Structural Optimization
with
GENESIS

Martin Liebscher*
martin.liebscher@dynamore.de

Outline

Overview

Optimization Capabilities / Examples

- Topology
- Sizing
- Shape
- Topography
- Topometry
- Composite

Outlook

GENESIS

- Product of Vanderplaats R&D
  15 years in marketplace / DYNA*more* distributor since 2007/2008

- design optimization by generating new designs based on user criteria such as mass minimization, frequency maximization, stress or displacement constraints...

- Large scale analysis and optimization (can handle extremely large numbers $>10^6$ of design variables)

- Fully integrated fast and robust (linear) finite element analysis

- Uses standard Nastran input files / standard post-processing files

Fully Integrated Structural Analysis

- Analysis options
  - Linear statics
  - Normal modes
  - Frequency response
  - Heat transfer
  - Buckling
  - ...

Genesis Analysis Capabilities

Element library

Genesis has a very complete finite element library that includes: bushing, rod, bar, beam, spring, shell, shear, composite, axisymmetric, tetra, penta, and hexa elastic elements along with the rbe1, rbe2, rbe3, rspline rigid elements. DMIG, GENEL and other general elements/matrices are also available.

Materials

Isotropic, orthotropic, and anisotropic.

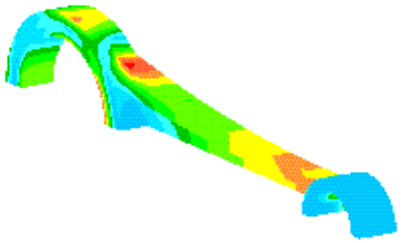
Loads

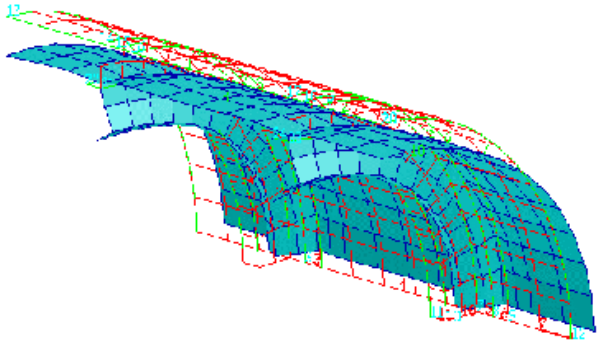
Point, pressure, gravity, centrifugal, temperature, etc.

FEA Output in GENESIS

Format: **Output2, Punch, Ideas, Patran, etc,**

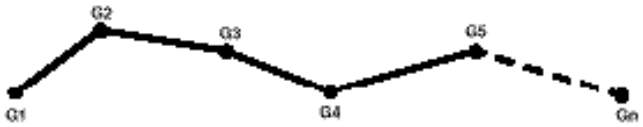
- **Displacements, velocities & accelerations**
- **Grid stresses**
- **Grid temperatures**
- **Element stresses, strains & forces**
- **Strain energies**
- **Frequencies & mode shapes**
- **Buckling load factor**
- **Mass & volume**
- **Inertia & center of mass**

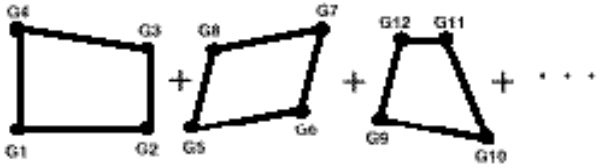


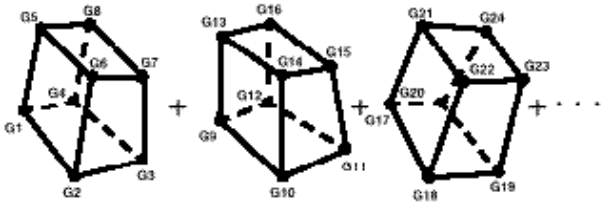


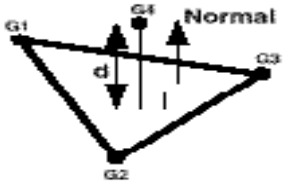
Geometric Responses

- Easy enforcement of package space constraints during shape design
- Easy way to avoid mesh distortion
- Available responses include:
  - Angle, Length, Area, Volume, Point to plane distance

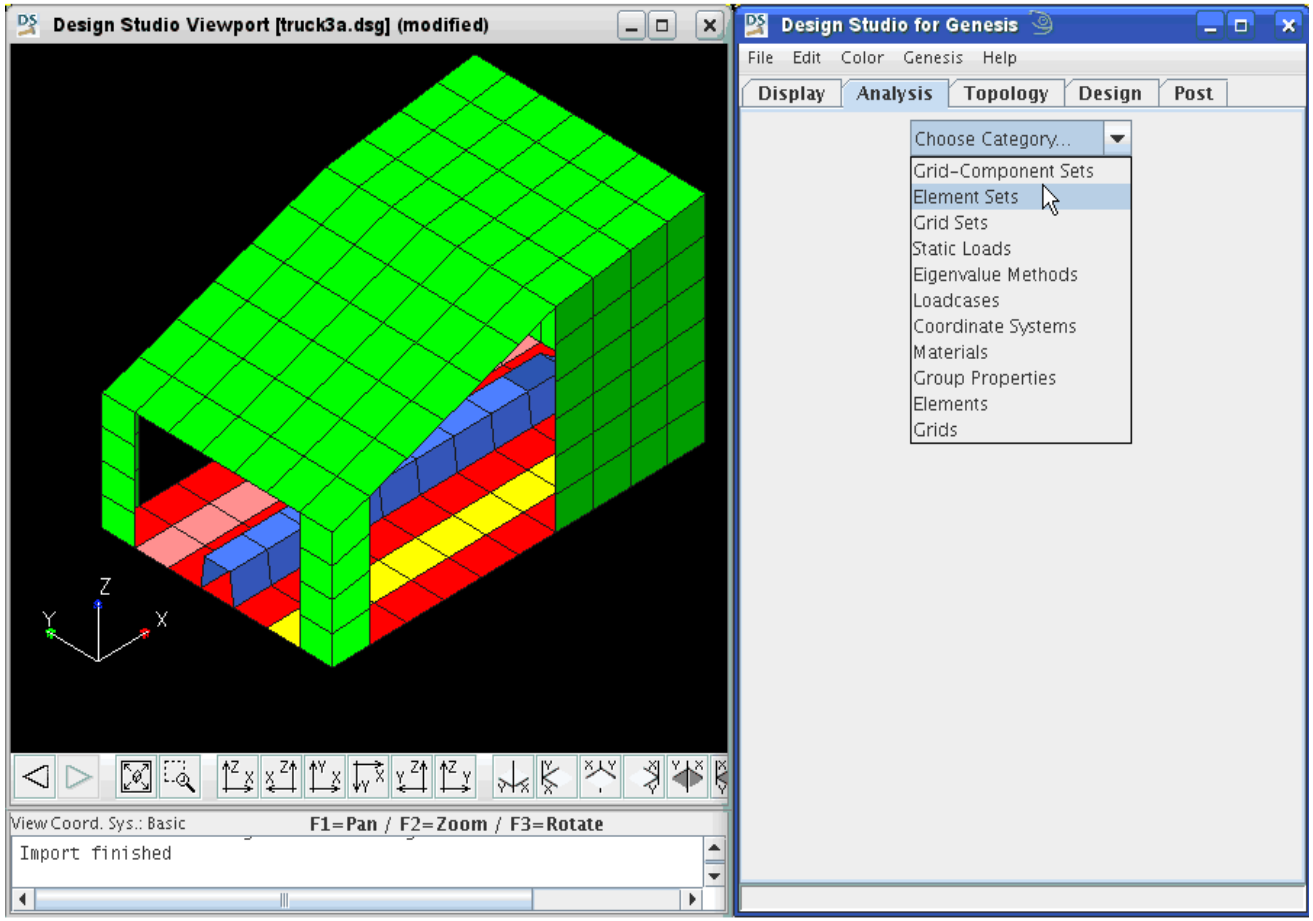






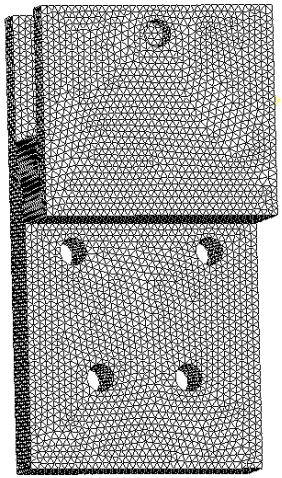


GENESIS Optimization Capabilities



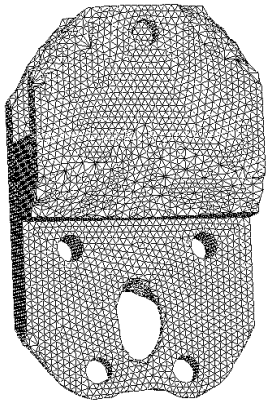
GENESIS Design Studio 9.0 (pre-/post processing)

Typical Design Process

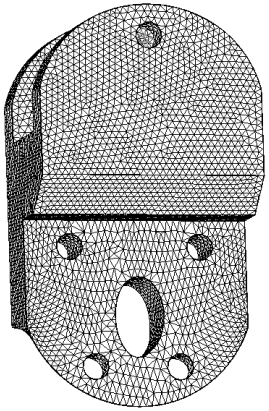


Preliminary design

Topology

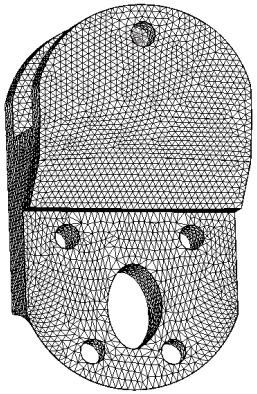


Designer's Interpretation



Final Design

Shape

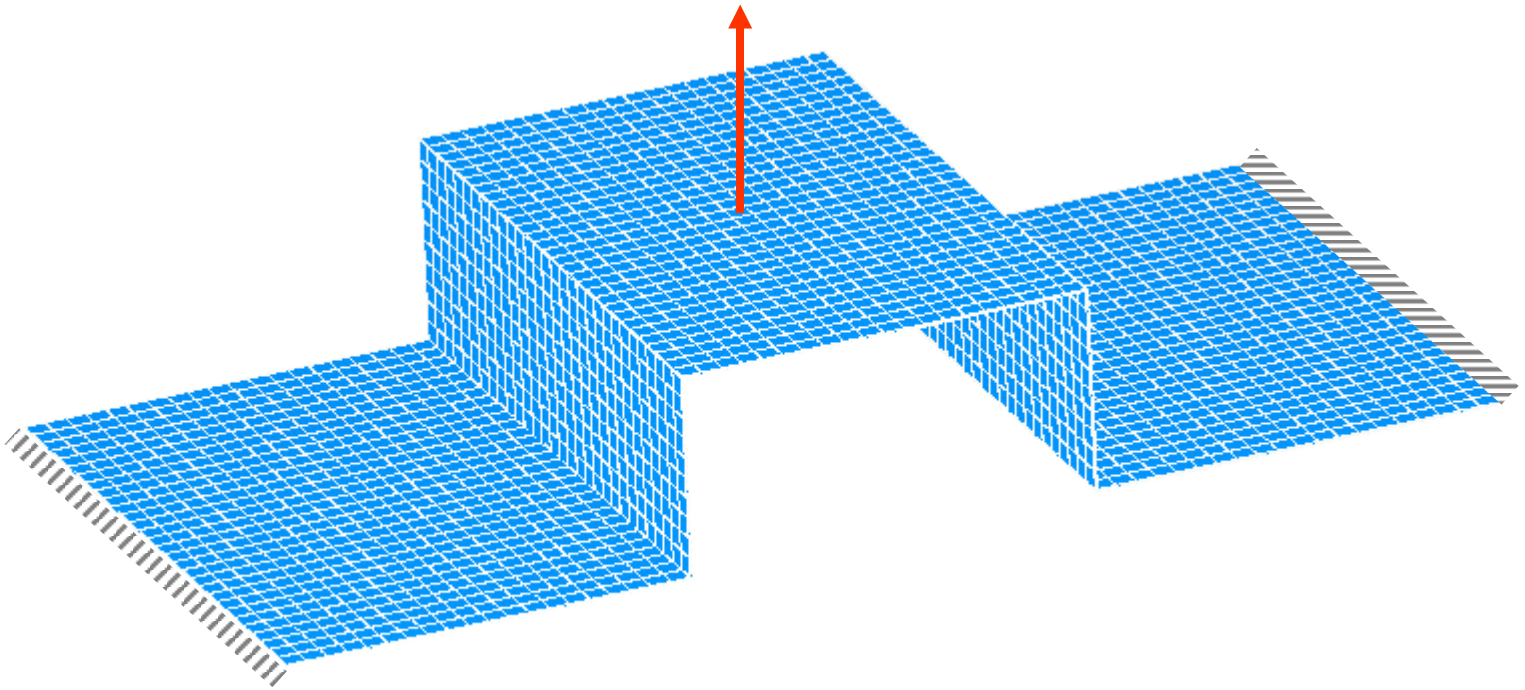


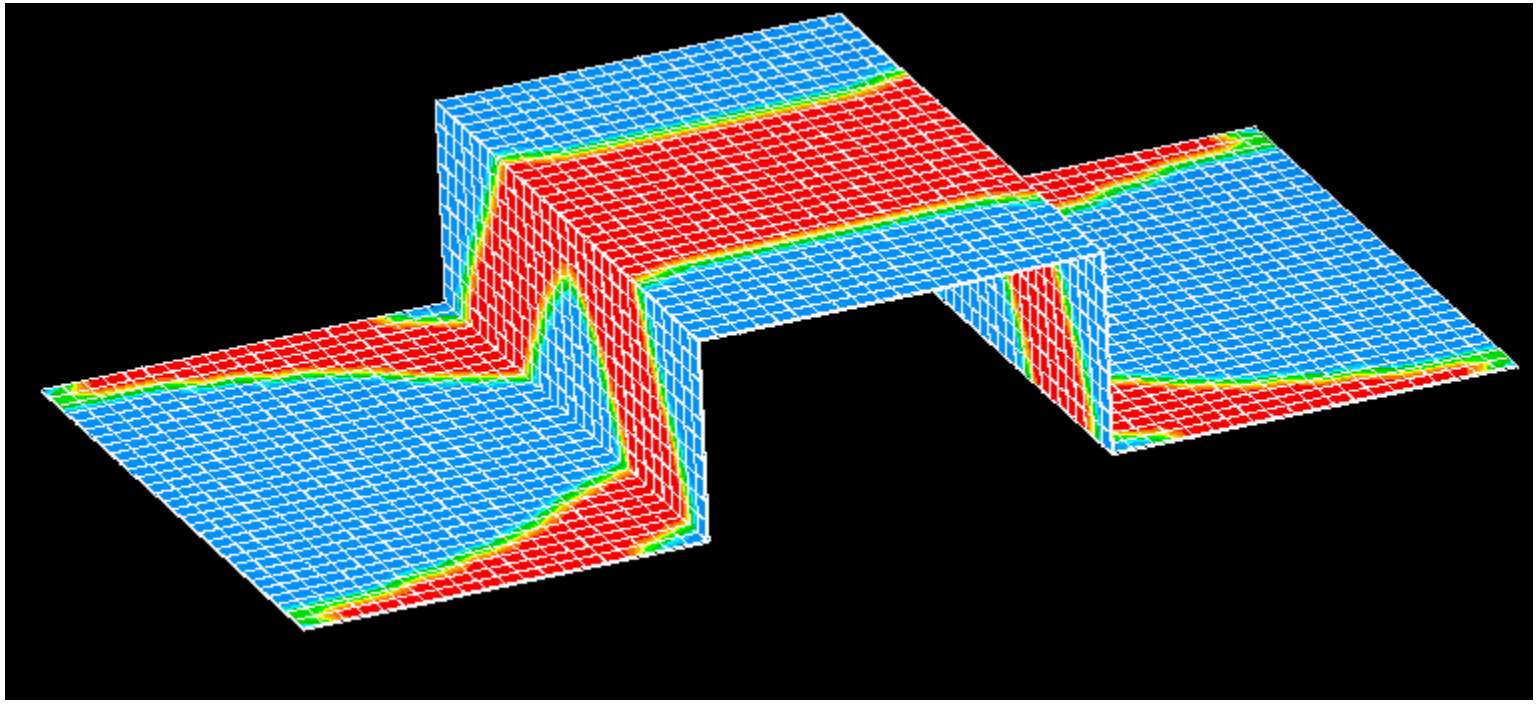
GENESIS Optimization Capabilities

- **Topology** best distribution of material
- **Sizing** best dimensions of any designable elements
- **Shape** best shape possible
- **Topography** location and shape of bead patterns to stiffen panel structures
- **Topometry** optimal distribution of sizing dimensions over the structure (element by element)
- **Composite** layer thickness, shape, angle, ...

Simple Topology Example

Find the Stiffest Structure Using 30%
of the Material to Carry the Given Load

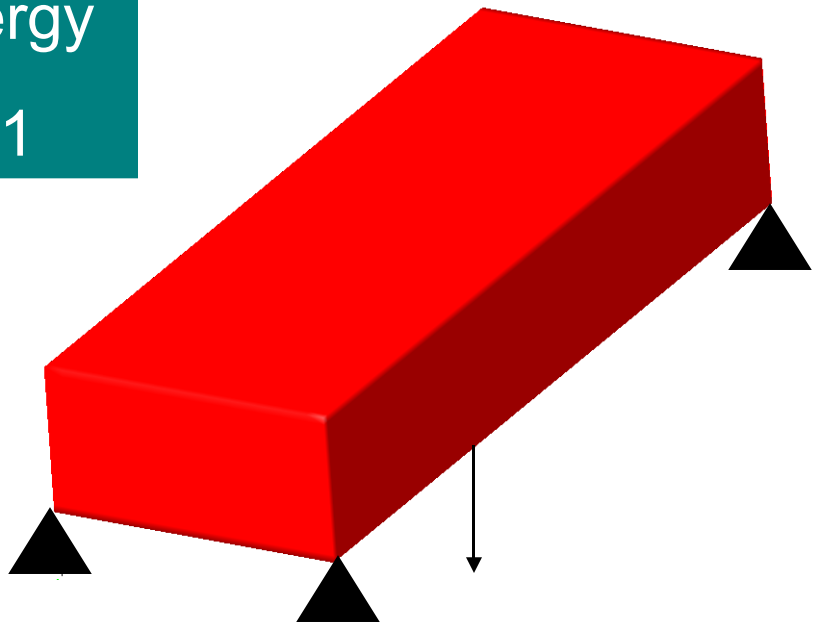




Topology Example

Minimize Strain Energy

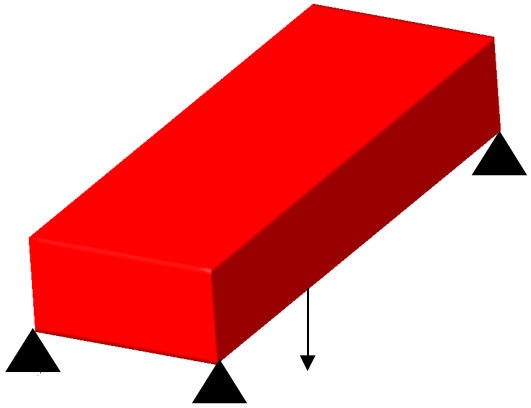
S.t. MASSFR <= 0.1



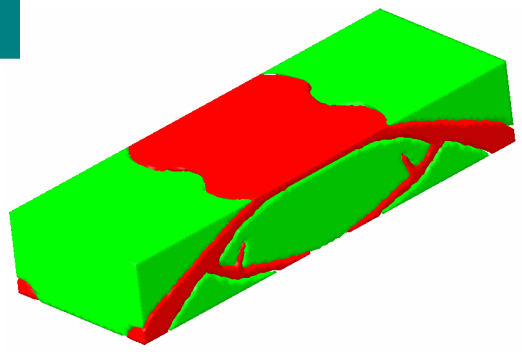
Load and Boundary Conditions

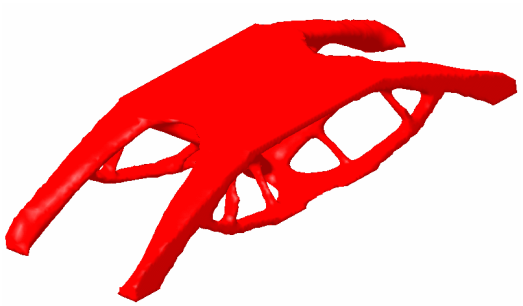
Standard Topology Results

Number of Elements = 1,003,520



Initial Design

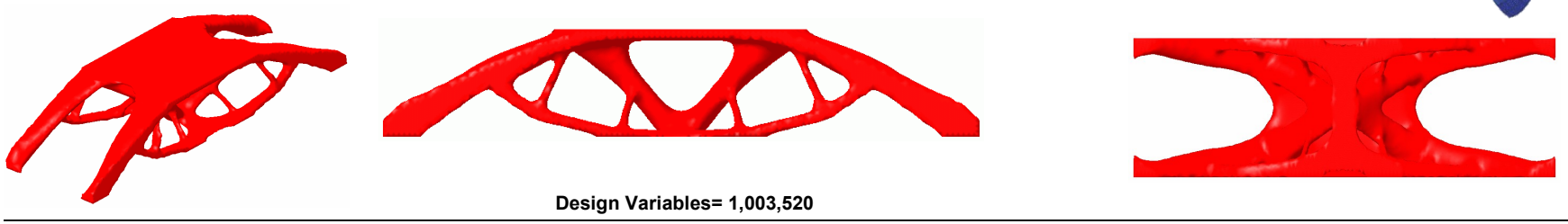




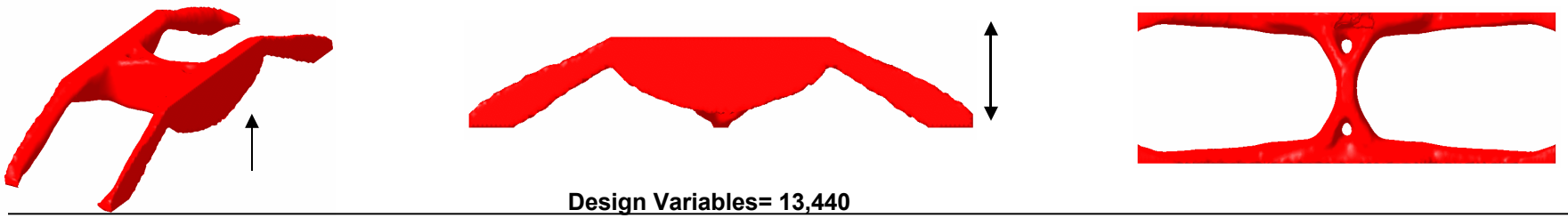
Final Design

No. of Design Variables= 1,003,520

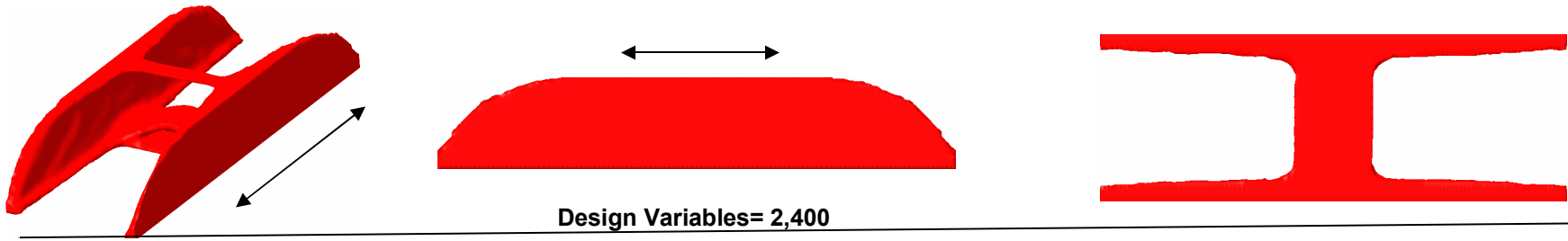
Topology Example



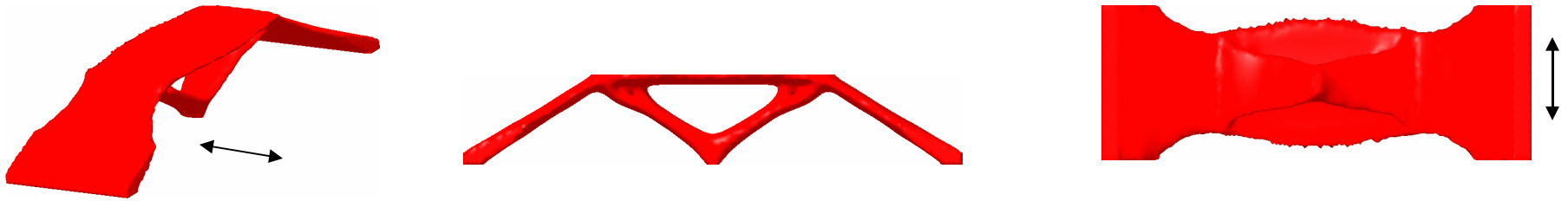
Design Variables= 1,003,520



Design Variables= 13,440

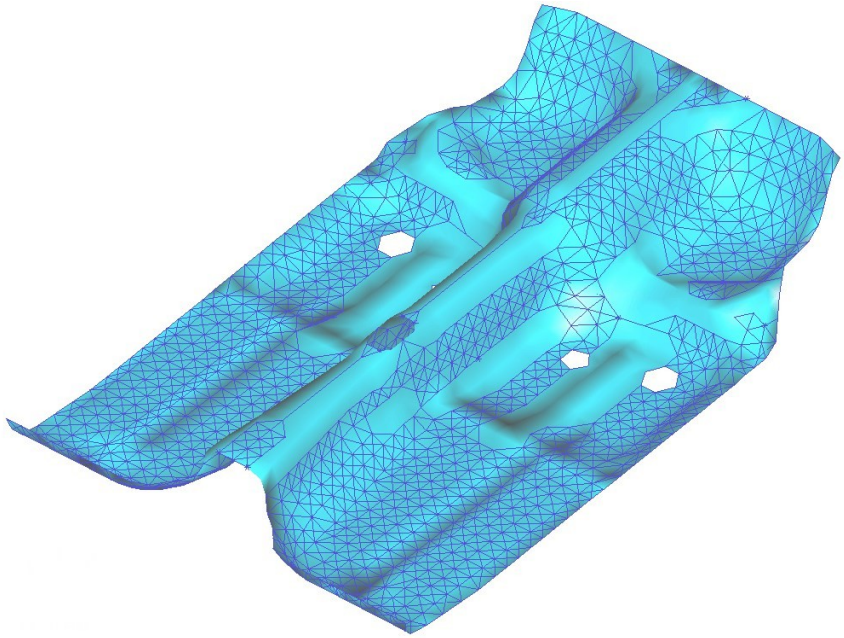


Design Variables= 2,400

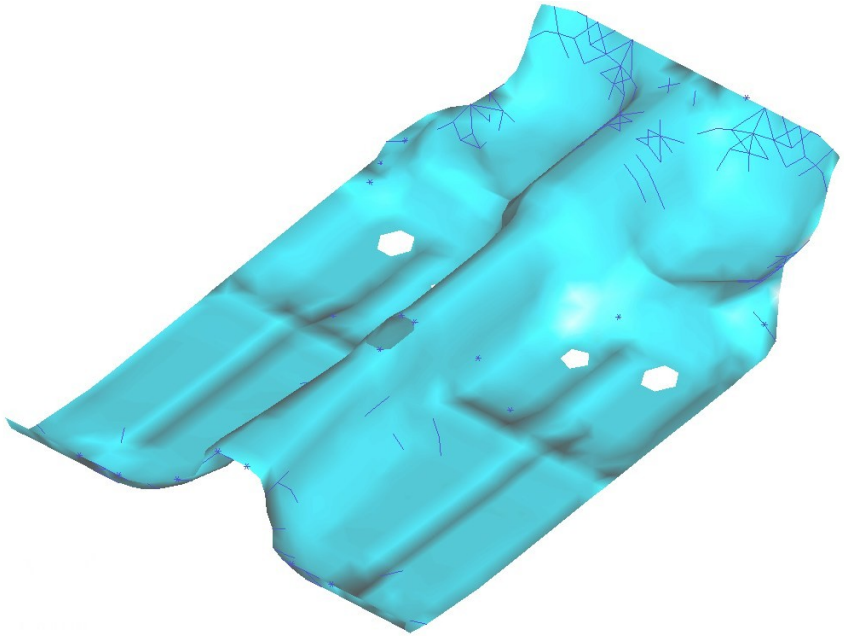


Design Variables= 6,720

Autorib Application



Automatically Generated
Candidate Rib Stiffeners



Best 5% of Ribs for Increased
Torsional Natural Frequency

GENESIS Optimization Capabilities

- **Topology** best distribution of material
- **Sizing** best dimensions of any designable elements
- **Shape** best shape possible
- **Topography** location and shape of bead patterns to stiffen panel structures
- **Topometry** optimal distribution of sizing dimensions over the structure (element by element)
- **Composite** layer thickness, shape, angle, ...

Sizing Optimization Example

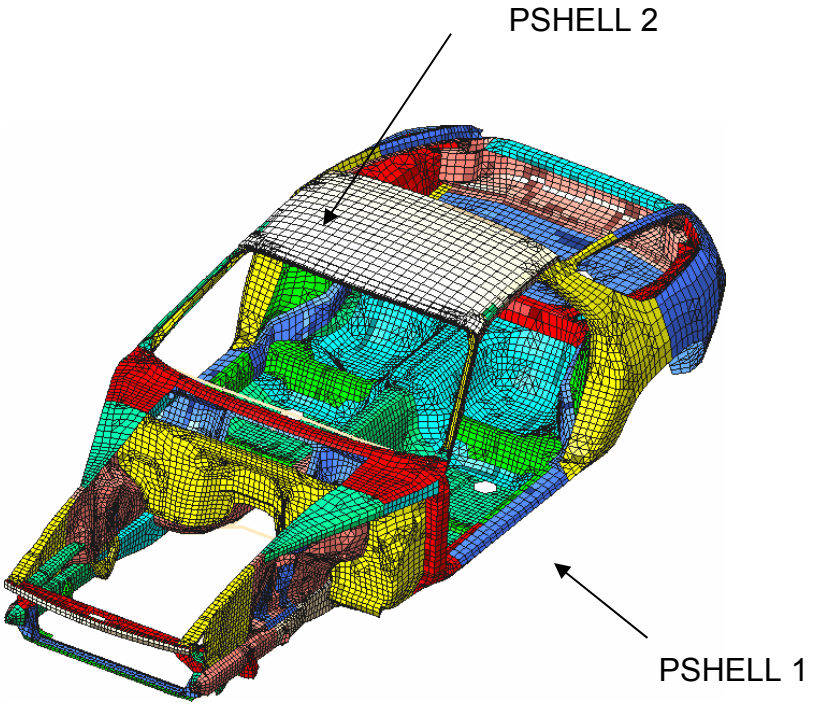
Design Variable x

$1.0 <= x <= 2.0mm$

PSHELL Properties

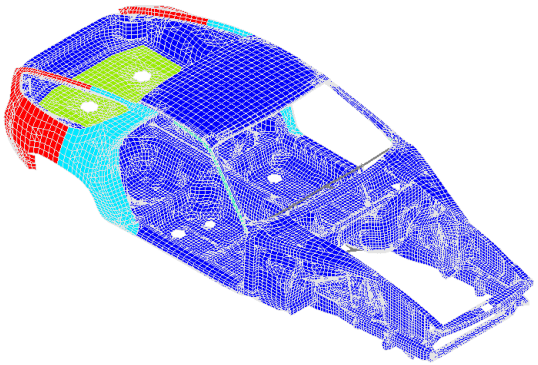
$T = x$
$TS = (5/6) * x$
$D = (1/12) * x**3$
$Z1 = -0.5x$
$Z2 = 0.5x$

PSHELL,ID,MID,T,MID2,D,MID3,TS + z1,z2



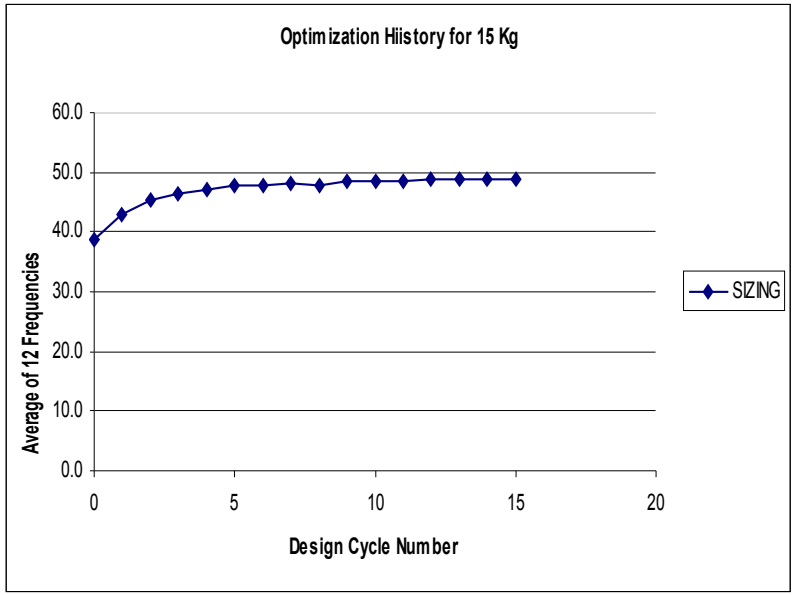
All Element that reference the same Property set will have same thickness

Sizing Optimization



Problem

- **Objective:**
  - Max Sum Of 12 Lowest frequencies
- **Constraints:**
  - Mass can increase up 15kg
- **Design Variables:**
  - 63 sizing variables
  - 1.0 <= X <=2.0 mm



Results

- **Objective:**
  - **Frequency increased from 38.6 to 48.9Hz**

    (10 hz, 27% Gain)
- **Constraints:**
  - **Mass Increased 15kg**
- **Design Variables:**
  - **63**
- **Number of Design Cycles**
  - **15**

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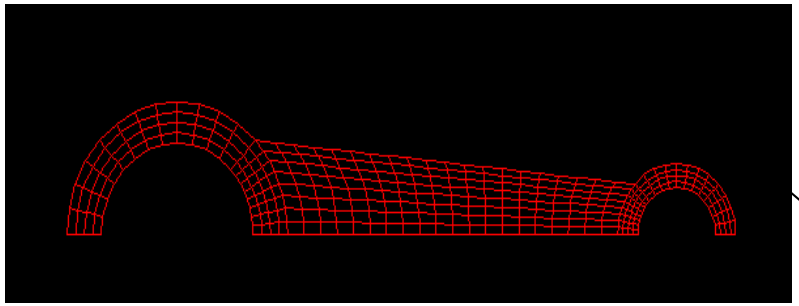
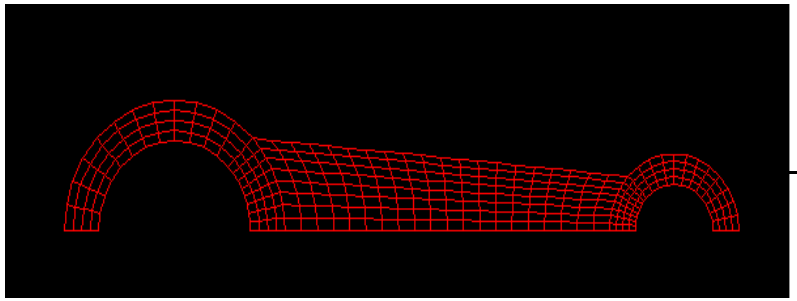
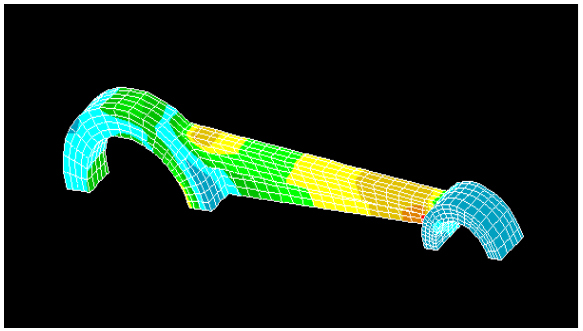
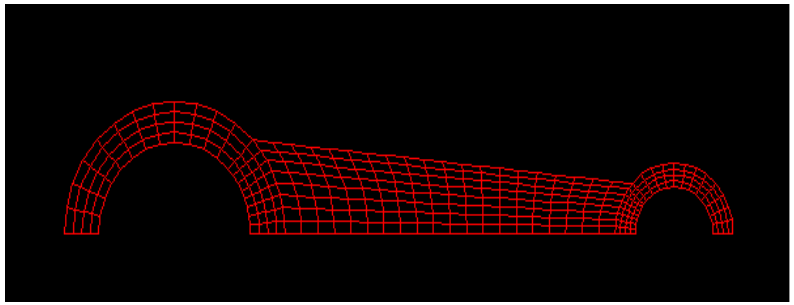
Shape Optimization





$$X_i = X_{io} + \sum_j DV_j * PX_{ij}$$
$$Y_i = Y_{io} + \sum_j DV_j * PY_{ij}$$
$$Z_i = Z_{io} + \sum_j DV_j * PZ_{ij}$$



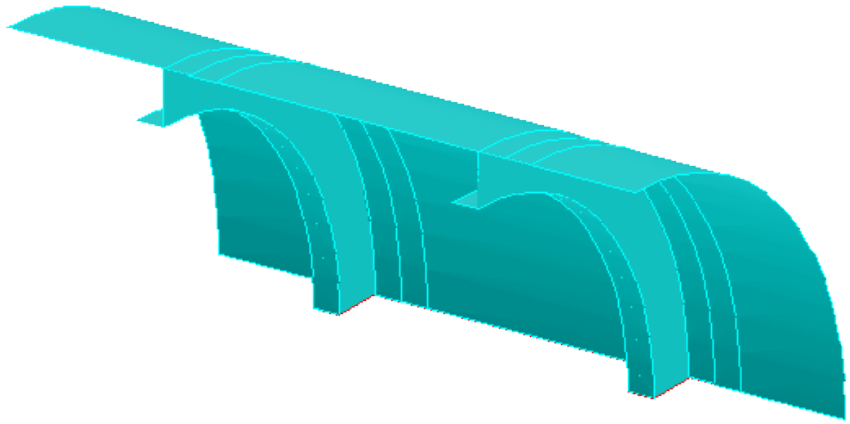


Optimization

Perturbation Vectors

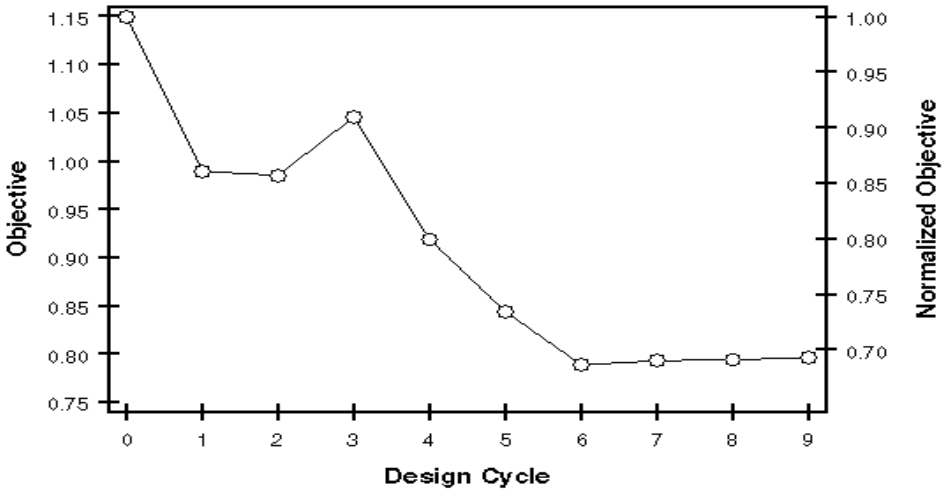
Shape and Sizing Example

- Objective:
  - Minimize mass of the aluminum, curved stiffened panel
- Constraints:
  - Frequency > 45 Hz
  - von Mises Stress
- Design Variables:
  - Thickness of skin and stiffeners
  - Stiffener web height
  - Stiffener flange widths

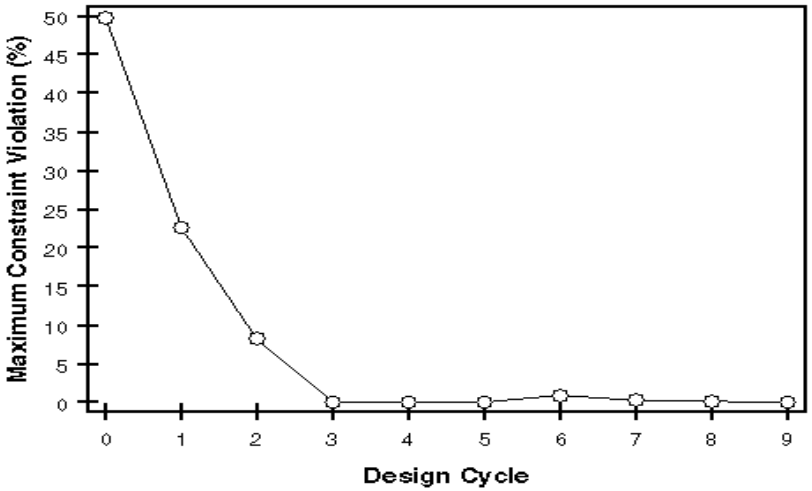


Shape and Sizing Results

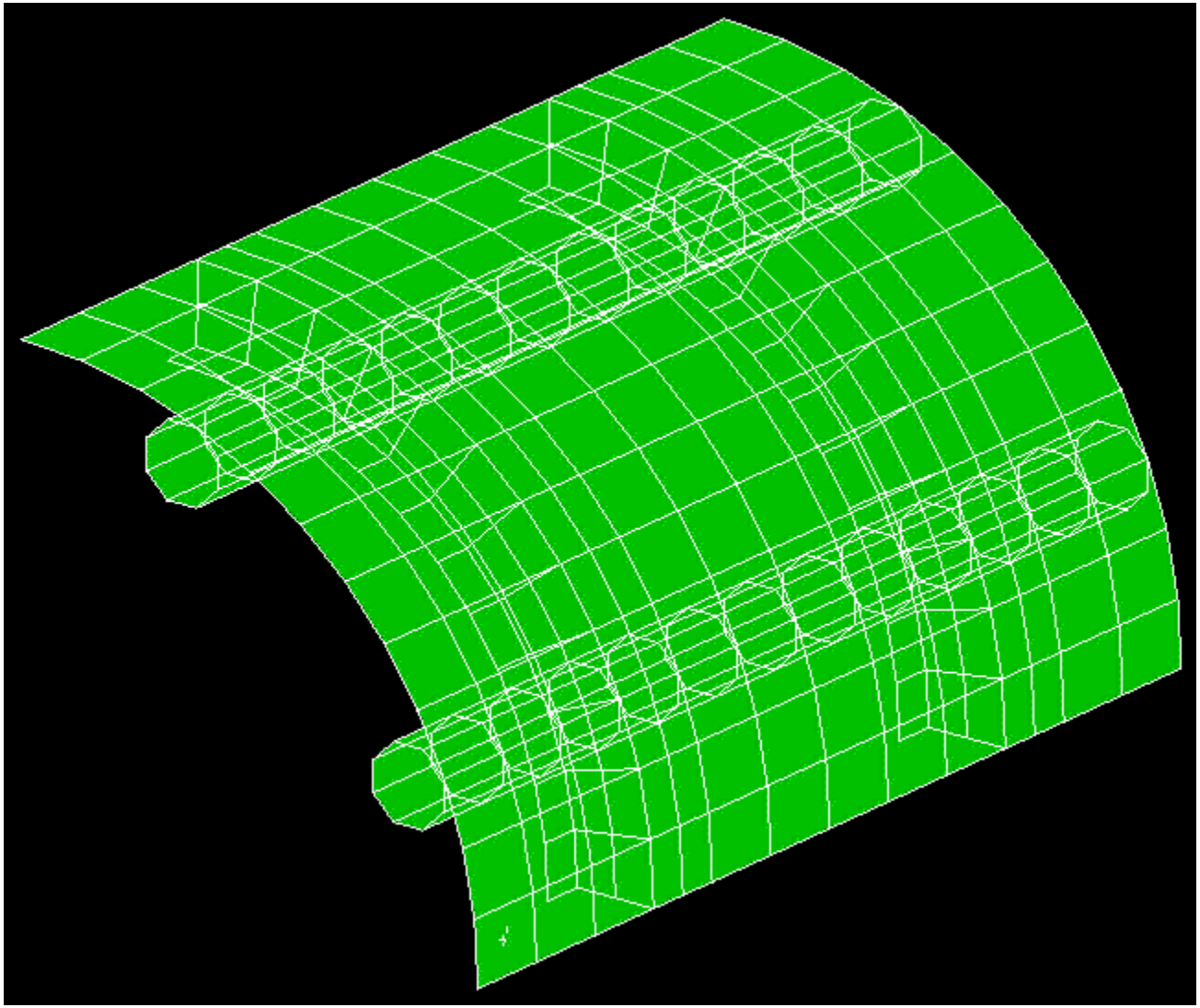
- **Objective**
  - Reduced mass by 30%



- **Constraints**
  - Initially infeasible
  - Frequency (23 Hz)



Shape and Sizing Results



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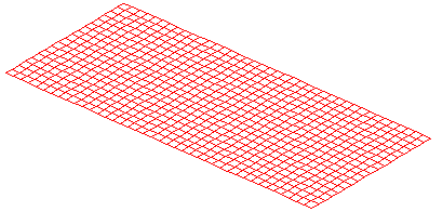
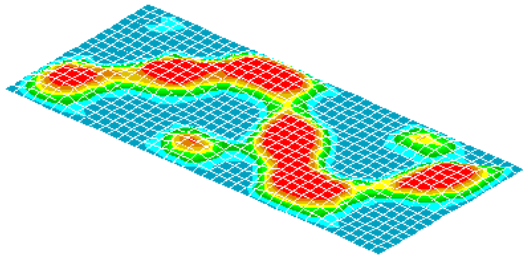
- **Composite** layer thickness, shape, angle, ...

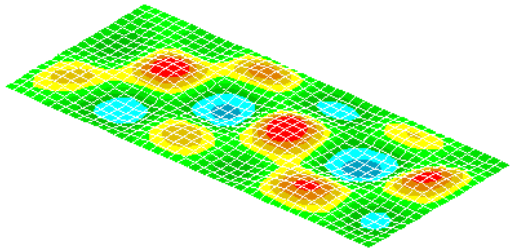
Topography Optimization



Initial Design



Grids allow to only move up



Grids allow to move up/down

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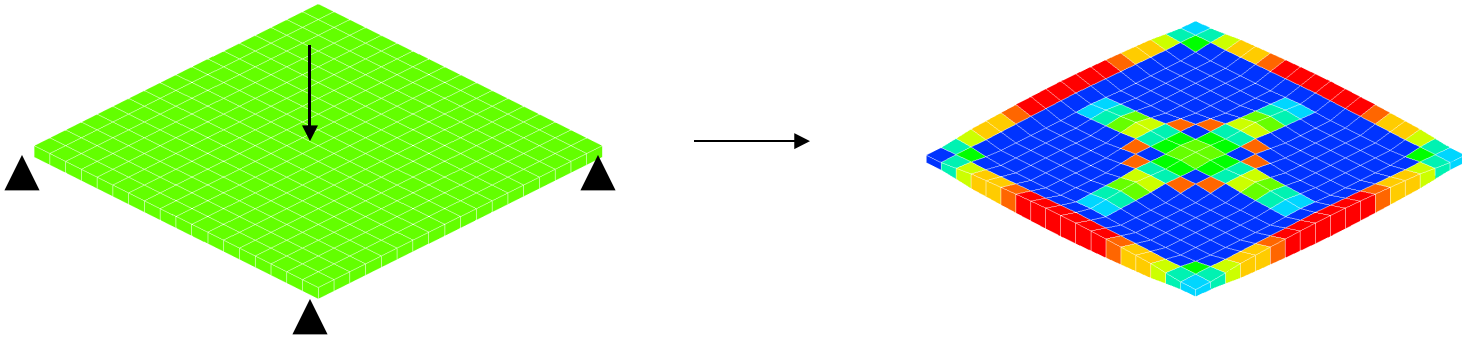
- **Composite** layer thickness, shape, angle, ...

Topometry Optimization

- Element by element sizing optimization
- Works with any element that can be size optimized
- Works with all type of load cases in GENESIS
- It can be mixed with shape and topography
- Easy to set up

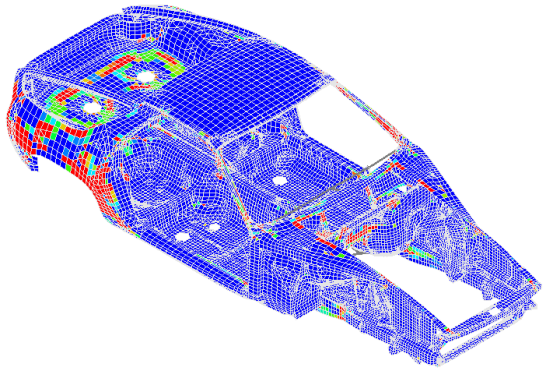
Adds new perspectives to topology optimization !!

Topometry Optimization Example



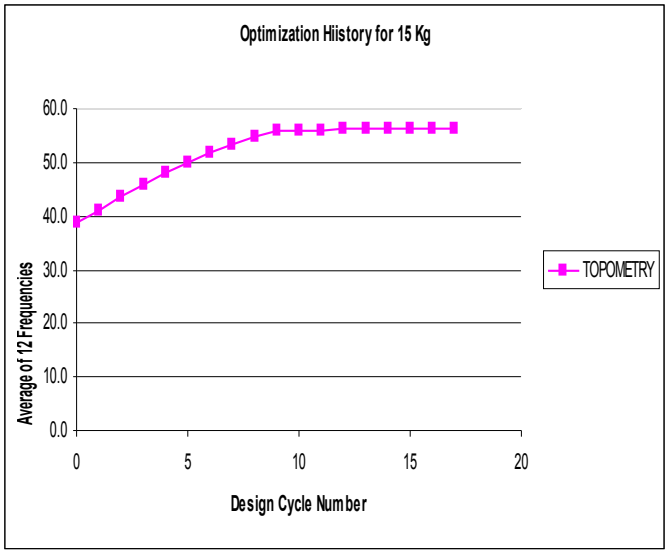
- **Objective:**
  - Minimize Strain Energy
- **Constraints:**
  - Mass
- **Design Variables: 324**
  - Each Element thickness

Example of Topometry Optimization



Problem

- **Objective:**
  - Max Sum Of 12 Lowest frequencies
- **Constraints:**
  - Mass can increase up 15kg
- **Design Variables:**
  - 34,560 sizing variables
  - 1.0 <= X <=2.0 mm



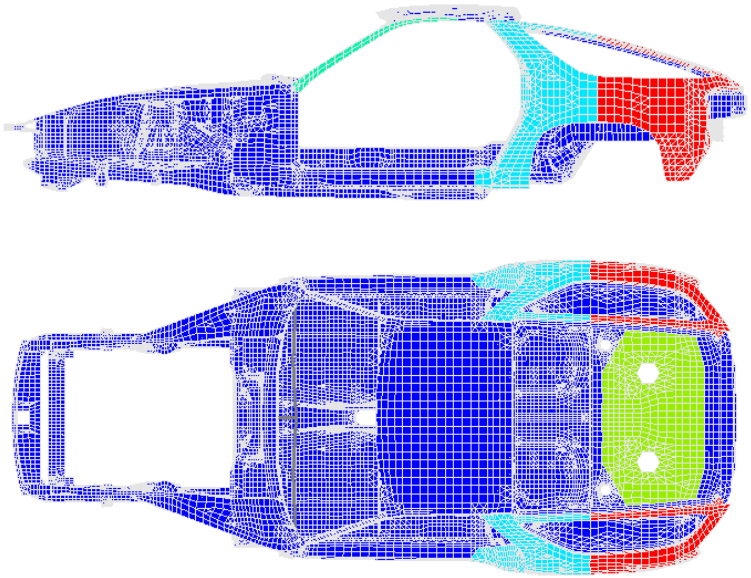
Results

- **Objective:**
  - **Frequency increased from 38.6 to 56.3Hz**

    (18 hz, 46% Gain)
- **Constraints:**
  - **Mass Increased 15kg**
- **Design Variables:**
  - **34,560**
- **Number of Design Cycles**
  - **15**

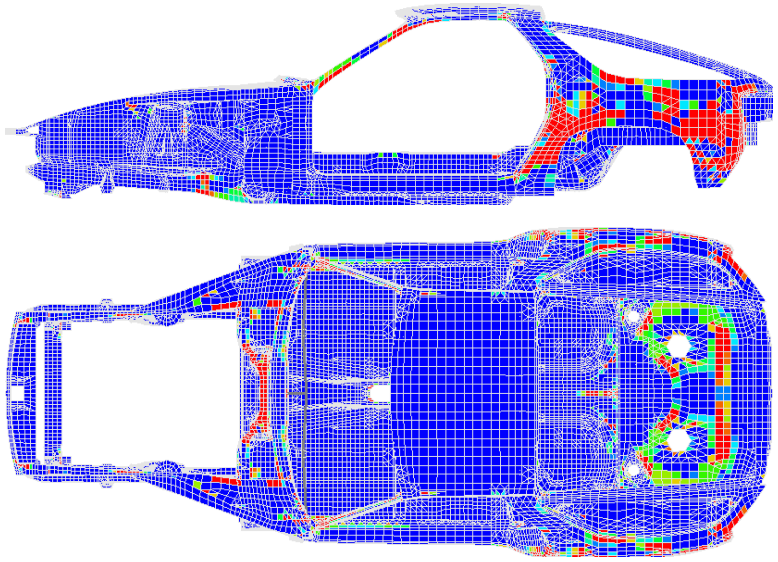
Sizing vs. Topometry

Sizing



+15 kg => 10 HZ Gains

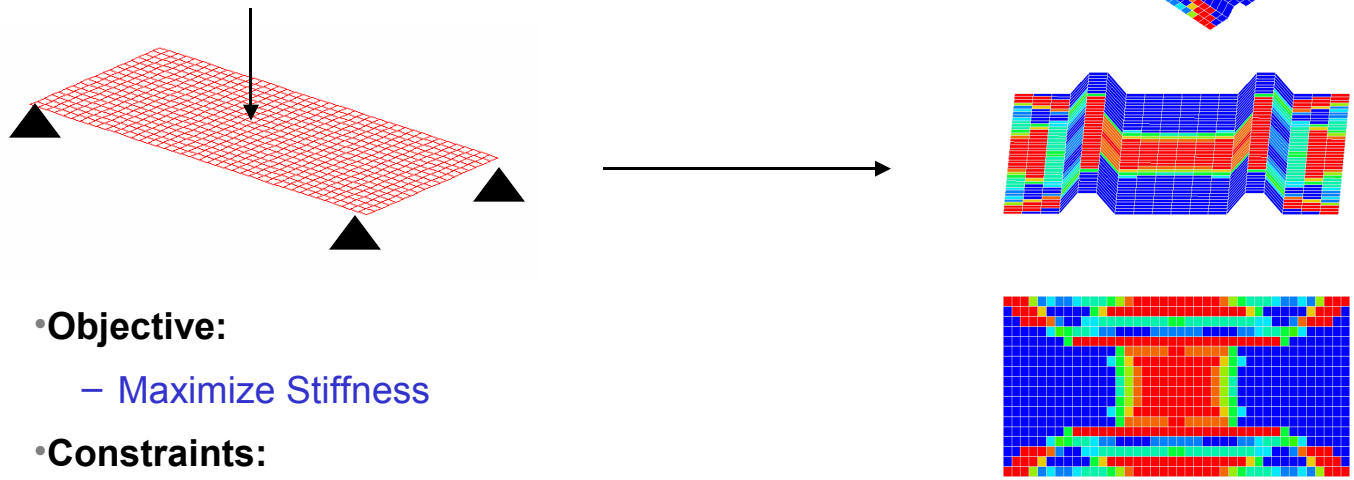
Topometry



+15 kg => 18 HZ Gains

Topometry helps to set targets and understand limits

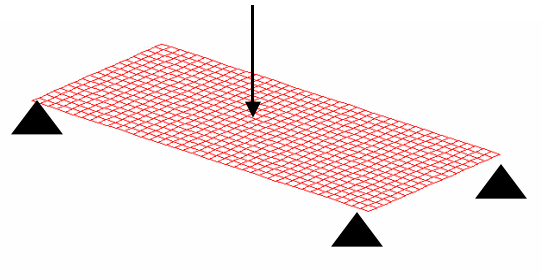
Topometry work with Other Types of Optimization

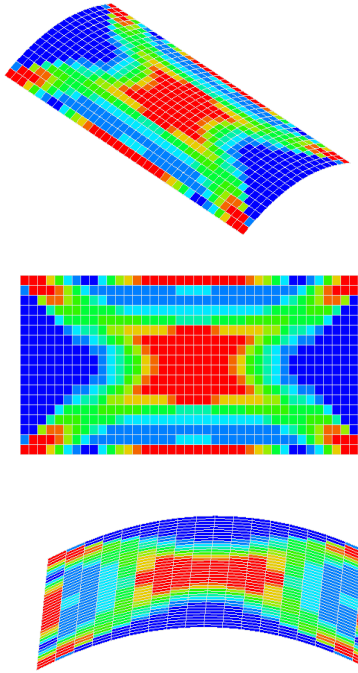


- **Objective:**
  - Maximize Stiffness
- **Constraints:**
  - Volume <=600mm^3
- **Design Variables: 726**
  - 720 Element thickness
  - 6 Topography

Topometry + Topography

Topometry work with Other Types of Optimization

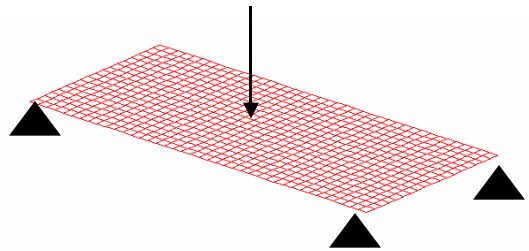


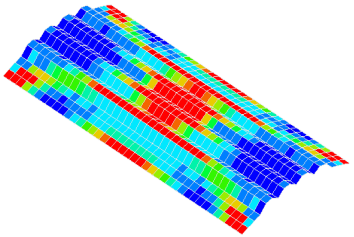


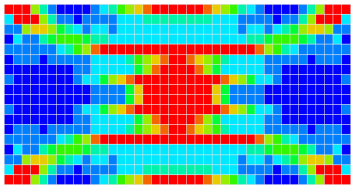
- **Objective:**
  - Maximize Stiffness
- **Constraints:**
  - Volume <=600mm^3
- **Design Variables: 726**
  - 720 Element thickness
  - 1 Shape

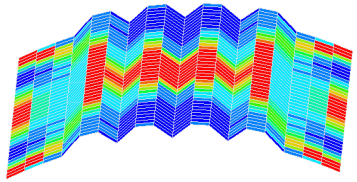
Topometry + Shape

Topometry work with Other Types of Optimization





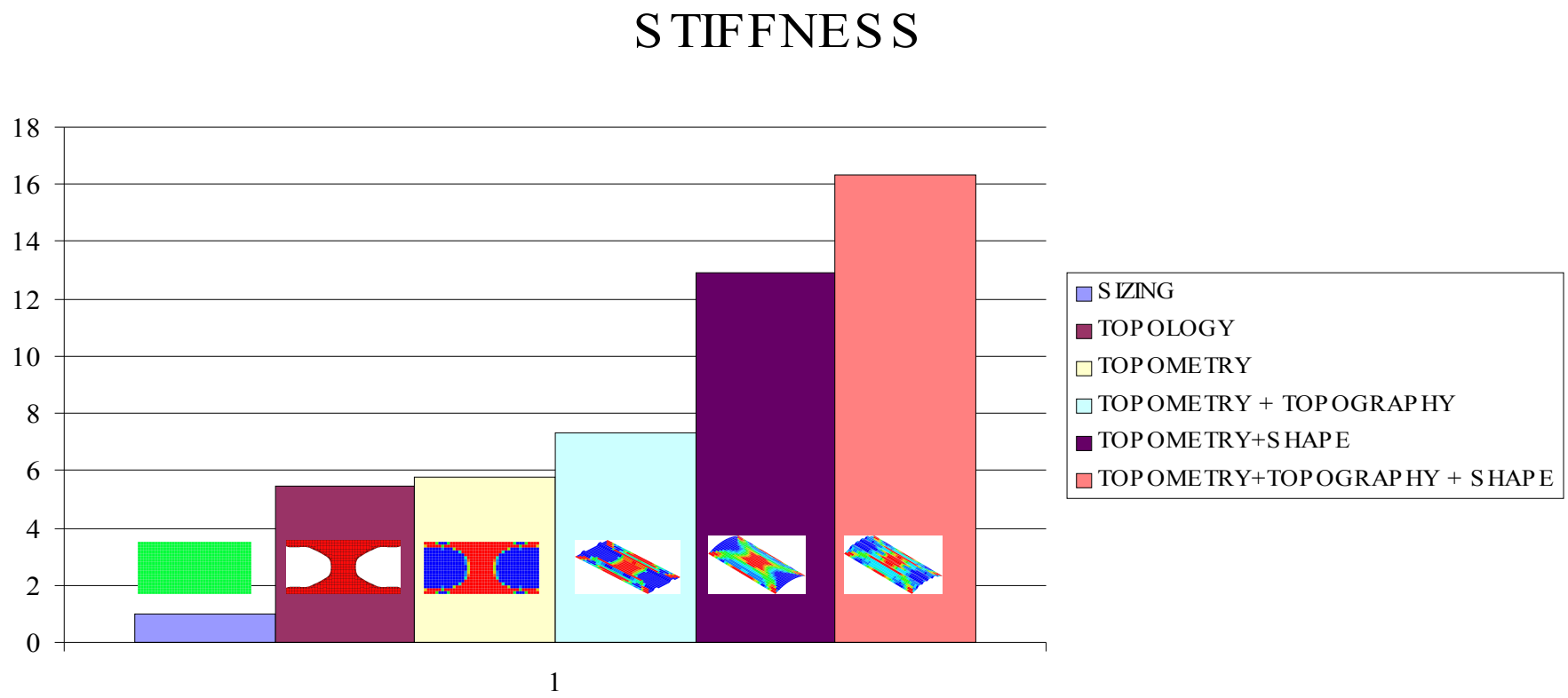




- **Objective:**
  - Maximize Stiffness
- **Constraints:**
  - Volume <=600mm^3
- **Design Variables: 726**
  - 720 Element thickness
  - 6 Topography
  - 1 Shape

Topometry + Topography + Shape

Topometry work with Other Types of Optimization



GENESIS Optimization Capabilities

- **Topology** best distribution of material
- **Sizing** best dimensions of any designable elements
- **Shape** best shape possible
- **Topography** location and shape of bead patterns to stiffen panel structures
- **Topometry** optimal distribution of sizing dimensions over the structure (element by element)
- **Composite** layer thickness, shape, angle, ...

Composite Optimization Tools

Design Variables:

- Thickness
- Angle
- Shape

Objective Function:

- Any response

e.g. reduce mass or cost

Constraint Function:

- Any response

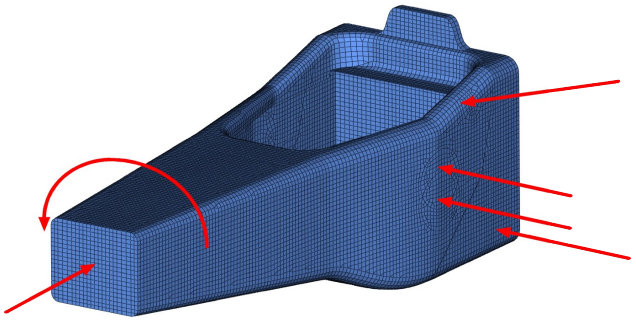
e.g. prevent buckling, Constrain failure indices, displacements, torsional/bending frequencies

Failure Theories Available:

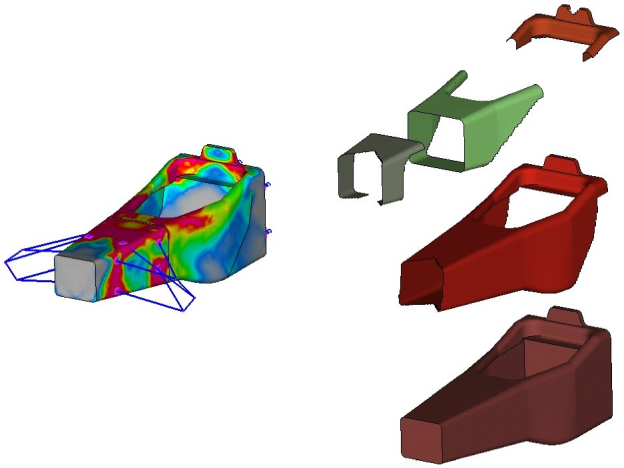
- Hill Theory
- Hoffman Theory
- Tsai-Wu Theory
- Maximum Strain Theory

From small parts to whole systems

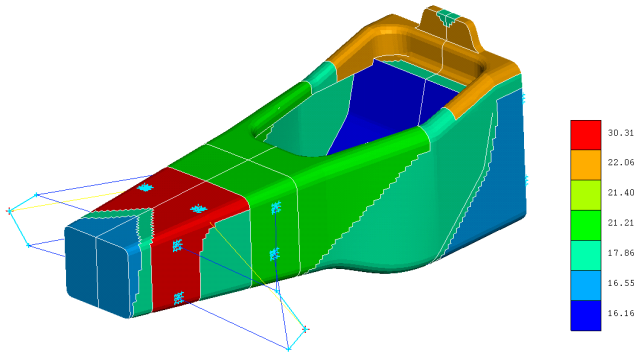
GENESIS Composite Optimization



Loading Conditions



Designable Areas



Designable Areas

Mass reduced by 18%

Courtesy GRM Consulting and P+Z

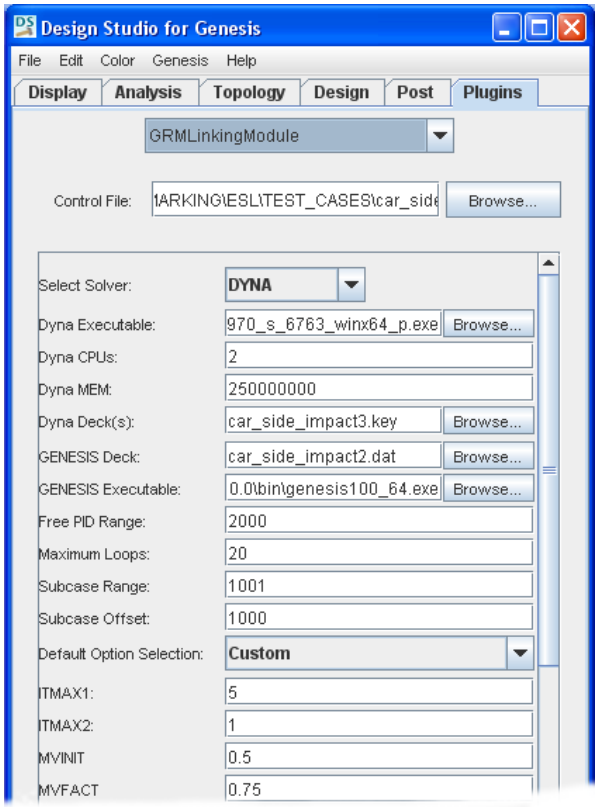
GRM Consulting Ltd

DYNA More

VR&D GENESIS < > LS-DYNA Interface

- Implemented as an add-on to Design Studio an interface to LS-DYNA is available for VR&D GENESIS

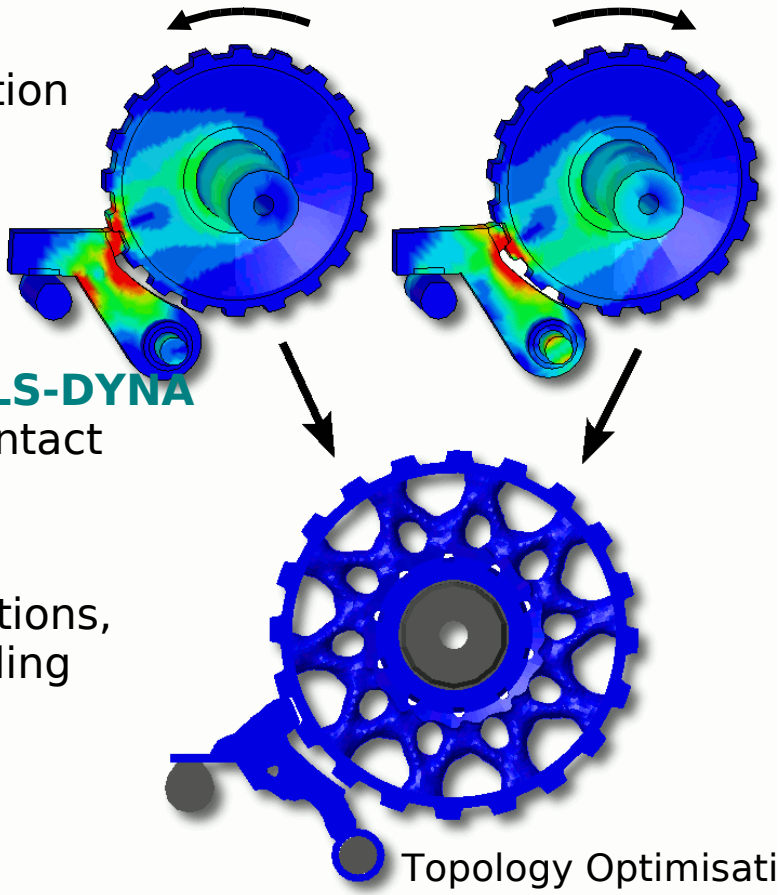
- Interface supports all capabilities of GENESIS optimisation including:
  - Topology
  - Topometry
  - Topography
  - Size & Shape



GENESIS / DYNA Topology

Parking Break Study (two loading directions)

- Topology Optimisation performed to determine optimum material distribution for:
  - Positive gear torque
  - Negative gear torque
- **Optimisation coupled to implicit LS-DYNA** models consider gear and lock-pin contact conditions
- Concept design developed in 39 iterations, optimising for **42,000 variables**, calling **LS-DYNA only 7 times** for each loading direction

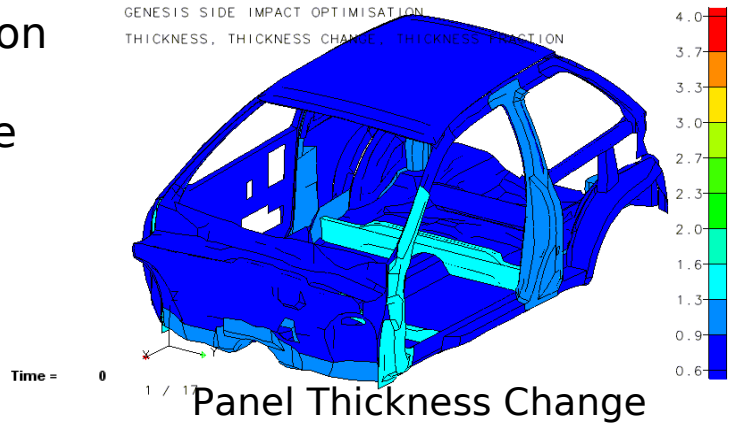


Topology Optimisation Results

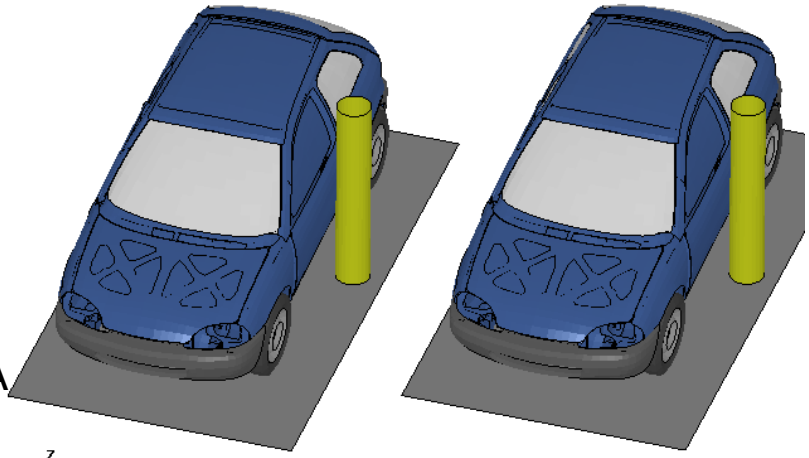
GENESIS / DYNA Sizing

Coupled Pole Impact and Static Torsion

- Vehicle BIW panel thickness optimisation performed for both static body torsion (GENESIS/NASTRAN load case) and side pole impact
- Torsional stiffness maintained whilst pole intrusion reduced from 600mm to 300mm.
- Required mass increase only 39kg
- Optimisation considered **59 panel thickness** changes using on **10 function calls to LS-DYNA**
- Method can consider multiple LS-DYNA impacts cases



Panel Thickness Change


Original Optimised

Pole Impact Performance

Conclusions

- Optimization is a mature technology that works
- Optimization allows engineers to:
  - Reduce weight
  - Improve performance
  - Satisfy design requirements
- Optimization allows corporations to make the design process more automatic which allows to:
  - Reduce time to market
  - Improve quality
  - Innovate
- Optimization allows to improve the environment by:
  - Reduce fuel consumption
  - Reduce pollution
- GENESIS allows to improve structural designs