Topology Optimization with MSC.Nastran and MSC.Patran

MSC.Software VPD Conference
Huntington Beach, CA
October 22, 2004

Presented by
Erwin Johnson
Wade Wu
Xiaoming Yu

Workshop Outline

Topology optimization overview

Topology optimization theory

Pre- and post-processing with MSC.Patran

MSC.Nastran User Interface

Examples

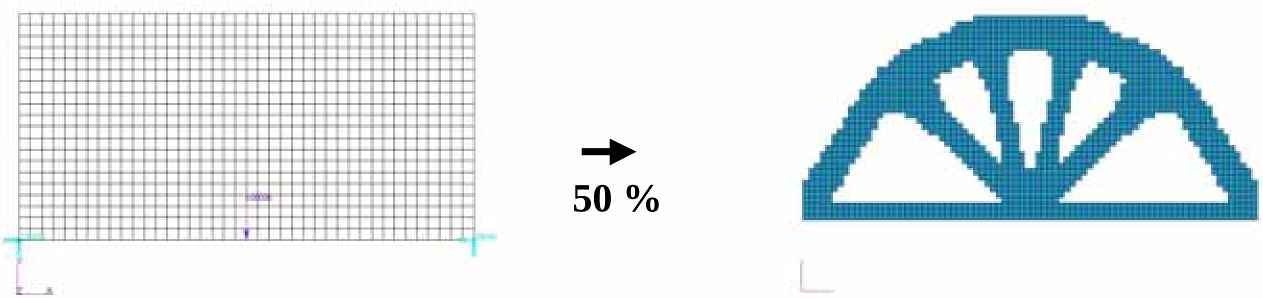
Ongoing Activity

Discussion

Topology Optimization

Concept

- Given a predefined domain with boundary conditions and load, find optimal mass distribution such that an objective takes a minimum (maximum) while satisfying constraints



Topology Optimization Background

Topology optimization has generated widespread academic and industrial interest for over 15 years

- Bendsoe and Kikuchi
- Early work related to optimality criteria methods
- A variety of products including Optistruct, MSC.Construct (now TOSCA), MSC.Optishape and Genesis

MSC.Nastran has had mathematical programming based optimization since 1989

- MSC.Patran Support was introduced around 1996
- Forms a basis for topology optimization

MSC Approach to Topology Optimization

Leverage Existing Multidisciplinary Design Optimization Capability in MSC.Nastran

Adapt to Special Topology Optimization Requirements

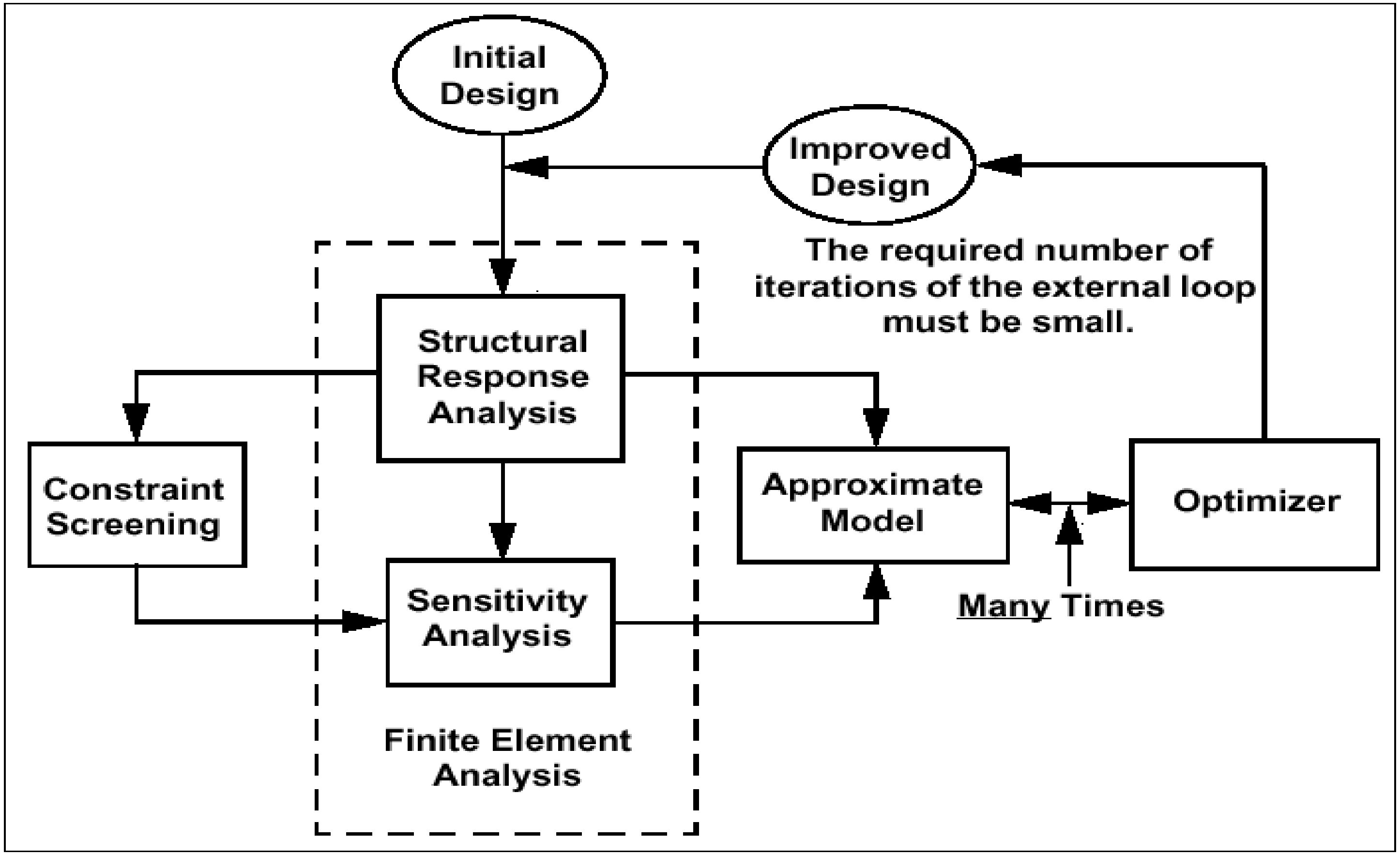
- Large Number of Design Variables
- Special Response Quantities
- Special Filtering Techniques

Leverage Existing MSC.Patran Support for Design Optimization

- Include Features from the Optishape Preference
- Provide Specialized Results Processing using Existing Tools

MSC.NASTRAN IMPLEMENTATION OF STRUCTURAL OPTIMIZATION

One time around the loop is referred to as a design cycle or design iteration



The BIGDOT Optimization Algorithm

- BIGDOT is an Optimization Algorithm provided by VR&D that is specialized for problems with many Design Variables
- MSC has embedded BIGDOT into MSC.Nastran primarily for performing Topology Optimization
- This Feature is provided as a separate, royalty based, option of MSC.Nastran

Two MSC.Nastran Optimization Options

Design Optimization

- Multidisciplinary Design Optimization (shape and sizing)
- Uses DOT or ADS as the optimization algorithm
- Limited number of Design Variables (<4000)
- Performs limited Topology Optimization

Topology Optimization

- Provides BIGDOT
- Enables large scale topology optimization
- Does not support Design Optimization

Design Optimization and Topology Optimization

- Enables all MSC.Nastran optimization
- Choice of optimization algorithm
- Can solve shape and sizing optimization tasks with thousands of design variables.

Topology Optimization Theory

Two Classic Topology Optimization Problems

- Statics

$$\min \mathrm{c} = \mathrm{f}^{\mathrm{T}} u(X) \text{ (compliance)}$$

$$\text{s.t.} \int_{\Omega} \rho(X) d\Omega \le M ; 0 \le \mathrm{X} \le 1 \text{ (mass target)}$$

- Normal Mode

$$\max \text{ frequency}$$

$$\text{s.t.} \int_{\Omega} \rho(X) d\Omega \le M ; 0 \le \mathrm{X} \le 1 \text{ (mass target)}$$

Topology Optimization Theory

Three Methods

- **Homogenization method** (Bendsoe & Kikuchi, 1988)
- **Density method** or **SIMP** (Solid Isotropic Microstructure with Penalization)
- **Hard-kill** and **soft kill** Methods

Density method is becoming popular due to its generality

Topology Optimization Theory

General Topology Optimization Problem

$$\text{minimize} \quad f(\mathbf{x})$$

$$\text{subject to} \quad g_j(\mathbf{x}) \leq 0, \quad j = 1, 2, \ldots, m$$

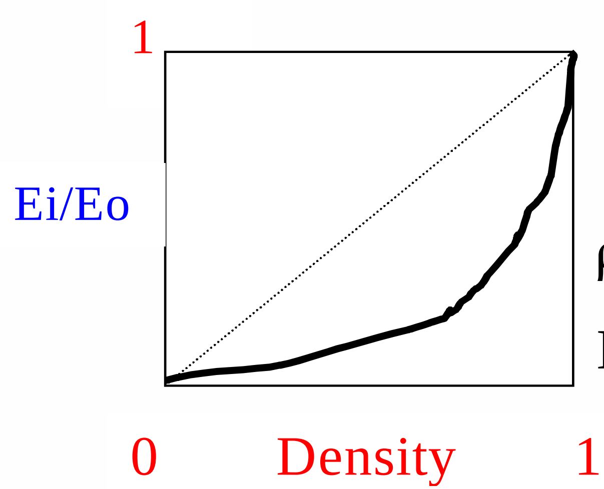
$$0.0 \leq x \leq 1.0$$

Here any design response (mass, displacement, eigenvalue, compliance, etc.) and their combinations can be the objective and/or constraints. In addition, more than one constraint is allowed.

SOL200 Topology Optimization Strategy

Density Method Used in SOL200

- Design variables are the normalized material density of each designed element (has fewer design variables compared to the homogenization method)
- The power law penalization on Young's modulus E is used to achieve a 0-1 density distribution



$$\rho_i = x_i \rho_0$$

$$E_i = x_i^p E_0 \quad \text{where penalty factor } p > 1$$

SOL200 Topology Optimization Strategy

Advanced Approximation

- The original optimization problems is solved by solving a series of explicit approximate problems
- Density and Young's modulus are used as intermediate design variables
- Intermediate design responses for eigenvalues (Rayleigh Quotient)

Adjoint method is used for topology design sensitivity analysis

SOL200 Topology Optimization Strategy

- Incorporate BIGDOT
- A move limit adjustment strategy is implemented to achieve faster convergence and robustness
- A filtering algorithm is used to prevent checkerboard-like material distribution
- A minimum member size is used to control the degree of manufacturing simplicity

SOL200 Topology Optimization Capability

Topology Designable Elements

SOL200 can topologically design any element with a property that references an isotropic material (MAT1); e.g., CROD, CBAR, CBEAM, CBEND, CTRIA3, CTRIA6, CTRIAR, CQUAD4, CQUAD8, CQUADR , CSHEAR, CHEXA, CTETRA, CPENTA, and CWELD

Multidisciplinary Analysis Types

Support all SOL200 existing analysis types: statics, normal modes, buckling, direct frequency, modal frequency, modal transient, complex eigenvalue, flutter and static aeroelasticity

SOL200 Topology Optimization Capability

Design Responses, Objective, and Constraints

- DRESP1- the analysis responses directly from an MSC.Nastran analysis. Such as compliance, mass fraction, displacement, stress, eigenvalue, etc.
- DRESP2 – a synthetic response that utilizes the equation input features in MSC.Nastran
- DRESP3 – an external response that is evaluated by invoking an external (to MSC.Nastran) process via an application programming interface (API)
- Any DRESP1/2/3 can be the topology design objective and/or constraints

How to Use SOL200 Topology

MSC.Nastran Input Bulk Data Eentry

- Topology designable regions (TOPVAR)

TOPVAR	ID	LABEL	PTYPE	XINIT	XLB	DELXV	POWER	ID	

- Two new DRESP1 responses are introduced for topology
  - RTYPE=COMP defines the compliance of structures
  - RTYPE =FRMASS defines the mass fraction of designed elements

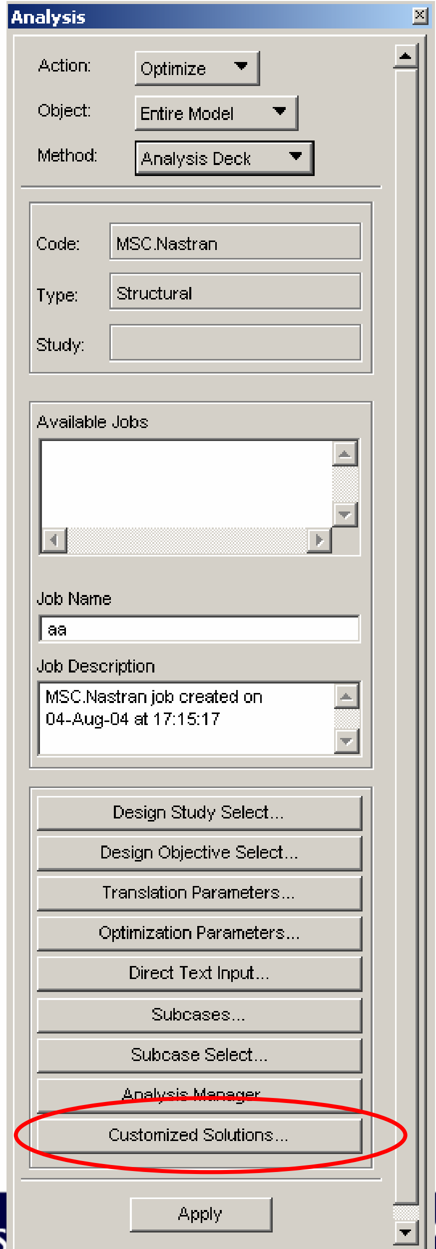
MSC.Patran supports Quick (Classic) Topology Optimization and displays topology results

Topology Optimization in MSC.Patran

MSC.Patran's Nastran preference has been enhanced to support quick topology optimization in SOL 200

- Derived from OPTISHAPE preference
- Retains some key features of OPTISHAPE preference
- More consistent look & feel
- More robust infrastructural support
  - Analysis types, element properties, …

Topology Optimization



"Customized Solution" option has been added in the Analysis form

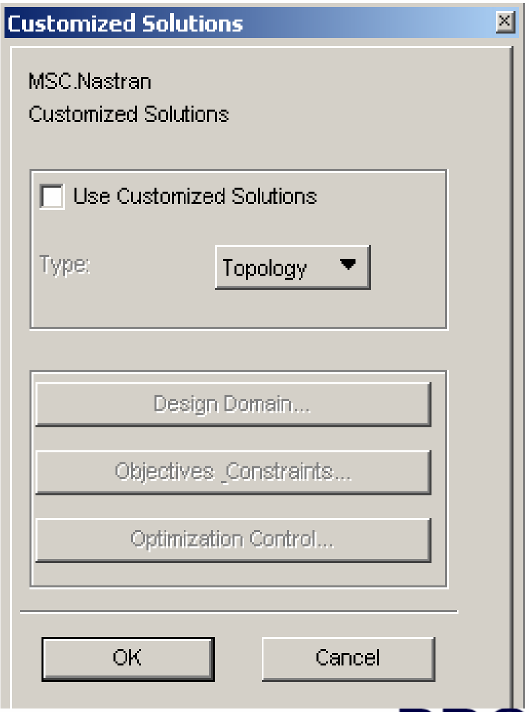
- Main entry to quick topology optimization

Topology Optimization

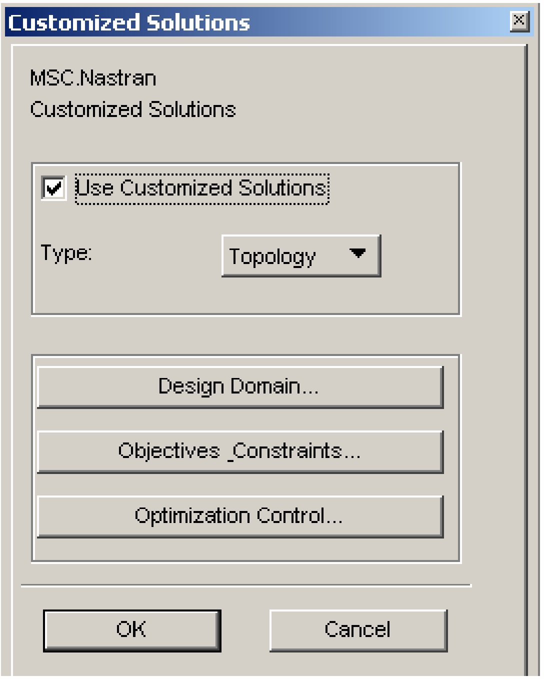
“Use Customized Solutions” option can be used to activate the quick topology optimization runs

- Default is off – normal SOL 200 optimization rum

Default – Normal SOL 200 run



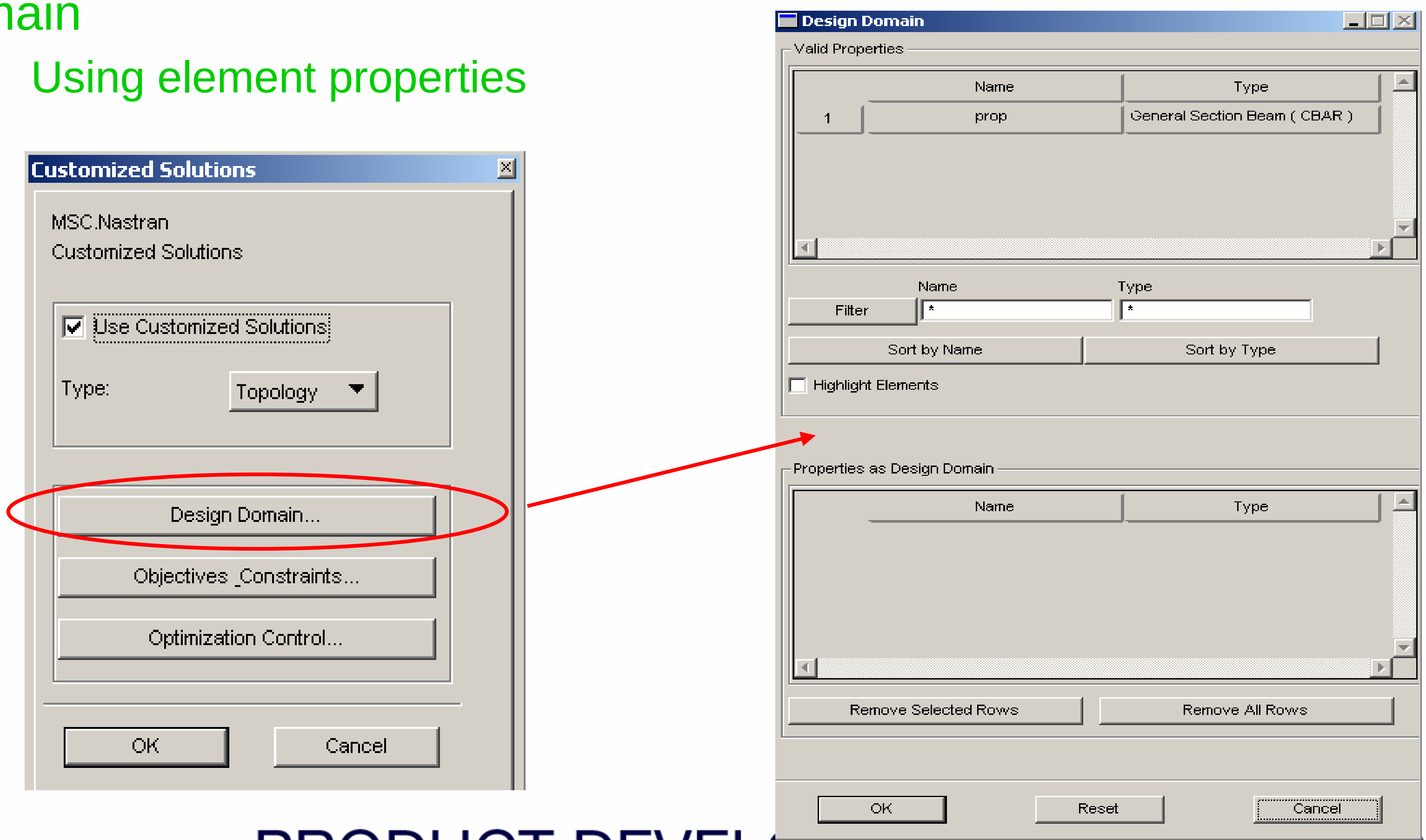
Quick topology optimization run



Topology Optimization

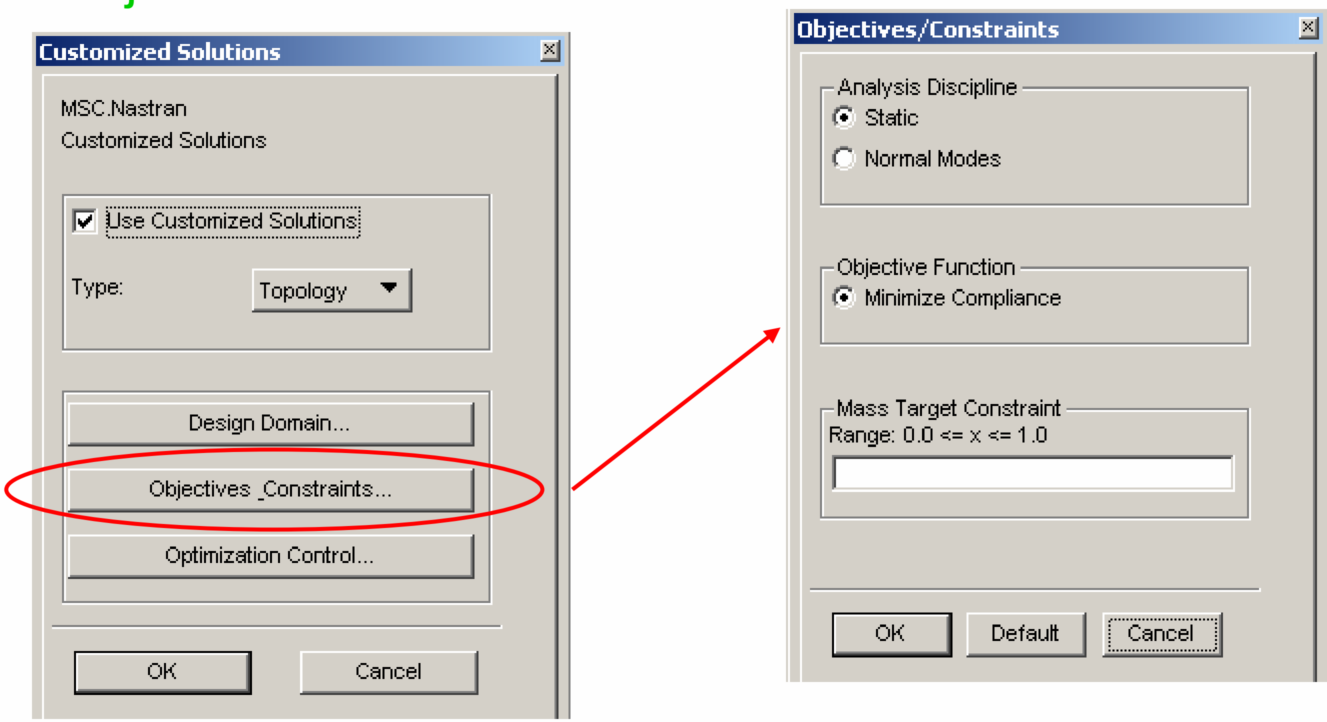
“Design Domain” option can be used to define the intended design domain

- Using element properties



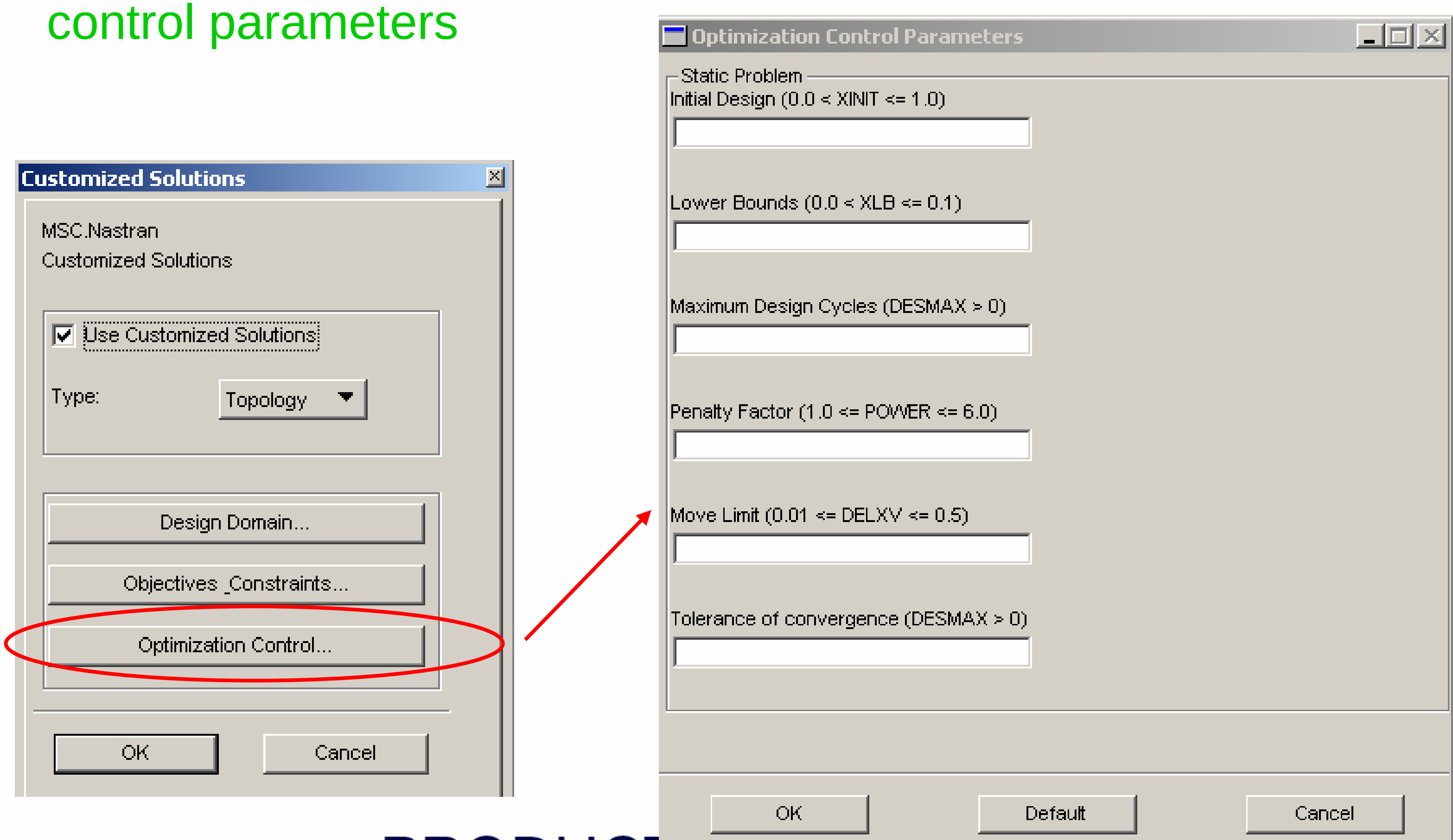
Topology Optimization

"Objective_Constraints" option can be used to define the optimization objectives and constraints



Topology Optimization

"Optimization Control" option can be used to define the optimization control parameters



DISPLAYING OPTIMIZATION RESULTS

MSC.Nastran produces a file with .des extension

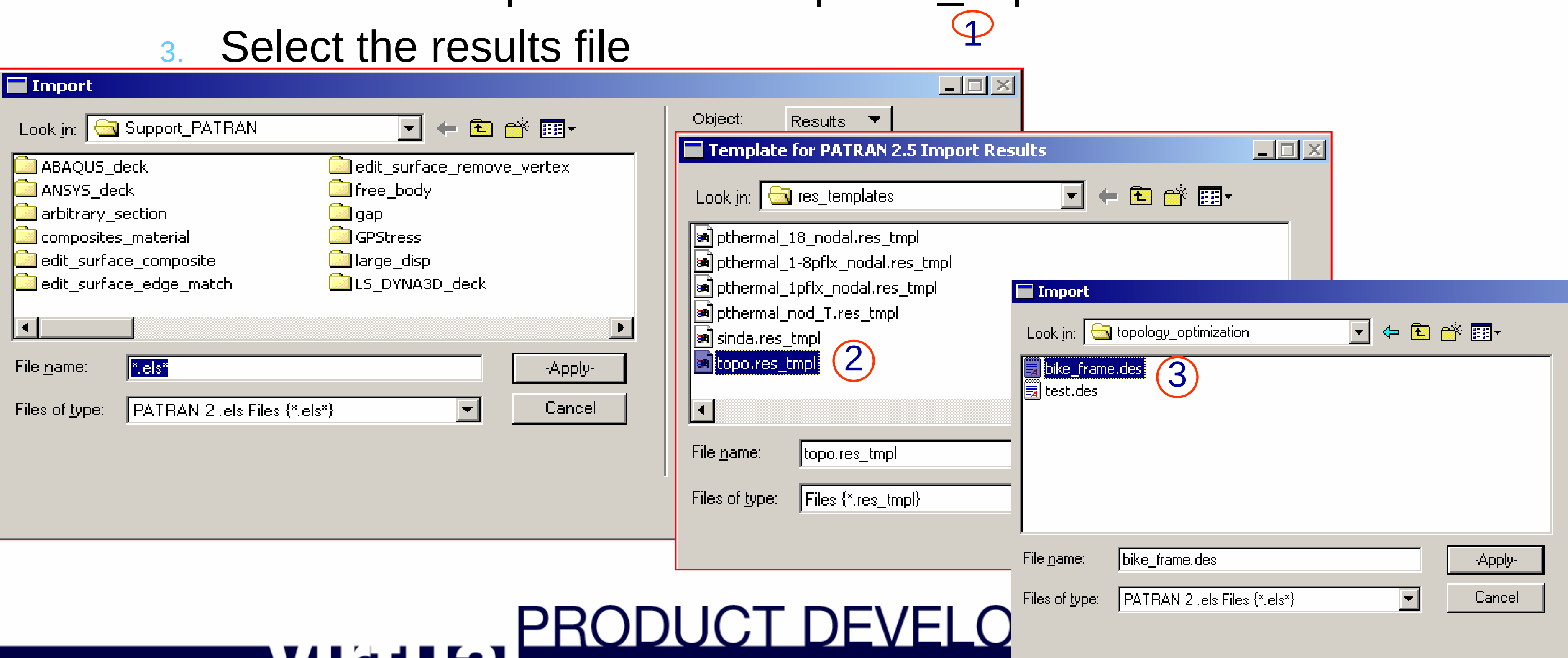
This file contains the resulting optimal element density distribution.

MSC.Patran 2005 only supports post-processing of 2D optimization results. Support of 3D optimization results is planned for 2005R2.

POST-PROCESSING OPTIMIZATION RESULTS

Importing optimization results

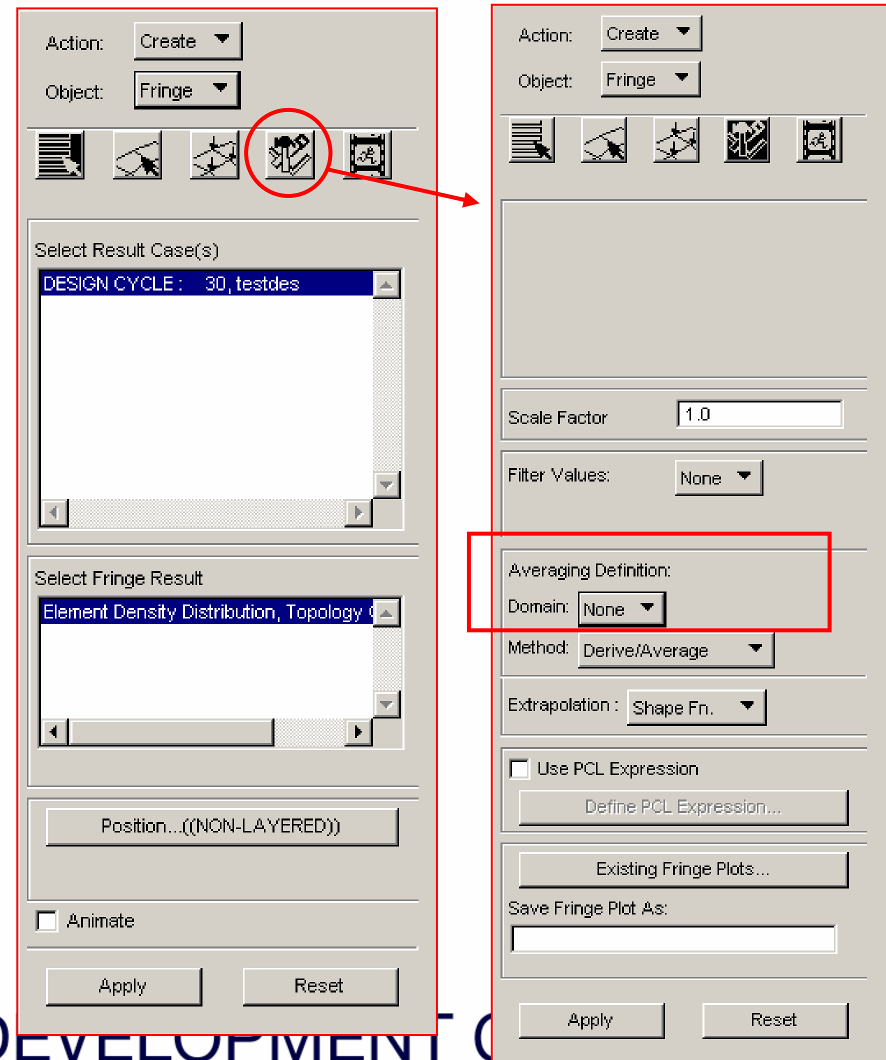
1. Under File/Import…, select Results and Patran 2 .els…
2. Select the template named “topo.res_tmpl”.
3. Select the results file



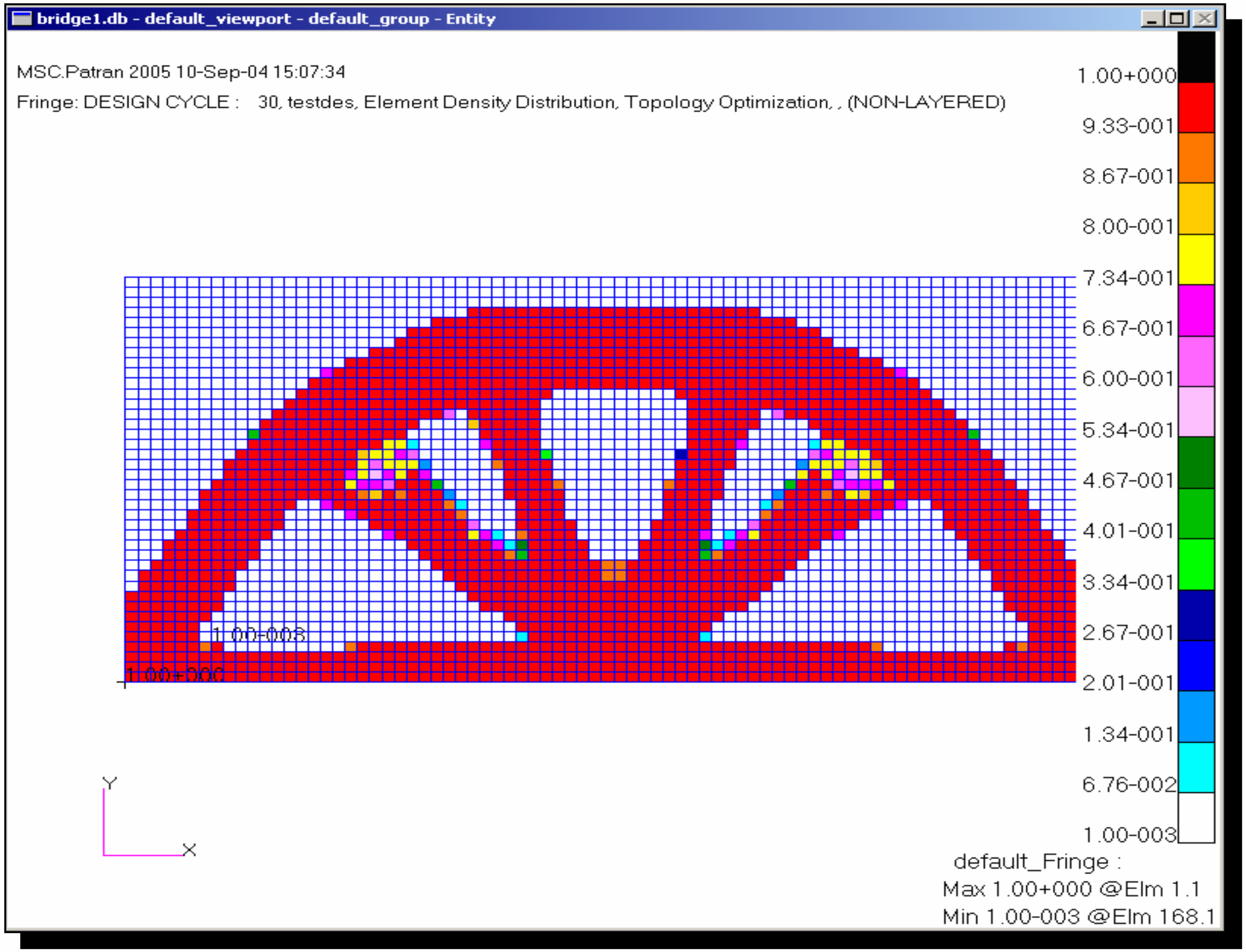
POST-PROCESSING OPTIMIZATION RESULTS

Displaying optimization results

- Go to Results/Create/Fringe
- Select Plot Options
- Set Averaging Definition Domain to None and Apply



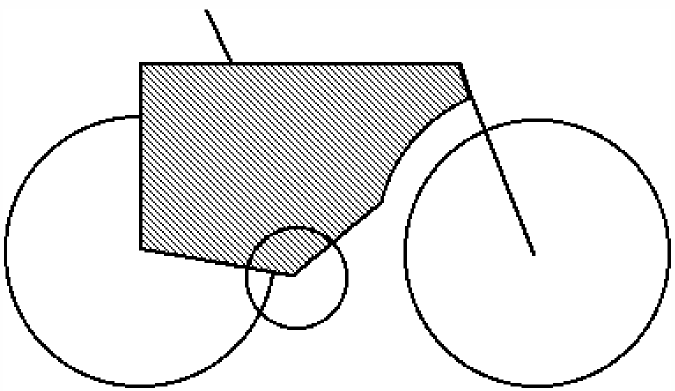
ELEMENT DENSITY DISTRIBUTION

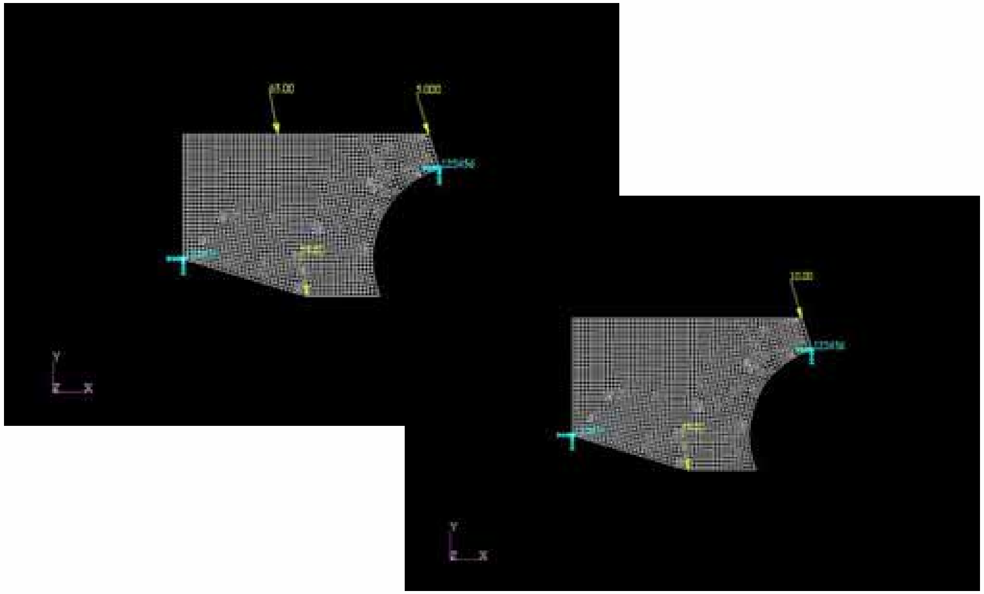


Examples

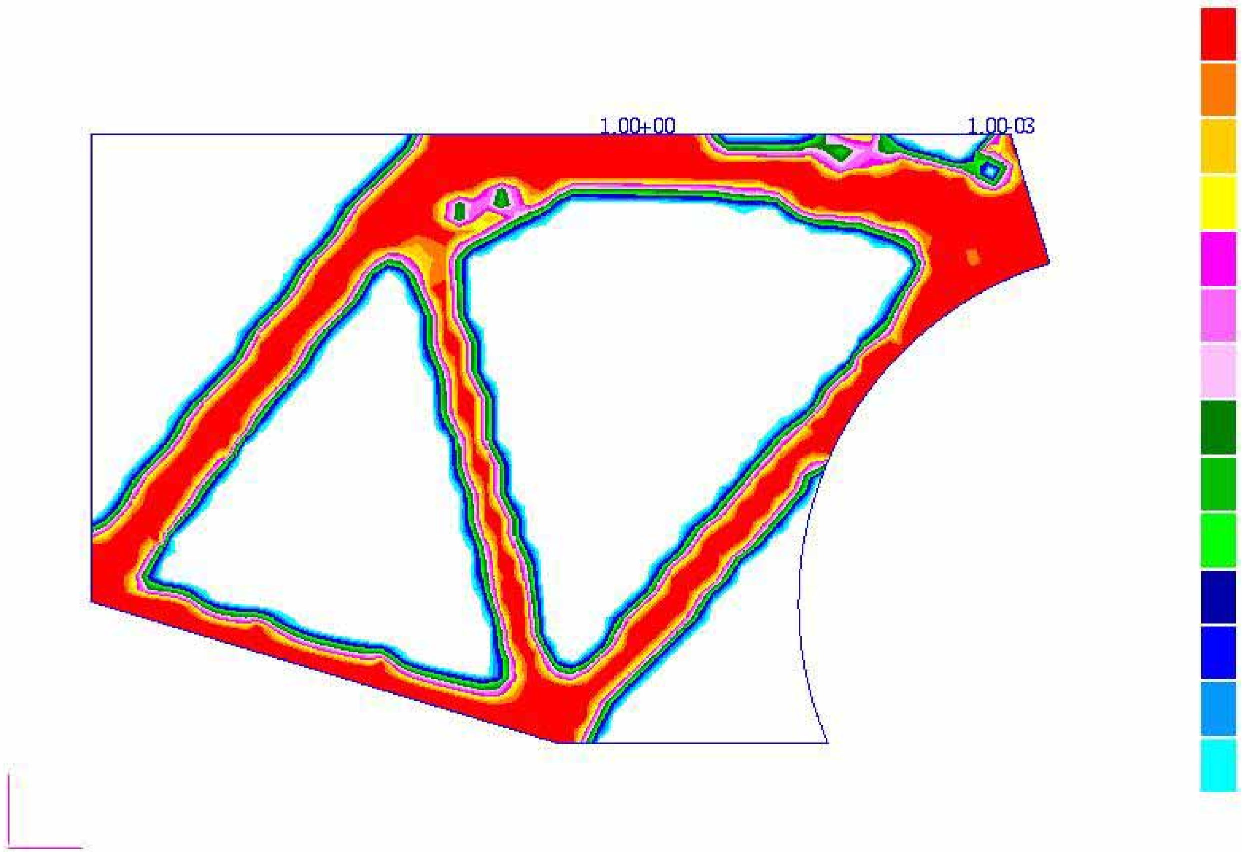
A Bicycle Frame

- 2442 CQUAD4 elements
- Minimize compliance with 30% mass target





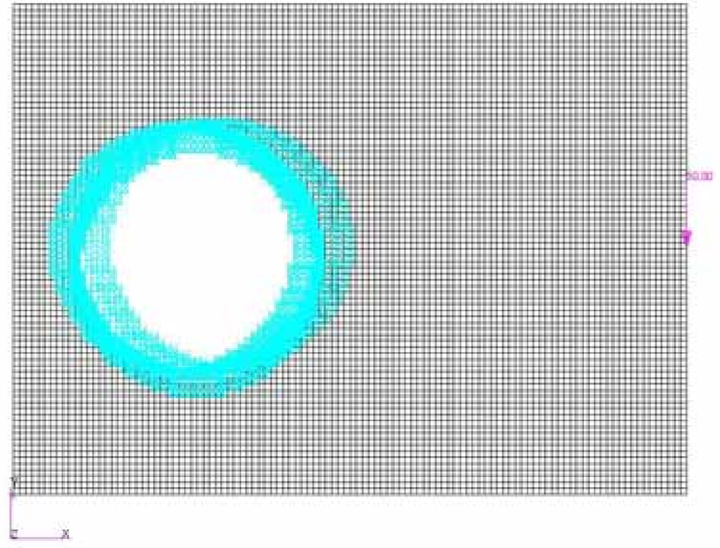
A Bicycle Frame



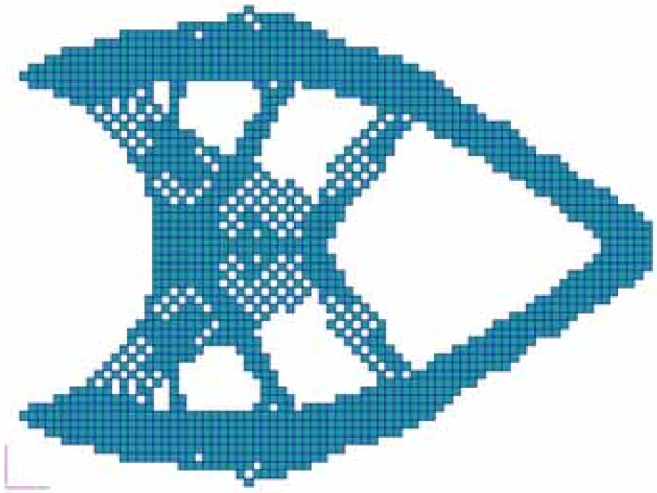
Examples

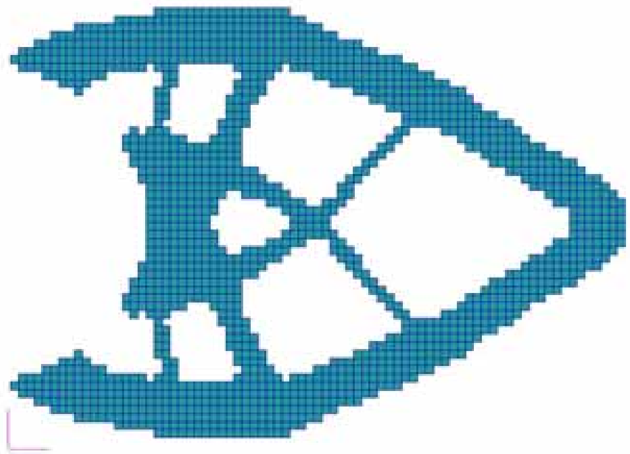
Michell Truss

- 7566 QUAD4 elements
- Minimize compliance with 20% mass target



Michell Truss





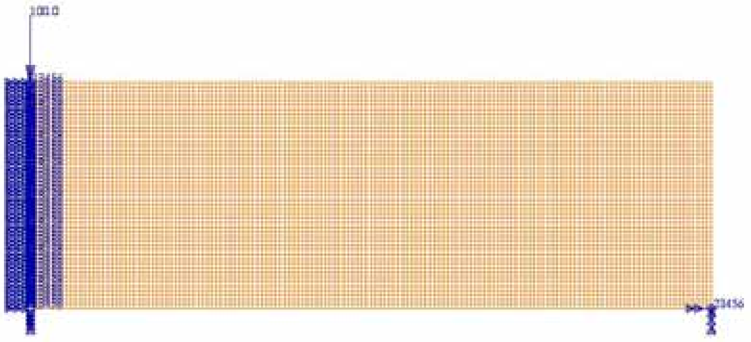
Without filtering

With filtering (TCHECK=1 as default)

MBB BEAM

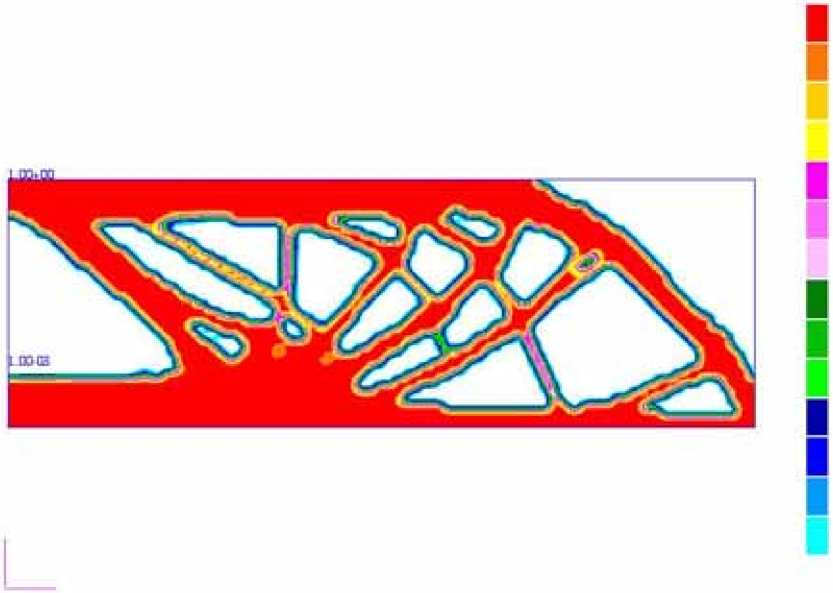
MBB Beam

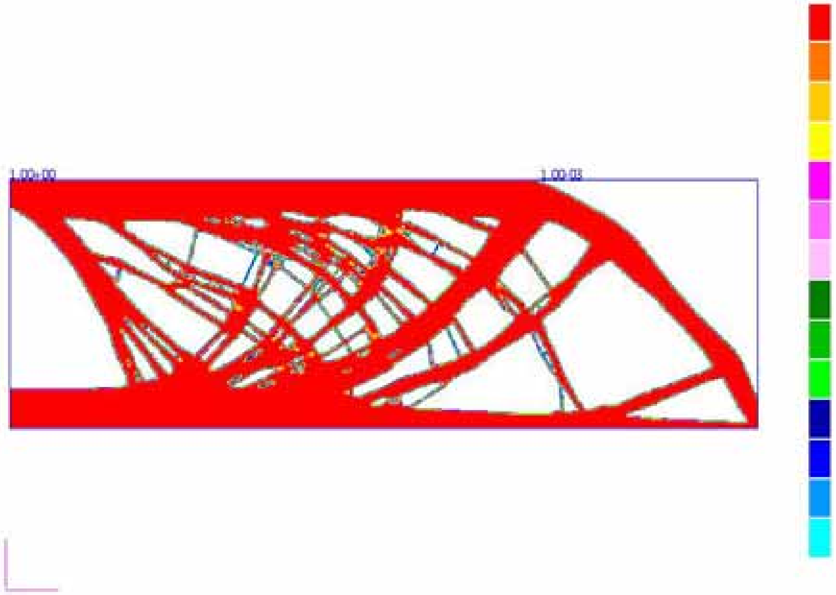
- Design space 2mm x 6mm
- Minimize compliance with 50% mass target



MBB BEAM

- Different mesh results in a different design
- Too many small members for a finer mesh model



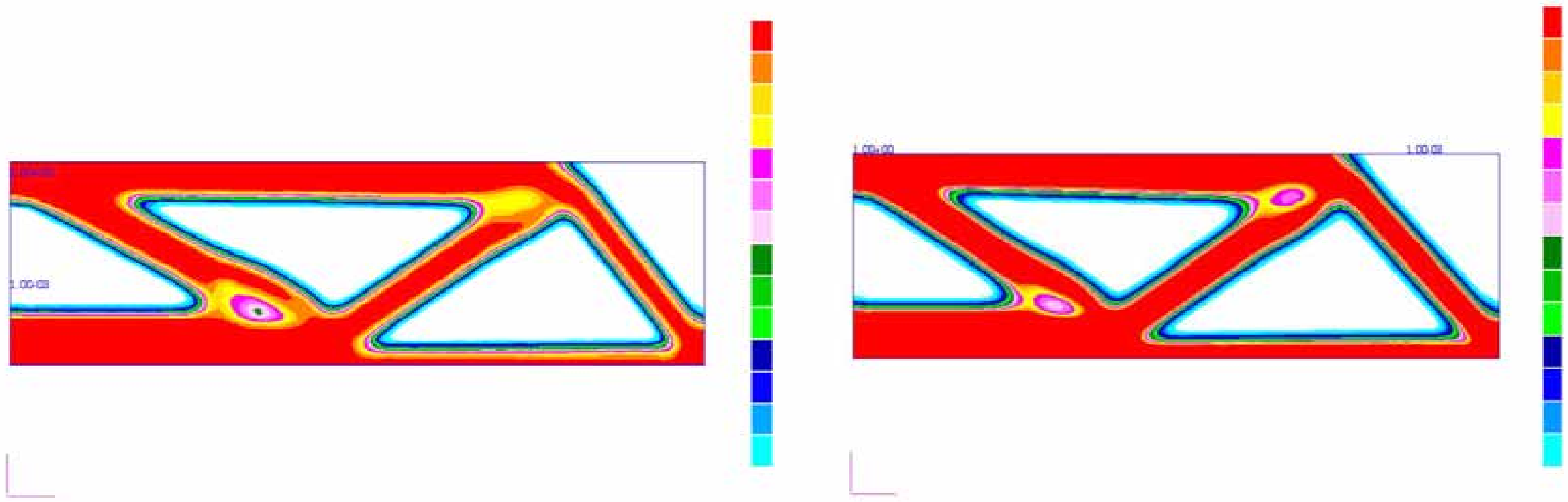


(a) 4,800 CQUAD4 (b)120,000 CQUAD4

Without minimum member size control

MBB Beam

Minimum member size (TDMIN on DOPTPRM) is used to control the degree of manufacturing simplicity and achieve a mesh-independent design



(a) 4,800 CQUAD4

(b)120,000 CQUAD4

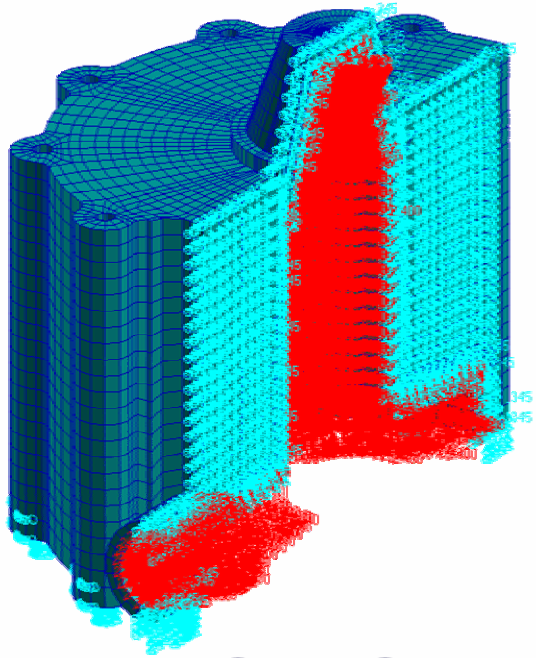
With minimum member size control (0.5mm)

Examples

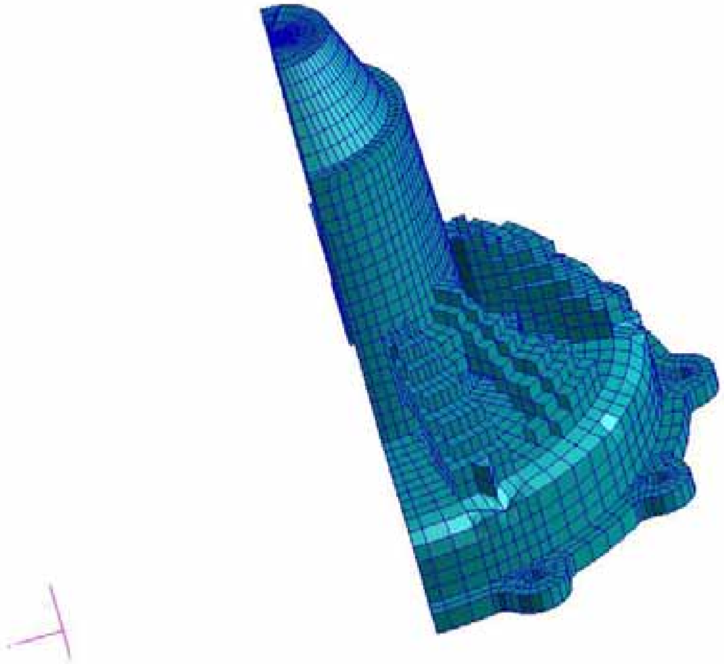
A Pump Lid

– 18821 HEXA8 elements

– Minimize compliance with 5% mass target



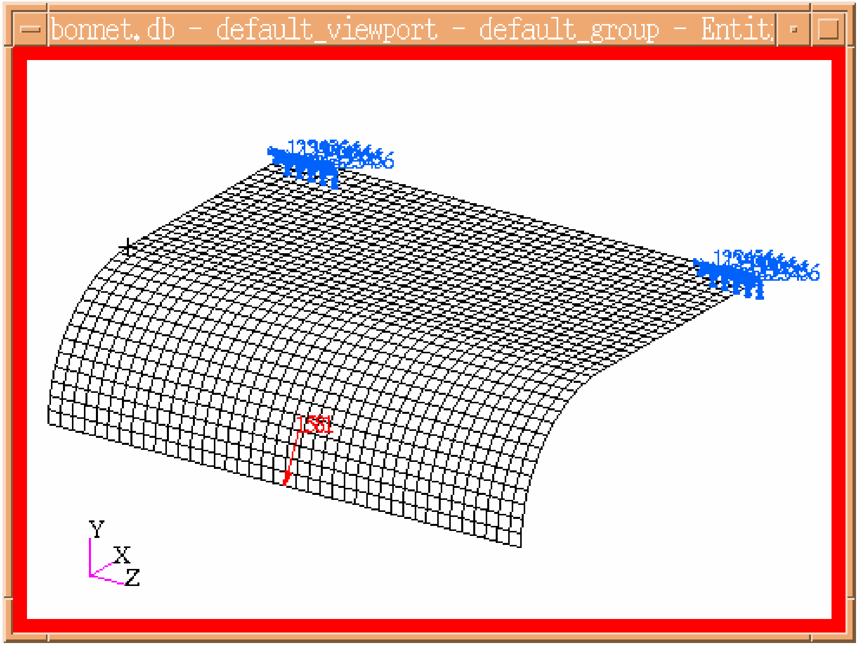
A Pump Lid



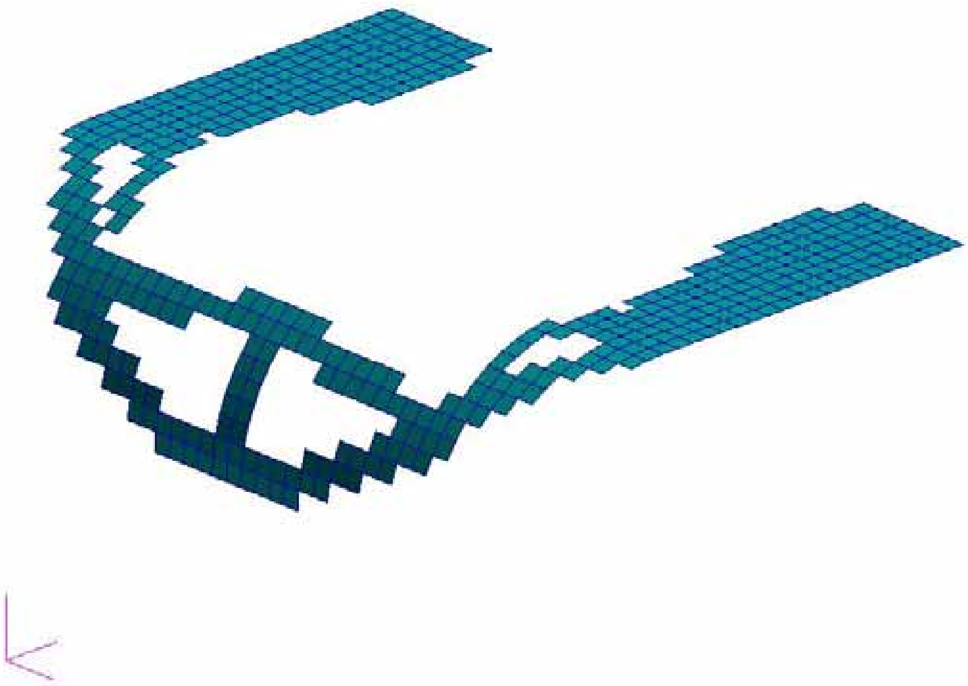
Benchmark Examples

A Bonnet Structure

- 1400 QUAD4 elements
- Minimize compliance with 30% mass target

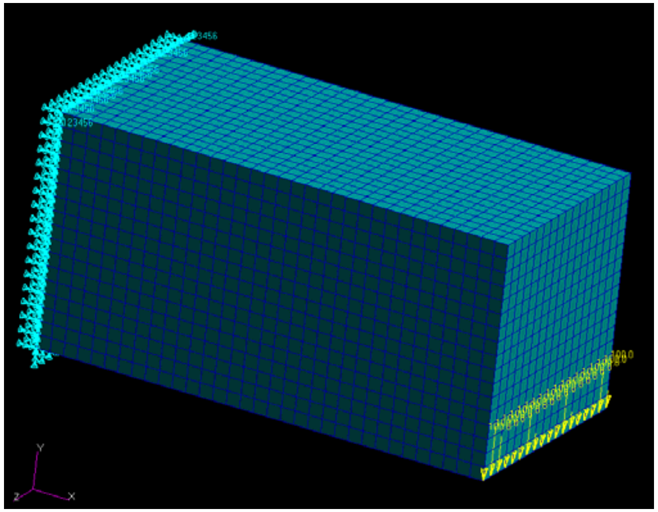


A Bonnet Structure

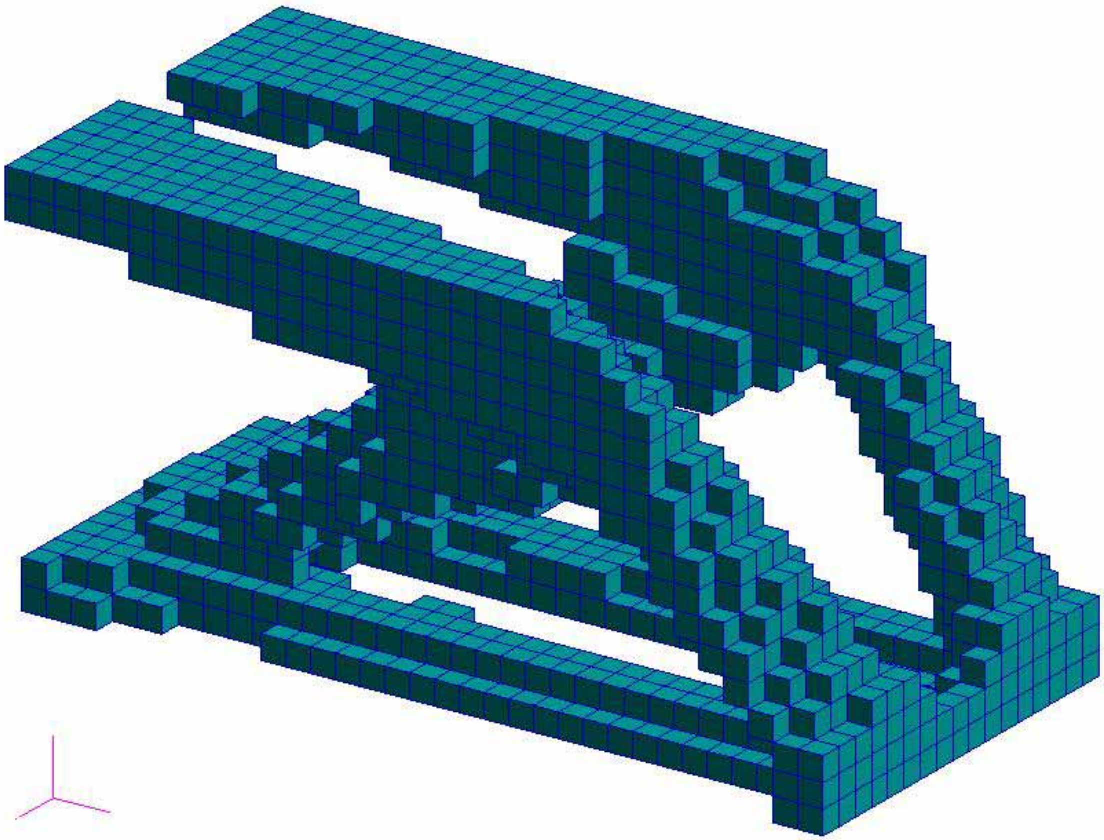


3D-Beam

- 3D Beam
  - –9537 HEXA8 elements
  - –Minimize compliance with 20% mass target



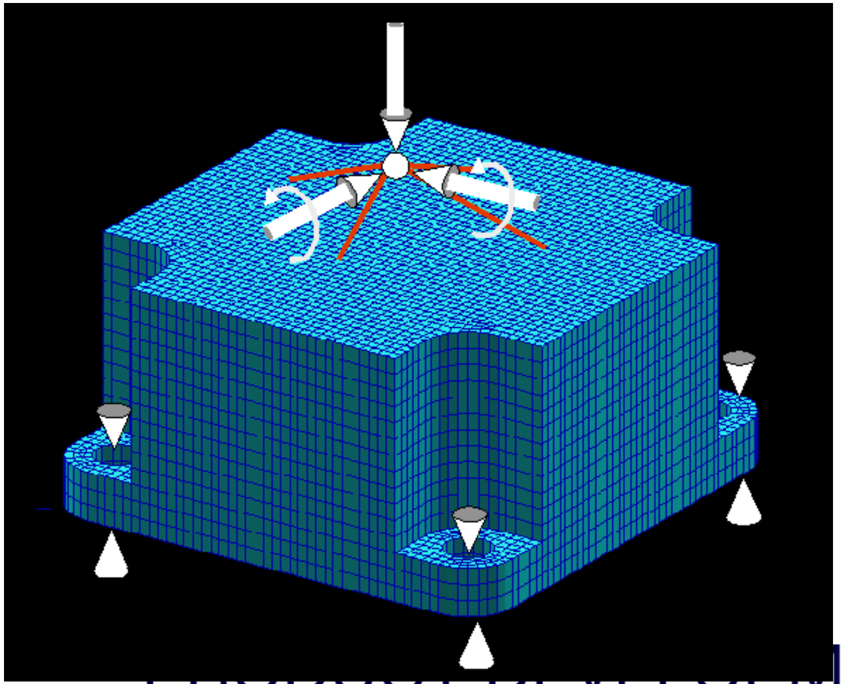
3D-Beam



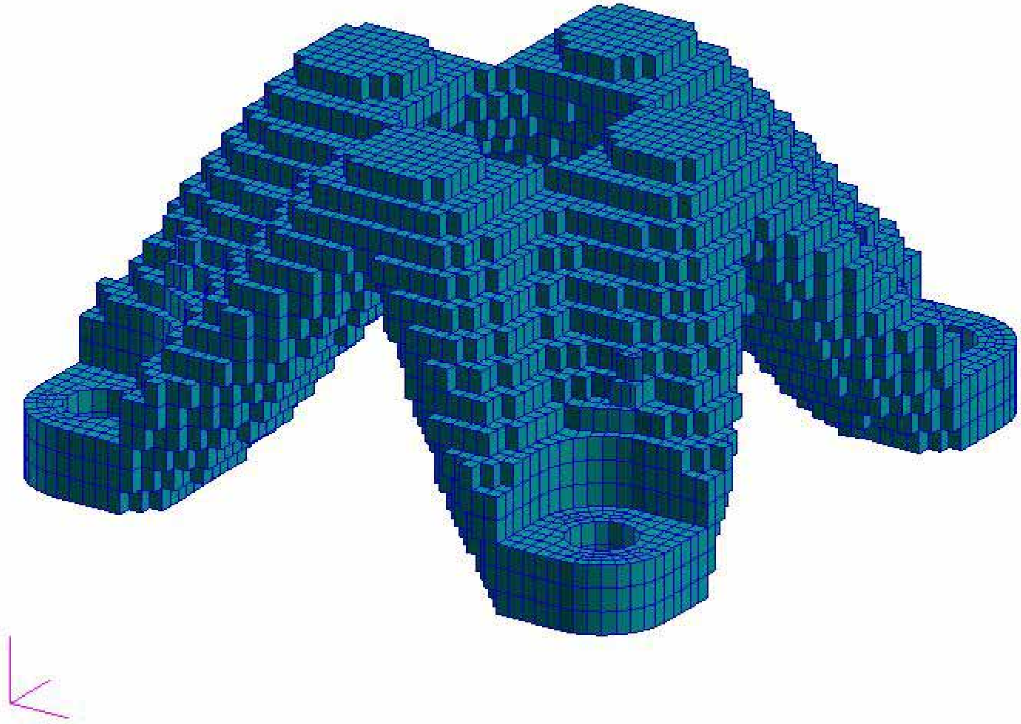
Spare Tire Mount

Spare Tire Mount

- 33,120 HEXA8 elements
- Minimize compliance with 30% mass target



Spare Tire Mount



Ongoing Activity

More functions for MSC.Nastran 2005R2 & beyond

- Support manufacturability requirements such as castability (draw direction), extrudability, and symmetry constraints
- Support composite elements and superelements
- Support regional mass fraction, compliance, and minimum member size control, and manufacturability requirements
- Support topology and non-topology design variables simultaneously

Discussion

Thank you!

Any Questions?