

Topology Optimization As First Step Towards Optimal Products

November 2013

INTES GmbH, Stuttgart

www.intes.de

INTES

INTES Ingenieurgesellschaft für technische Software mbH



Privately held and independent Finite Element Technology company since 1984 located in Stuttgart, Paris, and Tokyo

Offering own FE analysis software PERMAS with VisPER, software development, and consulting services

Unified software for thermo-mechanics, vibro-acoustics, and optimization



INTES

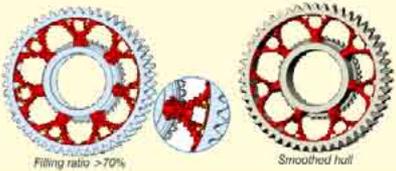
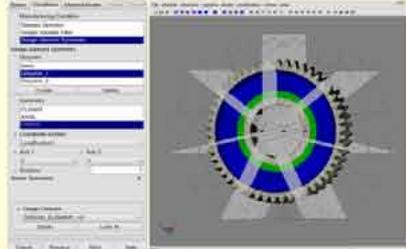
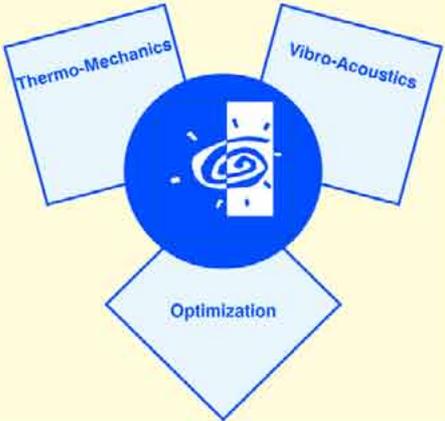
INTES GmbH
Schulze-Delitzsch-Str. 16
D-70585 Stuttgart
Phone +49-711-78499-0
Fax +49-711-78499-10
E-mail: info@intes.de
http://www.intes.de



High performance computing by parallelization (multi-threading) and special algorithms (contact, MLDR, fluid-structure coupling)

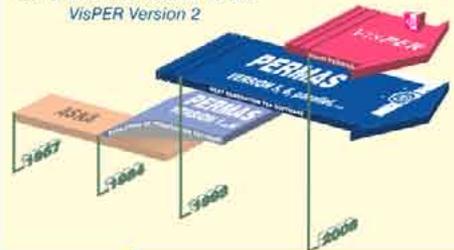
Unified concepts like incompatible meshes, substructuring, submodelling

Simulation-driven design by integrated optimization (topology, shape, sizing, bead) with local and global methods



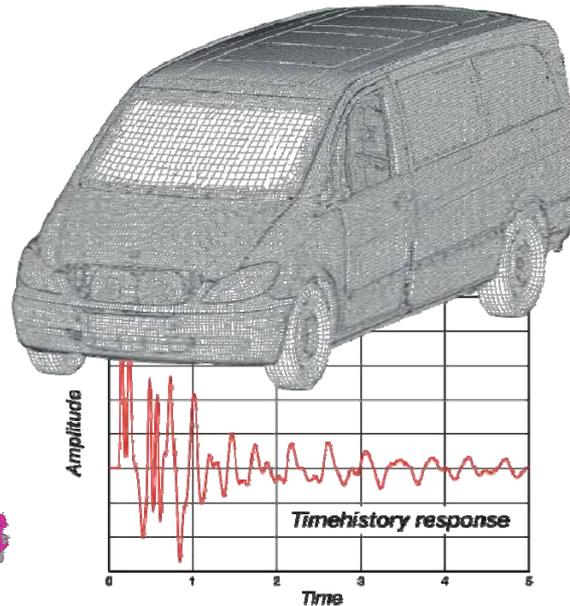
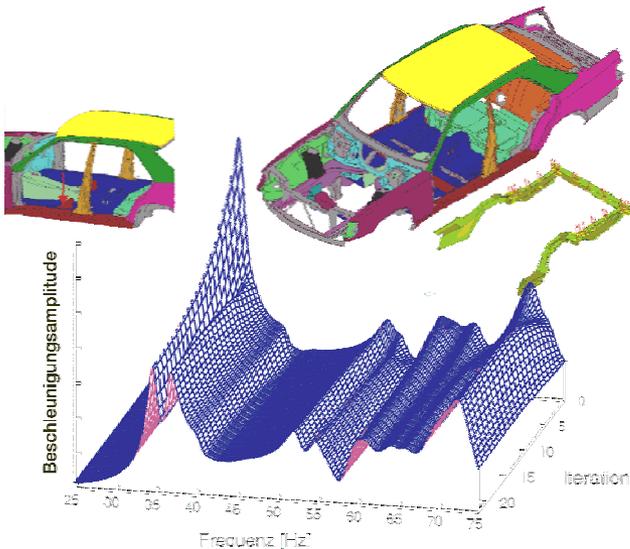
By courtesy of Daimler Trucks Germany

- 1984: Start of software industrialization and new developments in optimization, acoustics, and reliability
- 1989: Start of full re-design of software for higher speed of development and Nastran compatibility
- 1993: PERMAS Version 5 available, the new software basis for further development
- 2005: Start of VisPER development, a new graphical user interface for PERMAS
- 2008: VisPER Version 1
- 2010: PERMAS Version 13 and VisPER Version 2



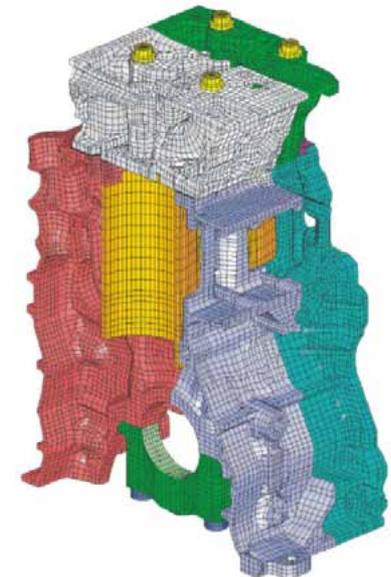
Vibro-acoustic analysis:

- Dynamic analysis (in time and frequency domain)
- Fluid-structure acoustics
- Spectral and random response analysis



Thermo-mechanical analysis:

- Linear and non-linear static analysis
- Contact analysis
- Linear and non-linear heat transfer



Integrated optimization:

- Topology optimization
- Sizing and shape optimization
- Reliability analysis and robust design

- **Methods:**
 - Topology optimization
 - Bead generation
 - Positioning optimization (bolts, ribs)
- **Starting from an existing model**
 - Generation of additional optimization model
- **Integrated simulation**
 - FE analysis and optimization
- **Simulation-driven design**
 - Analyst provides conceptual design
 - Integrated proof of concept by simulation

FE Analysis (Forward problem)

Structural Design

- loading
- kinematic constraints
- model properties



analysis results



Optimization (Inverse problem)

Design Space

- loading
- kinematic constraints
- model properties
- **analysis results**



Structural Design



The result of an optimization is a FE model with predefined properties which is optimal with respect to a given criterion.

Filling Ratios as Switches



- filling ratio ≈ 1 \Rightarrow full stiffness and material density in the respective finite element
- $0 < \text{filling ratio} \ll 1$ \Rightarrow stiffness and material density in the respective finite element ≈ 0

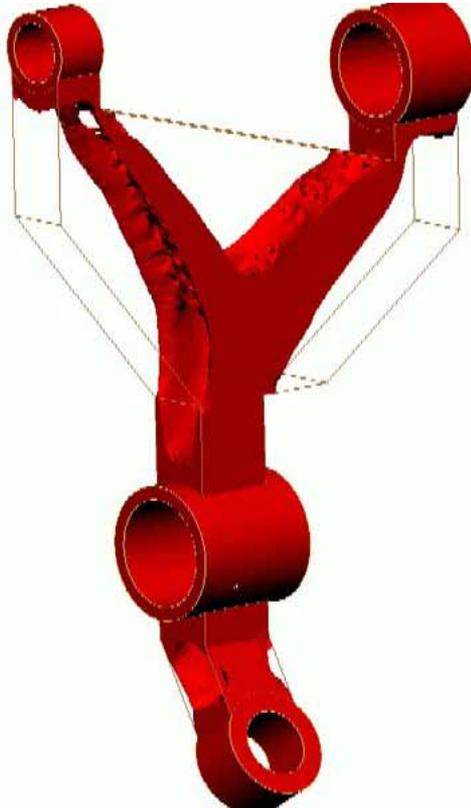
The optimizer uses filling ratios to switch the influence of finite elements on the mechanical behavior of the structure on or off.

\Rightarrow Finite elements, which are irrelevant for fulfilling the optimization conditions or for reaching the optimization objective, can be switched off by reducing their filling ratios close to zero.

Important to note:

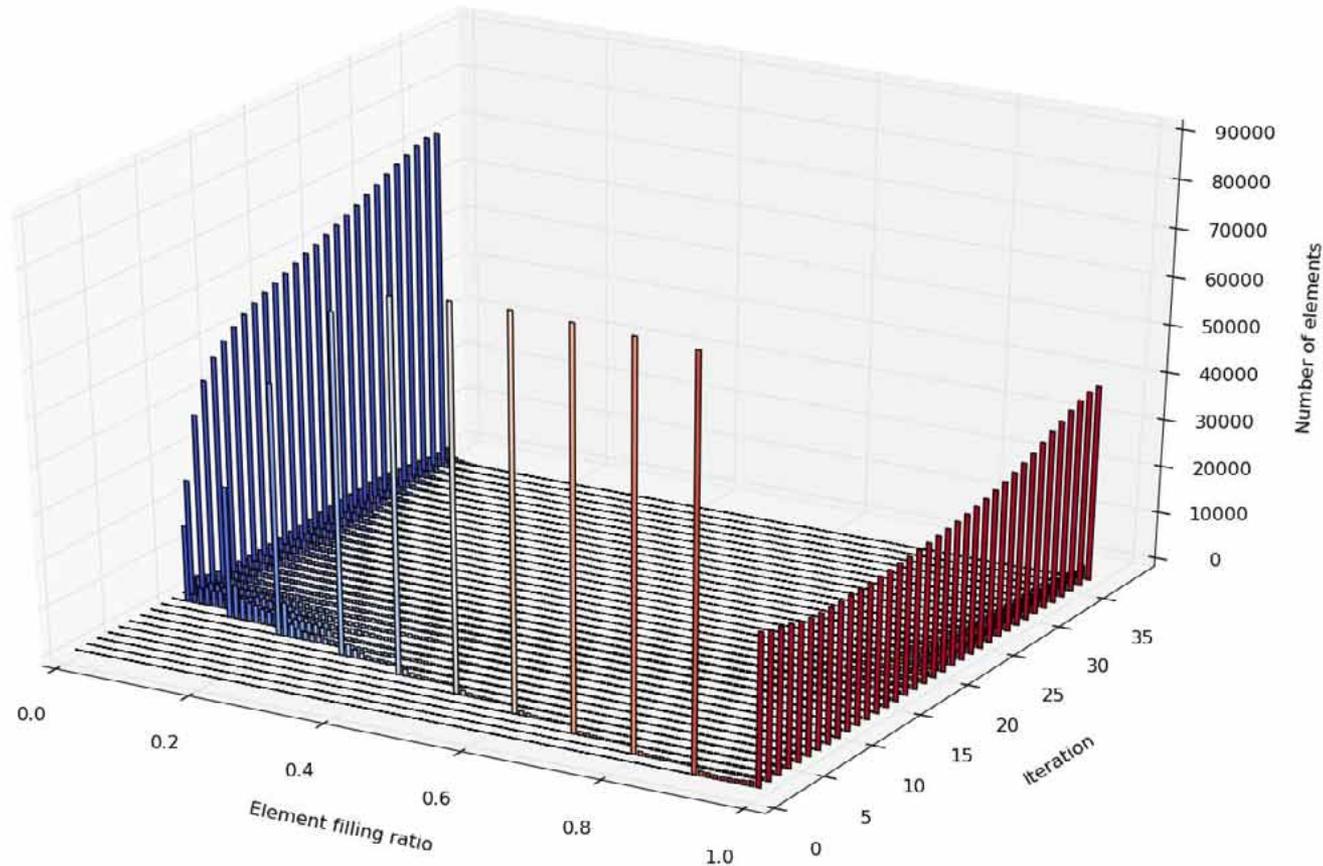
The quality of the result achieved by topology optimization depends on a clear separation between filling ratios of almost 1 and almost 0.

Filling Ratios as Switches



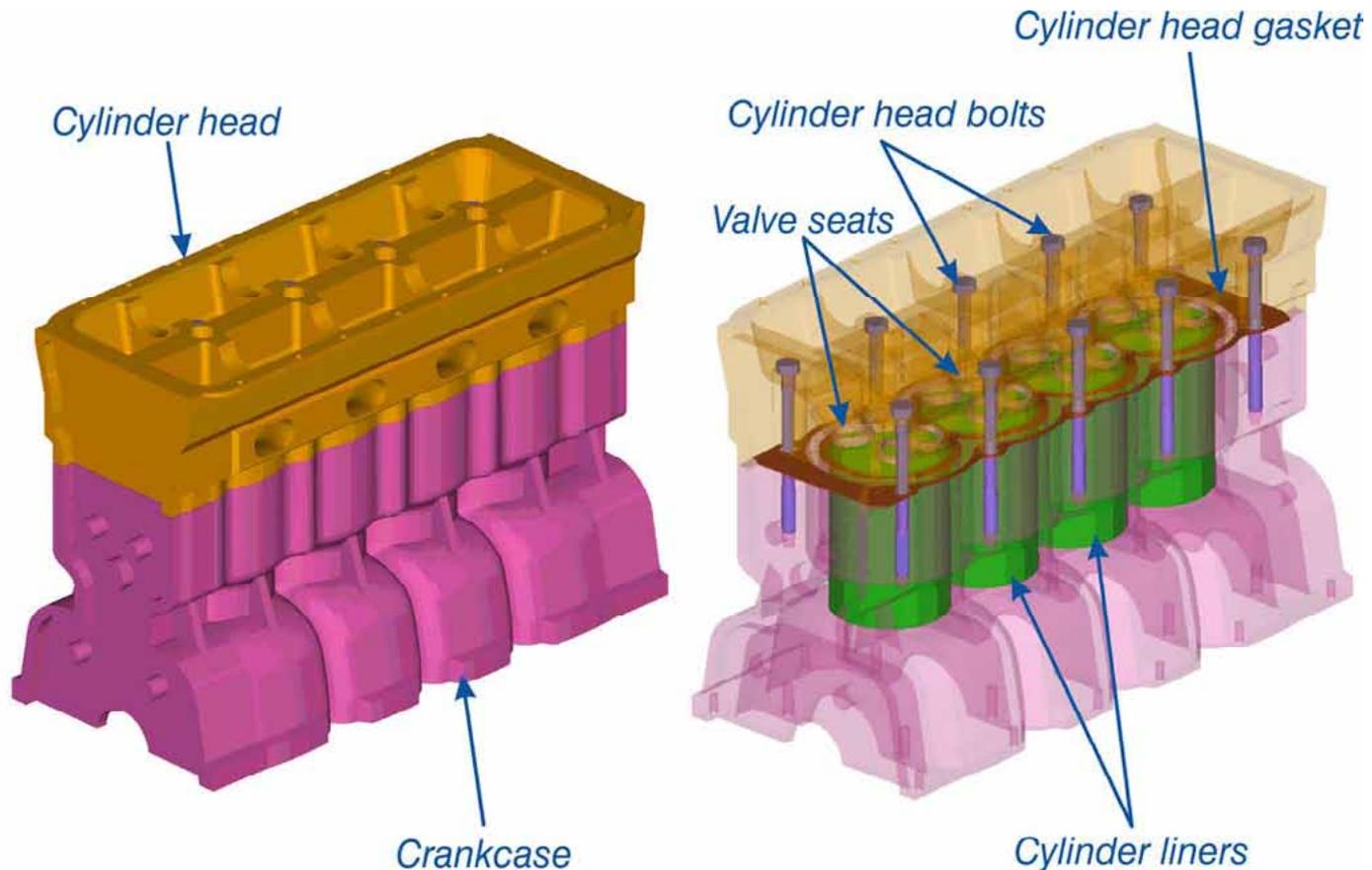
Example taken from:
J.-C. Cuilliere, V. Francois,
J.-M. Drouet
Automatic mesh generation and
transformation for topology
optimization methods
Computer-Aided Design Vol. 45
(2013), pp. 1489--1506

Evolution of the Element Filling Ratio



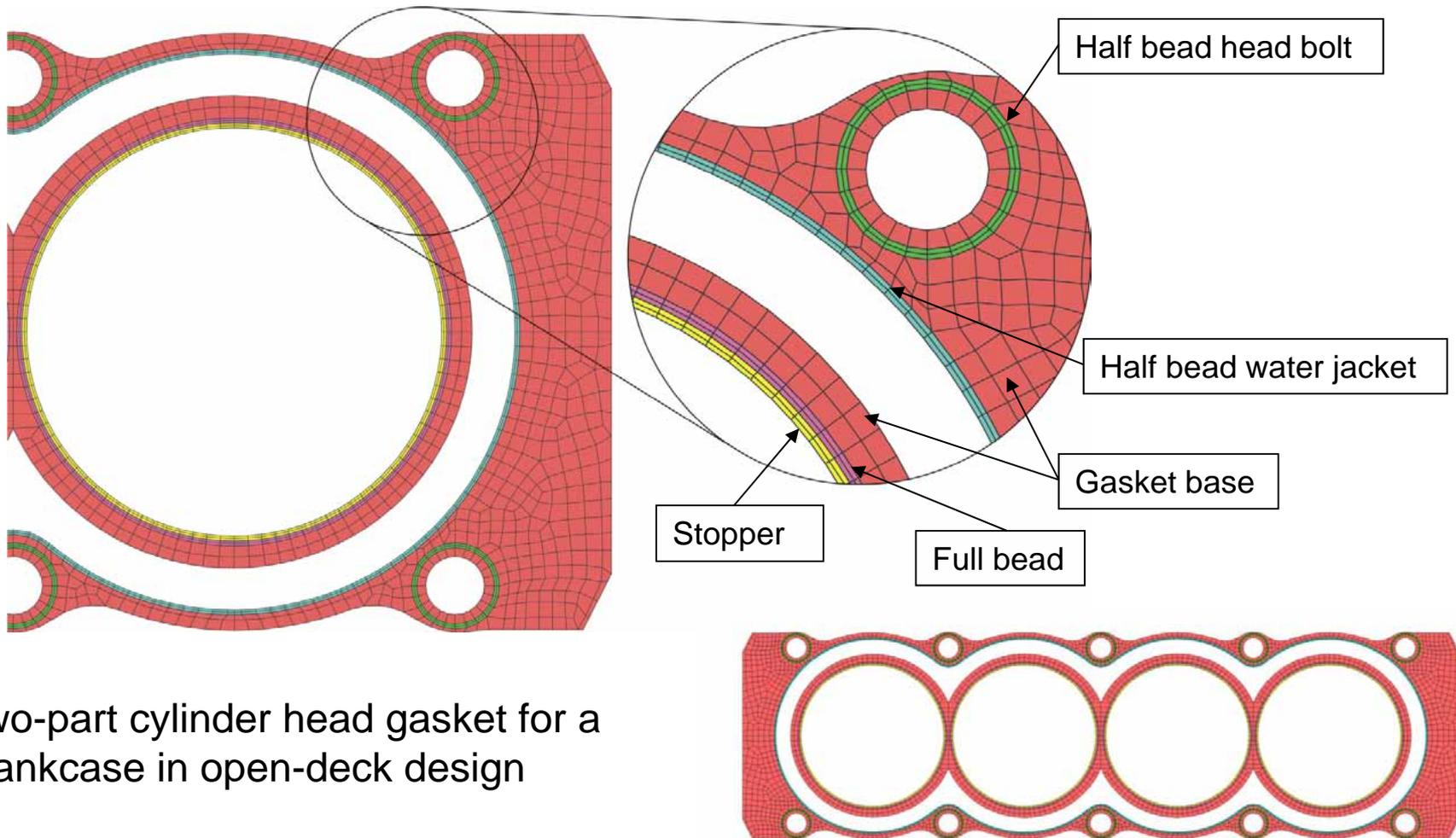
- A clear separation between void and *full* elements becomes apparent with proceeding number of iterations

Engine Model



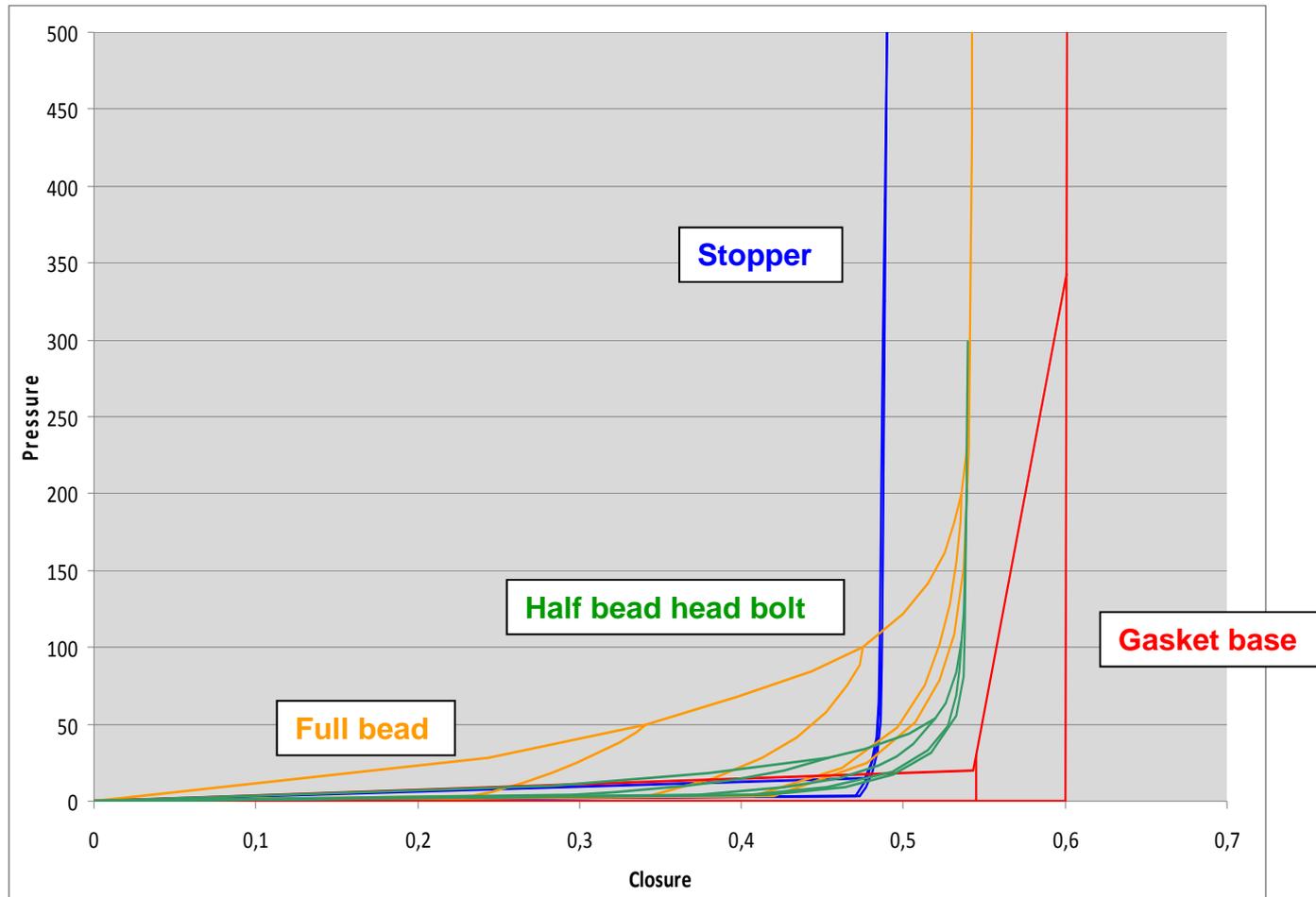
The support of the engine is made at the lower end of the engine block by a so-called minimal support which does not introduce any constraints.

Structure of Cylinder Head Gasket



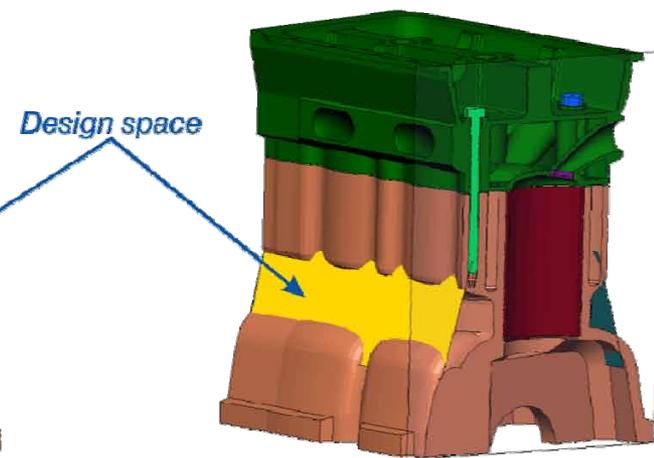
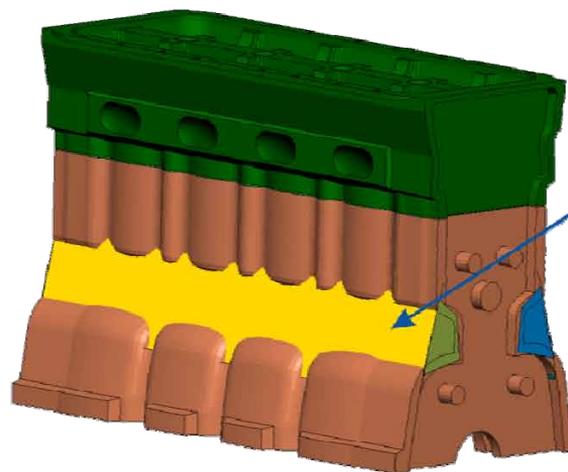
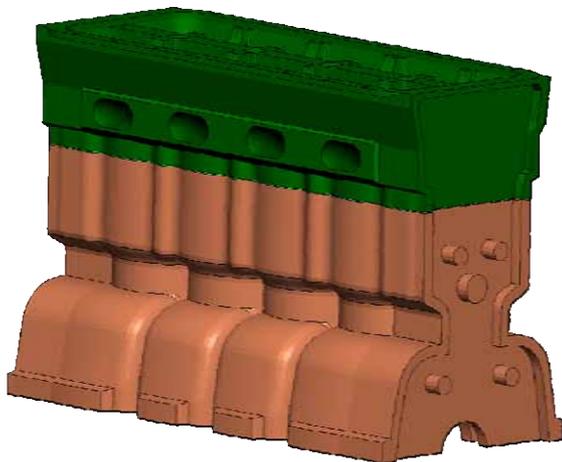
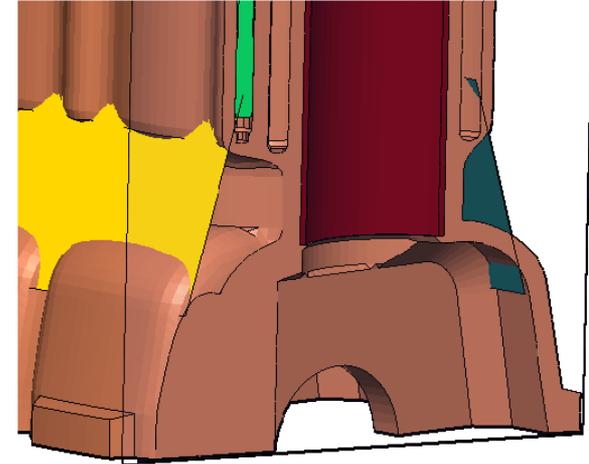
Two-part cylinder head gasket for a crankcase in open-deck design

Pressure-Closure Curve of Cylinder Head Gasket



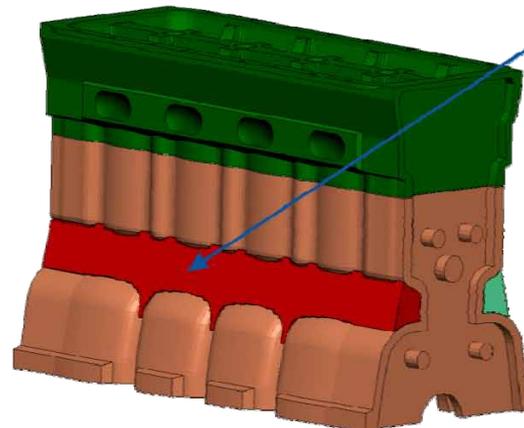
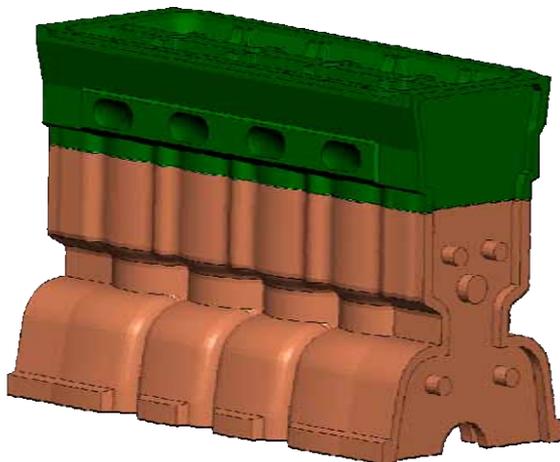
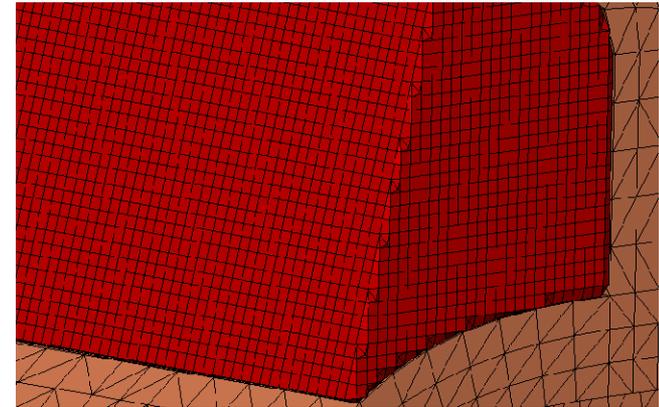
Definition of Design Space

- Existing ribs are eliminated.
- The boundary of the design space is defined by the surface of the crankcase and
- by an outer plane surface (yellow and green).
- The open faces of the design space are closed.

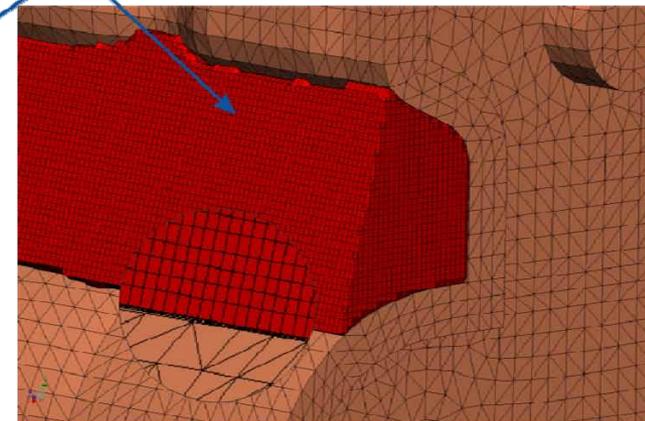


Meshing of Design Space

- Automatic meshing with cube (and wedge) elements (using VisPER).
- Size of elements depends on the desired size of achieved structures (like ribs).
- Coupling with wall of crankcase is achieved by projection and interpolation (surface coupling using incompatible meshes)



*Meshed
design
space*



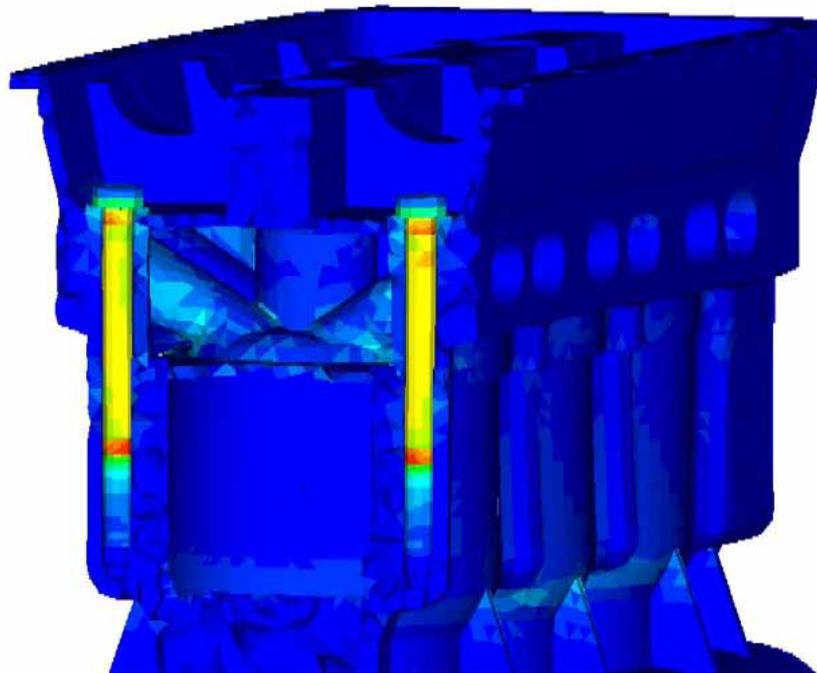
Modelling for Topology Optimization

Multi-Modeling

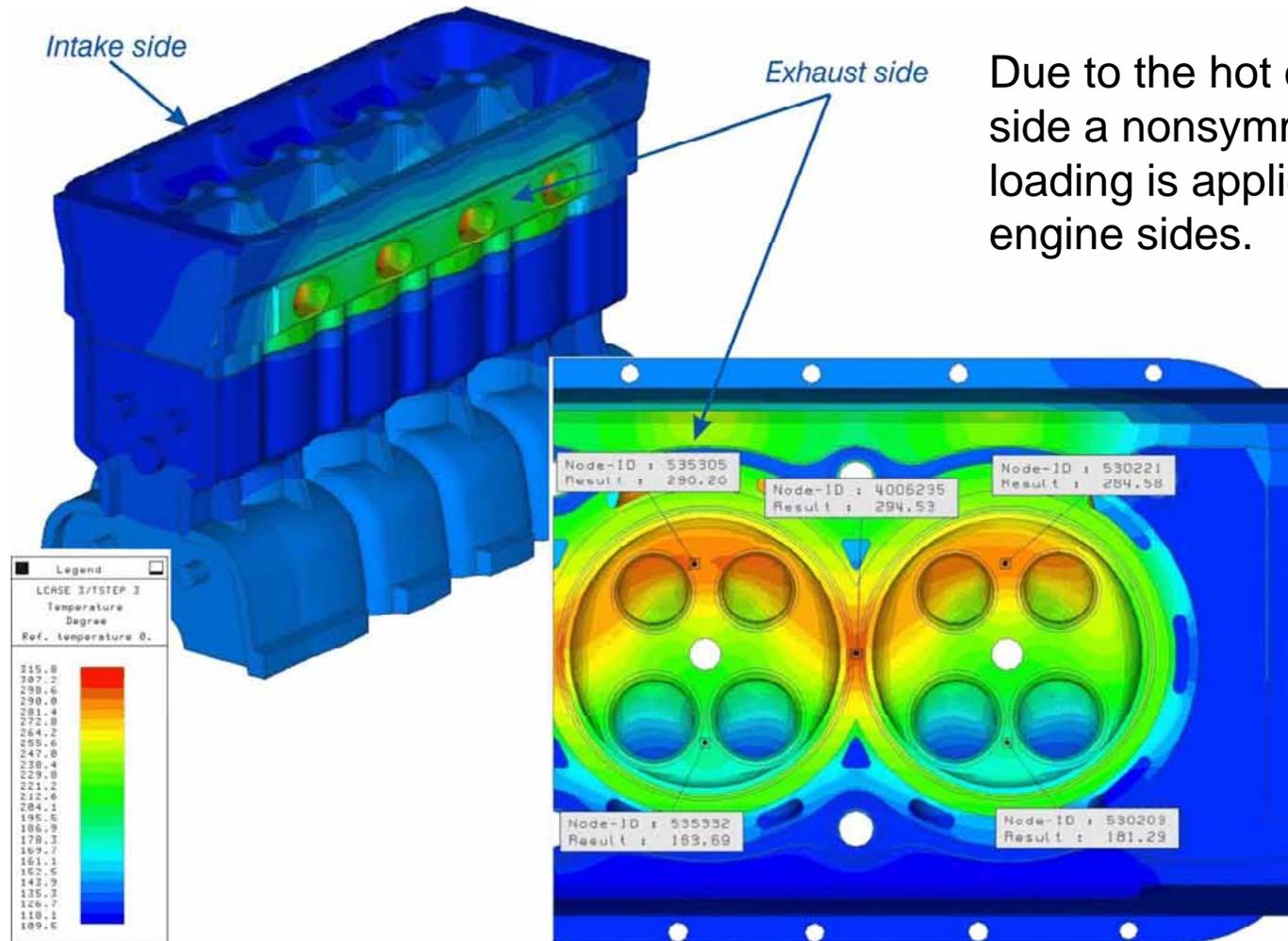


- Several load cases with various combination options
- Different design variants (e.g. different boundary conditions)
- Several different analysis options
 - Linear static analysis
 - Contact analysis
 - Dynamic eigenvalue analysis (with mode tracking)
 - Modal frequency response analysis

Bolt Pretension



Temperature Loading



Modelling for Topology Optimization

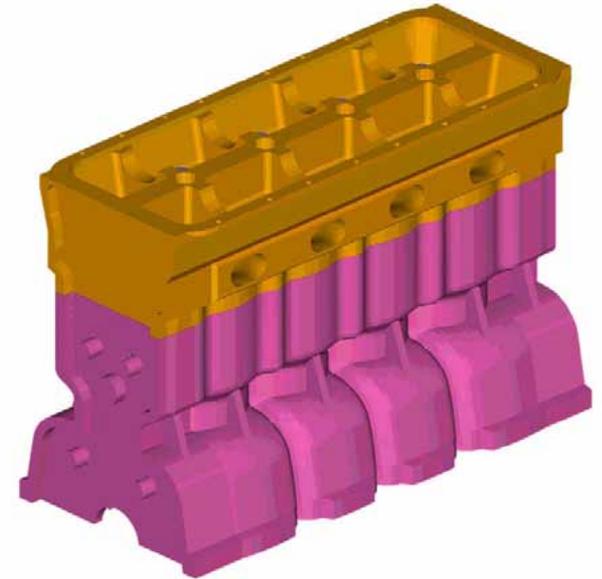
Optimization Constraints



- Compliance (strain energy)
- Weight
- Reaction forces
- Real eigenfrequencies
- Critical complex eigenfrequencies (Campbell diagram)
- Displacements
- Accelerations, velocities
- Stresses (outside of the design space)
- Stress resultants (outside of the design space)
- Sound radiation power (outside of the design space)

- These basic constraints can be combined to more complex constraints
- Even using max/min, absmax/absmin, RMS

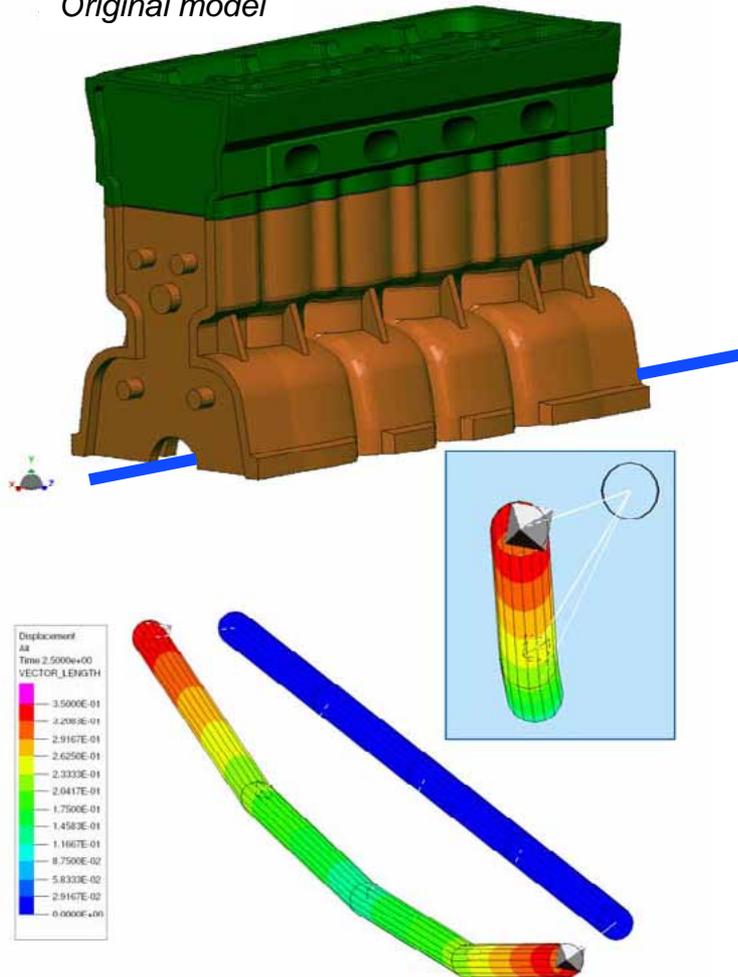
- Stiffness objectives are considered as most important.
- Then, two methods can be used:
 - The smallest global compliance as objective (corresponds to maximum global stiffness).
 - Limiting **local deformations** at certain locations due to quality requirements.
- The mass of the original ribs is also available for the new rib design (i.e. 348 g while the total mass of the engine is 21.3 kg incl. steel bolts and gasket).



Pretension and Temperature with Local Deformation



Original model

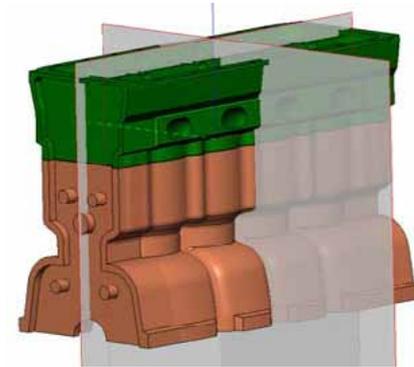


- The bending line of the crankshaft axis is taken as reference.
- The design criterion is built from the sum of displacements on this axis at the main bearings.
- This criterion shall be minimized by a new rib design.

Modelling for Topology Optimization Manufacturing Constraints

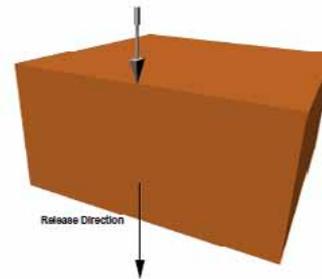
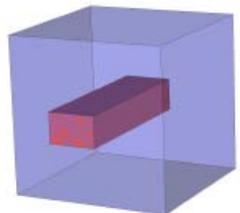
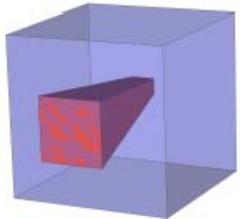
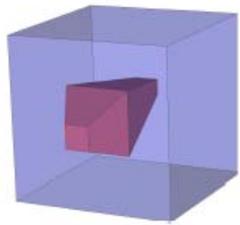


- Release directions (with or without shrinking)
- Parting line
- Symmetry conditions (planar, axial, cyclic)
- Repetition of patterns
- Maximum and minimum wall thickness
- Frozen regions



example:

Optimization of a corbel



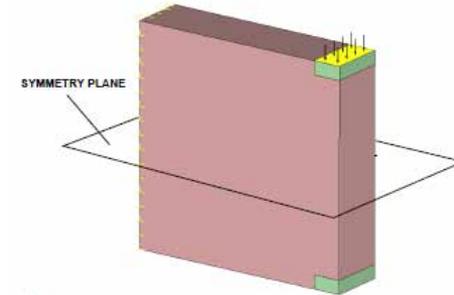
no maxsize



maxsize = 0.375

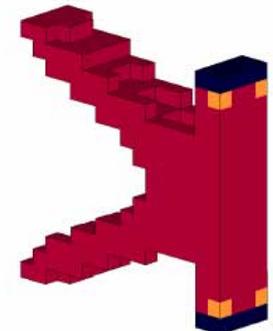


maxsize = 0.25



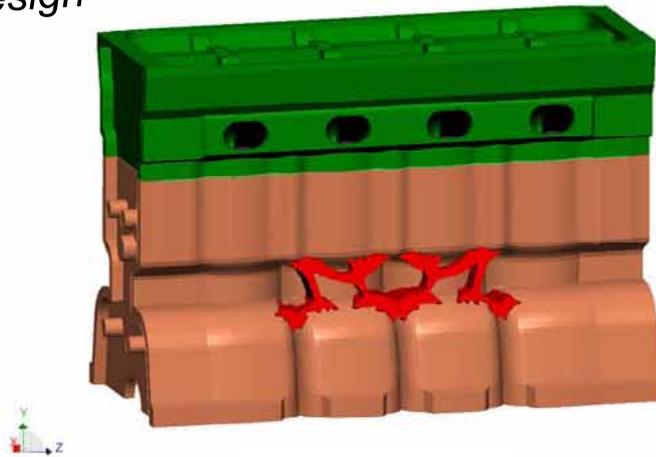
1-

1-

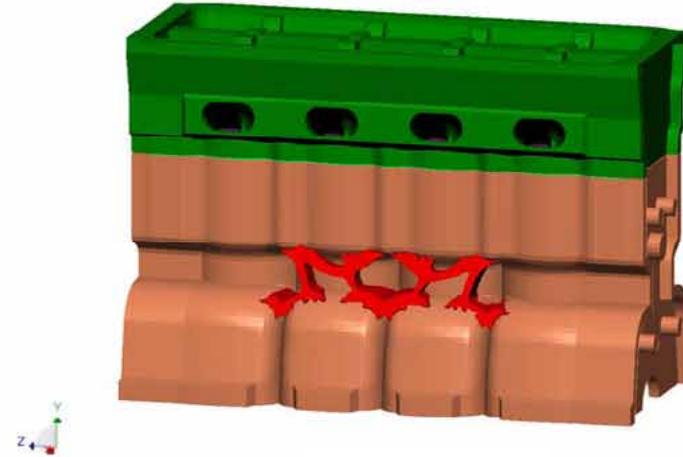


Pretension and Temperature with Local Deformation

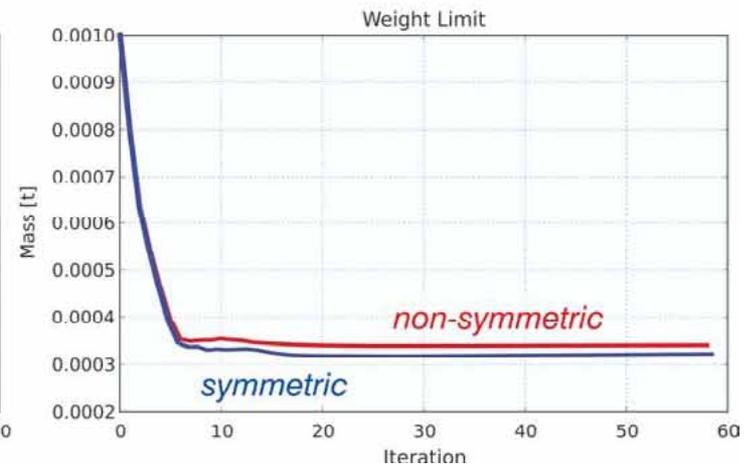
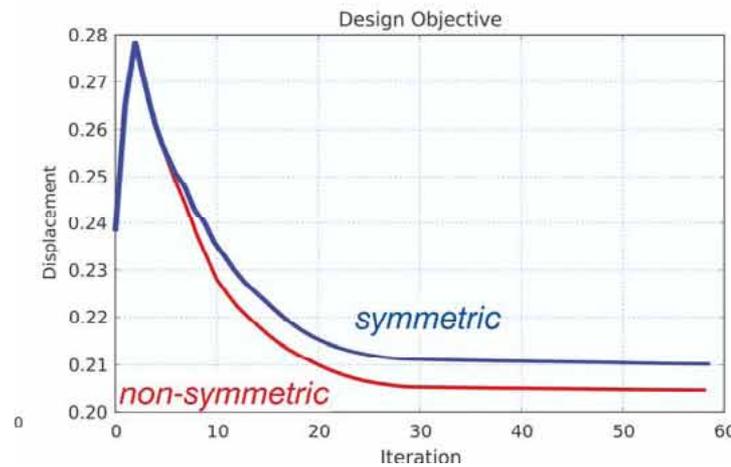
Symmetric design



Exhaust side



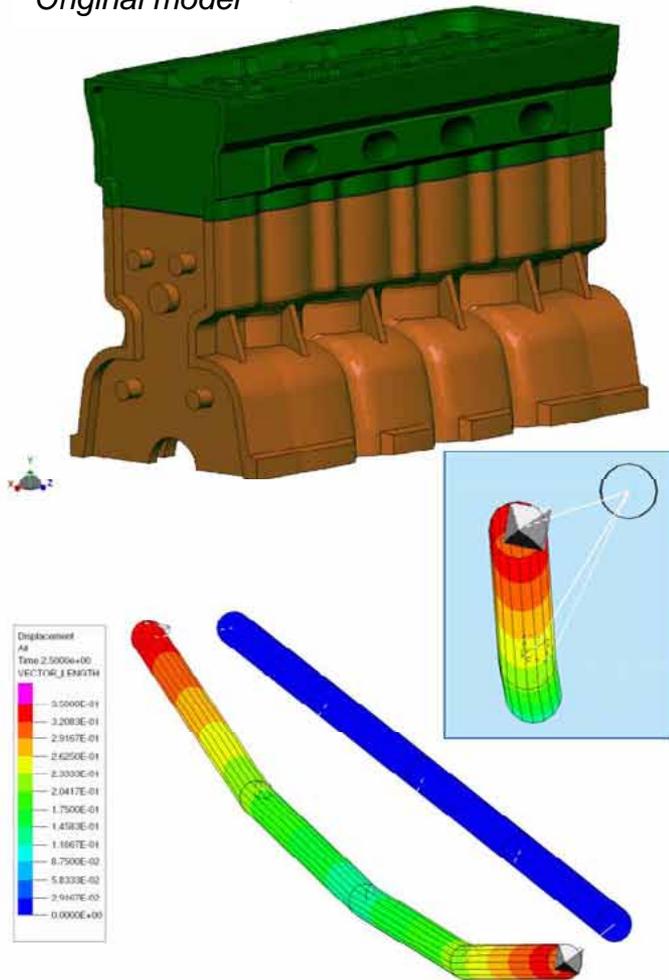
Intake side



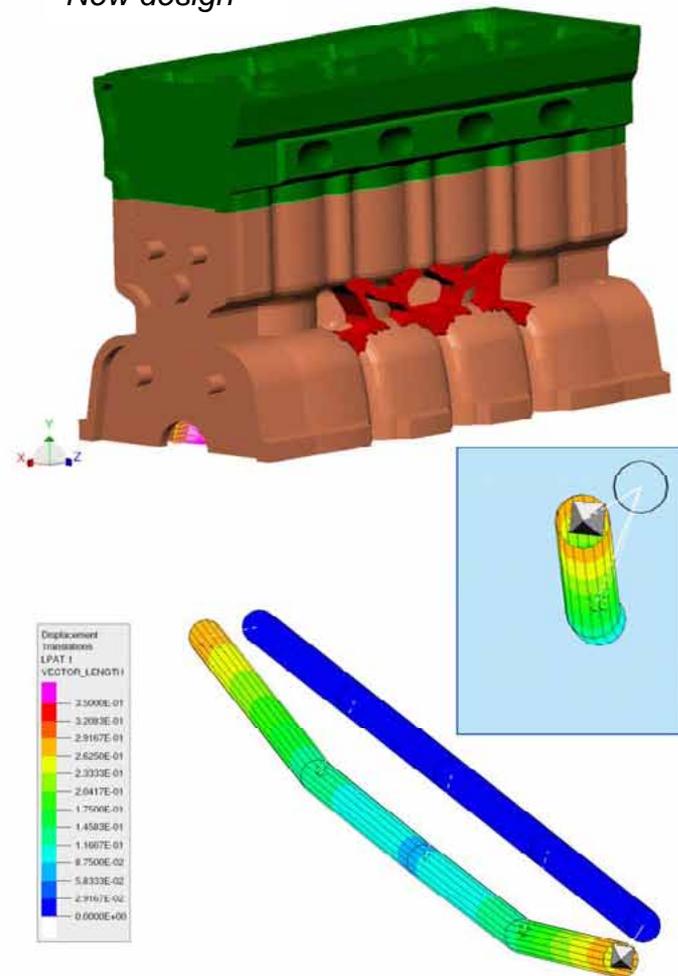
Bending Line Under Local Deformation

Symmetric design

Original model



New design



Optimization Results

Residual Structure, Hull, Smoothing

- Residual structure

The optimized structure, the so-called residual structure, consists of all elements of the design space with a filling ratio above a user-defined limit.

- Hull

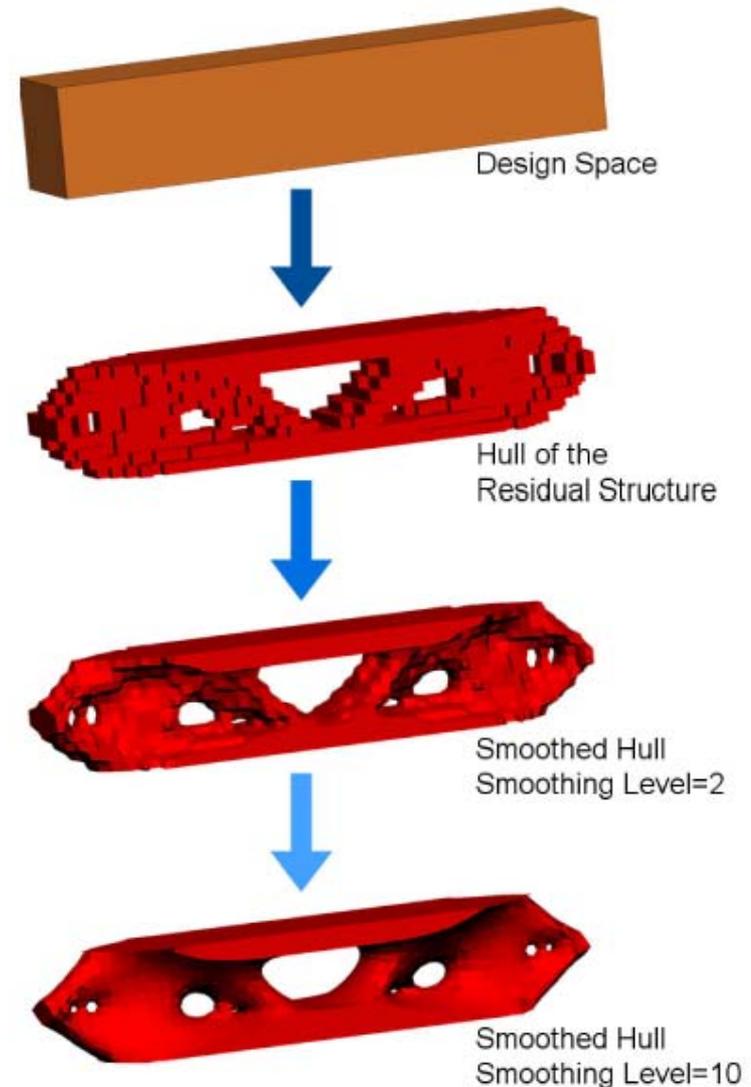
The boundary of the residual structure is denoted as hull.

- Smoothed hull

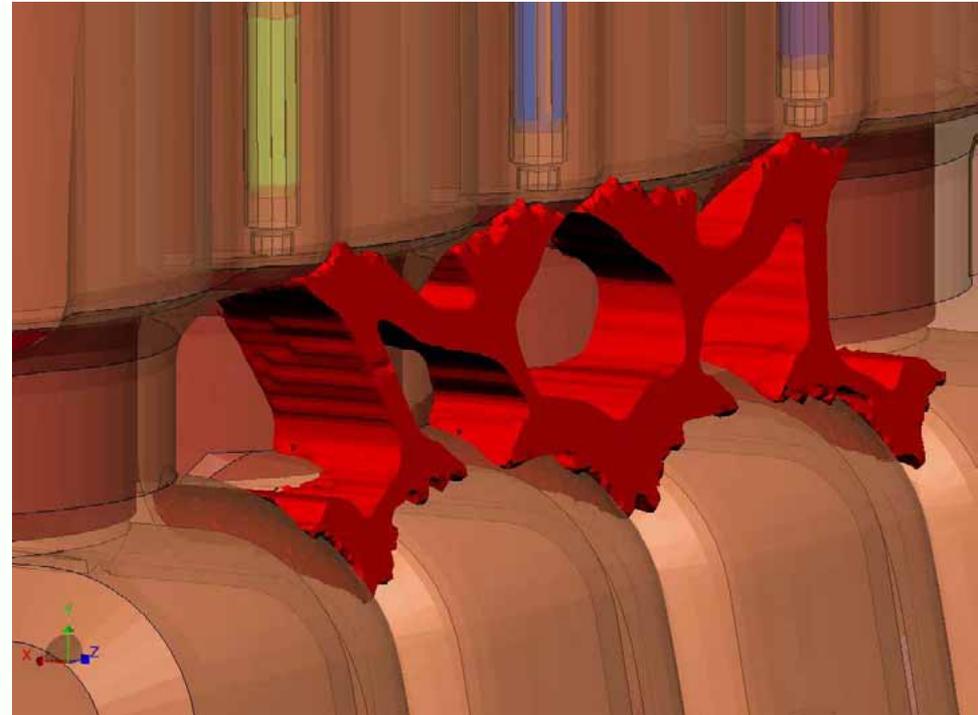
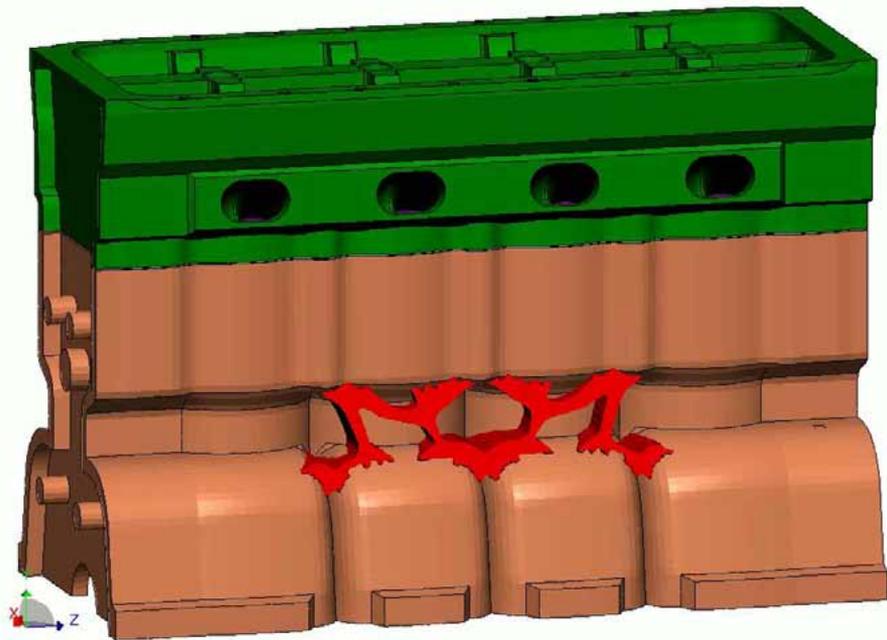
To eliminate the stepped structure the hull can be smoothed. The degree of smoothing is controlled by the number of smoothing steps (1-100) and by a smoothing level (1-10).

- Export

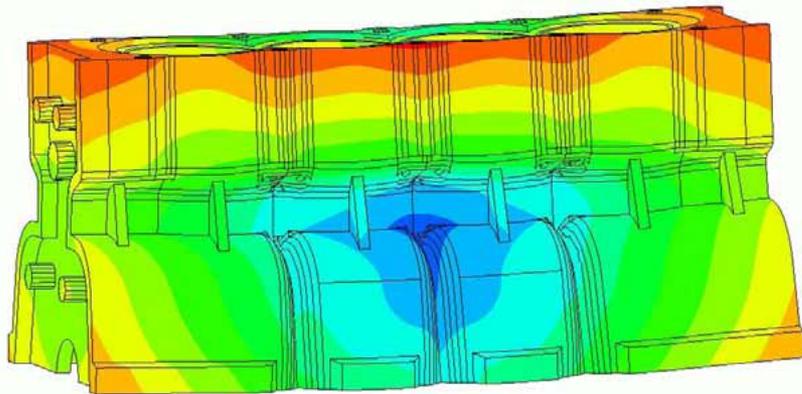
In VisPER the smoothed hull can be exported in PERMAS .dat format or in STL standard format.



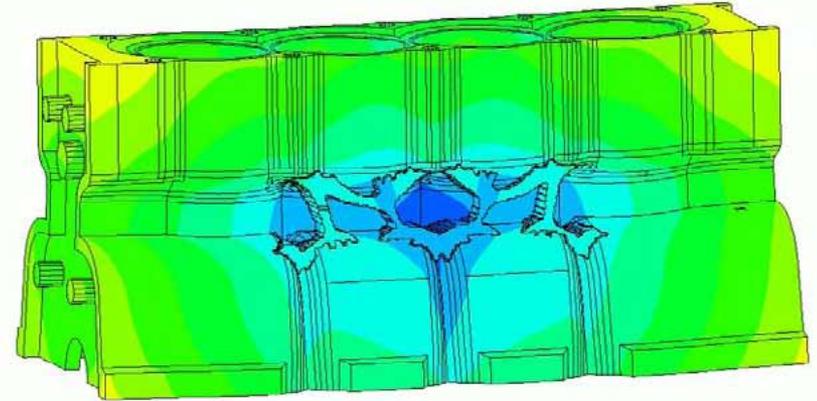
Rib Generation



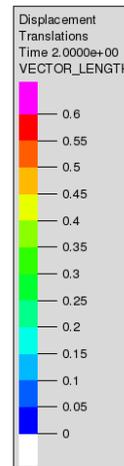
Comparison of Deformation



Original design



Local deformation



Further Steps



- Re-design of part using results from topology optimization
- Checking stresses in design space
 - possibly followed by a shape optimization of the re-designed part

Summary



- Concept design by topology optimization,
- Topology optimization under nonlinear conditions (Contact and gasket material nonlinearities),
- Definition and meshing of design space using an existing FE model,
- Selection of relevant loading cases (pretension and temperature),
- Evaluation of filling ratio, design objective and weight side constraint,
- Clear development of final design.