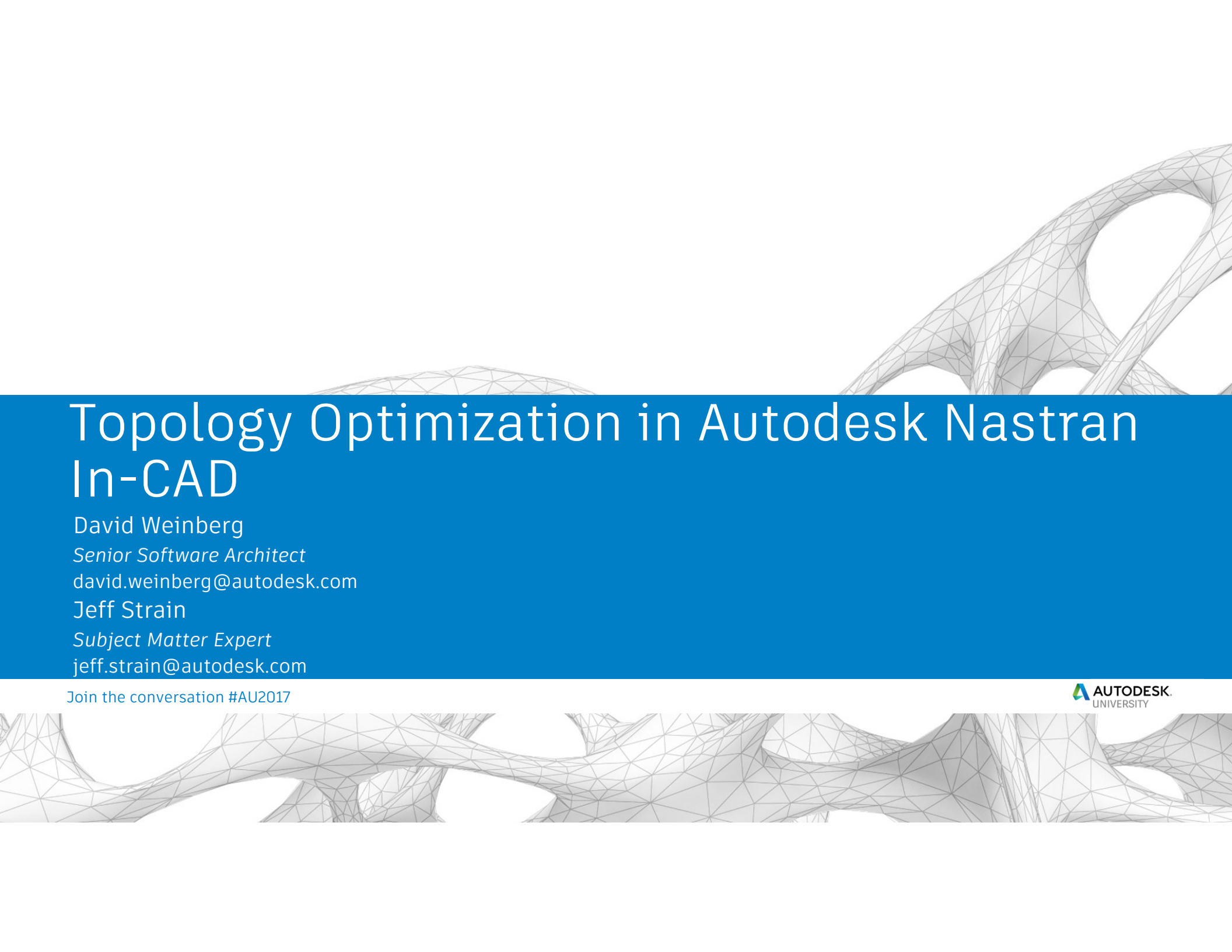


The background of the slide features a complex, organic wireframe mesh structure. It consists of numerous interconnected triangles forming a fluid, undulating shape that resembles a stylized, skeletal form or a topologically optimized structure. The mesh is rendered in a light gray color against a white background.

Topology Optimization in Autodesk Nastran In-CAD

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Subject Matter Expert

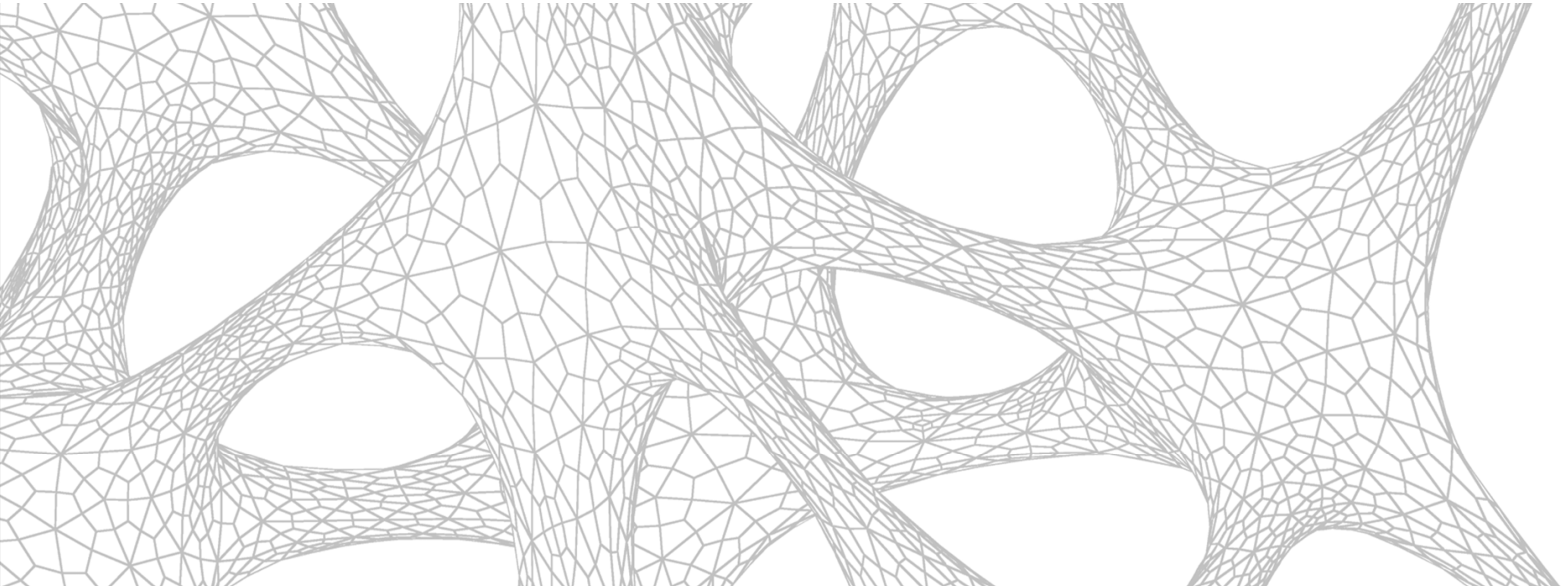
jeff.strain@autodesk.com

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Contents

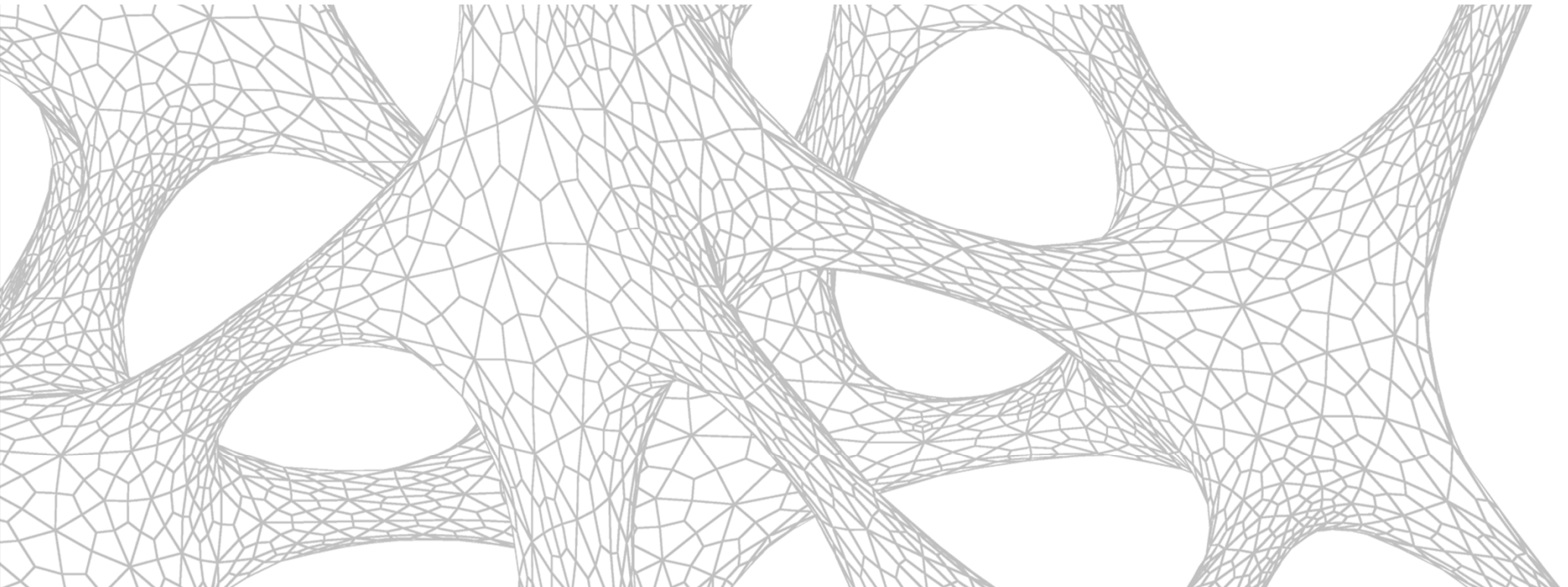
- Learning Objectives
- Definitions
- Topology Optimization Basics
- Objectives and Constraints
- In-CAD Topology Optimization User Interface
- GE Bracket Challenge Problem
- Live Demo Problems



Learning Objectives

Learning Objectives

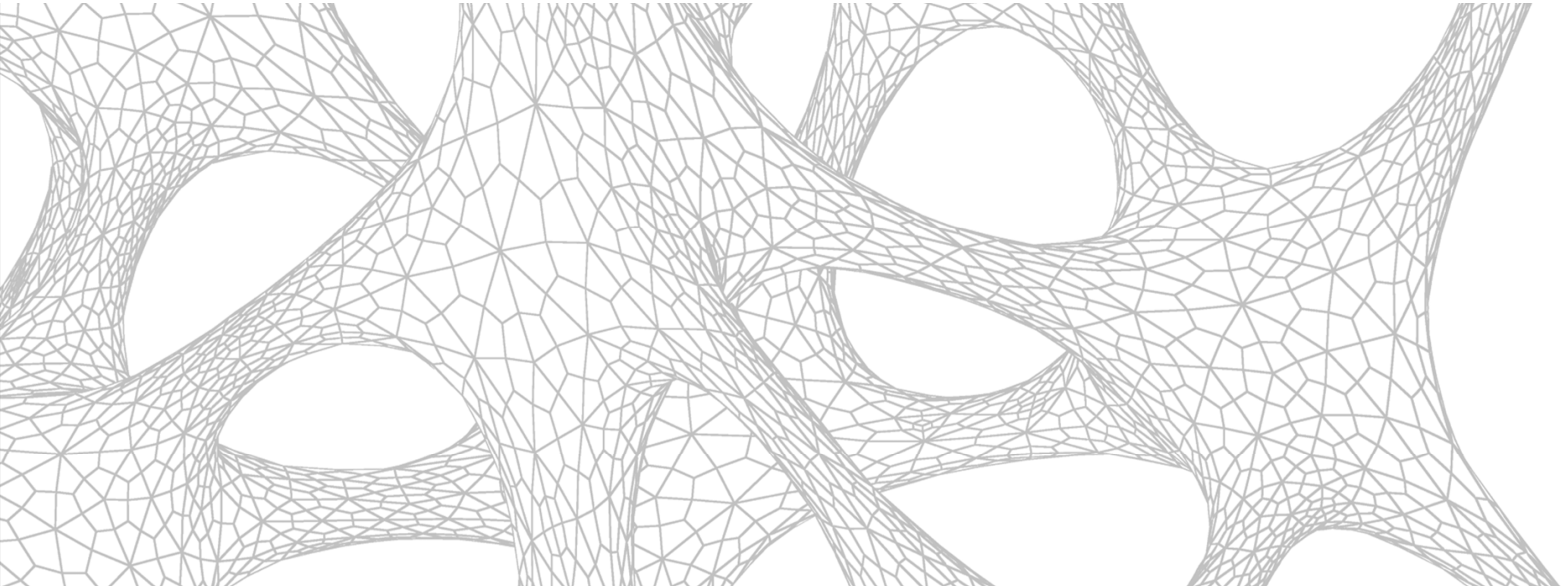
- Understand the basics of Topology Optimization in Autodesk Nastran In-CAD
- Learn how to modify an existing design to remove unnecessary material and make it more efficient and how to generate a design from an empty design space
- Understand the limitations of Topology Optimization in Autodesk Nastran In-CAD
- Understand the workflow involved in setting up and performing a Topology Optimization and how to generate an optimized design



Definitions

Definitions

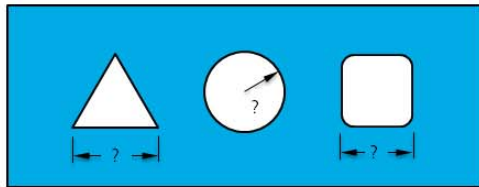
- **Objective** – The goal of the design analysis
- **Design Constraint** – Specific limits on results such as displacement at point, temperature, stress, etc.
- **Manufacturing Constraint** – Specifies how a design region will be manufactured such as extruded along an axis or symmetric about a plane
- **Compliance** – The inverse of stiffness
- **Volume Fraction** – The ratio of full volume to reduced volume (effectively the same as mass fraction when density is constant in a design region)
- **Design Sensitivity** – The gradient (change) of the objective (or constraint) with respect to the design variable (element density)



Topology Optimization Basics

Topology Optimization

- Shape optimization: Maintain the topology, change dimensions
- Topology optimization: Determine layouts



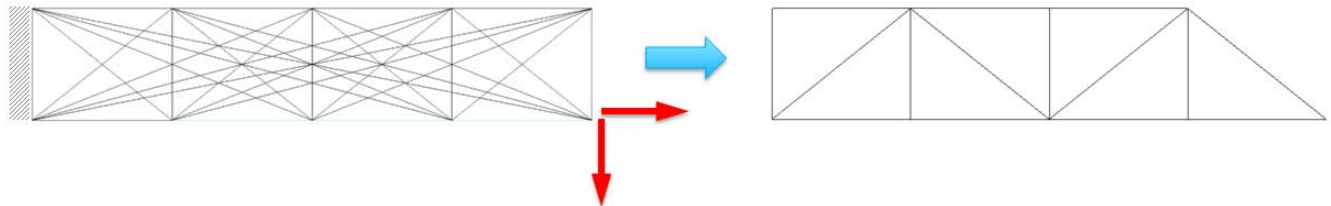
Shape Optimization



Topology Optimization

- Method with Finite Element Analysis

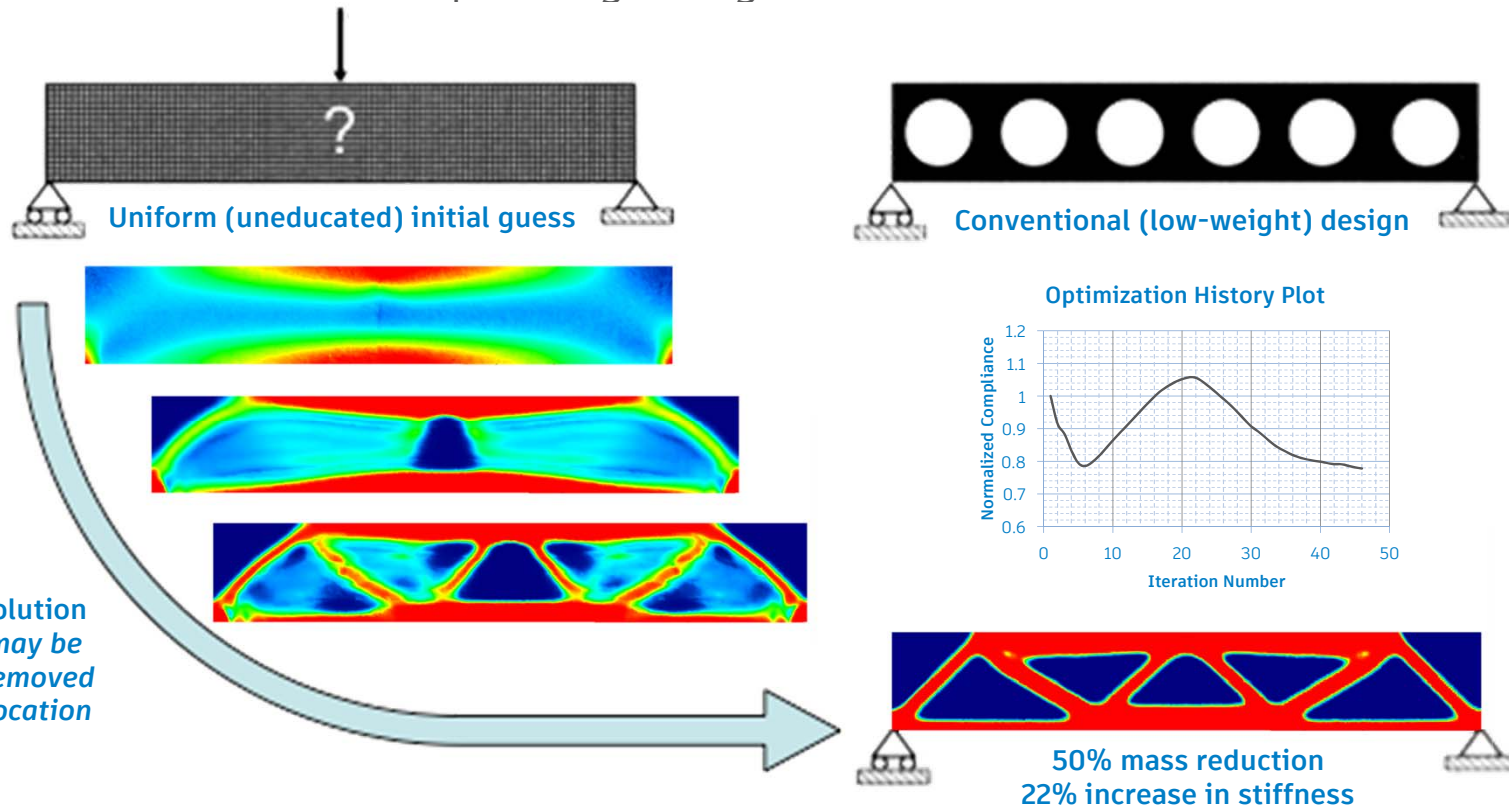
- Initial method...truss



- Change member area and remove when area goes to zero
- Discrete variables, predetermined nodal locations

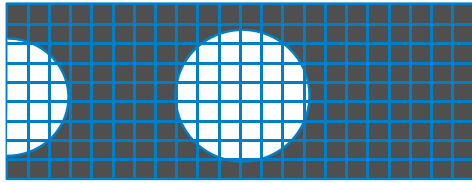
Topology Optimization with FEA

- Determination of optimal principal material distribution for a given problem
- A powerful tool for concept design stage



Topology Optimization Using SIMP - Nastran

- For fixed mesh, determine **density** (x_e) of each element



$x_e = 0$: void
 $x_e = 1$: material

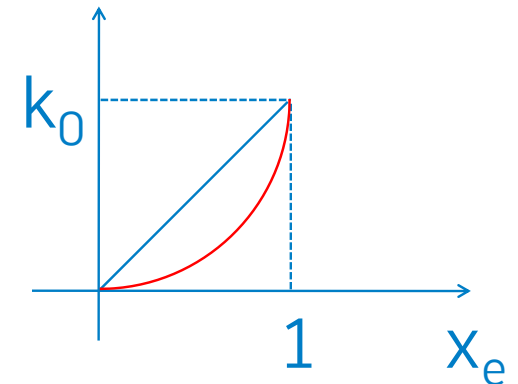
} Design variable

- Structural volume $V(\mathbf{x}) = \sum_{e=1}^{NE} x_e v_0$ v_0 : volume of an element

- Element stiffness $[\mathbf{k}_e] = (x_e)^p [\mathbf{k}_0]$

- SIMP = **S**olid **I**sotropic **M**aterial **P**enalization

(Not limited to isotropic materials)



- Exponent p :
 - Reduce grey area, force zero or one
 - Typically, $p = 3$

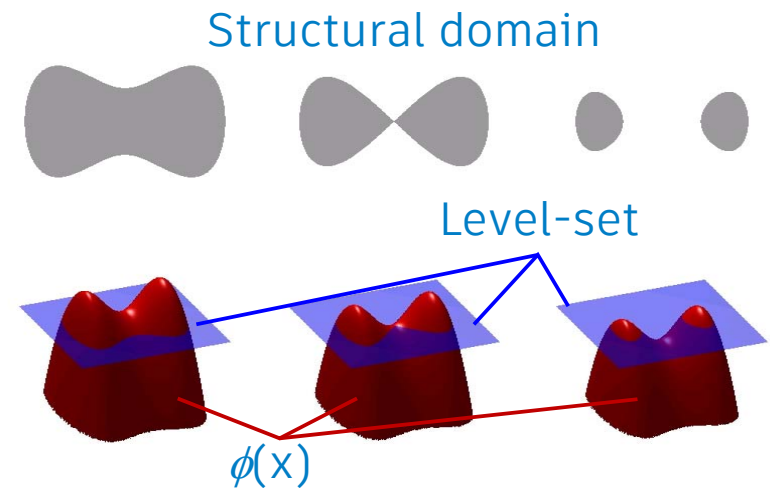
Topology Optimization Using Level-Set

- Front or boundary tracking method
- Commonly used in image processing, moving boundary problems, multiphase problems, movies, etc.
- Structural domain is defined by level-set function $f(\mathbf{x})$

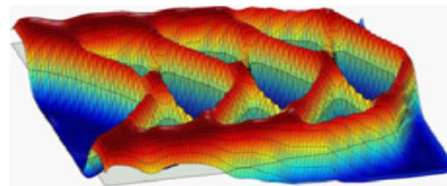
$$\rho = \begin{cases} 0 & : \phi < 0 \\ 1 & : \phi \geq 0 \end{cases}$$

- Level-set function $f(\mathbf{x})$ is defined using nodal values and interpolation
- Boundary = zero level-set

$$\phi(\mathbf{x}) = 0$$



Structural domain defined by different level-set values



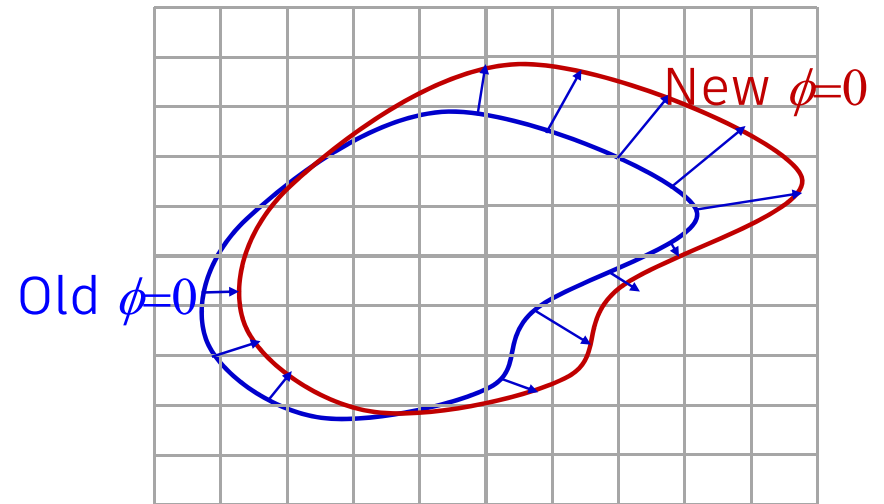
Level-set function $\phi(\mathbf{x})$



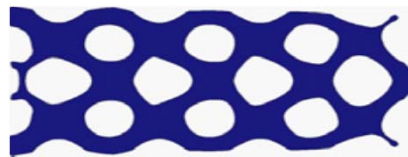
Structural domain

Topology Optimization Using Level-Set

- How to change the shape?
 - Moving the boundary of level-set (solving Jacobi-Hamilton diff. eq.)
 - Introducing new holes
 - Merging holes



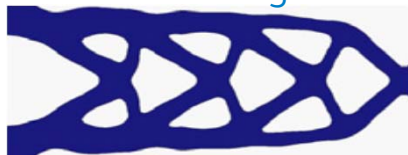
Initial design



Step 15



Step 45



Step 150



Step 245



Step 386

Misconception of Level-Set Method

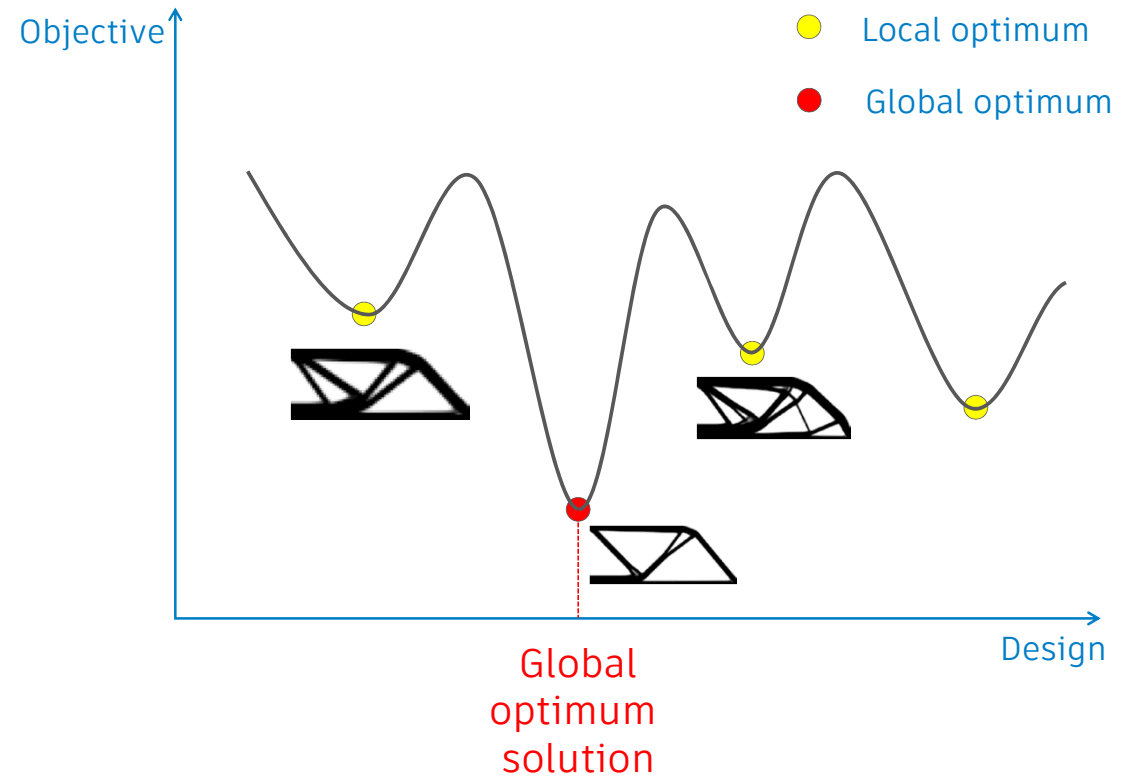
- Smooth and crisp boundary descriptions
 - Most level-set methods do not use clear boundary information in FEA simulation, but the same grey-scale information
 - It is claimed by some that level-set is more accurate than SIMP
 - In reality, when the boundary cuts an element, the level-set calculates the volume fraction (similar concept as SIMP) of the boundary and use it for FEA simulation
 - **The quality of FEA result will be the same as SIMP**

Density method versus Level-Set Method

Density method (SIMP)	Level Set
Difficult to define objective and constraints on the boundary	Explicit formulation objective and constraints on the interface and boundary
Need an extra process to integrate shape and topology optimization (generate geometry)	Convenient to integrate the shape and topology optimization
Versatile in terms of additive design	Restricted to evolve geometry from existing boundaries
Holes and cutouts can be introduced anytime during optimization	Difficult to introduce a new hole, affecting the convergence
Well studied convergence	Convergence is strongly influenced by spatial gradients near the boundary
Optimum results are insensitive to starting volume fraction	The results strongly depend on starting guess
Most mature method (most commercial software uses the density method)	Presence of unresolved challenges (regularization, spatial gradients control, member size control, etc)
Need filtering to prevent checker-boarding	Need special treatments on the boundary in order to prevent oscillation and too-fast growth

Global Versus Local Minimum

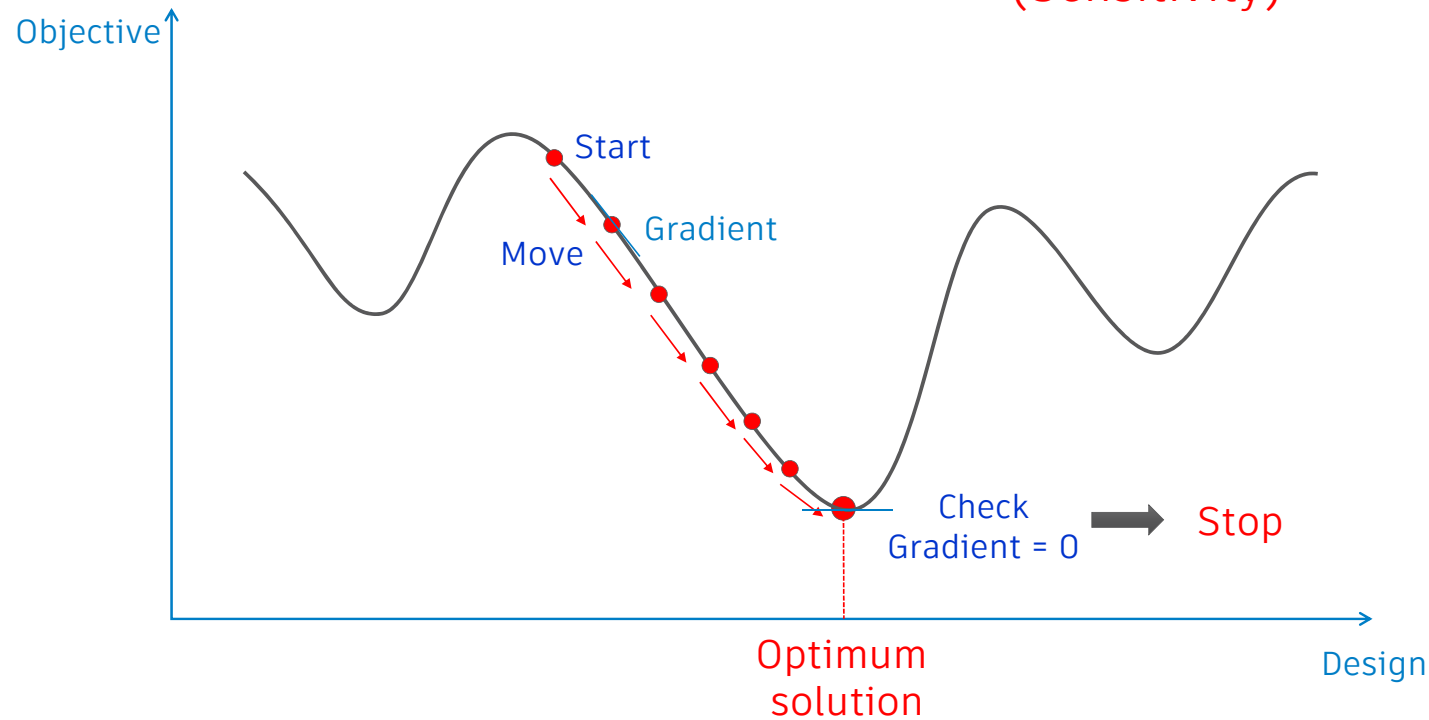
- Optimization algorithm searches for local minimum...global minimum is not guaranteed
- Starting with different initial volume fractions and different mesh densities will result in different designs



Gradient-based Methods

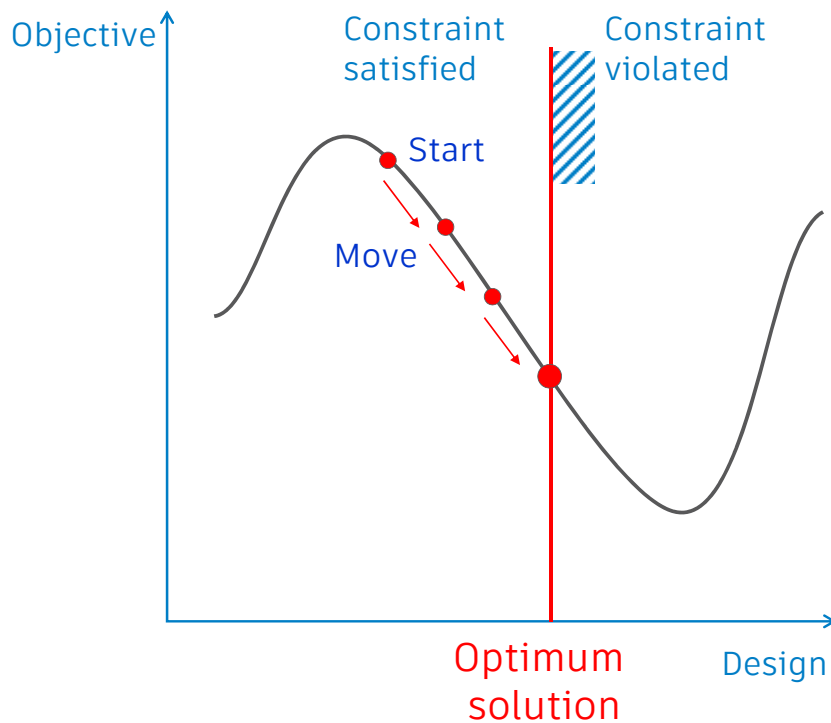
We do not know the function before optimization

We can only evaluate the function and gradient at a given design
(Sensitivity)

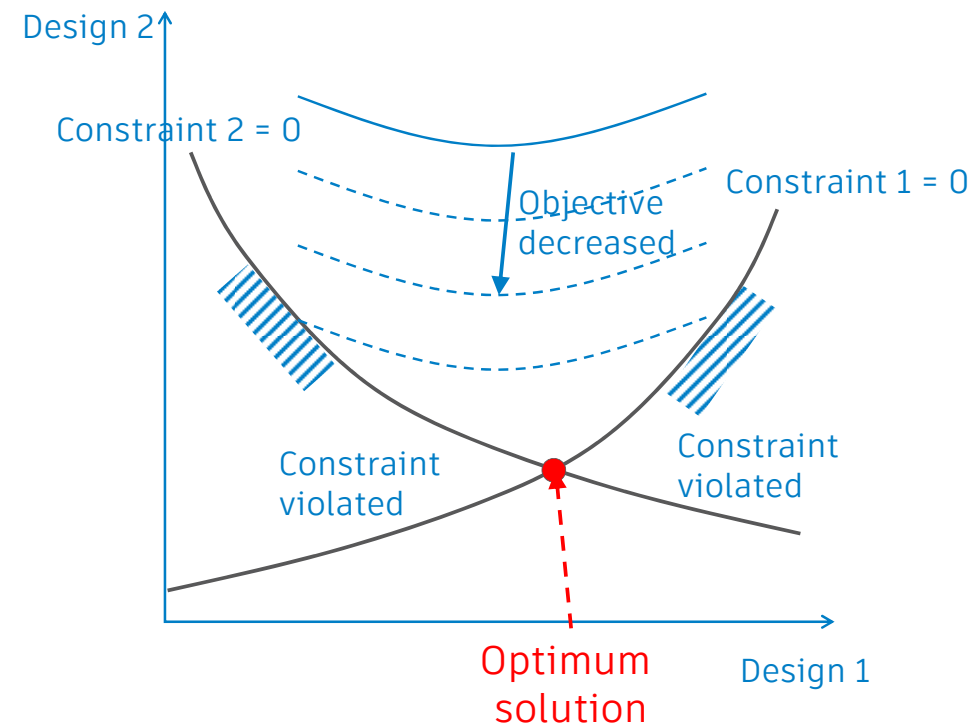


How Constraints Play in Optimization?

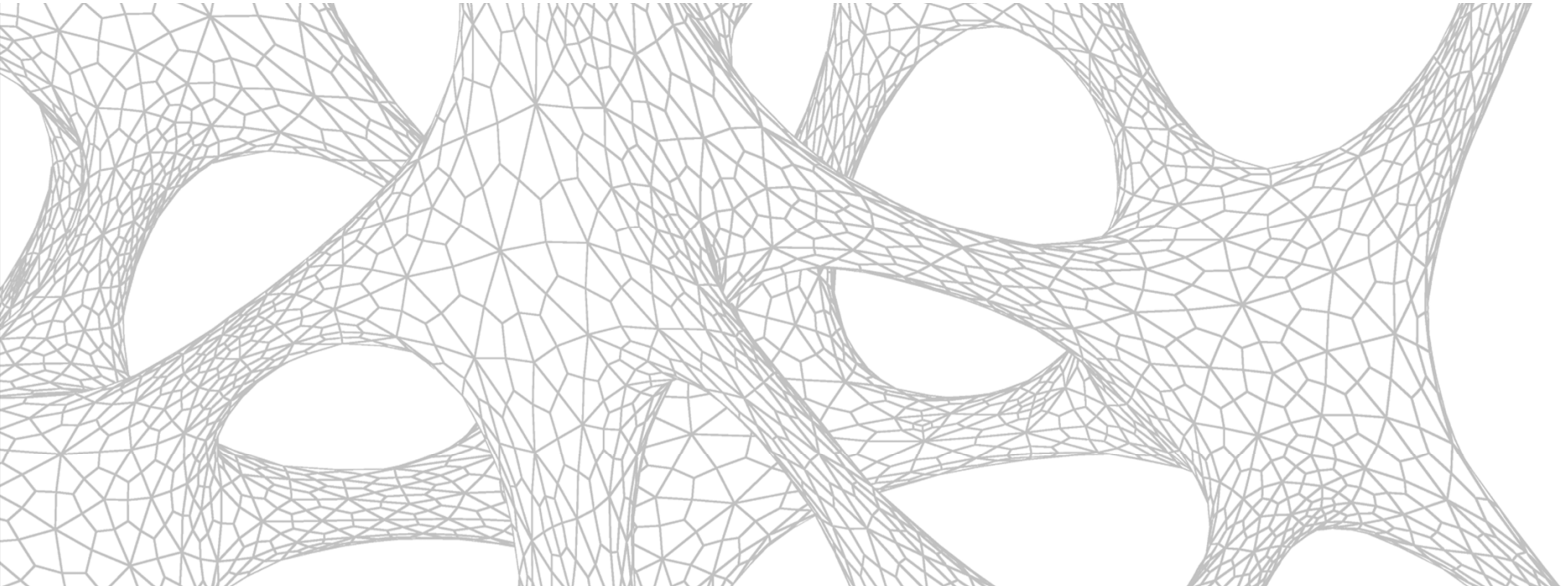
Most cases, constraints determine optimal design



Single constraint example



Two constraints example



Objectives and Constraints

In-CAD Topology Optimization Objectives

Objective	Min/Max/Either	Multiple Load Cases	Solution Sequence
Compliance	Min	Yes	LS
Compliance Index	Min	Yes	LS
Max Displacement Component in Model	Min	No	LS
Specific Grid Point Displacement Component	Min	No	LS
Max Constraint Force Component in Model	Min	No	LS
Specific Constraint Force Component	Min	No	LS
Stress of a Specific TOPVAR Region	Min	No	LS
Stress of all TOPVAR Regions	Min	No	LS
Volume Fraction (Mass Fraction) of a specific TOPVAR Region	Min	Yes	LS
Volume Fraction (Mass Fraction) of all TOPVAR Regions	Min	Yes	LS
Thermal Energy of a Specific TOPVAR Region (Compliance)	Min	Yes	LSSHT
Thermal Energy of all TOPVAR Regions (Compliance)	Min	Yes	LSSHT
Average Temperature of a Specific Set of Nodes	Either	No	LSSHT
Delta Temperature of a Specific Set of Nodes	Either	No	LSSHT
Global Temperature of a Specific Set of Nodes	Either	No	LSSHT
Normal Modes Frequency	Max	Yes	NM
Normal Modes Eigenvalue	Max	Yes	NM
Buckling Modes Eigenvalue (load factor)	Max	No	LB

LS = Linear Statics, LSSHT = Linear Steady-State Heat Transfer, NM= Normal Modes, LB = Linear Buckling

In-CAD Topology Optimization Design Constraints

Design Constraints	Range	Multiple Load Cases	Individual Load Cases	Solution Sequence
Compliance	Range	Yes	Yes	LS
Compliance Index	< Upper	Yes	Yes	LS
Max Displacement Component in Model	< Upper	Yes	Yes	LS
Specific Grid Point Displacement Component	Range	Yes	Yes	LS
Max Constraint Force Component in Model	< Upper	Yes	Yes	LS
Specific Constraint Force Component	Range	Yes	Yes	LS
Stress of a Specific TOPVAR Region	< Upper	Yes	Yes	LS
Stress of all TOPVAR Regions	< Upper	Yes	Yes	LS
Volume Fraction (Mass Fraction) of a specific TOPVAR Region	< Upper	Yes	Yes	LS
Volume Fraction (Mass Fraction) of all TOPVAR Regions	< Upper	Yes	Yes	LS
Thermal Energy of a Specific TOPVAR Region	Range	Yes	Yes	LSSHT
Thermal Energy of all TOPVAR Regions	Range	Yes	Yes	LSSHT
Average Temperature of a Specific Set of Nodes	Range	Yes	Yes	LSSHT
Delta Temperature of a Specific Set of Nodes	Range	Yes	Yes	LSSHT
Global Temperature of a Specific Set of Nodes	Range	Yes	Yes	LSSHT
Normal Modes Frequency	> Lower	No	No	NM
Normal Modes Eigenvalue	Range	No	No	NM
Buckling Modes Eigenvalue (load factor)	Range	No	No	LB

LS = Linear Statics, LSSHT = Linear Steady-State Heat Transfer, NM= Normal Modes, LB = Linear Buckling

Maximum Stress Constraint

- We want to limit max stress, but...
 - Discontinuous and oscillating
 - Occurs at a localized small number of elements
- We need a smooth and global stress
 - Approximately the same as local, max stress

$$\sigma_{\text{global}} \equiv \sigma_{\text{max}} \left\{ \frac{1}{N} \sum_{e=1}^N \left(\frac{\sqrt{\rho_e} \sigma_{\text{VM}}^e}{\sigma_{\text{max}}} \right)^p \right\}^{\frac{1}{p}} \leq \sigma_{\text{max}}$$

σ_{max} : allowable stress

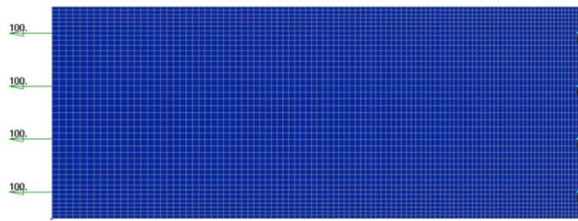
σ_{VM} : Von Mises stress

N: # of TO elements

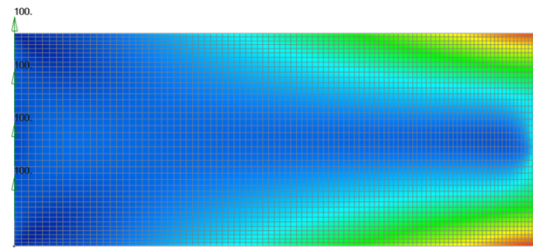
p ~ 10: approximation
exponent

Global Stress Performance

- Global stress is good when stress is uniform



$$\sigma_{\text{global}} = \max(\sigma_{vM}^e)$$



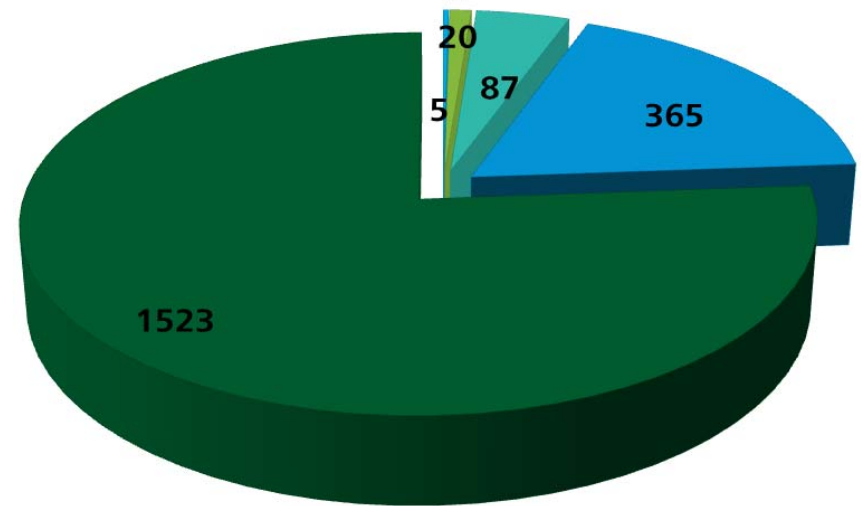
$$\sigma_{\text{global}} < \max(\sigma_{vM}^e)$$

- So, it is necessary to group elements to have uniform stress with each group

Global Stress Subdivisions

- Divide domain into a user defined number of subdomains or sub-regions
- Number of elements in each sub-region starts small and increases rapidly with higher stress elements in smaller sub-regions
- Use a sub-region update strategy to allow design convergence
- The number of sub-regions used is a tradeoff between performance and accuracy

2000 elements Divided Over 5 Subregions



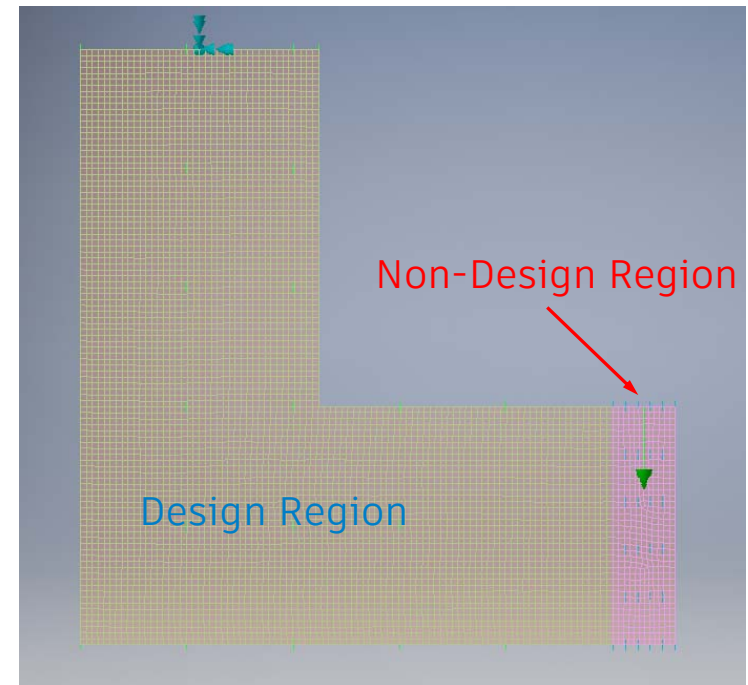
Subdivision/Constraint	Number of Elements
1	5
2	20
3	87
4	365
5	1523

In-CAD Topology Optimization Manufacturing Constraints

Manufacturing Constraints	Combinable With
Non-Design Regions	All
Minimum Member Size	All
Symmetry	Min Member Size
Design for Extrusion	Min Member Size
Design for Milling	Min Member Size
Design for AM	Min Member Size

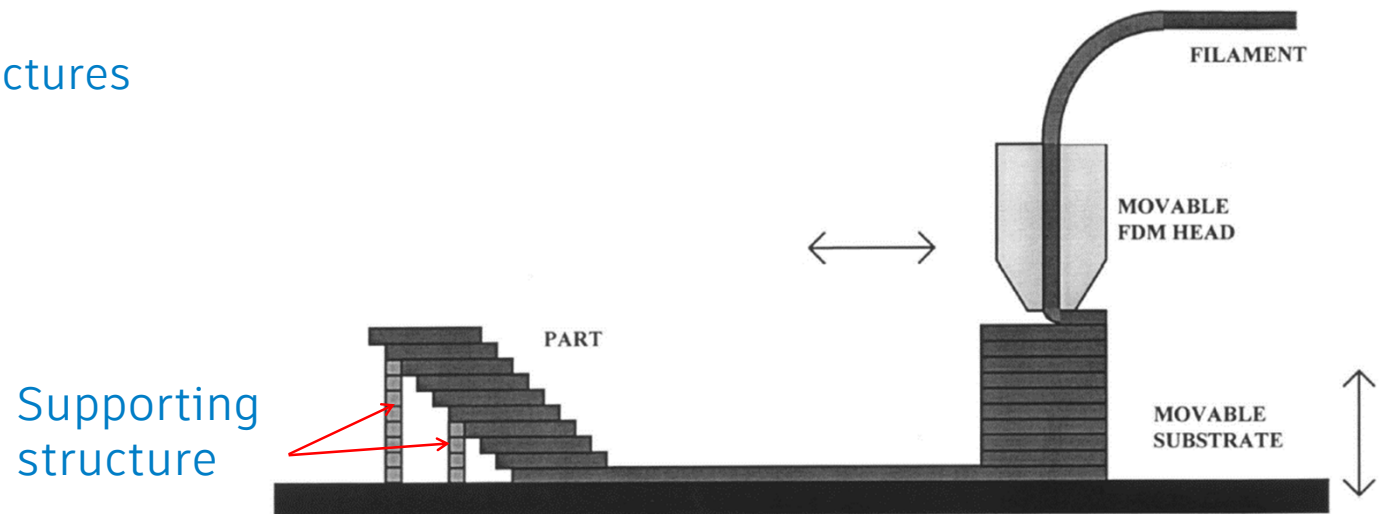
Region-Based Topology Optimization

- In-CAD allows for one design region
 - Default is property 1
 - Can be changed using Nastran Parameters if different
- All other properties or regions will not have material removed but can affect the design
- Ideally loads should be applied to non-design regions

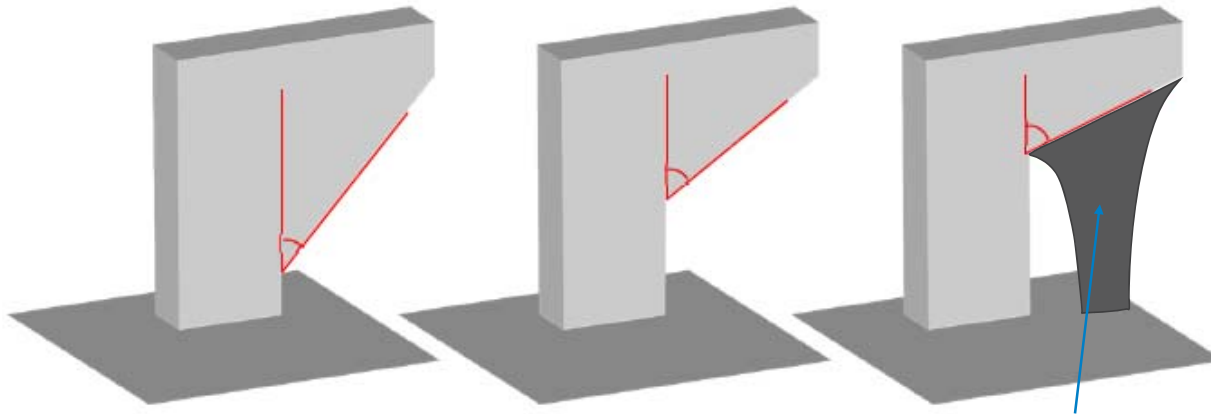


Additive Manufacturing Constraint

- Additive Manufacturing (AM) – 3D Printing
 - Bottom-up layer-by-layer manufacturing process
 - Allow for more manufacturing options
 - Possible for traditionally impossible designs
 - Flexible process time
 - Need supporting structures



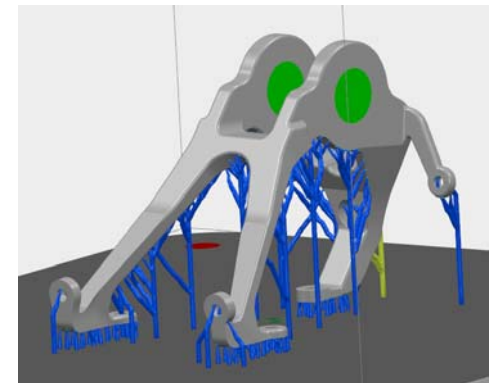
AM Limitation: Critical Overhang Angle



Manufacturable

Supporting structure

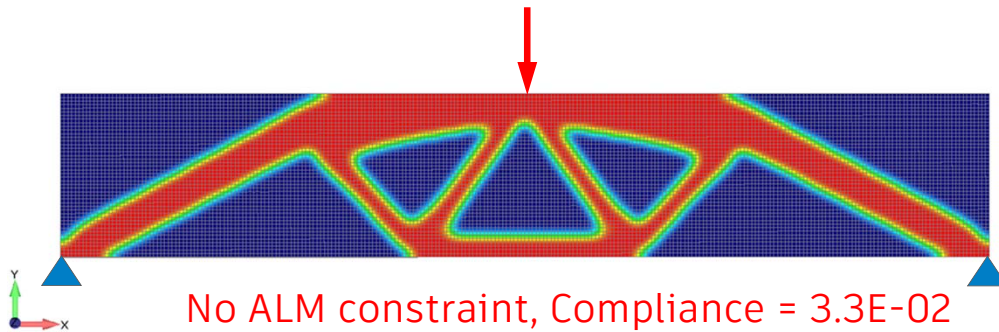
- Overhang structure must be removed using machining
 - Manually design overhang structure
 - Requires extra cost
 - Sometimes impossible to remove (inside feature)



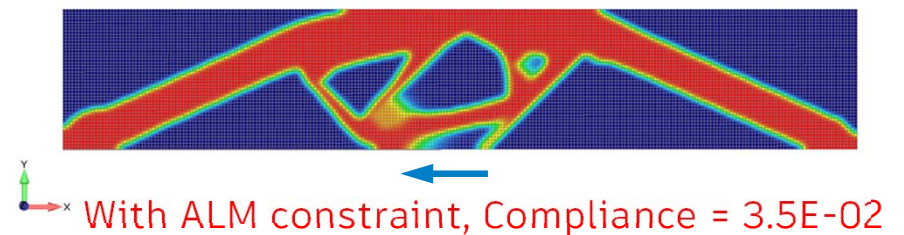
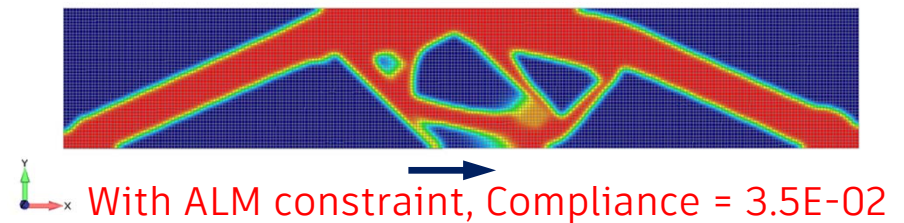
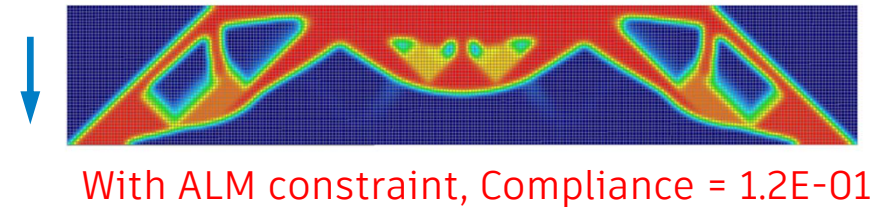
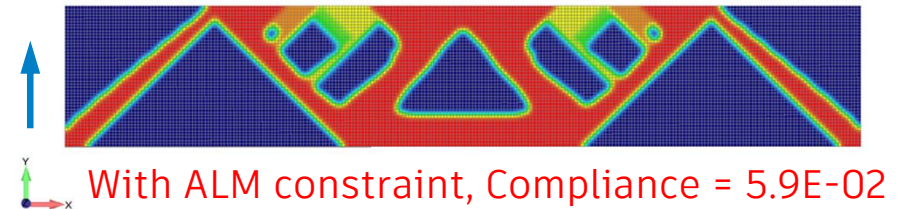
Existing Solutions to Overhang Problem

- Adjust part orientation
- Adjust part itself
- Add support structures
- The aim is to include overhang restrictions in topology optimization
 - No need for support structures: less material usage
 - Less pre-processing for AM
 - Less post-processing: faster production, lower costs

Additive Manufacturing Constraint - ALM

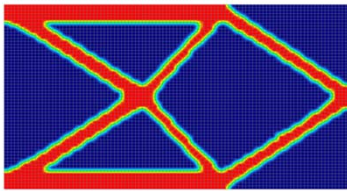


- Fixed at lower corners and point loaded at the top, mid-span
- Objective is minimize compliance (maximize stiffness)
- Constraint is **fixed volume fraction of 0.4** (reduce volume to 40% of its original)
- Manufacturing constraints: ALM or Additive Manufacturing, 45 deg. max overhang angle



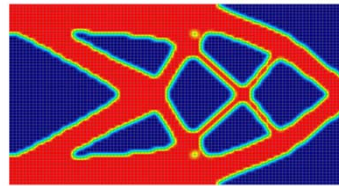
Effect of Mesh Density and Volume Fraction Constraint

Objective: minimize compliance, Constraint: Volume fraction (VF)

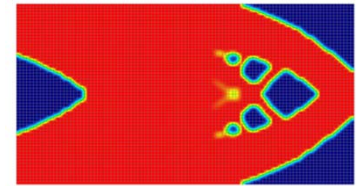


Mesh: 100x60

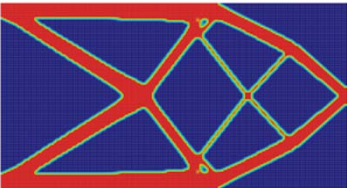
VF = 0.3



VF = 0.5

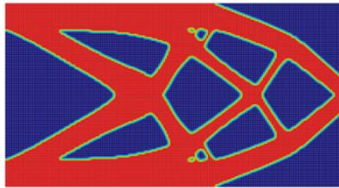


VF = 0.8



Mesh: 200x120

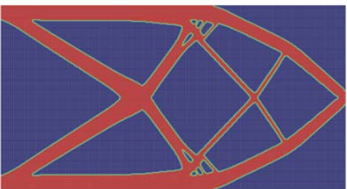
VF = 0.3



VF = 0.5

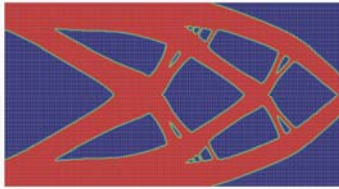


VF = 0.8

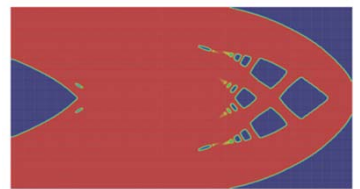


Mesh: 400x240

VF = 0.3

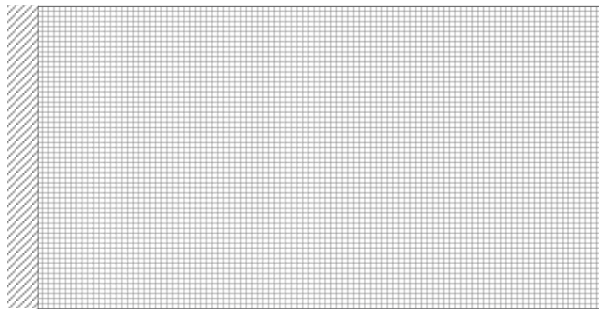


VF = 0.5

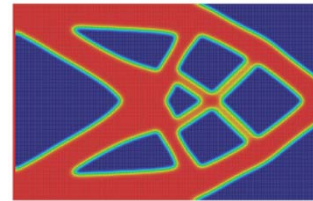


VF = 0.8

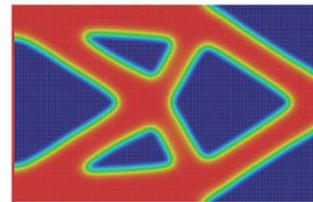
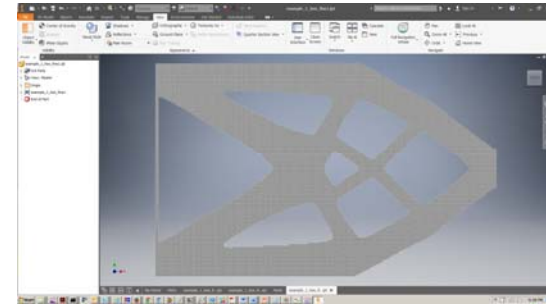
Minimum Member Size Manufacturing Constraint



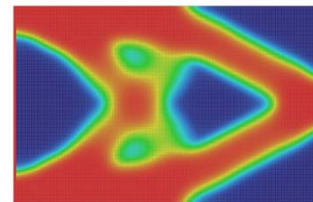
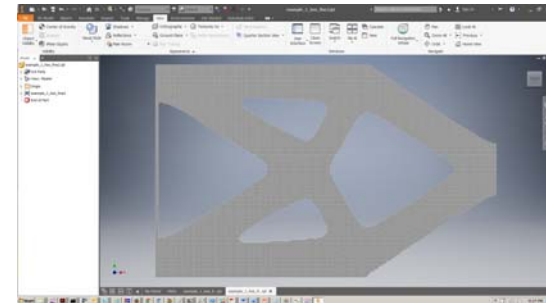
- Fixed at one end and edge loaded at the other end
- Objective is minimize mass
- Constraint is maximum vertical displacement at loaded edge
- Manufacturing constraint: minimum member size (prevents non-designable feature generation)



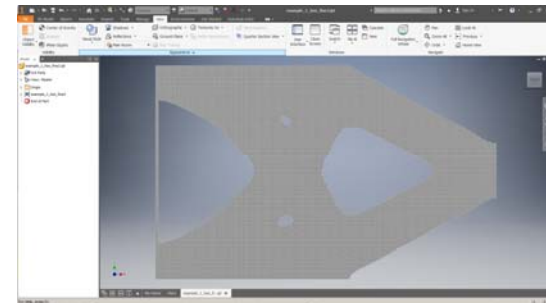
Min member size = 2.0
50.6% mass reduction



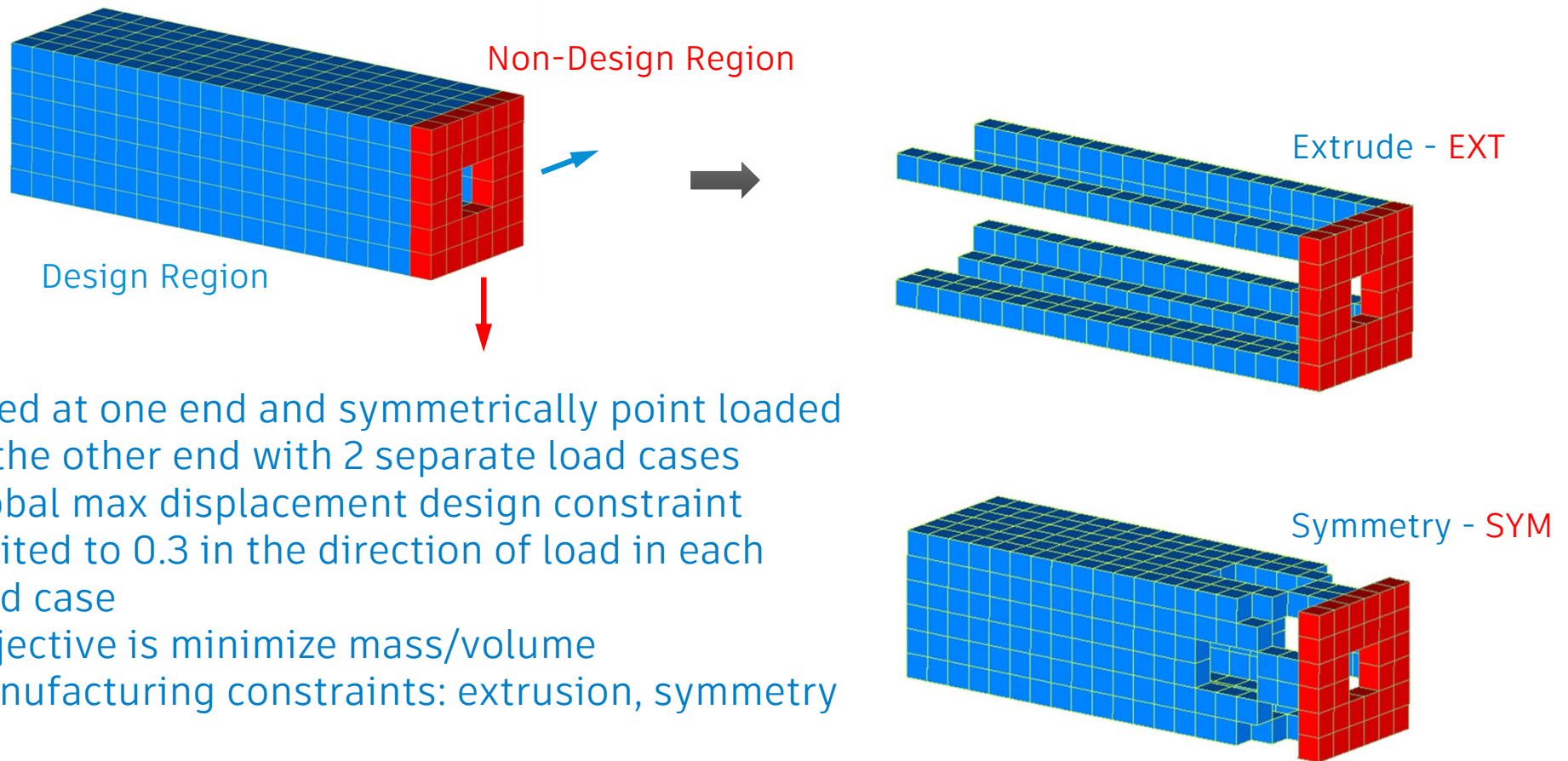
Min member size = 4.0
47.2% mass reduction



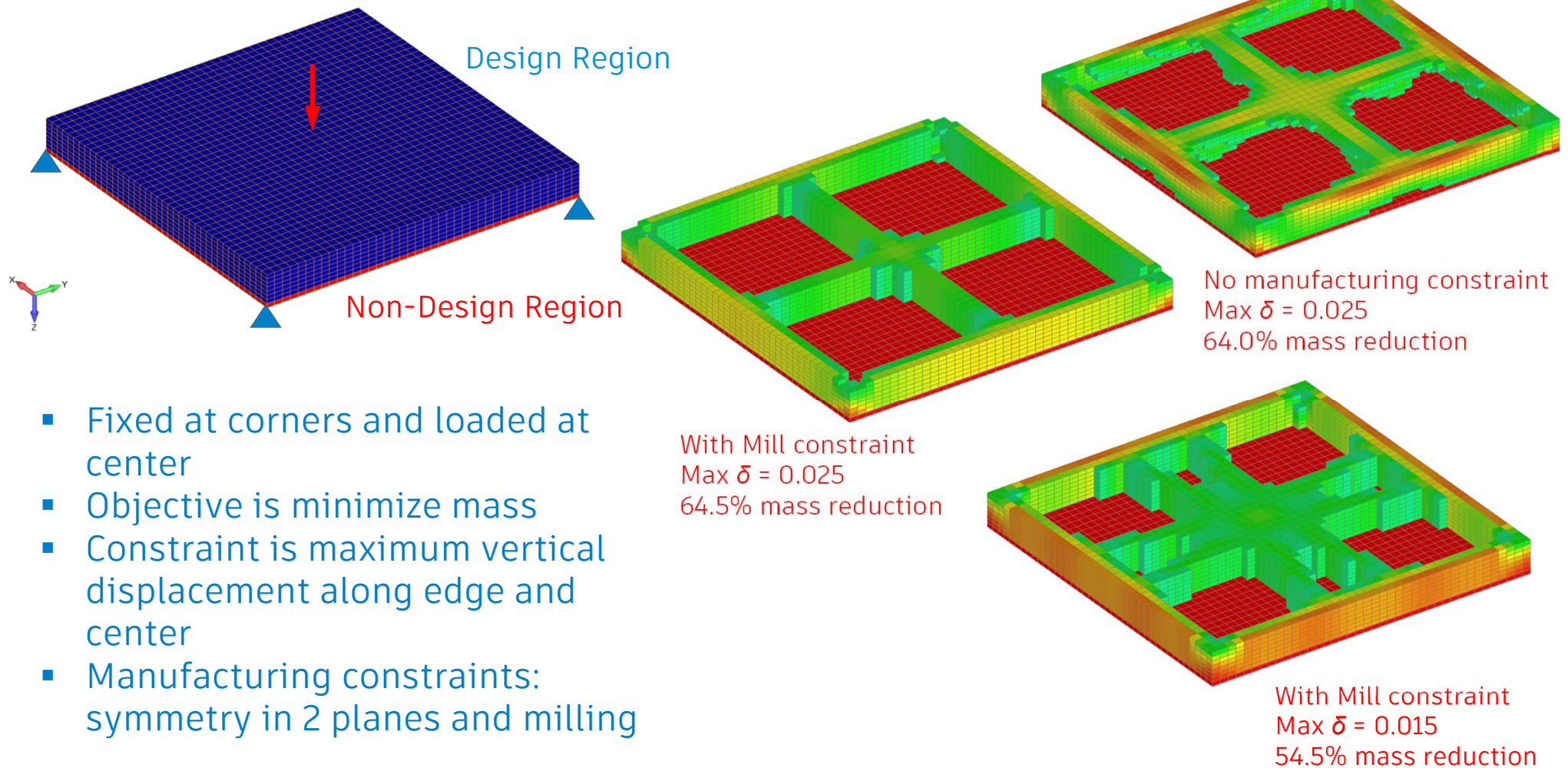
Min member size = 6.0
40.4% mass reduction

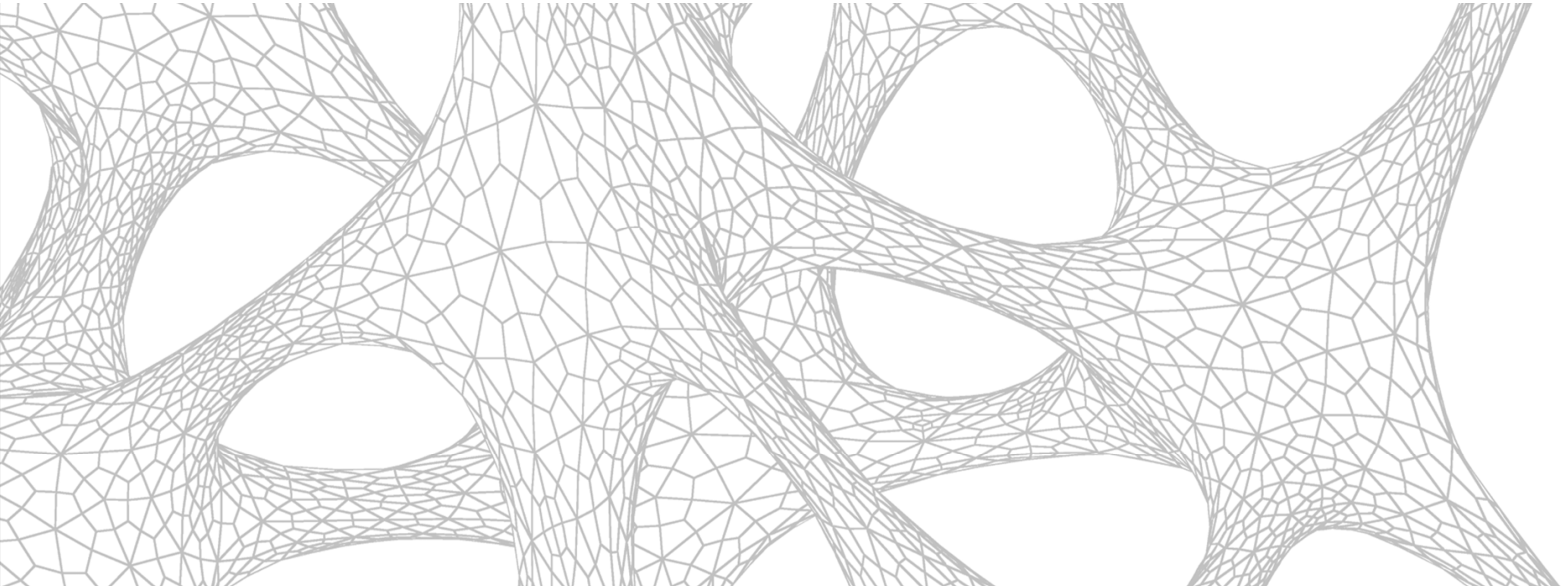


Extrude and Symmetry Manufacturing Constraints



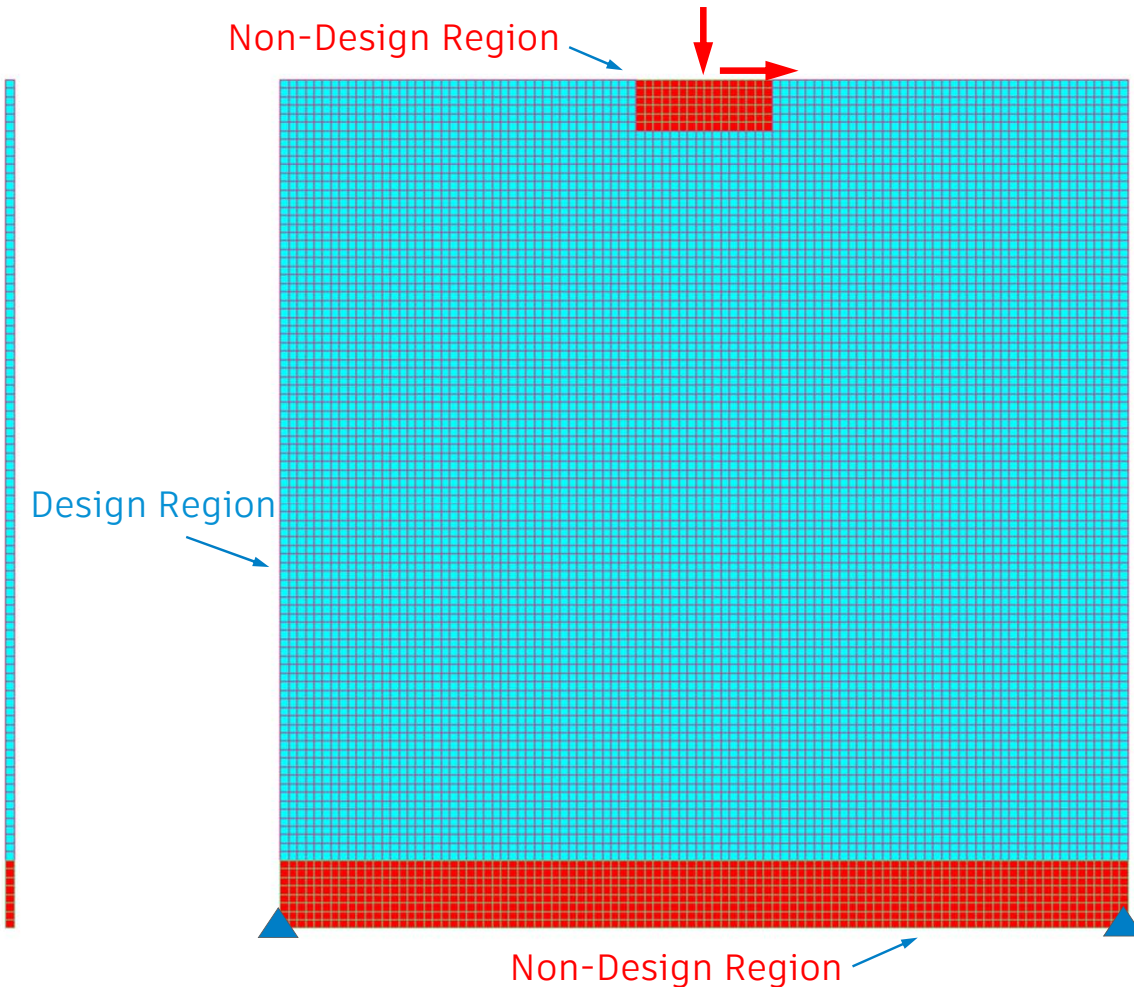
Milling Manufacturing Constraint - **MILL**





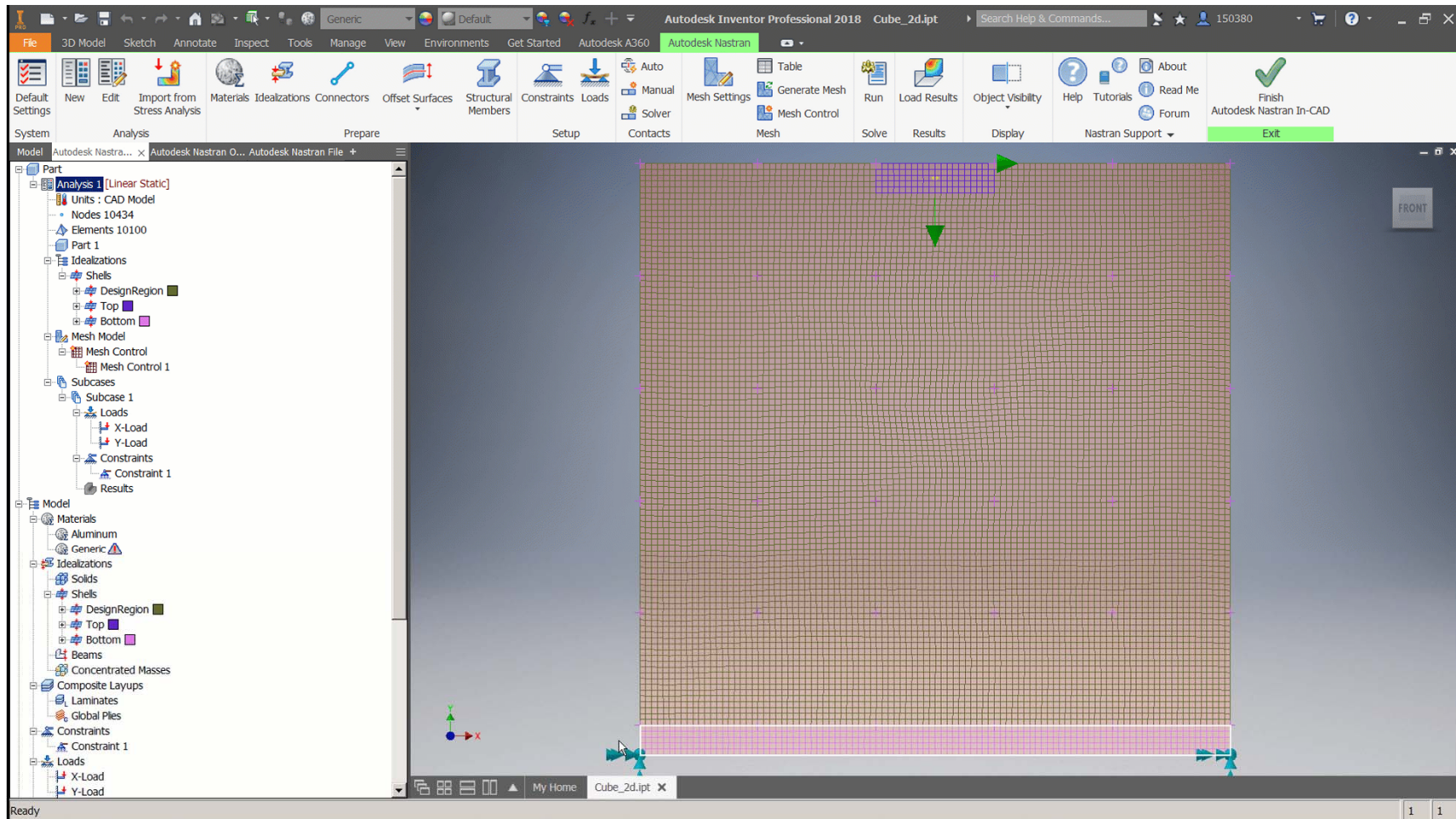
In-CAD Topology Optimization User Interface

Example #1 Model Definition

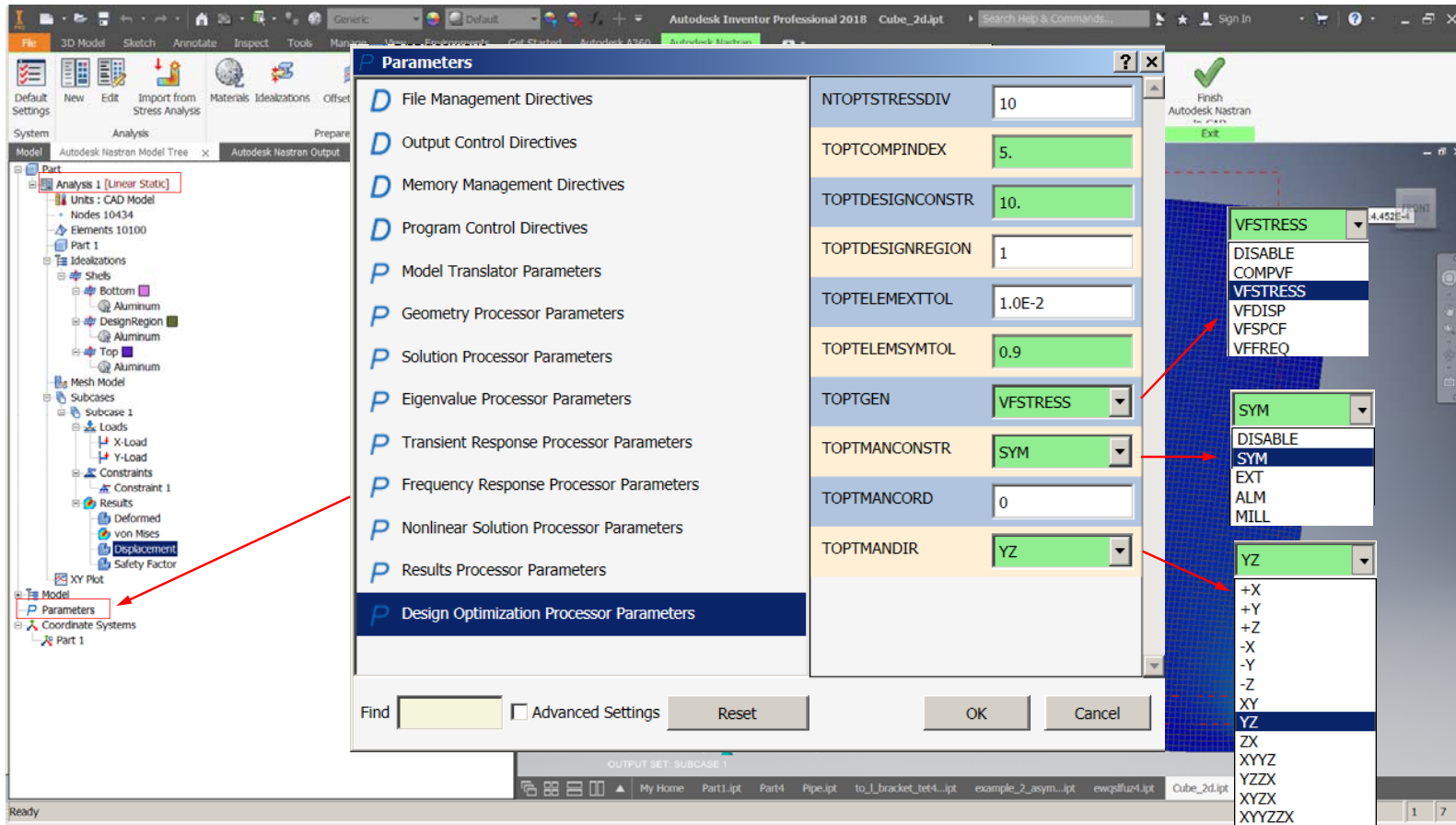


- **Boundary Condition:** Fixed at bottom corners
- **Loading:**
 - Point load in vertical and shear directions
- **Design constraints:**
 - Desired volume fraction
 - Stress limit
 - Displacement limit
 - Lowest frequency
- **Objectives:**
 - Minimize compliance
 - Minimize mass/volume
- **Manufacturing constraints:**
 - No symmetry
 - With symmetry

Topology Optimization Example #1



Topology Optimization Example #1



In-CAD Optimization Parameters - **TOPTGEN**

The screenshot shows the 'Parameters' dialog box with the 'Design Optimization Processor Parameters' section selected. The 'TOPTGEN' parameter is highlighted with a red box, and its dropdown menu is open, showing the following options: DISABLE, COMPVF, VFSTRESS, VFDISP, VFSPCF, and VFFREQ. Other parameters visible include MAXTOPTITER (200), NTOPTSTRESSDIV (10), TOPTBTHRESHOLD (0.5), TOPTCOMPINDEX (1.0E+10), TOPTDATABASE (DELETE), TOPTDESIGNCONSTR (5), TOPTDESIGNREGION (3), TOPTDESIGNTOL (1.0E-13), TOPTLEMTXTOL (1.0E-2), TOPTLEMSYMTOL (1.0E-2), TOPTTITERTOL, TOPTMANCONSTR, TOPTMNCORD (0), TOPTMANDIR (XY), TOPTMAXACTDIST (AUTO), and TOPTMAXBETA (AUTO).

Keyword	Objective	Design Constraint(s)	Solution Type
DISABLE	N/A	Topology optimization is disabled	N/A
COMPVF	Minimize compliance	Mass/volume fraction below	Linear Statics
VFSTRESS	Minimize mass	Max stress and compliance index in design region below a specified value	Linear Statics
VFDISP	Minimize mass	Max displacement and compliance index in model below a specified value	Linear Statics
VFSPCF	Minimize mass	Max reaction force and compliance index in model below a specified value	Linear Statics
VFFREQ	Minimize mass	Frequency above a specified value	Normal Modes

In-CAD Optimization Parameters - **TOPTDESIGNCONSTR**

The screenshot shows the 'Parameters' dialog box with the 'Design Optimization Processor Parameters' section selected. The 'TOPTDESIGNCONSTR' parameter is highlighted with a red box. The value is set to 5.0. Other parameters visible include MAXTOPTITER (200), NTOPTSTRESSDIV (10), TOPTBTHRESHOLD (0.5), TOPTCOMPINDEX (1.0E+10), TOPTDATABASE (DELETE), TOPTDESIGNREGION (3), TOPTDESIGNTOL (1.0E-13), TOPTTELEMTTOL (1.0E-2), TOPTTELEMSYMTOL (1.0E-2), TOPTGEN (VFSTRESS), TOPTTITERTOL (5.0E-3), TOPTMANCONSTR (DISABLE), TOPTMANCORD (0), TOPTMANDIR (XY), TOPTMAXACTDIST (AUTO), and TOPTMAXBETA (AUTO).

Description	Type	Default
Topology design optimization design constraint value based on the TOPTGEN setting. See TOPTGEN.	Real > 0.0	1.0E+10

TOPTGEN Setting	TOPTDESIGNCONSTR Description
COMPVF	Volume fraction upper limit between 0.05 and 1.0
VFSTRESS	Stress upper limit
VFDISP	Displacement upper limit
VFSPCF	Reaction force upper limit
VFFREQ	Frequency lower limit

In-CAD Optimization Parameters - **NTOPTSTRESSDIV**

The screenshot shows the 'Parameters' dialog box with the 'Design Optimization Processor Parameters' section selected. The 'NTOPTSTRESSDIV' parameter is highlighted with a red box, showing a value of 10. Other parameters visible include MAXOPTITER (200), TOPTBTHRESHOLD (0.5), TOPTCOMPINDEX (1.0E+10), TOPTDATABASE (DELETE), TOPTDESIGNCONSTR (5), TOPTDESIGNREGION (3), TOPTDESIGNTOL (1.0E-13), TOPTTELEXTTOL (1.0E-2), TOPTTELEMSYMTOL (1.0E-2), TOPTGEN (VFSTRESS), TOPTTITERTOL (5.0E-3), TOPTMANCONSTR (DISABLE), TOPTMANCORD (0), TOPTMANDIR (XY), TOPTMAXACTDIST (AUTO), and TOPTMAXBETA (AUTO).

Description	Type	Default
Topology design optimization number of stress divisions. Applicable when a stress constraint is specified. A larger value will produce a more accurate result with a reduction in performance. A value between 5 and 10 is recommended.	$1 \leq \text{Integer} \leq 100$	10

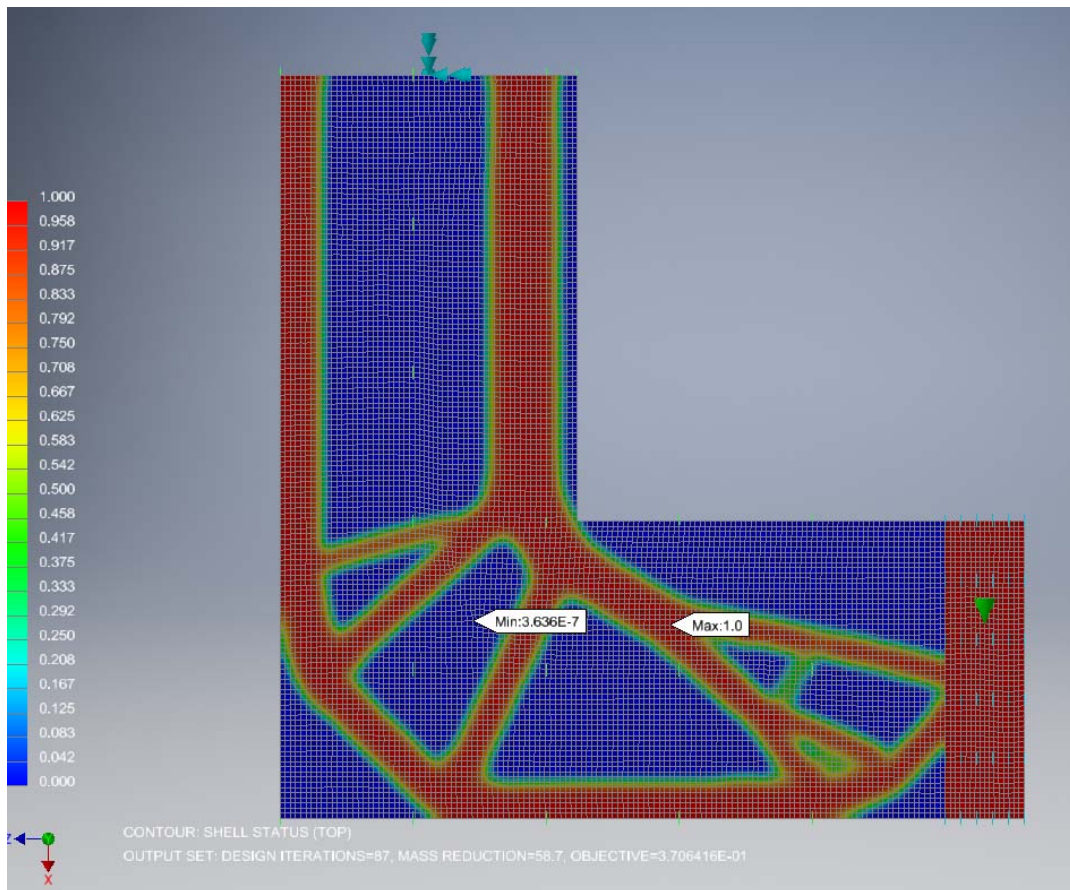
The screenshot shows the 'Autodesk Nastran Output' window. A red box highlights the 'DESIGN CONSTRAINT' table, which lists various stress constraints and their current values, all of which are within the limit values and marked as 'PASS'.

DESIGN CONSTRAINT	CURRENT VALUE	LIMIT VALUE	STATUS
DRESP 3_1	1.081E+00	1.000E+10	PASS
DRESP 2_1_1	4.443E+00	5.000E+00	PASS
DRESP 2_1_2	4.030E+00	5.000E+00	PASS
DRESP 2_1_3	4.890E+00	5.000E+00	PASS
DRESP 2_1_4	5.003E+00	5.000E+00	PASS
DRESP 2_1_5	5.034E+00	5.000E+00	PASS
DRESP 2_1_6	4.835E+00	5.000E+00	PASS
DRESP 2_1_7	4.595E+00	5.000E+00	PASS
DRESP 2_1_8	4.247E+00	5.000E+00	PASS
DRESP 2_1_9	4.121E+00	5.000E+00	PASS
DRESP 2_1_10	2.583E+00	5.000E+00	PASS

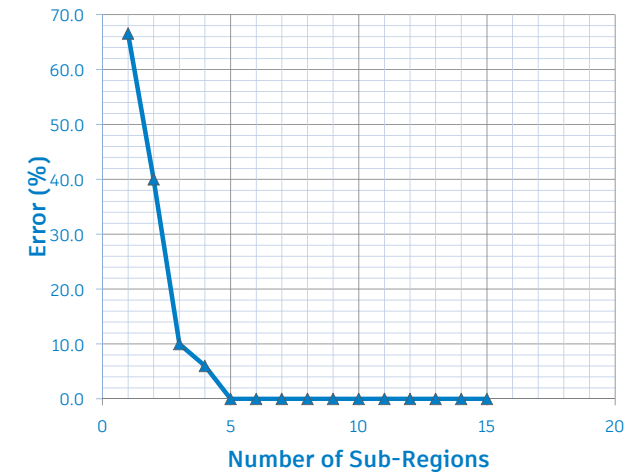
DESIGN ITERATION CONVERGENCE = 100.0
DENSITY MASS REDUCTION = 58.8
ESTIMATED REMAINING DESIGN ITERATIONS = 0
ESTIMATED REMAINING SOLUTION TIME = 0.0 SECONDS
DESIGN OPTIMIZATION ITERATION 87

L-Bracket Test Case - NTOPTSTRESSDIV

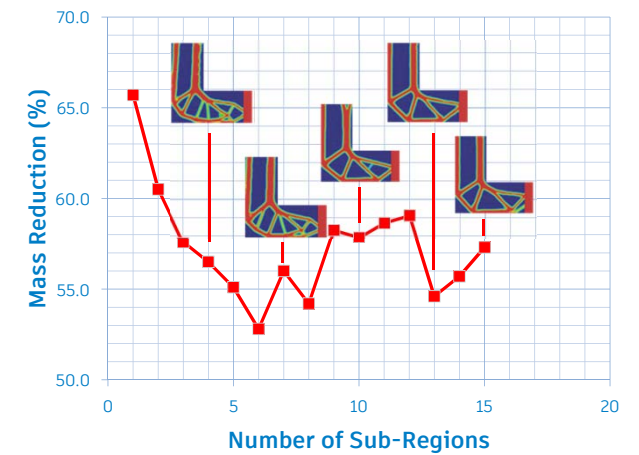
- A value between 3 – 10 works best



Stress Error



Mass Reduction



In-CAD Optimization Parameters - **TOPTCOMPINDEX**

The screenshot shows the 'Parameters' dialog box with the 'Design Optimization Processor Parameters' section selected. The 'TOPTCOMPINDEX' parameter is highlighted with a red box, showing a value of 1.0E+10. Other parameters visible include MAXTOPTITER (200), NTOPTSTRESSDIV (10), TOPTBTHRESHOLD (0.5), TOPTDATABASE (DELETE), TOPTDESIGNCONSTR (5), TOPTDESIGNREGION (3), TOPTDESIGNTOL (1.0E-13), TOPTTELEXTTOL (1.0E-2), TOPTTELEMSYMTOL (1.0E-2), TOPTGEN (VFSTRESS), TOPTTITERTOL (5.0E-3), TOPTMANCONSTR (DISABLE), TOPTMANCORD (0), TOPTMANDIR (XY), TOPTMAXACTDIST (AUTO), and TOPTMAXBETA (AUTO).

Description	Type	Default
Topology design optimization compliance index design constraint value. Applicable only when TOPTGEN is set to 2, 3, or 4.	Real > 1.0	1.0E+10

Model Autodesk Nastran Model Tr... Autodesk Nastran Output x Autodesk Nastran File +



DESIGN OBJECTIVE	CURRENT VALUE
DRESP 1	3.706E-01

DESIGN CONSTRAINT	CURRENT VALUE	LIMIT VALUE	STATUS
DRESP 3_1	1.081E+00	1.000E+10	PASS
DRESP 2_1_1	4.443E+00	5.000E+00	PASS
DRESP 2_1_2	4.030E+00	5.000E+00	PASS
DRESP 2_1_3	4.890E+00	5.000E+00	PASS
DRESP 2_1_4	5.003E+00	5.000E+00	PASS
DRESP 2_1_5	5.034E+00	5.000E+00	PASS
DRESP 2_1_6	4.835E+00	5.000E+00	PASS
DRESP 2_1_7	4.595E+00	5.000E+00	PASS
DRESP 2_1_8	4.247E+00	5.000E+00	PASS
DRESP 2_1_9	4.121E+00	5.000E+00	PASS
DRESP 2_1_10	2.583E+00	5.000E+00	PASS

DESIGN ITERATION CONVERGENCE = 100.0

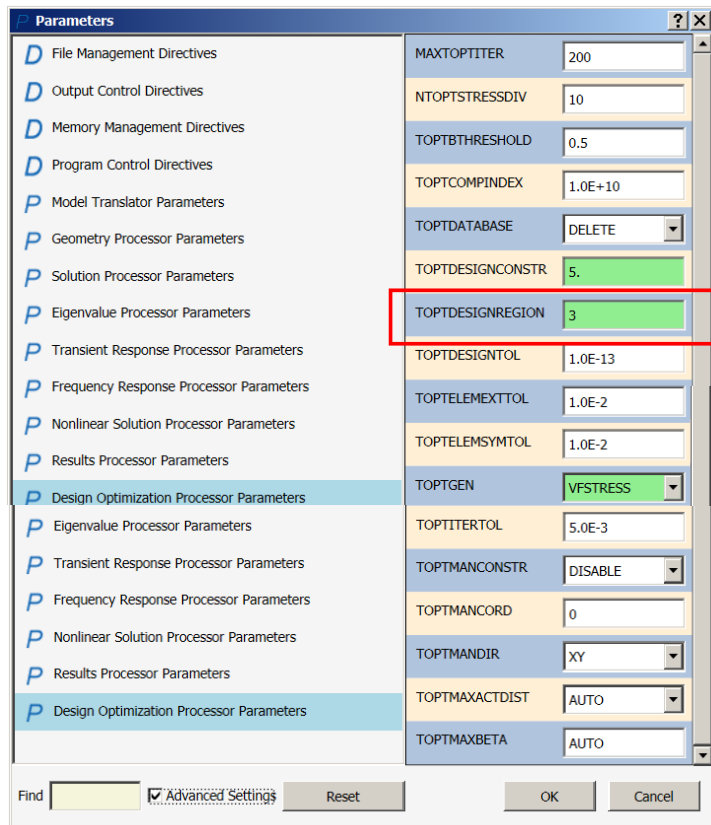
DENSITY MASS REDUCTION = 58.8

ESTIMATED REMAINING DESIGN ITERATIONS = 0

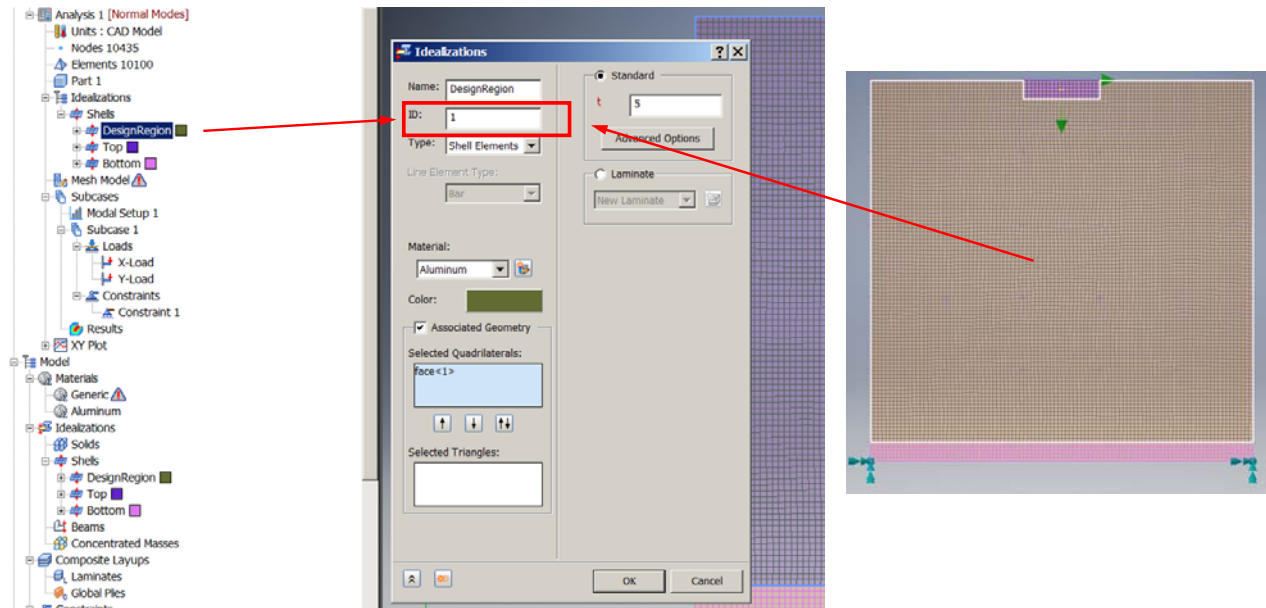
ESTIMATED REMAINING SOLUTION TIME = 0.0 SECONDS

DESIGN OPTIMIZATION ITERATION 87

In-CAD Optimization Parameters - TOPTDESIGNREGION

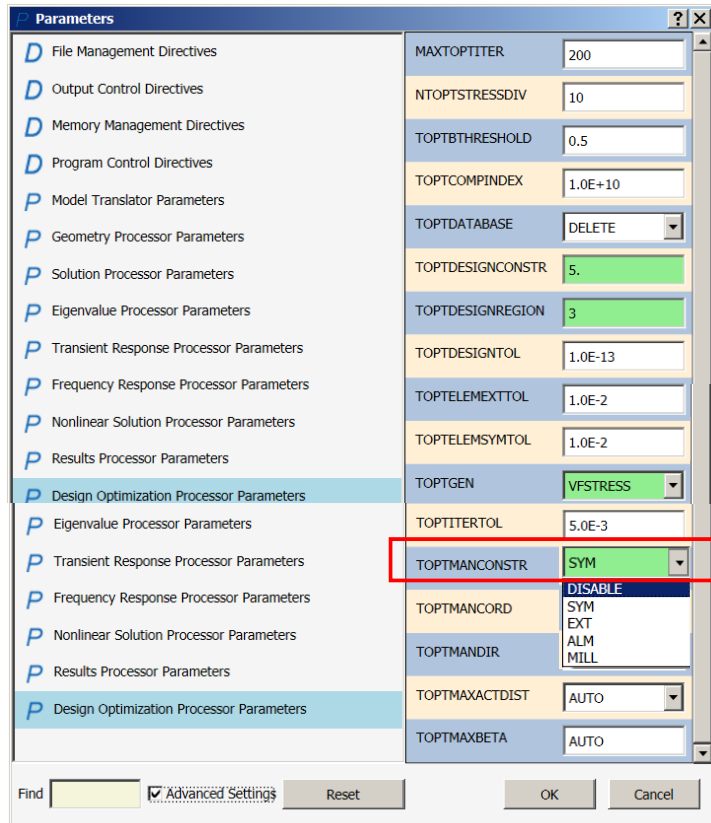


Description	Type	Default
Topology design optimization design region property identification number.	Integer > 0	1



- Note: Specifying the wrong ID may result in an 2299 or 5125 fatal error

In-CAD Optimization Parameters - **TOPTMANCONSTR**



Description	Type	Default
Defines the type of manufacturing constraint to be used in Automated Topology Optimization Generation (ATOG). There are three options: 0 - No manufacturing constraint is specified. 1 - Symmetry using either 1, 2, or 3 planes of symmetry is specified. 2 - Extrude design constraint is specified. 3 - Additive layer manufacturing design constraint is specified. 4 - 3-axis milling manufacturing design constraint is specified. The character variables: DISABLE, SYM, EXT, and ALM may be used in place of the numerical options 0 through 3. See also TOPTMANDIR and TOPTMANCORD.	$0 \leq$ Integer $\leq$ 3 DISABLE/ SYM/ EXT/ ALM/ MILL	0

In-CAD Optimization Parameters - **TOPTMANCORD**

Parameters

File Management Directives

Output Control Directives

Memory Management Directives

Program Control Directives

Model Translator Parameters

Geometry Processor Parameters

Solution Processor Parameters

Eigenvalue Processor Parameters

Transient Response Processor Parameters

Frequency Response Processor Parameters

Nonlinear Solution Processor Parameters

Results Processor Parameters

Design Optimization Processor Parameters

Eigenvalue Processor Parameters

Transient Response Processor Parameters

Frequency Response Processor Parameters

Nonlinear Solution Processor Parameters

Results Processor Parameters

Design Optimization Processor Parameters

MAXTOPTITER

200

NTOPTSTRESSDIV

10

TOPTBTHRESHOLD

0.5

TOPTCOMPINDEX

1.0E+10

TOPTDATABASE

DELETE

TOPTDESIGNCONSTR

5.

TOPTDESIGNREGION

3

TOPTDESIGNTOL

1.0E-13

TOPTLEMEXTTOL

1.0E-2

TOPTLEMSYMTOL

1.0E-2

TOPTGEN

VFSTRESS

TOPTITERTOL

5.0E-3

TOPTMANCONSTR

DISABLE

TOPTMANCORD

1

TOPTMANDIR

XY

TOPTMAXACTDIST

AUTO

TOPTMAXBETA

AUTO

Find

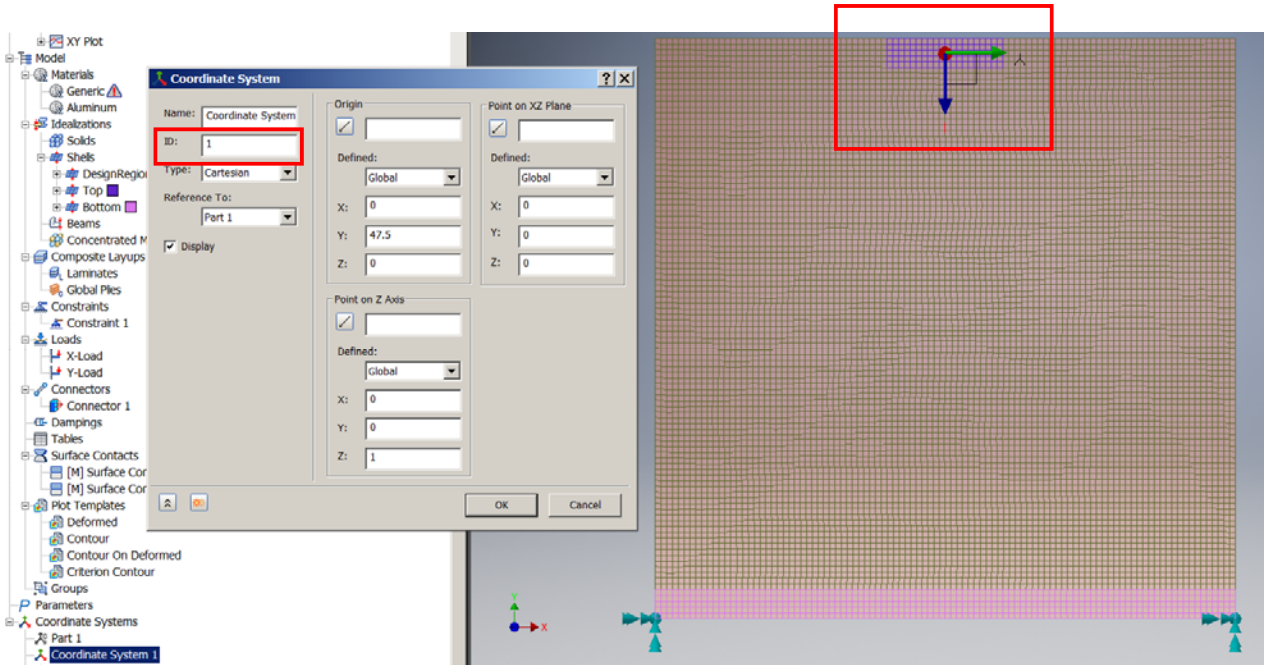
Advanced Settings

Reset

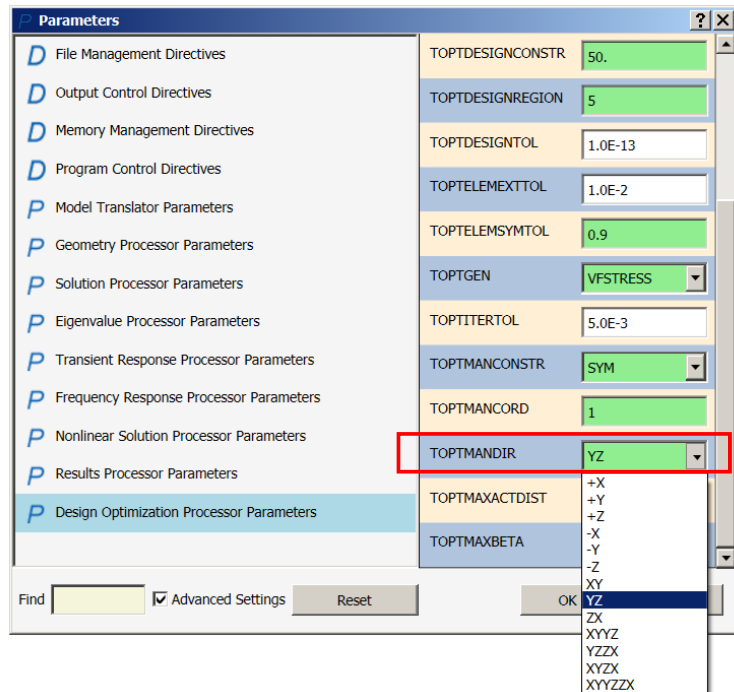
OK

Cancel

Description	Type	Default
Specifies the topology design optimization manufacturing constraint coordinate system corresponding to TOPTMANCONSTR . See also TOPTMANDIR .	Integer > 0	0



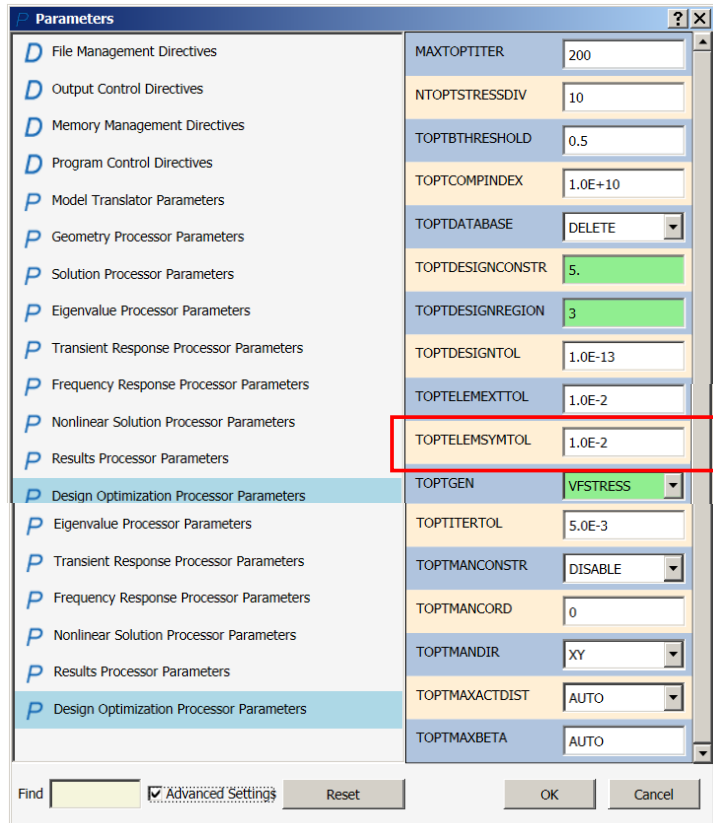
In-CAD Optimization Parameters - **TOPTMANDIR**



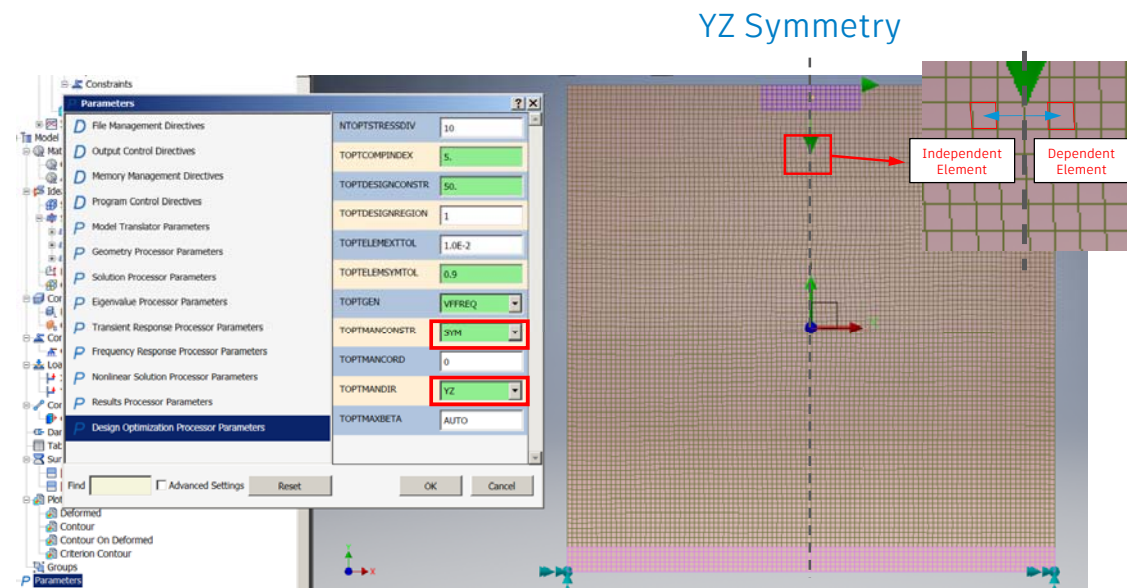
Description	Type	Default
Specifies the topology design optimization manufacturing constraint symmetry plane(s), extrude direction, or print direction depending on the TOPTMANCONSTR value specified.	+X/+Y/+Z/ -X/-Y/-Z/ XYYZ/YZZX/ XYYZ/YZZX/ XYYZ/ XYYZZX	XY

Keyword	TOPTMANDIR Definition
DISABLE	No manufacturing constraints specified
SYM	Symmetry plane or planes specified in the TOPTMANCORDER system
EXT	Extrude direction axis specified in the TOPTMANCORDER system
ALM	Print direction axis specified in the TOPTMANCORDER system
MILL	Mill direction axis specified in the TOPTMANCORDER system

In-CAD Optimization Parameters - TOPTELEMSYMTOL

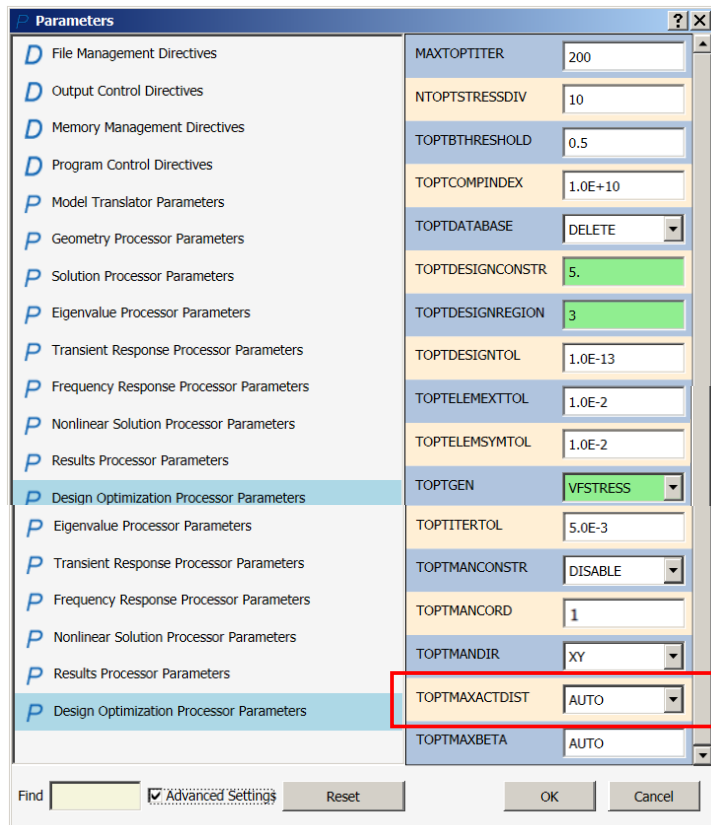


Description	Type	Default
Near tolerance used to identify elements which are symmetric with respect to the specified TOPVAR Bulk Data entry mirror symmetry plane. The actual tolerance is derived using TOPTELEMSYMTOL and an element reference dimension.	Real	1.0E-2



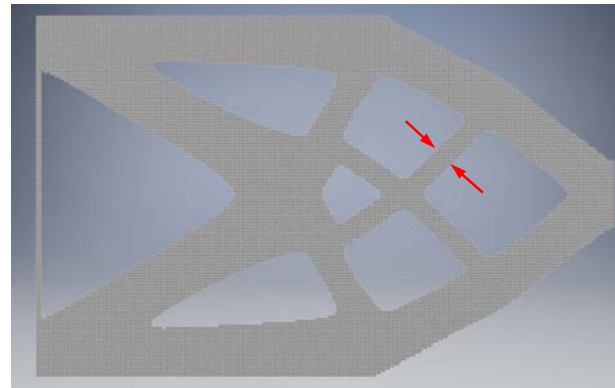
In-CAD Optimization Parameters - **TOPTMAXACTDIST**

Use this to specify a minimum member size



Description	Type	Default
Topology design optimization maximum distance for identifying adjacent elements. Elements within distance TOPTMAXACTDIST are used for sensitivity filtering. The default AUTO setting is recommended since large values may result in slower performance and undesired results.	Real AUTO	AUTO

- TOPTMAXACTDIST is 1/2 minimum member size
- To specify a minimum member size of 1 use 0.5.



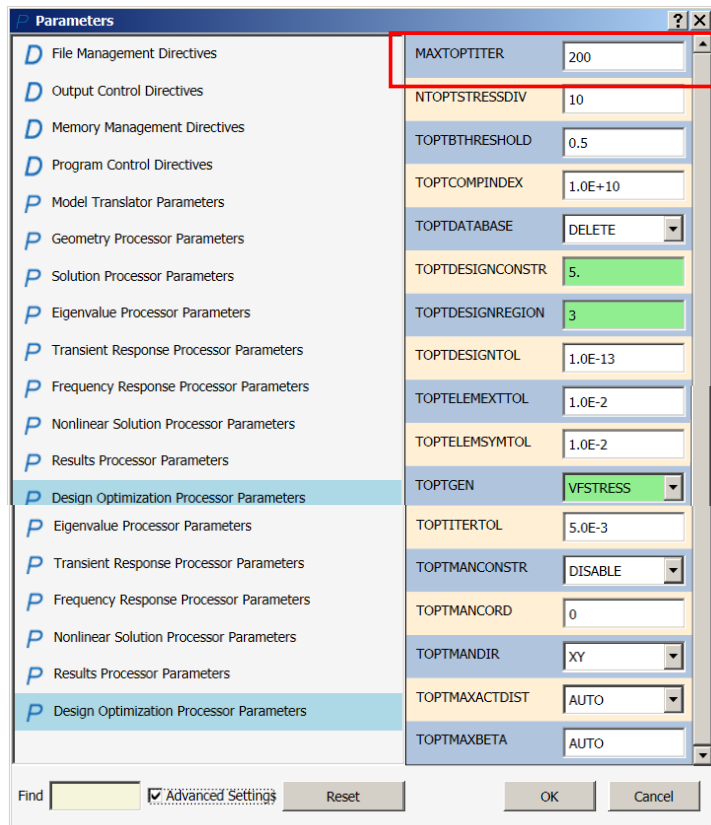
In-CAD Optimization Parameters - **TOPTMAXBETA**

The screenshot shows the 'Parameters' dialog box with the 'Design Optimization Processor Parameters' section selected. The 'TOPTMAXBETA' parameter is highlighted with a red box. The 'Find' field is empty, and the 'Advanced Settings' checkbox is checked. The 'Reset', 'OK', and 'Cancel' buttons are visible at the bottom.

Category	Parameter	Value
File Management Directives	MAXTOPTITER	200
Output Control Directives	NTOPTSTRESSDIV	10
Memory Management Directives	TOPTBTHRESHOLD	0.5
Program Control Directives	TOPTCOMPINDEX	1.0E+10
Model Translator Parameters	TOPTDATABASE	DELETE
Geometry Processor Parameters	TOPTDESIGNCONSTR	5.
Solution Processor Parameters	TOPTDESIGNREGION	3
Eigenvalue Processor Parameters	TOPTDESIGNTOL	1.0E-13
Transient Response Processor Parameters	TOPTTELEXTTOL	1.0E-2
Frequency Response Processor Parameters	TOPTTELEMSYMTOL	1.0E-2
Nonlinear Solution Processor Parameters	TOPTGEN	VFSTRESS
Results Processor Parameters	TOPTTITERTOL	5.0E-3
Design Optimization Processor Parameters	TOPTMANCONSTR	DISABLE
Eigenvalue Processor Parameters	TOPTMANCORD	1
Transient Response Processor Parameters	TOPTMANDIR	XY
Frequency Response Processor Parameters	TOPTMAXACTDIST	AUTO
Nonlinear Solution Processor Parameters	TOPTMAXBETA	AUTO
Results Processor Parameters		
Design Optimization Processor Parameters		

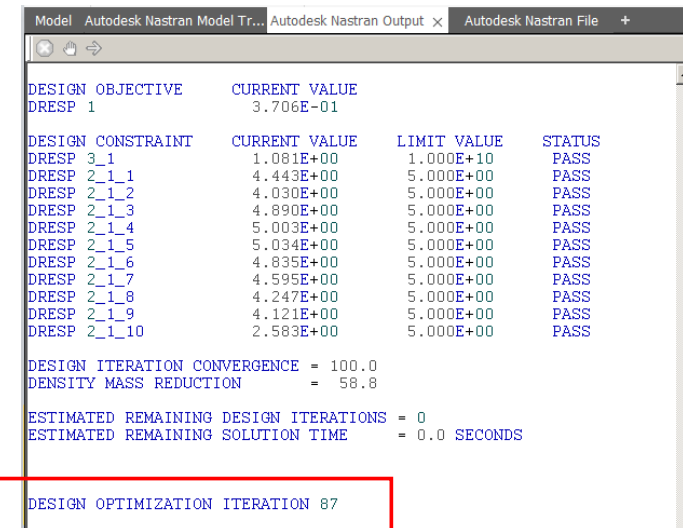
Description	Type	Default
Specifies the penalty value for enforcing minimum member size manufacturing constraints. A value between 1.0 and 16.0 is recommended. The default AUTO value selects the best value depending on what other constraints are specified.	Real AUTO	AUTO

In-CAD Optimization Parameters - MAXTOPTITER



The screenshot shows the 'Parameters' dialog box with the 'Design Optimization Processor Parameters' section selected. The 'MAXTOPTITER' parameter is highlighted with a red box, showing a value of 200. Other parameters visible include NTOPTSTRESSDIV (10), TOPTBTHRESHOLD (0.5), TOPTCOMPINDEX (1.0E+10), TOPTDATABASE (DELETE), TOPTDESIGNCONSTR (5), TOPTDESIGNREGION (3), TOPTDESIGNTOL (1.0E-13), TOPTTEMEXTTOL (1.0E-2), TOPTTEMSYMTOL (1.0E-2), TOPTGEN (VFSTRESS), TOPTTITERTOL (5.0E-3), TOPTMANCONSTR (DISABLE), TOPTMANCORD (0), TOPTMANDIR (XY), TOPTMAXACTDIST (AUTO), and TOPTMAXBETA (AUTO).

Description	Type	Default
Topology design optimization maximum number of convergence iterations permitted. The solver will iterate until the convergence factor set by TOPTTITERTOL is reached or MAXOPTITER iterations have been performed. A zero setting will result in iteration until convergence is reached.	Integer ≥ 0	200



The screenshot shows the Autodesk Nastran Output window with the following text:

```
Model Autodesk Nastran Model Tr... Autodesk Nastran Output x Autodesk Nastran File +
DESIGN OBJECTIVE      CURRENT VALUE
DRESP 1              3.706E-01
DESIGN CONSTRAINT     CURRENT VALUE    LIMIT VALUE    STATUS
DRESP 3_1            1.081E+00    1.000E+10    PASS
DRESP 2_1_1          4.443E+00    5.000E+00    PASS
DRESP 2_1_2          4.030E+00    5.000E+00    PASS
DRESP 2_1_3          4.890E+00    5.000E+00    PASS
DRESP 2_1_4          5.003E+00    5.000E+00    PASS
DRESP 2_1_5          5.034E+00    5.000E+00    PASS
DRESP 2_1_6          4.835E+00    5.000E+00    PASS
DRESP 2_1_7          4.595E+00    5.000E+00    PASS
DRESP 2_1_8          4.247E+00    5.000E+00    PASS
DRESP 2_1_9          4.121E+00    5.000E+00    PASS
DRESP 2_1_10         2.583E+00    5.000E+00    PASS
DESIGN ITERATION CONVERGENCE = 100.0
DENSITY MASS REDUCTION      = 58.8
ESTIMATED REMAINING DESIGN ITERATIONS = 0
ESTIMATED REMAINING SOLUTION TIME   = 0.0 SECONDS
DESIGN OPTIMIZATION ITERATION 87
```

In-CAD Optimization Parameters - **TOPTITERTOL**

The screenshot shows the 'Parameters' dialog box with the 'Design Optimization Processor Parameters' section selected. The 'TOPTITERTOL' parameter is highlighted with a red box. The 'Find' field is empty, and the 'Advanced Settings' checkbox is checked.

Parameter	Value
MAXTOPTITER	200
NTOPTSTRESSDIV	10
TOPTBTHRESHOLD	0.5
TOPTCOMPINDEX	1.0E+10
TOPTDATABASE	DELETE
TOPTDESIGNCONSTR	5.
TOPTDESIGNREGION	3
TOPTDESIGNTOL	1.0E-13
TOPTHEMEXTTOL	1.0E-2
TOPTHEMSYMTOL	1.0E-2
TOPTGEN	VFSTRESS
TOPTITERTOL	5.0E-3
TOPTMANCONSTR	DISABLE
TOPTMANCORD	0
TOPTMANDIR	XY
TOPTMAXACTDIST	AUTO
TOPTMAXBETA	AUTO

Description	Type	Default
Topology design optimization Iterative solver convergence factor. The topology optimization solver will iterate until the convergence factor set by TOPTITERTOL is reached or MAXTOPTITER iterations have been performed.	Real	5.0E-3

Model Autodesk Nastran Model Tr... Autodesk Nastran Output x Autodesk Nastran File +



DESIGN OBJECTIVE CURRENT VALUE

DRESP 1 3.706E-01

DESIGN CONSTRAINT CURRENT VALUE LIMIT VALUE STATUS

DRESP 3_1 1.081E+00 1.000E+10 PASS

DRESP 2_1_1 4.443E+00 5.000E+00 PASS

DRESP 2_1_2 4.030E+00 5.000E+00 PASS

DRESP 2_1_3 4.890E+00 5.000E+00 PASS

DRESP 2_1_4 5.003E+00 5.000E+00 PASS

DRESP 2_1_5 5.034E+00 5.000E+00 PASS

DRESP 2_1_6 4.835E+00 5.000E+00 PASS

DRESP 2_1_7 4.595E+00 5.000E+00 PASS

DRESP 2_1_8 4.247E+00 5.000E+00 PASS

DRESP 2_1_9 4.121E+00 5.000E+00 PASS

DRESP 2_1_10 2.583E+00 5.000E+00 PASS

DESIGN ITERATION CONVERGENCE = 100.0

DENSITY MASS REDUCTION = 58.6

ESTIMATED REMAINING DESIGN ITERATIONS = 0

ESTIMATED REMAINING SOLUTION TIME = 0.0 SECONDS

DESIGN OPTIMIZATION ITERATION 87

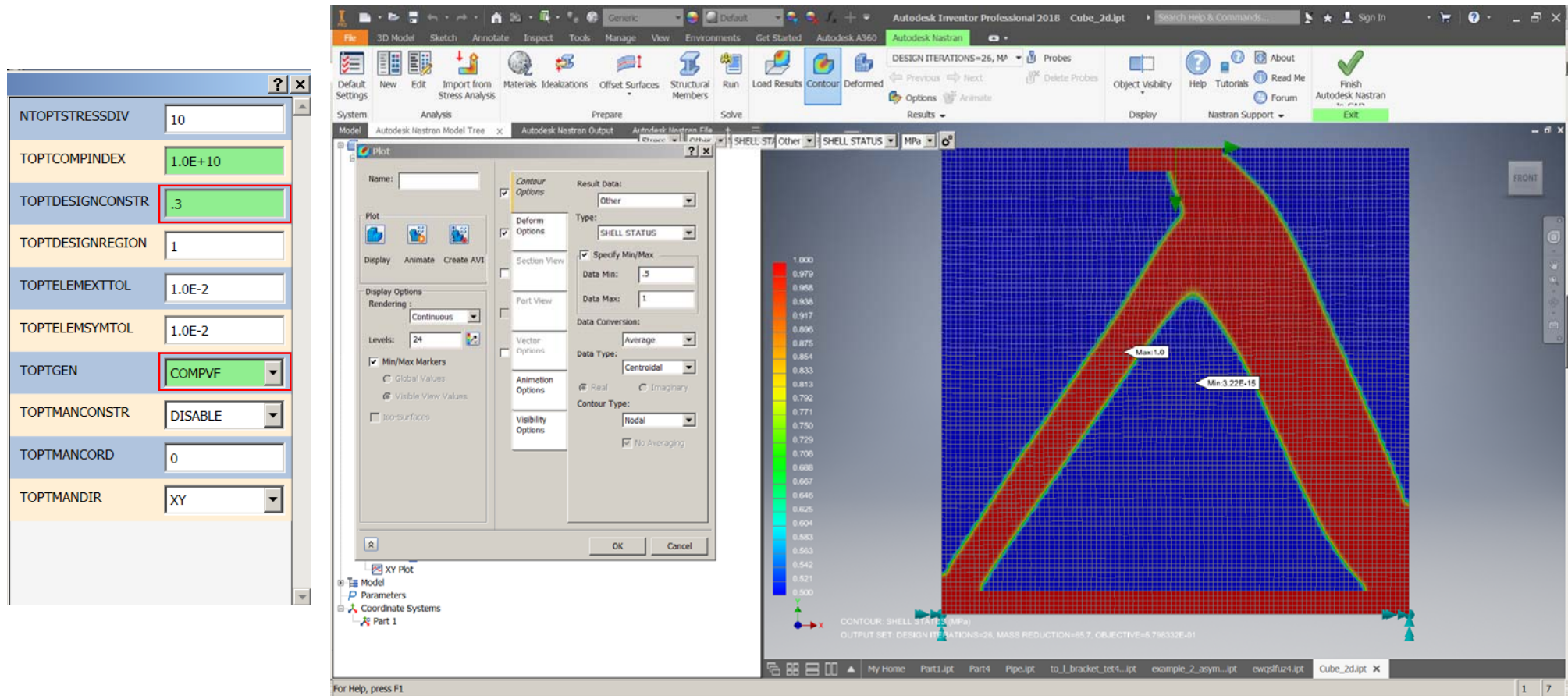
In-CAD Optimization Parameters - TOPTDATABASE

The screenshot shows the 'Parameters' dialog box in In-CAD. The left pane lists various parameter categories, with 'Design Optimization Processor Parameters' selected. The right pane displays a list of parameters for this category. The 'TOPTDATABASE' parameter is highlighted with a red box, showing a dropdown menu with the value 'DELETE'. Other parameters include MAXTOPTITER (200), NTOPTSTRESSDIV (10), TOPTBTHRESHOLD (0.5), TOPTCOMPINDEX (1.0E+10), TOPTDESIGNCONSTR (5), TOPTDESIGNREGION (3), TOPTDESIGNTOL (1.0E-13), TOPTTEMEXTTOL (1.0E-2), TOPTTEMSYMTOL (1.0E-2), TOPTGEN (VFSTRESS), TOPTTERTOL (5.0E-3), TOPTMANCONSTR (DISABLE), TOPTMANCORD (0), TOPTMANDIR (XY), TOPTMAXACTDIST (AUTO), and TOPTMAXBETA (AUTO). The bottom of the dialog has a 'Find' field, a checked 'Advanced Settings' checkbox, and 'Reset', 'OK', and 'Cancel' buttons.

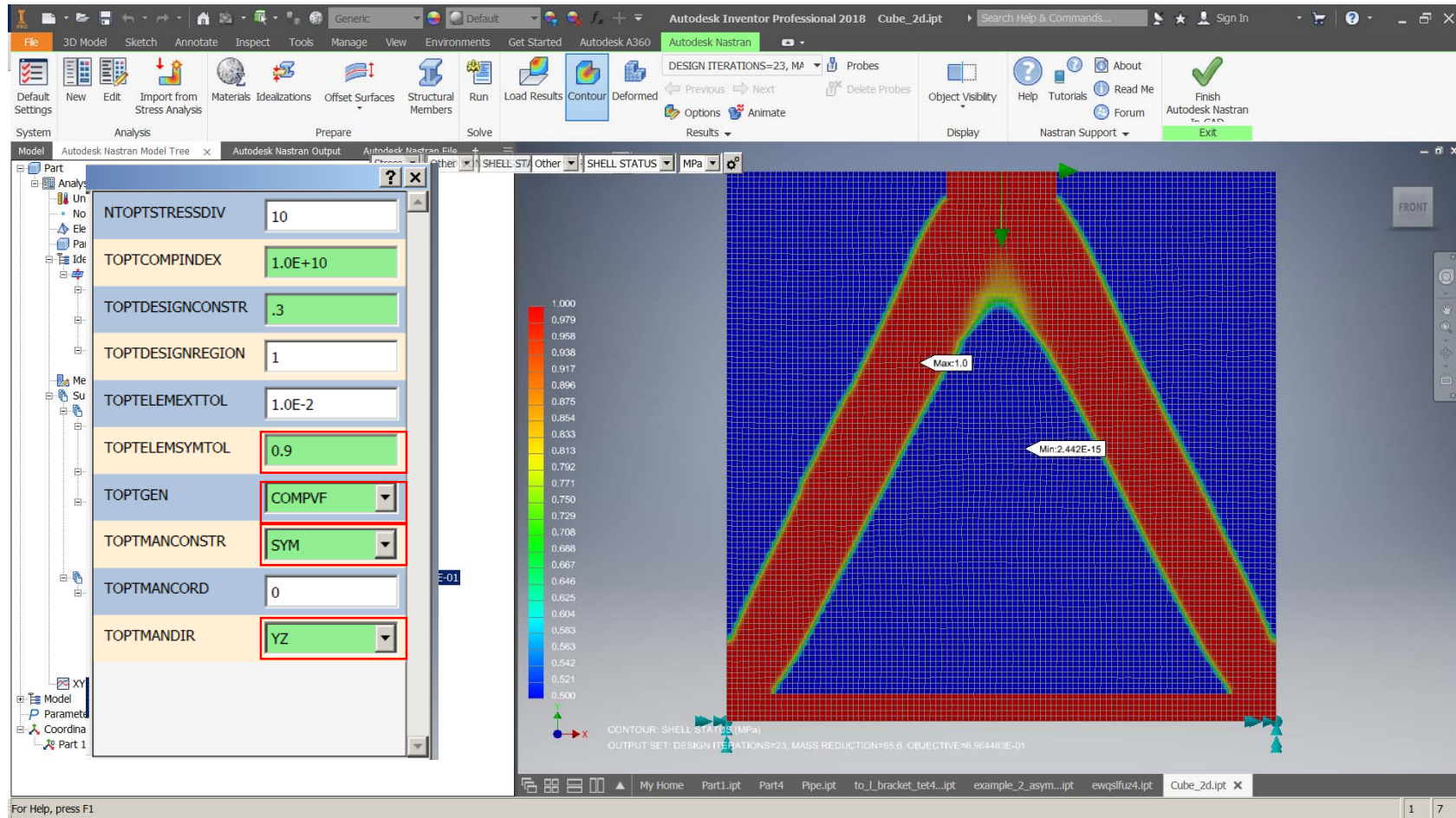
Parameter	Value
MAXTOPTITER	200
NTOPTSTRESSDIV	10
TOPTBTHRESHOLD	0.5
TOPTCOMPINDEX	1.0E+10
TOPTDATABASE	DELETE
TOPTDESIGNCONSTR	5
TOPTDESIGNREGION	3
TOPTDESIGNTOL	1.0E-13
TOPTTEMEXTTOL	1.0E-2
TOPTTEMSYMTOL	1.0E-2
TOPTGEN	VFSTRESS
TOPTTERTOL	5.0E-3
TOPTMANCONSTR	DISABLE
TOPTMANCORD	0
TOPTMANDIR	XY
TOPTMAXACTDIST	AUTO
TOPTMAXBETA	AUTO

Description	Type	Default
Controls the storage and retrieval of topology design optimization density data. The default value DELETE purges all element density data when the program terminates normally. When set to STORE, the converged optimized design is stored in a single file with the same base name as the Model Results Output File and a .ODB file extension. When set to FETCH, the optimized design specified by the TOPTDATFILE directive is retrieved and used as the starting point for the subsequent topology design optimization solution sequence. When set to UPDATE, the optimized design data will be retrieved and stored.	DELETE FETCH STORE UPDATE	DELETE

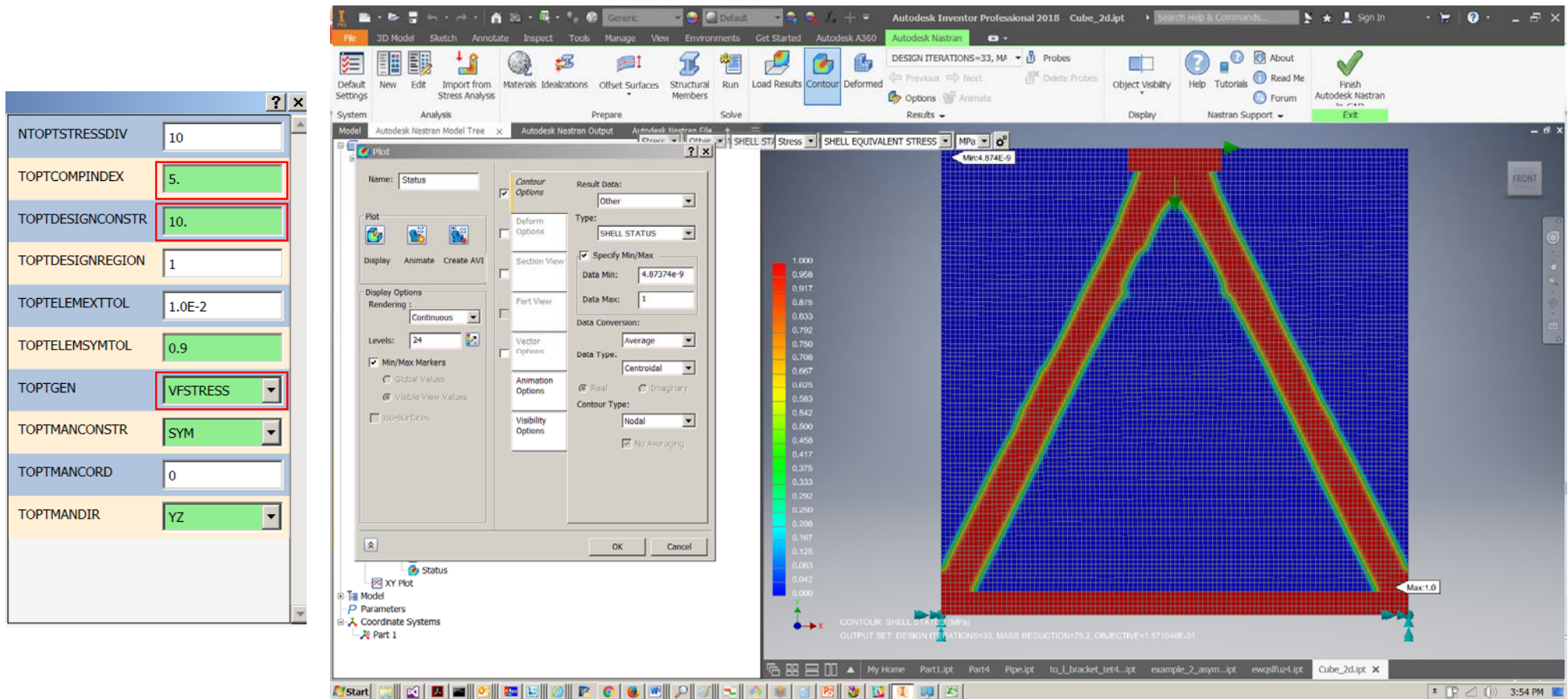
Obj: Min. Compliance, Constraint: Desired VF, no Sym



Obj: Min. Compliance, Constraint: Desired VF, with Sym

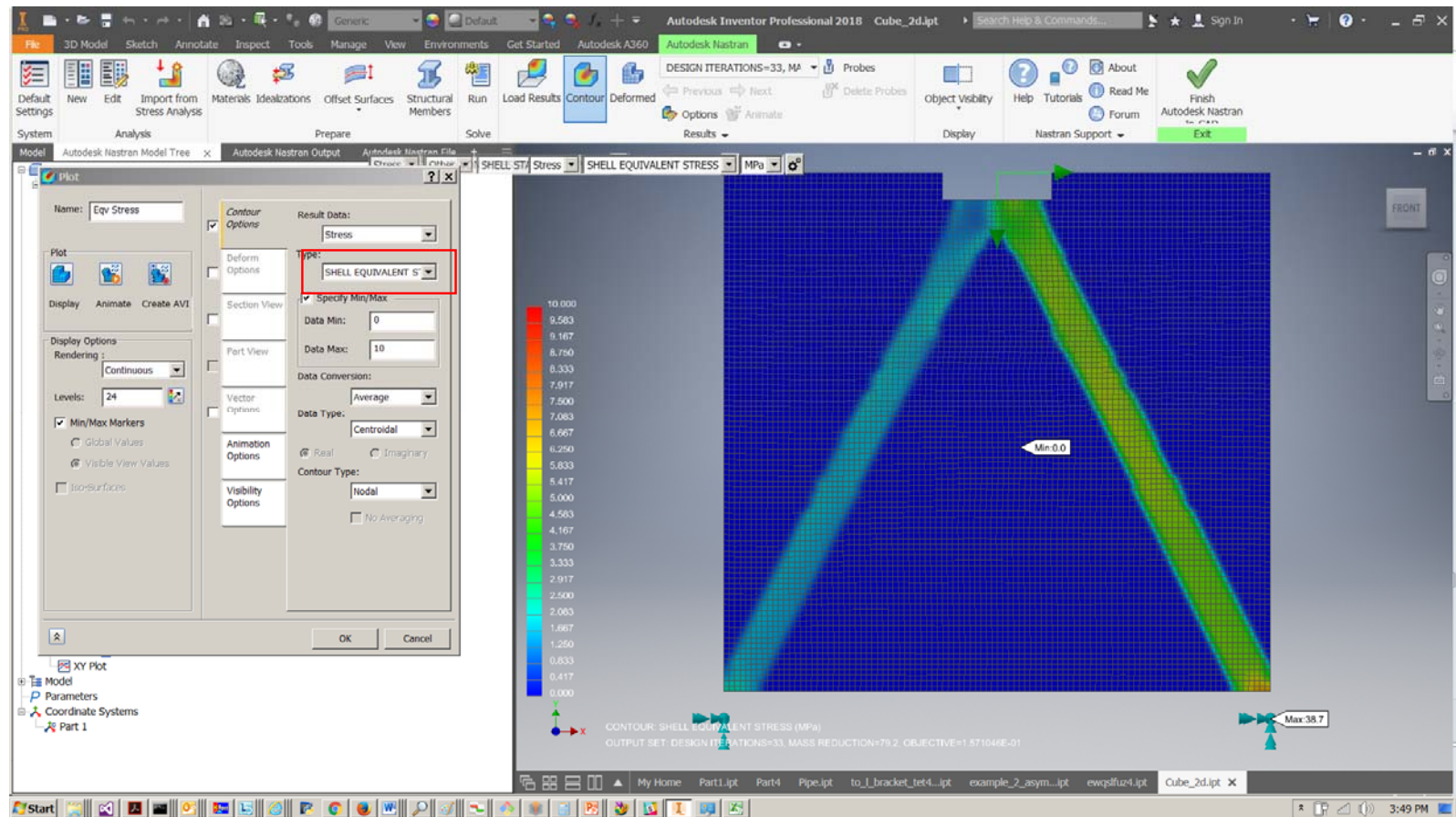


Obj: Min. VF (mass), Constraint: Stress & Comp. Index

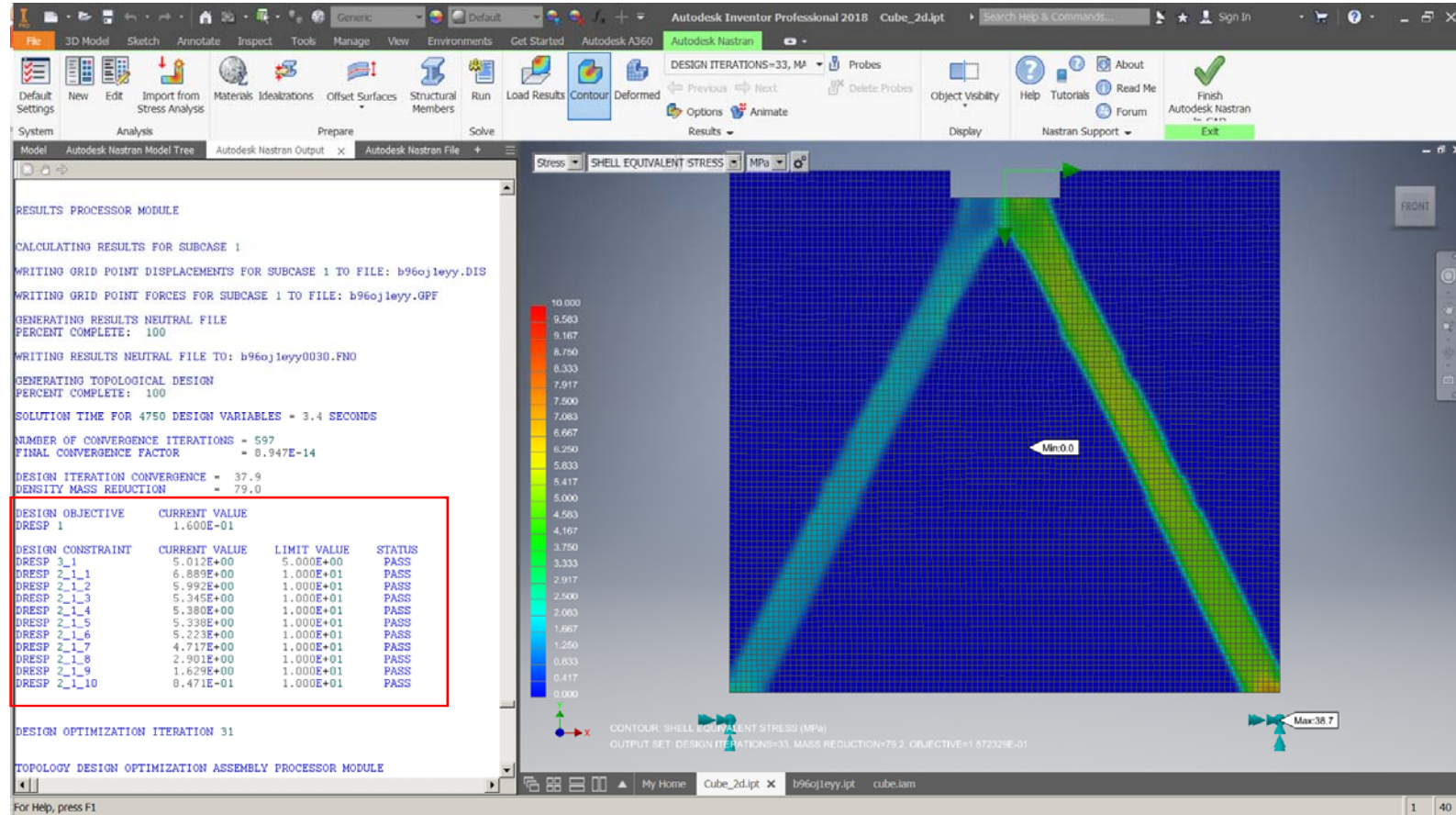


Verify Stress Constraint Using Equivalent Stress

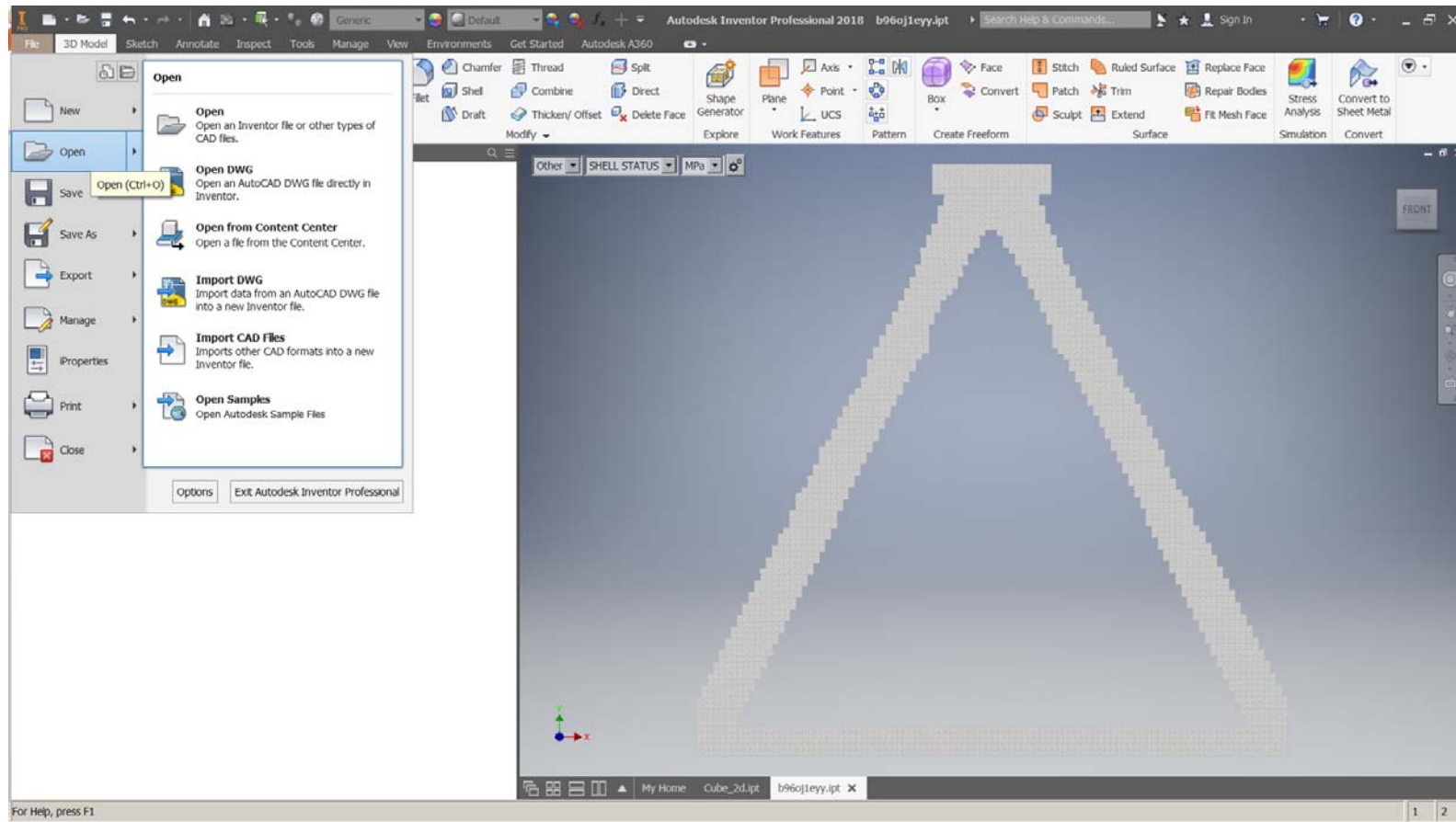
NTOPTSTRESSDIV	10
TOPTCOMPINDEX	5.
TOPTDESIGNCONSTR	10.
TOPTDESIGNREGION	1
TOPTTELEMEXTOL	1.0E-2
TOPTTELEMSYMTOL	0.9
TOPTGEN	VFSTRESS
TOPTMANCONSTR	SYM
TOPTMANCORD	0
TOPTMANDIR	YZ



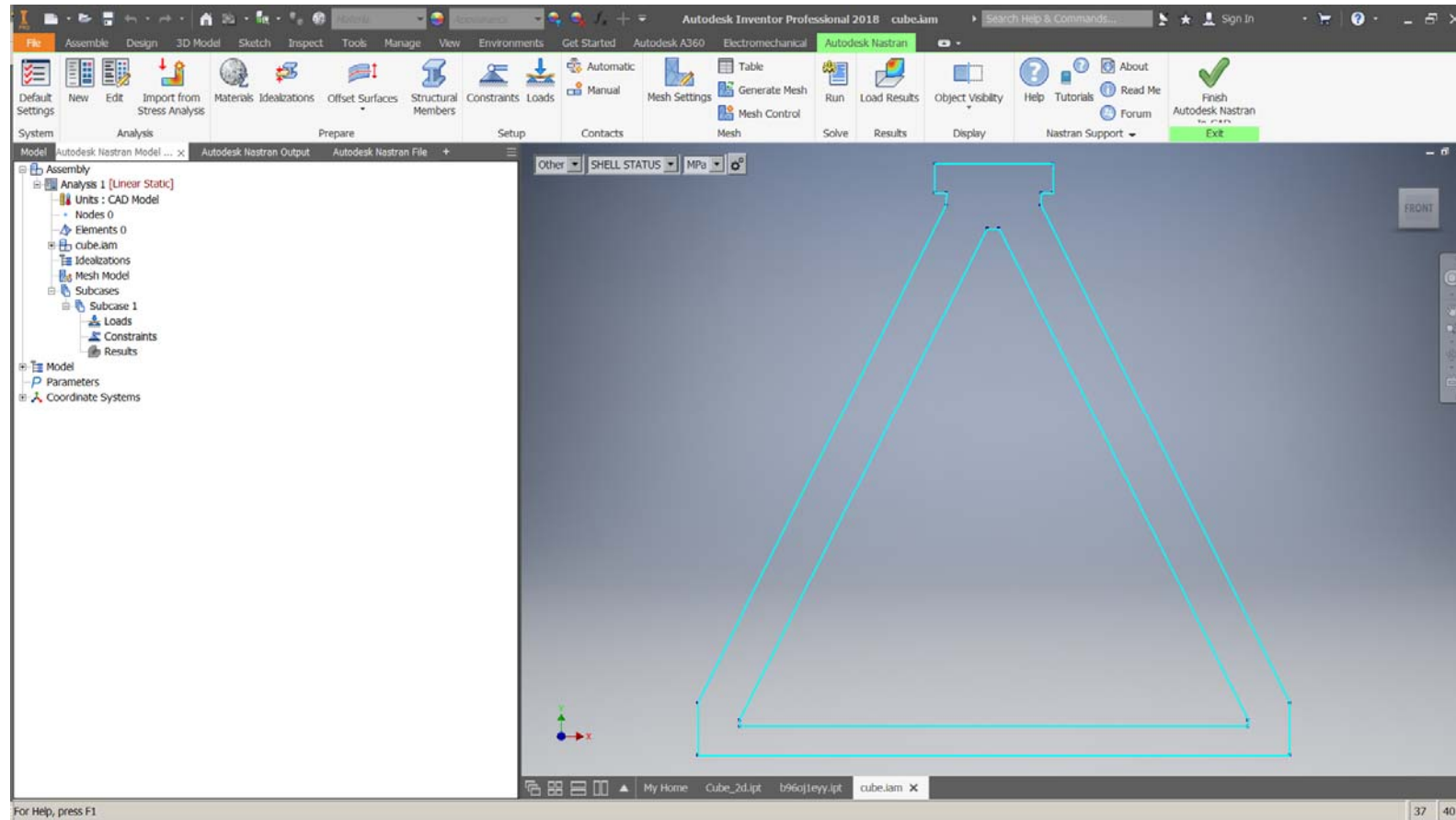
Verify Stress Constraint Using Equivalent Stress



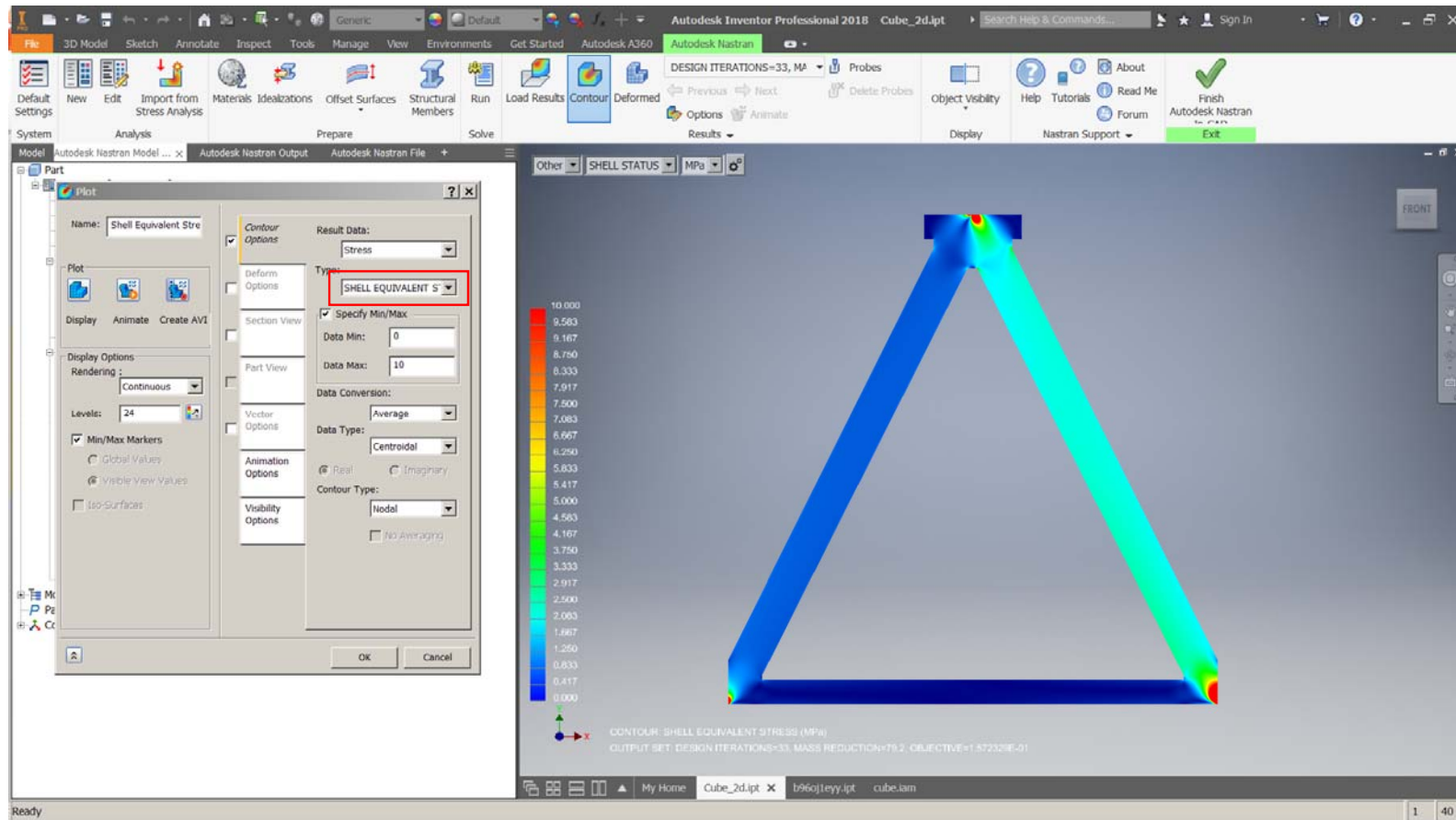
Import Generated Geometry to Build New Design



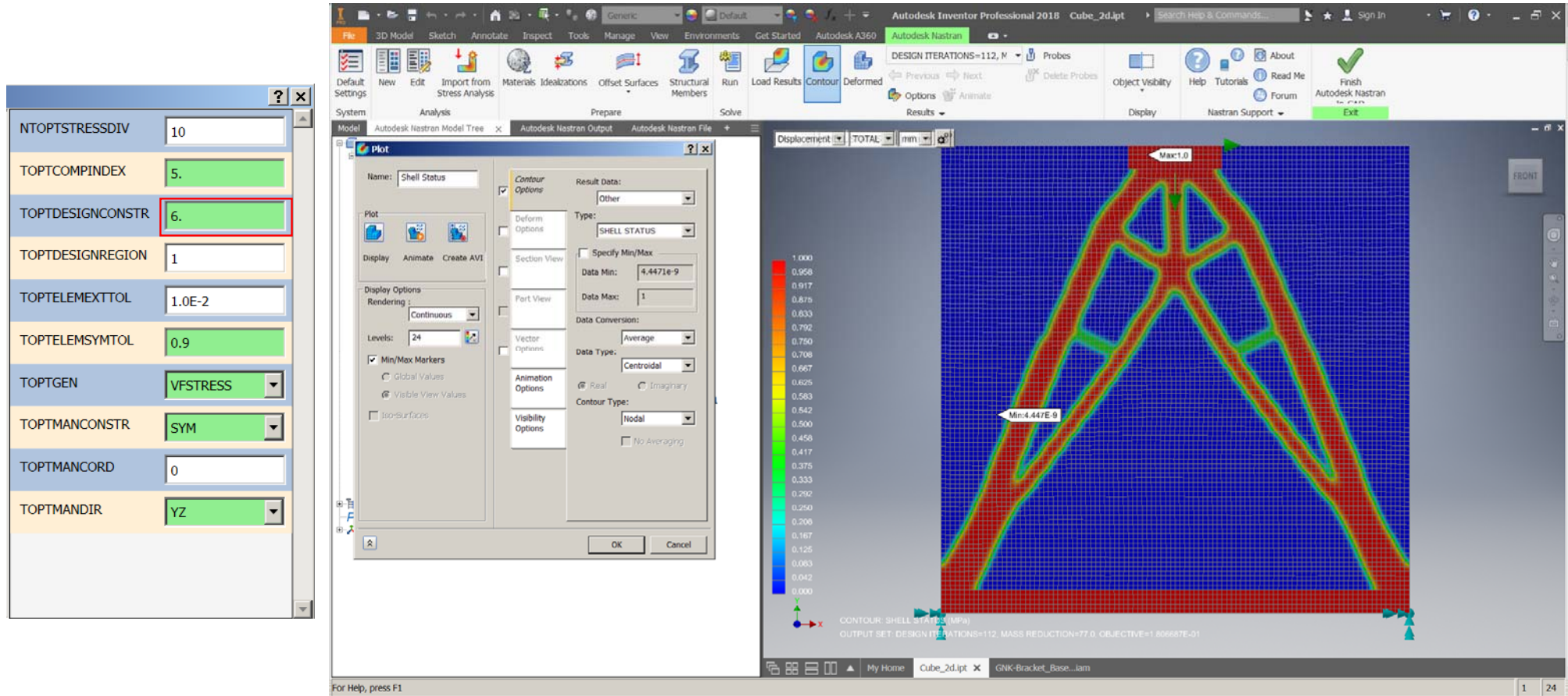
Import Generated Geometry to Build New Design



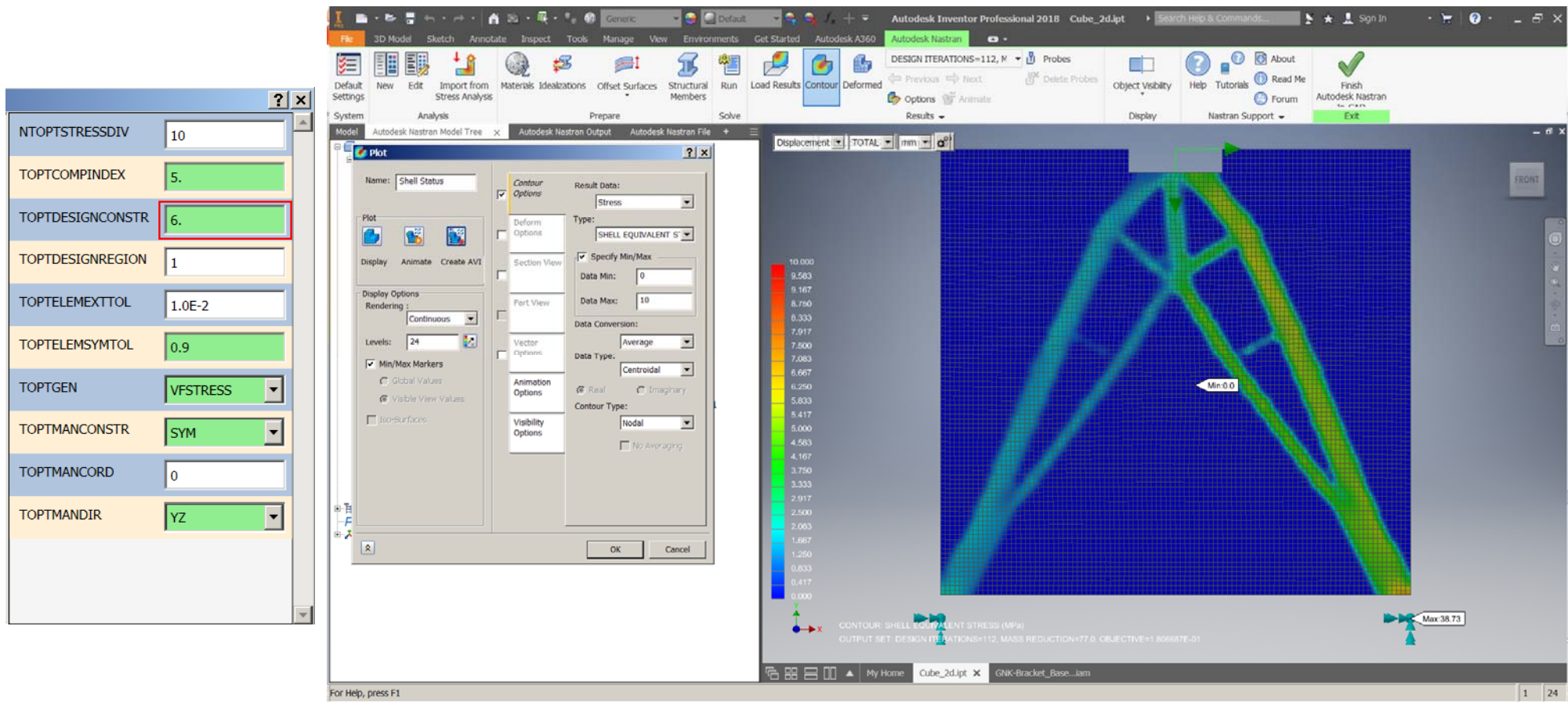
Import Generated Geometry to Build New Design



Obj: Min. VF (mass), Constraint: Stress & Comp. Index

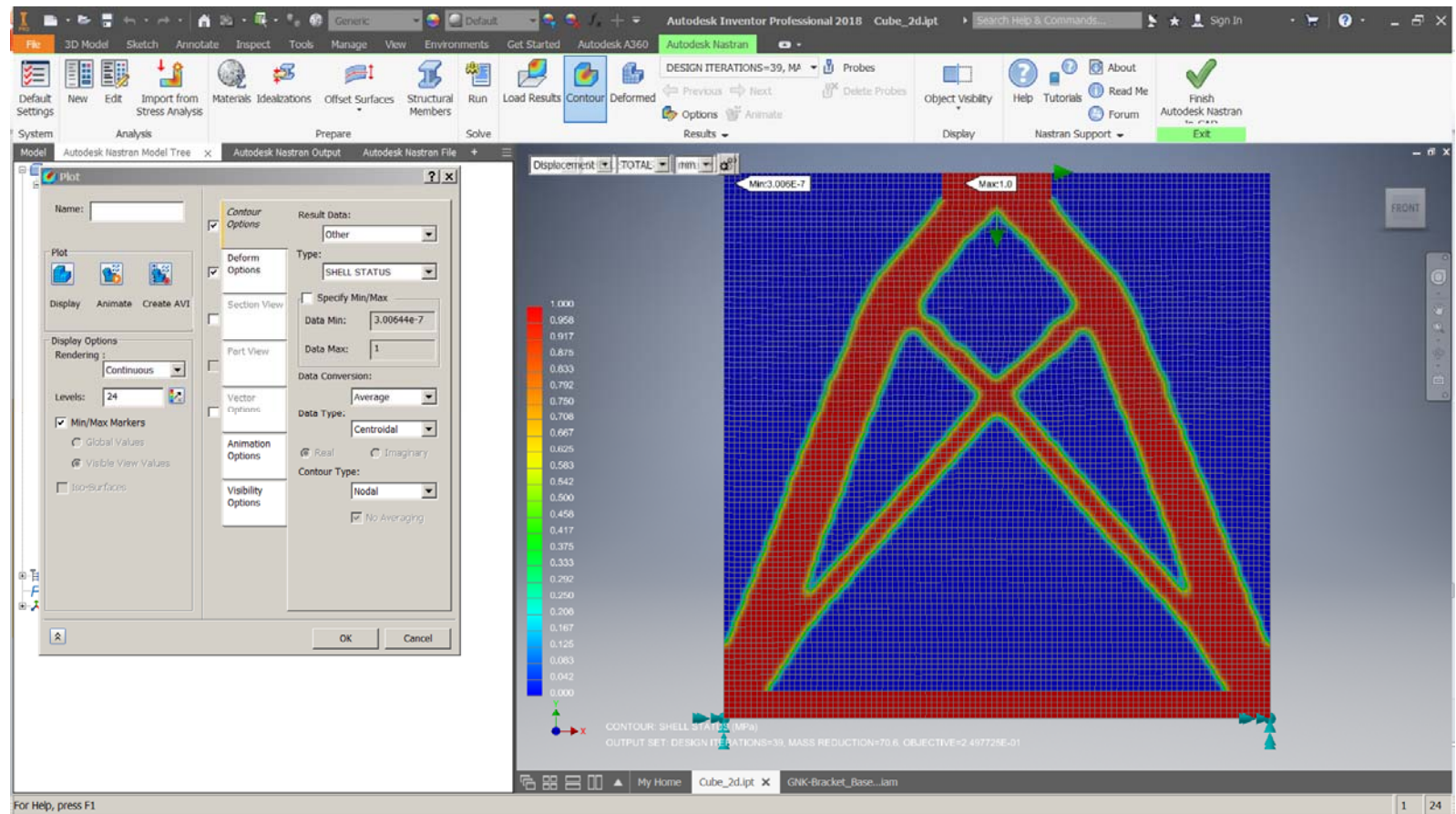


Obj: Min. VF (mass), Constraint: Stress & Comp. Index



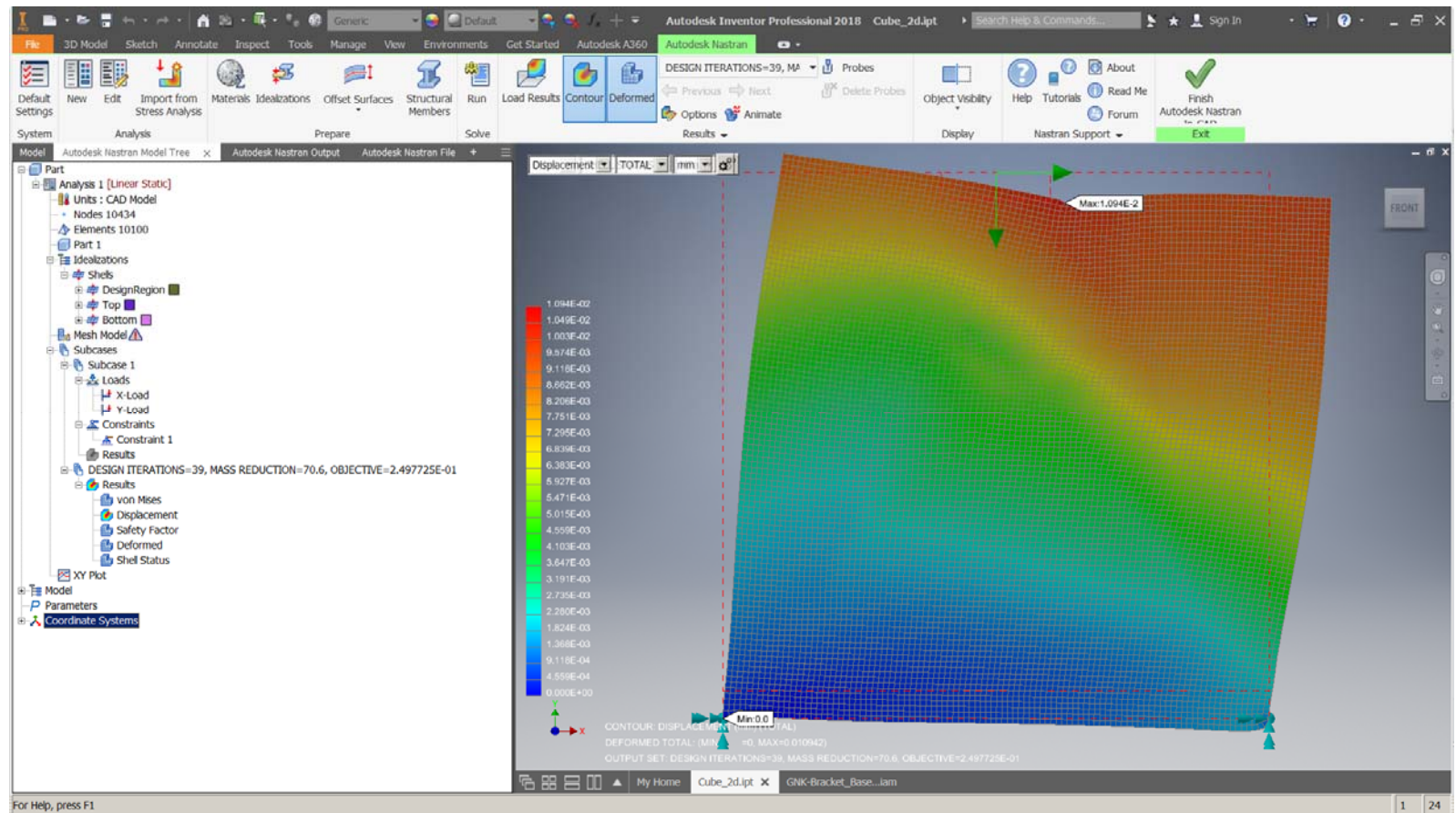
Obj: Min. VF (mass), Constraint: Disp. & Comp. Index

NTOPTSTRESSDIV	10
TOPTCOMPINDEX	5.
TOPTDESIGNCONSTR	0.01
TOPTDESIGNREGION	1
TOPTTELEMEXTTOL	1.0E-2
TOPTTELEMSYMTOL	0.9
TOPTGEN	VFDISP
TOPTMANCONSTR	SYM
TOPTMANCORD	0
TOPTMANDIR	YZ

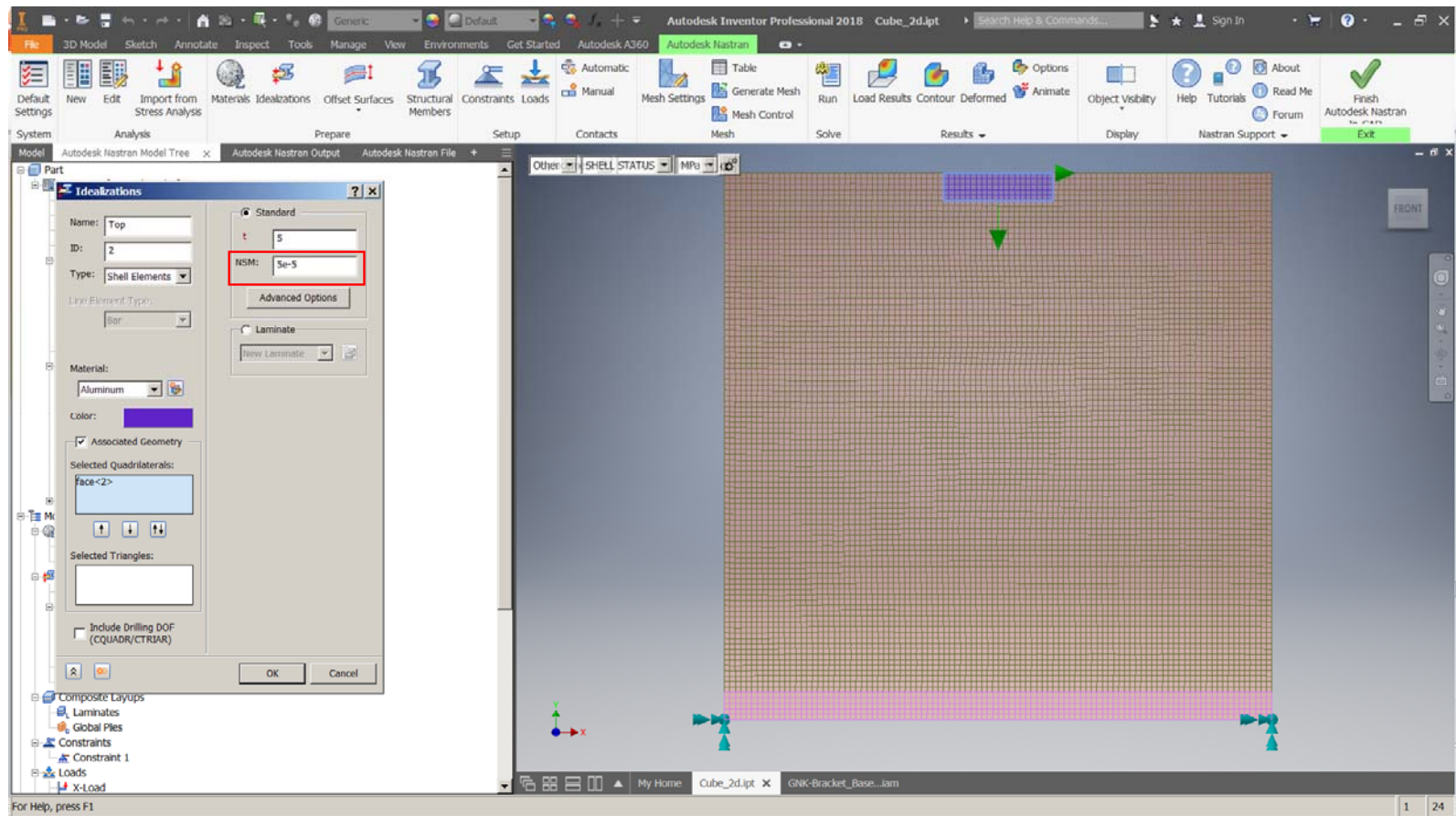


Obj: Min. VF (mass), Constraint: Disp. & Comp. Index

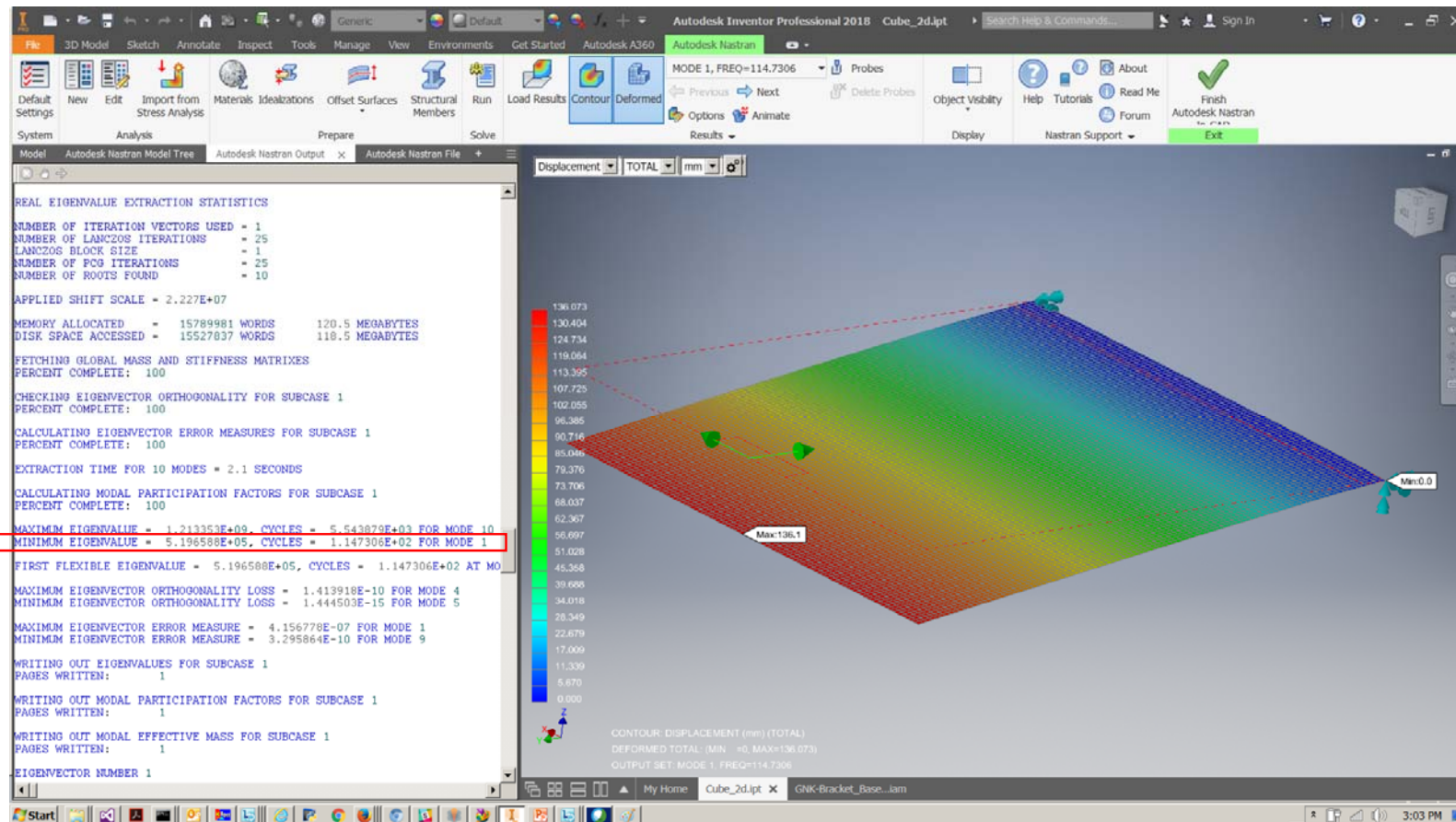
NTOPTSTRESSDIV	10
TOPTCOMPINDEX	5
TOPTDESIGNCONSTR	0.01
TOPTDESIGNREGION	1
TOPTTELEMEXTTOL	1.0E-2
TOPTTELEMSYMTOL	0.9
TOPTGEN	VFDISP
TOPTMANCONSTR	SYM
TOPTMANCORD	0
TOPTMANDIR	YZ



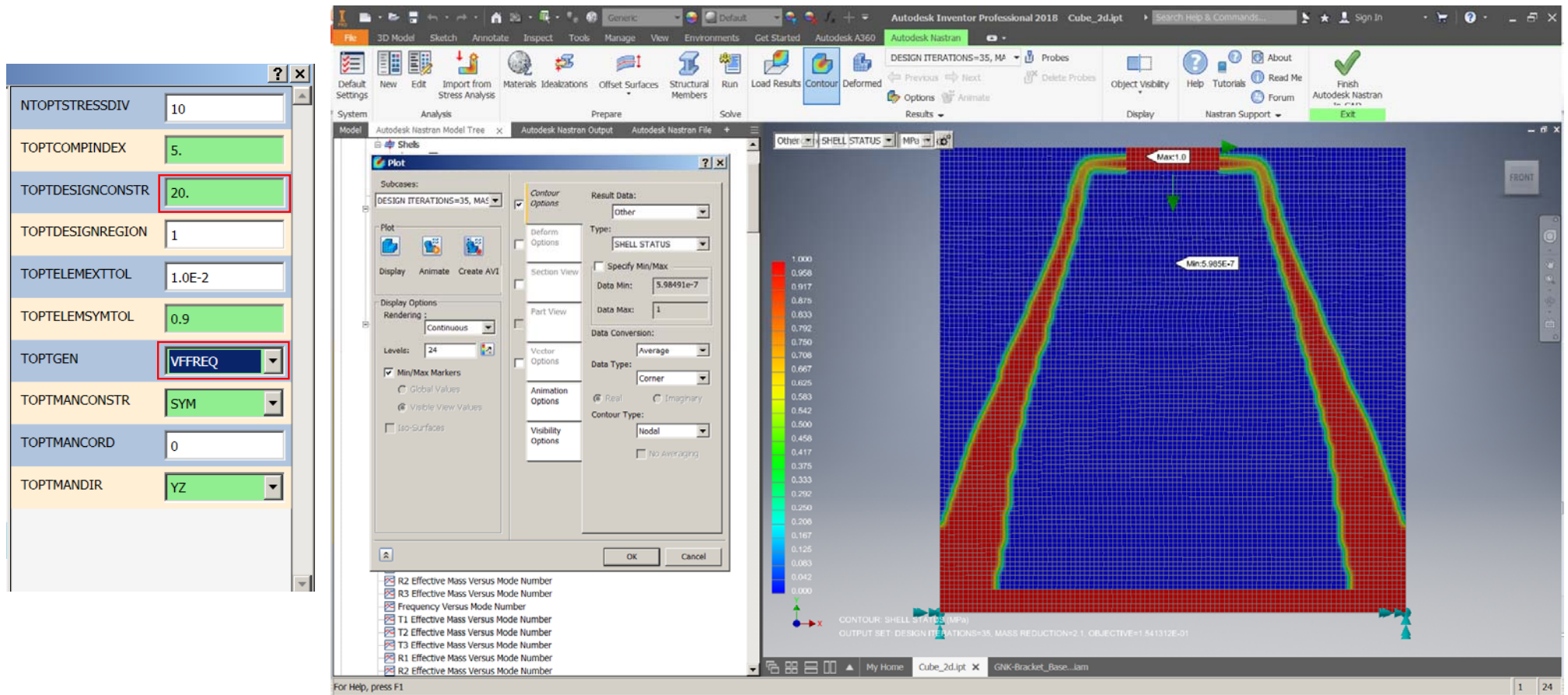
Obj: Min. VF (mass), Constraint: Frequency



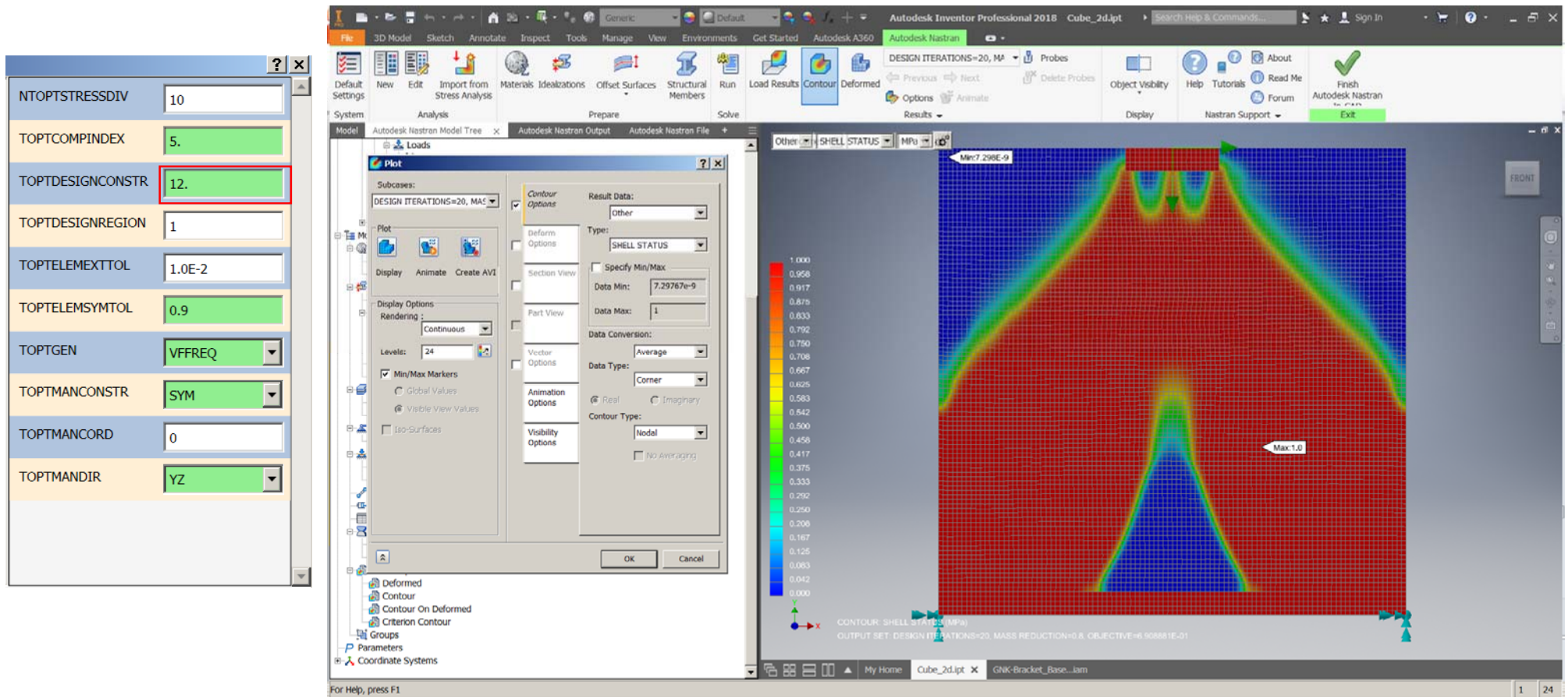
Obj: Min. VF (mass), Constraint: Frequency



Obj: Min. VF (mass), Constraint: Frequency > 10Hz

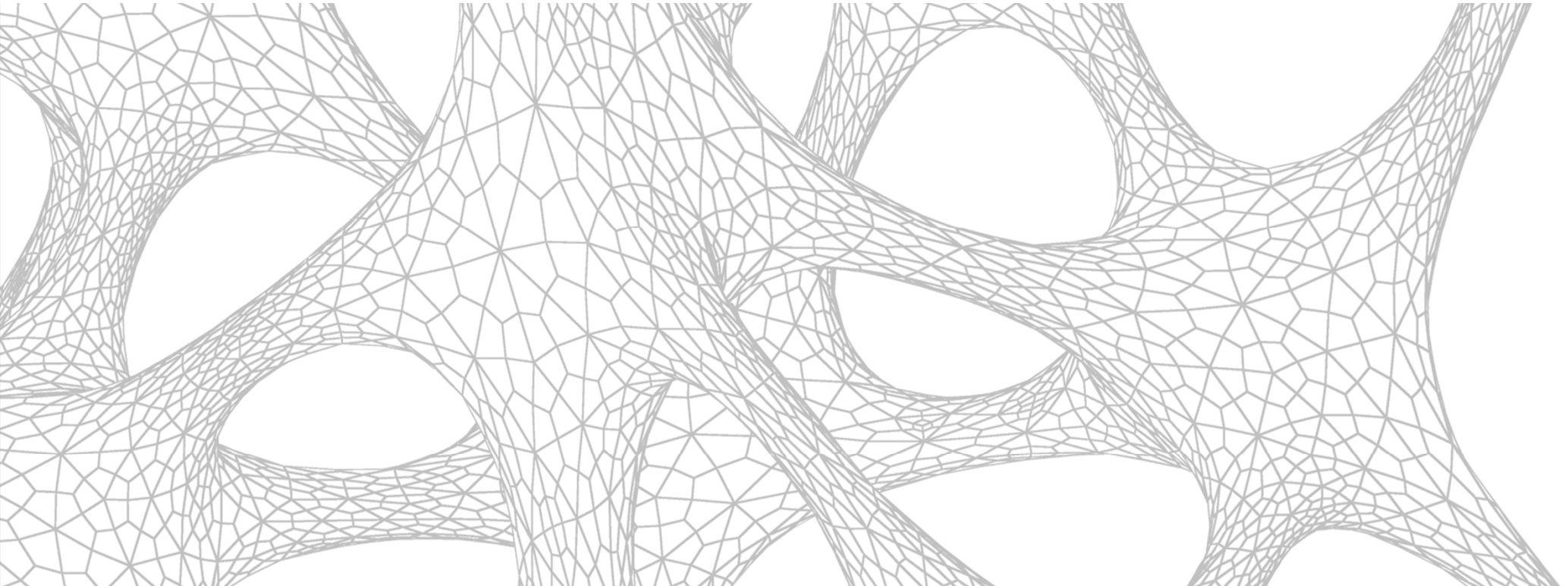


Obj: Min. VF (mass), Constraint: Frequency > 12Hz



Commonly Used Topology Optimization Parameters

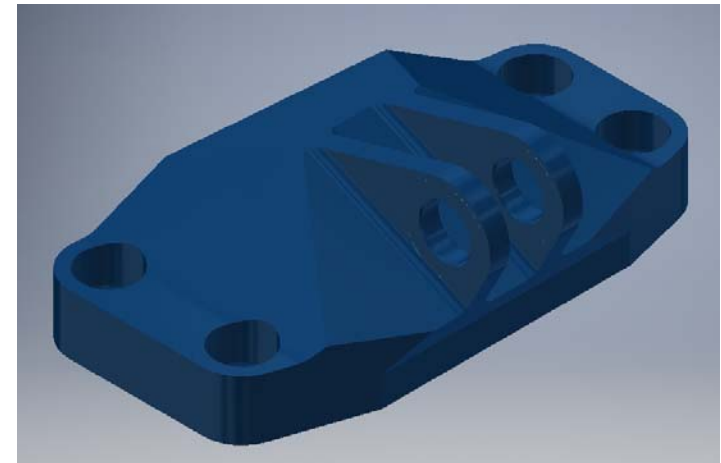
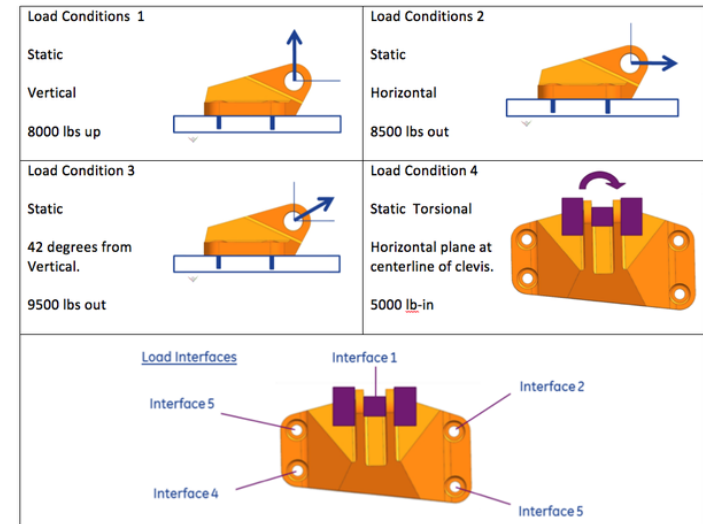
Parameter	Description	Default	Suggested Range	Remarks
MAXTOPTITER	Limits the number of design iterations	200	100 - 300	Increase when iteration limit exceeded
NTOPTSTRESSDIV	Number of stress sub-divisions	10	3 - 10	Reduce for better performance/increase for better accuracy
TOPTELEMEXTTOL	Tolerance for extrusion manufacturing constraint	1.0E-02	< 1.0	Increase if elements are not linked
TOPTELEMSYMTOL	Tolerance for symmetry manufacturing constraint	1.0E-02	< 1.0	Increase if elements are not linked
TOPTITERTOL	Tolerance for overall design iteration tolerance	5.0E-03	< 1.0E-02	Reduce for better accuracy/increase for better performance



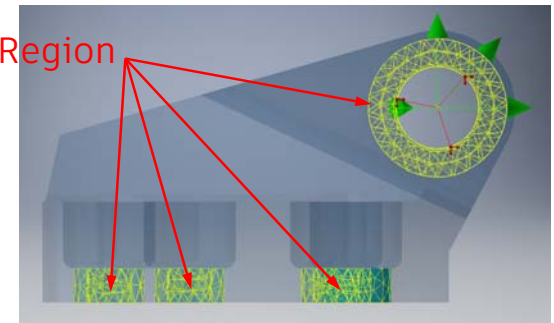
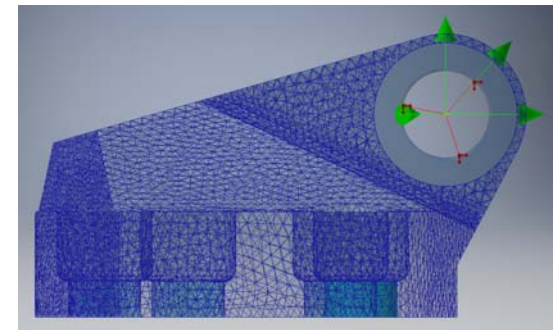
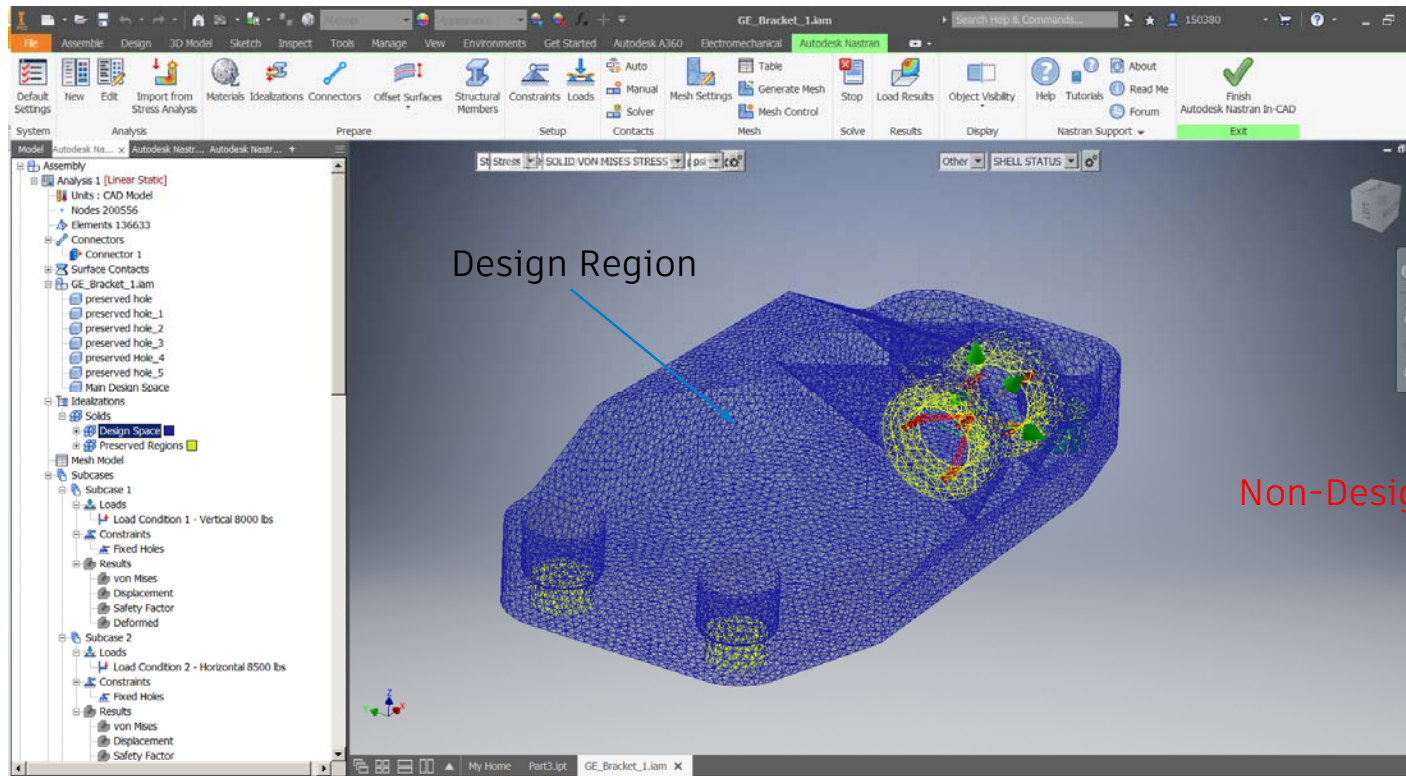
GE Bracket Challenge Problem

GE Bracket Challenge Problem

- Material: Titanium Ti-6Al-4V
- BC constraints: At inside of bolt holes
- Load conditions
 - Vertical 8000 lbs
 - Horizontal 8500 lbs
 - 42 deg 9500 lbs
 - 5000 in-lbs torque about horizontal plane
- Design constraint: Factor of Safety (FOS) = 1.2
- Manufacturing constraint: AM
- Objective: minimize mass
- Original volume: 27.58 in³
- Mesh density: 133k tet10 elements
- Run on a Dell M4800 laptop with 32GB of RAM
- Geometry generated automatically as a smoothed STL and then a BREP



GE Demo Bracket Model



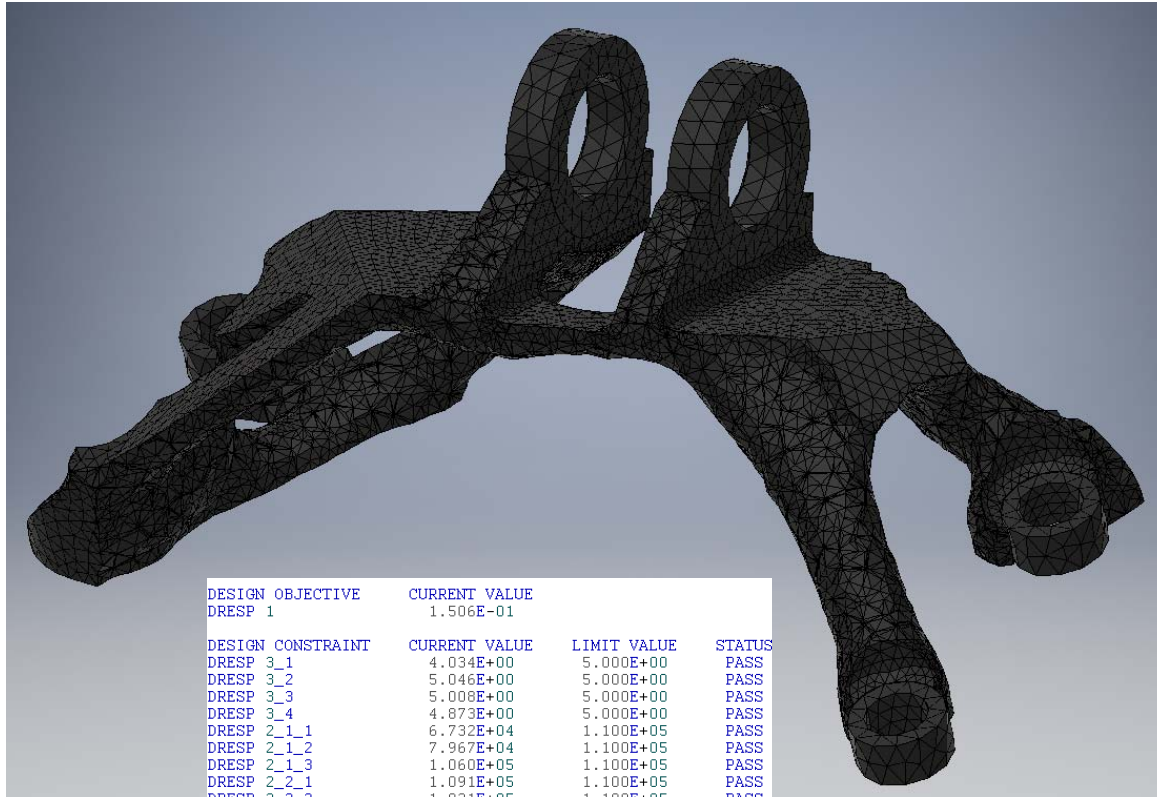
GE Demo Bracket With Stress Constraints Only

Parameters ? X

D File Management Directives	MAXTOPTITER	200
D Output Control Directives	NTOPTSTRESSDIV	3
D Memory Management Directives	TOPTBTHRESHOLD	0.5
D Program Control Directives	TOPTCOMPIINDEX	5.
P Model Translator Parameters	TOPTDATABASE	DELETE
P Geometry Processor Parameters	TOPTDESIGNCONSTR	1.1e+5
P Solution Processor Parameters	TOPTDESIGNREGION	1
D Output Control Directives	TOPTDESIGNTOL	1.0E-13
D Memory Management Directives	TOPTTELEMEXTTOL	1.0E-2
D Program Control Directives	TOPTTELEMSYMTOL	1.0E-2
P Model Translator Parameters	TOPTGEN	VFSTRESS
P Geometry Processor Parameters	TOPTITERTOL	5.0E-3
P Solution Processor Parameters	TOPTMANCONSTR	DISABLE
P Eigenvalue Processor Parameters	TOPTMANCORD	d
P Transient Response Processor Parameters	TOPTMANDIR	XY
P Frequency Response Processor Parameters	TOPTMAXACTDIST	0.2
P Nonlinear Solution Processor Parameters	TOPTMAXBETA	AUTO
P Results Processor Parameters		
P Design Optimization Processor Parameters		

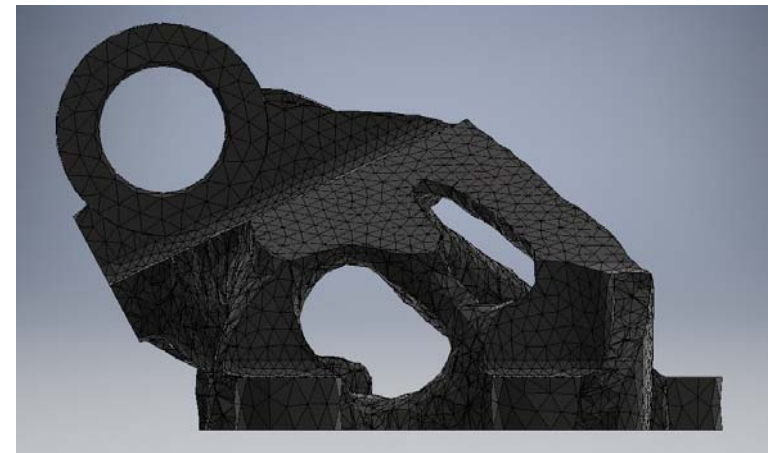
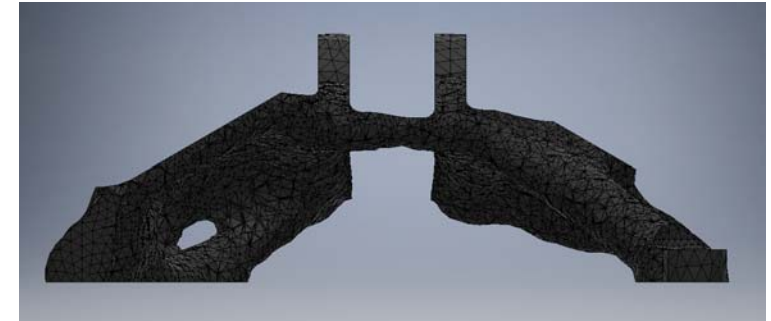
Find ☒ Advanced Settings

GE Demo Bracket With Stress Constraints Only



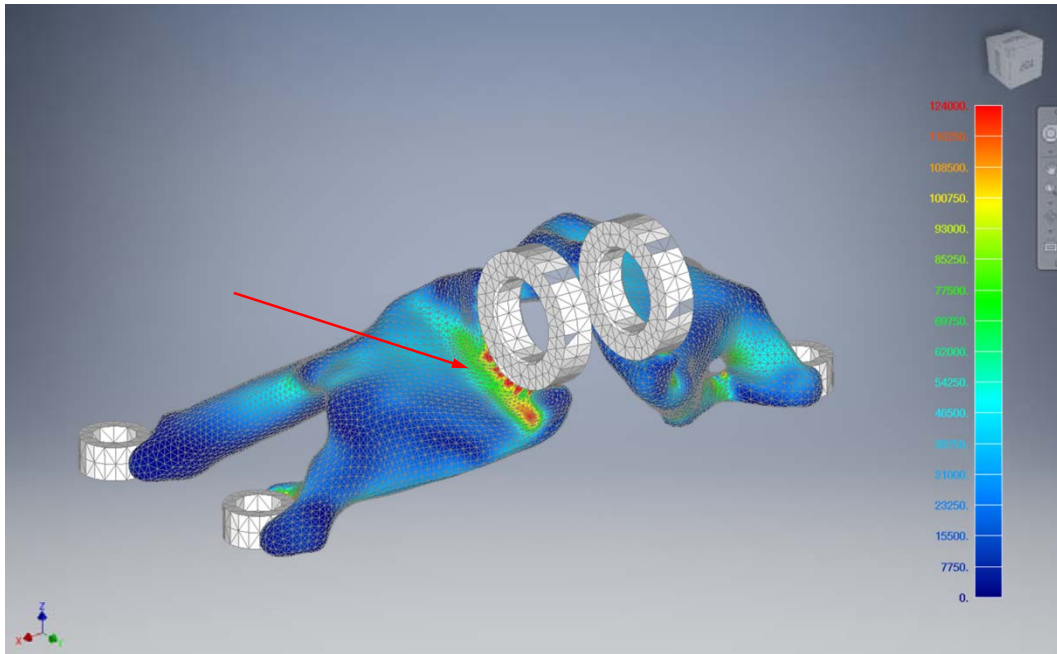
DESIGN OBJECTIVE		CURRENT VALUE		
DRESP	1	1.506E-01		
DESIGN CONSTRAINT		CURRENT VALUE	LIMIT VALUE	STATUS
DRESP	3_1	4.034E+00	5.000E+00	PASS
DRESP	3_2	5.046E+00	5.000E+00	PASS
DRESP	3_3	5.008E+00	5.000E+00	PASS
DRESP	3_4	4.873E+00	5.000E+00	PASS
DRESP	2_1_1	6.732E+04	1.100E+05	PASS
DRESP	2_1_2	7.967E+04	1.100E+05	PASS
DRESP	2_1_3	1.060E+05	1.100E+05	PASS
DRESP	2_2_1	1.091E+05	1.100E+05	PASS
DRESP	2_2_2	1.021E+05	1.100E+05	PASS
DRESP	2_2_3	7.344E+04	1.100E+05	PASS
DRESP	2_3_1	5.517E+04	1.100E+05	PASS
DRESP	2_3_2	9.751E+04	1.100E+05	PASS
DRESP	2_3_3	7.815E+04	1.100E+05	PASS
DRESP	2_4_1	1.058E+05	1.100E+05	PASS
DRESP	2_4_2	8.080E+04	1.100E+05	PASS
DRESP	2_4_3	4.139E+04	1.100E+05	PASS

DESIGN ITERATION CONVERGENCE = 100.0
DENSITY MASS REDUCTION = 82.9



- New volume = 4.68 in³
- Design space weight reduction = 83%
- Total weight reduction = 80.5%

Verification Analysis



	Original Model		Stress Only	
Load Case	von Mises Stress (ksi)	FOS	von Mises Stress (ksi)	FOS
1	96.0	1.15	124.0	0.89
2	76.8	1.43	95.8	1.15
3	62.0	1.77	95.6	1.15
4	47.5	2.32	106.5	1.03

- TO models do not use corner stress data unlike the verification model shown
- Using a 20% higher stress limit is recommended to account for center stresses and variations in smoothed geometry

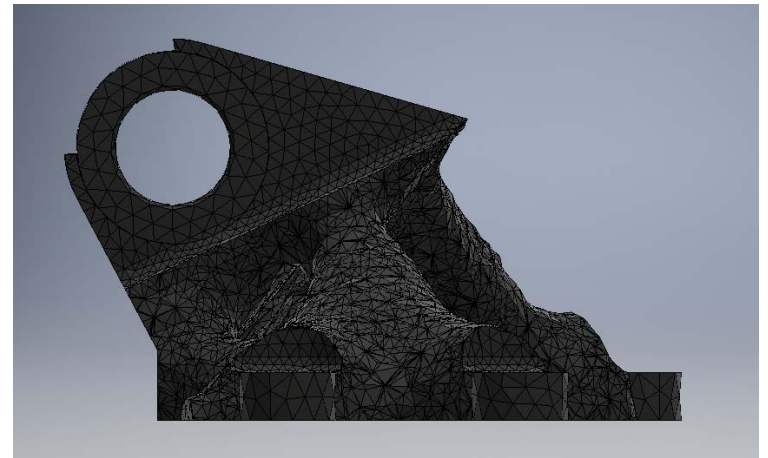
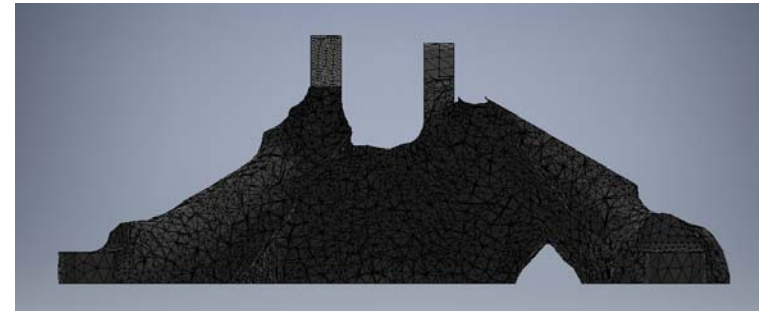
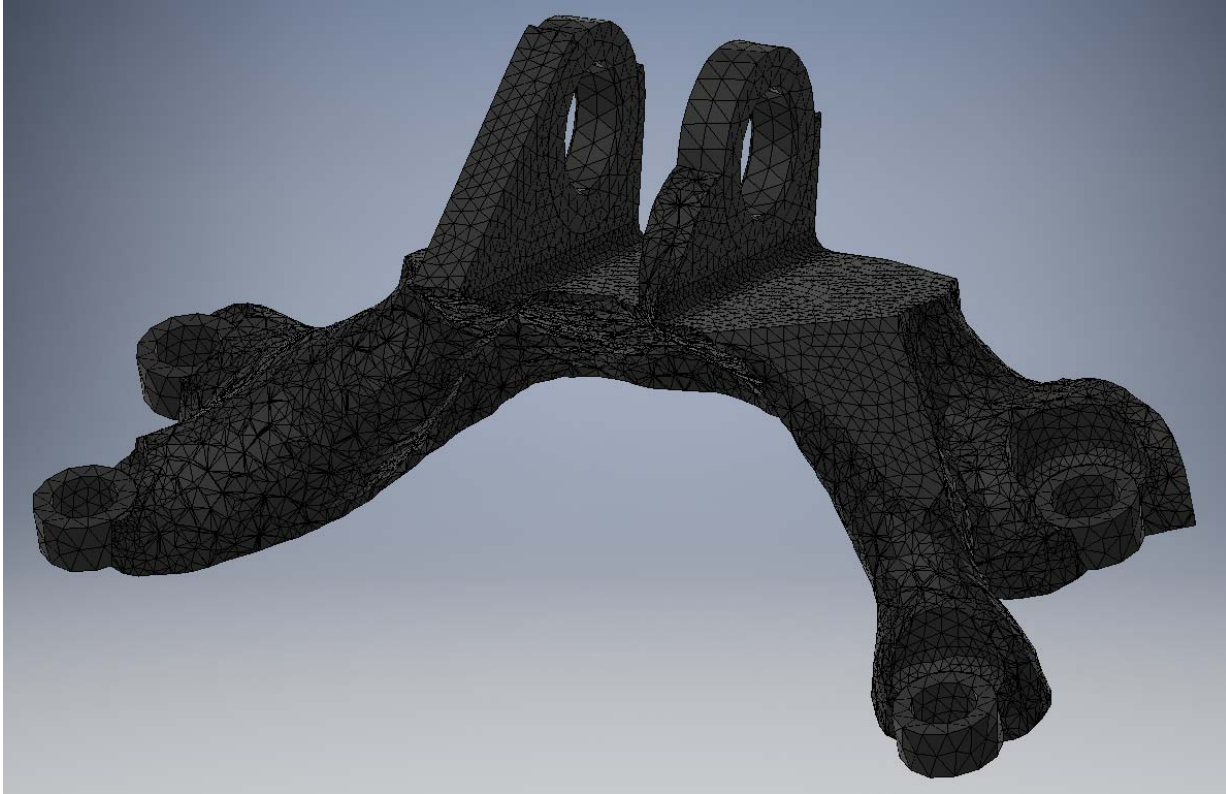
GE Demo Bracket With Stress & AM Constraints

Parameters ? X

D File Management Directives	MAXTOPTITER	300
D Output Control Directives	NTOPTSTRESSDIV	3
D Memory Management Directives	TOPTBTHRESHOLD	0.5
D Program Control Directives	TOPTCOMPIINDEX	5.
P Model Translator Parameters	TOPTDATABASE	DELETE
P Geometry Processor Parameters	TOPTDESIGNCONSTR	1.1e+5
P Solution Processor Parameters	TOPTDESIGNREGION	1
D Output Control Directives	TOPTDESIGNTOL	1.0E-13
D Memory Management Directives	TOPTTELEMEXTTOL	1.0E-2
D Program Control Directives	TOPTTELEMSYMTOL	1.0E-2
P Model Translator Parameters	TOPTGEN	VFSTRESS
P Geometry Processor Parameters	TOPTTERTOL	5.0E-3
P Solution Processor Parameters	TOPTMANCONSTR	ALM
P Eigenvalue Processor Parameters	TOPTMANCORD	d
P Transient Response Processor Parameters	TOPTMANDIR	+Z
P Frequency Response Processor Parameters	TOPTMAXACTDIST	AUTO
P Nonlinear Solution Processor Parameters	TOPTMAXBETA	AUTO
P Results Processor Parameters		
P Design Optimization Processor Parameters		

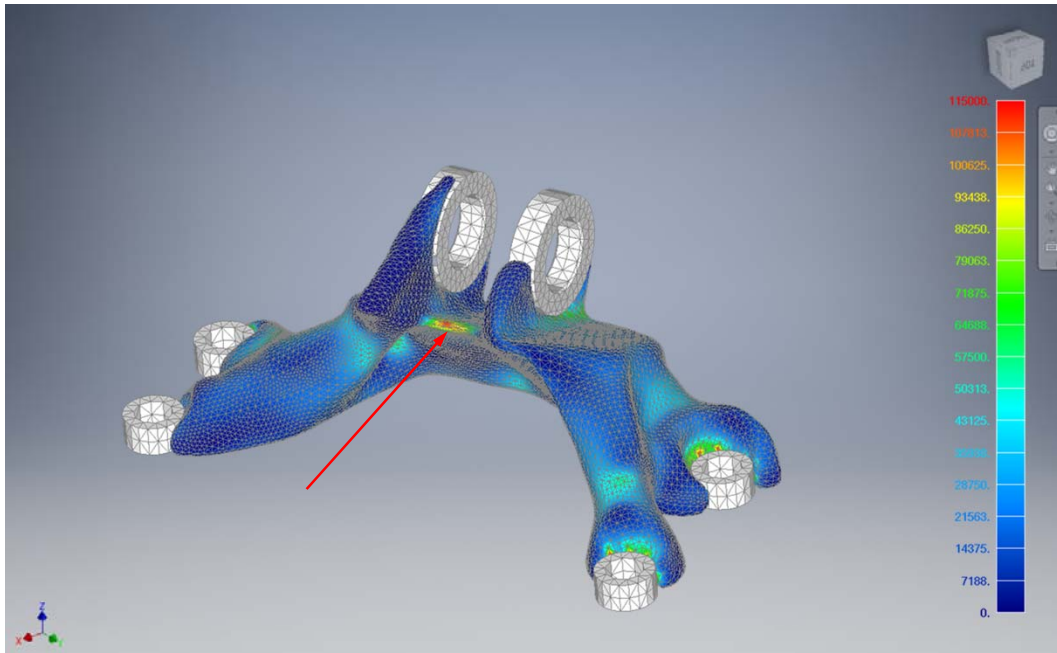
Find ☒ Advanced Settings

GE Demo Bracket With Stress & AM Constraints



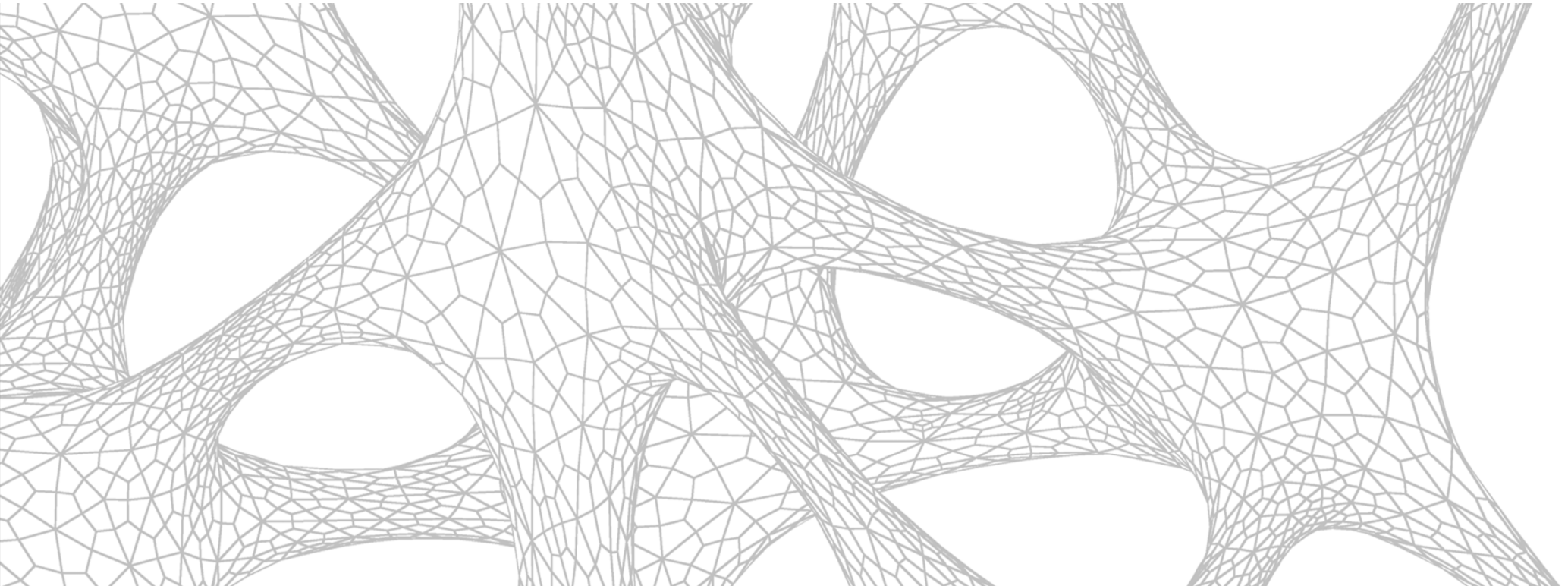
- New volume = 4.68 in³
- Design space weight reduction = 72%
- Total weight reduction = 68.1%

Verification Analysis



	Original Model		Stress Only	
Load Case	von Mises Stress (ksi)	FOS	von Mises Stress (ksi)	FOS
1	96.0	1.15	115.7	0.95
2	76.8	1.43	71.5	1.54
3	62.0	1.77	80.2	1.37
4	47.5	2.32	77.5	1.42

- TO models do not use corner stress data unlike the verification model shown
- Using a 20% higher stress limit is recommended to account for center stresses and variations in smoothed geometry



Live Demo Problems

Questions?





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