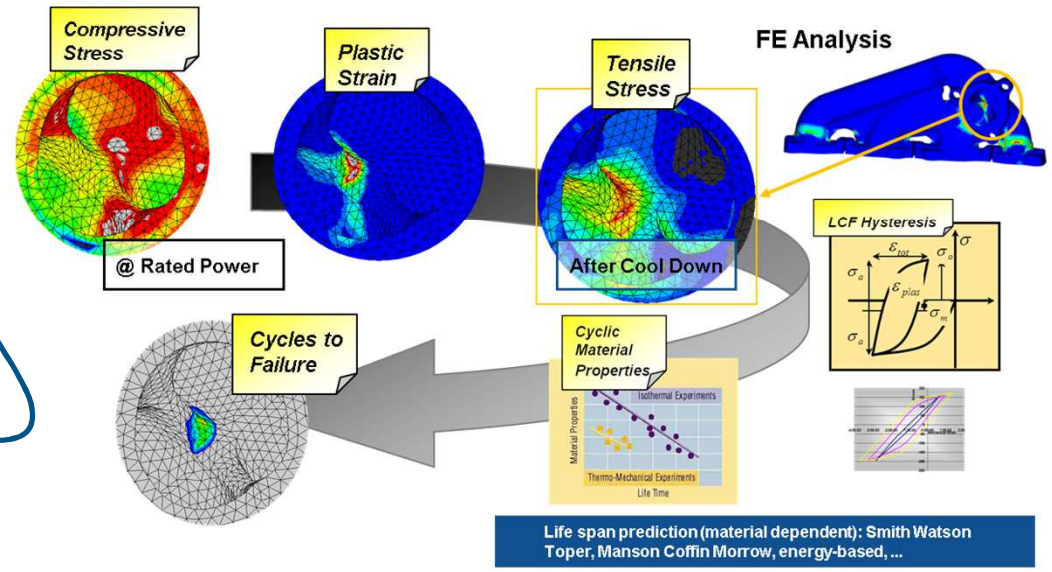
Step 5: Temperature Loading: Heat Up
Step 6: Temperature Loadung: Cool Down } Cycle 2

Step 7: Temperature Loading: Heat Up
Step 8: Temperature Loadung: Cool Down } Cycle 3

} Fatigue

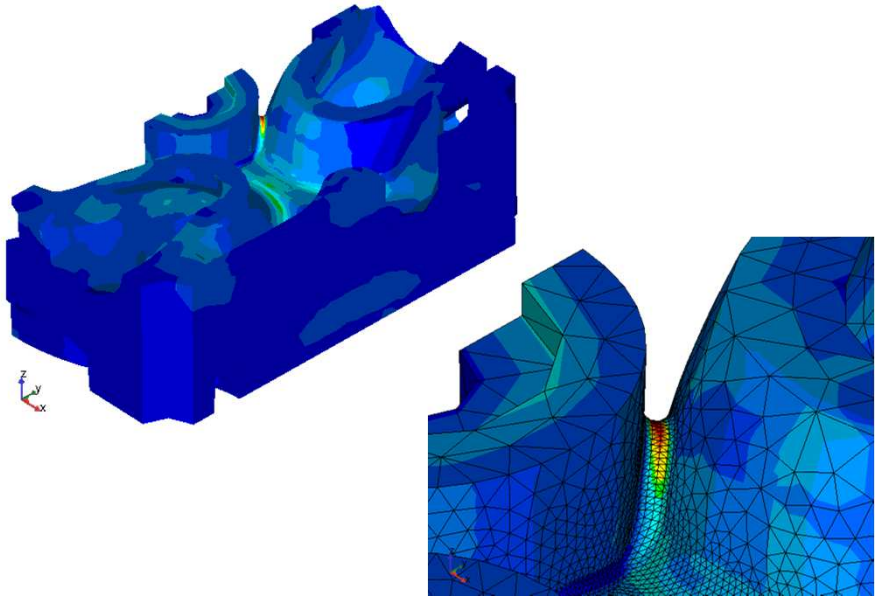
3.) Fatigue Analysis (FE-Safe, Inhouse Codes)

Nonlinearities:
- material plasticity
- contact

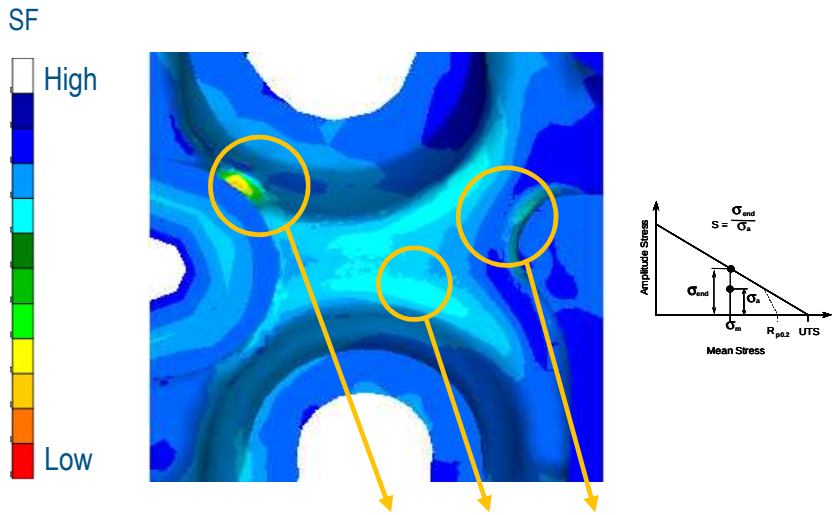


Shape optimization results of submodel

Shape optimization



Optimized design

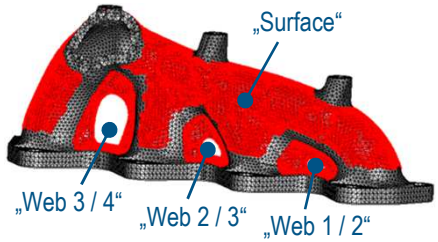


Safety factor increase: +40%; +10%; +43%

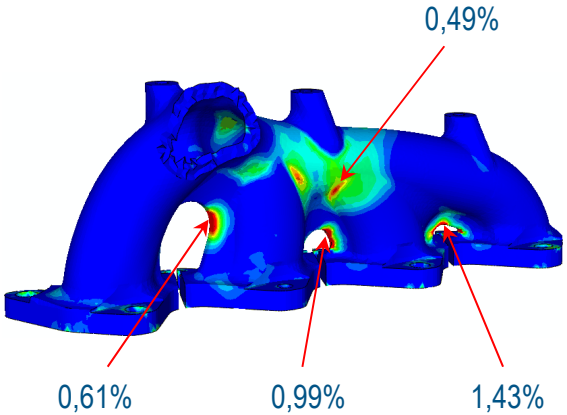
Optimization strategy for exhaust manifold

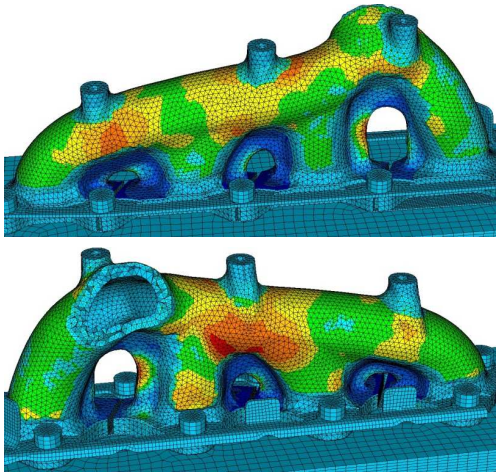
Optimization based directly on the equivalent plastic strain (PEEQ)

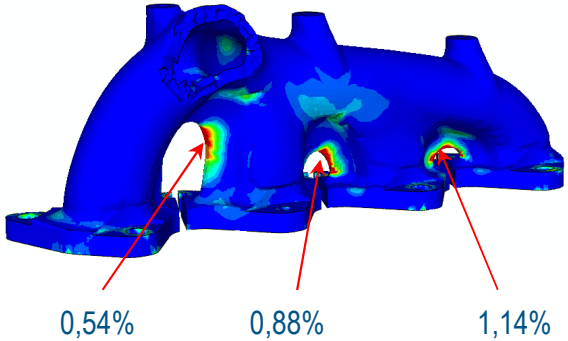
- ▶ Goal is fatigue life improvement, no target for weight reduction



Initial design	Surface change	Optimized design

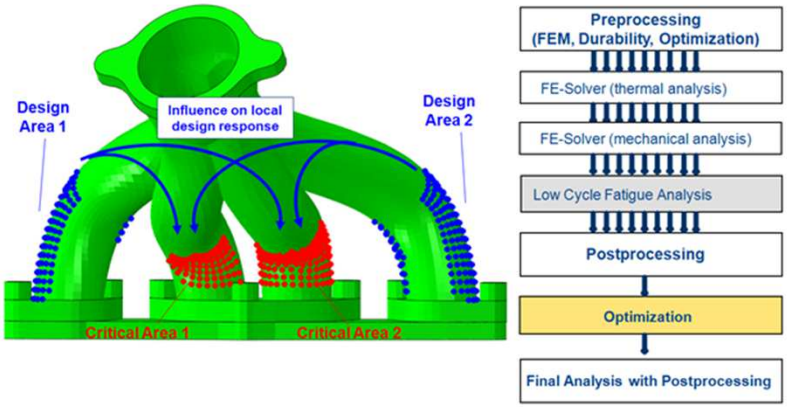






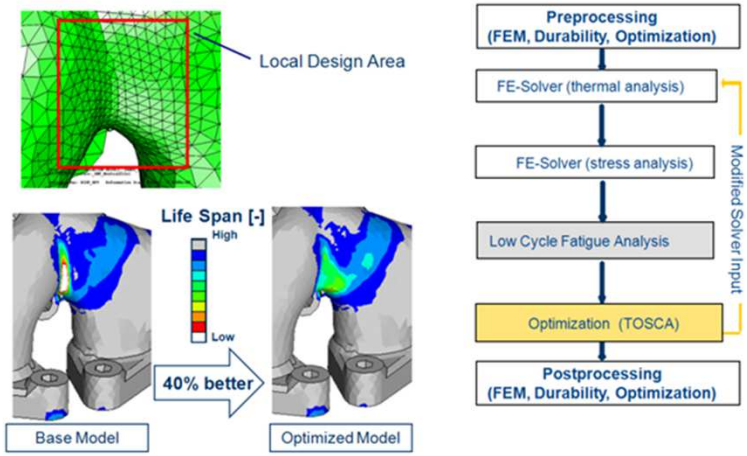
Optimization strategy 4 – Multilevel shape optimization

Global Indirect Optimization



- Stage 1: User-defined parametric modification of the wall thickness in low-stressed areas for changing the stiffness and thermal expansion behavior with the morphing module of TOSCA
- Simultanous increase of the fatigue life in critical areas and weight reduction

Result of Local Shape Optimization

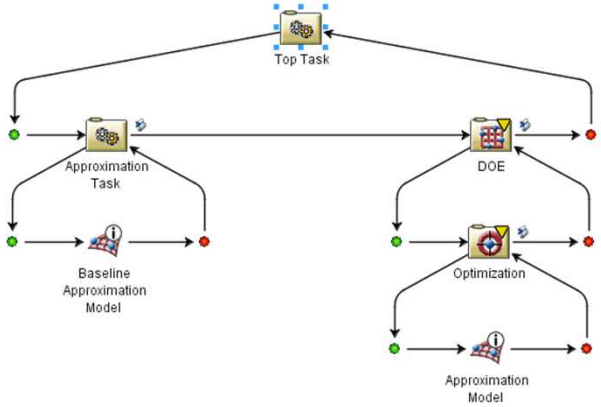


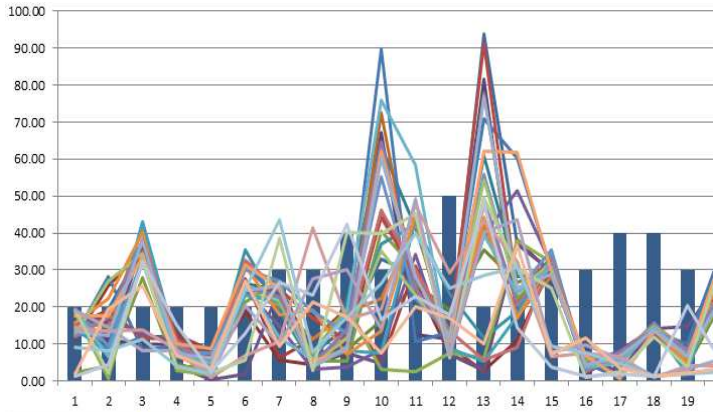
- Stage 2: Standard shape optimization based on the result from Stage 1 for further increase of the fatigue life

SIMULIA Tosca Structure.morph: Manifold-Example

Automated generation of the best morphing combinations using Isight

Priorizing design/tracking areas → calculation of surrogate models → performing an evolutionary based optimization → evaluation of the best designs





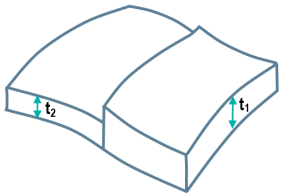
Sizing Optimization

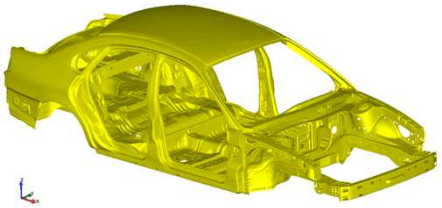
SIMULIA Tosca Structure.sizing

SIMULIA Tosca Structure.sizing

Thickness as design variables

- Elemental thickness of shell elements as design variables





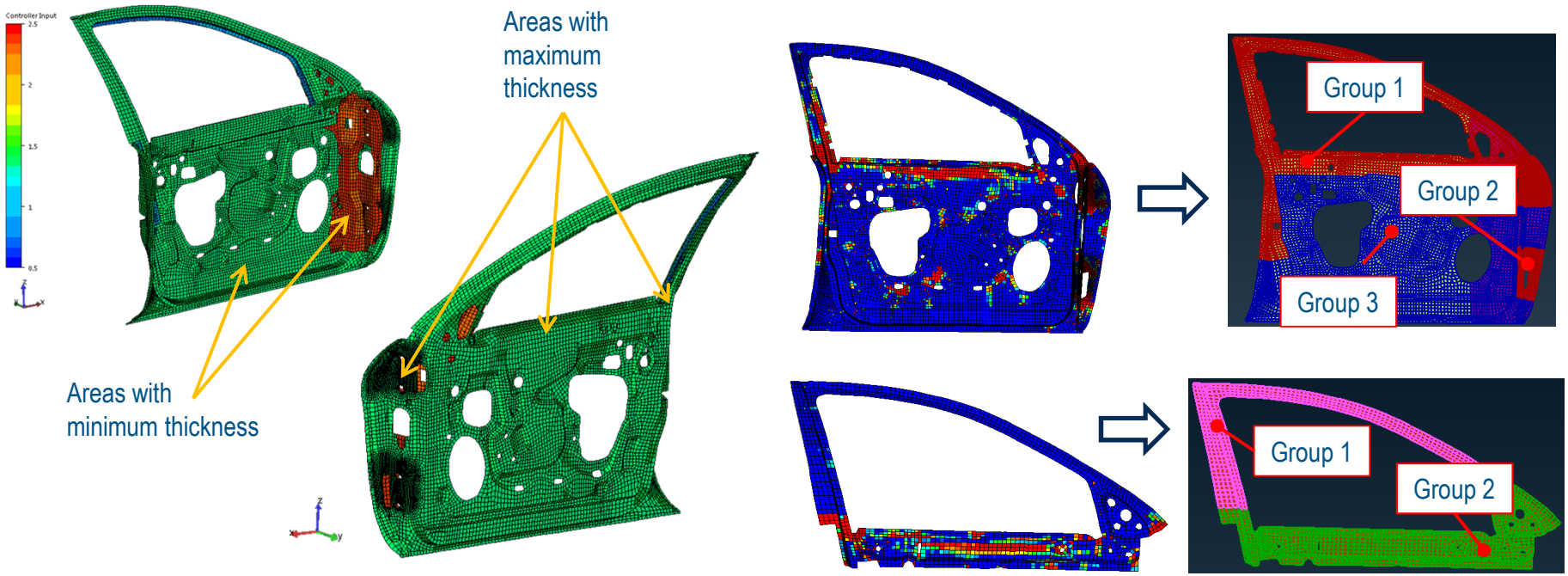
- Define lower and upper bounds on the thicknesses
- The thicknesses of the most typical shell element types are supported as design variables

Two optimization approaches

- Shell element thicknesses can be optimized
  - clustered
    - Combine shell thicknesses to combined design variables via element and property groups

  - individually
    - The shell thickness of each element is a design variable
    - Handle several millions of design variables

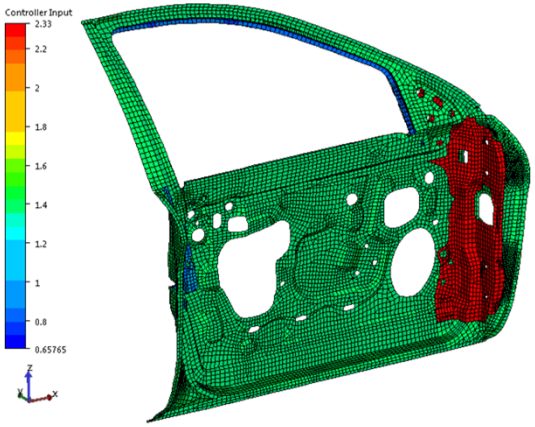
Free thickness optimization of a car door



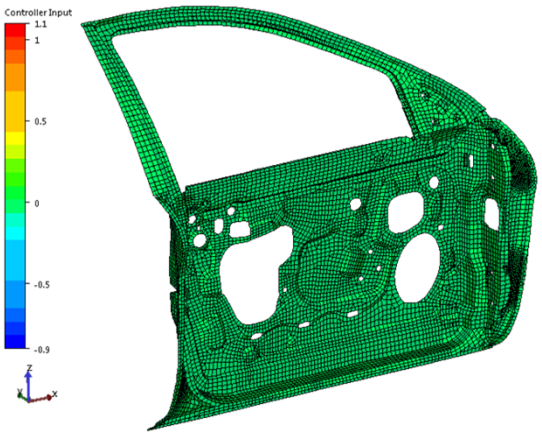
Evolution of the thickness distribution

Optimization results

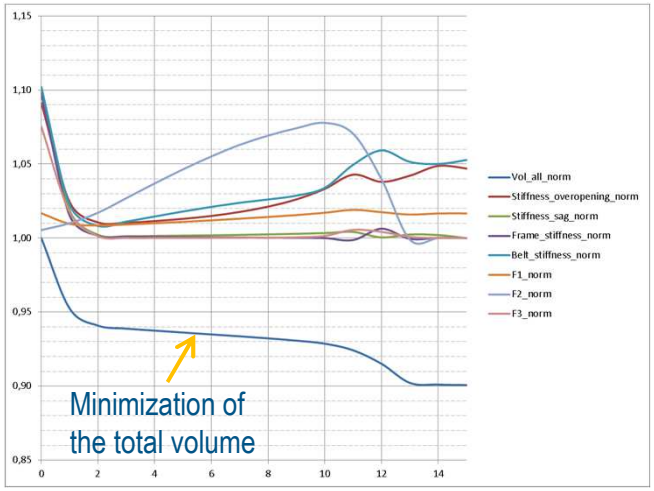
Second clustered sizing run



Absolute thickness distribution



Evolution of the thickness change

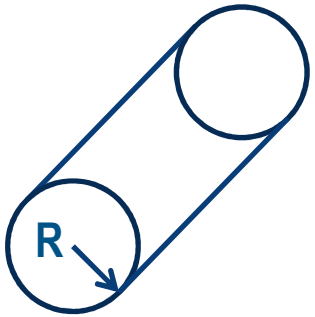


Convergence plots:
Normalized stiffness, eigenfrequencies and total volume over the iterations

10% weight reduction while fulfilling all the stiffness and eigenfrequency constraints

Sizing Optimization of Circular Beams

- All commands are exactly the same as those for sizing of shells
- Support for beam **TYPE=B31** and **SECTION=CIRC**

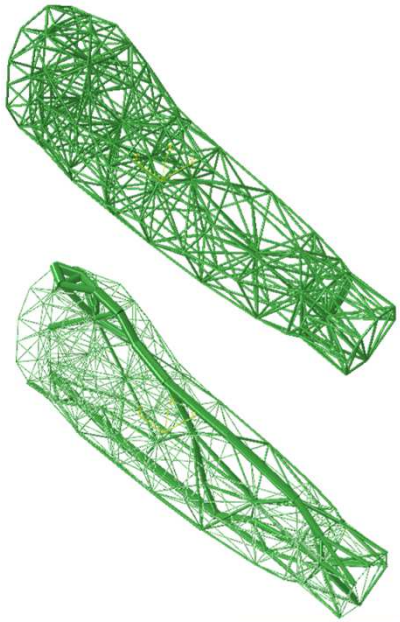


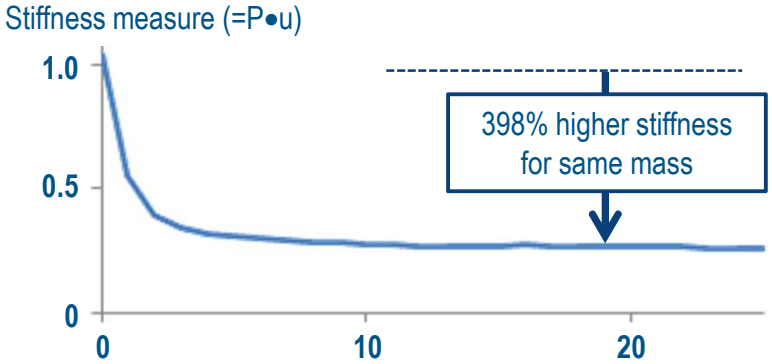
Radius is design variable

- To be released

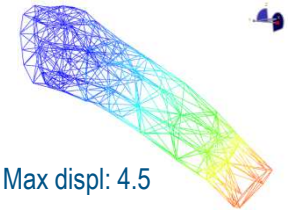
Initial

Optimized



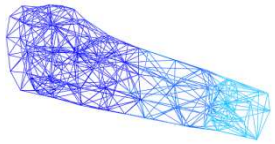


Original design



Max displ: 4.5

Optimized design



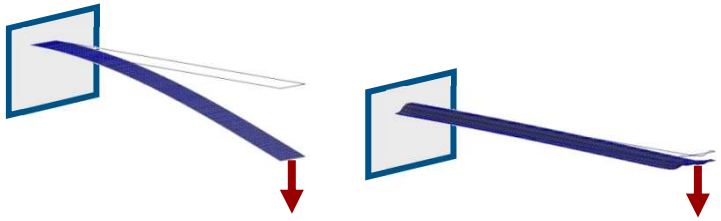
Max displ: 1.2

SIMULIA Tosca Structure.bead

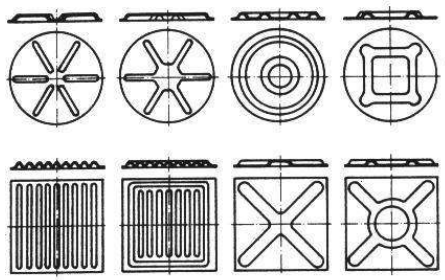
Calculate an optimal bead layout to improve bending stiffness or vibration behavior for sheet metal components

Optimization of beads using Tosca Structure.bead

- Automatic determination of location and orientation of beads for an increase of the moment of inertia
- Fast and stable optimization algorithms using special optimality criterion based on the bending stress
- Solution is independent from mesh
- Support of static or modal analysis
- Fast convergence using a controller based algorithm
- More soffisticated sensitivity based algorithm
- Good transfer and easy interpretation of results due to low scattering



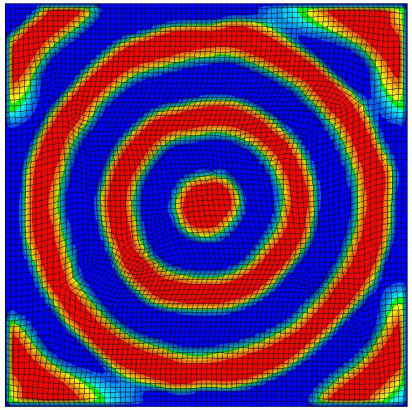
Deflection without and with bead stiffener



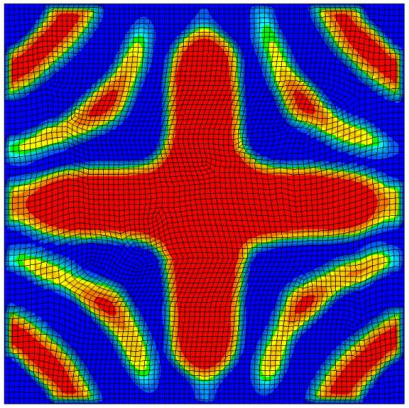
Source: Oehler, „Steife Blech- und Kunstoffkonstruktion“

Preprocessing bead optimization

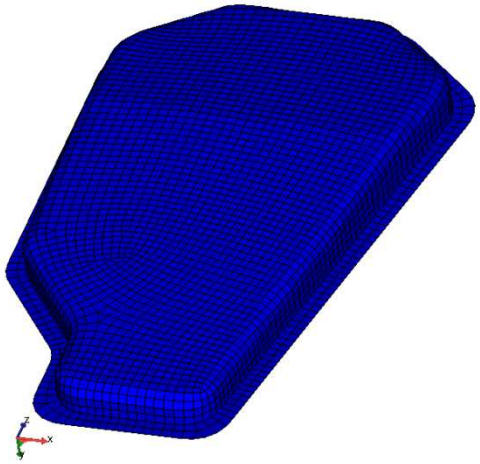
- Static or modal analysis
- Shell or plate elements must be present
  - All nodes at shell / plate elements may be used as design nodes
  - The optimization displacement direction can be inverted using a SCALE parameter



Simply supported plate optimized with respect to a static force



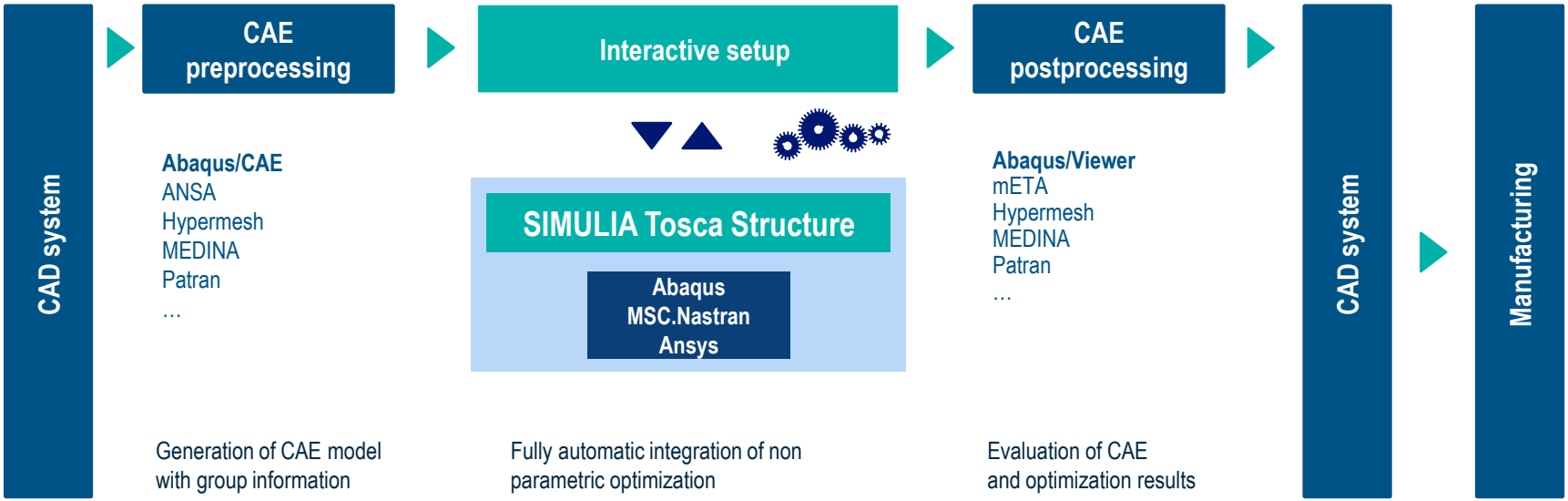
Simply supported plate optimized with respect to 1st eigenfrequency



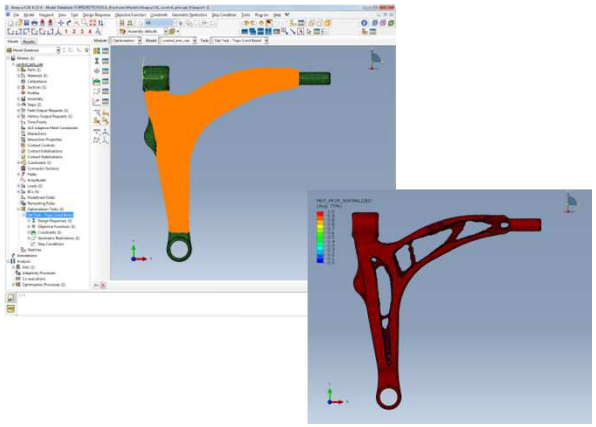
Tosca Structure Workflow

Integration of SIMULIA Tosca Structure

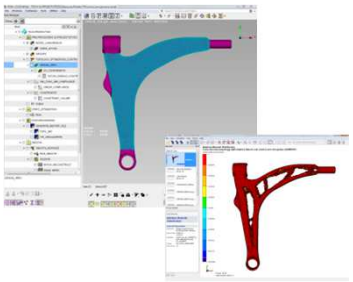
in the existing CAE environment



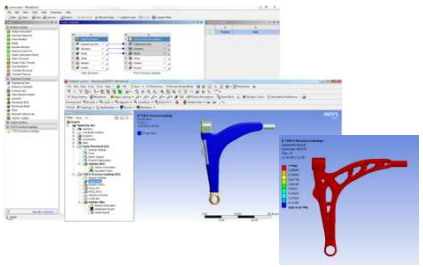
Tosca Structure Optimization User Interfaces



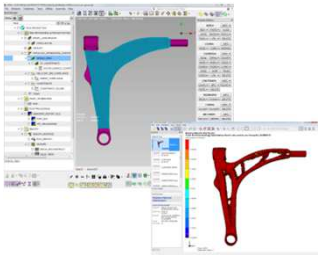
Optimization Module in Abaqus/CAE



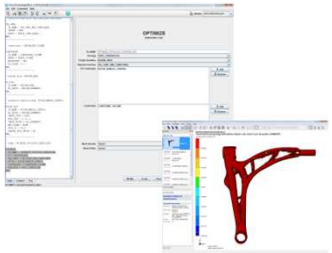
Tosca ANSA environment (TAe)



Tosca Extension for ANSYS Workbench



Tosca within ANSA



Tosca Structure.gui

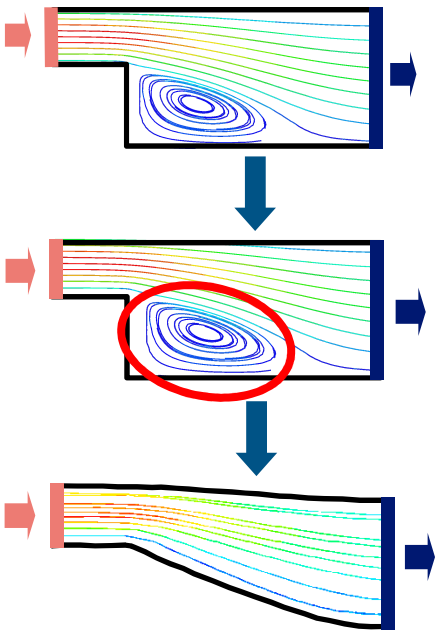
Fluid Optimization

SIMULIA Tosca Fluid

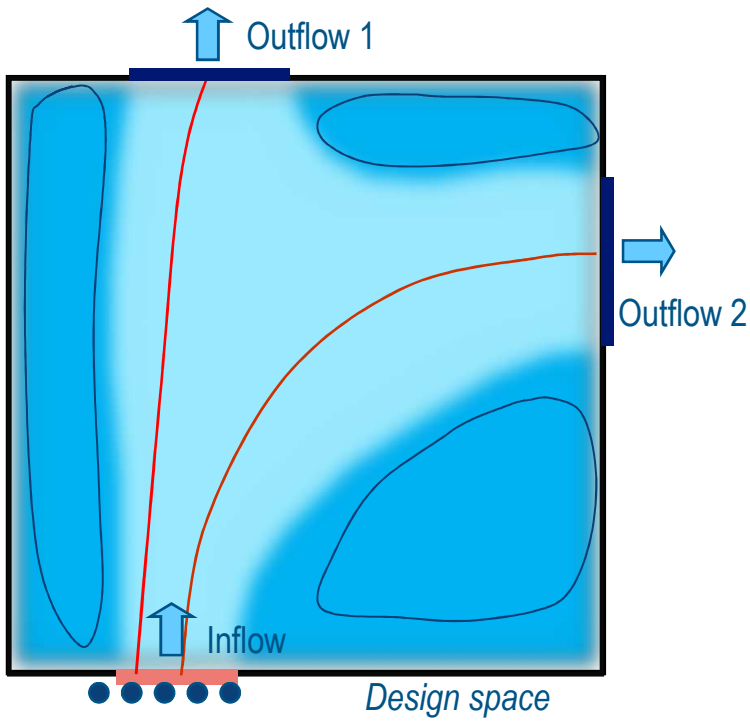
OC-based topology optimization

Sedimentation method

- The optimality criterion is to avoid flow recirculation
- An achieved consequence is (for many technical flows) a reduction of pressure drop
- Redesign rule: elimination of local backflow and recirculation by “blocking out” of backflow areas
- Provides an “optimization” approach by means of “improvement”
- **Physics: Internal steady single-phase duct flow with low compressibility**

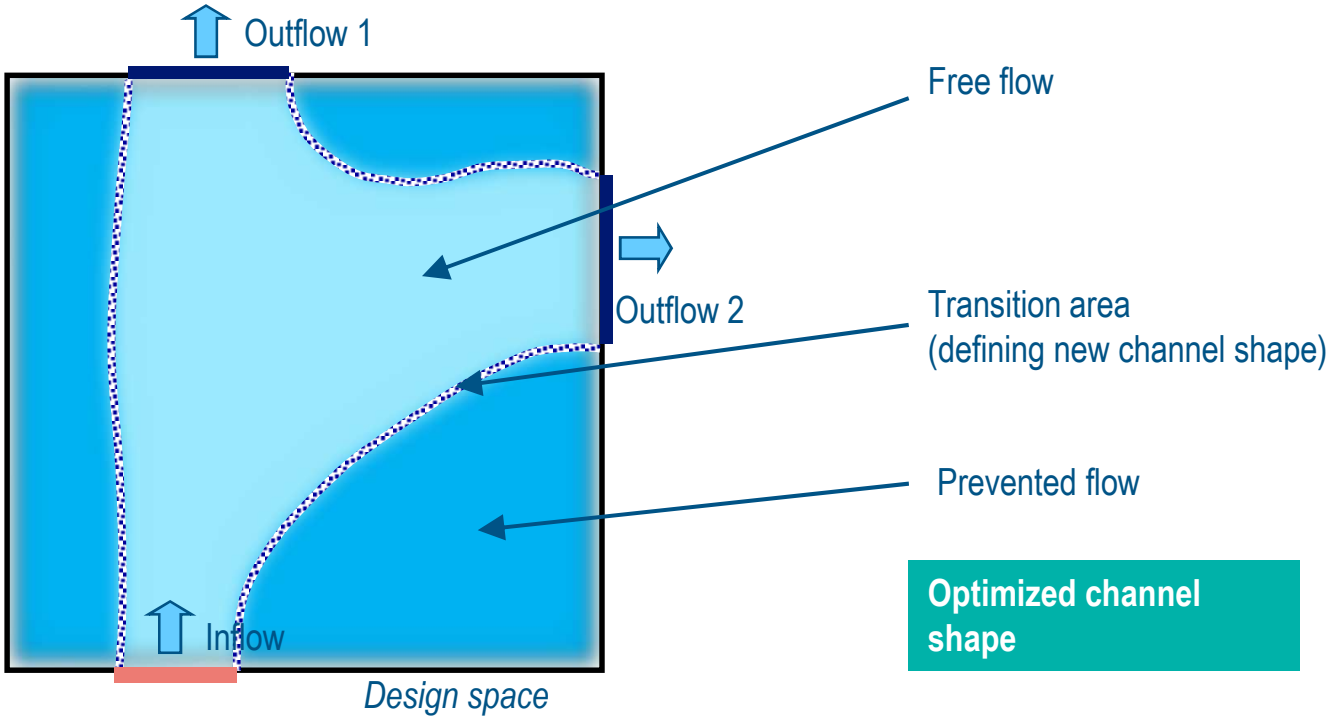


Topology optimization with Tosca Fluid: Step by step



- Define the design space (e.g. CAD)
- Meshing “as usual”
- Define boundary conditions
- Run the optimization

Topology optimization with Tosca Fluid: Step by step



Automotive HVAC flow splitter manifold

CFD model and design space

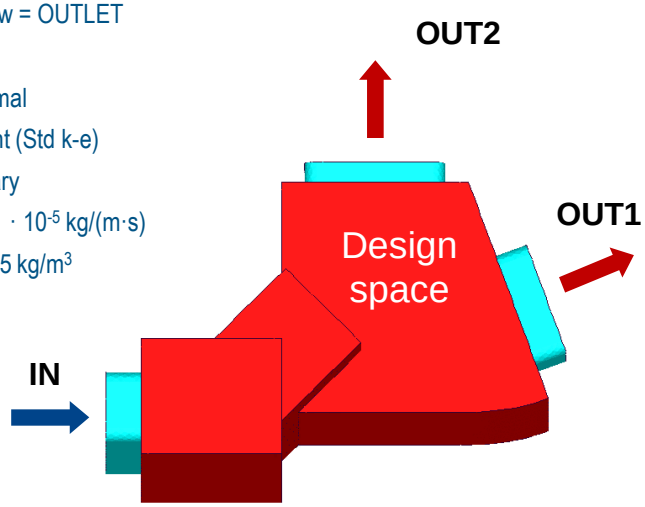
Dimensions = 0,2 m x 0,14 m x 0,12 m

Boundary Conditions:

- Inflow = INLET
- Outflow = OUTLET

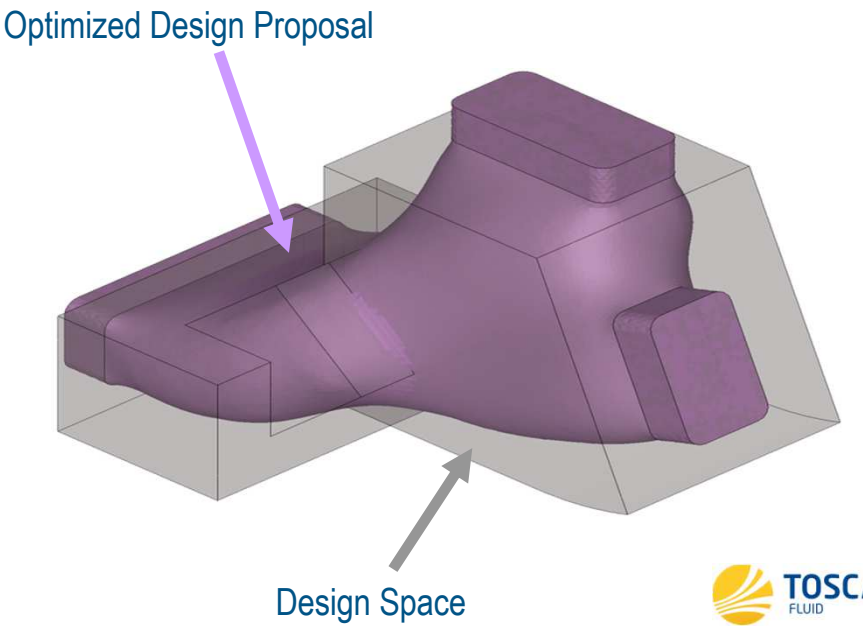
Fluid AIR

- Isothermal
- turbulent (Std k-e)
- stationary
- $h = 1.81 \cdot 10^{-5}$ kg/(m·s)
- $r = 1.205$ kg/m^3



Air,
w_{in} = 5 m/s

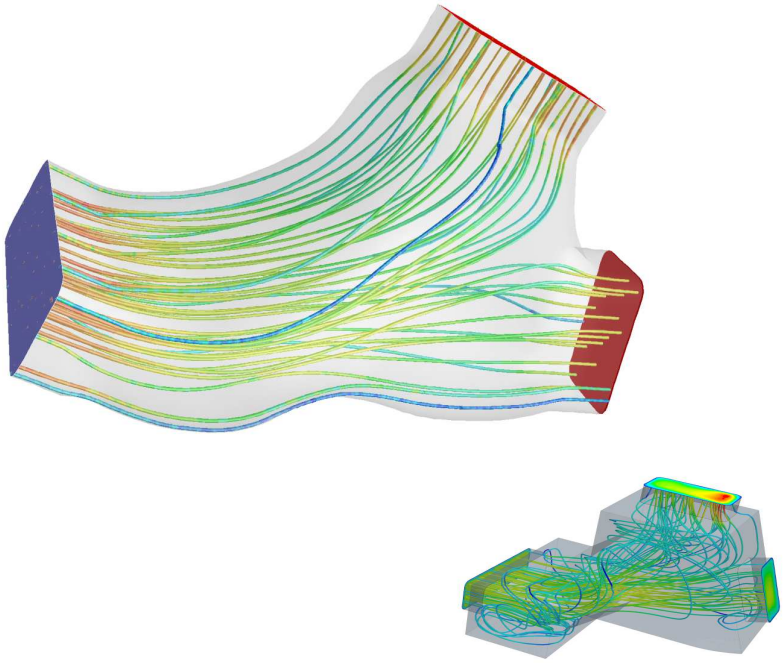
Optimized design



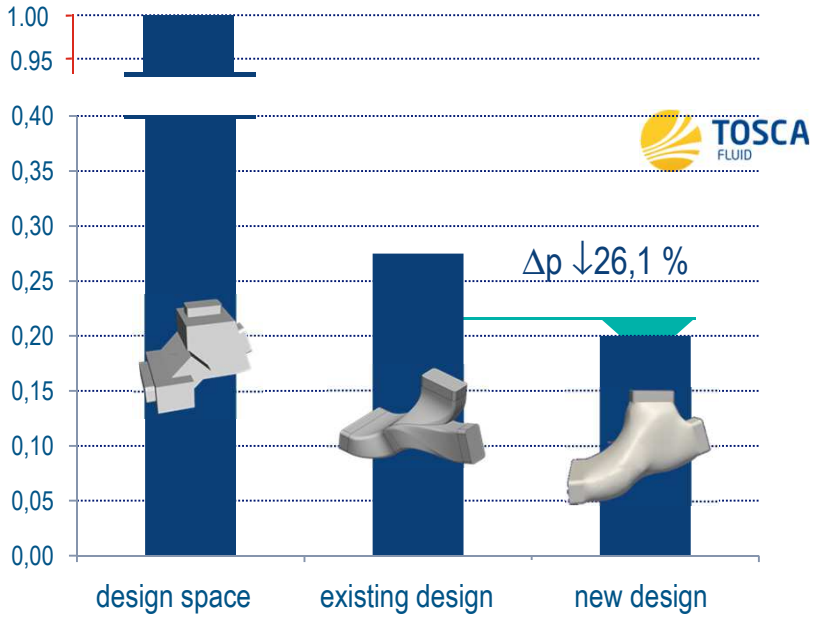
TOSCA FLUID

Automotive HVAC flow splitter manifold

Optimized design proposal (new design)

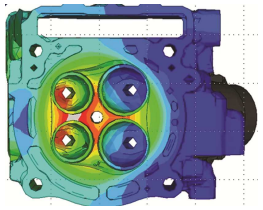


Relative mean total pressure drop



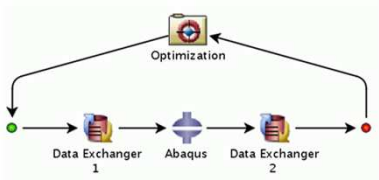
Innovative Powerful Simulation Technology

Abaqus 6.14



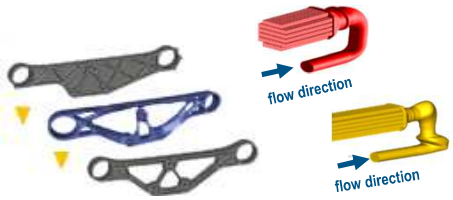
FEA Multiphysics Simulation

Isight 5.9



Process Integration & Design Optimization

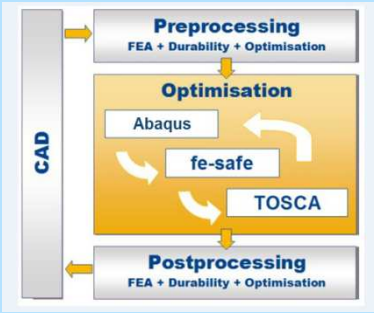
Tosca 8.1 & 2.4



Non-parametric Optimization For Fluids and Structures

fe-safe 6.5

Durability & Fatigue



Improve Accuracy and Efficiency of Simulation Workflows

Leverage *ALL* through Extended Packaging licensing

IF WE™