Optimierung als wesentlicher Punkt in der Leichtbau-Konzeptentwicklung

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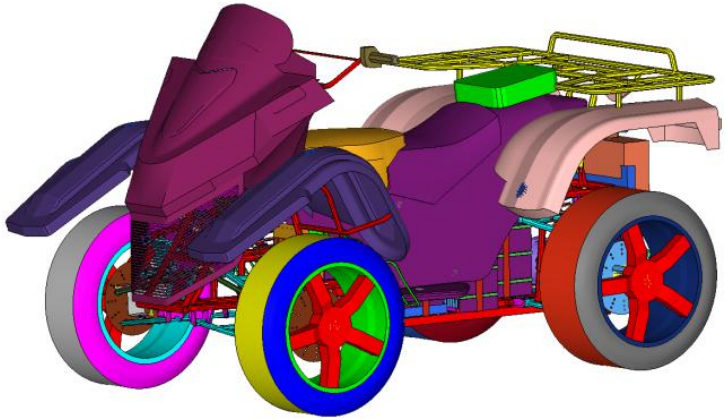
VIRTUAL VEHICLE Research Center



COMET K2 Competence Center - Initiated by the Federal Ministry of Transport, Innovation & Technology (BMVIT) and the Federal Ministry of Science, Research & Economics (BMWFW). Funded by FFG, Land Steiermark and Steirische Wirtschaftsförderung (SFG)

Agenda

1. Problem Definition

2. Optimization Process

3. Structural Design

- Topology optimization
- Topography optimization
- Free-size optimization
- Size optimization
- Composite optimization

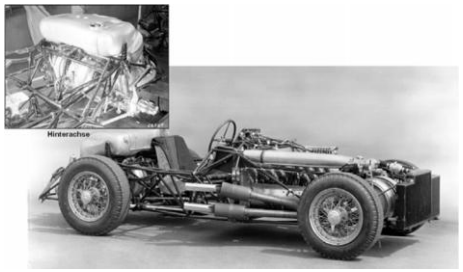
4. Design Optimization - eQuad

5. Summary

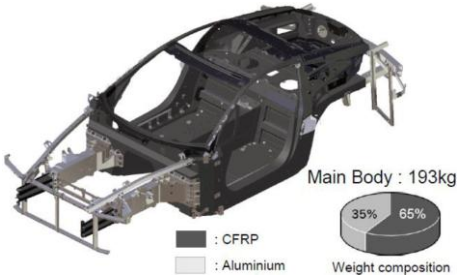
Problem Definition

How to find the suitable design for a new structure?

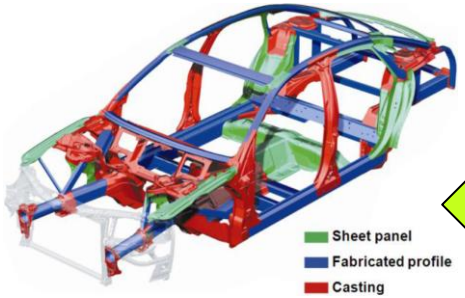
Tubular space-frame



Monocoque



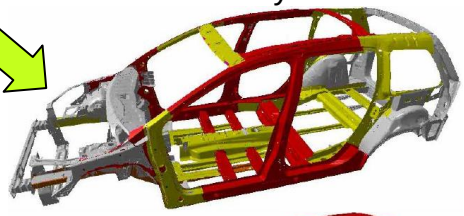
Space-frame

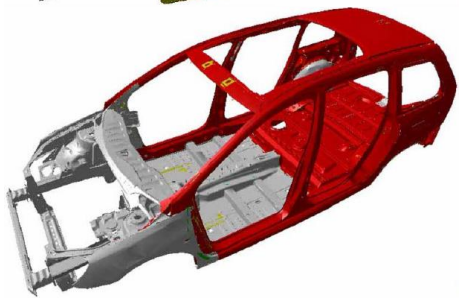


Optimal Design

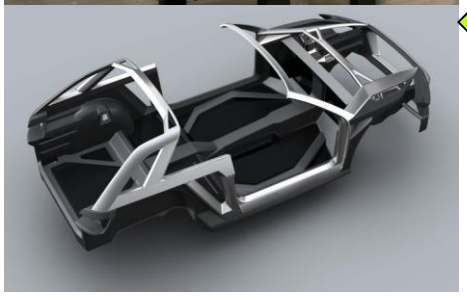
Engineer

Unibody





Multi material mix structure



Source: Daimler, AUDI, Toyota, PSA, Internet

Optimization Process

The Optimization Problem Statement:

- Objective *(What do I want?)*

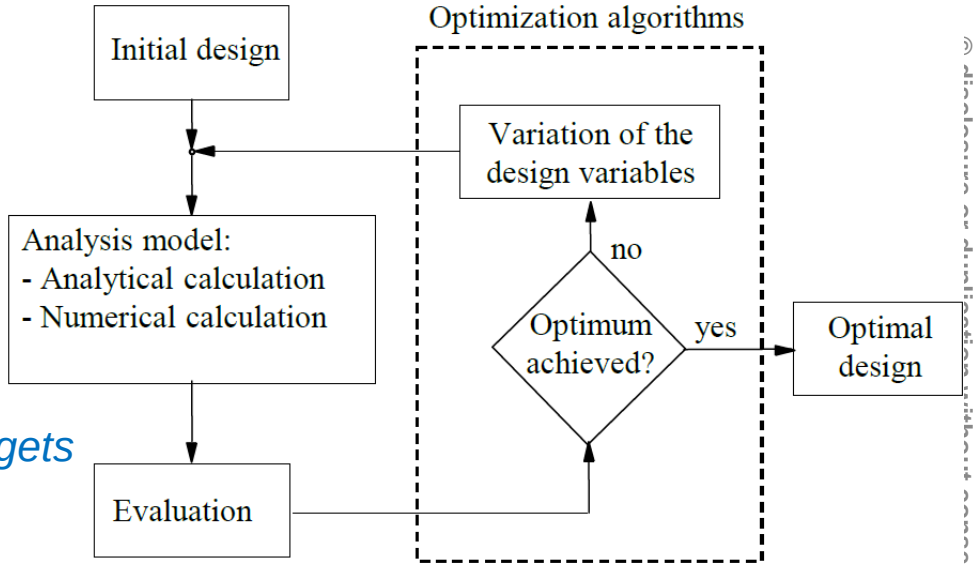
  min f(x) also min [max f(x)]

- Design Variables *(What can I change?)*

  $X_i^L \le X_i \le X_i^U \quad i = 1,2,3,\ldots N$

- Design Constraints *(What performance targets must be met?)*

  $g_j(x) \le 0 \qquad j = 1, 2, 3, \ldots, M$

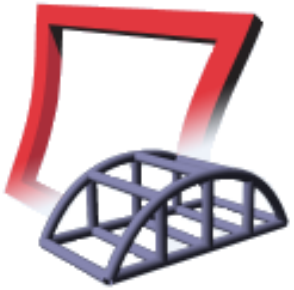


Source: Altair

The functions f(x), $g_j(x)$, can be linear, non-linear, implicit or explicit, and are continuous

Example: Explicit $y(x) = x^2 - 2x$

Implicit $y^3 - y^2x + yx - \sqrt{x} = 0$

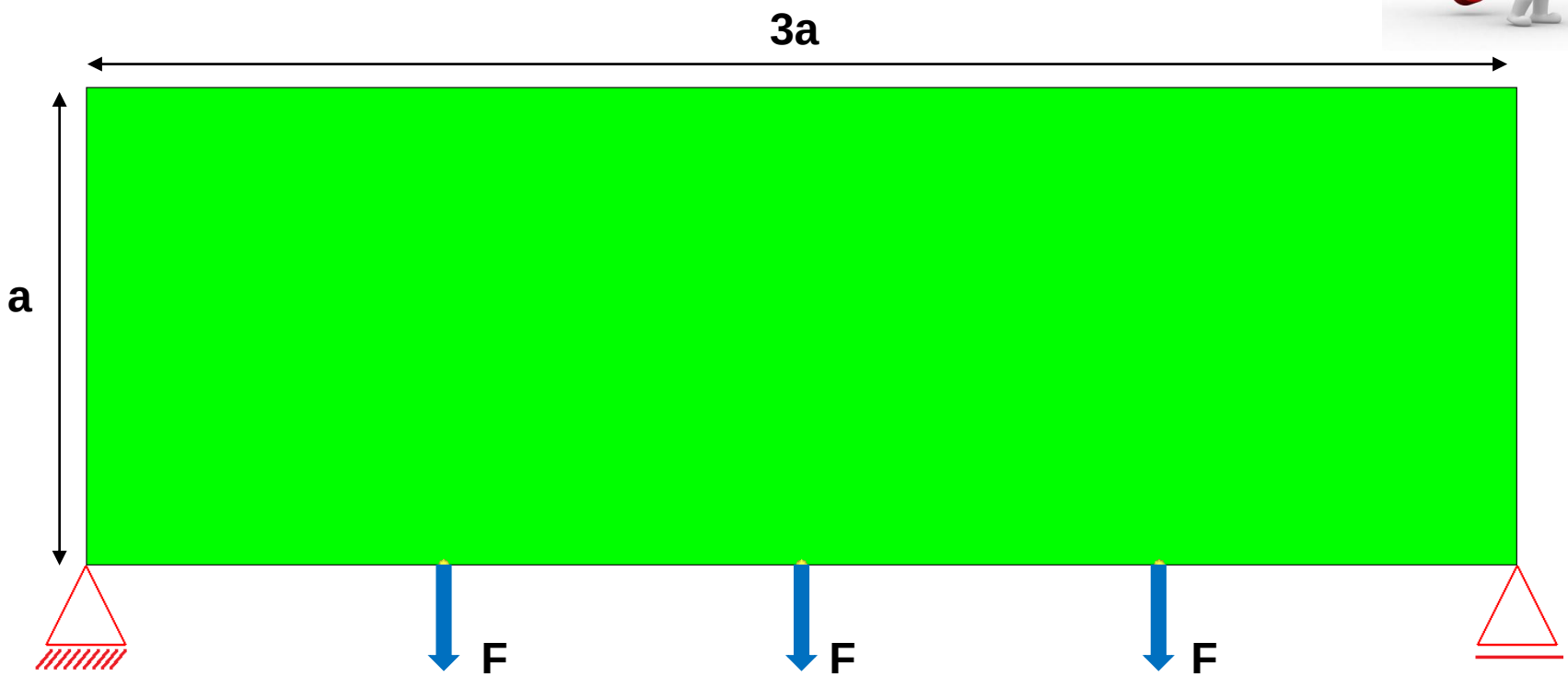


OptiStruct ®

Structural Design – Topology optimization

- **New solution – how to find the best one for the given boundary conditions?**

Steel, linear static, thickness = 1mm



- **What is a possible solution with only 30% of the initial mass?**

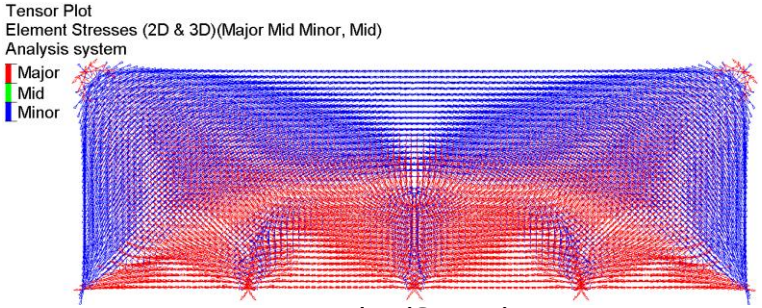
Structural Design – Topology optimization

- **New solution with only 30% of the initial mass**

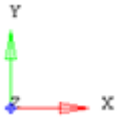
Old design

Y-Displacement, [mm]

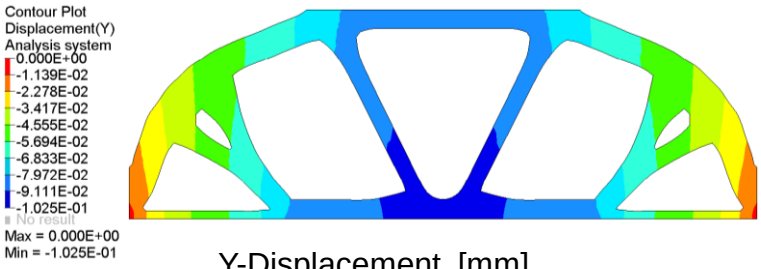
Stress (von Mises), [GPa]



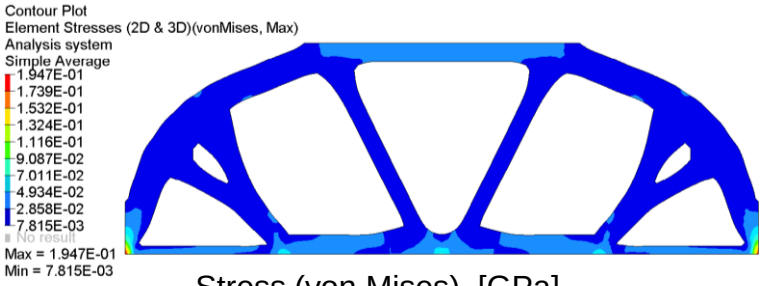
Tensor Plot (Stress)



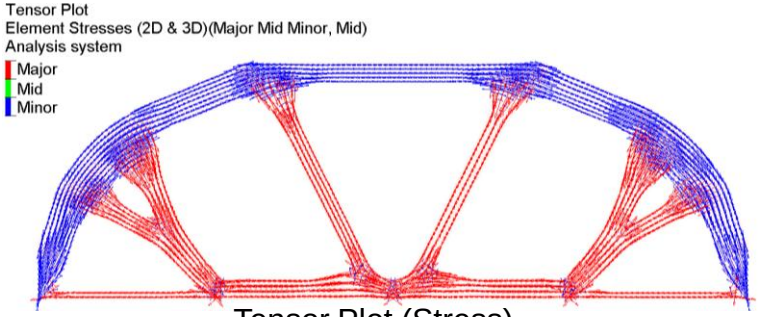
New design



Y-Displacement, [mm]



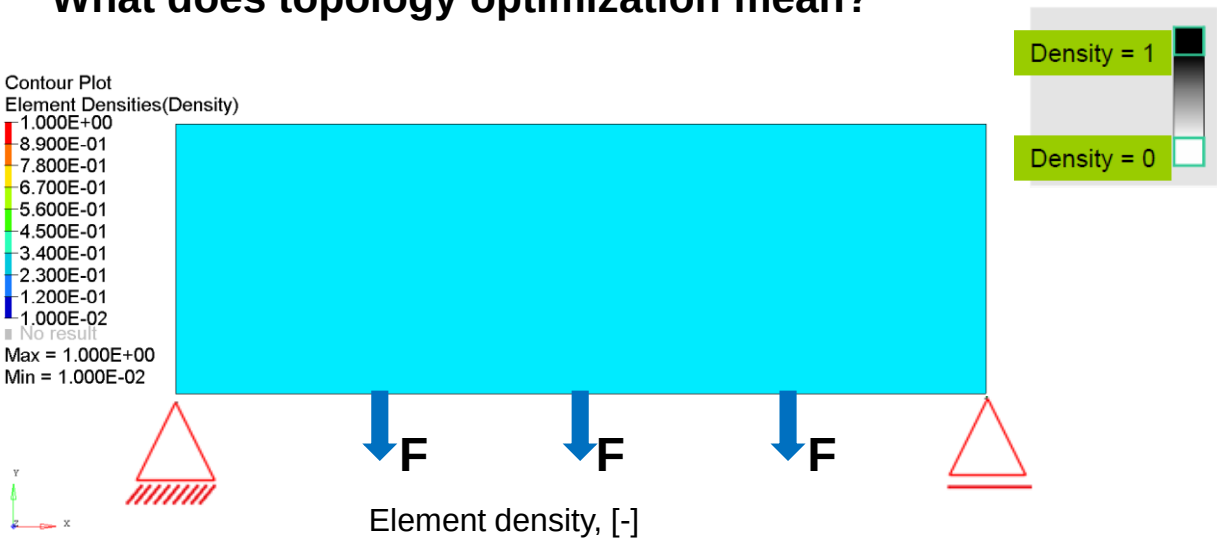
Stress (von Mises), [GPa]



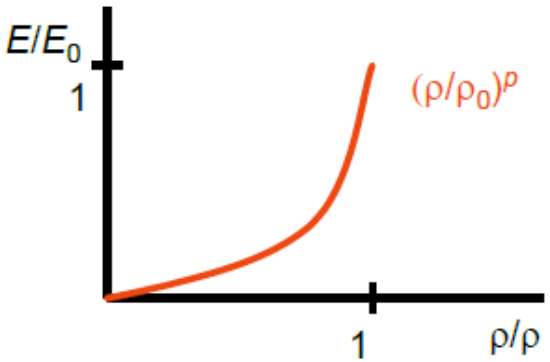
Tensor Plot (Stress)

Structural Design – Topology optimization

What does topology optimization mean?



Source: Altair



Solid **I**sotropic **M**aterial with **P**enalty aka **Density Method**

Penalty Factor, *p*

$$\underline{K}(\rho) = \rho^p K$$

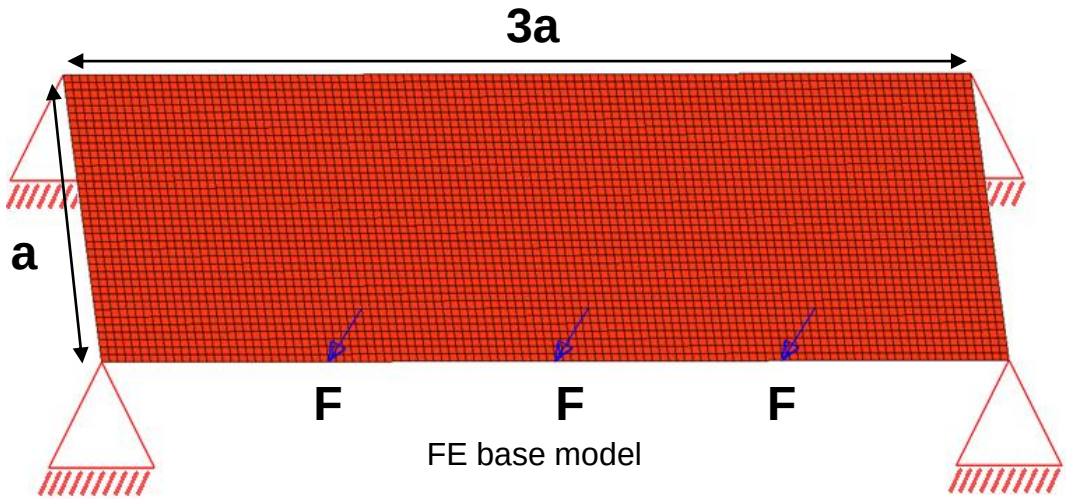
Compliance is the objective function to minimize:

$$C = \frac{1}{2} u^T K u = \frac{1}{2} \int \varepsilon^T \sigma \, dv$$

$$C_W = \sum W_i C_i$$

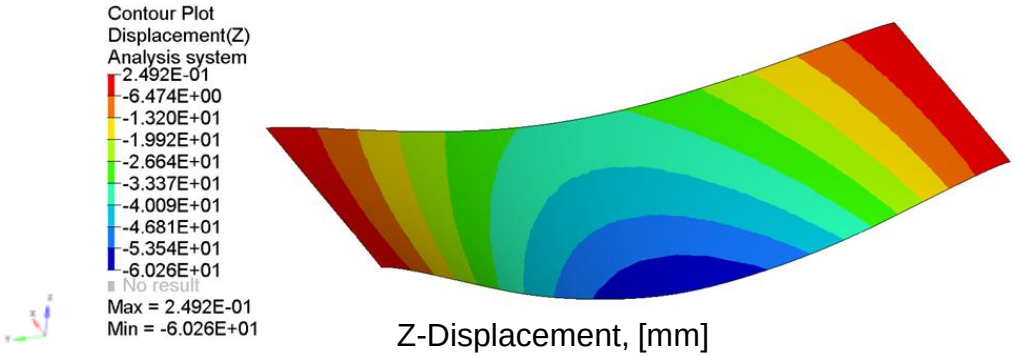
Structural Design – Topography optimization

- **New solution – how to find the best one for the given boundary conditions?**



FE base model

Steel, linear static, thickness = 1mm



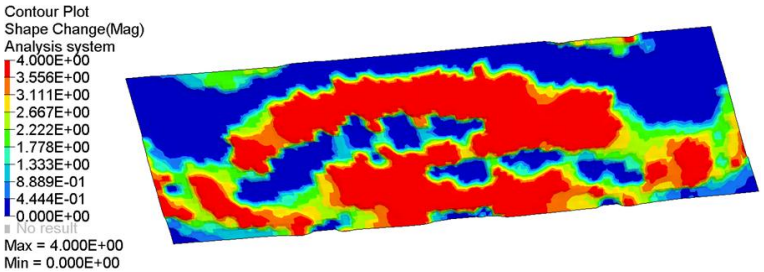
Z-Displacement, [mm]

- **What is a possible solution to minimize nodal displacement?**

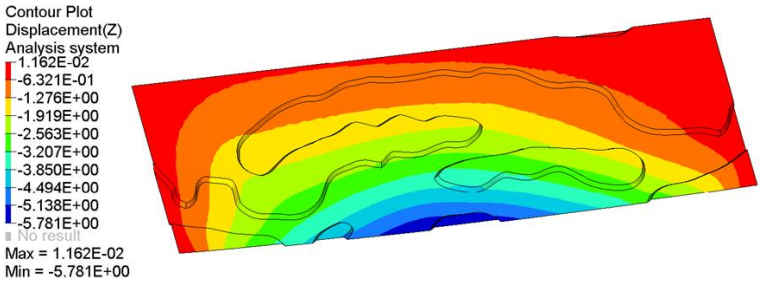
Structural Design – Topography optimization

- **New solution**

No manufacture constraints – production complexity

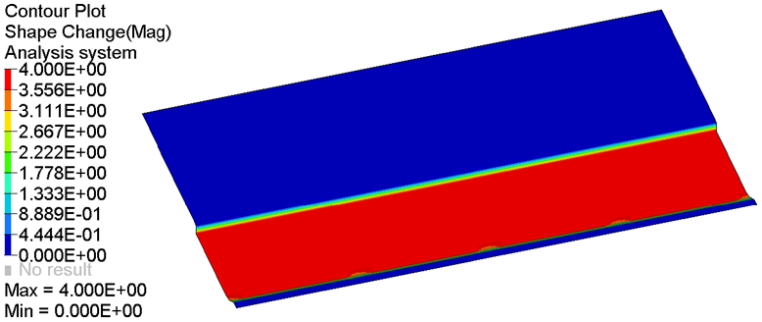


Mag-Shape change, [mm]

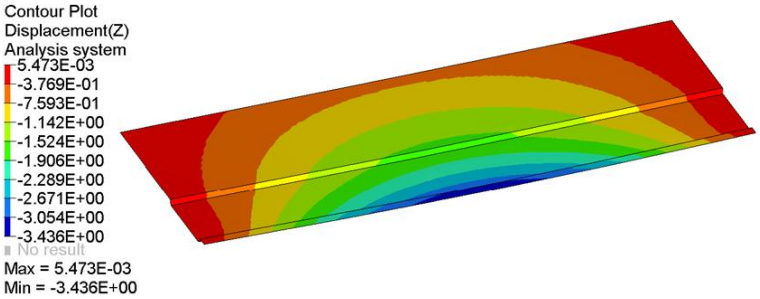


Z-Displacement, [mm]

Manufacture constraints – possible additional stiffness benefits



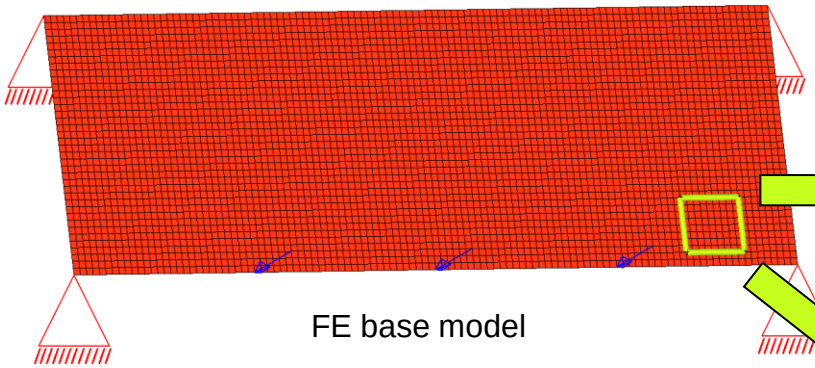
Mag-Shape change, [mm]



Z-Displacement, [mm]

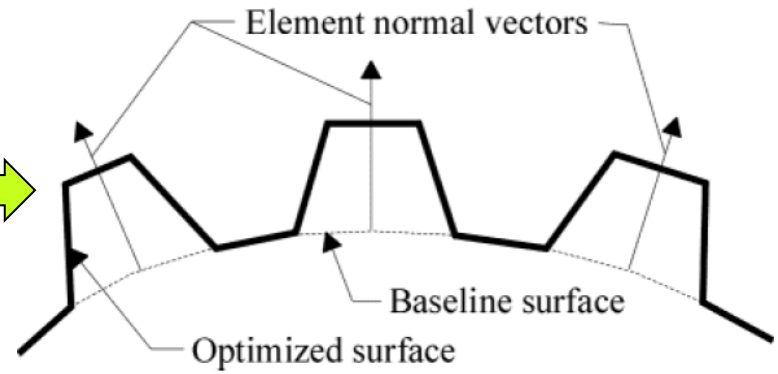
Structural Design – Topography optimization

What does topography optimization mean?

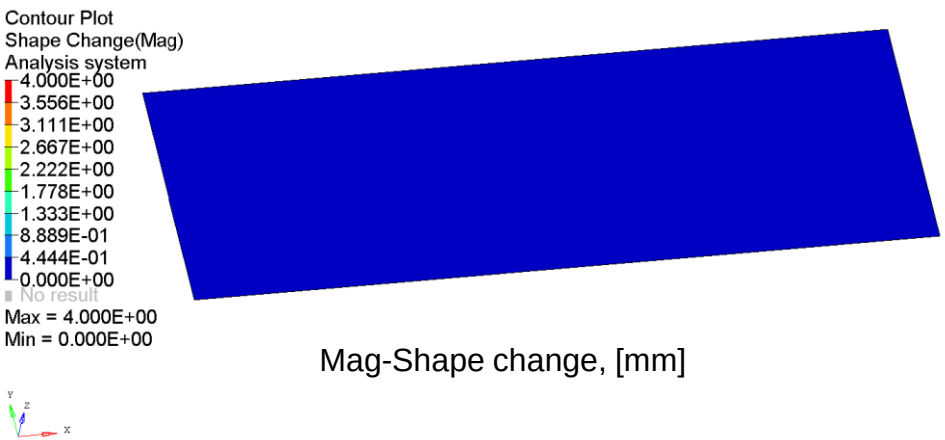


FE base model

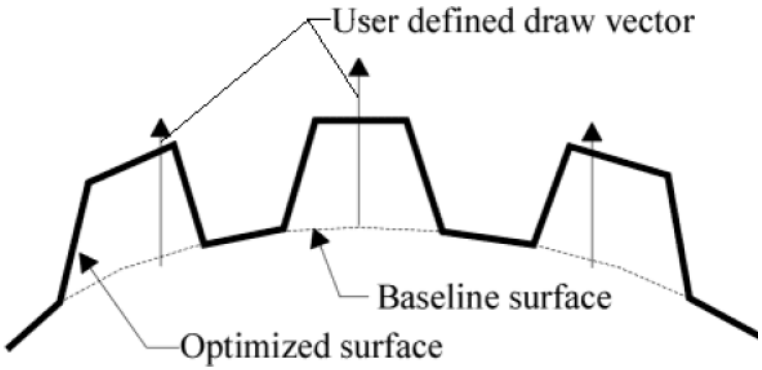
Shape change variants



Source: Altair



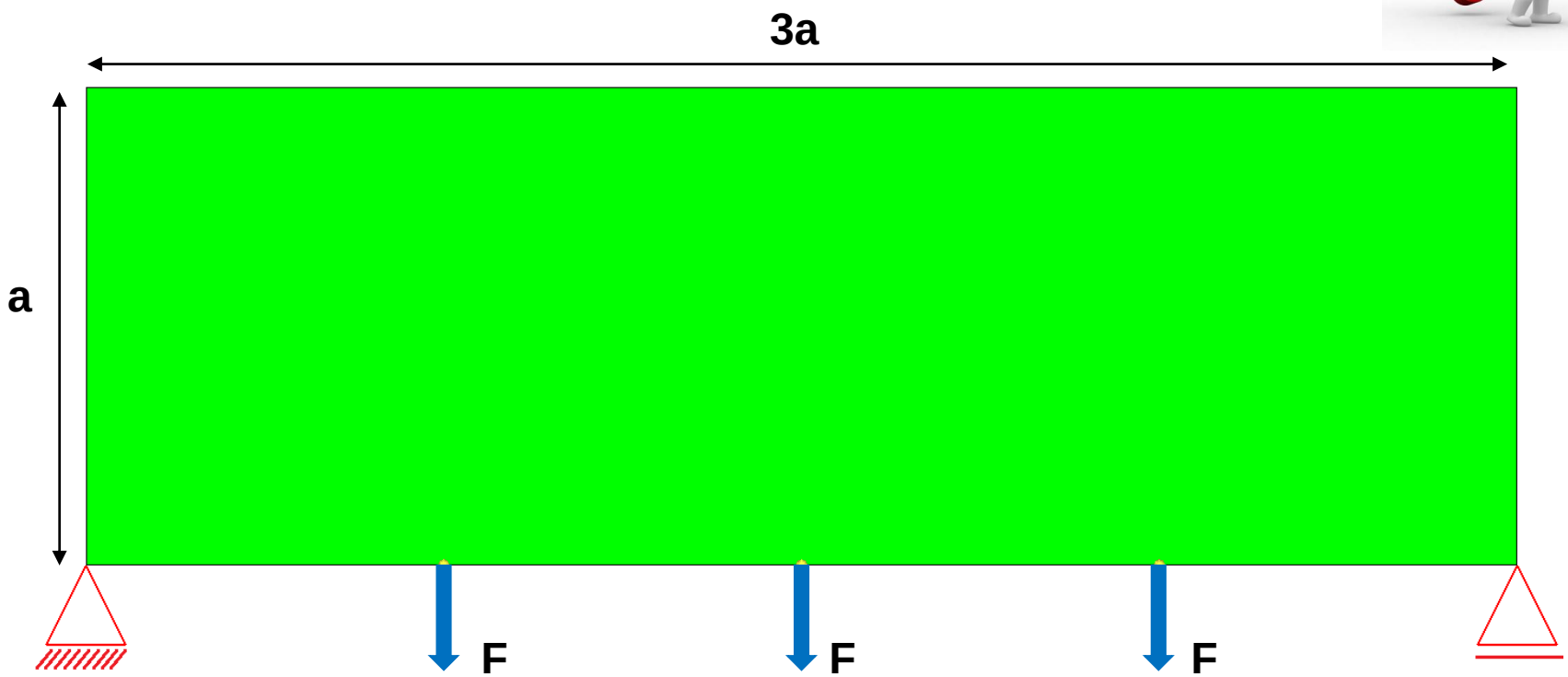
Mag-Shape change, [mm]



Structural Design – Free-size optimization

- **New solution – how to find the best one for the given boundary conditions?**

Steel, linear static, thickness = 1mm

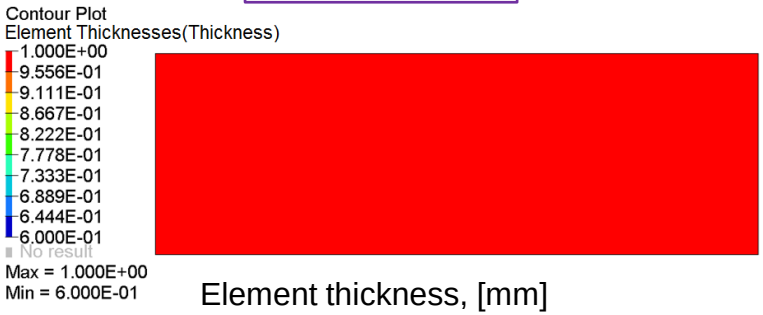


- **What is a possible solution with only 30% of the initial mass?**

Structural Design – Free-size optimization

- **New solution with only 30% of the initial mass**

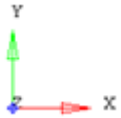
Old design



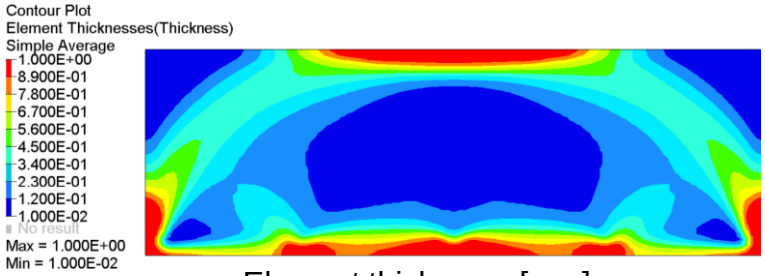
Element thickness, [mm]

Y-Displacement, [mm]

Stress (von Mises), [GPa]



New design



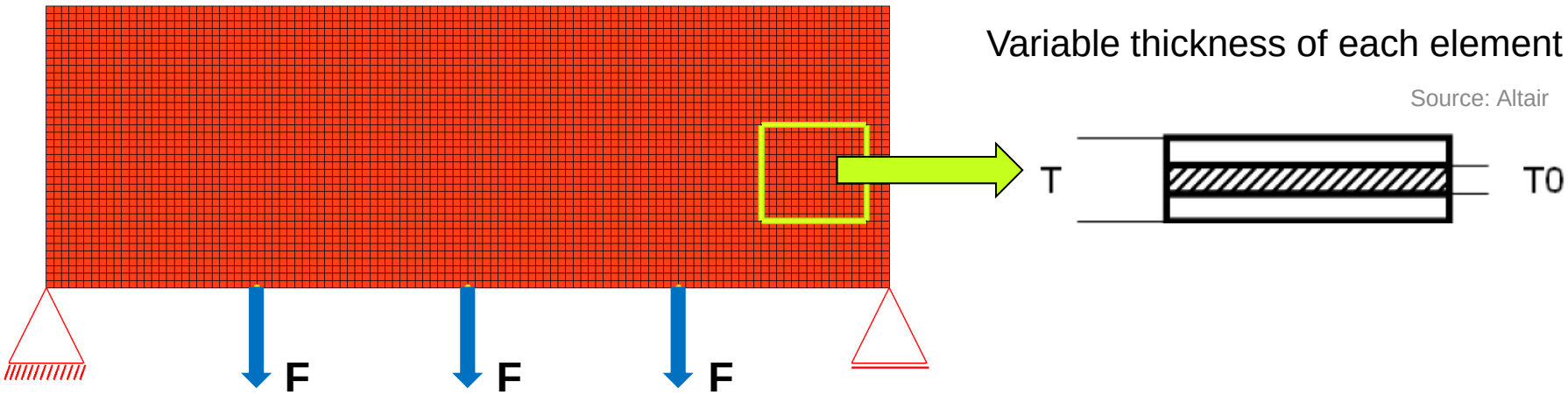
Element thickness, [mm]

Y-Displacement, [mm]

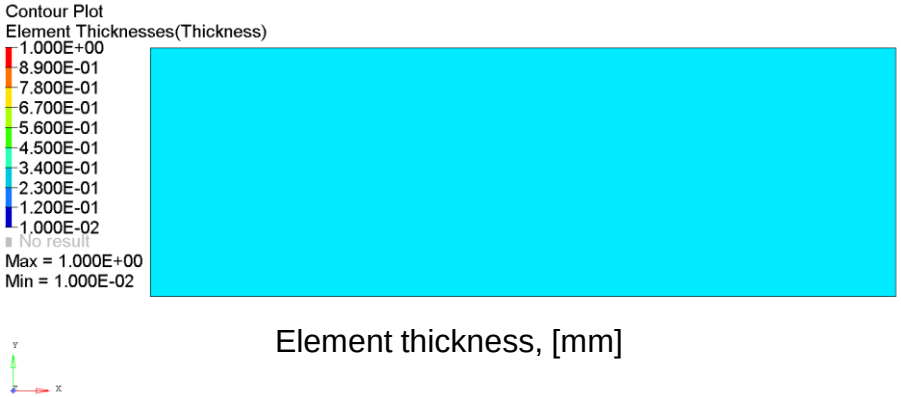
Stress (von Mises), [GPa]

Structural Design – Free-size optimization

What does free-size optimization mean?



FE base model

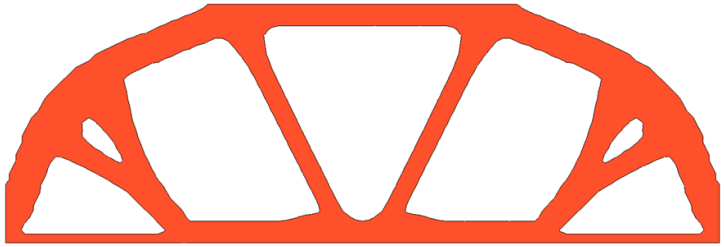


Element thickness, [mm]

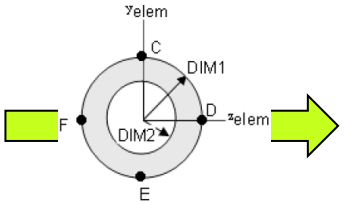
Structural Design – Size optimization

- **New solution based on the topology optimization results**

Topology results interpretation

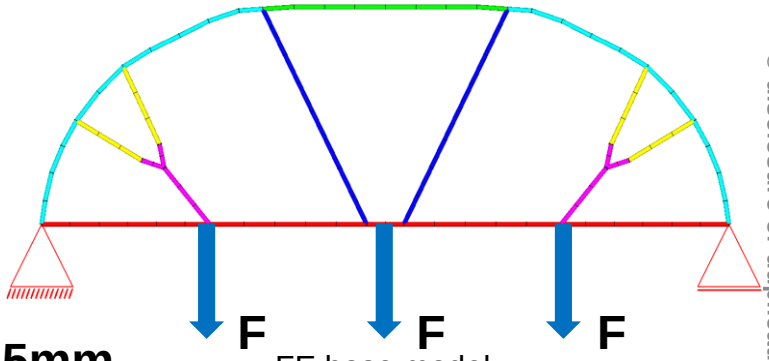


Tube sections



Source: Altair

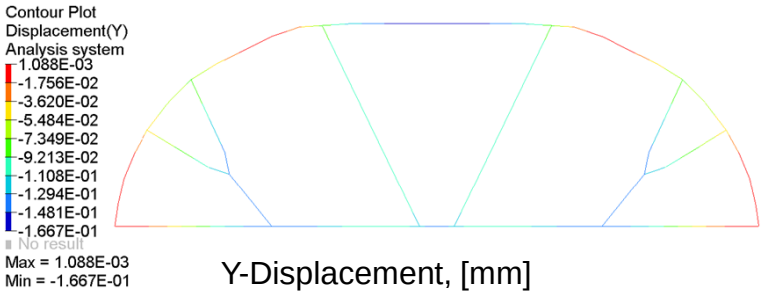
Tube-like structure



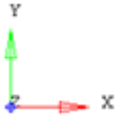
FE base model

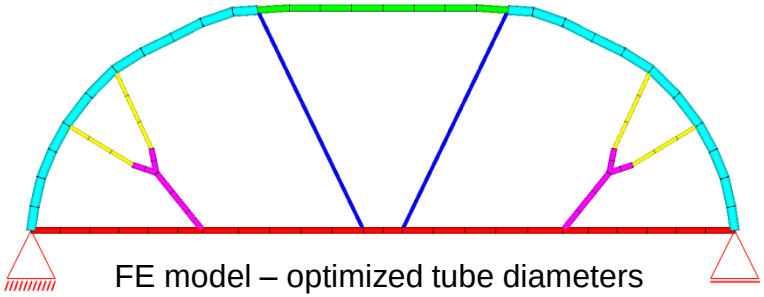
Steel, linear static, DIM1 = 1.5mm, DIM2 = 0.5mm

Size optimization results



Y-Displacement, [mm]



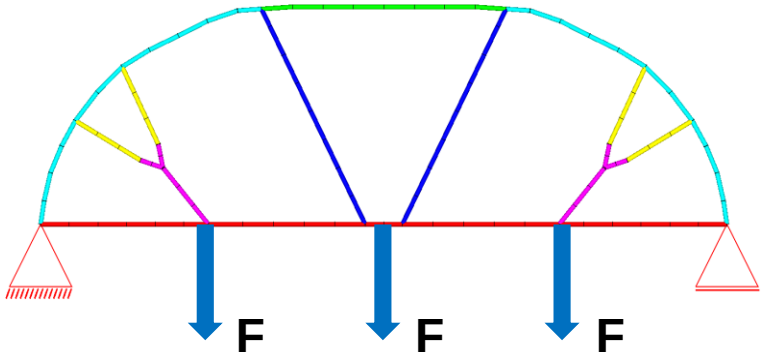


FE model – optimized tube diameters

Structural Design – Size optimization

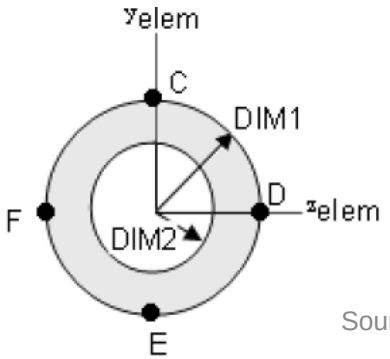
What does size optimization mean?

Tube-like structure



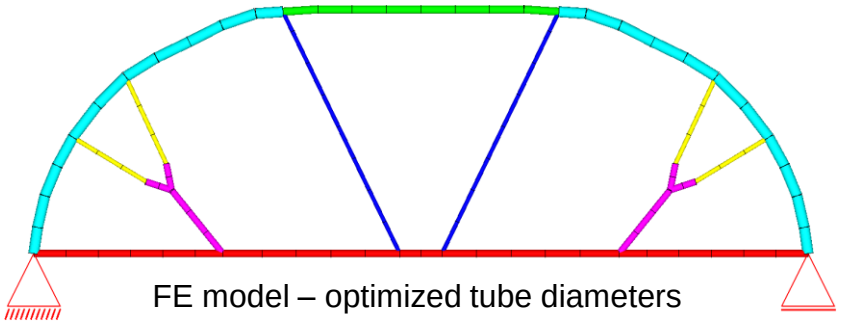
FE base model

Section dimensions (DIM1 & DIM2) as variables



Source: Altair

Size optimization results



FE model – optimized tube diameters

Optimized tube diameters table

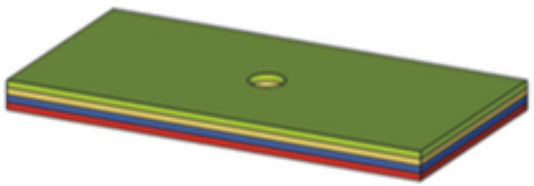
DESIGNED PROPERTY ITEMS TABLE

DVPREL1/2	USER-ID	PROP-TYPE	PROP-ID	ITEM-CODE	PROP-VALUE
DVPREL1	12	PBEAM	5600001	DIM2	9.000E-01
DVPREL1	11	PBEAM	5600001	DIM1	1.900E+00
DVPREL1	10	PBEAM	5500001	DIM2	2.100E+00
DVPREL1	9	PBEAM	5500001	DIM1	3.100E+00
DVPREL1	8	PBEAM	5400001	DIM2	3.000E-01
DVPREL1	7	PBEAM	5400001	DIM1	1.300E+00
DVPREL1	6	PBEAM	5300001	DIM2	2.000E-01
DVPREL1	5	PBEAM	5300001	DIM1	1.200E+00
DVPREL1	4	PBEAM	5200001	DIM2	2.300E+00
DVPREL1	3	PBEAM	5200001	DIM1	3.300E+00
DVPREL1	2	PBEAM	5100001	DIM2	1.100E+00
DVPREL1	1	PBEAM	5100001	DIM1	2.100E+00

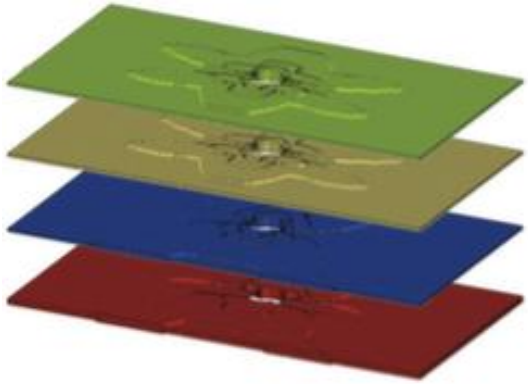
Structural Design – Composite optimization

- **How it works?**

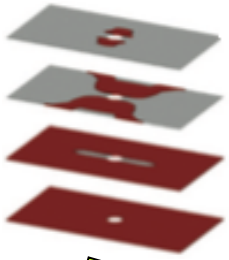
Initial design
e.g. [0,45,-45,90]



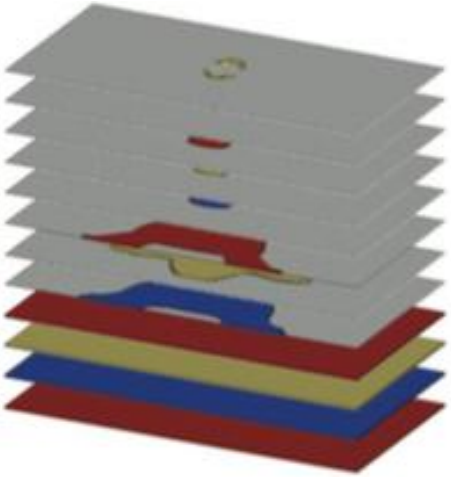
Free-size optimization
Definition of most efficient ply shapes



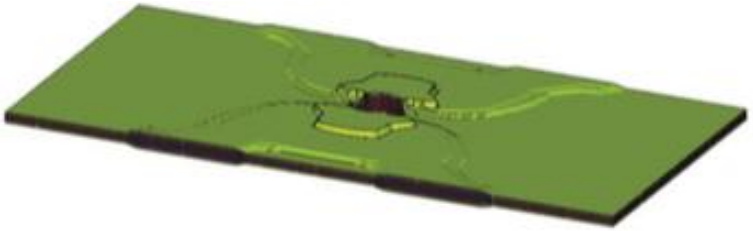
Ply slicing
Ply shapes determination



Size optimization
Plies number of each ply shape
to satisfy engineering requests



Composite shuffling
Stacking sequence to satisfy
manufacturing specifications



Source: Altair

Design Optimization – Vehicle overview

Vehicle class category – L7e

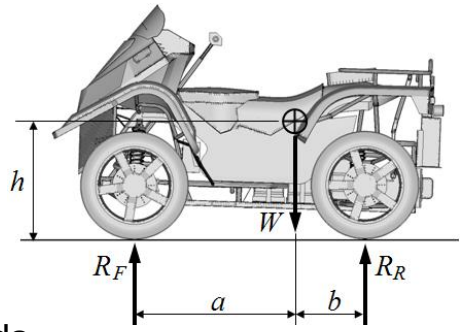
Design Optimization – Vehicle overview

Vehicle class category – L7e

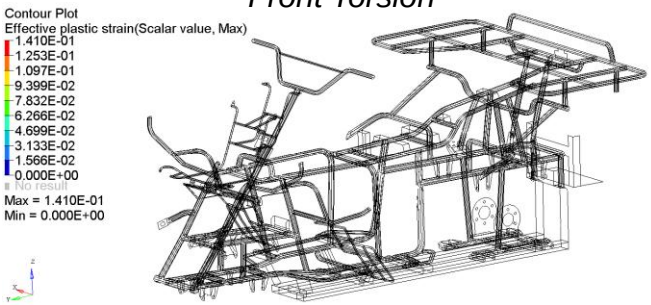
Design Optimization – Loadcases definition

The principal ‘normal running’ global road loadcases were selected as follows:

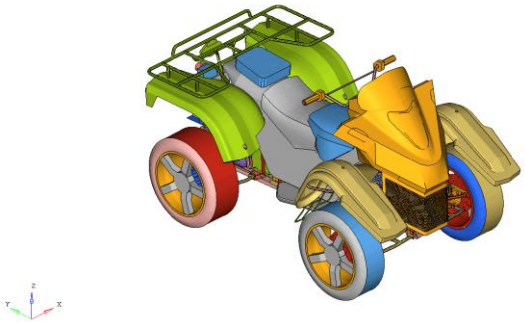
1. *Three Point Bending*
2. *Front & Rear Torsion*
3. *Braking into Front & Rear*
4. *Cornering*
5. *Vertical Bump Front & Rear*
6. *Bending* for the front & rear axle loads
7. *Equivalent Static Front, Rear & Side Crash*

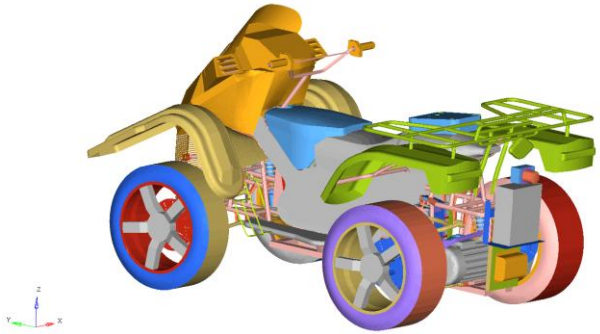


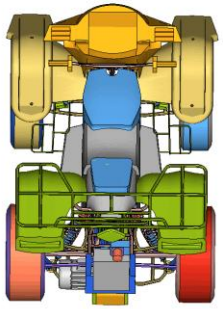
Front Torsion

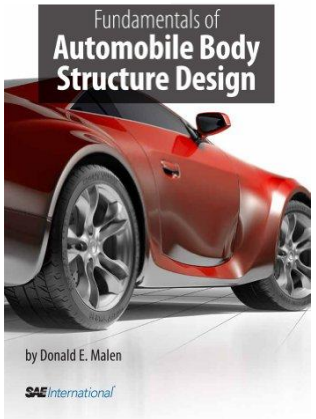


Effective plastic strain, [-]





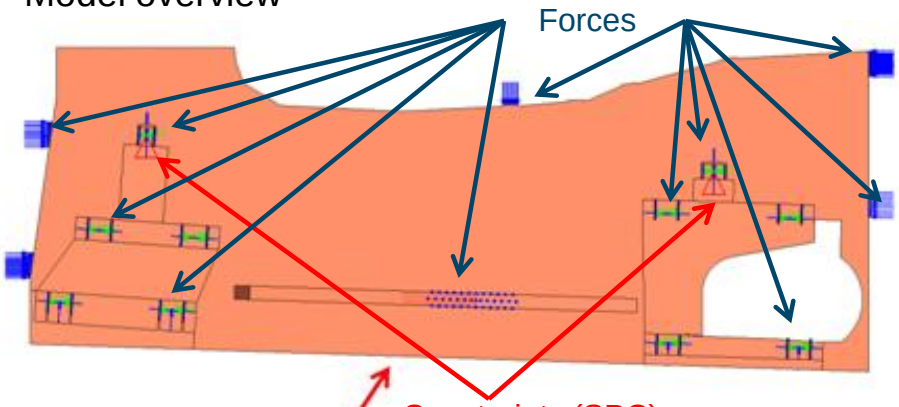


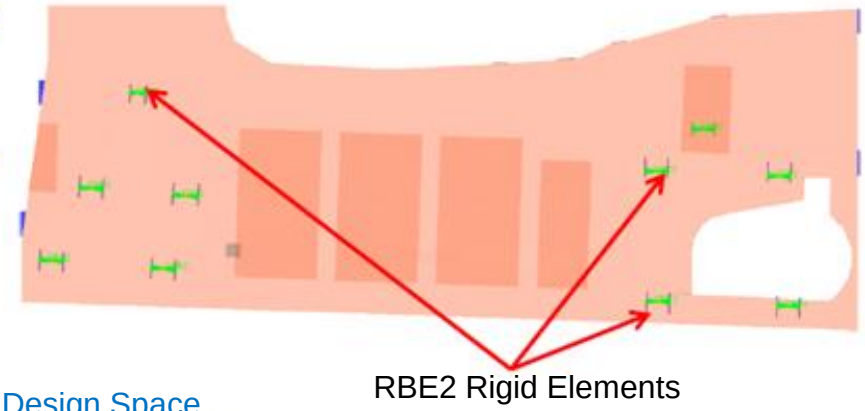


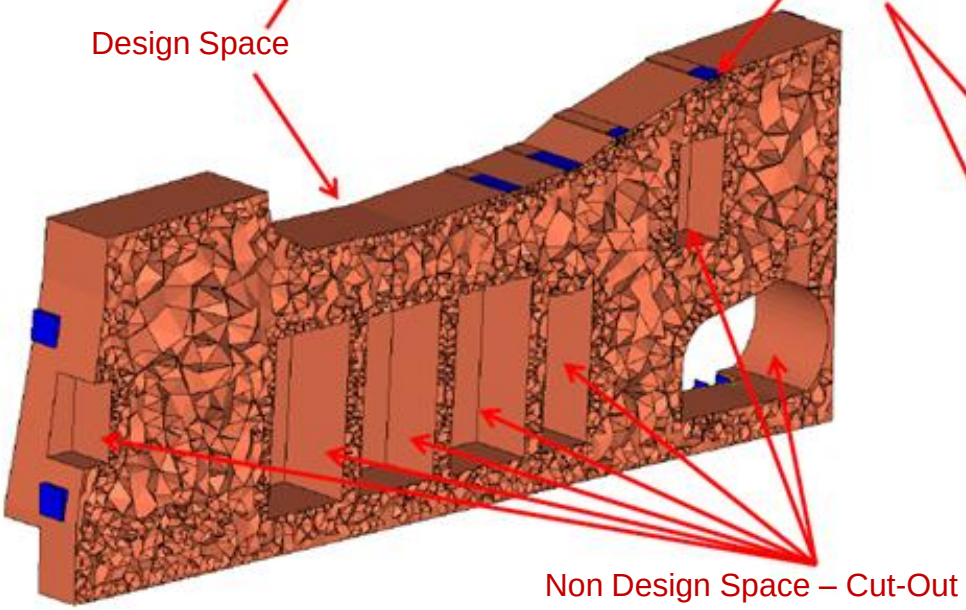
First-order models enable instant analysis for the what-if questions during early design phase, Donald E. Malen

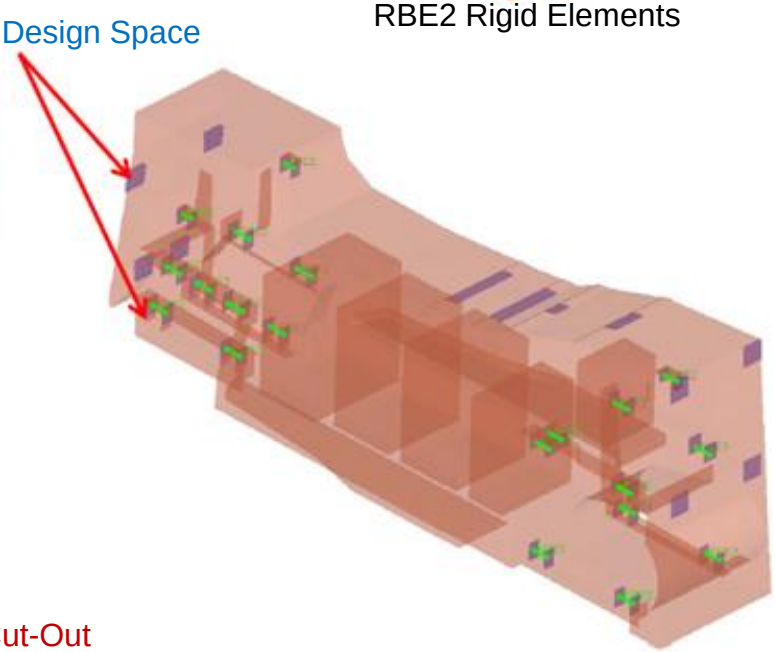
Design Optimization – FE model

Model overview







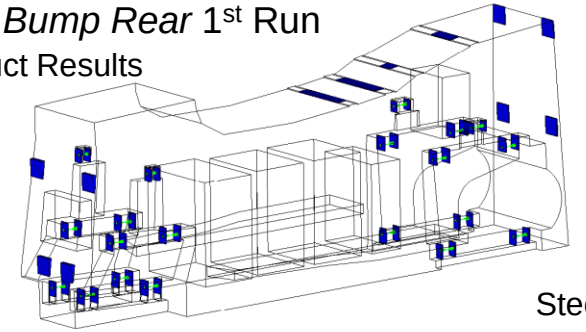


Material: steel, linear static

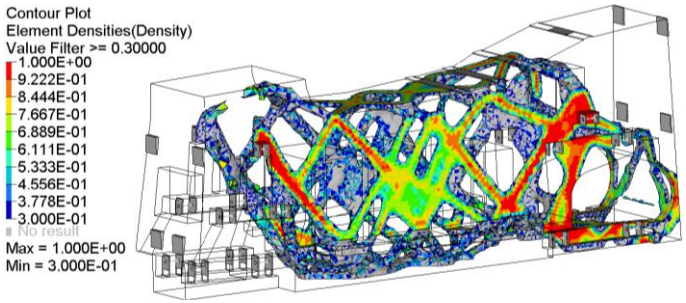
Design Optimization – Topology

Vertical Bump Rear 1st Run

OptiStruct Results

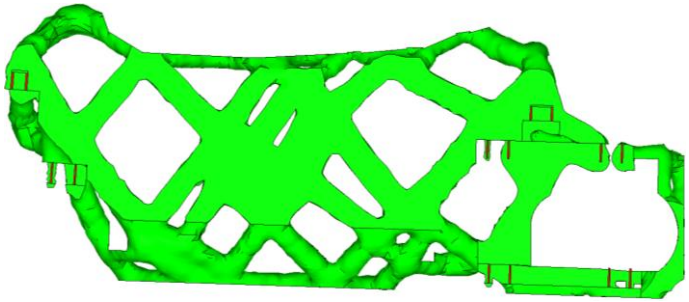


Steel, Vol. Fraction = 0.055

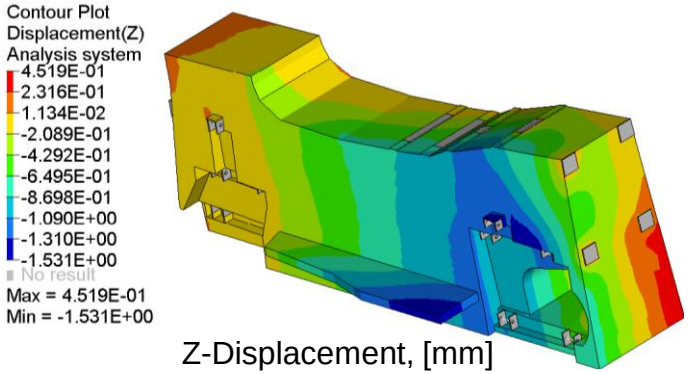


Element density, [-]

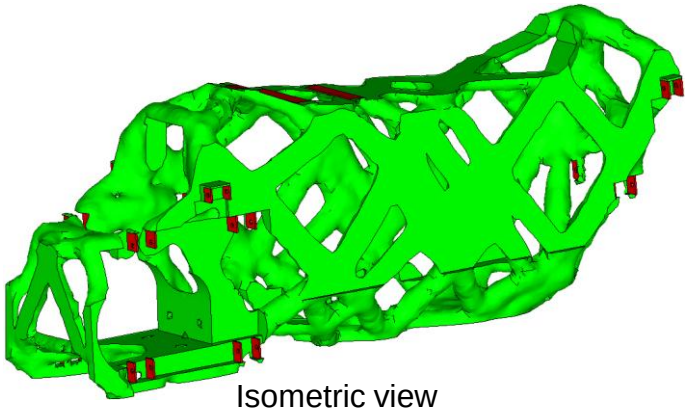
OSSmooth Results for 2nd Run



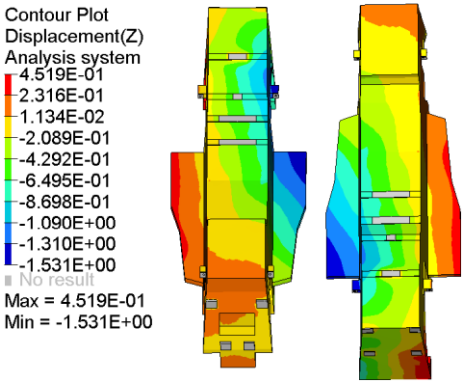
Side view



Z-Displacement, [mm]



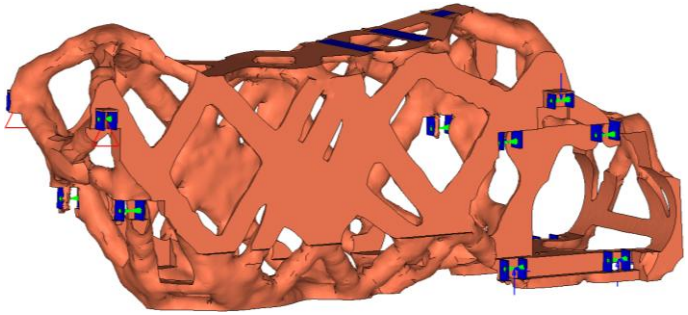
Isometric view



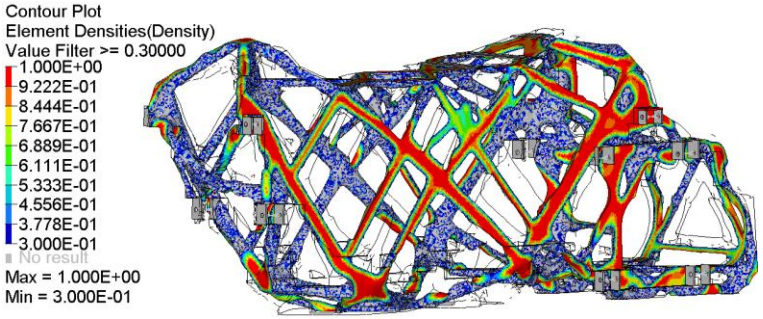
Z-Displacement, [mm]

Design Optimization – Topology

Vertical Bump Rear 2nd Run



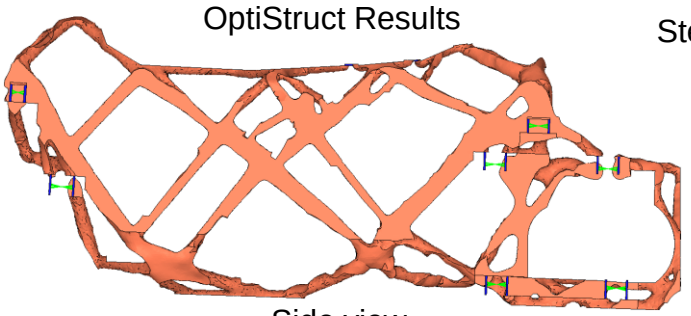
FE model for 2nd Run



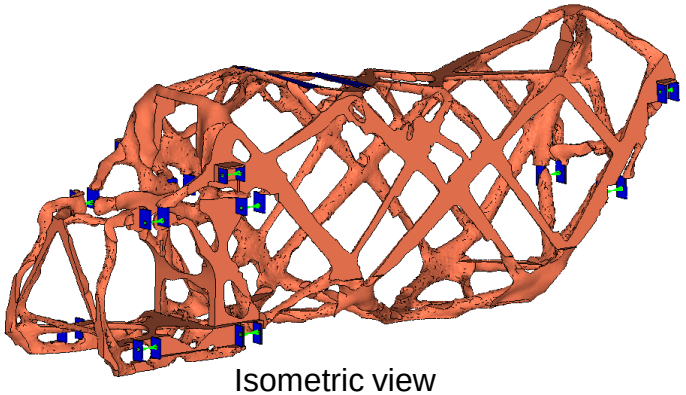
Element density, [-]

OptiStruct Results

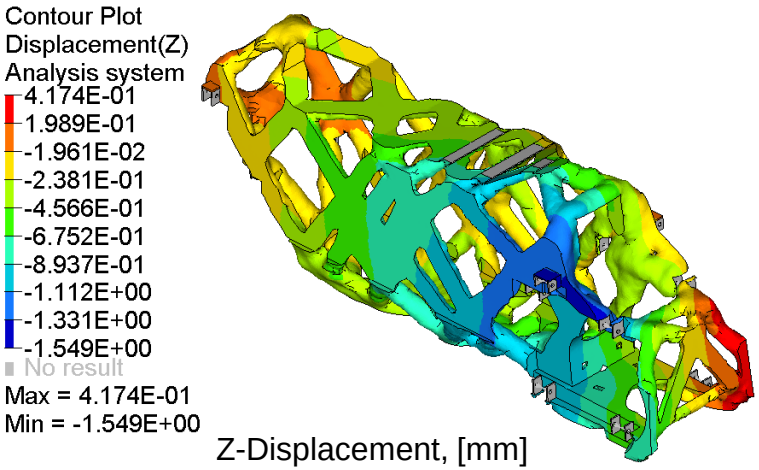
Steel, Vol. Fraction = 0.230



Side view



Isometric view

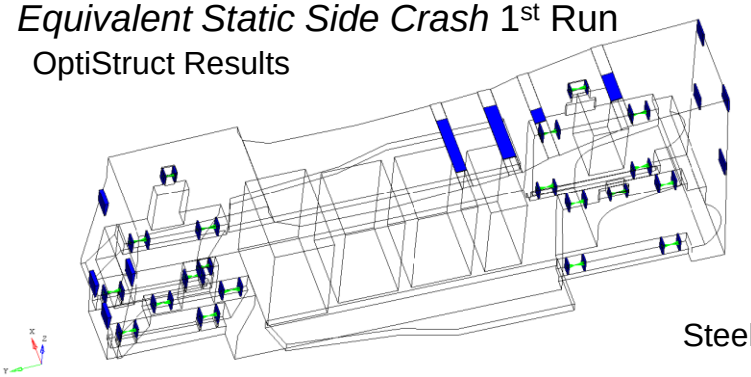


Z-Displacement, [mm]

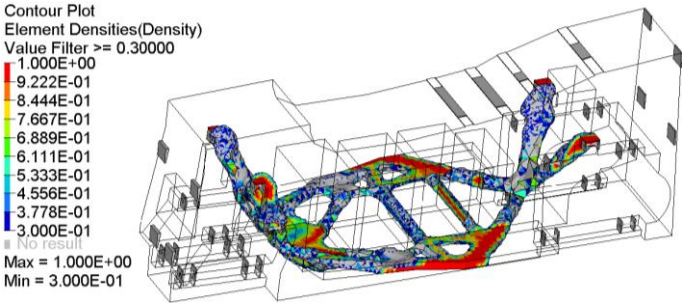
Design Optimization – Topology

Equivalent Static Side Crash 1st Run

OptiStruct Results

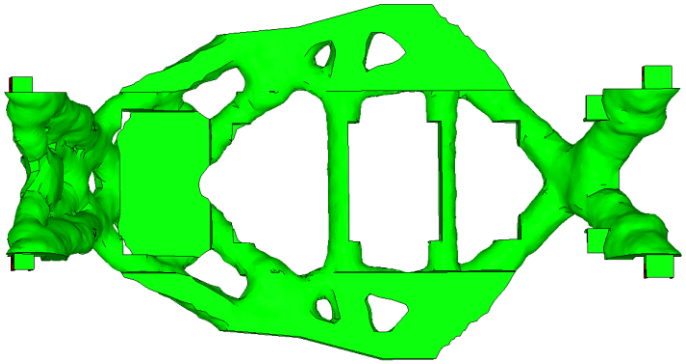


Steel, Vol. Fraction = 0.030

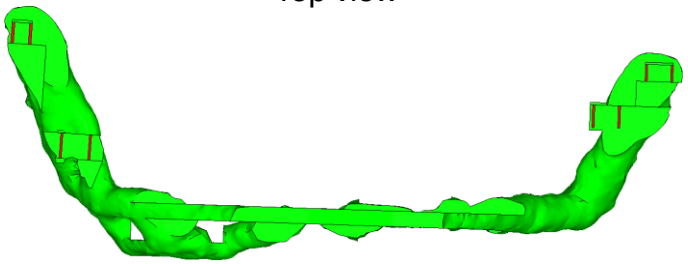


Element density, [-]

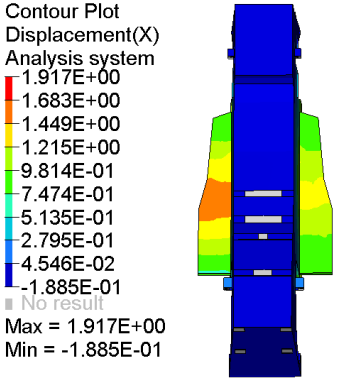
OSSmooth Results for 2nd Run



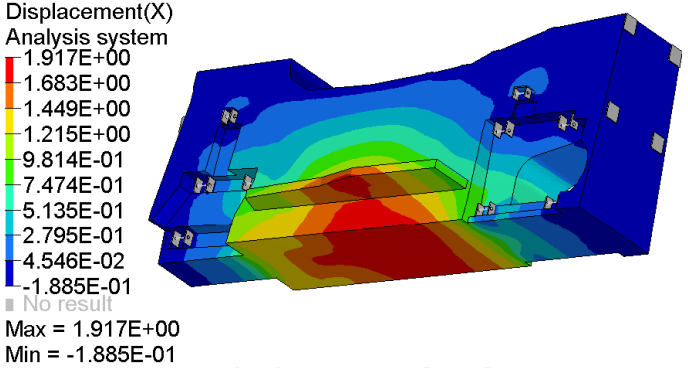
Top view



Side view



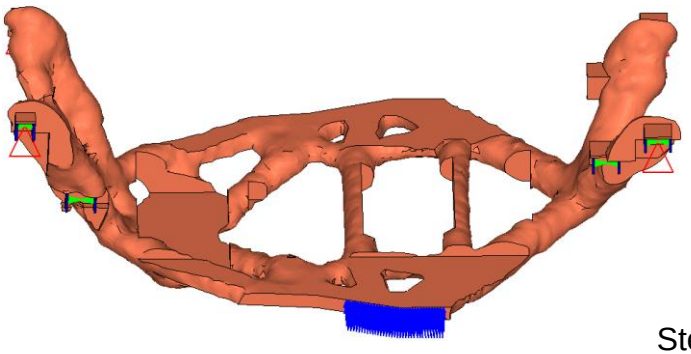
X-Displacement, [mm]



X-Displacement, [mm]

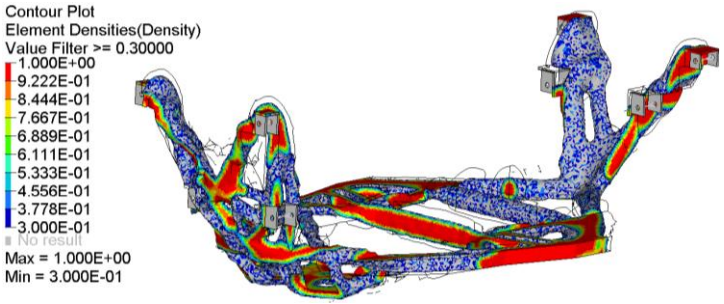
Design Optimization – Topology

Equivalent Static Side Crash 2nd Run



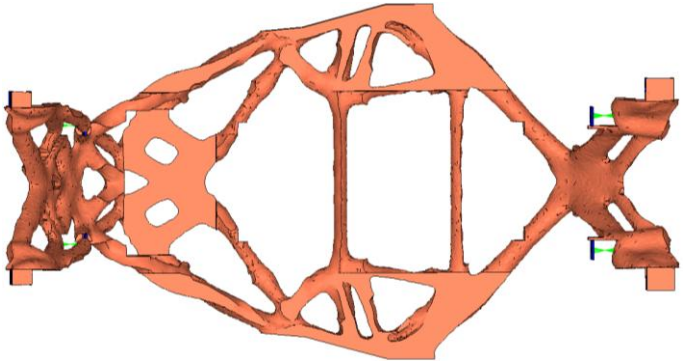
FE model for 2nd Run

Steel, Vol. Fraction = 0.320

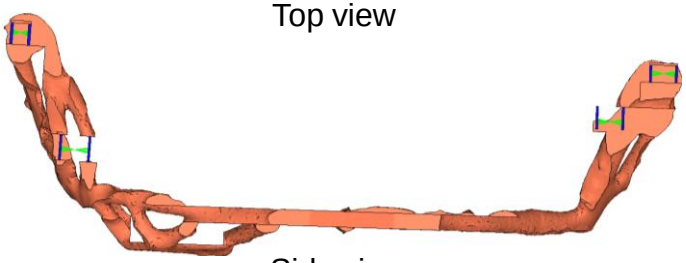


Element density, [-]

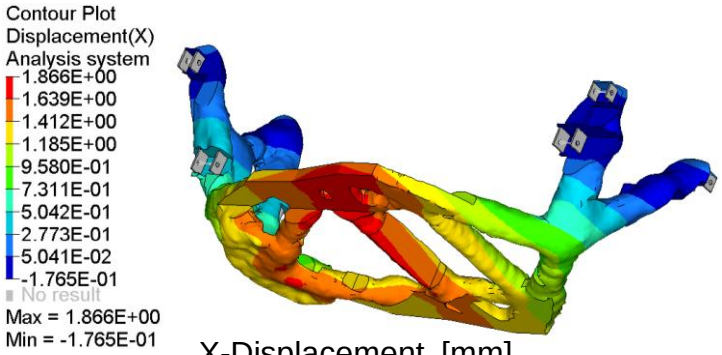
OptiStruct Results



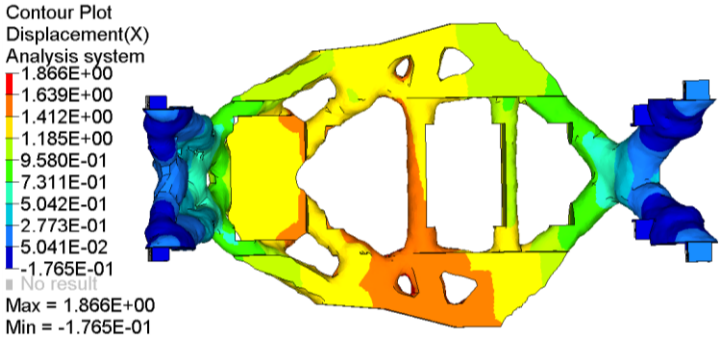
Top view



Side view



X-Displacement, [mm]

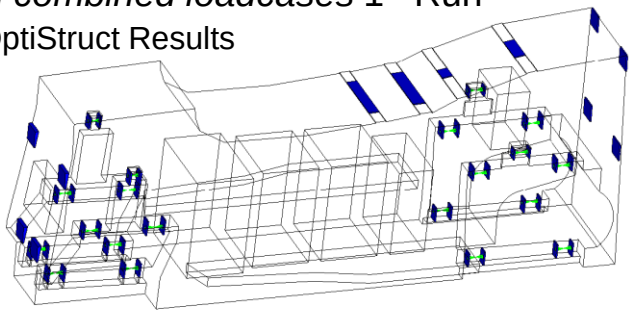


X-Displacement, [mm]

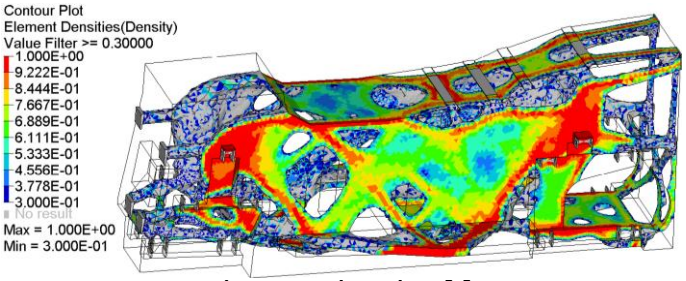
Design Optimization – Topology

All combined loadcases 1st Run

OptiStruct Results

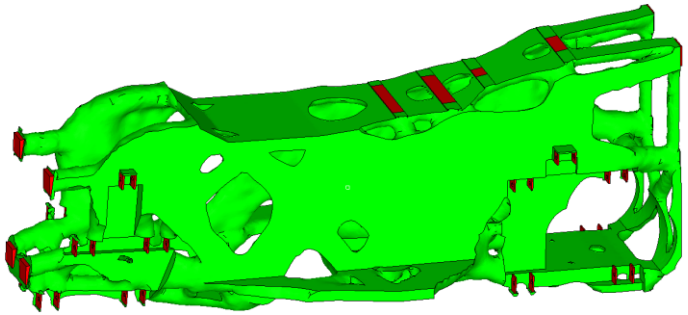


Steel, Vol. Fraction = 0.100



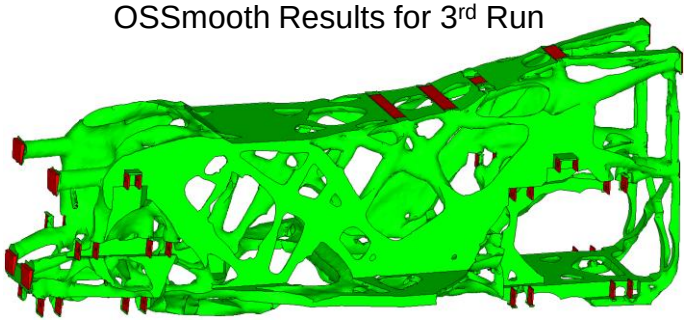
Element density, [-]

OSSmooth Results for 2nd Run



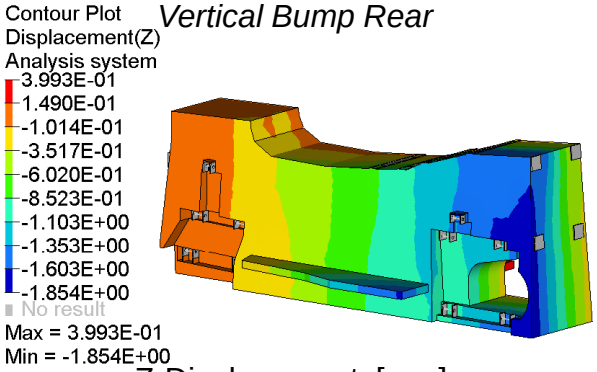
Isometric view

OSSmooth Results for 3rd Run



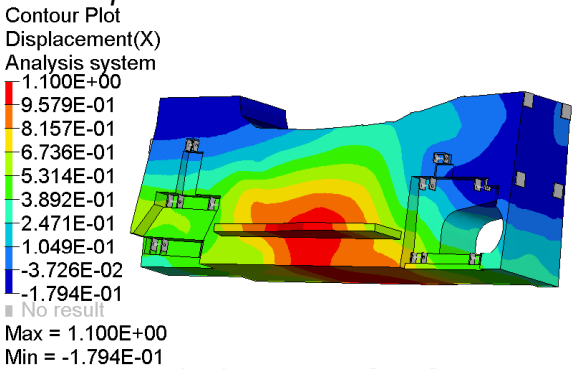
Isometric view

Vertical Bump Rear



Z-Displacement, [mm]

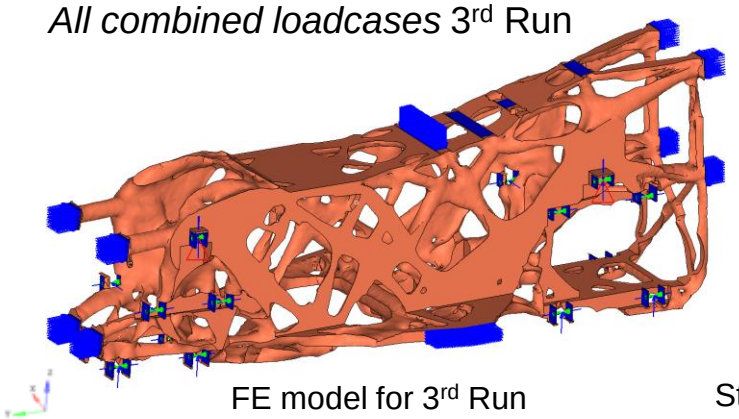
Equivalent Static Side Crash



X-Displacement, [mm]

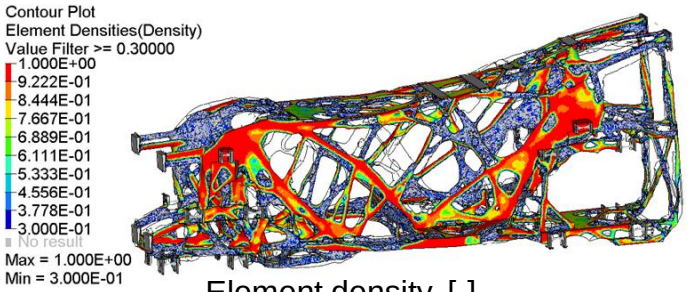
Design Optimization – Topology

All combined loadcases 3rd Run



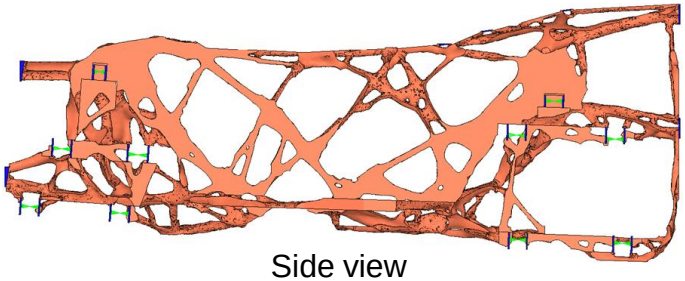
FE model for 3rd Run

Steel, Vol. Fraction = 0.325

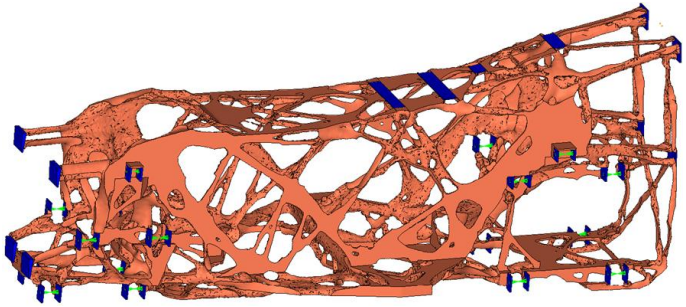


Element density, [-]

OptiStruct Results

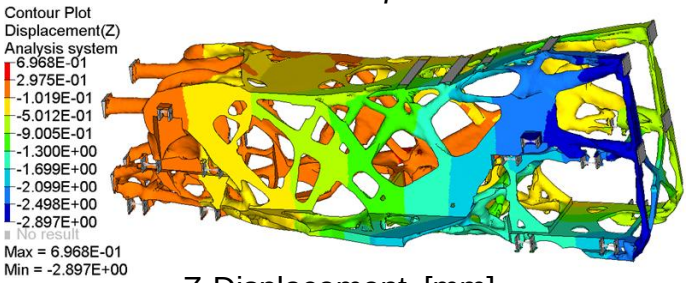


Side view



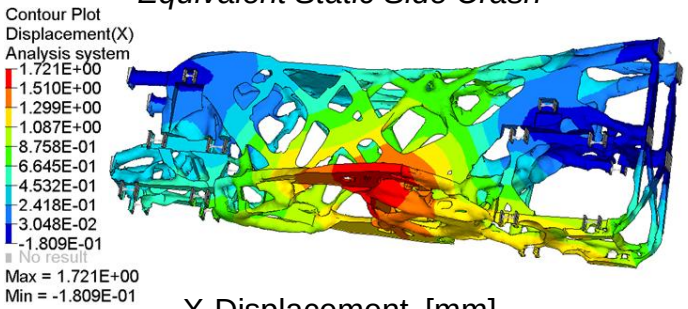
Isometric view

Vertical Bump Rear



Z-Displacement, [mm]

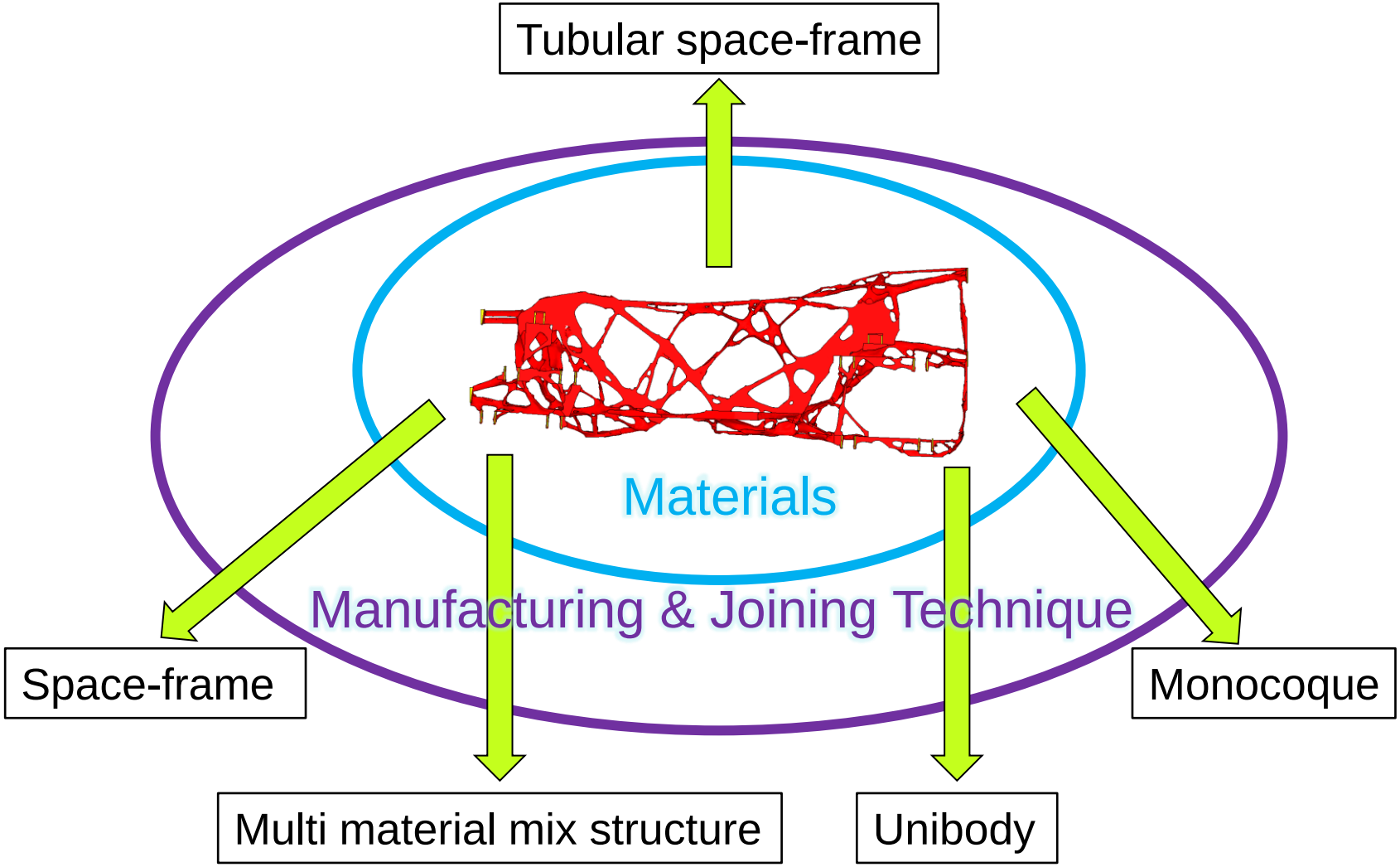
Equivalent Static Side Crash



X-Displacement, [mm]

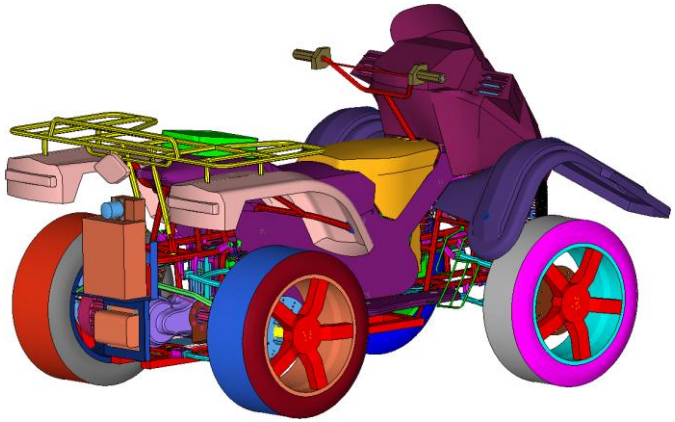
Design Optimization – Topology

Available interpretation possibilities of the topology optimization results



Summary

- The optimization (especially topology) is only an advice tool, not a “magic black box” for ready-made solution
- Topology optimization shows the flow of forces for given boundary conditions
- For all types of optimization the boundary conditions need to be defined precisely
- There is a further potential to reduce the mass of the structure – results interpretation plays a very important role at this stage of development to use the full advantage of the optimization process



Danke für Ihre Aufmerksamkeit!

Roman Jedrzejczyk
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RomanPawel.Jedrzejczyk@v2c2.at