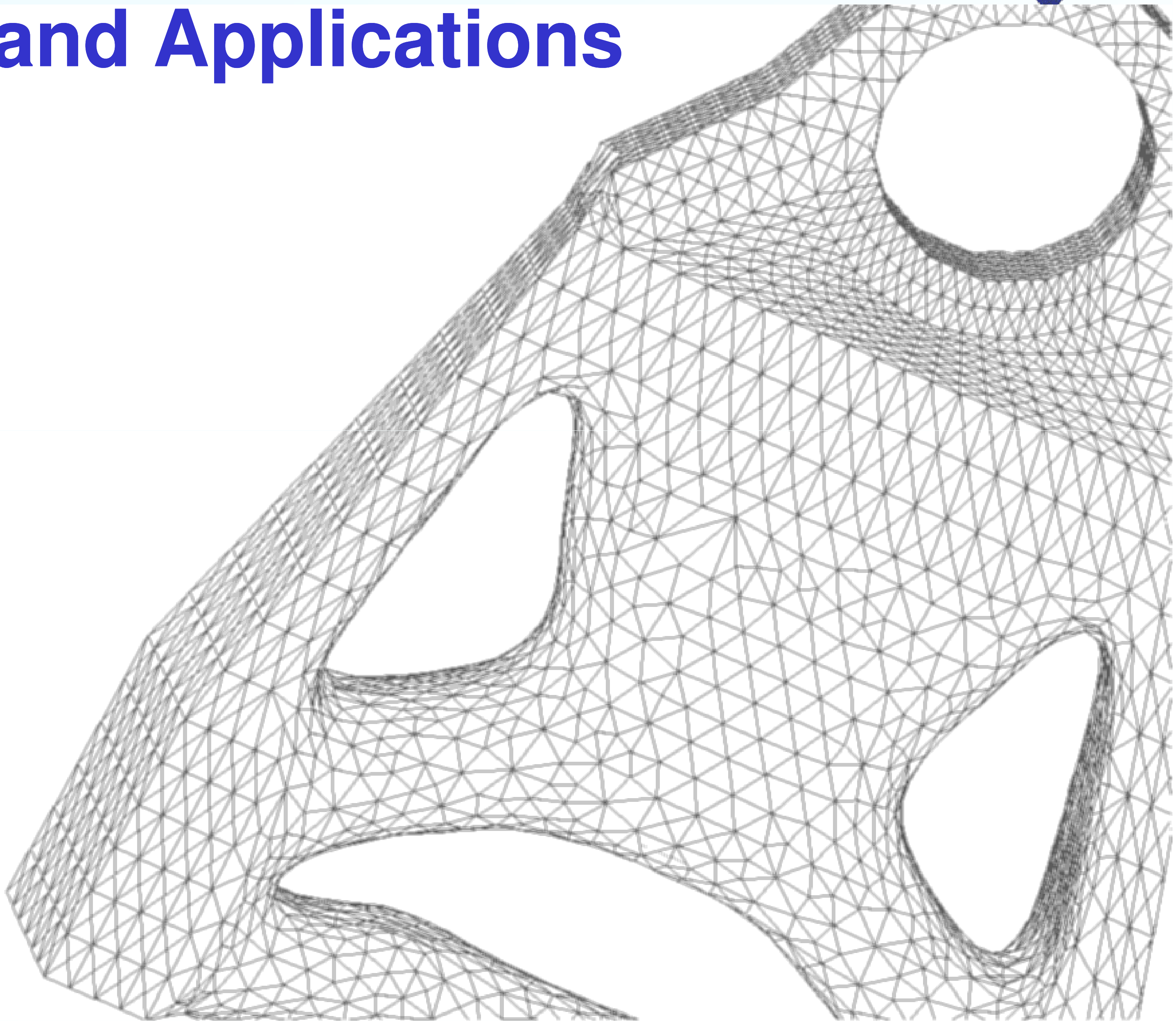
Optimization Ideas, Software and Applications



Presented by:

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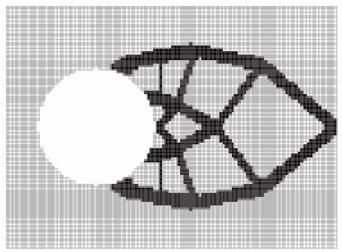
GENESIS

- 20 years in marketplace
- Large scale analysis and optimization
- Uses standard Nastran input files
- Uses standard post-processing files
- Fast and robust solvers

GENESIS

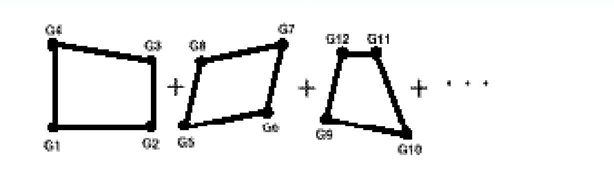
Fully Integrated Structural Analysis/Design Package

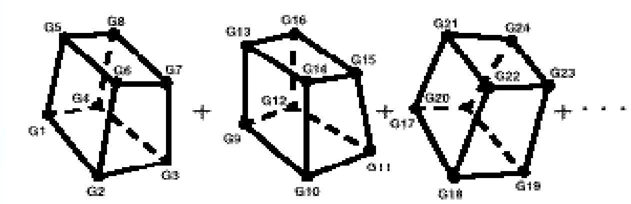
- **Analysis options**
  - Linear statics
  - Inertia relief
  - Normal modes
  - Frequency response
  - Heat transfer
  - Buckling
  - Random response
- **Optimization options**
  - Topology
  - Sizing
  - Shape
  - Topography
  - Topometry



Elements in GENESIS

- **Spring elements:**
  CELAS1, CELAS2, CBUSH, CVECTOR
- **Truss elements:**
  CROD
- **Beam elements:**
  CBAR, CBEAM
- **Shear panel elements:**
  CSHEAR
- **Plate/shell/composite elements :**
  CTRIA3, CQUAD4
- **Axisymmetric elements:**
  CTRIAX6
- **Solid elements:**
  CTETRA, CPENTA, CHEXA, CHEX20
- **Mass elements:**
  CMASS1, CMASS2, CONM2, CONM3
- **Viscous damping elements:**
  CDAMP1, CDAMP2, CVISC
- **Heat boundary elements:**
  CHBDY
- **Rigid elements:**
  RROD, RBAR, RBE1, RBE2
- **Interpolation elements:**
  RBE3, RSPLINE
- **User defined elements:**
  GENEL, K2UU, M2UU

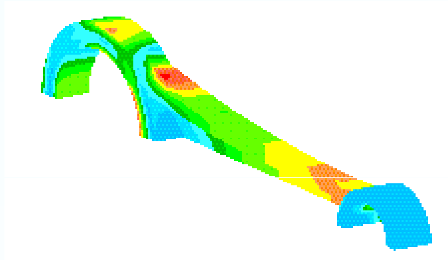


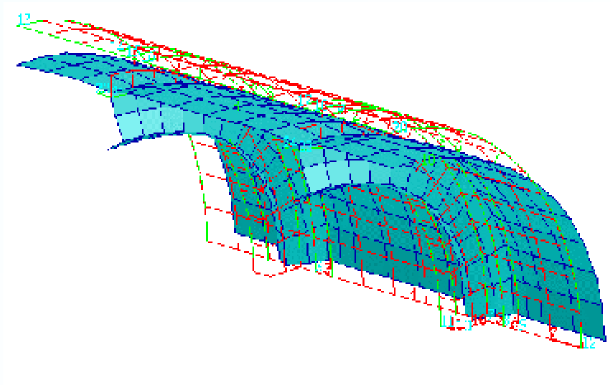


FEA Output in GENESIS

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

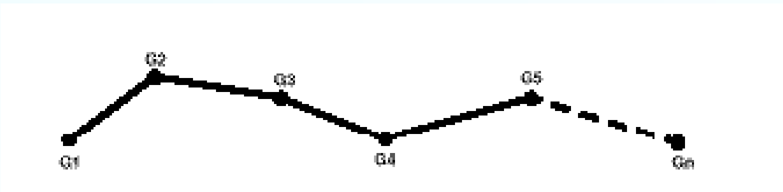
- **Displacements, velocities & accelerations**
- **Grid stresses**
- **Grid temperatures**
- **Element stresses, strains & forces**
- **Strain energies**
- **Frequencies & mode shapes**
- **Buckling load factor**
- **Mass & volume**
- **Inertia & center of mass**

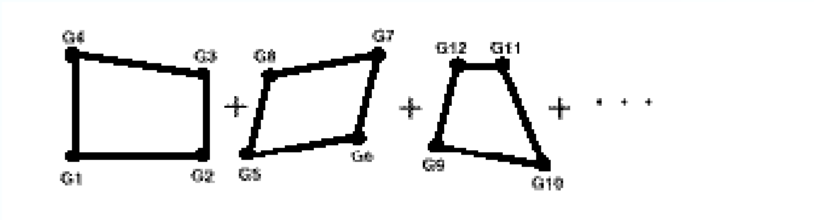


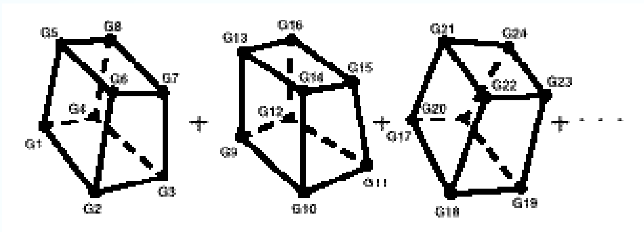


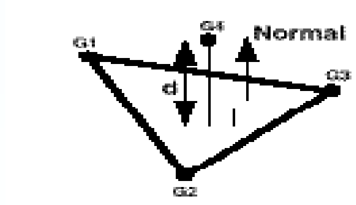
Geometric Responses

- 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









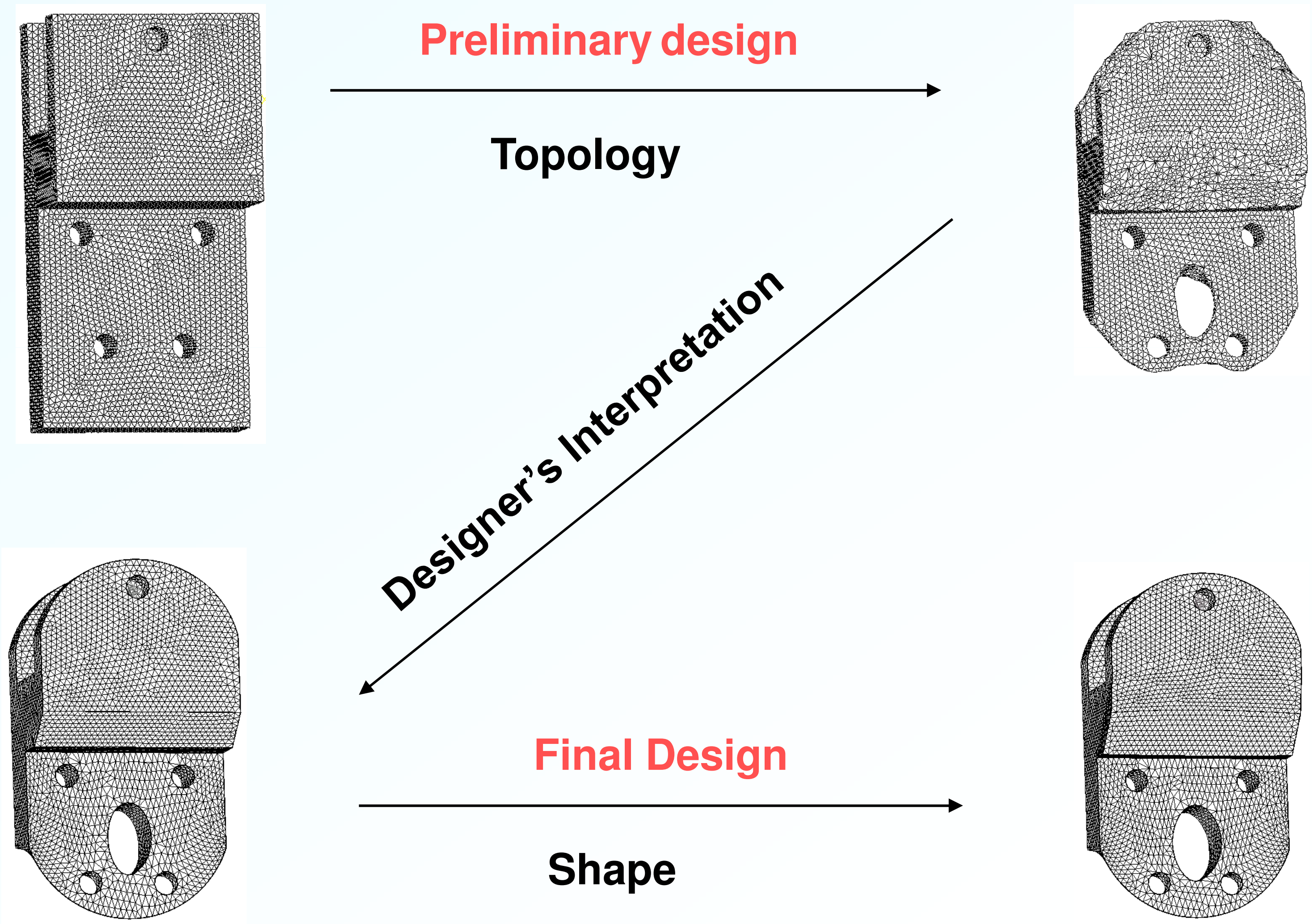
User Responses

- **Equations – DRESP2**
  - Resp = F(design variables, grid locations, built-in responses)
- **User-written Subroutines – DRESP3**
  - Resp = F(design variables, grid locations, built-in responses)
- **External Programs – DRESPU**
  - CALL SYSTEM (’abaqus f.inp’)

GENESIS Optimization Capabilities

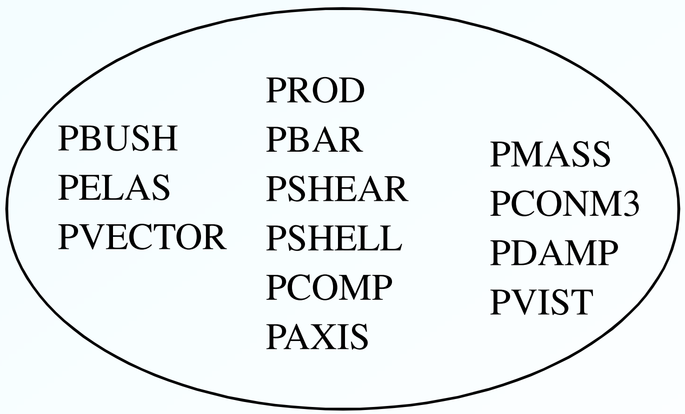
- Topology
- Sizing
- Shape
- Topography
- Topometry

Typical Design Process



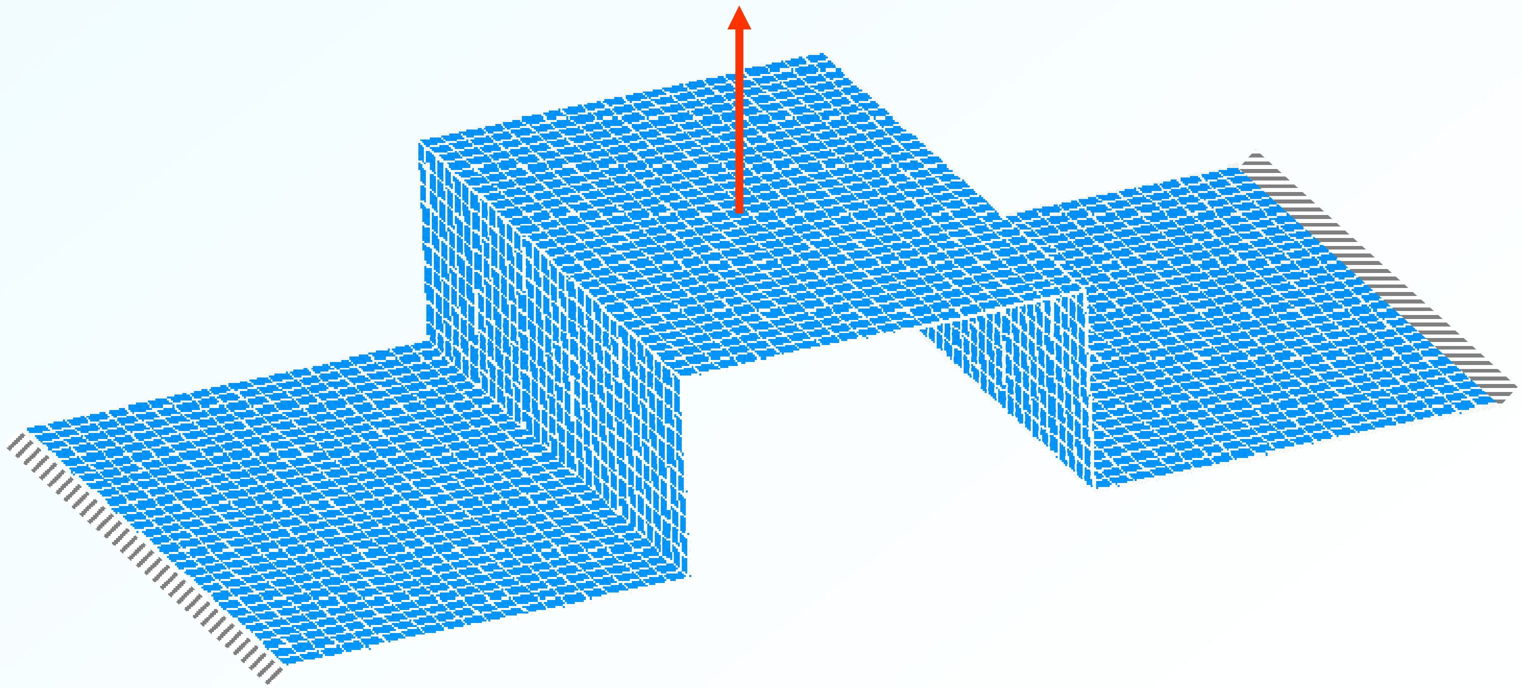
What is Topology Optimization?

- Allow to select the best elements to keep in an finite element mesh

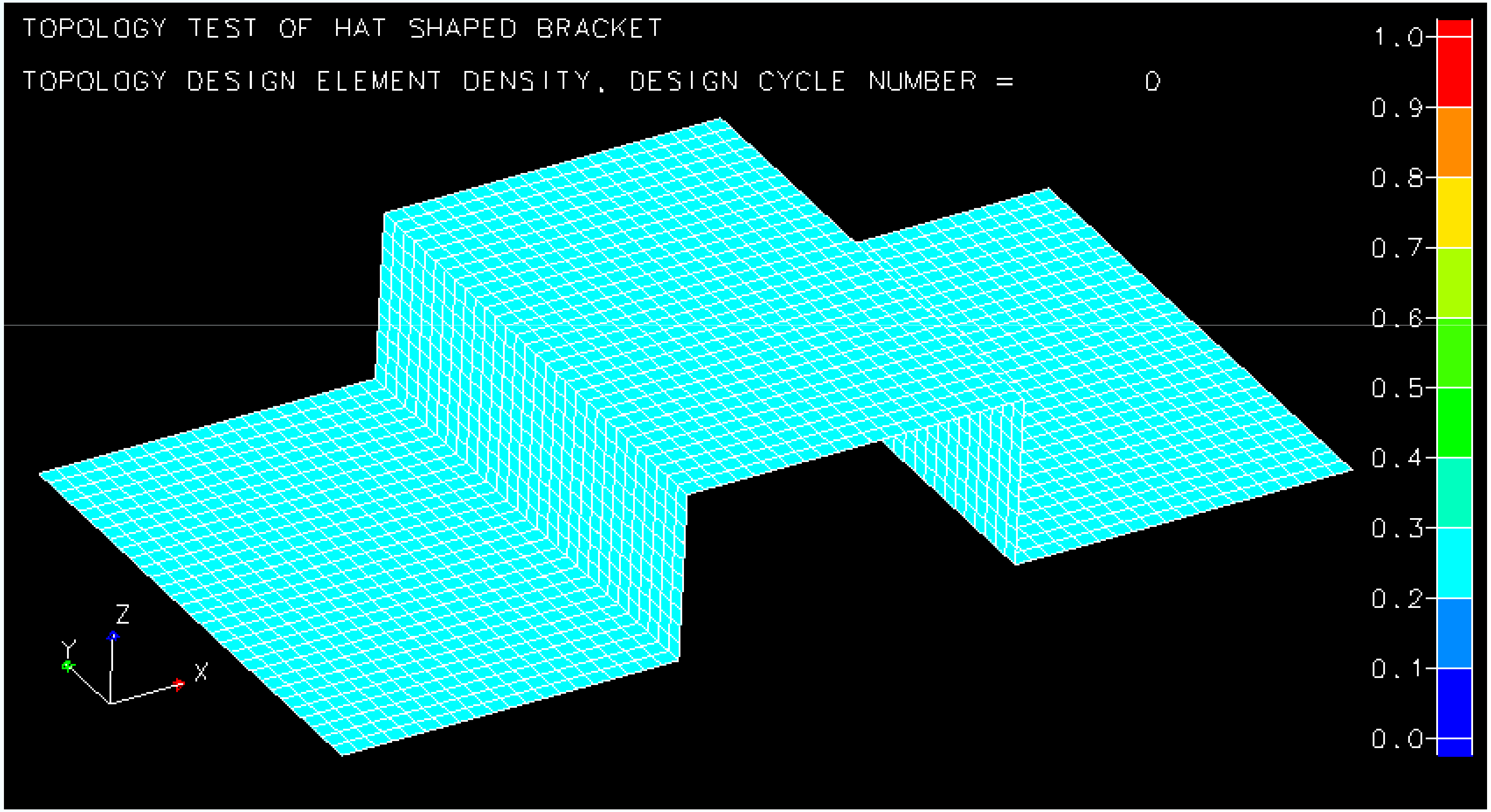


Simple Topology Example

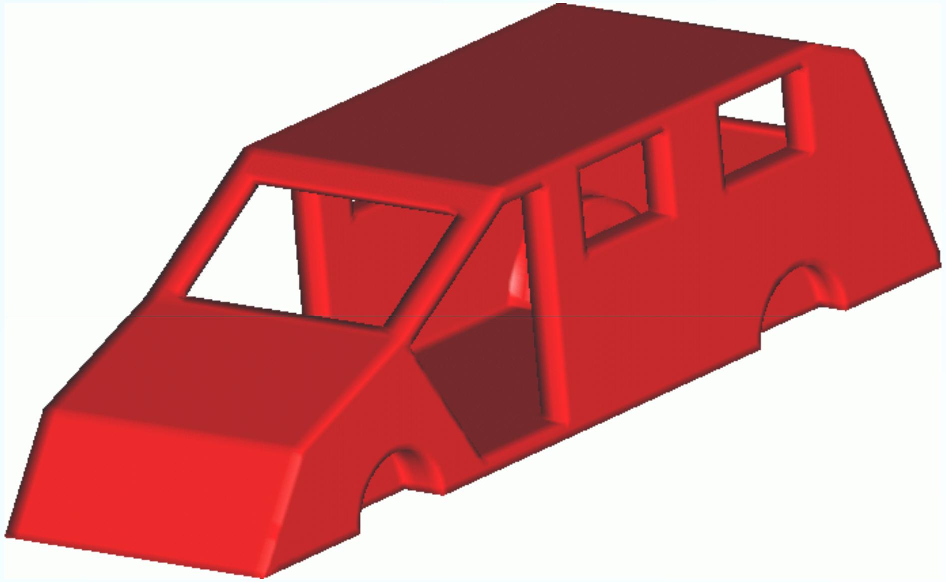
Find the Stiffest Structure Using 30% of the Material to Carry the Given Load



Topology Results



Conceptual Design of an SUV



Problem Statement:

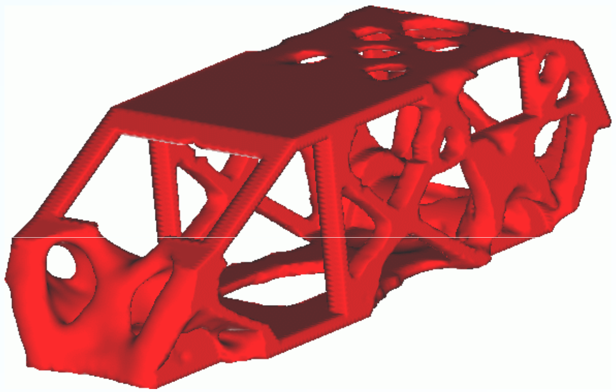
Determine where to keep material to make a stiff, lightweight structure.

SUV Topology Result

Minimize Strain Energy

Mass < 40%

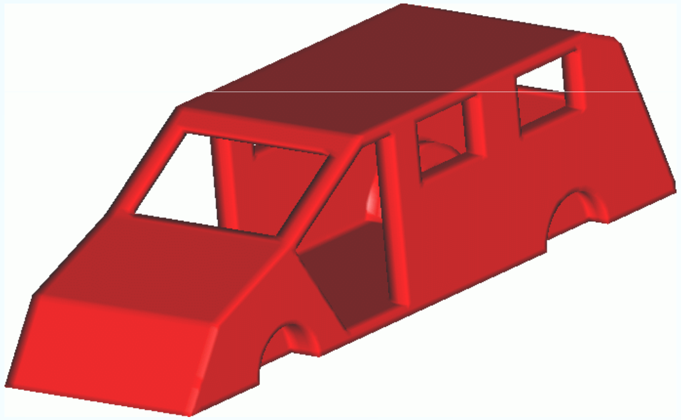
Top View



Side View

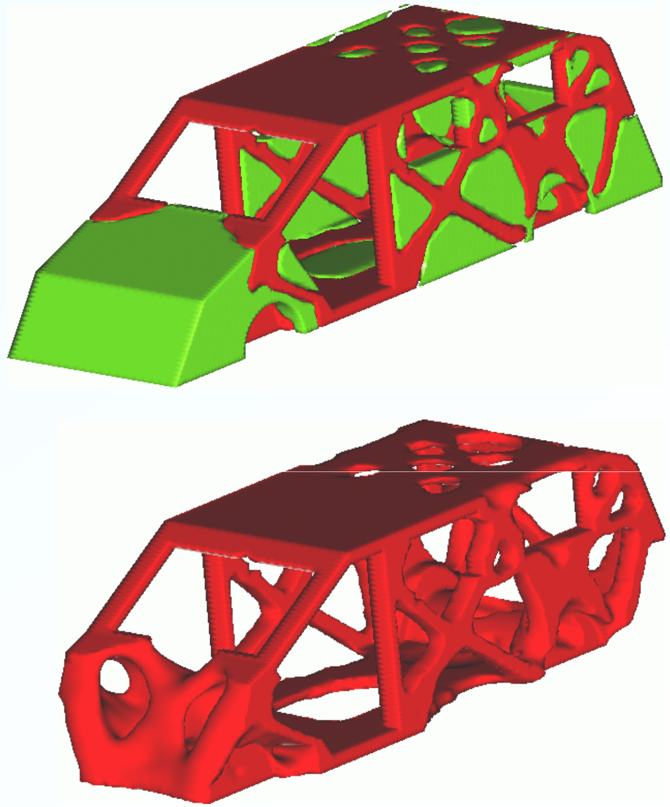
Rear View

SUV Topology Result



Initial Design

Topology →

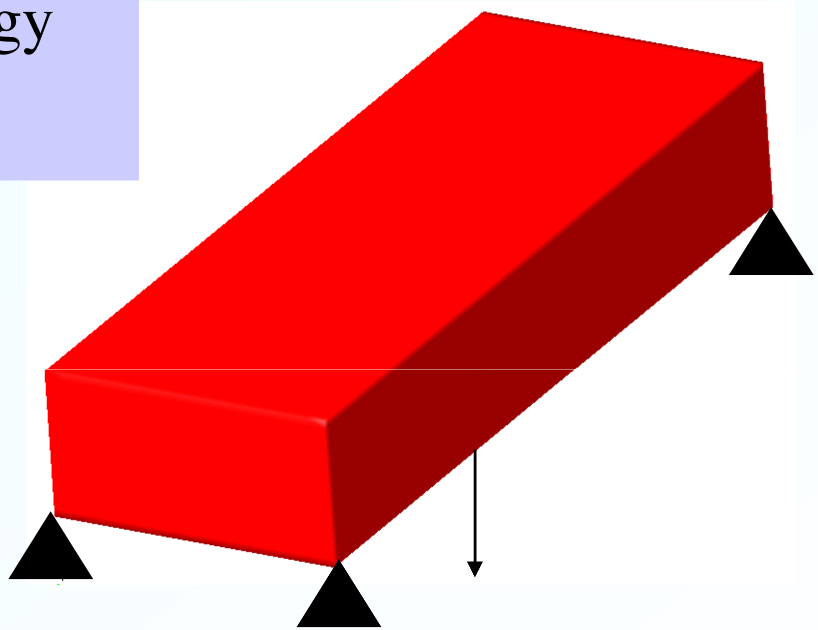


GENESIS Results

Topology Example

Minimize Strain Energy

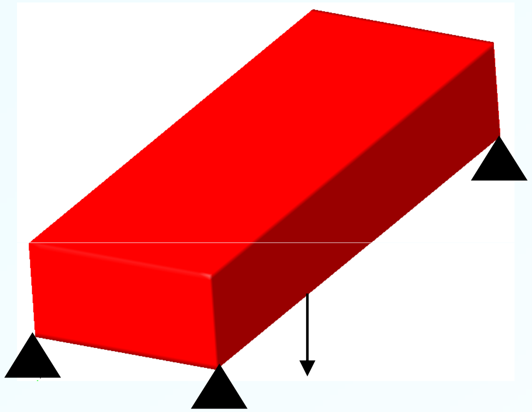
S.t. MASSFR <= 0.1



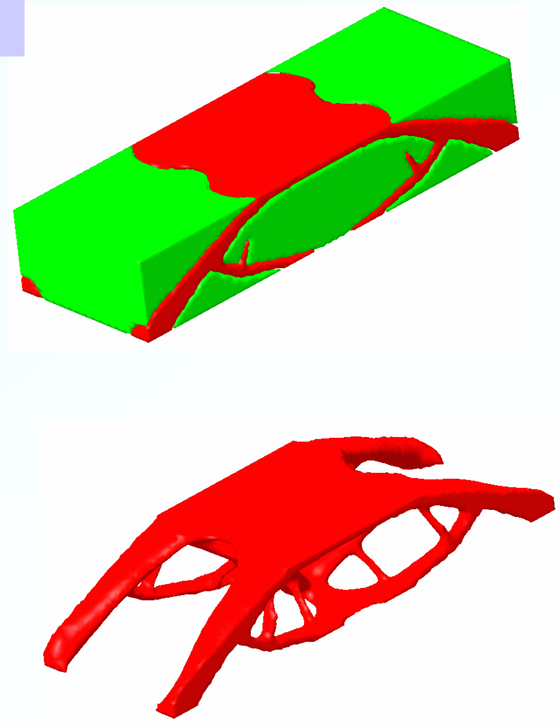
Load and Boundary Conditions

Standard Topology Results

Number of Elements= 1,003,520



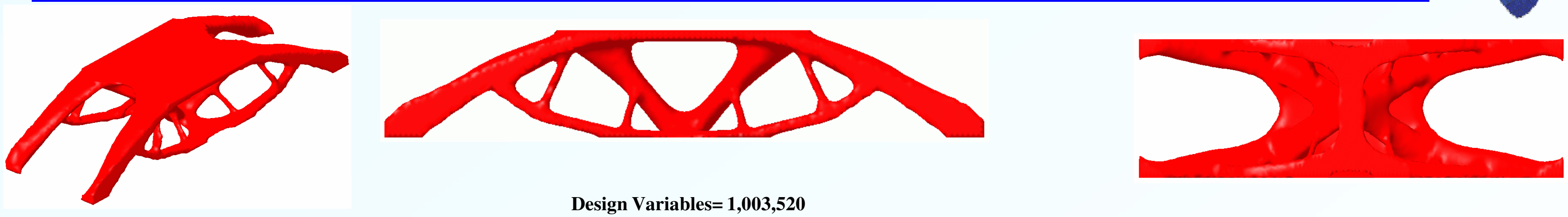
Initial Design



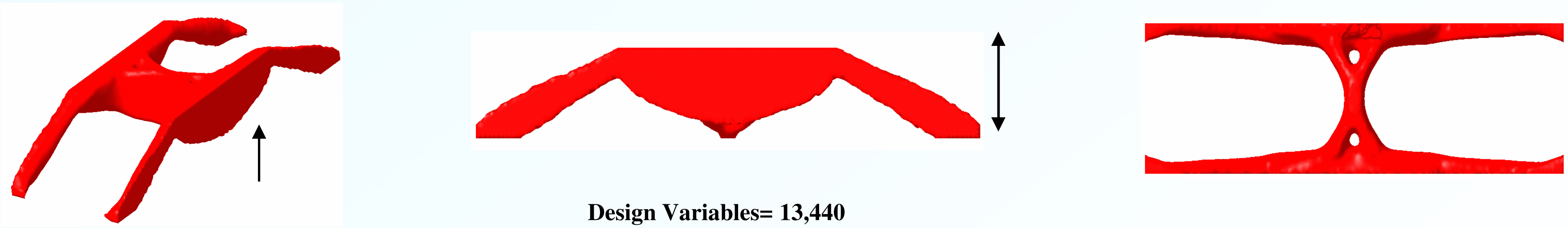
Final Design

No. of Design Variables= 1,003,520

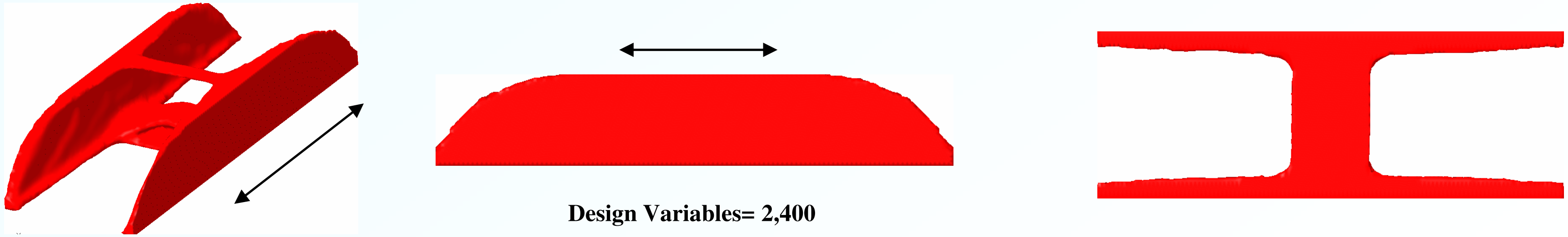
Topology Example



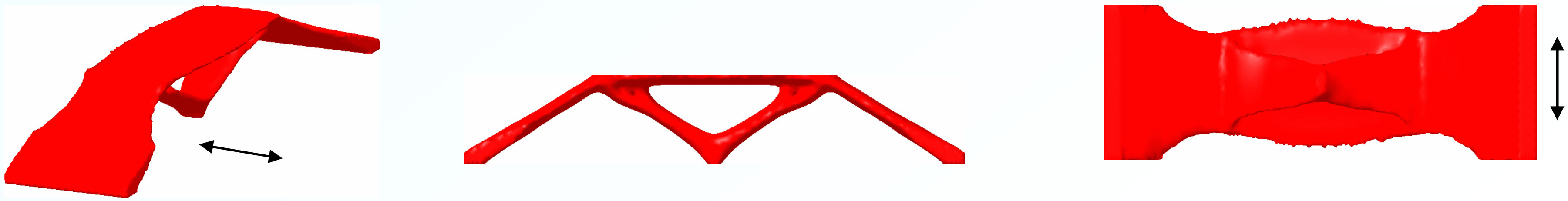
Design Variables= 1,003,520



Design Variables= 13,440



Design Variables= 2,400

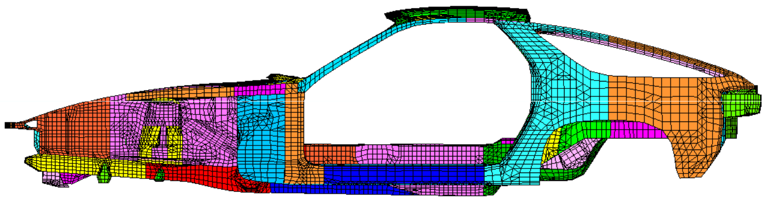


Design Variables= 6,720

Topology Applications

Where to reinforce?

- Add a second layer of elements on places where is possible to reinforce
- Topology optimize second layer



Item	Original Model	Sheath-added Model
Number of Grid Points	27252	27252
Number of CQUAD4 Elements	22072	44144
Number of CTRIA3 Elements	12488	24976
Number of degrees of freedom	163512	163512
Number of designable elements	-	34560
Number of design variables	-	34560

Topology Applications

•**Objective:**

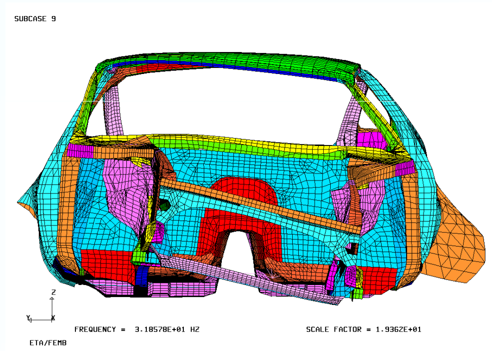
–Maximize first natural torsional frequency

•**Constraints**

–Added Mass < 3.1 kg → Case 1

–Added Mass < 7.8 kg → Case 2

–Added Mass < 15.2 kg → Case 3

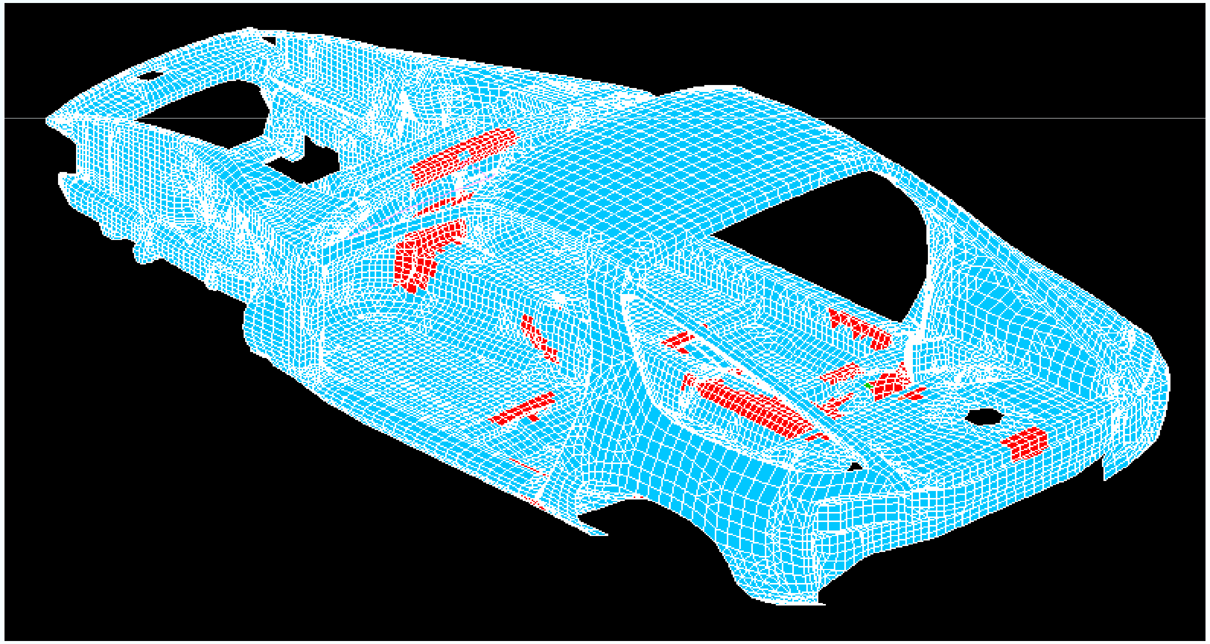


•**Design Variables:**

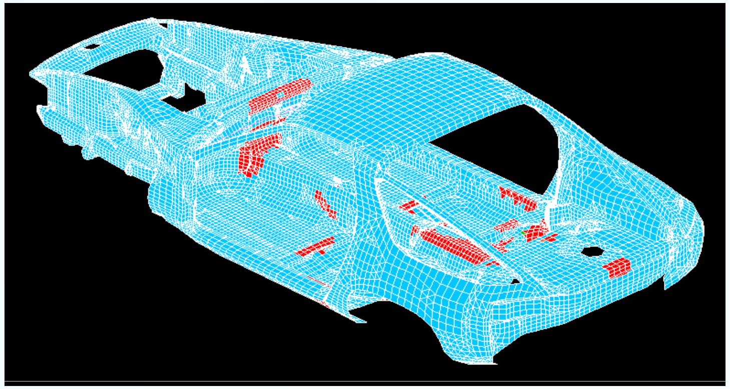
– Each element in second layer: 34 560

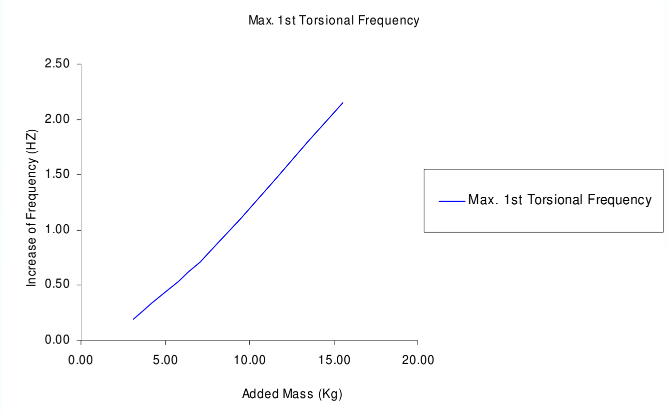
Topology Applications

Maximizing 1st Torsion Frequency

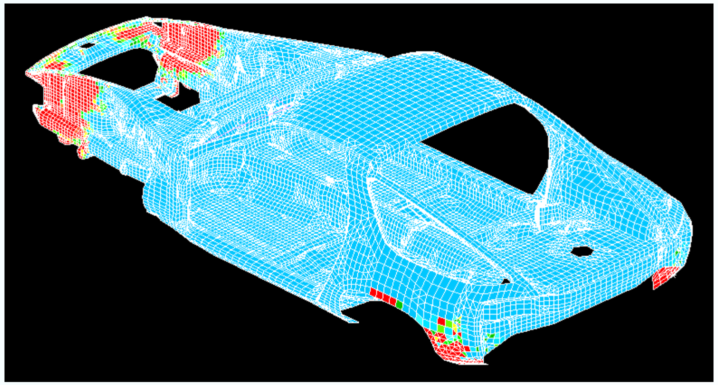


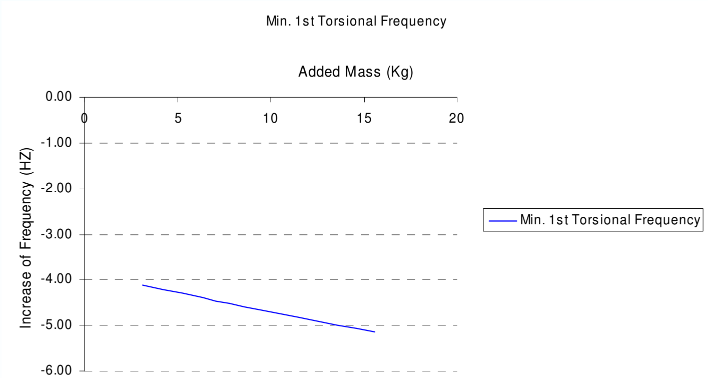
Topology Applications





Maximizing 1st Torsional Frequency

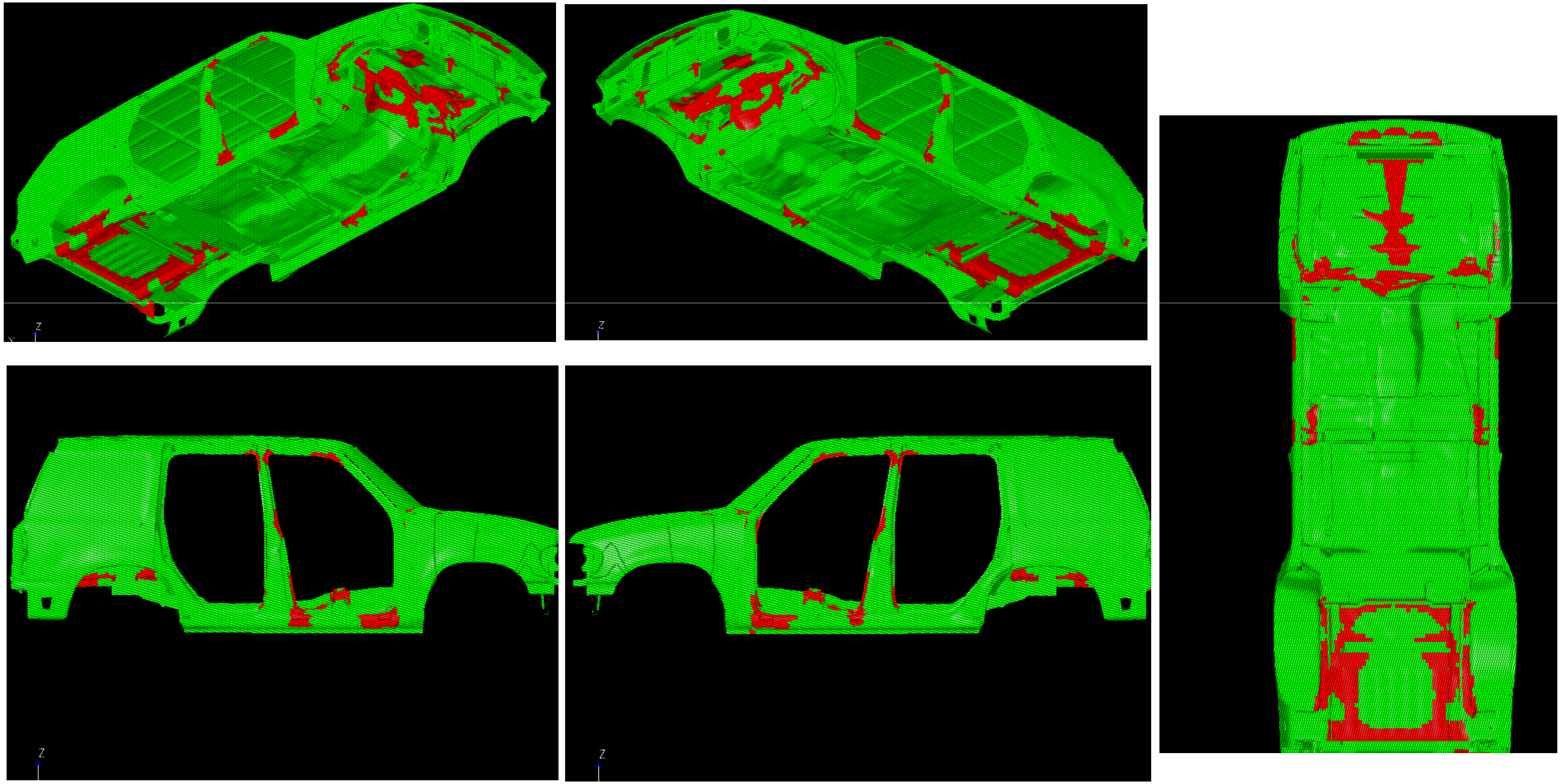




Minimizing 1st Torsional Frequency

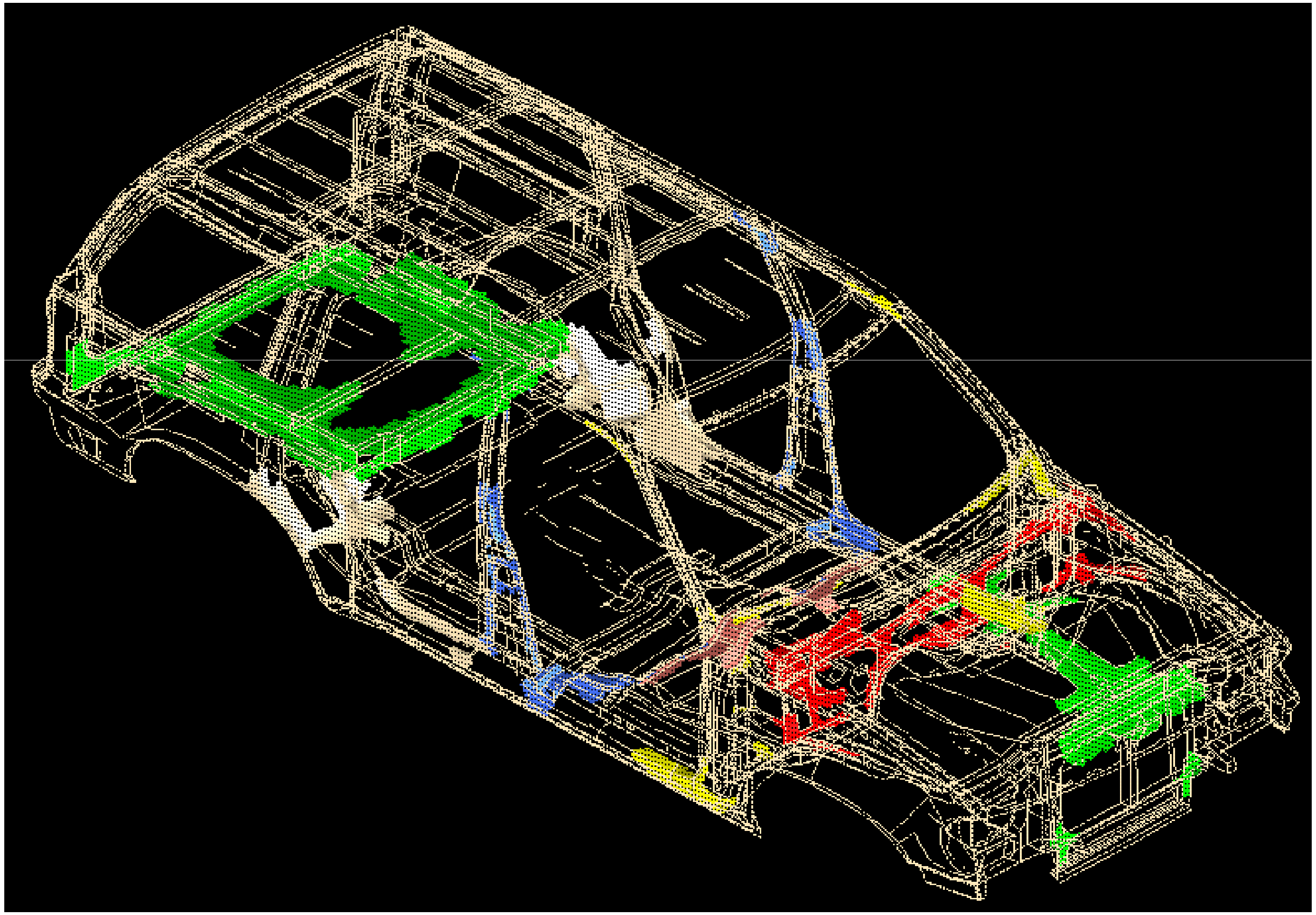
Topology Applications

- Red: elements to keep
- Green: elements to discard



Topology Applications

7 Reinforcement Patches are selected



Front:4.3 kg

Firewall: 8.8 kg

Front Sill: 3.6 kg

Tunnel: 1.6 kg

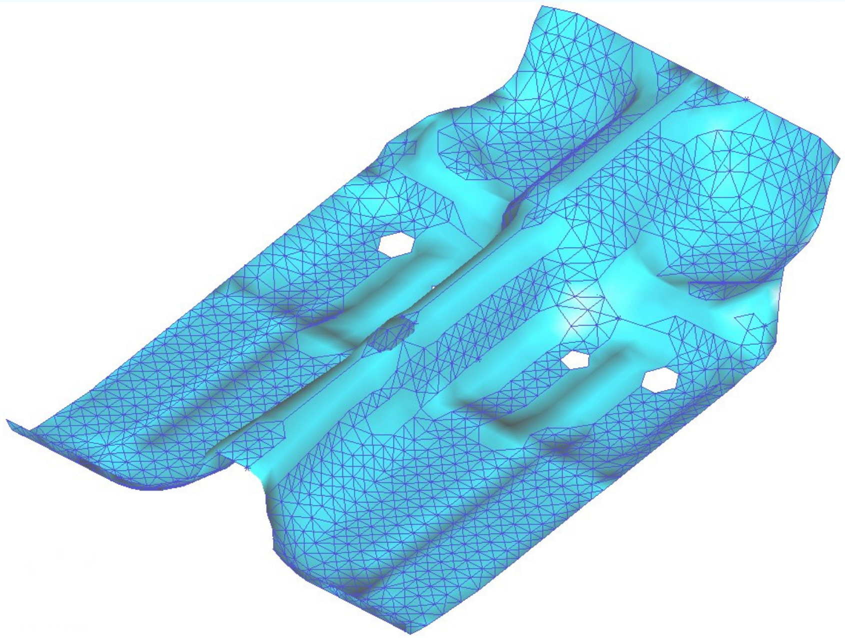
B-Pillars:5.6 kg

Back Fenders:6.7 kg

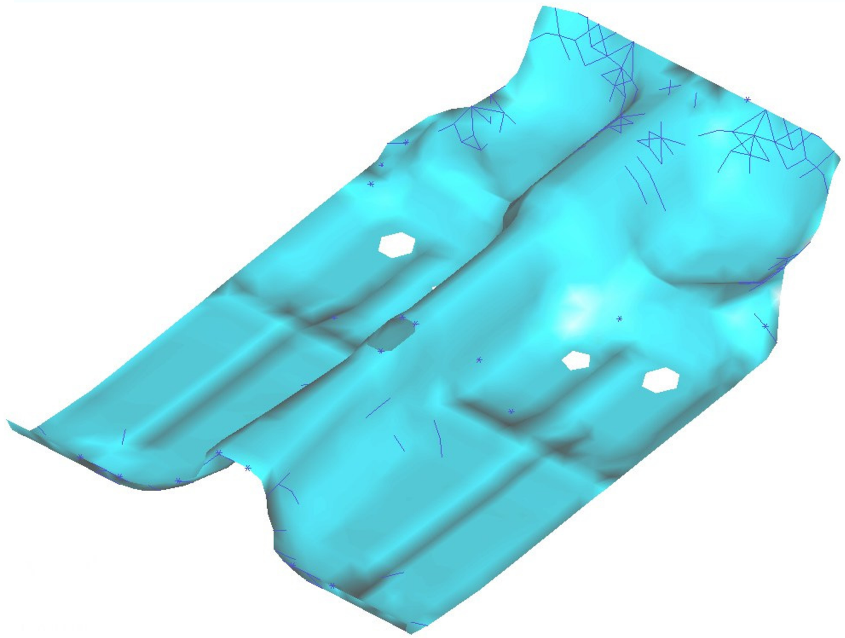
Back Floor: 15.3 kg

Total: 46.1 kg

Autorib Application



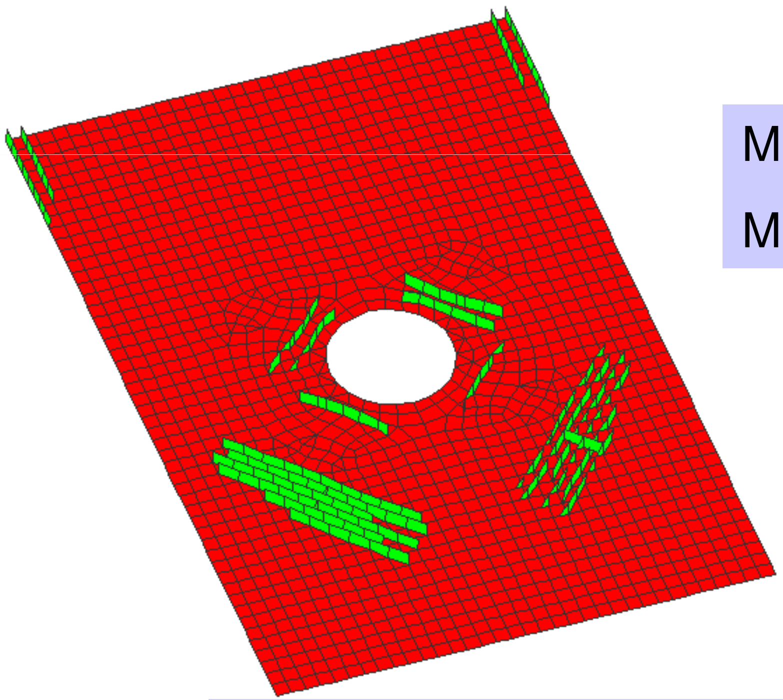
Automatically Generated Candidate Rib Stiffeners



Best 5% of Ribs for Increased Torsional Natural Frequency

Autorib Application

Design of rib pattern for the plate with hole subject to torsional load



Max initial disp : 3.61

Max final disp :2.82

Mass constraint : 10.25%

What is Sizing Optimization?

- Allow to design dimensions of many different types of elements

PBUSH	PROD	PMASS
PELAS	PBAR	PCONM3
PVECTOR	PSHEAR	PDAMP
	PSHELL	PVIST
	PCOMP	
	PAXIS	

Sizing Optimization

- Allow to design dimension (not just properties A, Izz)

Plate and Shell Elements

$$T = x$$

$$TS = (5/6) * x$$

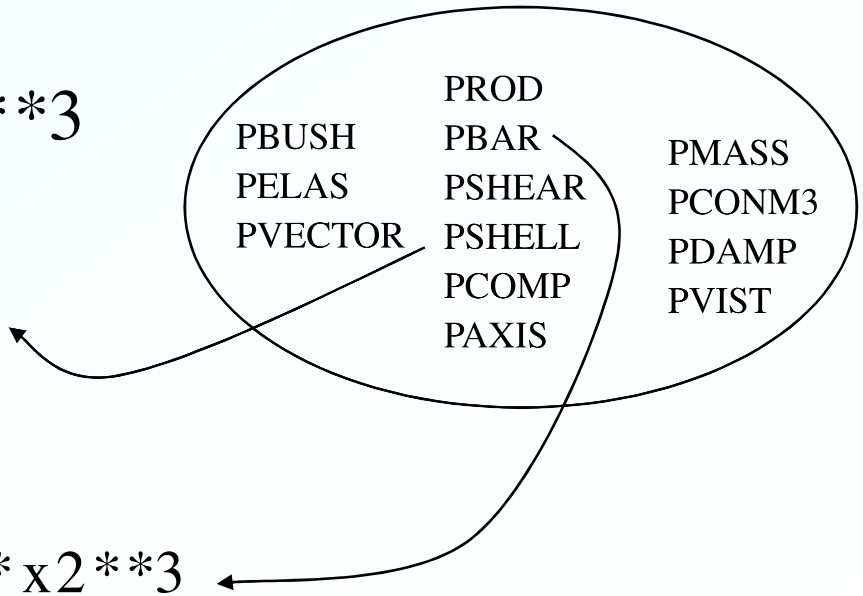
$$D = (1/12) * x**3$$

$$Z1 = -0.5x$$

$$Z2 = 0.5x$$

Bar Elements

$$A = x1 * x2$$
$$Izz = 1/12 * x1 * x2**3$$
etc



Sizing Optimization

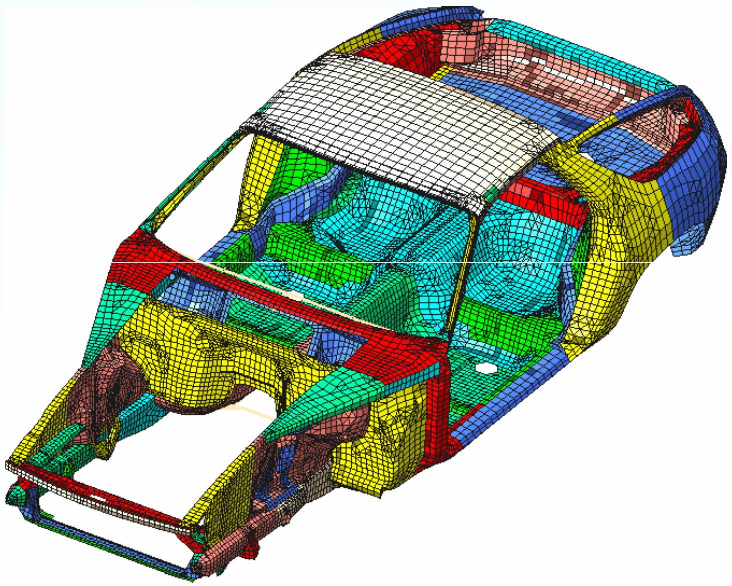
Example

Design Variable x

$1.0 <= x <= 2.0$mm

PSHELL Properties

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

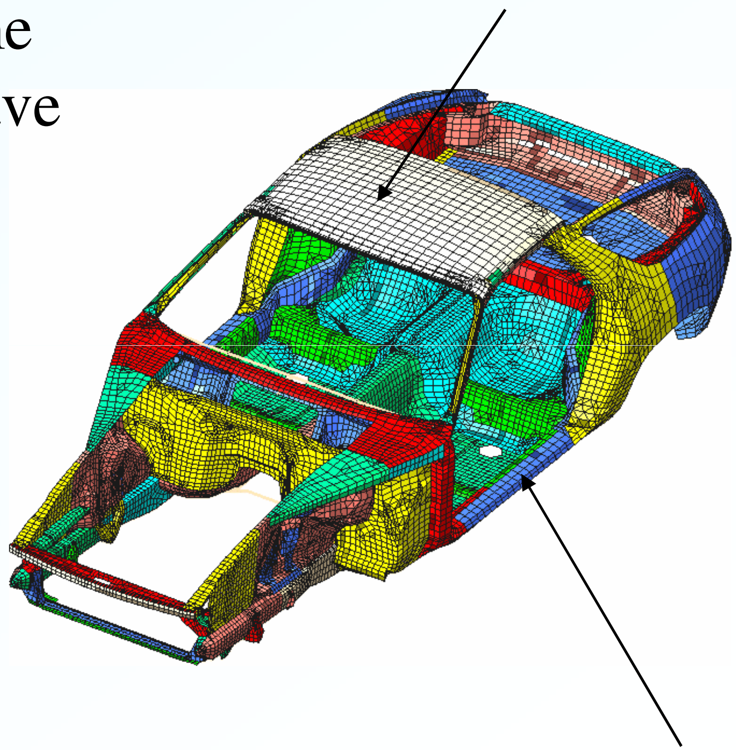


PSHELL,ID,MID,T,MID2,D,MID3,TS

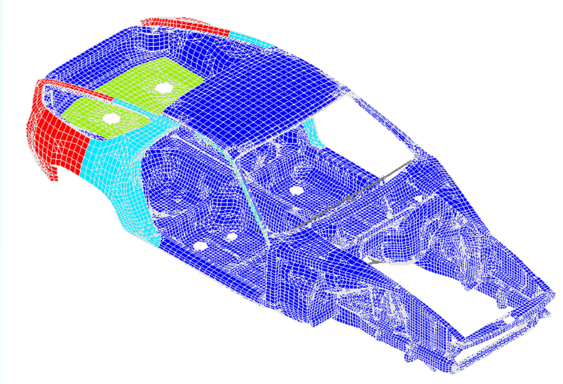
+ z1,z2

Sizing Optimization

All Element that reference the same Property set (e.g PSHELL) will have same thickness



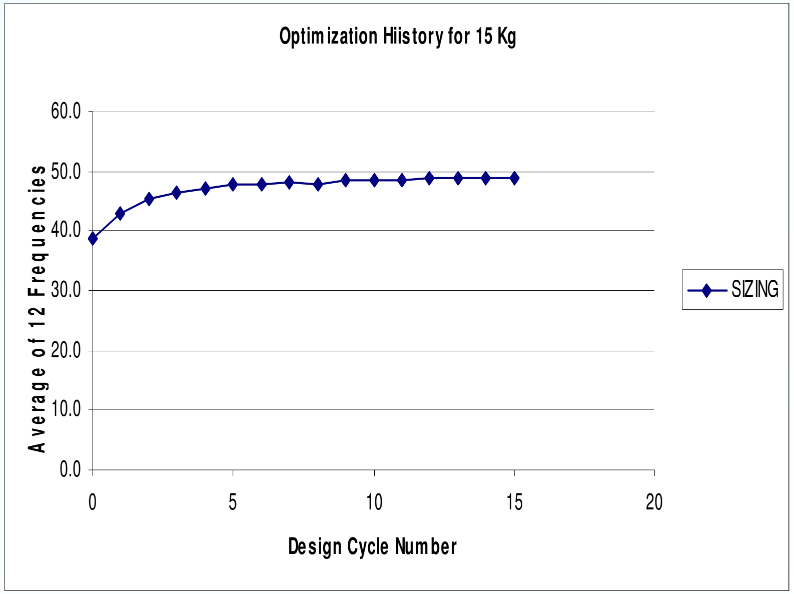
Sizing Optimization



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:

- **Strain Energy Reduced From:**

  38.6 to 48.9Hz

  (10 hz, 27% Gain)

Constraints:

- **Mass Increased 15kg**

Design Variables:

- **63**

Number of Design Cycles

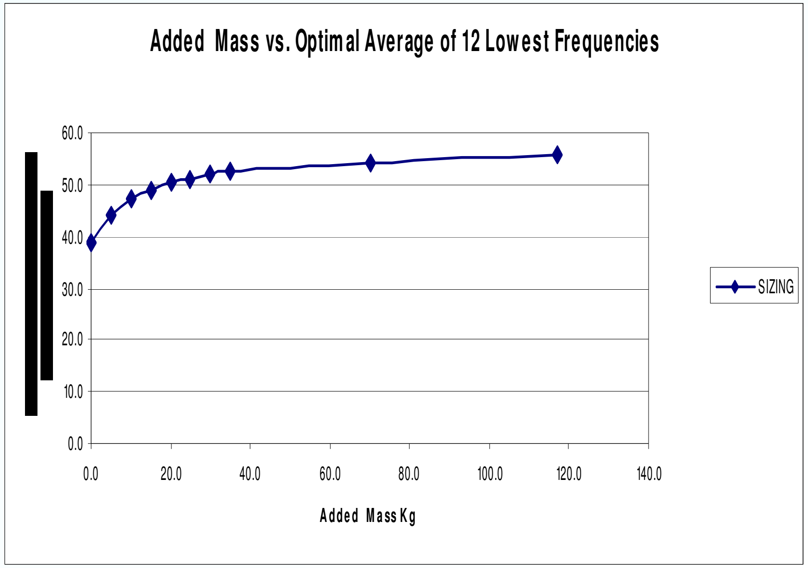
- **15**

Example of Sizing Optimization:
Trade of Study Mass vs Sum of 12 Lowest Frequencies

Problem

- **Objective:**
  - Max Sum Of 12 Lowest frequencies
- **Constraints:**
  - Mass can increase up

    5, 10, 15, .., 70, free
- **Design Variables:**
  - 63 sizing variables
  - 1.0 <= X <=2.0 mm



Results

Objective:

- **Average Summ of 12 Lowest Frequencies can increase from:**

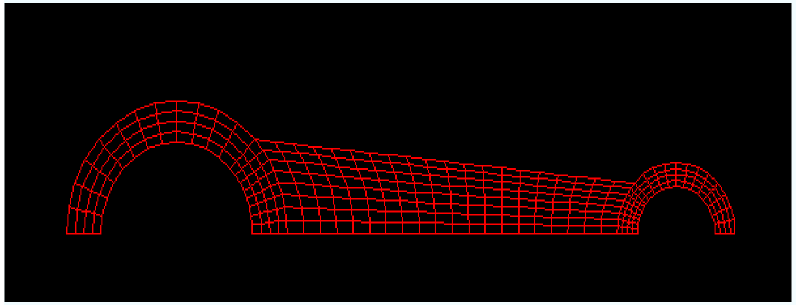
  38.6 to 55.7Hz

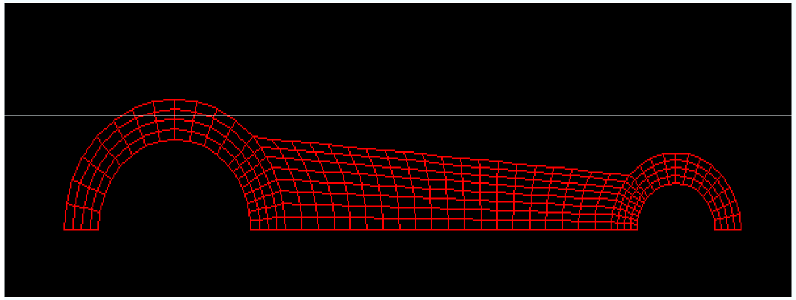
  (17 hz, 44% Gain

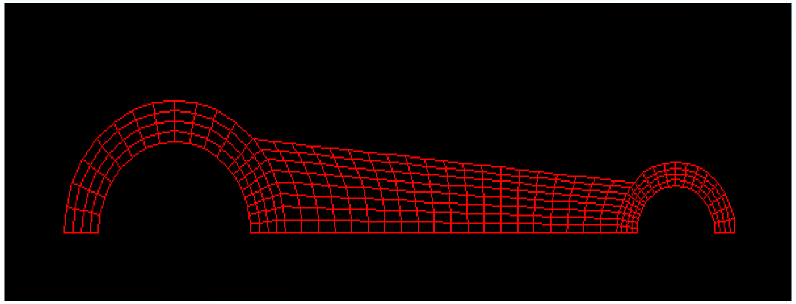
Added Mass for unconstraint minimization:

117 Kg

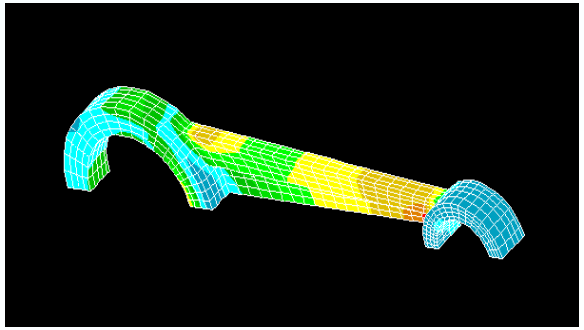
Shape Optimization







$$\left.\begin{aligned} X_i &= X_{io} + \sum_j DV_j * PX_{ij} \\ Y_i &= Y_{io} + \sum_j DV_j * PY_{ij} \\ Z_i &= Z_{io} + \sum_j DV_j * PZ_{ij} \end{aligned}\right\}$$

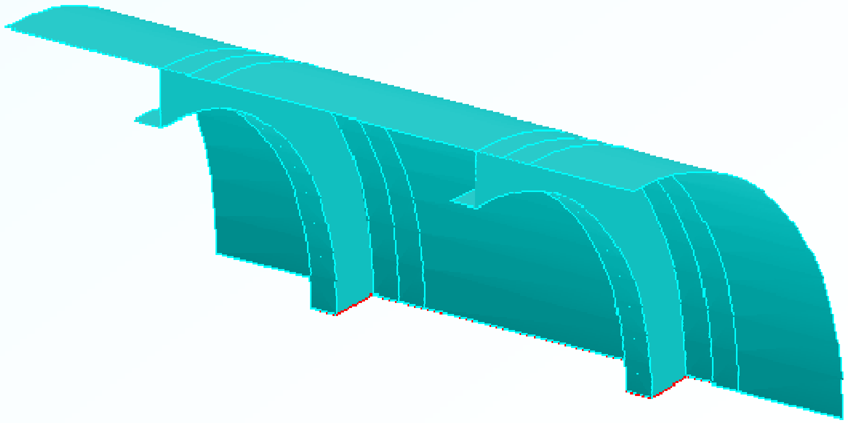


Optimization

Perturbation Vectors

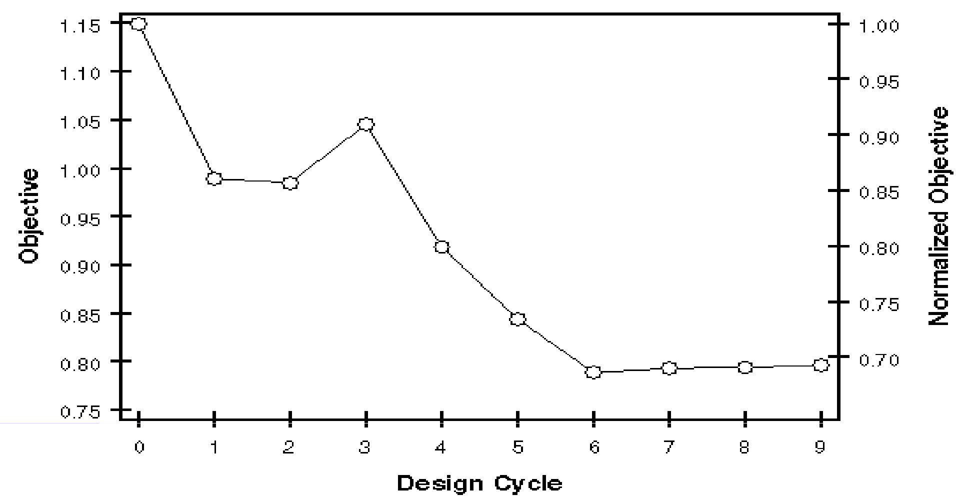
Shape and Sizing Example

- **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

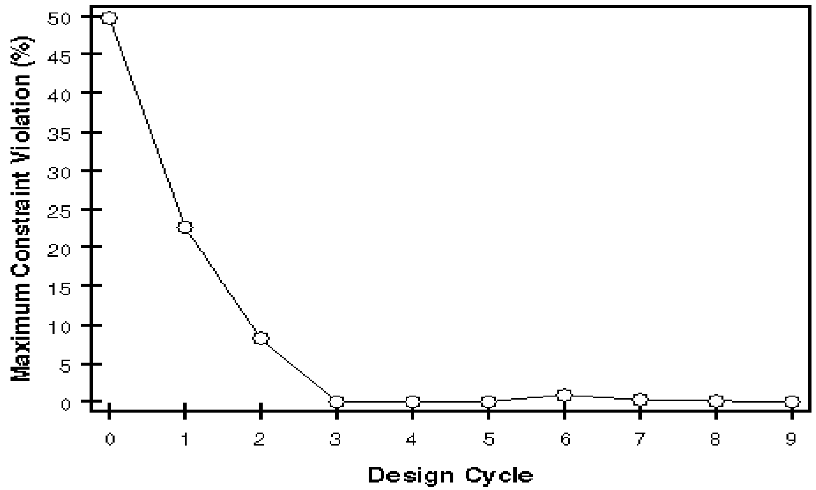


Shape and Sizing Results

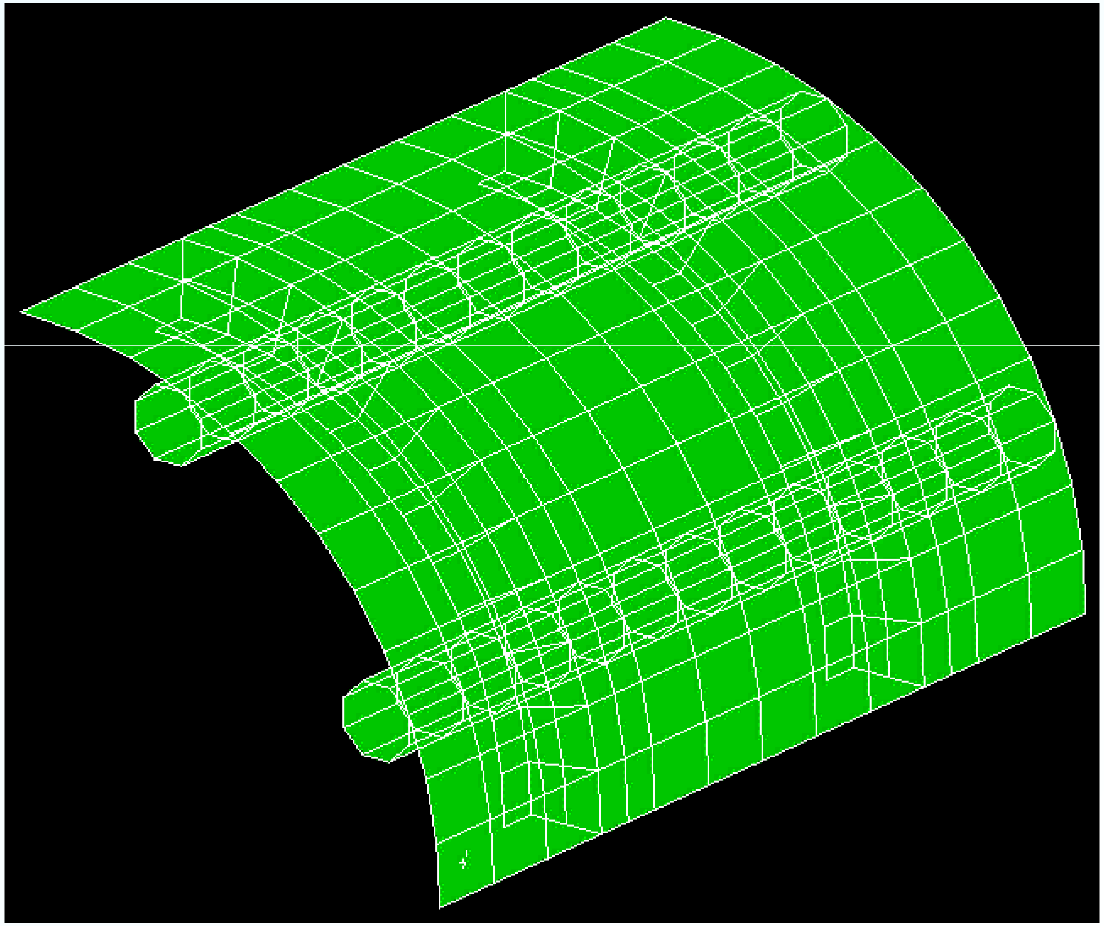
- **Objective**
  - Reduced mass by 30%



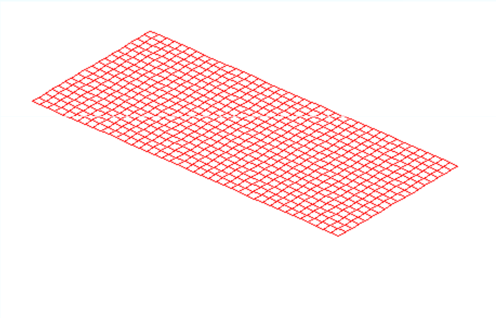
- **Constraints**
  - Initially infeasible
  - Frequency (23 Hz)



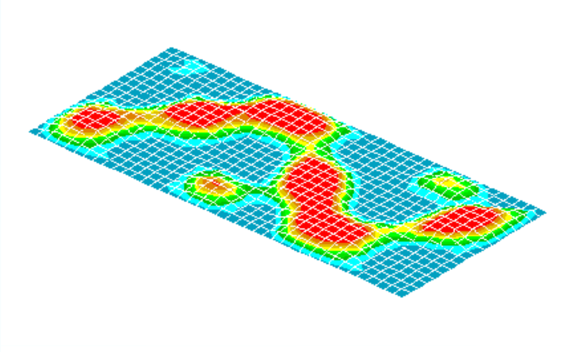
Shape and Sizing Results



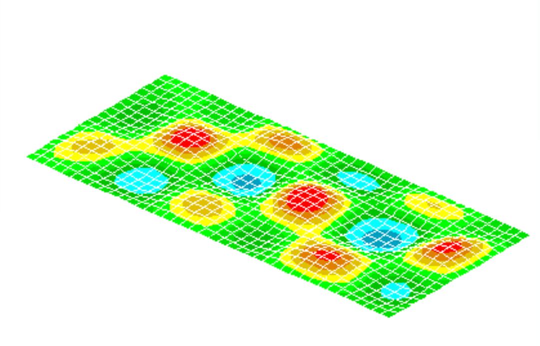
Topography Optimization



Initial Design

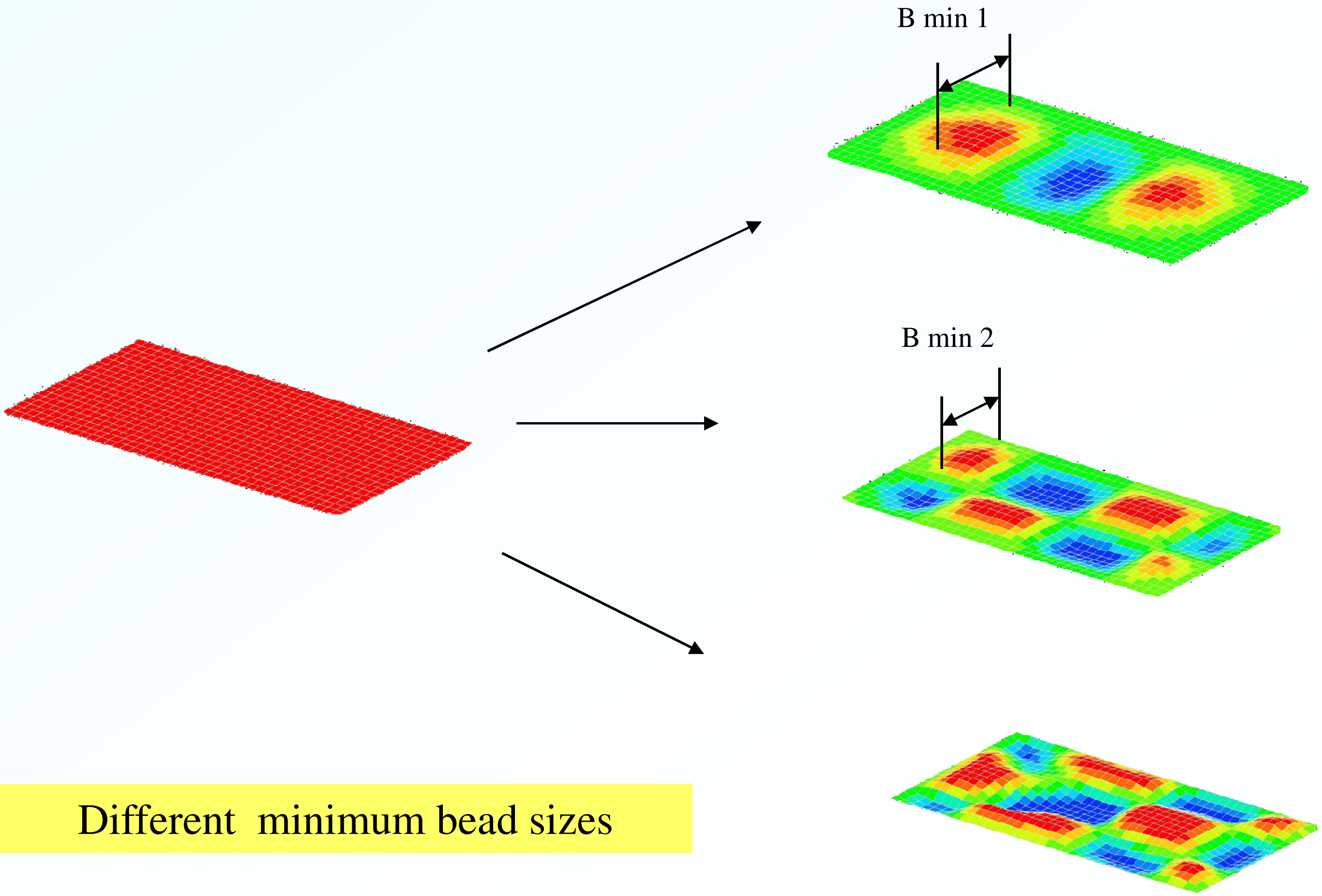


Grids allow to only move up



Grids allow to move up/down

Topography Optimization with Manufacturing Constraints



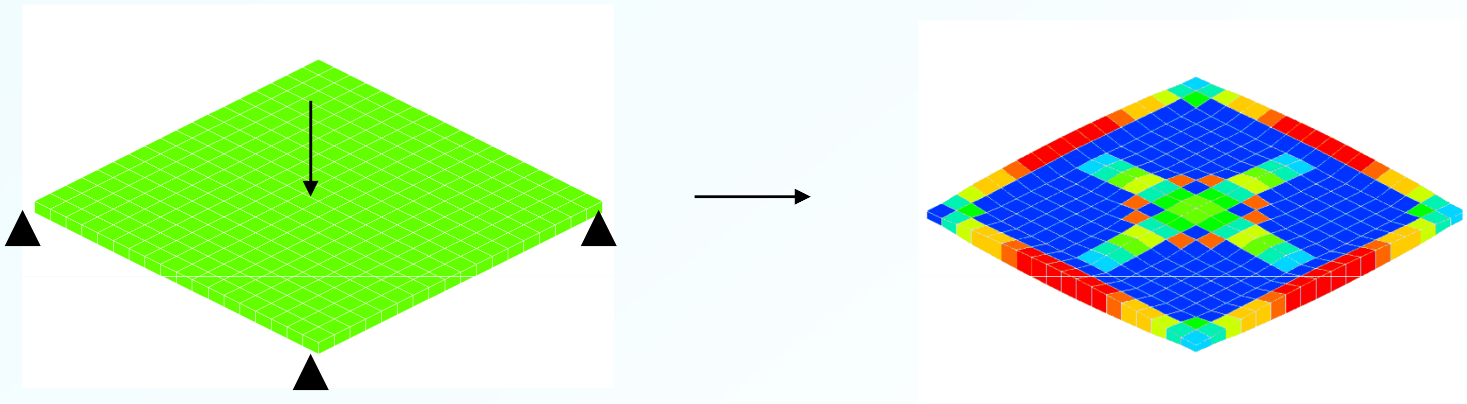
Different minimum bead sizes

Topometry Optimization

- New capability to perform 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

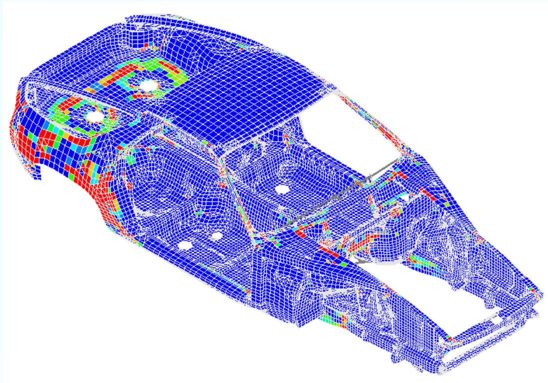


- **Objective:**
  - Minimize Strain Energy
- **Constraints:**
  - Mass
- **Design Variables: 324**
  - Each Element thickness

Motivation for Topometry

- Sizing Optimization sometimes does not give enough improvements
- Topology optimisation can not work with all GENESIS capabilities
- Topology optimisation is limited to 0-1 answers

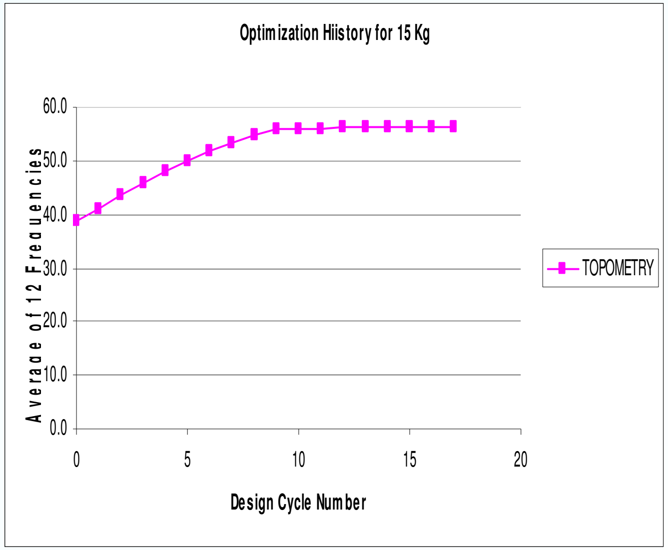
Example of Topometry Optimization



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



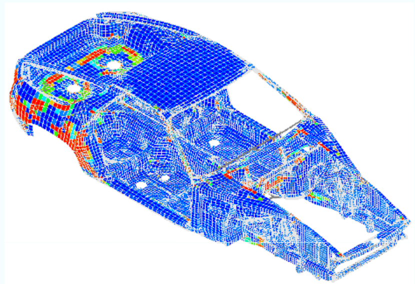
Results

- **Objective:**
  - **Strain Energy Reduced From:**

  38.6 to 56.3Hz

  (18 hz, 46% Gain)
- **Constraints:**
  - **Mass Increased 15kg**
- **Design Variables:**
  - **63**
- **Number of Design Cycles**
  - **15**

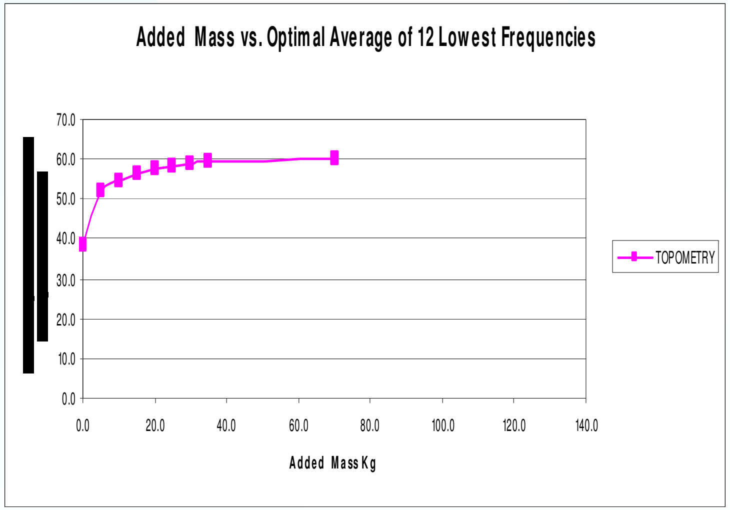
Example of Topometry Optimization:
Trade of Study Mass vs Sum of 12 Lowest Frequencies



Problem

- **Objective:**
  - Max Sum Of 12 Lowest frequencies
- **Constraints:**
  - Mass can increase up

    5, 10, 15, .., 70, free
- **Design Variables:**
  - 34,560 sizing variables
  - 1.0 <= X <=2.0 mm



Results

- **Objective:**
  - **Strain Energy Reduced From:**

    38.6 to 60.2Hz

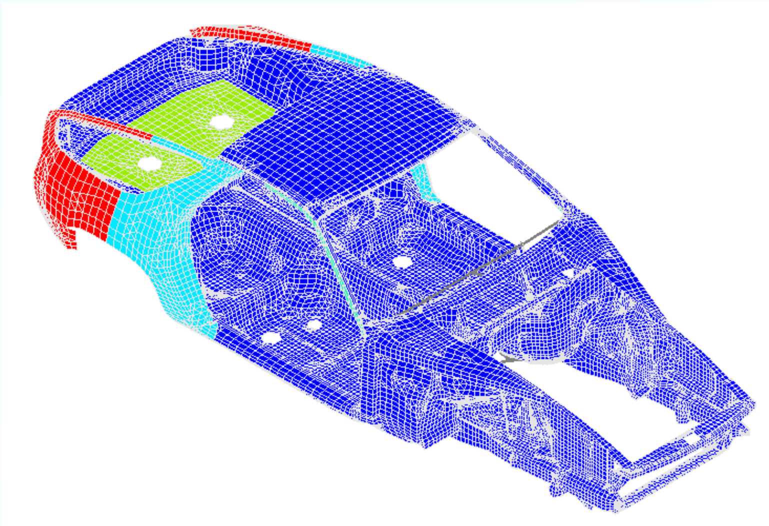
    (22 hz, 56% Gain)
- **Constraints:**

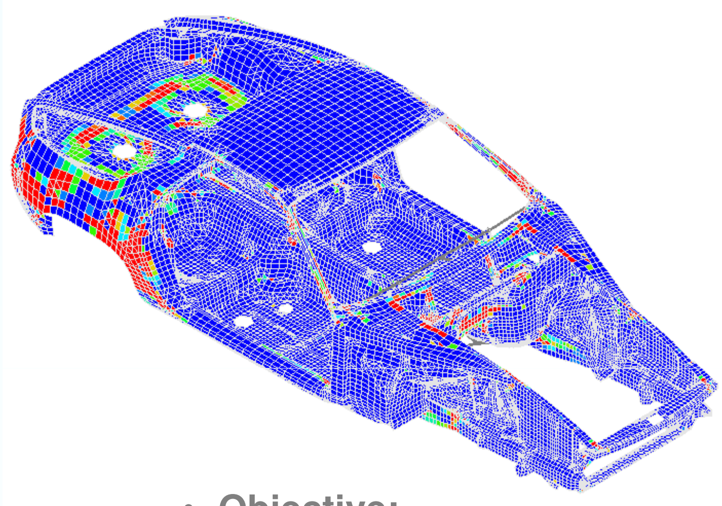
Added Mass for unconstraint minimization:

70 Kg

Topometry Optimization Example: Where to Reinforce?

- **Objective:**
  - Maximize Sum of 12 Lowest Natural frequencies
- **Constraints:**
  - Mass
- **Design Variables: 63**
  - Each Element thickness

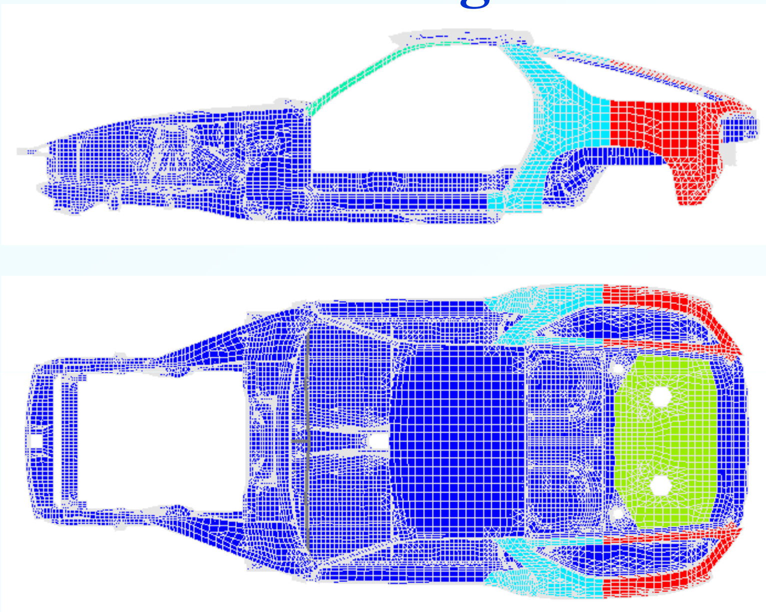




- **Objective:**
  - Maximize Sum of 12 Lowest Natural frequencies
- **Constraints:**
  - Mass
- **Design Variables: 34,560**
  - Each Element thickness

Where to Reinforce?

Sizing

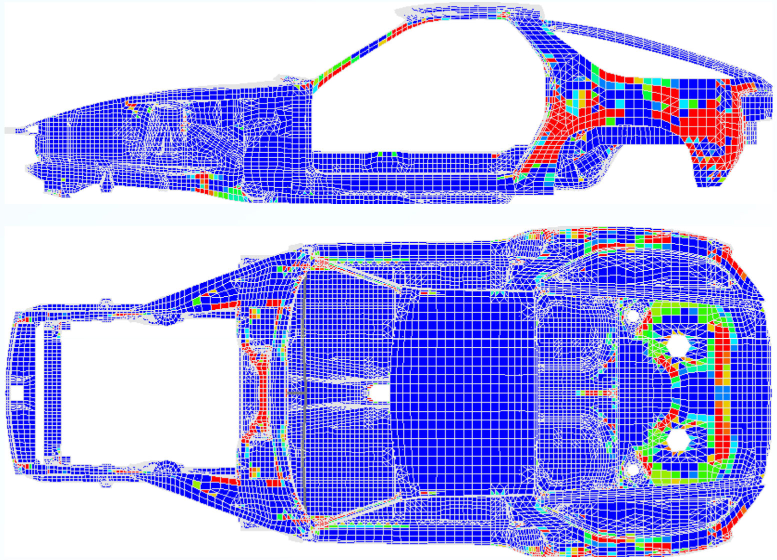


+15 kg => 10 HZ Gains

Optimal answer:

117 Kg: 17 Hz

Topometry



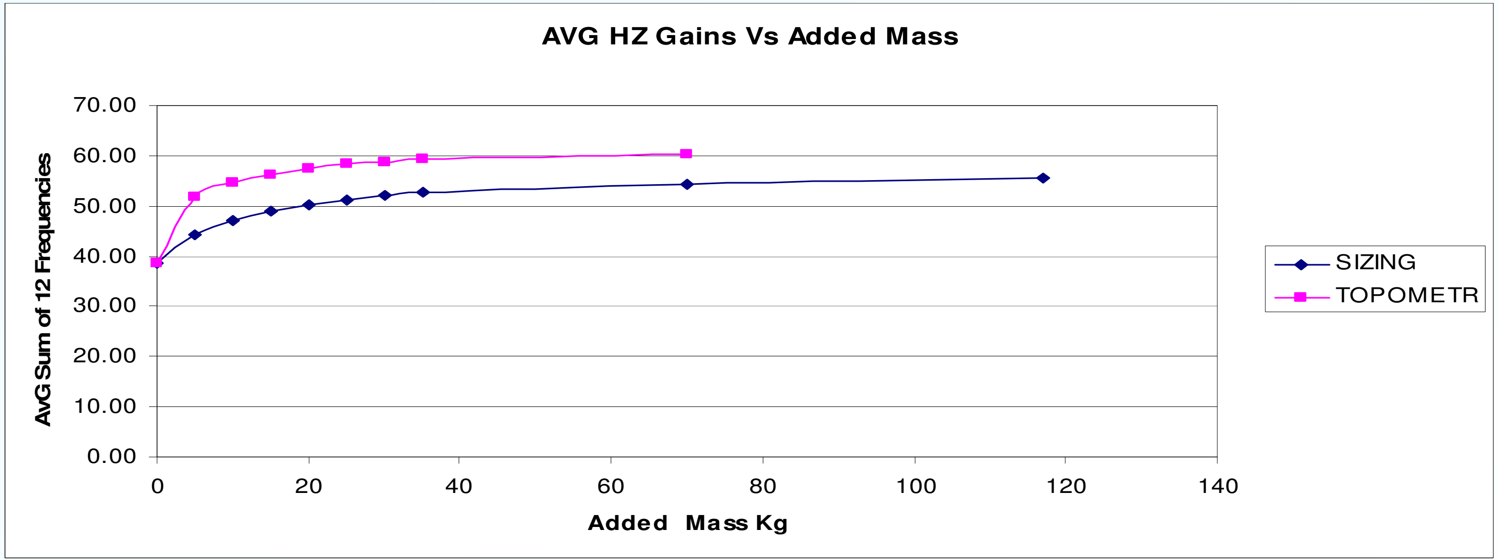
+15 kg => 18 HZ Gains

Optimal answer:

70 Kg: 22 Hz

Topometry helps to set targets and understand limits

Where to Reinforce?



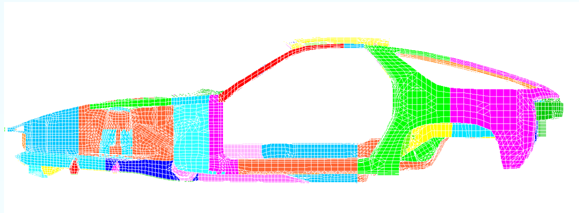
Is this really needed?

There are natural limits. Once reached no more progress can be made➔ Need to change technology or methodology etc

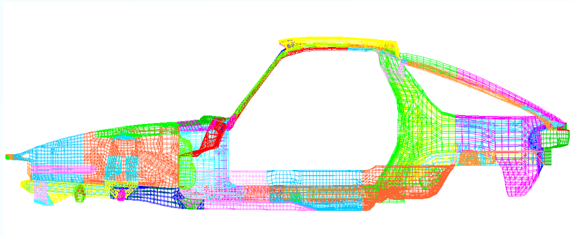
Sizing → Topometry?

Where to Reinforce?

Sizing → Shape?



→



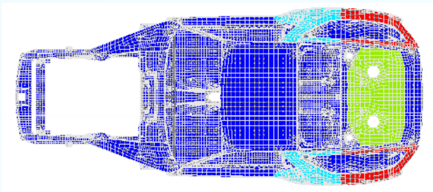
Maybe not!

Where to Reinforce?

How is Possible?

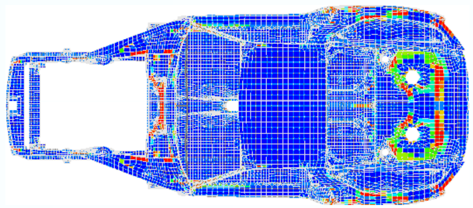
Sizing

63 Design Variable



Topometry

34,560 Design variables



Just add 63 "DSPLIT" to input

DSPLIT 1

DSPLIT 2

…

DSPLIT 63

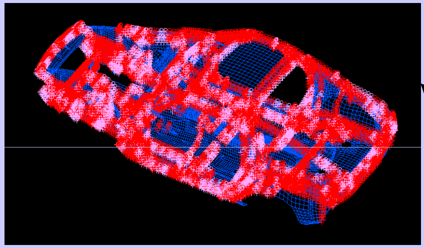
Topometry vs. Topology

- Continuous vs. Discrete
- Intermediate Design Cycles
- Designable Elements
- Responses available (Class of Problem each can solve)
- Can Topometry solve Topology problems?
- Can Topology solve Topometry Problems?

Designable Elements

Topometry
Designable Properties

Topology
Designable Properties



PCOMP

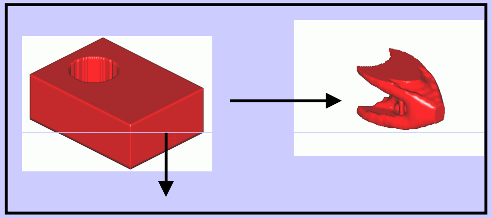
PBUSH
PELAS
PVECTOR

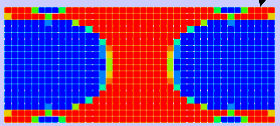
PHBDY
PELASH

PMASS
PCONM3
PDAMP
PVISC

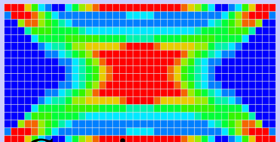
PROD
PSHEAR
PSHELL
PAXIS
PBAR

PSOLID

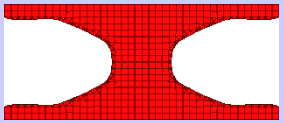




0-1 Discrete

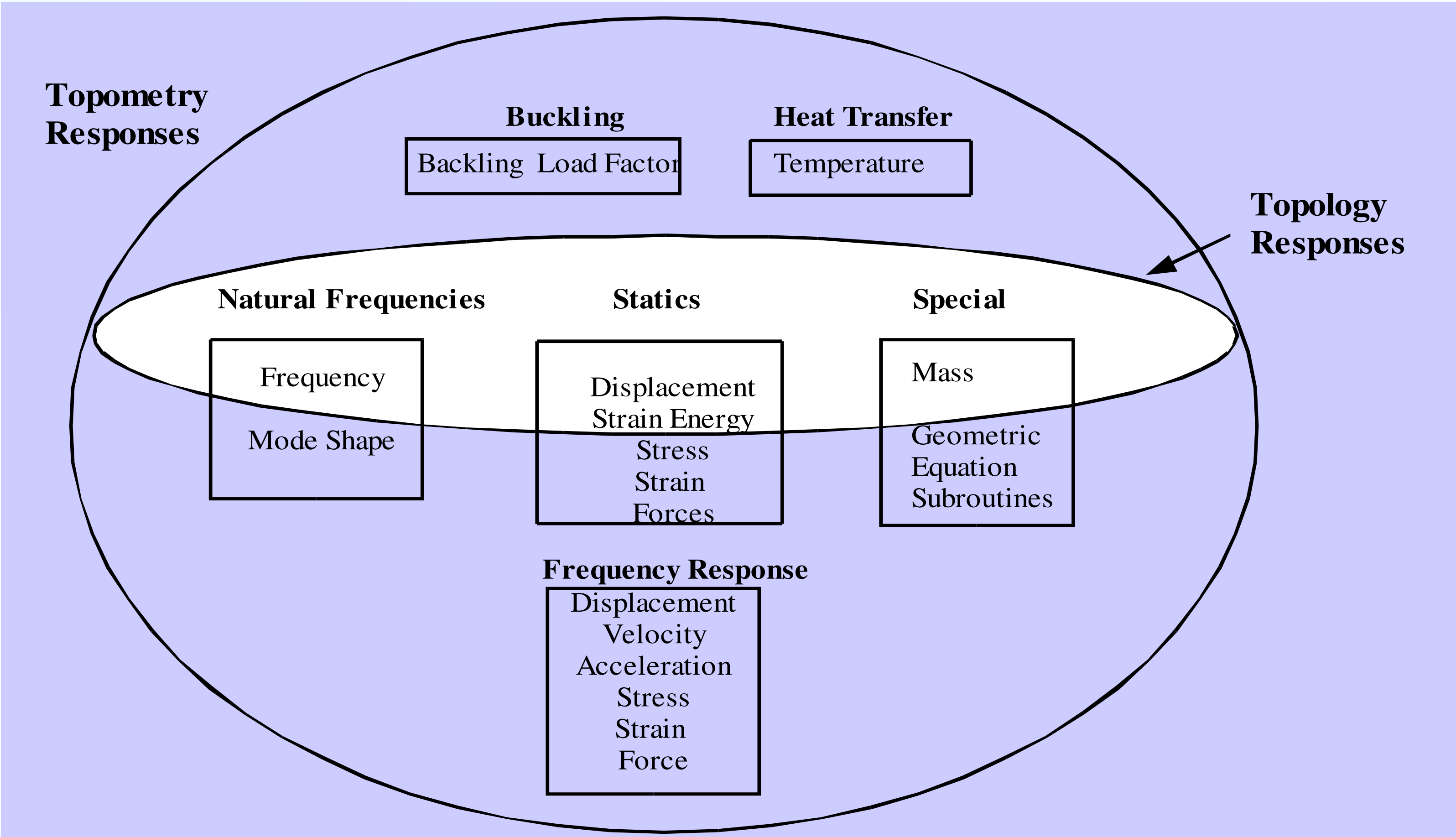


Continuous

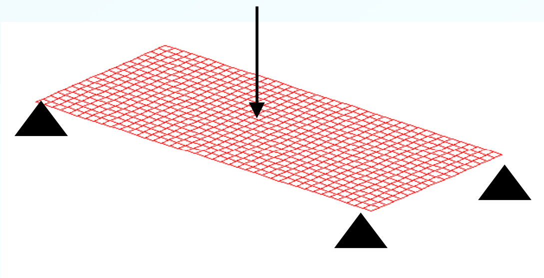


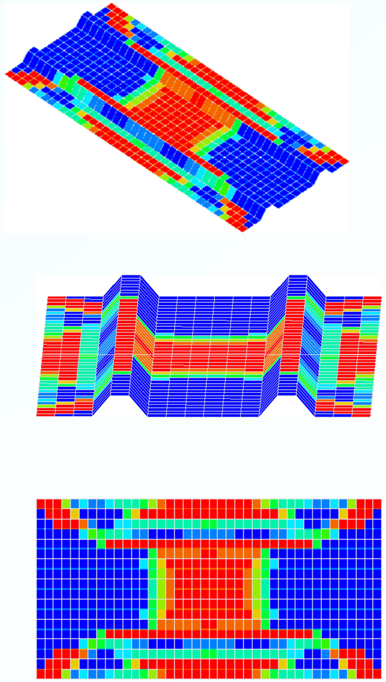
0-1 Discrete

Response Comparison



Topometry work with Other Types of Optimization

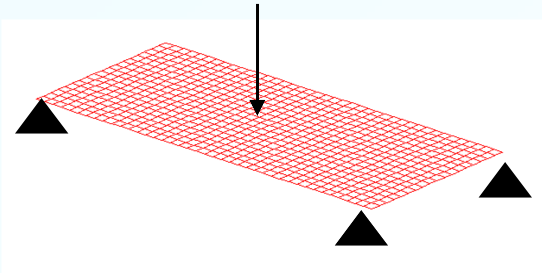


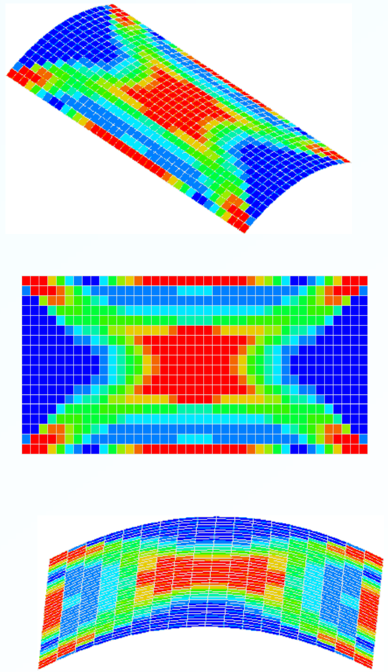


- **Objective:**
  - Maximize Stiffness
- **Constraints:**
  - Volume <=600mm^3
- **Design Variables: 726**
  - 720 Element thickness
  - 6 Topography

Topometry + Topography

Topometry work with Other Types of Optimization

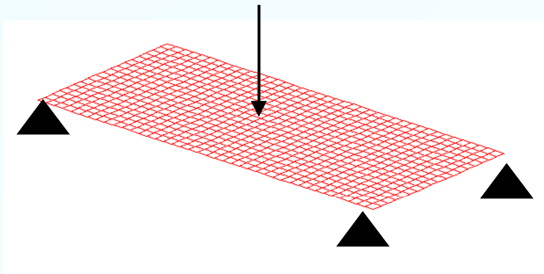


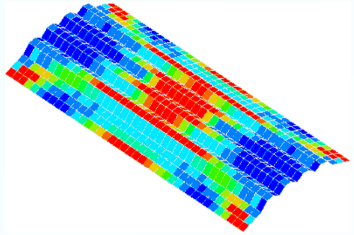


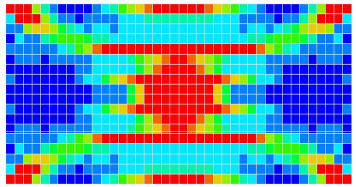
- **Objective:**
  - Maximize Stiffness
- **Constraints:**
  - Volume <=600mm^3
- **Design Variables: 726**
  - 720 Element thickness
  - 1 Shape

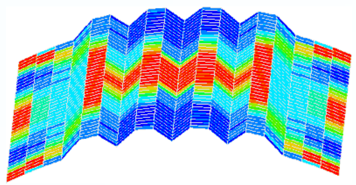
Topometry + Shape

Topometry work with Other Types of Optimization





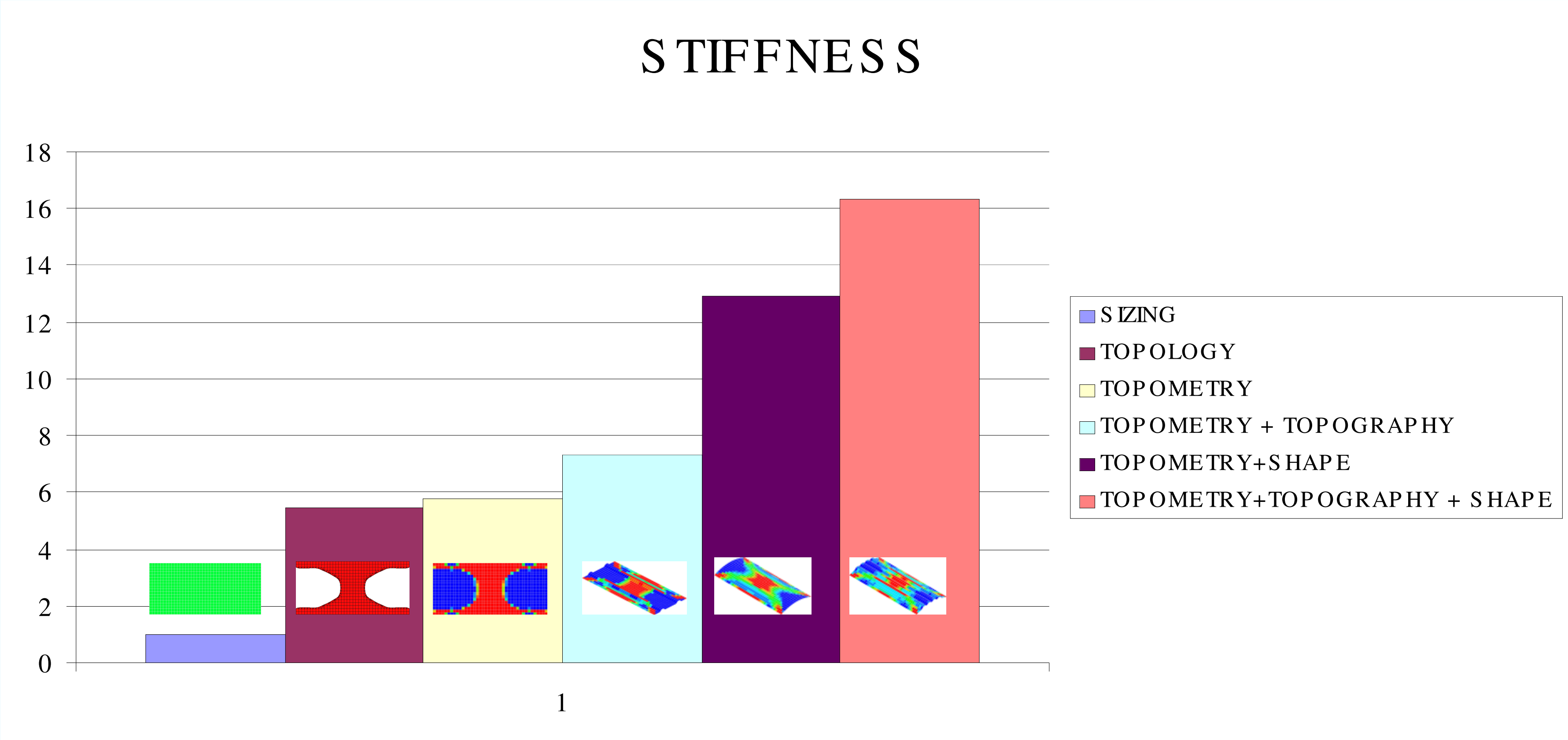




- **Objective:**
  - Maximize Stiffness
- **Constraints:**
  - Volume <=600mm^3
- **Design Variables: 726**
  - 720 Element thickness
  - 6 Topography
  - 1 Shape

Topometry + Topography + Shape

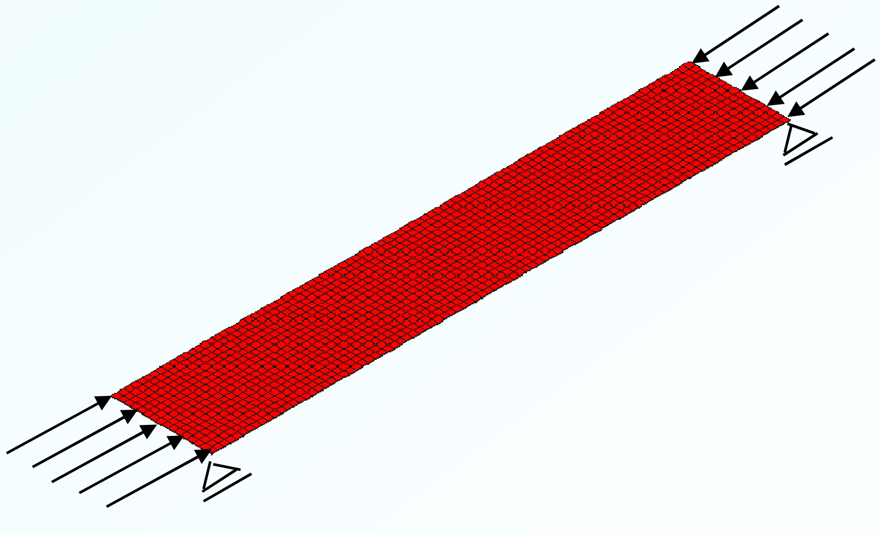
Topometry work with Other Types of Optimization



Buckling Topometry Optimization of a Thin Plate

Design Requirements:

Find Optimal thickness distribution that will maximize the Buckling Load Factor



Material: Steel

E = 207,000 psi.

Dimension

L = 46 mm

W = 8

T (initial) = 1.2 mm

Tmin = 0.8 mm

Tmax = 2.0 mm

Load

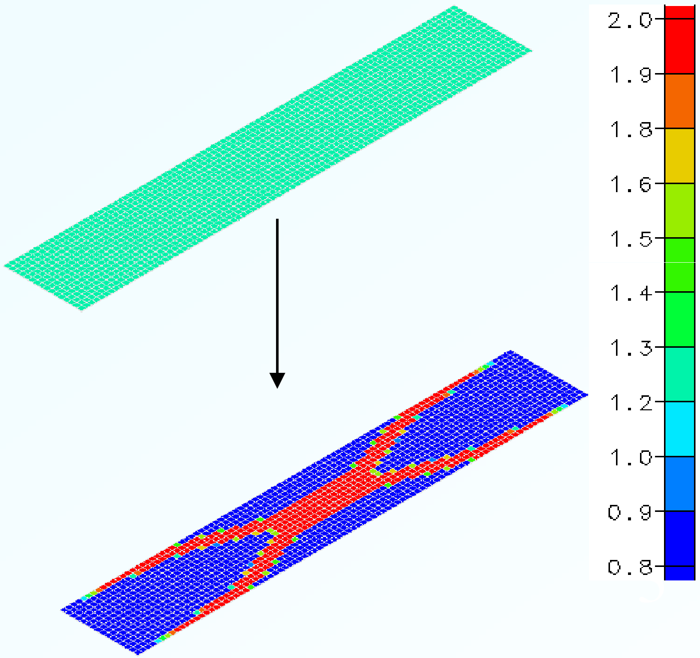
P =160 N

Mass(initial) = 3.4g

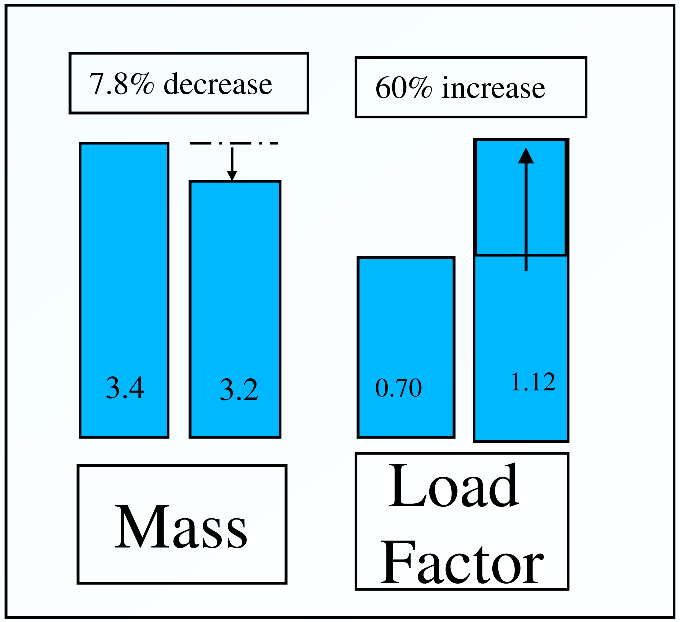
Mass(max allowed) = 3.2g

Buckling Topometry Optimization of a Thin Plate

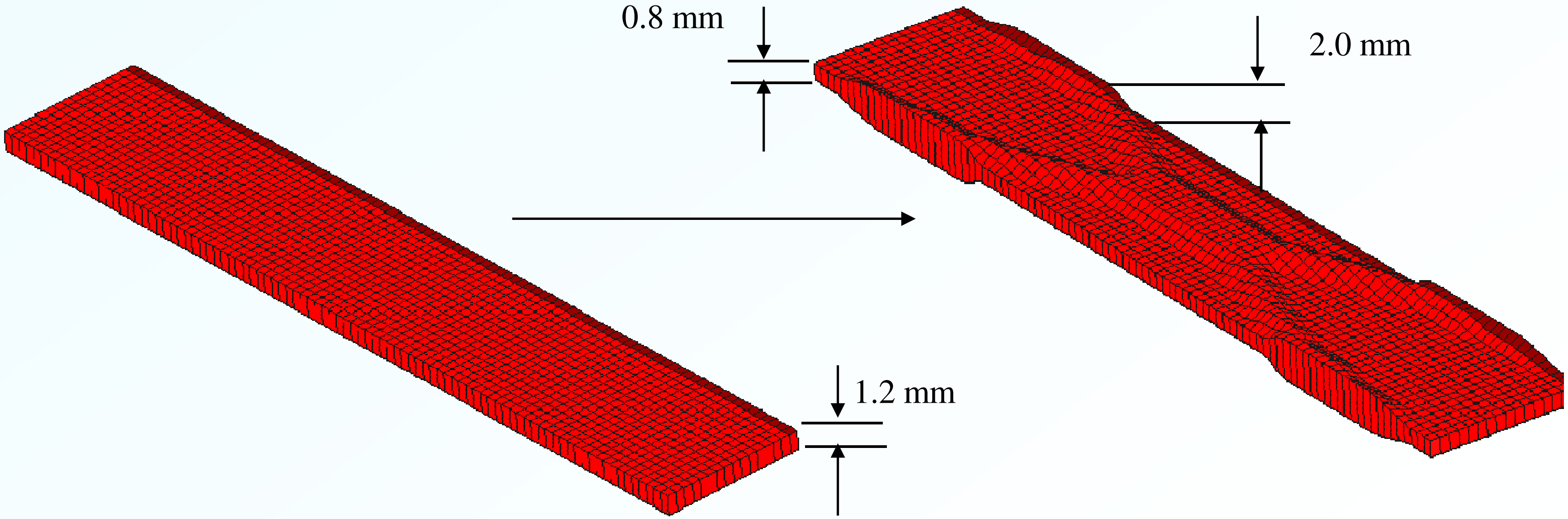
λ= 0.70 < 1.0 => Unstable



λ= 1.12 > 1.0 => Stable



Buckling Topometry Optimization of a Thin Plate



$\lambda = 0.70 < 1.0 \Rightarrow$ Unstable

$\lambda = 1.12 > 1.0 \Rightarrow$ Stable

Composite Optimization Tools

Design Variables:

- Thickness
- Angle
- Shape

Objective Function:

- **Any response**

e.g. reduce mass or cost

Constraint Function:

- **Any response**

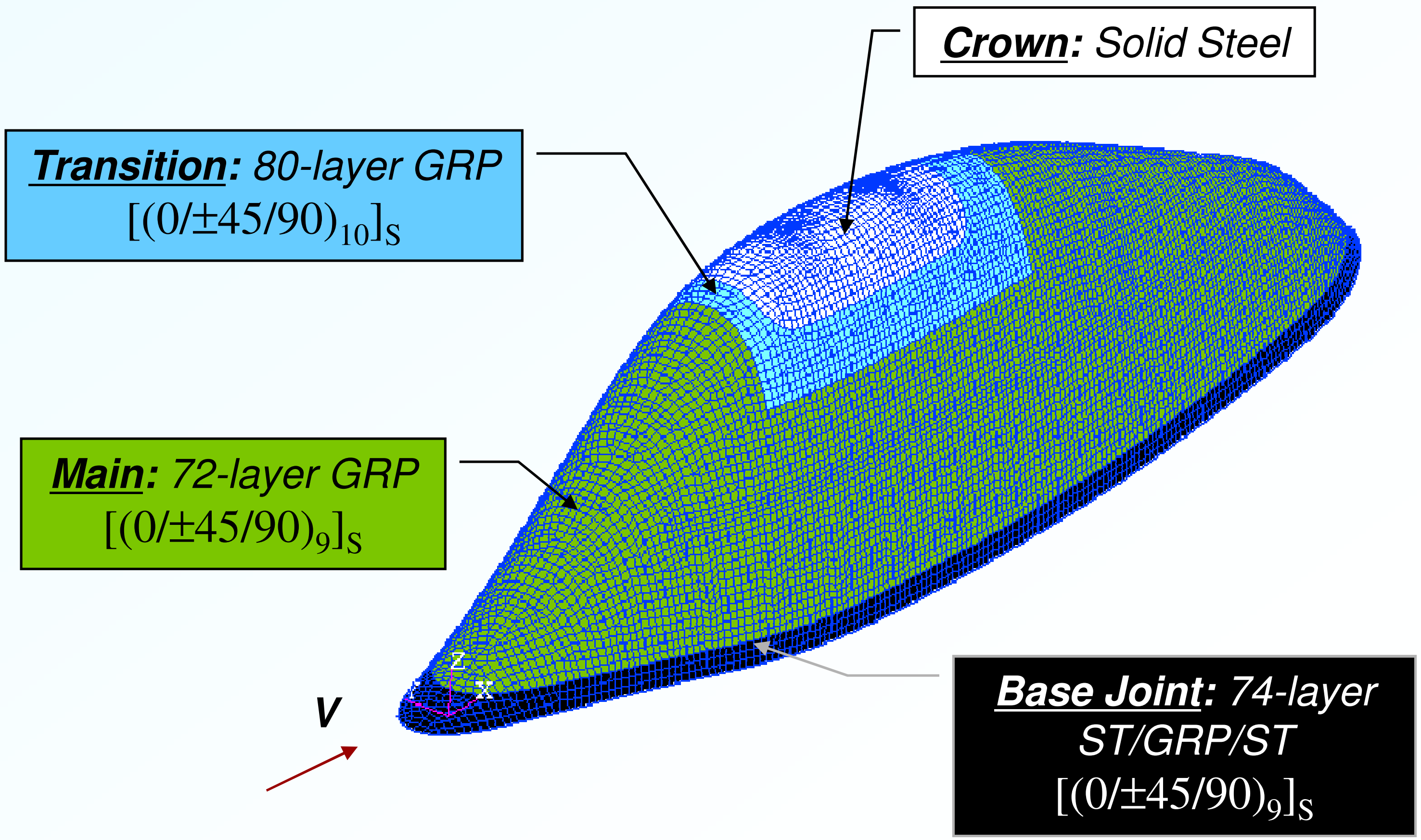
e.g. prevent buckling,
Constrain failure indices, displacements, torsional/bending frequencies

Failure Theories Available:

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

From small parts to whole systems

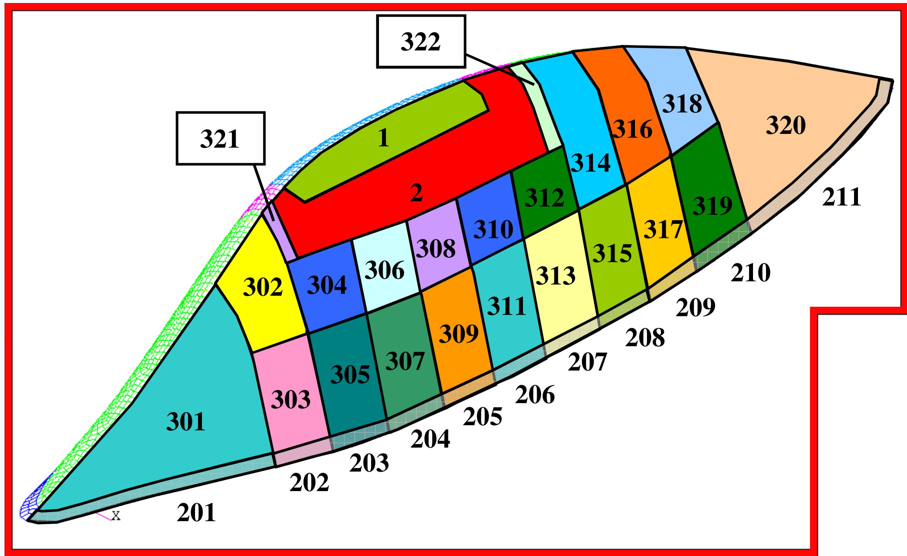
Submarine Sail Design



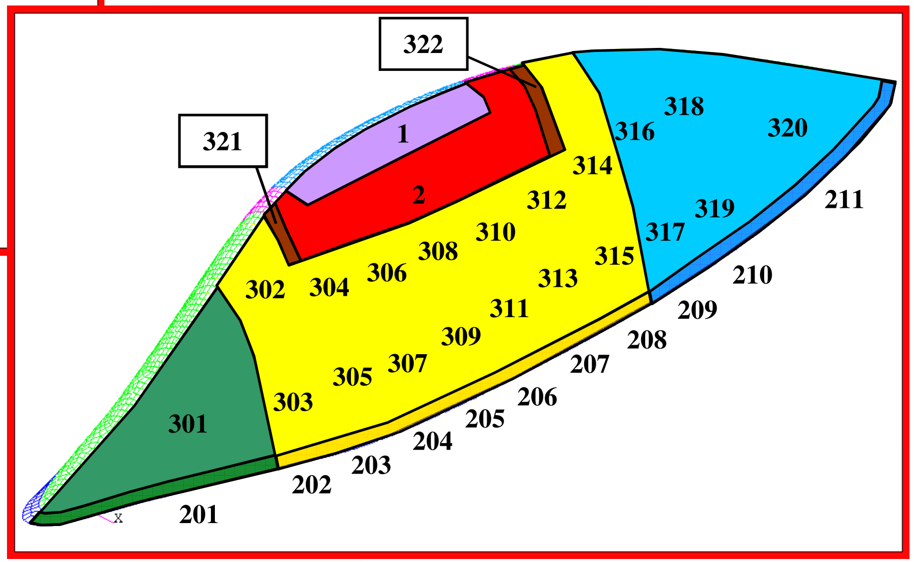
Courtesy M. Rais-Rohani, Mississippi State University

Submarine Sail Design

Concept 1: *23* Thickness Design Variables



Concept 2: *4* Thickness Design Variables



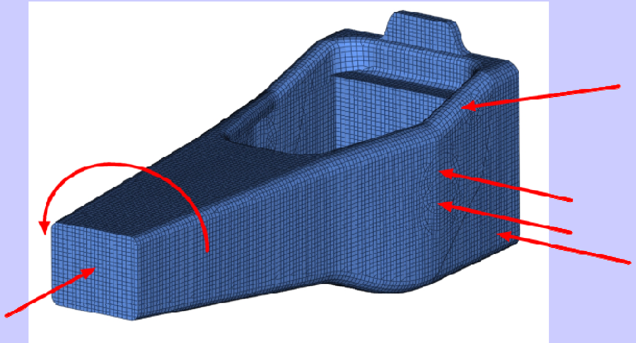
Courtesy M. Rais-Rohani, Mississippi State University

Submarine Sail Design

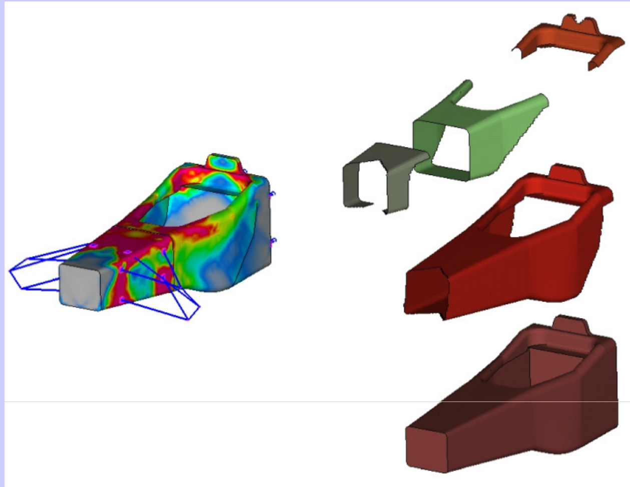
Structural Group	Baseline Weight, lb	Concept 1 Weight, lb	Concept 2 Weight, lb
Main	39,076	29,679 (-24%)	31,655 (-19%)
Transition	5,101	6,910 (35.5%)	6,069 (19%)
Crown	6,551	6,551 (0%)	6,551 (0%)
Base Joint	20,241	19,101 (-5.6%)	19,169 (-5.3%)
Transverse Stiffeners	8,644	7,023 (-18.6%)	7,944 (-8.1%)
Longitudinal Stiffeners	2,237	1,287 (-42.5%)	1,122 (-50%)
Total	**81,850**	**70,551 (-14%)**	**72,510 (-11.4%)**

Courtesy M. Rais-Rohani, Mississippi State University

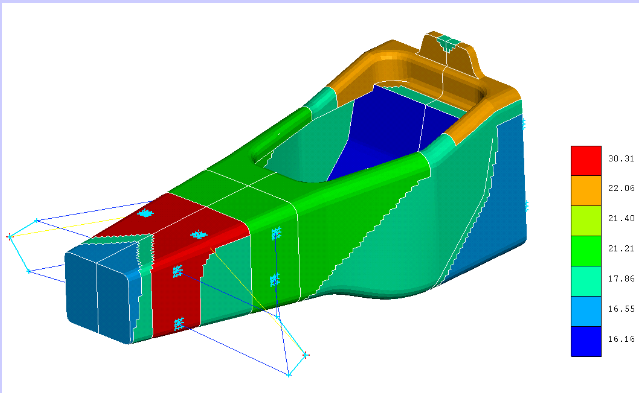
GENESIS Composite Optimization



Loading Conditions



Designable Areas



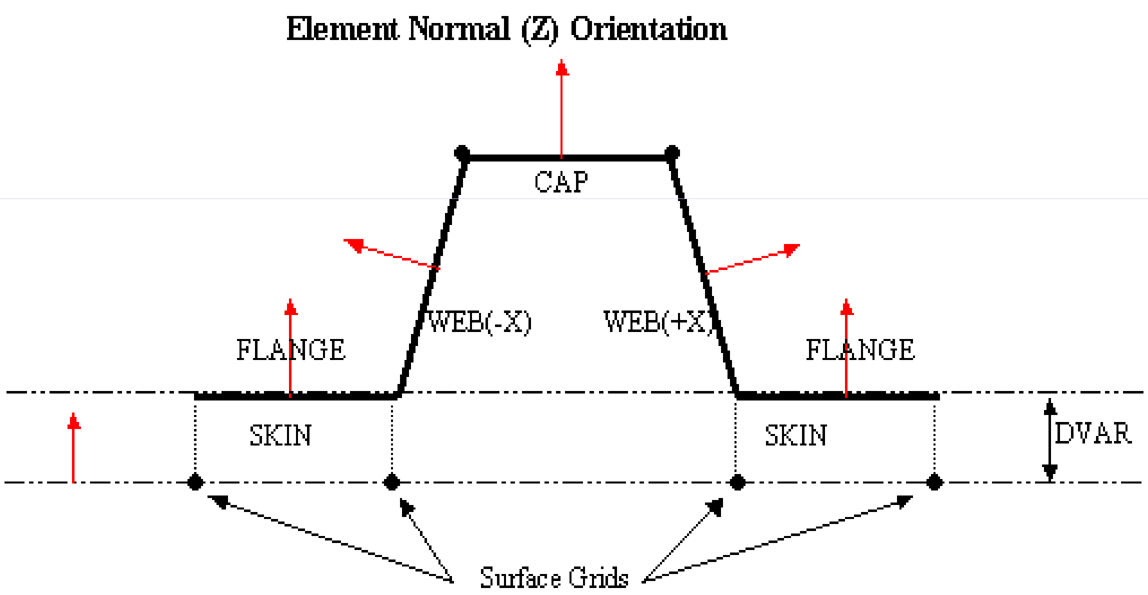
Designable Areas

Mass reduced by 18%

Courtesy GRM Consulting and P+Z

Composite Optimization

- **Design Variables:**
  - Thickness of skin and stiffeners
  - Stiffener web height
  - Stiffener flange height
  - Stiffener cap height



The surface (or skin) elements have had their normals reversed so that all material grows inward from surface grids in order to insure a smooth outer surface. Zo for the skin is thus zero. Zo for the flanges is linked to the DVAR assigned to the Adjacent skin thickness during optimization. Zo for the cap and webs are both zero.

Composite Optimization

- **GENESIS SSOL Command**
  - Creates post-processing file of solid elements that reveal the thickness of shell and composite elements