Topology Optimization in Autodesk Nastran In-CAD

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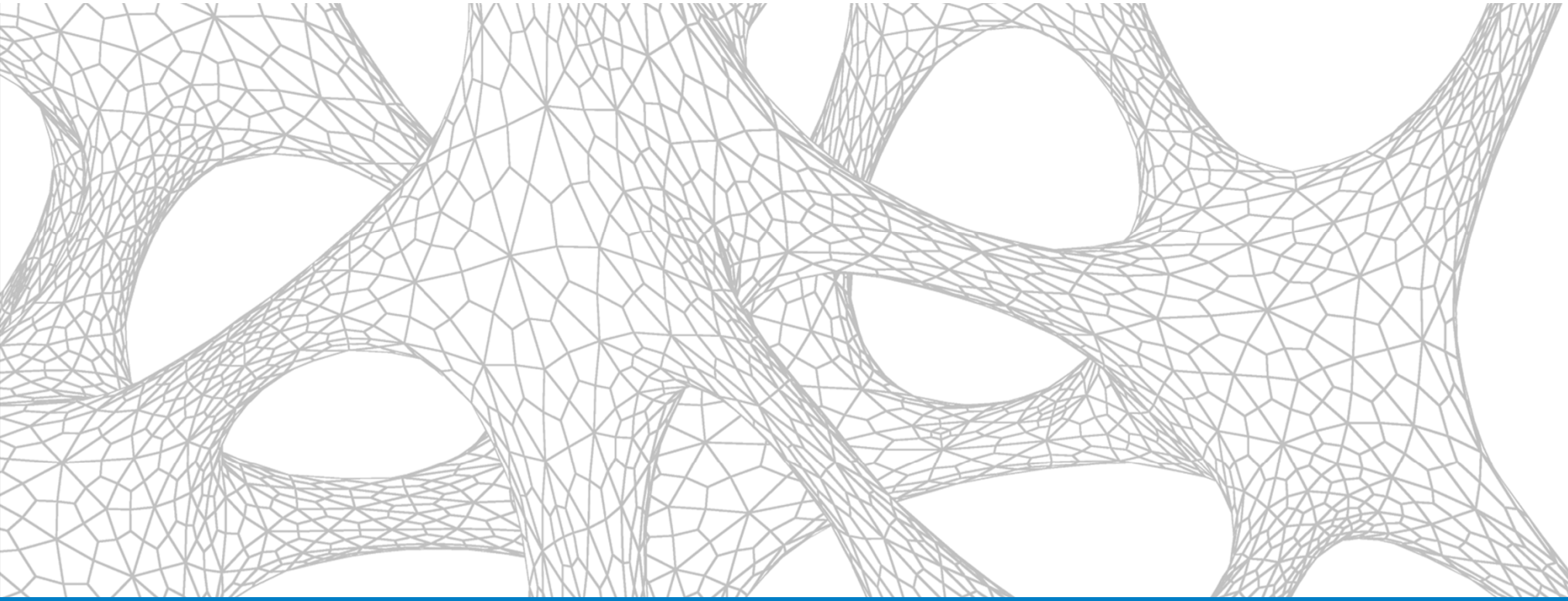
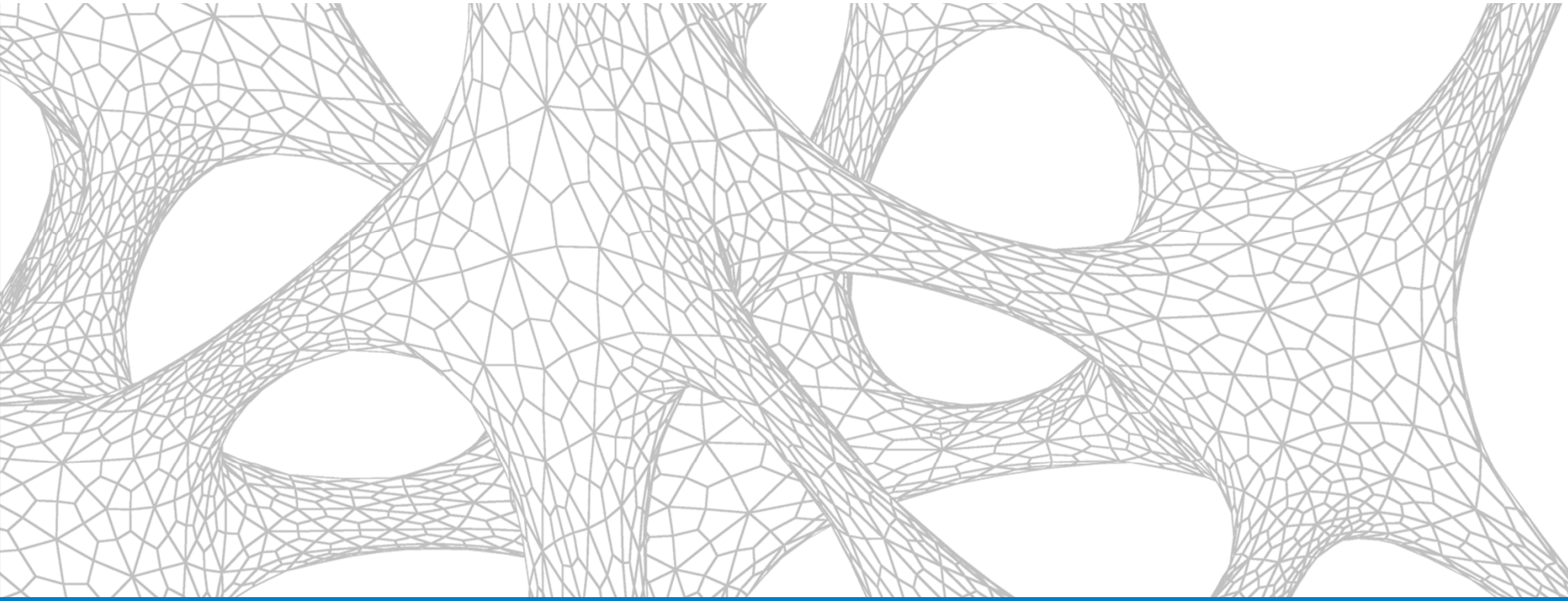


Learning Objectives

Learning Objectives

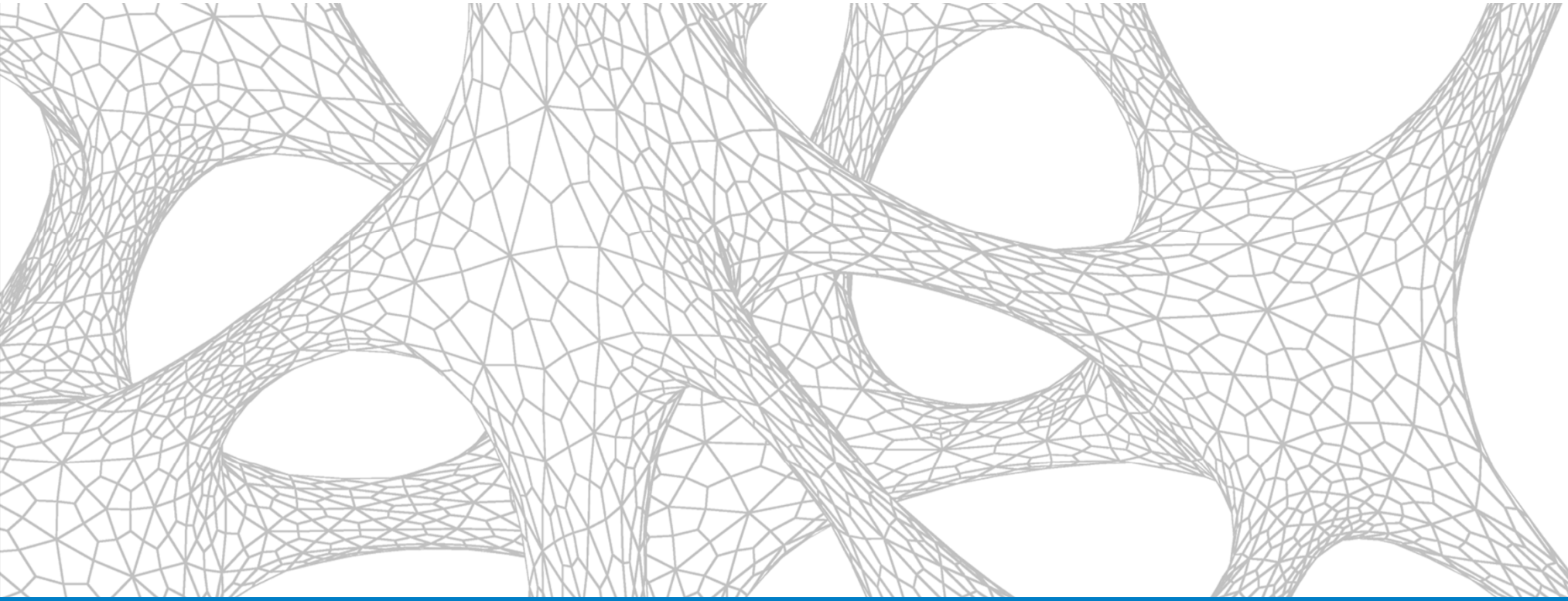
- Understand the basics of Topology Optimization in Autodesk Nastran In-CAD
- Learn how to modify an existing design to remove unnecessary material and make it more efficient and how to generate a design from an empty design space
- Understand the limitations of Topology Optimization in Autodesk Nastran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



Definitions

Definitions

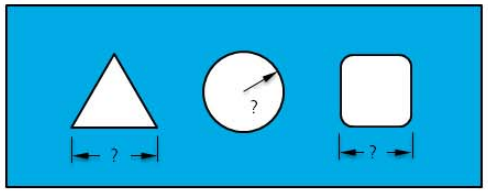
- **Objective** – The goal of the design analysis
- **Design Constraint** – Specific limits on results such as displacement at point, temperature, stress, etc.
- **Manufacturing Constraint** – Specifies how a design region will be manufactured such as extruded along and axis or symmetric about a plane
- **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)



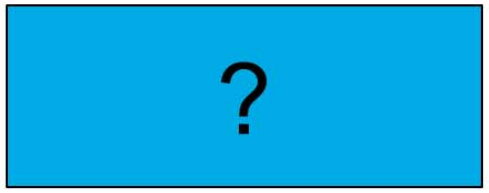
Topology Optimization Basics

Topology Optimization

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

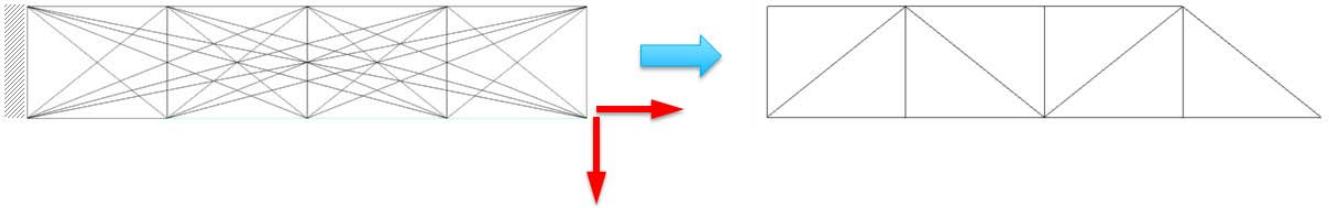


Shape Optimization



Topology Optimization

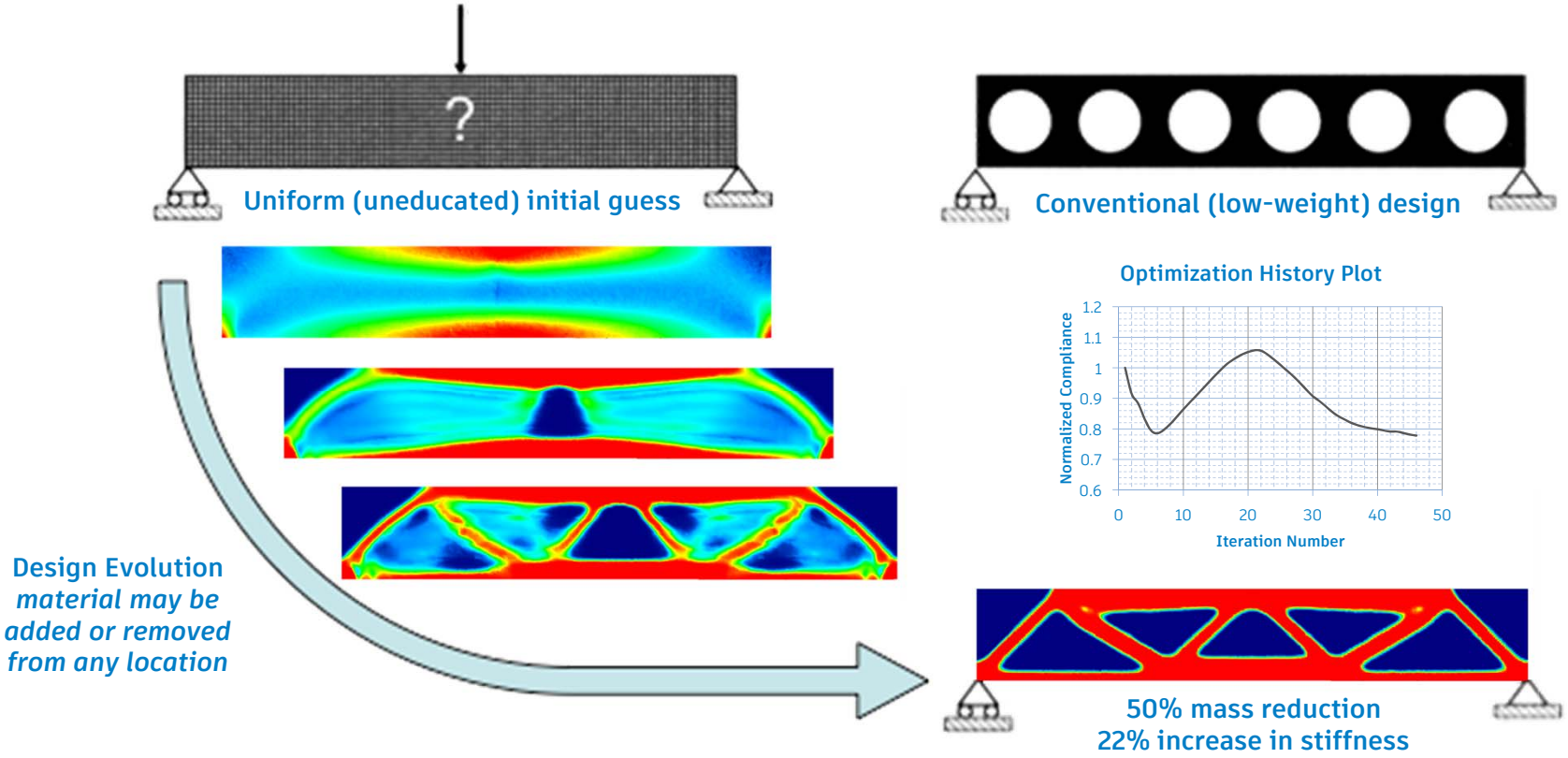
- Method with Finite Element Analysis
  - Initial method…truss



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

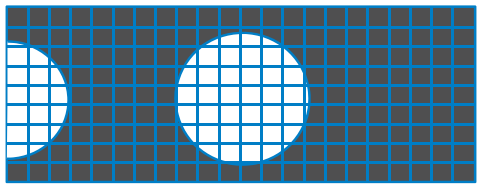
Topology Optimization with FEA

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



Topology Optimization Using SIMP - Nastran

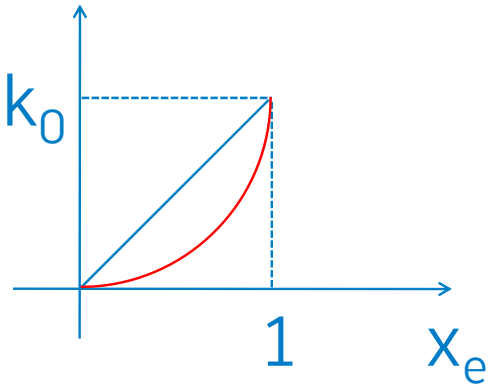
- For fixed mesh, determine density (x_e) of each element



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 = Solid Isotropic Material Penalization

(Not limited to isotropic materials)

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

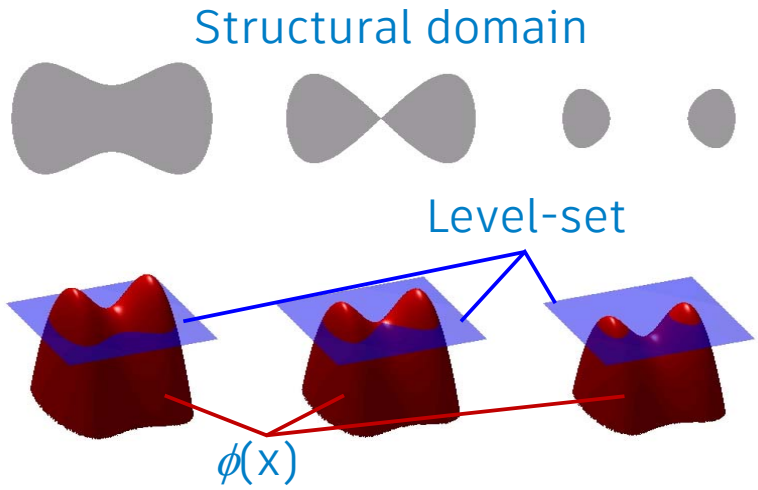
Topology Optimization Using Level-Set

- 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 $f(\mathbf{x})$

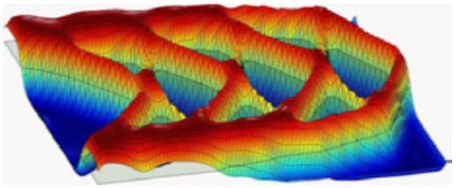
$$\rho = \begin{cases} 0 : \phi < 0 \\ 1 : \phi \geq 0 \end{cases}$$

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

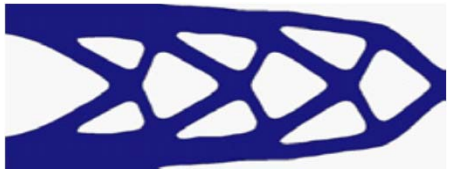
$$\phi(\mathbf{x}) = 0$$



Structural domain defined by different level-set values



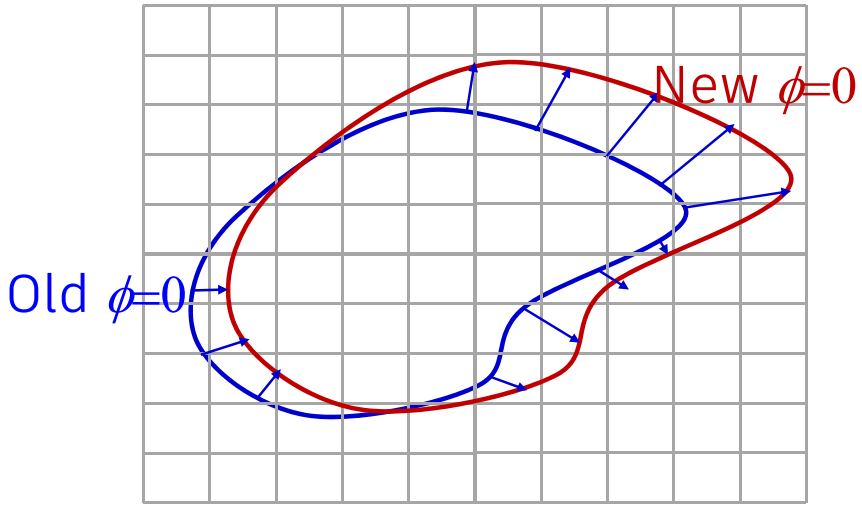
Level-set function $\phi(x)$

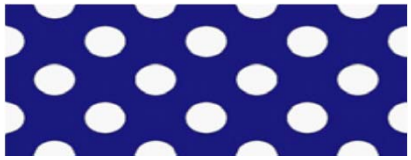


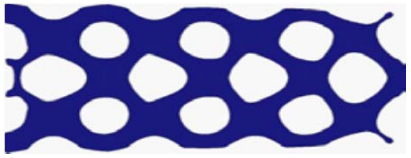
Structural domain

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

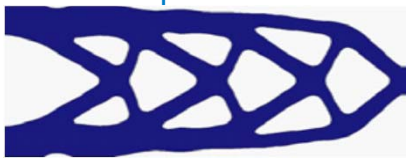


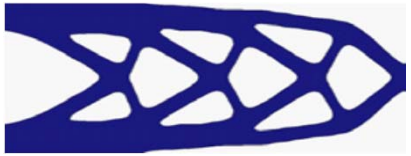

Initial design


Step 15


Step 45


Step 150


Step 245


Step 386

Z. Luo Appl. Mech. Eng. 2013

Misconception of Level-Set Method

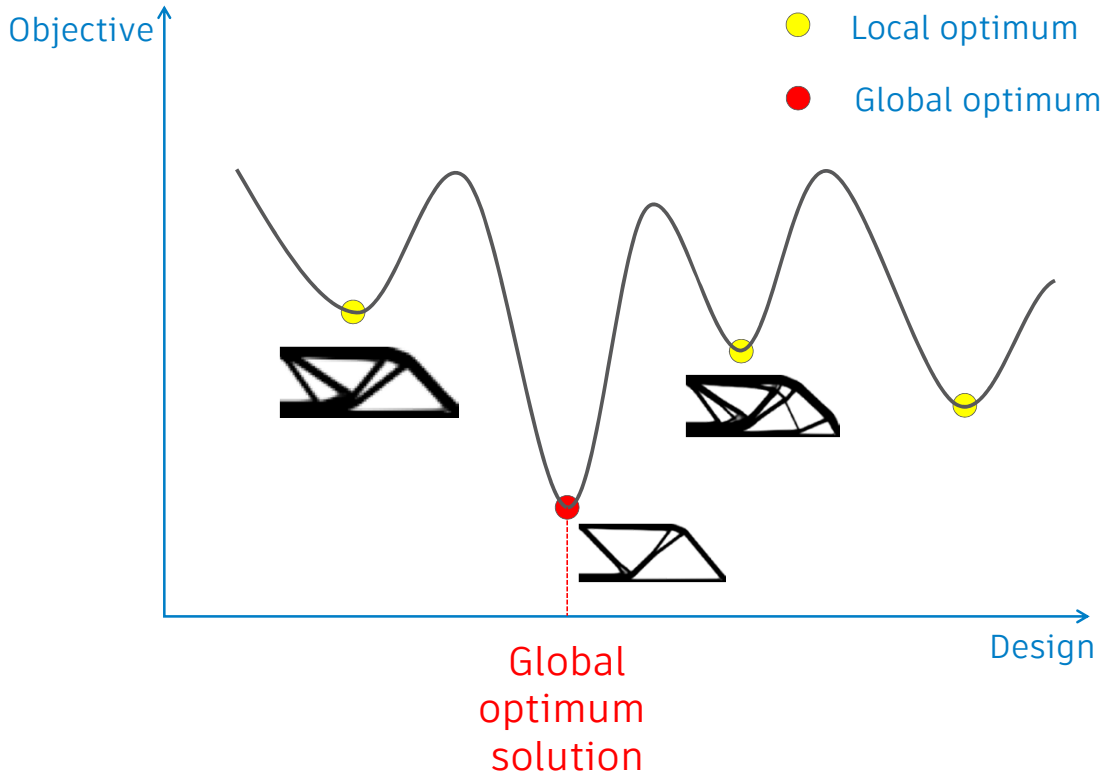
- Smooth and crisp boundary descriptions
  - Most level-set methods do not use clear boundary information in FEA simulation, but the same grey-scale information
  - It is claimed by some that level-set is more accurate than SIMP
    - In reality, when the boundary cuts an element, the level-set calculates 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

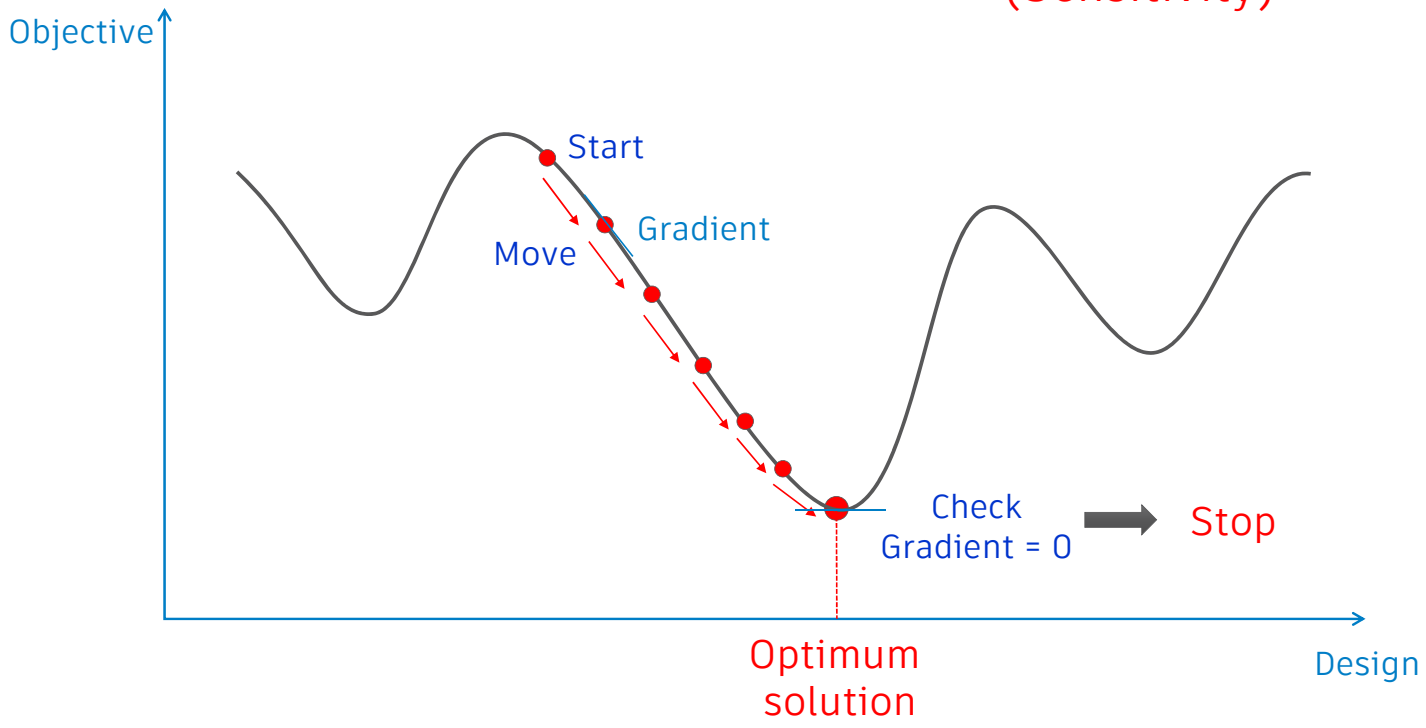
- Optimization algorithm searches for local minimum…global minimum is not guaranteed
- Starting with different initial volume fractions and different mesh densities will result in different designs



Gradient-based Methods

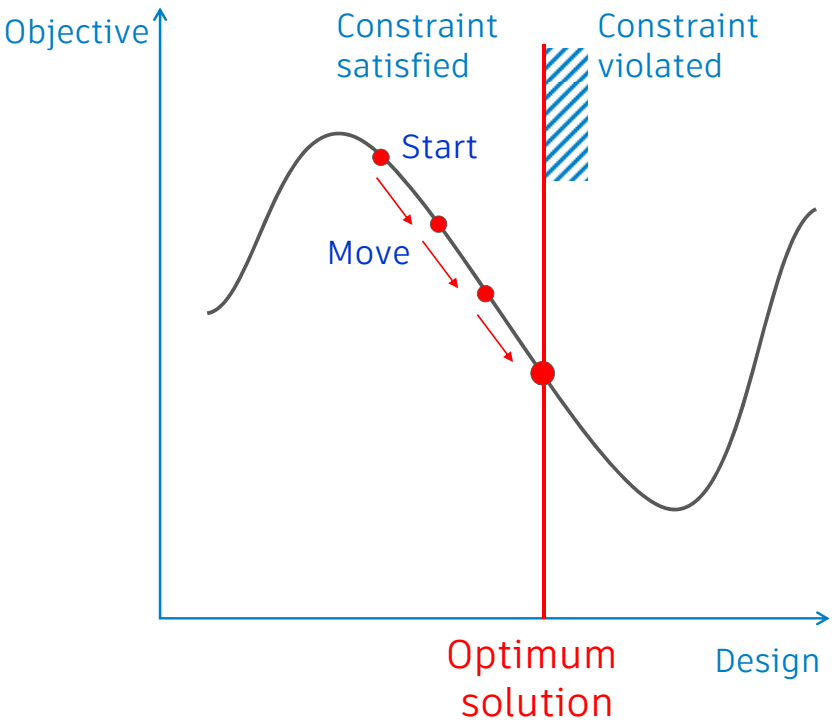
We do not know the function before optimization

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

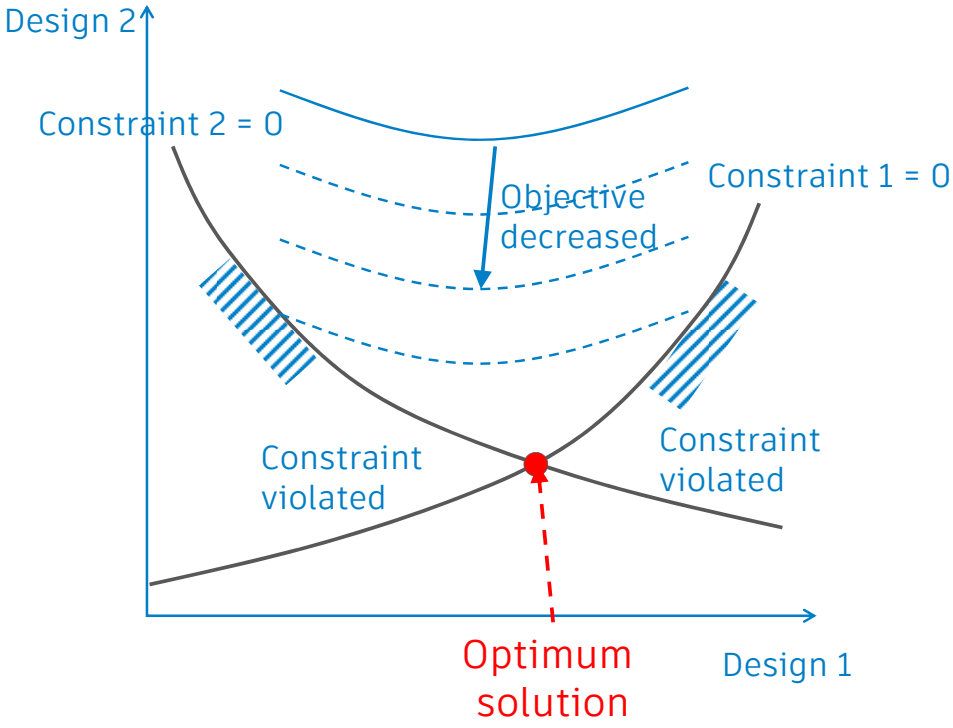


How Constraints Play in Optimization?

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

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

σ_{max}: allowable stress

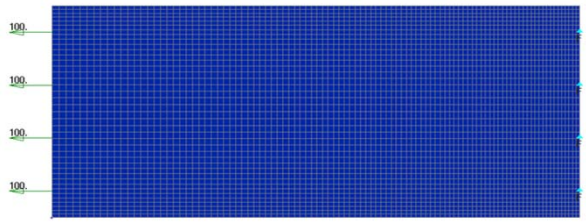
σ_{vM}: Von Mises stress

N: # of TO elements

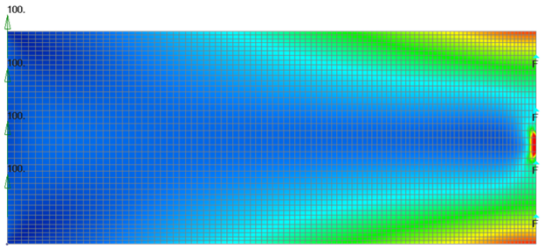
p ~ 10: approximation exponent

Global Stress Performance

- Global stress is good when stress is uniform



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

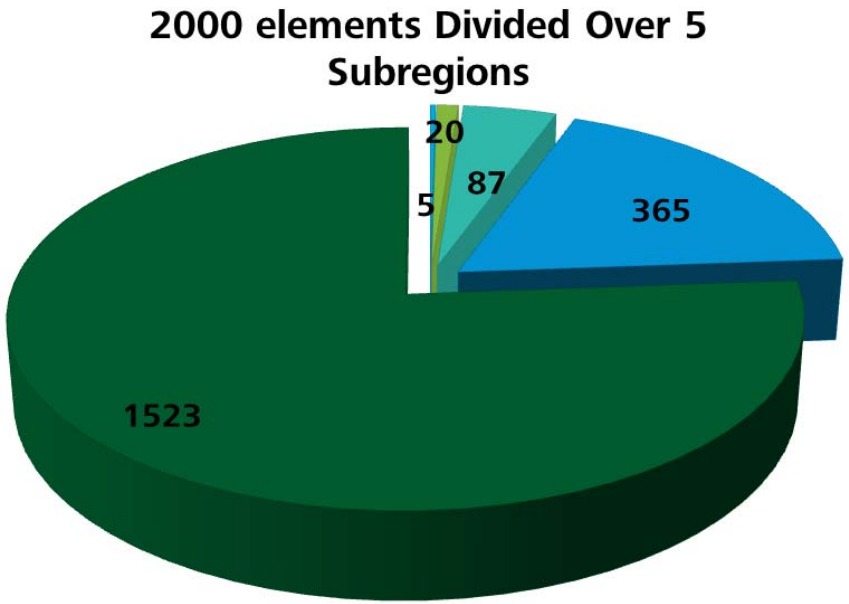


$$\sigma_{\text{global}} < \max(\sigma_{vM}^{e})$$

- 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



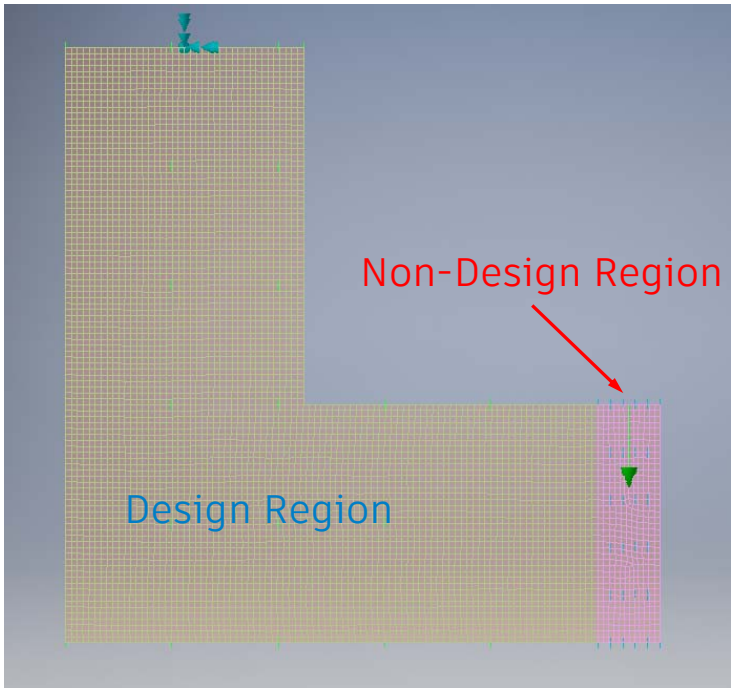
Subdivision/Constraint	Number of Elements
1	5
2	20
3	87
4	365
5	1523

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

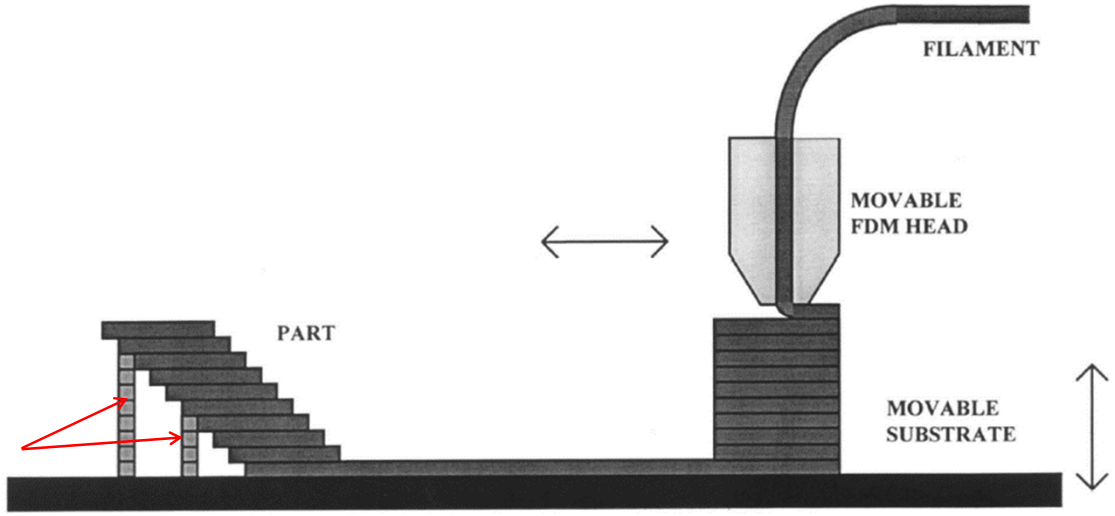
Region-Based Topology Optimization

- 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

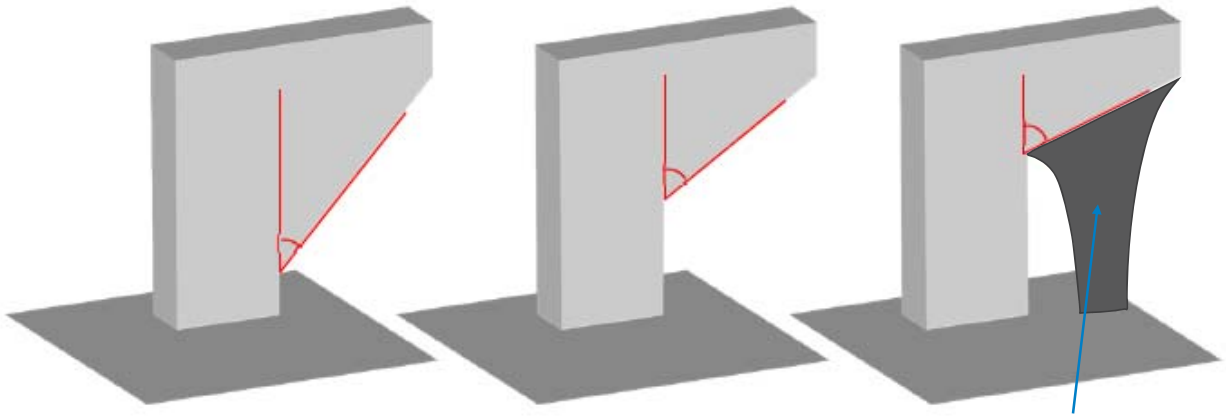


Additive Manufacturing Constraint

- 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



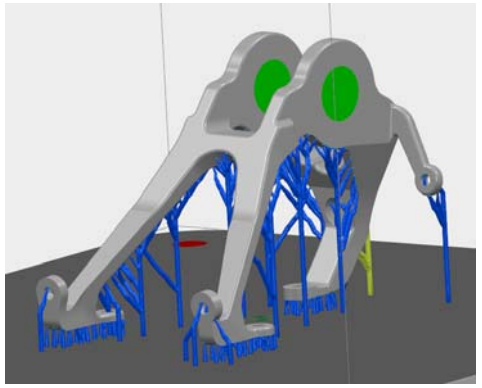
AM Limitation: Critical Overhang Angle



Manufacturable

Supporting structure

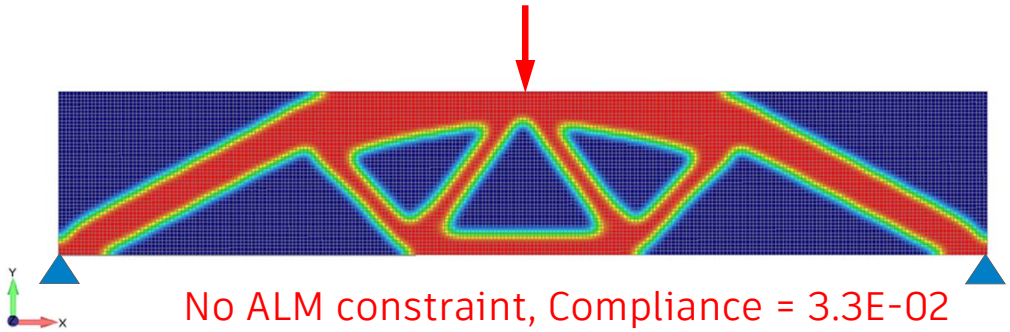
- Overhang structure must be removed using machining
  - Manually design overhang structure
  - Requires extra cost
  - Sometimes impossible to remove (inside feature)



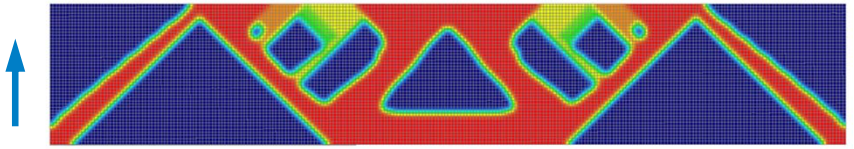
Existing Solutions to Overhang Problem

- 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

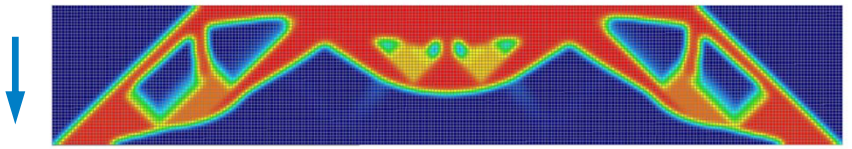
Additive Manufacturing Constraint - ALM



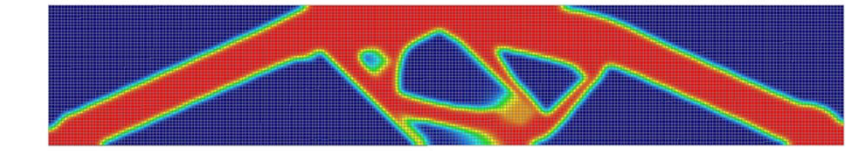
No ALM constraint, Compliance = 3.3E-02



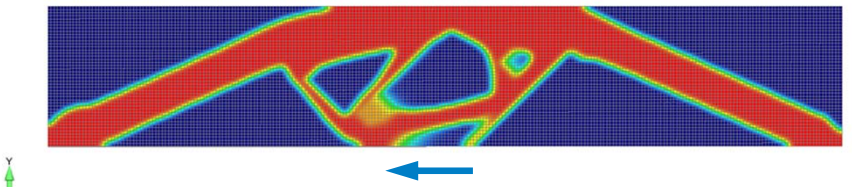
With ALM constraint, Compliance = 5.9E-02



With ALM constraint, Compliance = 1.2E-01



With ALM constraint, Compliance = 3.5E-02

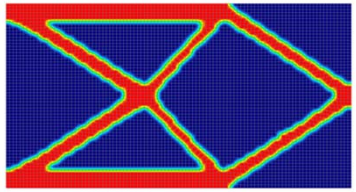


With ALM constraint, Compliance = 3.5E-02

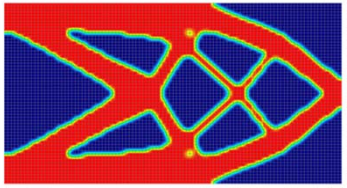
- Fixed at lower corners and point loaded at the top, mid-span
- Objective is minimize compliance (maximize stiffness)
- Constraint is fixed volume fraction of 0.4 (reduce volume to 40% of its original)
- Manufacturing constraints: ALM or Additive Manufacturing, 45 deg. max overhang angle

Effect of Mesh Density and Volume Fraction Constraint

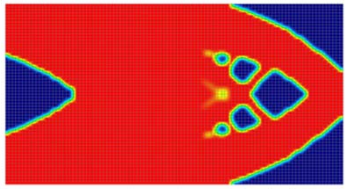
Objective: minimize compliance, Constraint: Volume fraction (VF)



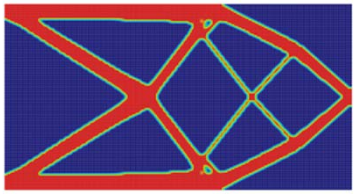
Mesh: 100x60 VF = 0.3



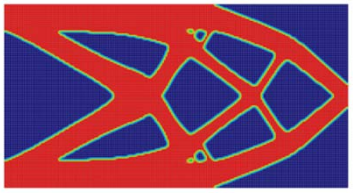
VF = 0.5



VF = 0.8

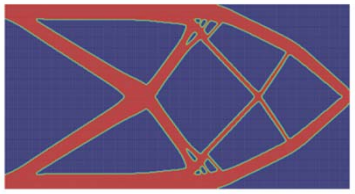


Mesh: 200x120 VF = 0.3

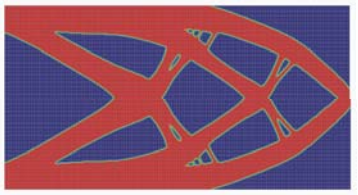


VF = 0.5

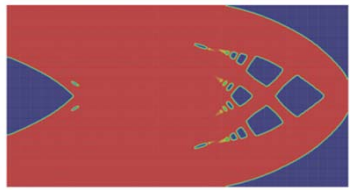
VF = 0.8



Mesh: 400x240 VF = 0.3

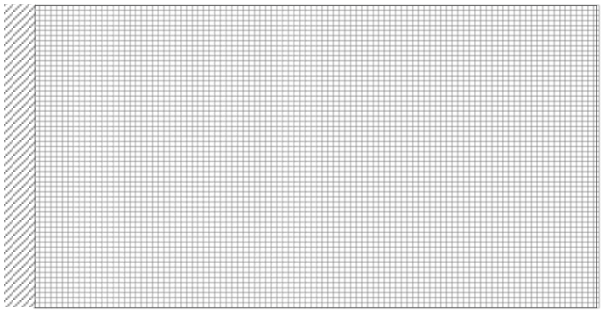


VF = 0.5

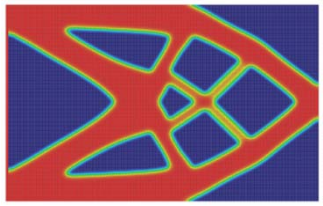


VF = 0.8

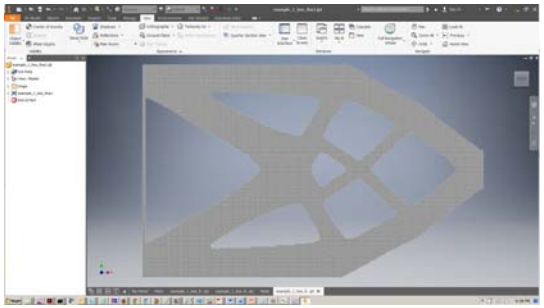
Minimum Member Size Manufacturing Constraint

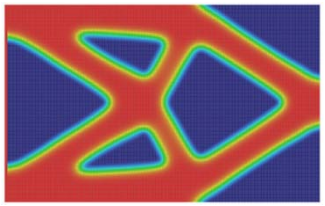


- Fixed at one end and edge loaded at the other end
- Objective is minimize mass
- Constraint is maximum vertical displacement at loaded edge
- Manufacturing constraint: minimum member size (prevents non-designable feature generation)

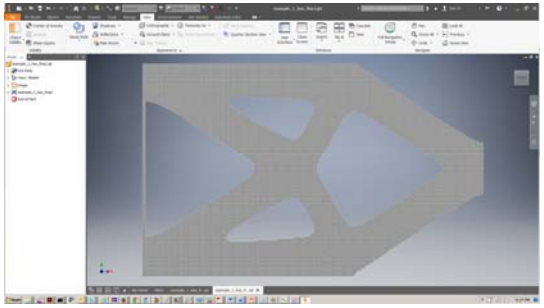


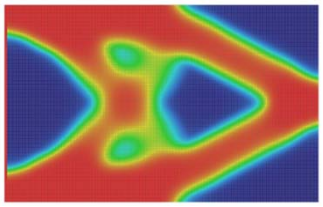
Min member size = 2.0
50.6% mass reduction



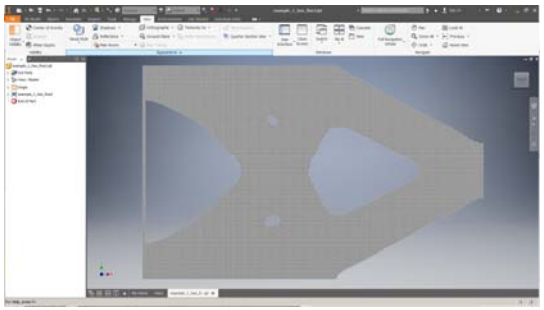


Min member size = 4.0
47.2% mass reduction

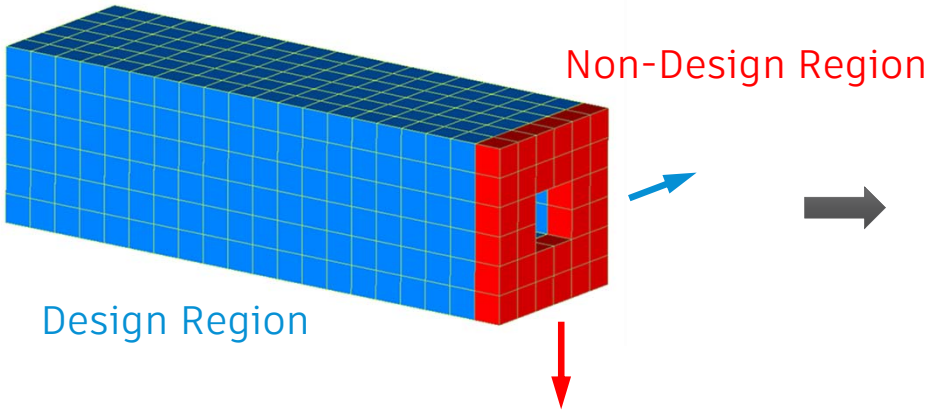


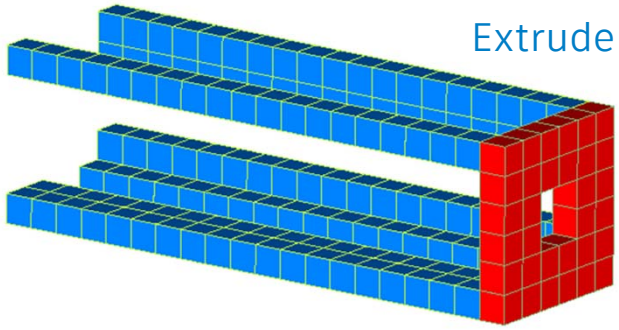


Min member size = 6.0
40.4% mass reduction

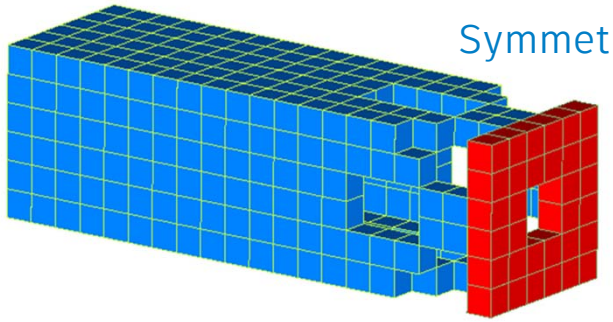


Extrude and Symmetry Manufacturing Constraints

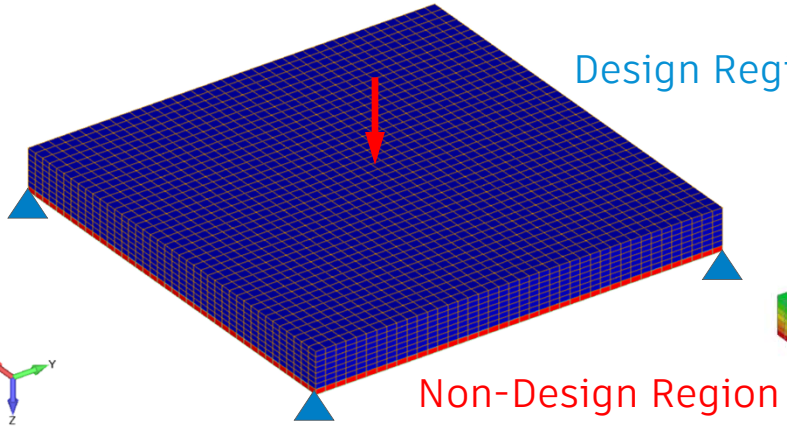


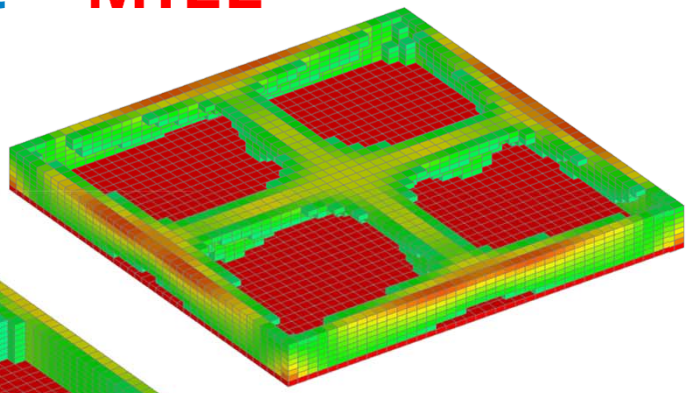


- Fixed at one end and symmetrically point loaded at the other end with 2 separate load cases
- Global max displacement design constraint limited to 0.3 in the direction of load in each load case
- Objective is minimize mass/volume
- Manufacturing constraints: extrusion, symmetry

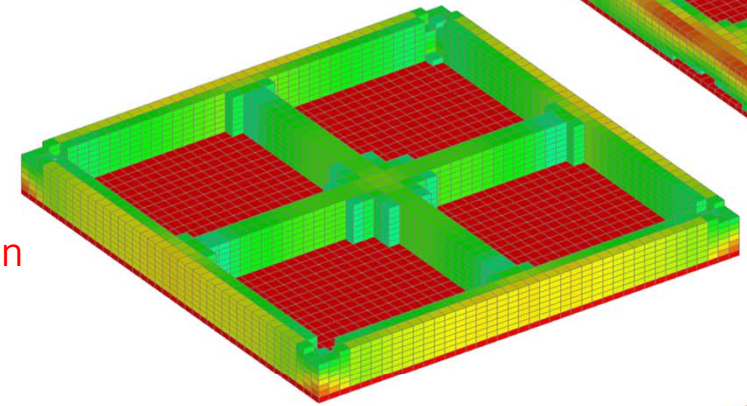


Milling Manufacturing Constraint - MILL

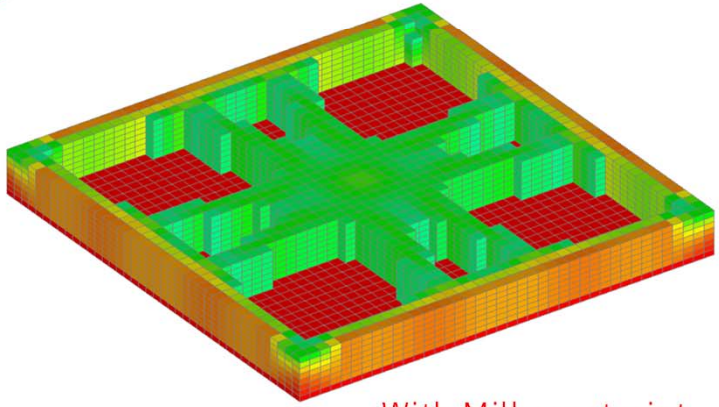




No manufacturing constraint
Max δ = 0.025
64.0% mass reduction

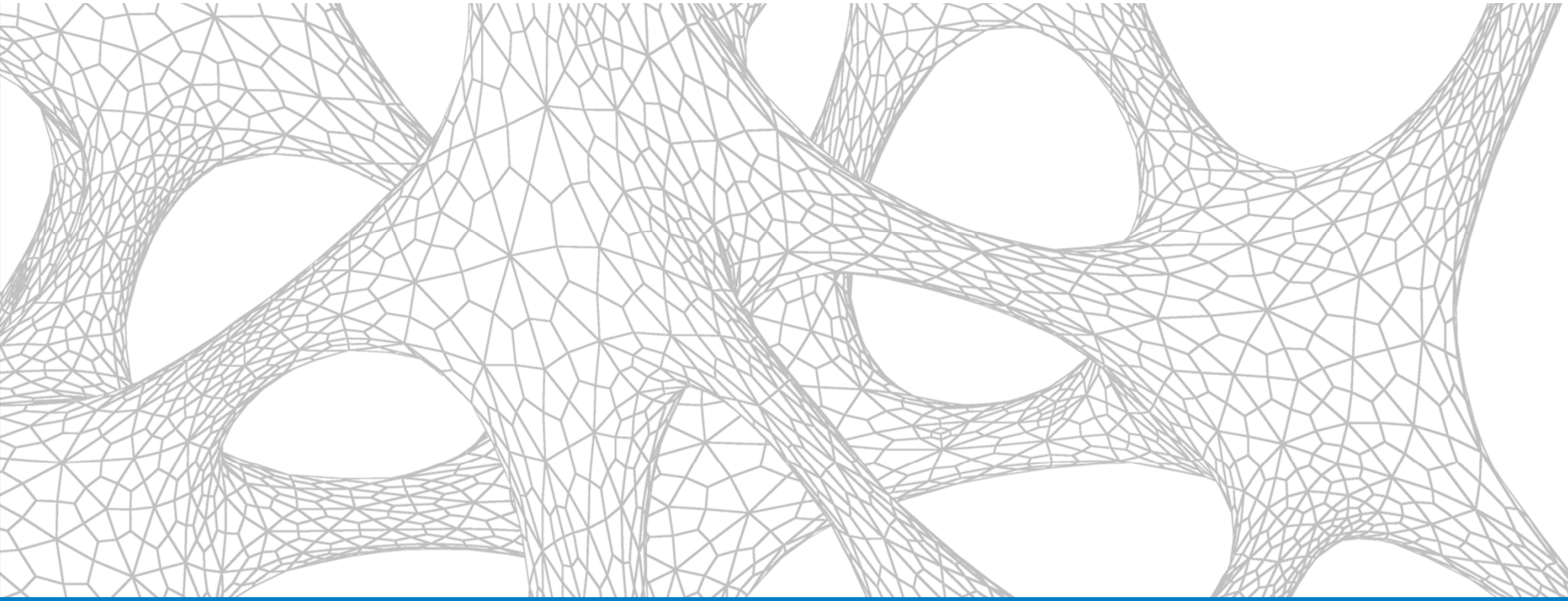


With Mill constraint
Max δ = 0.025
64.5% mass reduction



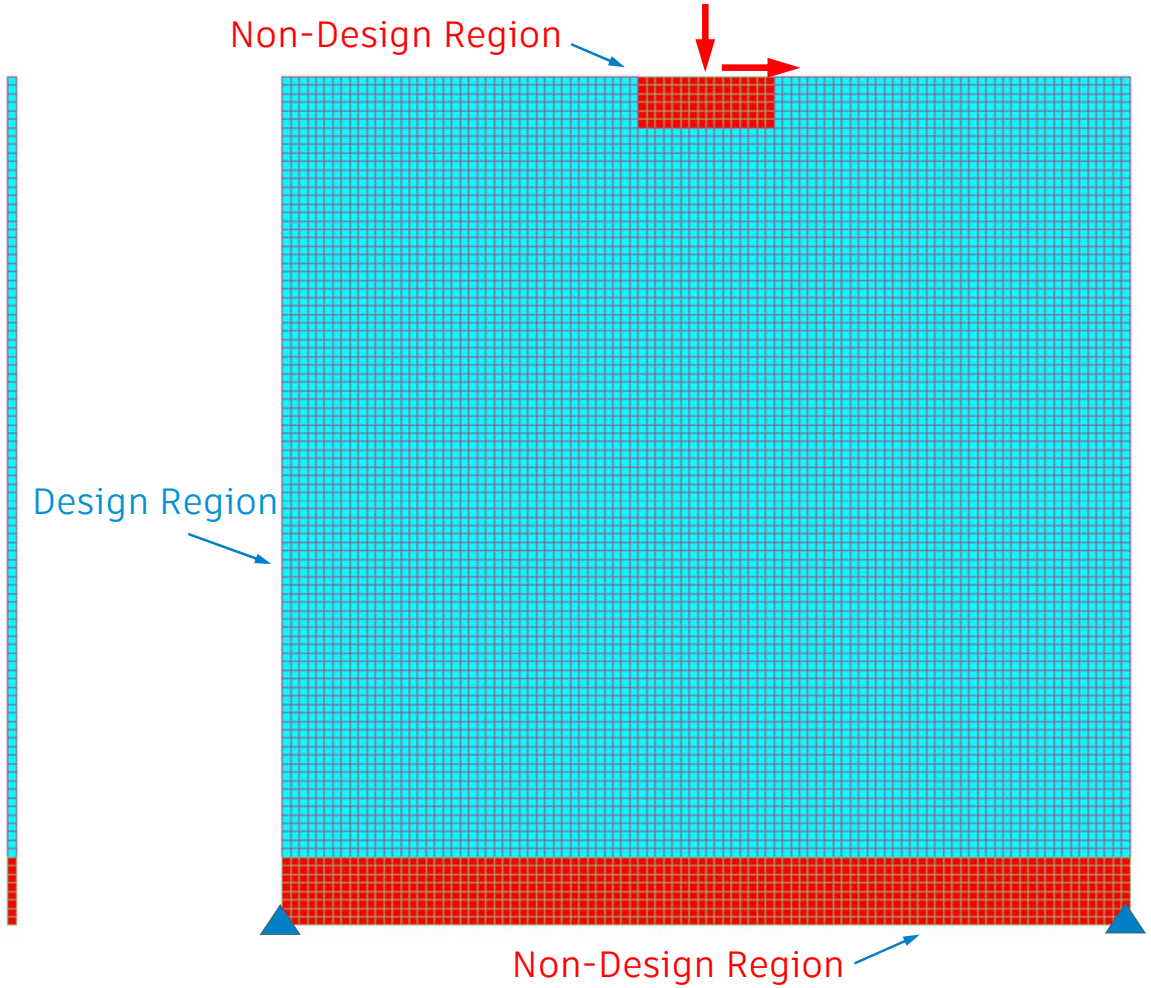
With Mill constraint
Max δ = 0.015
54.5% mass reduction

- Fixed at corners and loaded at center
- Objective is minimize mass
- Constraint is maximum vertical displacement along edge and center
- Manufacturing constraints: symmetry in 2 planes and milling



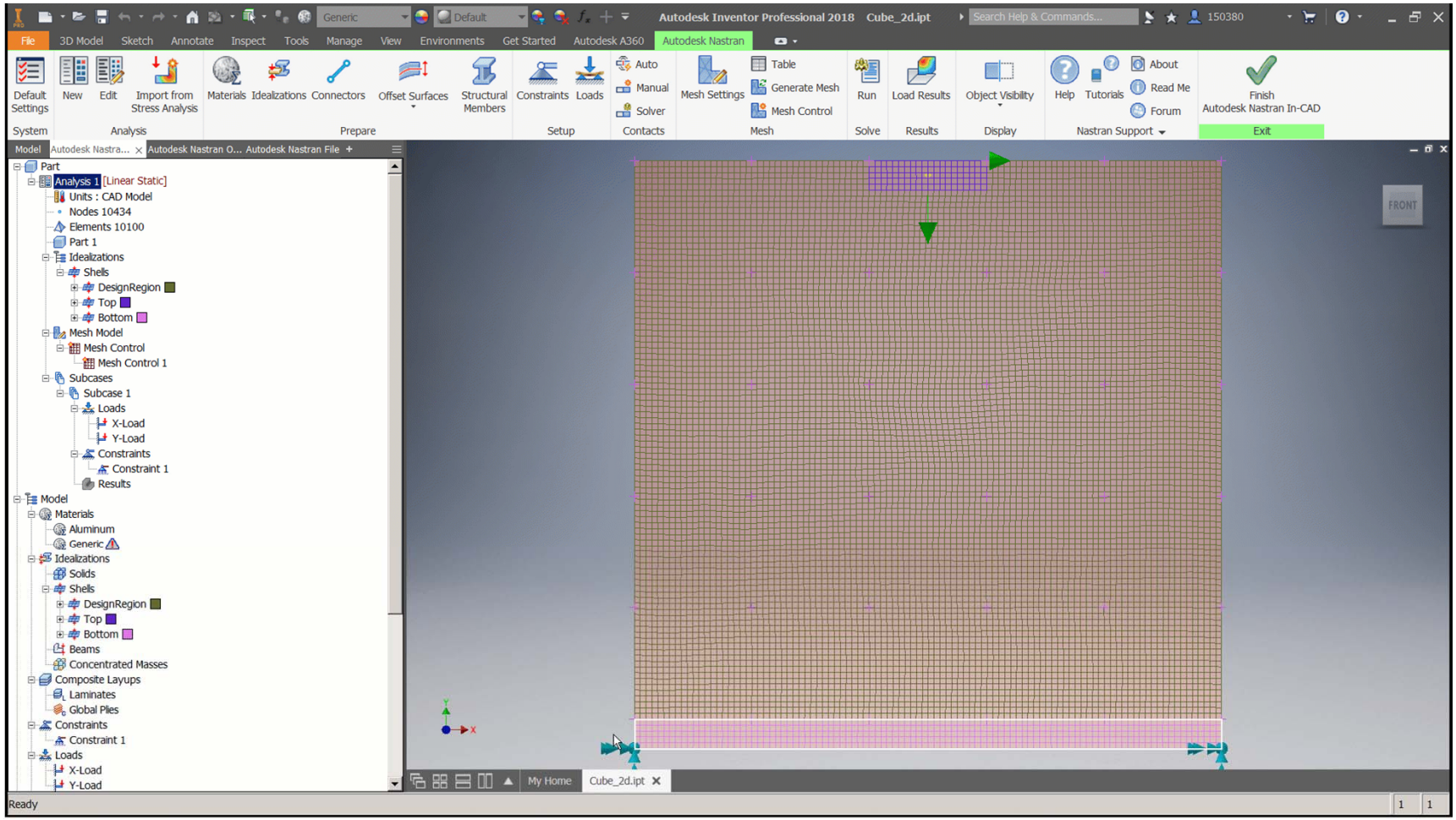
In-CAD Topology Optimization User Interface

Example #1 Model Definition

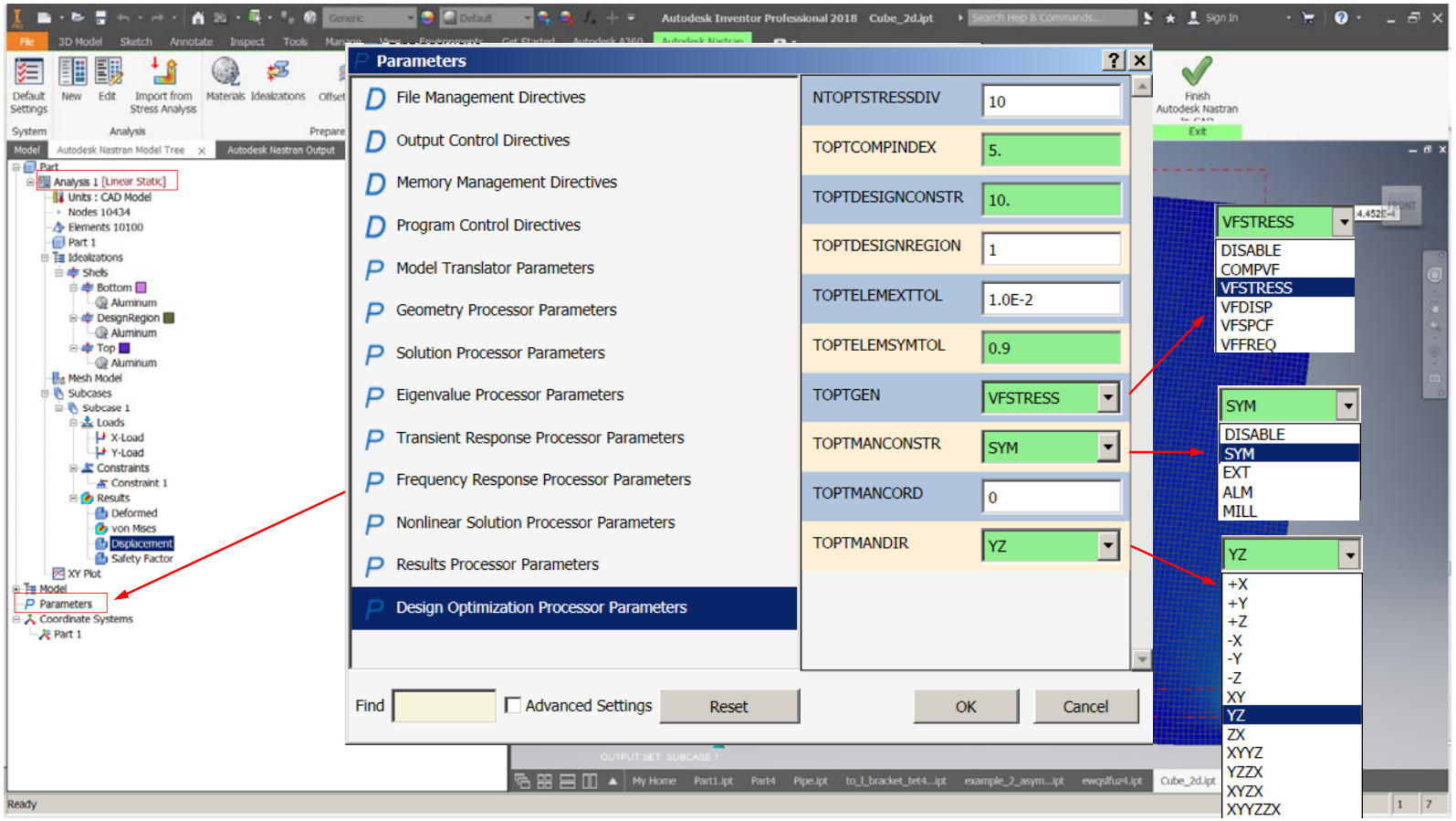


- **Boundary Condition:** Fixed at bottom corners
- **Loading:**
  - Point load in vertical and shear directions
- **Design constraints:**
  - Desired volume fraction
  - Stress limit
  - Displacement limit
  - Lowest frequency
- **Objectives:**
  - Minimize compliance
  - Minimize mass/volume
- **Manufacturing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

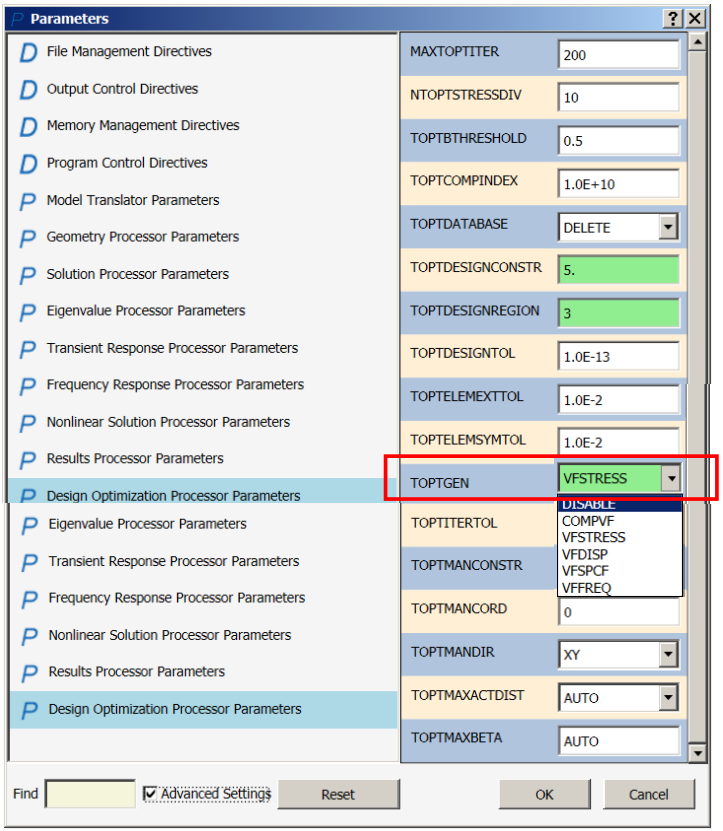
Topology Optimization Example #1



Topology Optimization Example #1

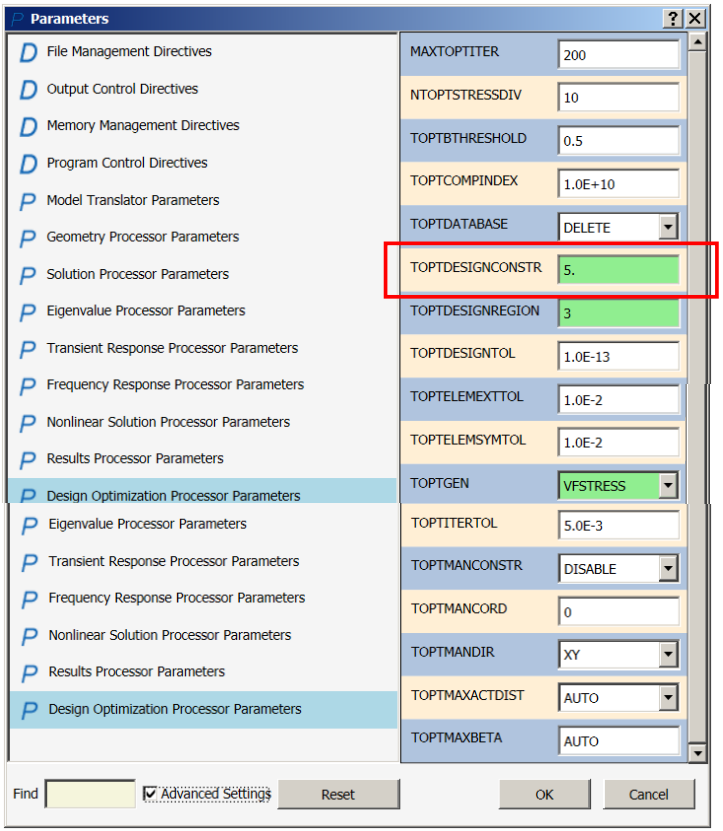


In-CAD Optimization Parameters - TOPTGEN



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

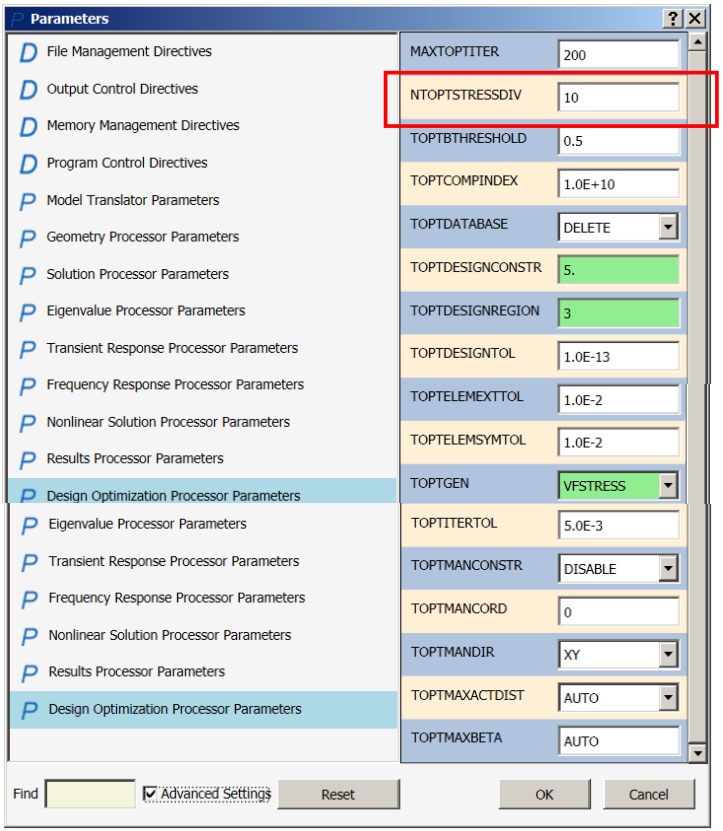
In-CAD Optimization Parameters - TOPTDESIGNCONSTR



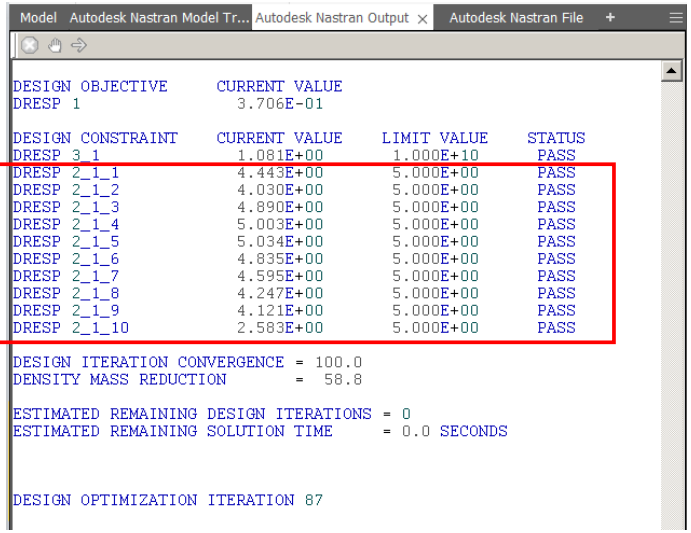
Description	Type	Default
Topology design optimization design constraint value based on the TOPTGEN setting. See TOPTGEN.	Real > 0.0	1.0E+10

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

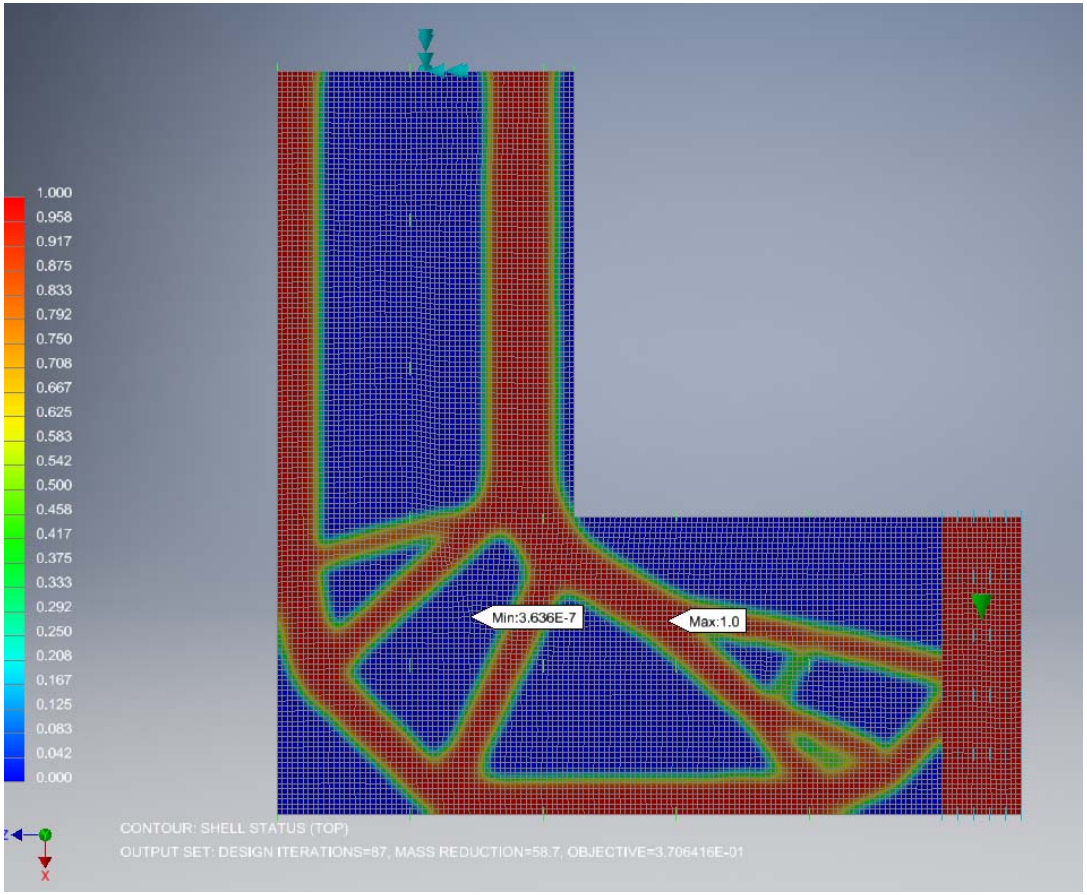


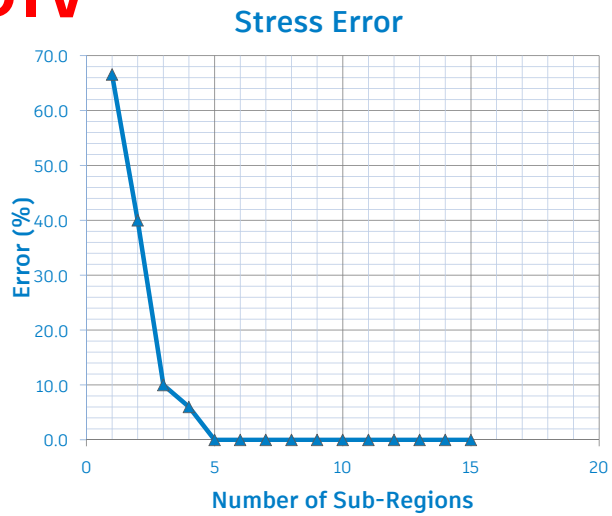
Description	Type	Default
Topology design optimization number of stress divisions. Applicable when a stress constraint is specified. A larger value will produce a more accurate result with a reduction in performance. A value between 5 and 10 is recommended.	1 ≤ Integer ≤ 100	10

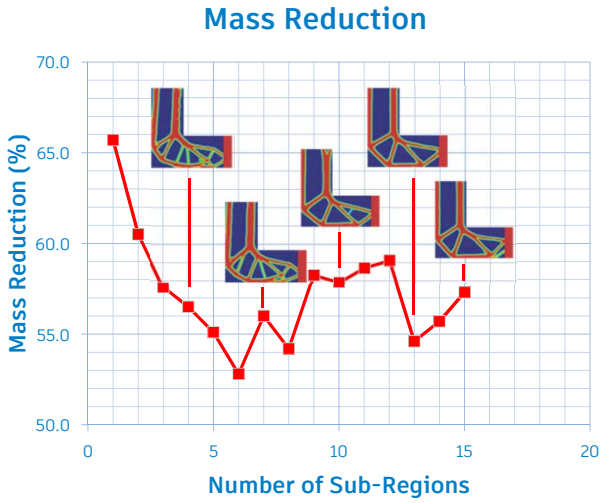


L-Bracket Test Case - NTOPTSTRESSDIV

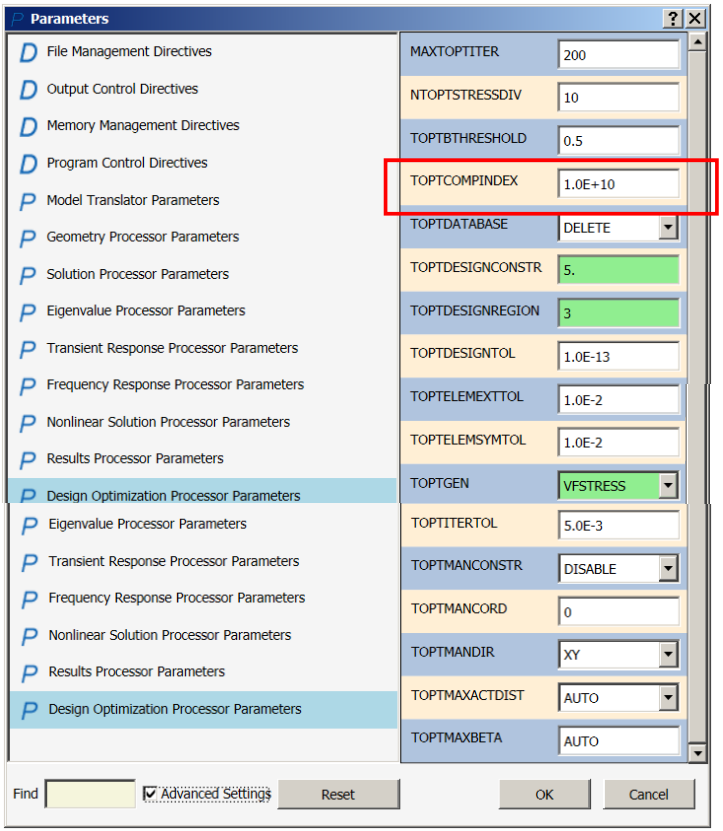
- A value between 3 – 10 works best



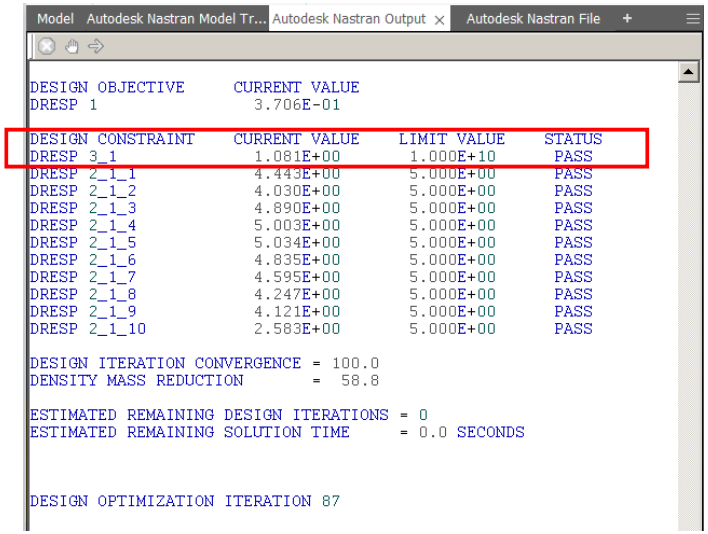




In-CAD Optimization Parameters - TOPTCOMPINDEX

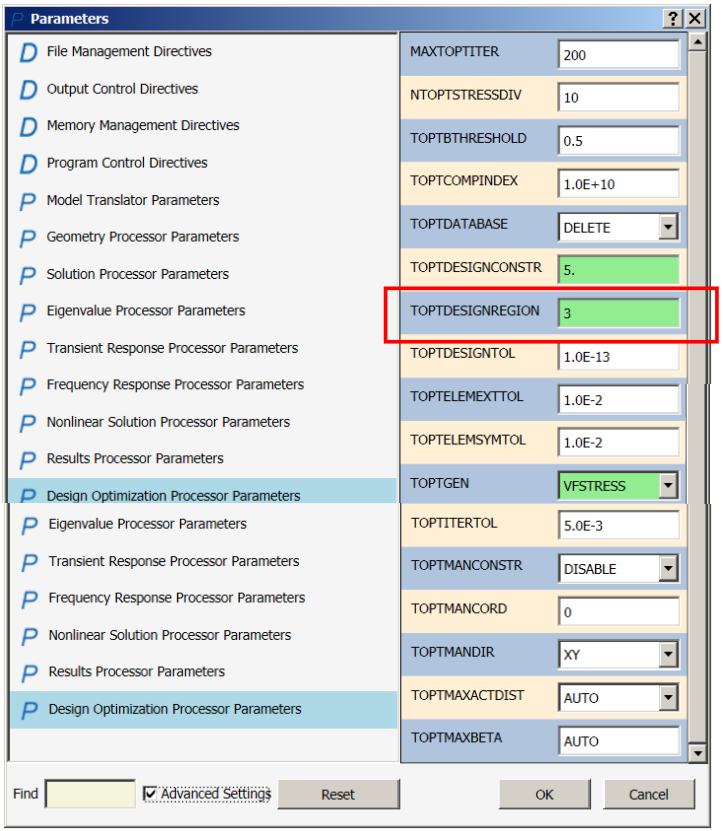


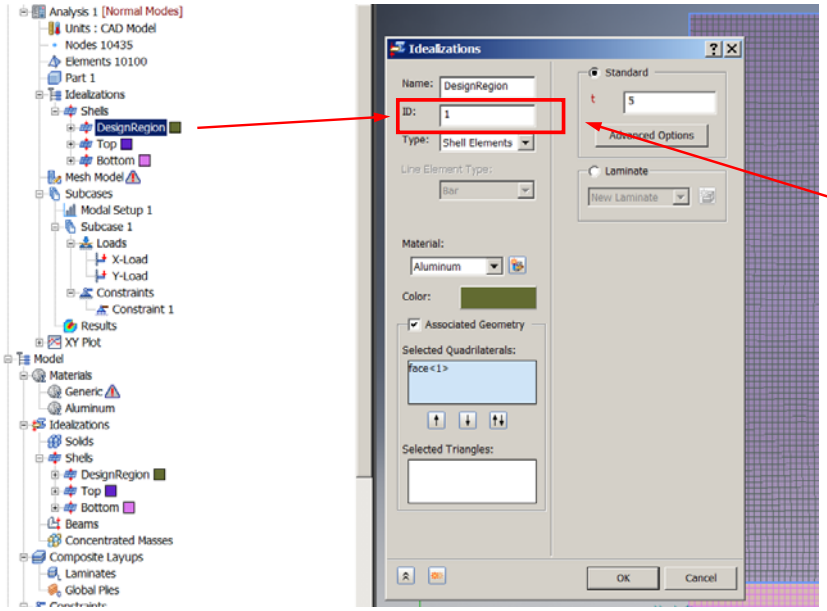
Description	Type	Default
Topology design optimization compliance index design constraint value. Applicable only when TOPTGEN is set to 2, 3, or 4.	Real > 1.0	1.0E+10

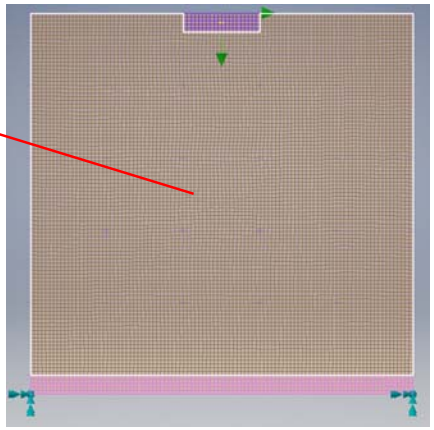


In-CAD Optimization Parameters - TOPTDESIGNREGION

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

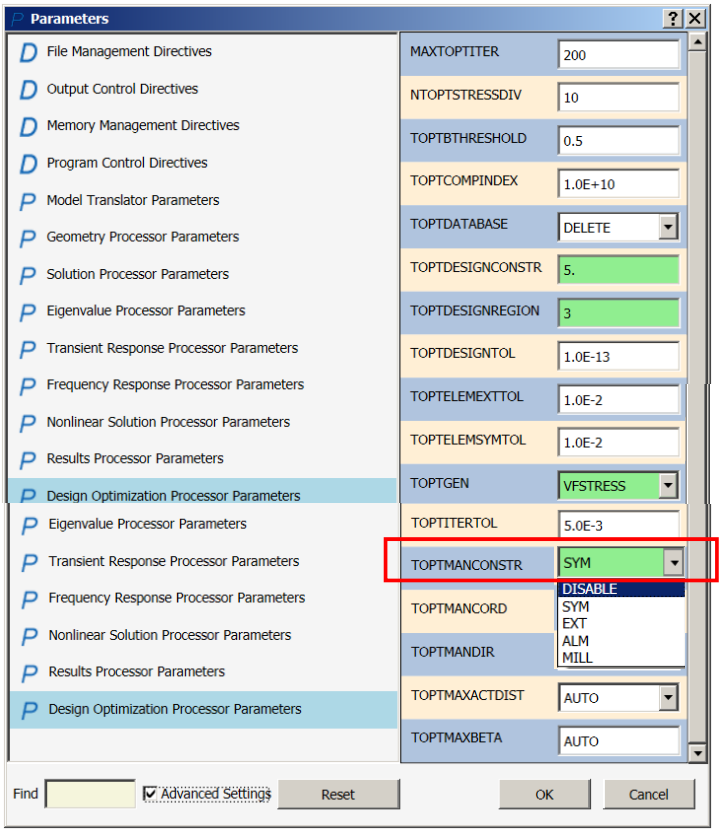






- Note: Specifying the wrong ID may result in an 2299 or 5125 fatal error

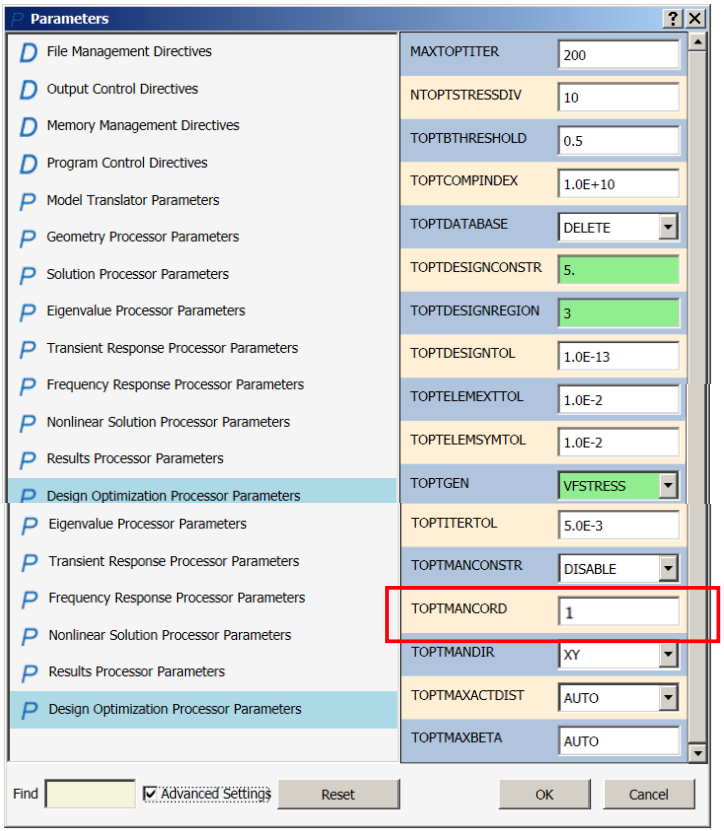
In-CAD Optimization Parameters - TOPTMANCONSTR

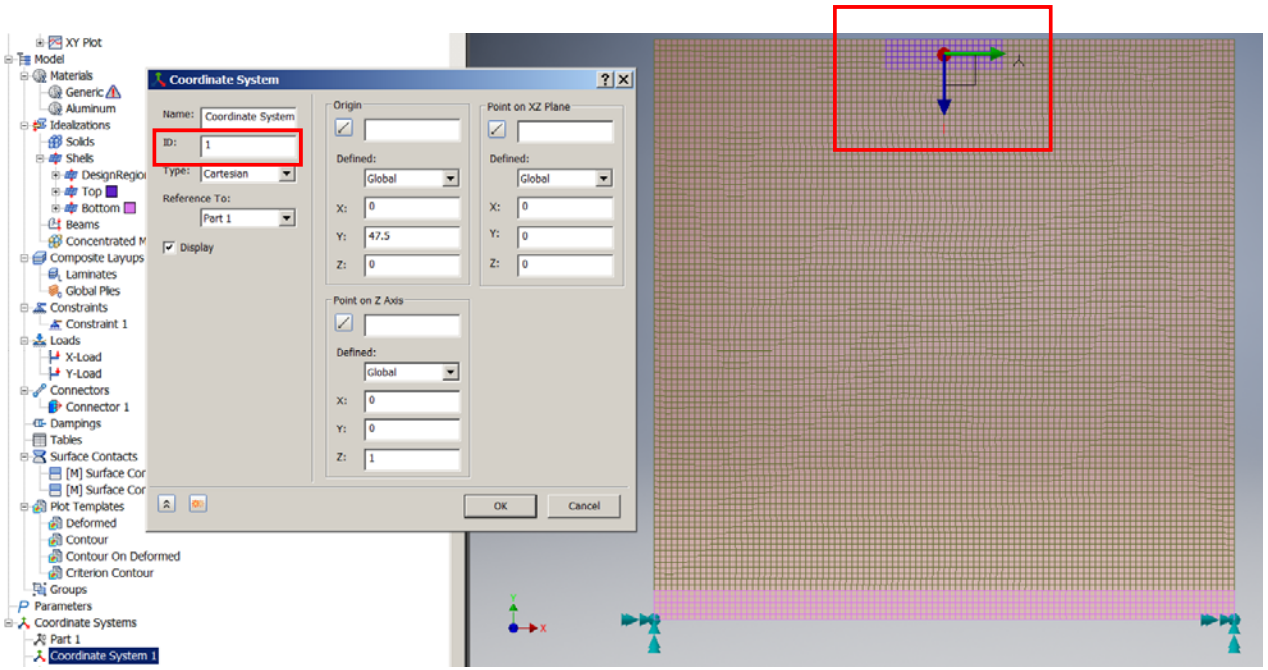


Description	Type	Default
Defines the type of manufacturing constraint to be used in Automated Topology Optimization Generation (ATOG). There are three options: 0 - No manufacturing constraint is specified. 1 - Symmetry using either 1, 2, or 3 planes of symmetry is specified. 2 - Extrude design constraint 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 ≤ Integer ≤ 3 DISABLE/ SYM/ EXT/ ALM/ MILL	0

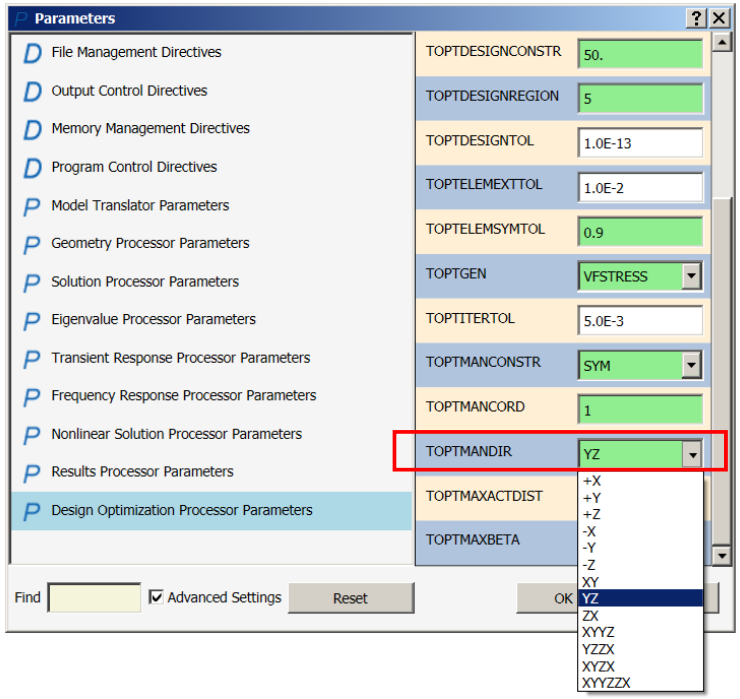
In-CAD Optimization Parameters - TOPTMANCORD

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





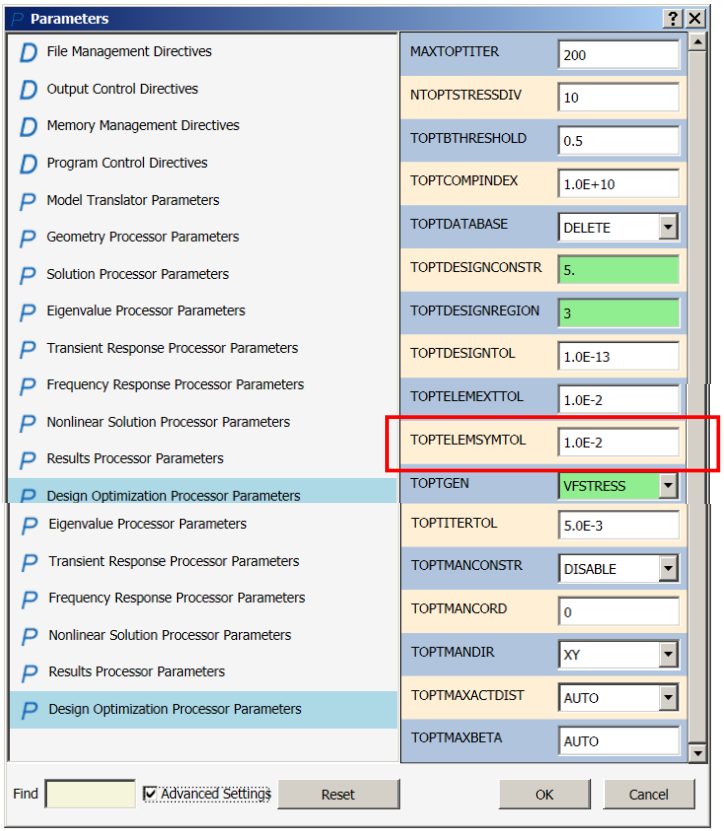
In-CAD Optimization Parameters - TOPTMANDIR



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/ XY/YZ/ZX/ XYYZ/YZZX/ XYZX/ XYYZZX	XY

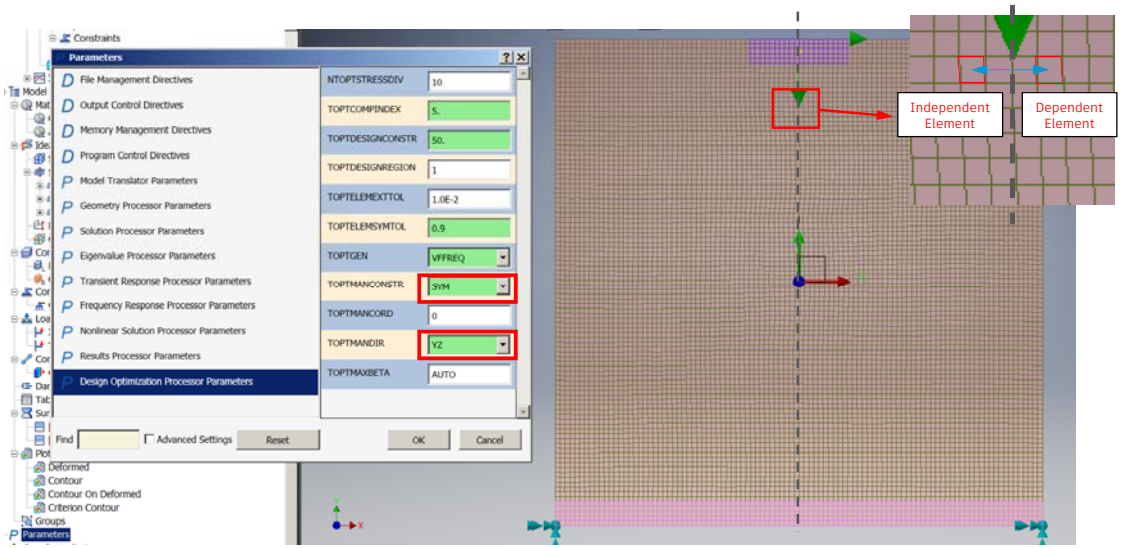
Keyword	TOPTMANDIR Definition
DISABLE	No manufacturing constraints specified
SYM	Symmetry plane or planes specified in the TOPTMANCORD system
EXT	Extrude direction axis specified in the TOPTMANCORD system
ALM	Print direction axis specified in the TOPTMANCORD system
MILL	Mill direction axis specified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

In-CAD Optimization Parameters - TOPTELEMSYMTOL



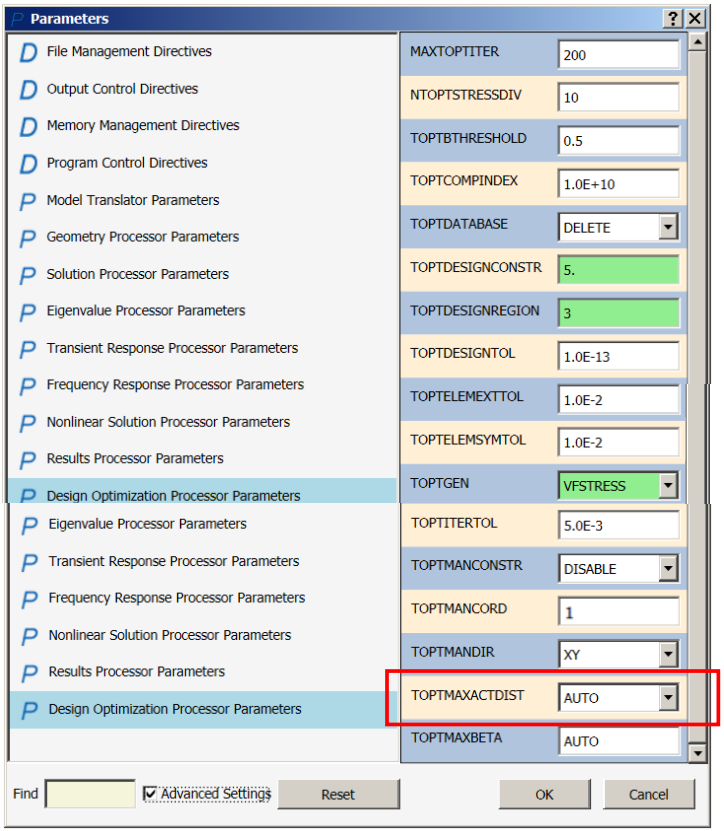
Description	Type	Default
Near tolerance used to identify elements which are symmetric with respect to the specified TOPVAR Bulk Data entry mirror symmetry plane. The actual tolerance is derived using TOPTELEMSYMTOL and an element reference dimension.	Real	1.0E-2

YZ Symmetry



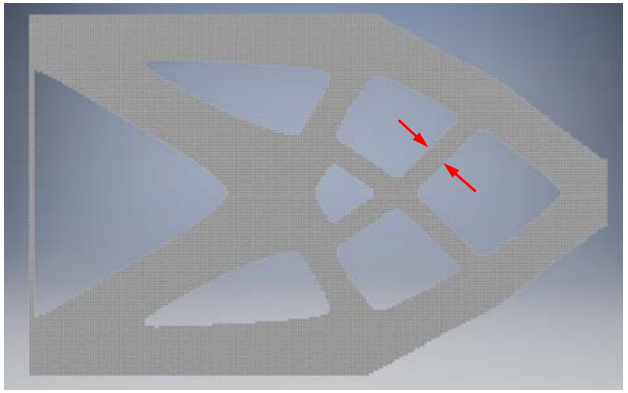
In-CAD Optimization Parameters - TOPTMAXACTDIST

Use this to specify a minimum member size

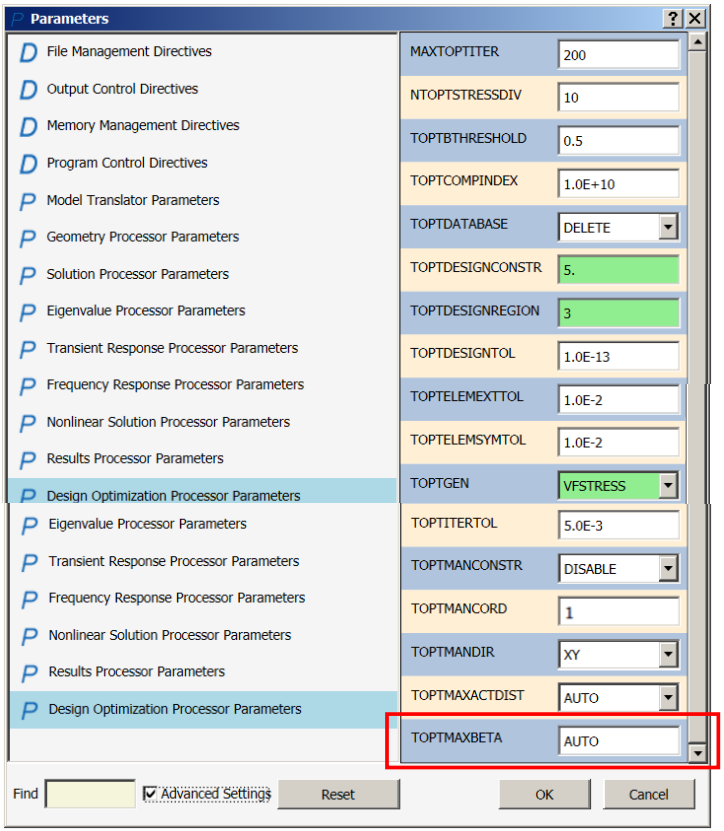


Description	Type	Default
Topology design optimization maximum distance for identifying adjacent elements. Elements within distance TOPTMAXACTDIST are used for sensitivity filtering. The default AUTO setting is recommended since large values may result in slower performance and undesired results.	Real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

- TOPTMAXACTDIST is ½ minimum member size
- To specify a minimum member size of 1 use 0.5.

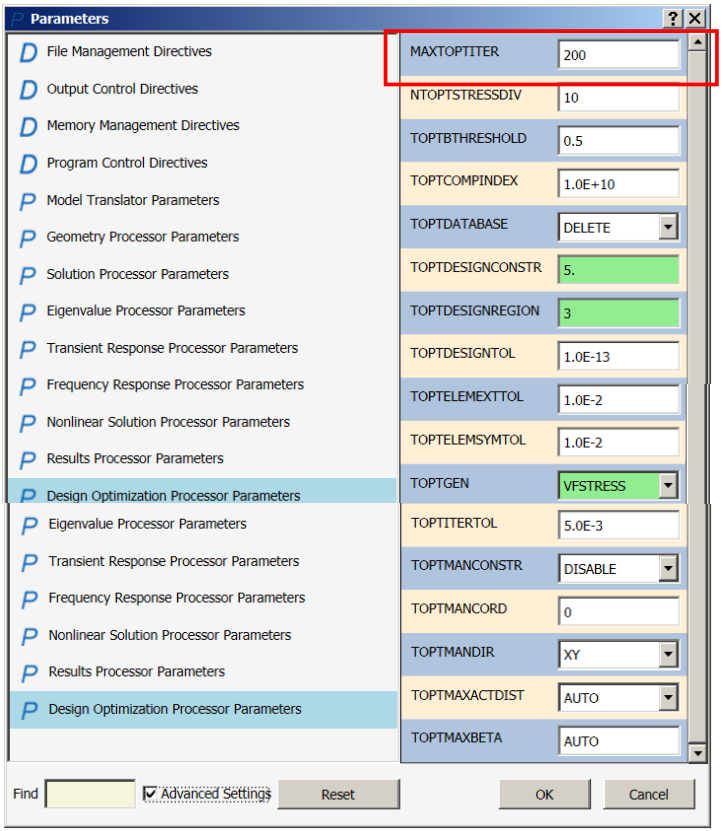


In-CAD Optimization Parameters - TOPTMAXBETA

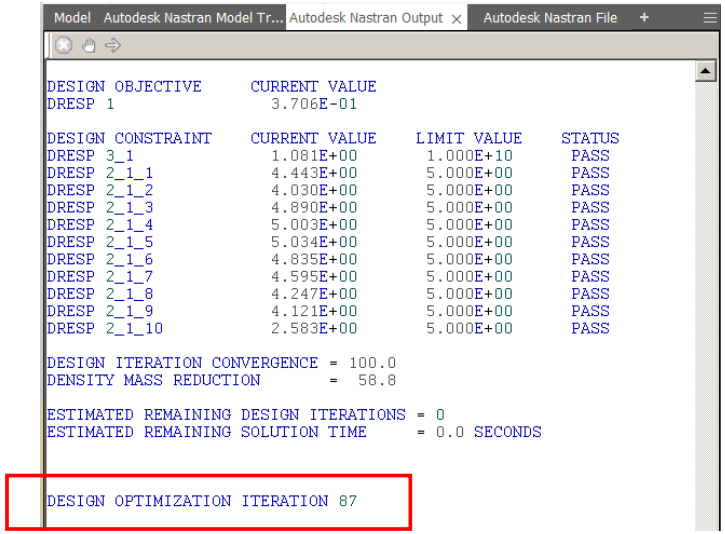


Description	Type	Default
Specifies the penalty value for enforcing minimum member size manufacturing constraints. A value between 1.0 and 16.0 is recommended. The default AUTO value selects the best value depending on what other constraints are specified.	Real AUTO	AUTO

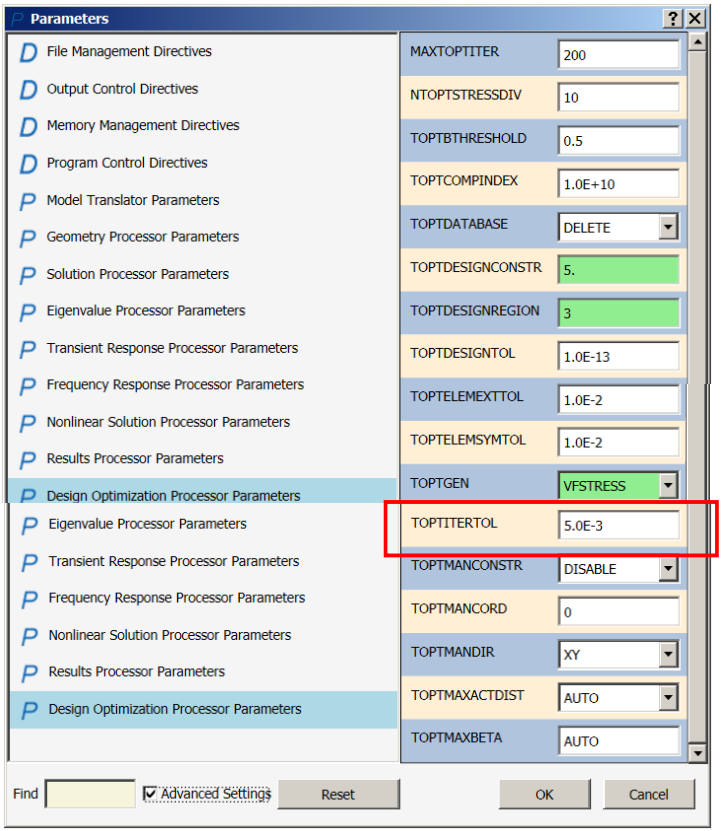
In-CAD Optimization Parameters - MAXTOPTITER



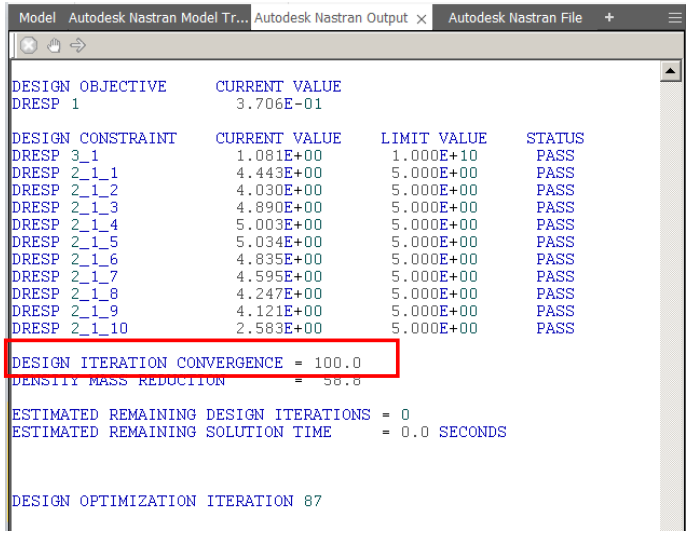
Description	Type	Default
Topology design optimization maximum number of convergence iterations permitted. The solver will iterate until the convergence factor set by TOPTITERTOL is reached or MAXOPTITER iterations have been performed. A zero setting will result in iteration until convergence is reached.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



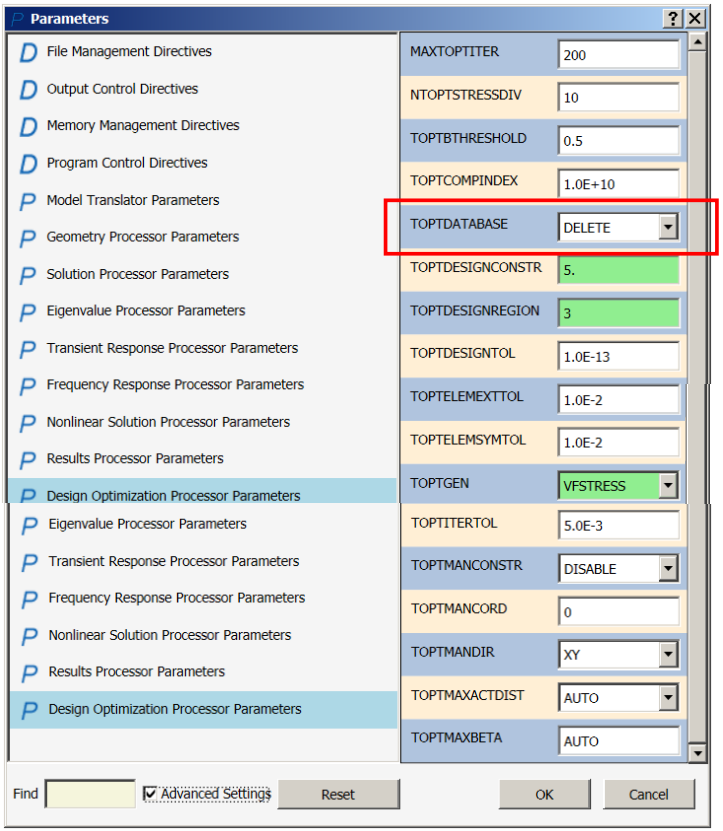
In-CAD Optimization Parameters - TOPTITERTOL



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



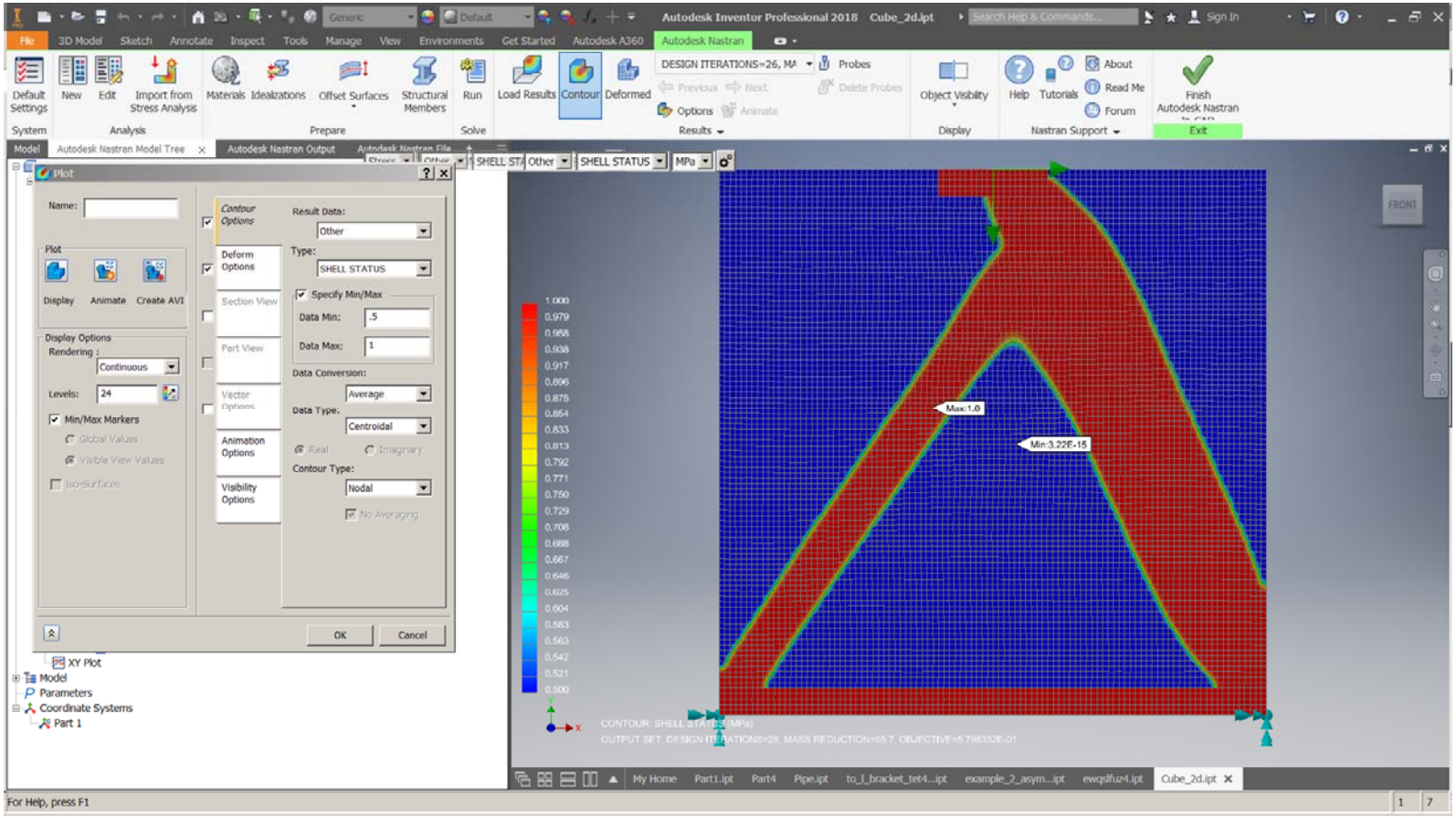
In-CAD Optimization Parameters - TOPTDATABASE



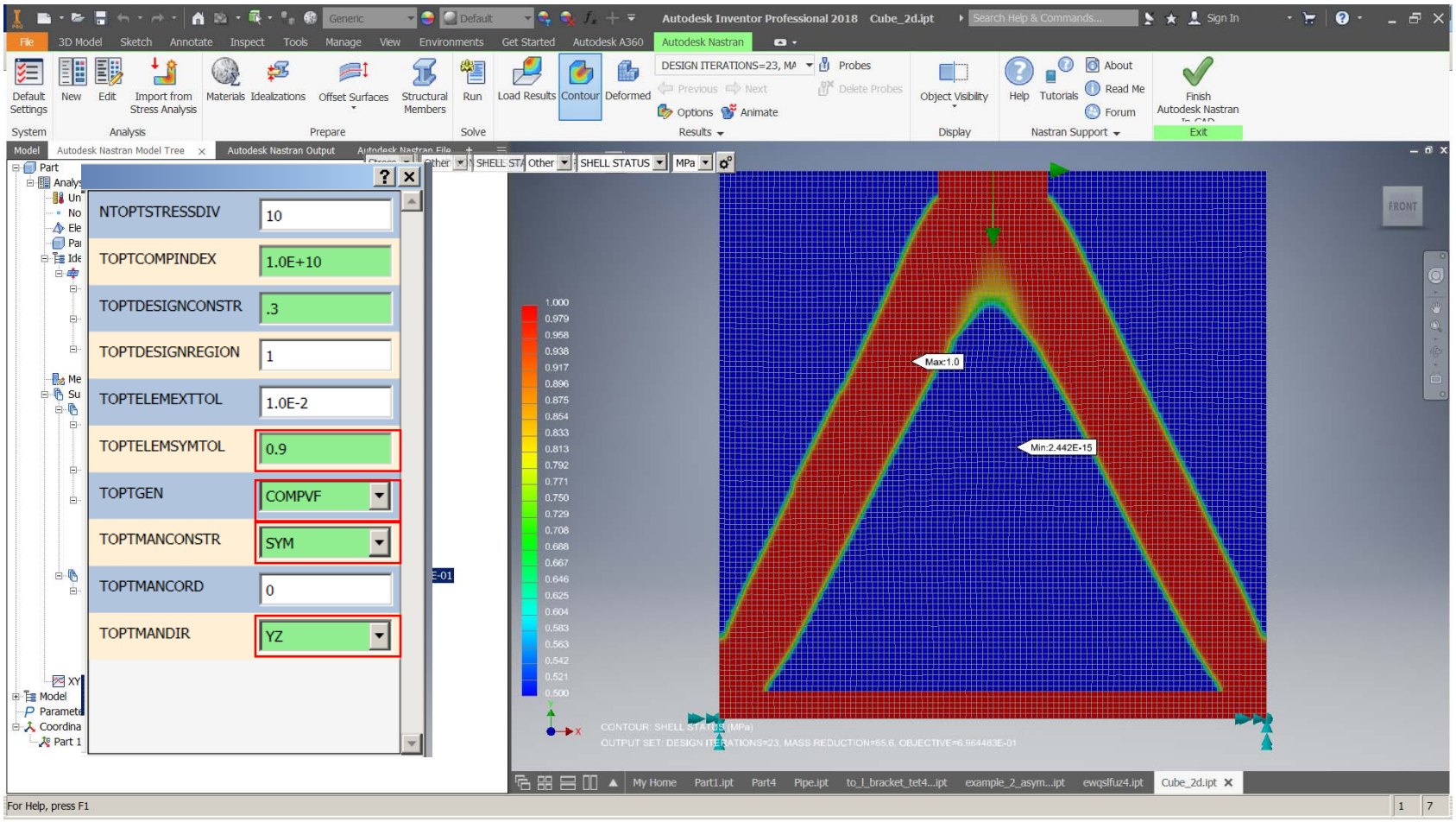
Description	Type	Default
Controls the storage and retrieval of topology design optimization density data. The default value DELETE purges all element density data when the program terminates normally. When set to STORE, the converged optimized design is stored in a single file with the same base name 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

NTOPTSTRESSDIV	10
TOPTCOMPINDEX	1.0E+10
TOPTDESIGNCONSTR	.3
TOPTDESIGNREGION	1
TOPTELEMEXTTOL	1.0E-2
TOPTELEMSYMTOL	1.0E-2
TOPTGEN	COMPVF
TOPTMANCONSTR	DISABLE
TOPTMANCORD	0
TOPTMANDIR	XY

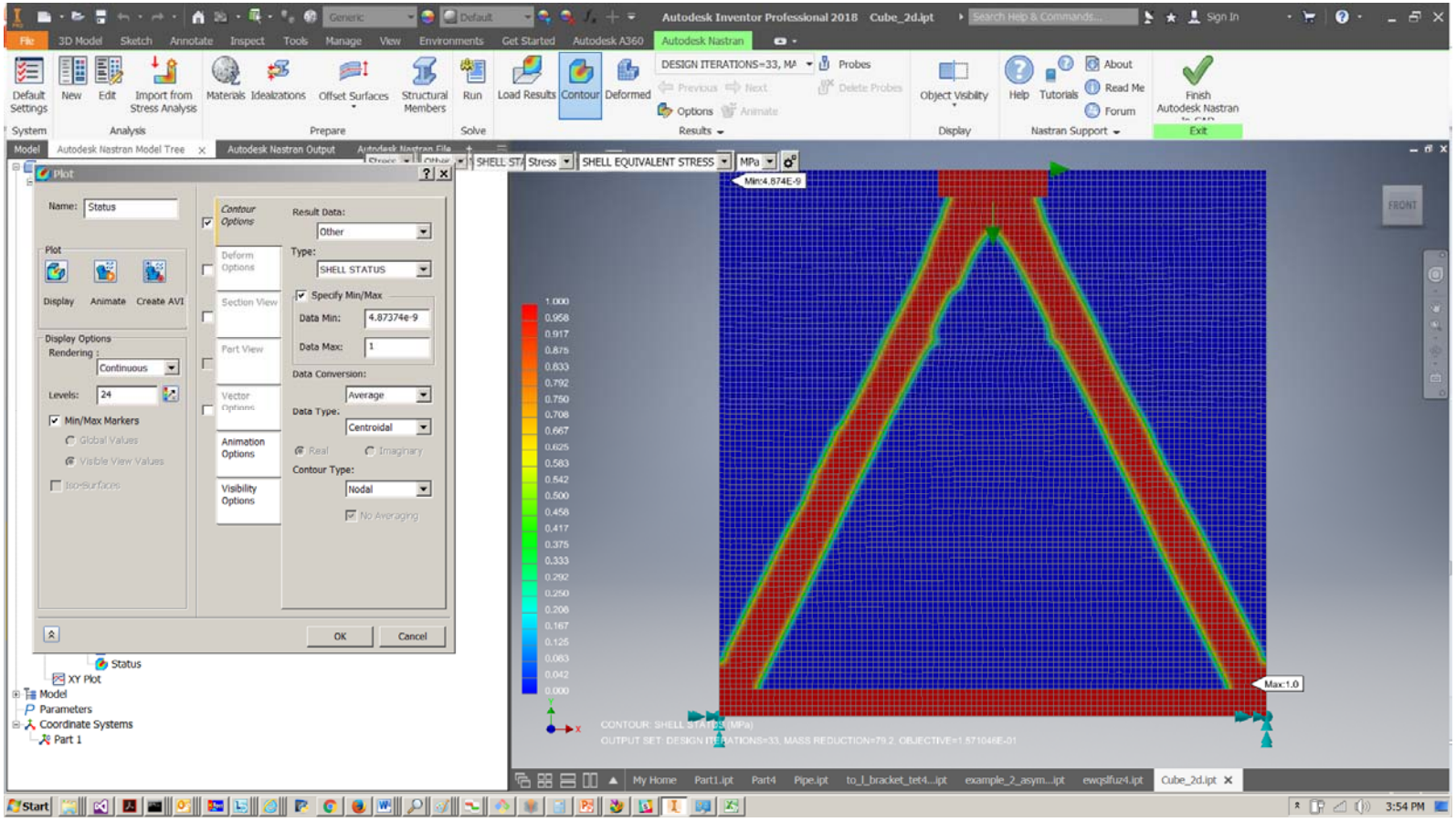


Obj: Min. Compliance, Constraint: Desired VF, with Sym



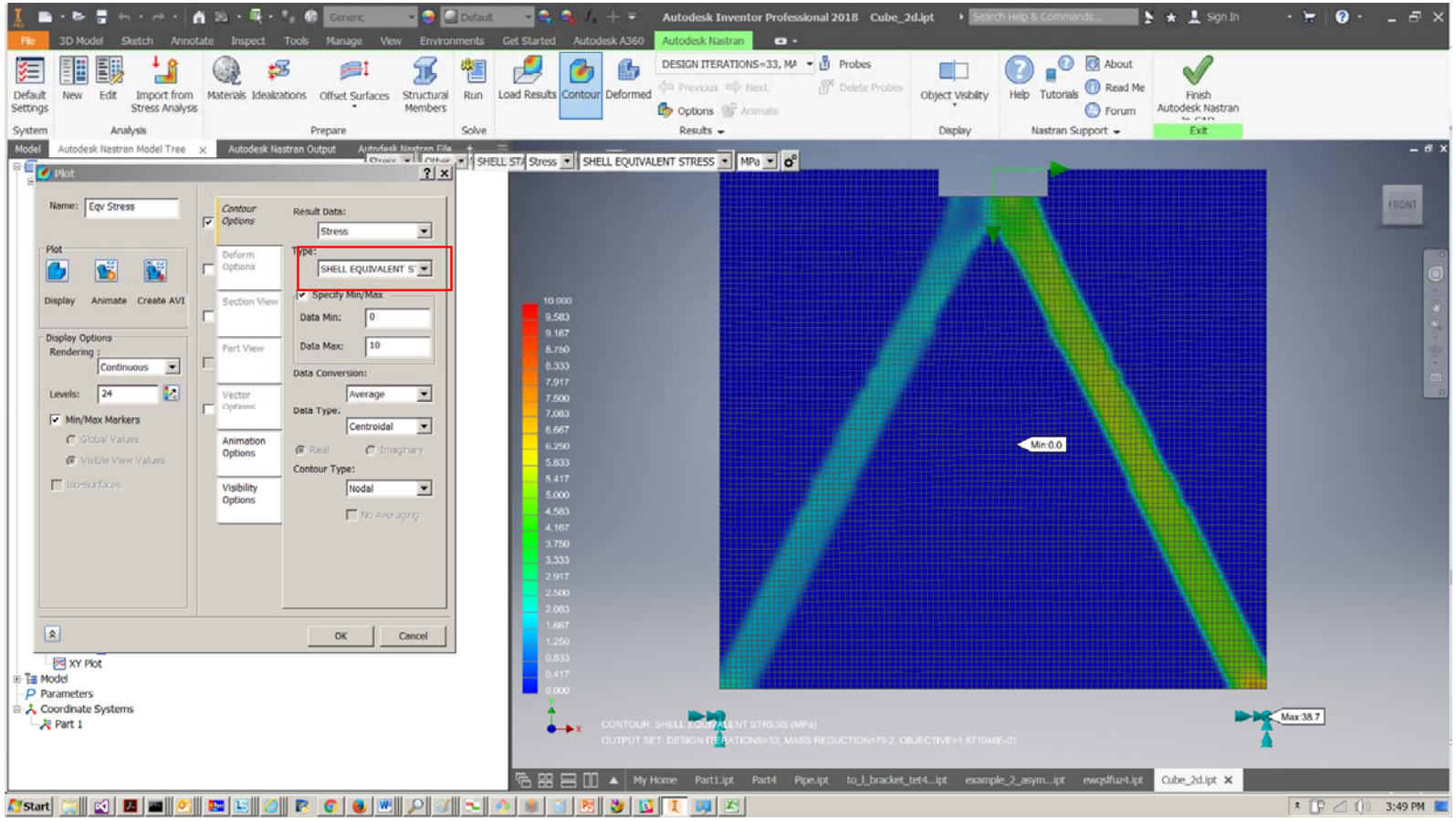
Obj: Min. VF (mass), Constraint: Stress & Comp. Index

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

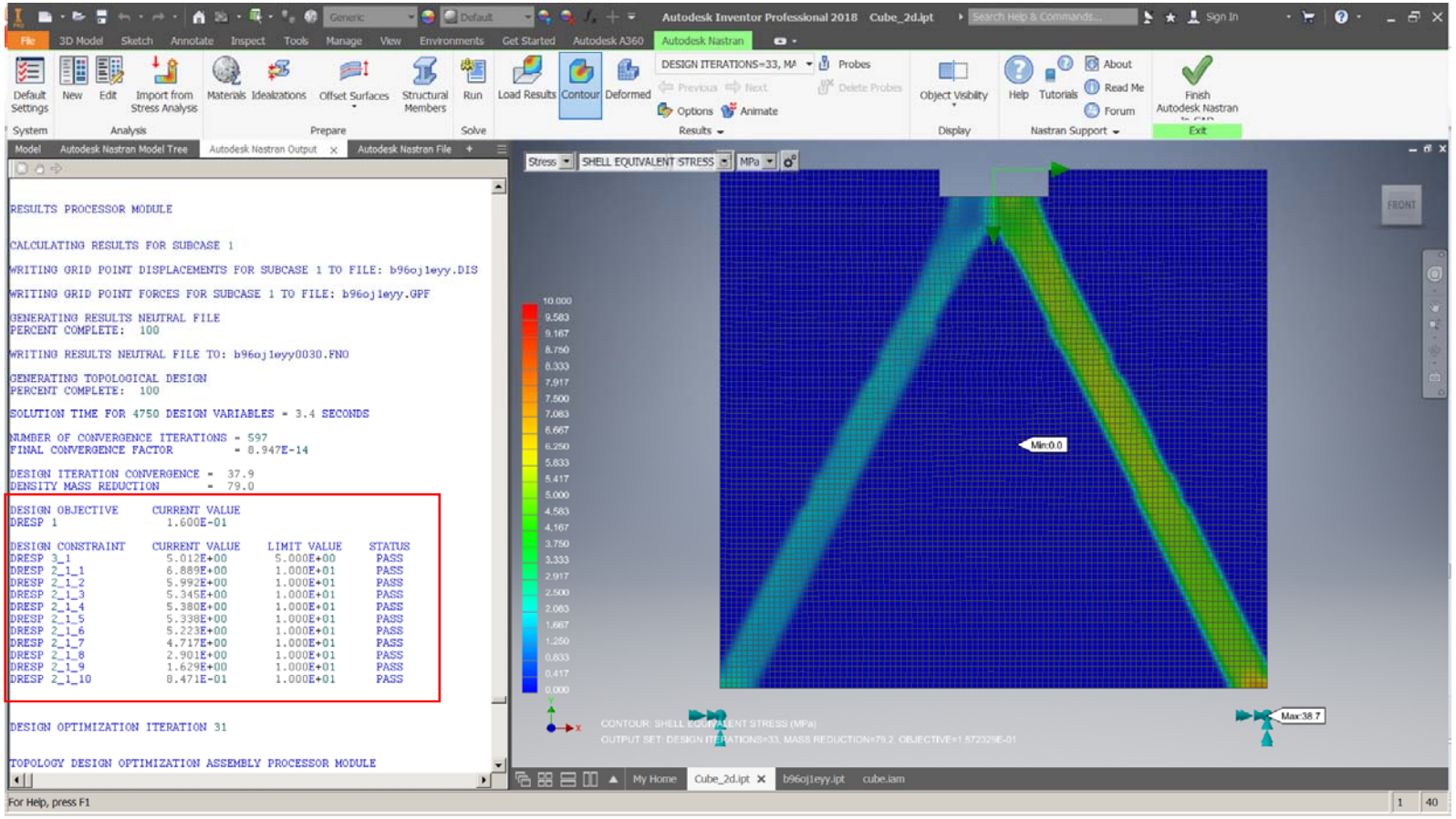


Verify Stress Constraint Using Equivalent Stress

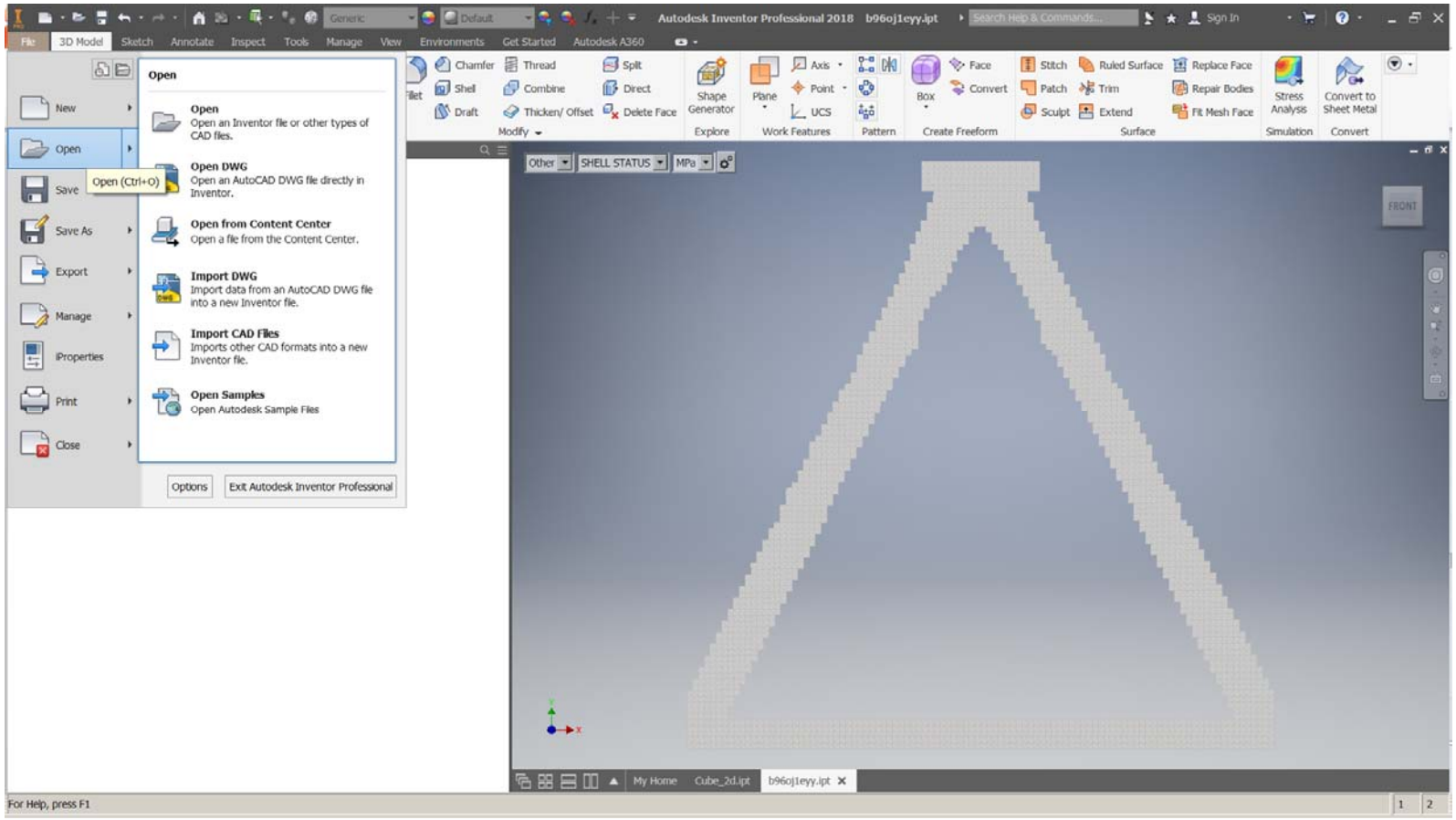
NTOPTSTRESSDIV	10
TOPTCOMPINDEX	5.
TOPTDESIGNCONSTR	10.
TOPTDESIGNREGION	1
TOPTELEMEXTTOL	1.0E-2
TOPTELEMSYMTOL	0.9
TOPTGEN	VFSTRESS
TOPTMANCONSTR	SYM
TOPTMANCORD	0
TOPTMANDIR	YZ



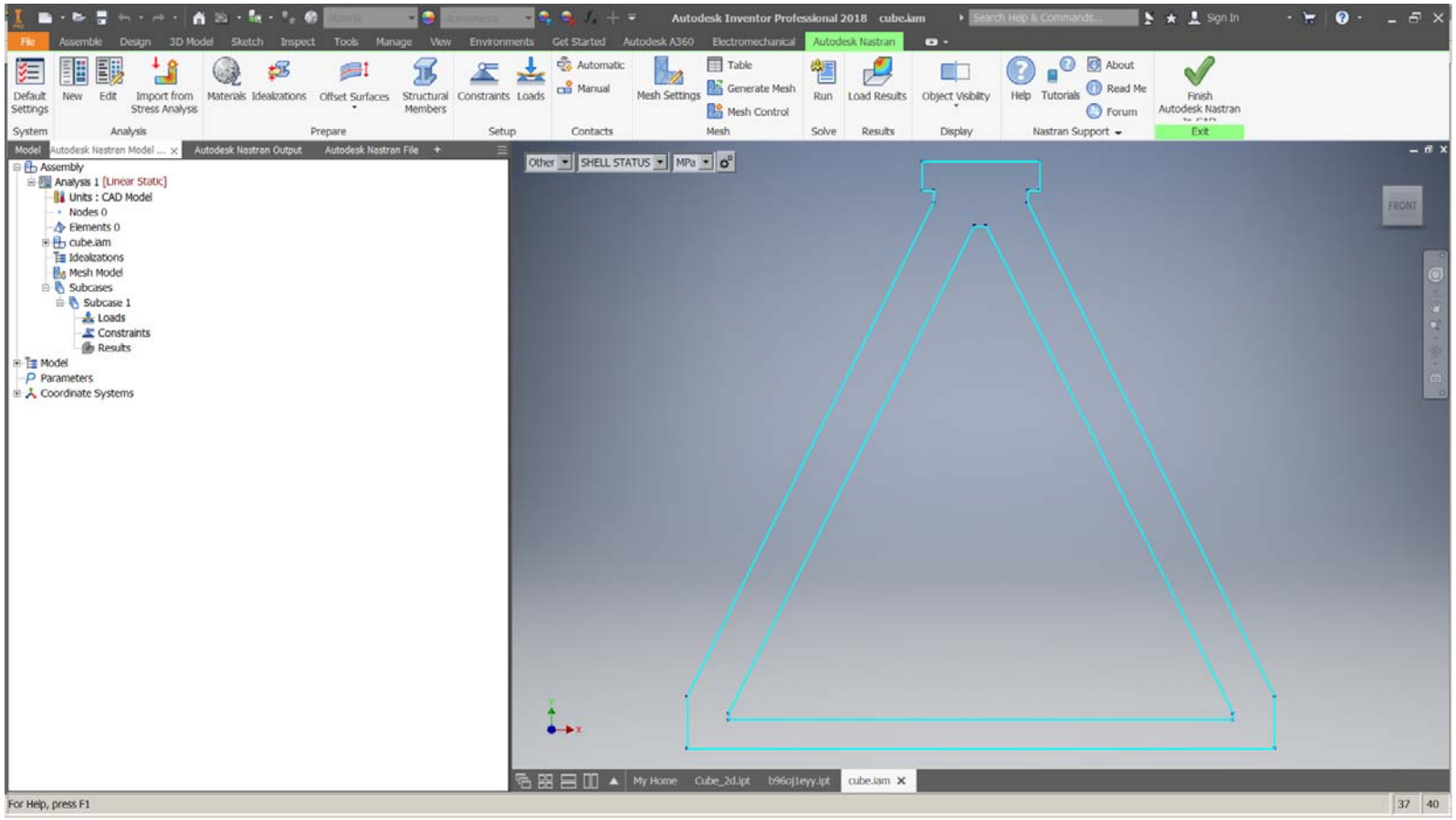
Verify Stress Constraint Using Equivalent Stress



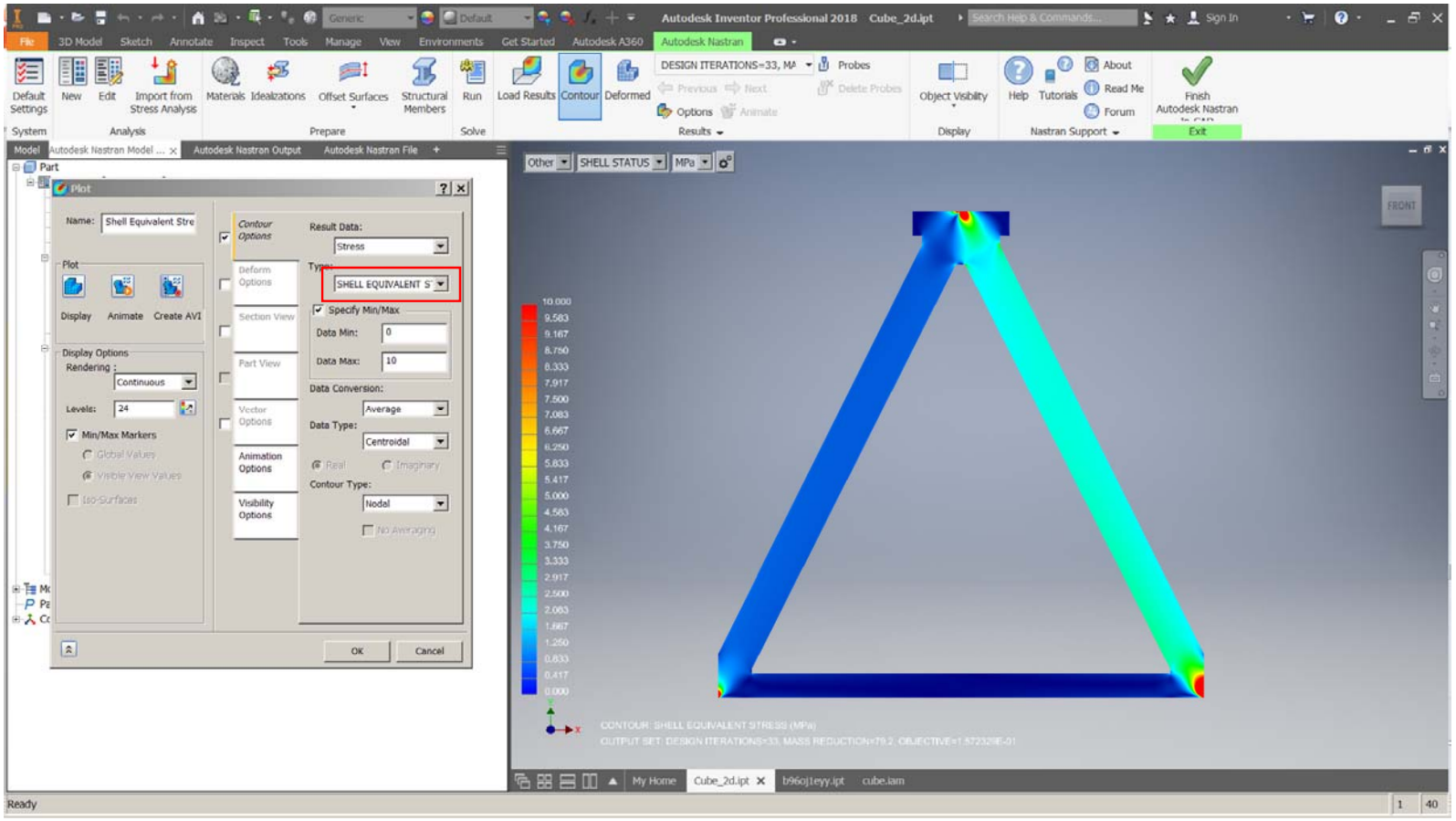
Import Generated Geometry to Build New Design



Import Generated Geometry to Build New Design

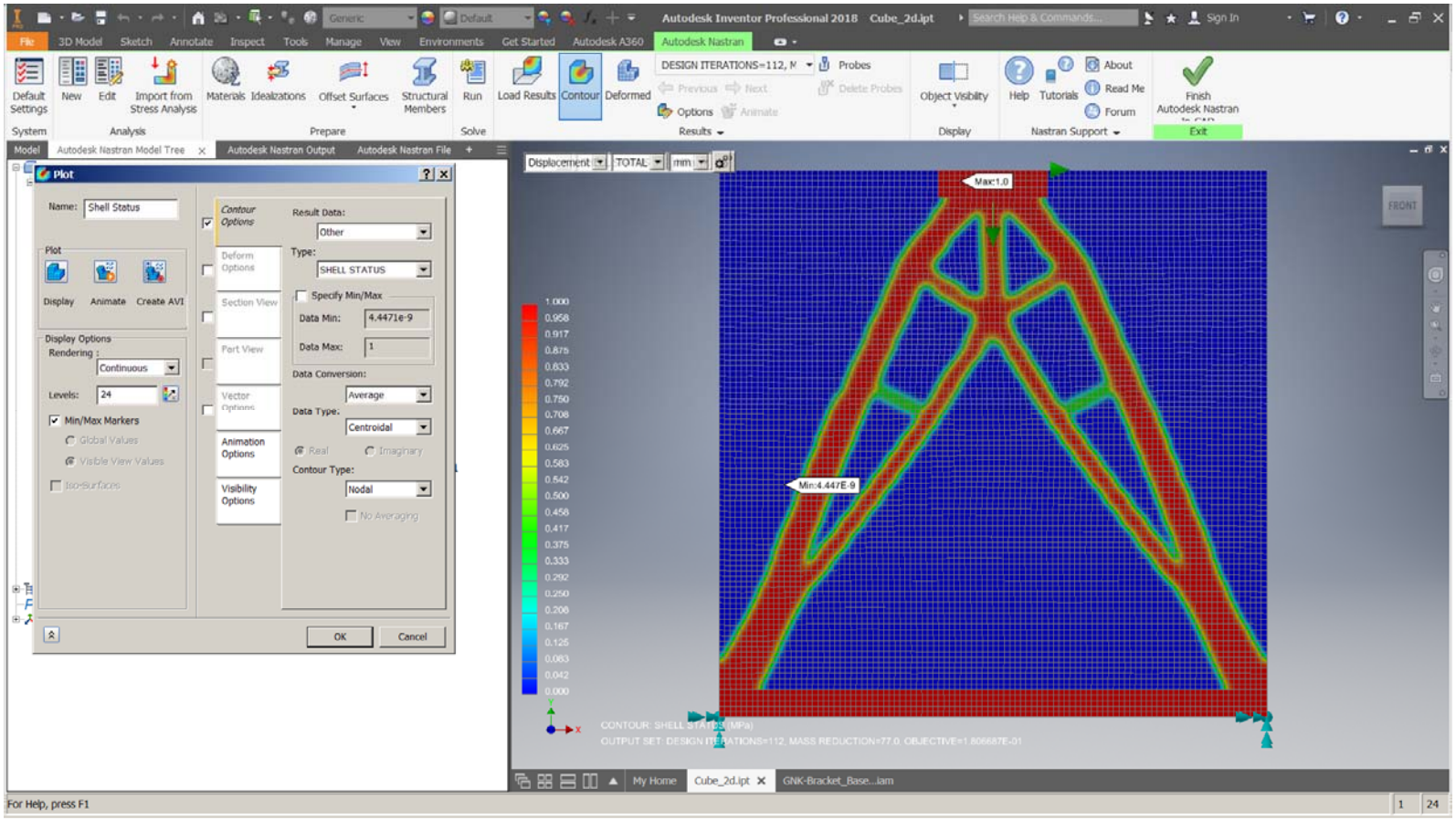


Import Generated Geometry to Build New Design



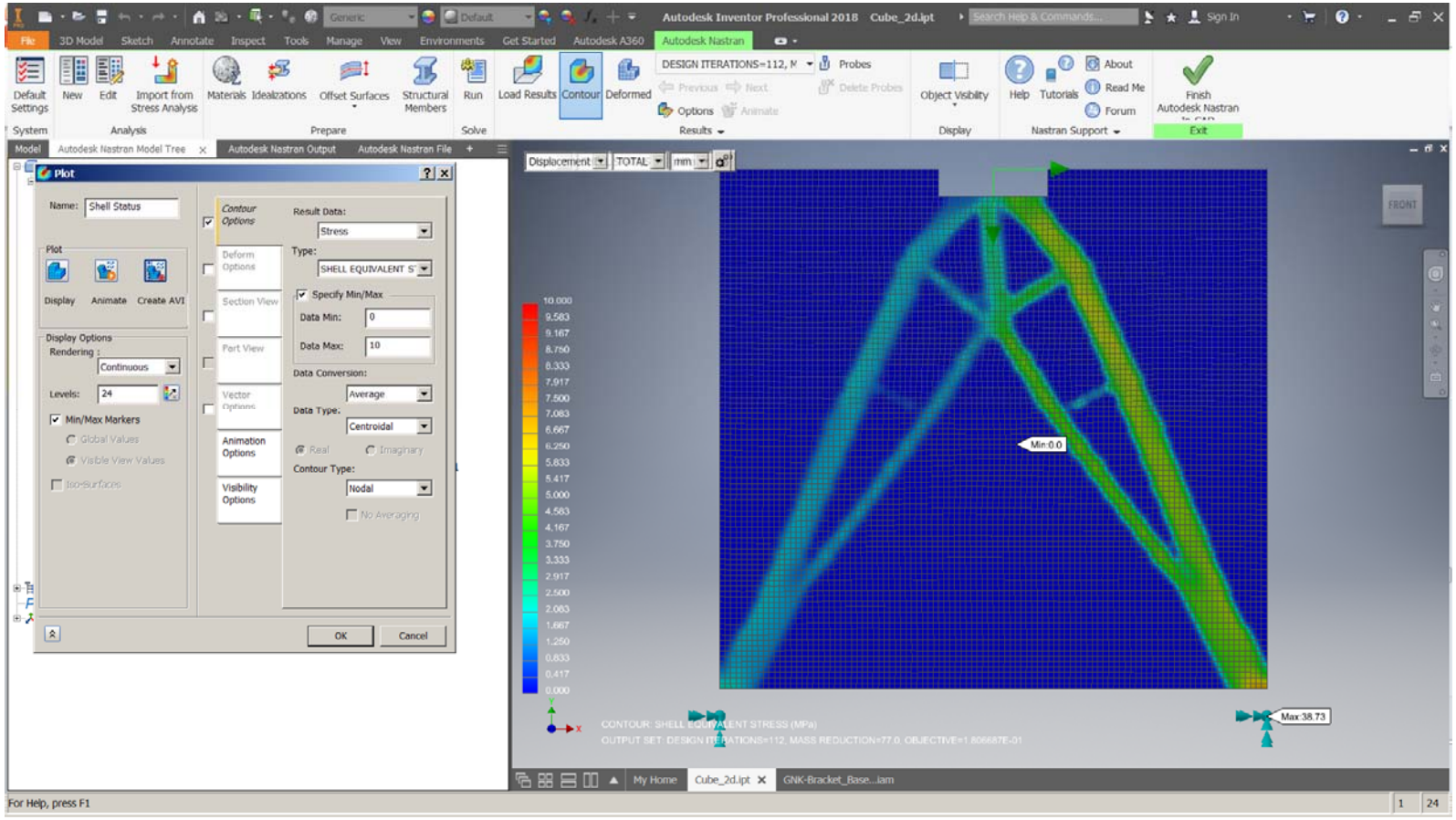
Obj: Min. VF (mass), Constraint: Stress & Comp. Index

NTOPTSTRESSDIV	10
TOPTCOMPINDEX	5.
TOPTDESIGNCONSTR	6.
TOPTDESIGNREGION	1
TOPTELEMEXTTOL	1.0E-2
TOPTELEMSYMTOL	0.9
TOPTGEN	VFSTRESS
TOPTMANCONSTR	SYM
TOPTMANCORD	0
TOPTMANDIR	YZ



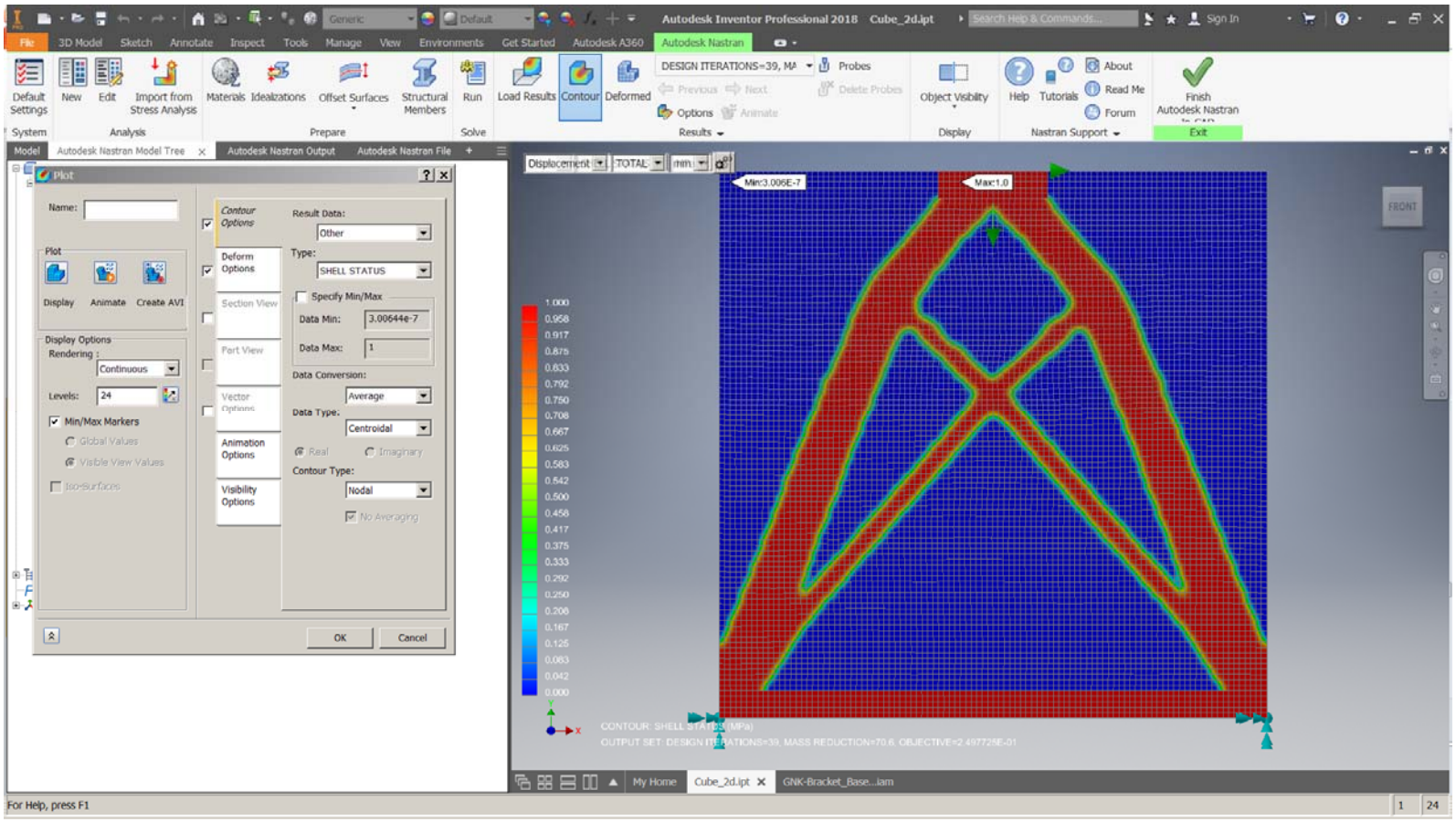
Obj: Min. VF (mass), Constraint: Stress & Comp. Index

NTOPTSTRESSDIV	10
TOPTCOMPINDEX	5.
TOPTDESIGNCONSTR	6.
TOPTDESIGNREGION	1
TOPTELEMEXTTOL	1.0E-2
TOPTELEMSYMTOL	0.9
TOPTGEN	VFSTRESS
TOPTMANCONSTR	SYM
TOPTMANCORD	0
TOPTMANDIR	YZ



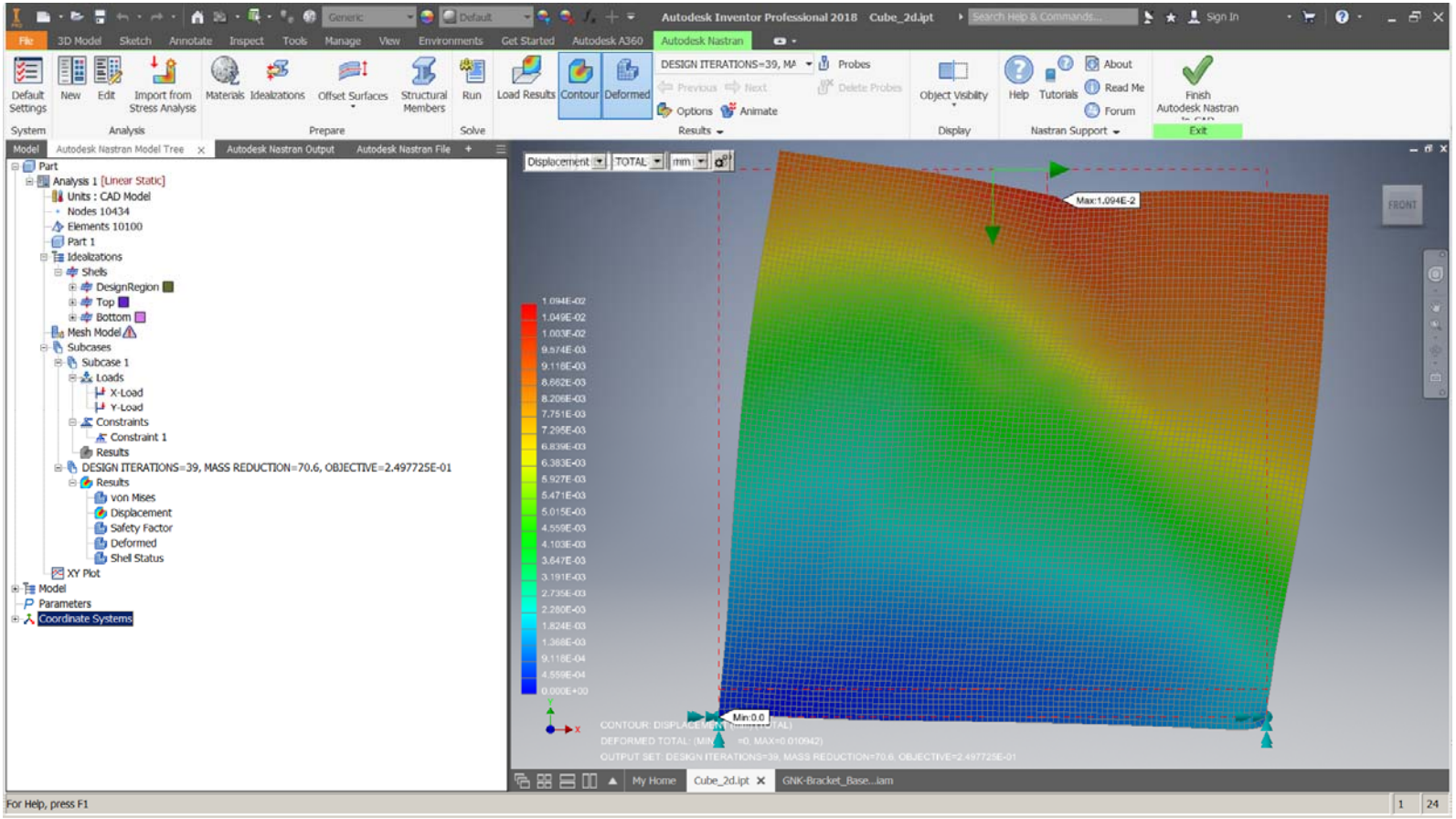
Obj: Min. VF (mass), Constraint: Disp. & Comp. Index

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

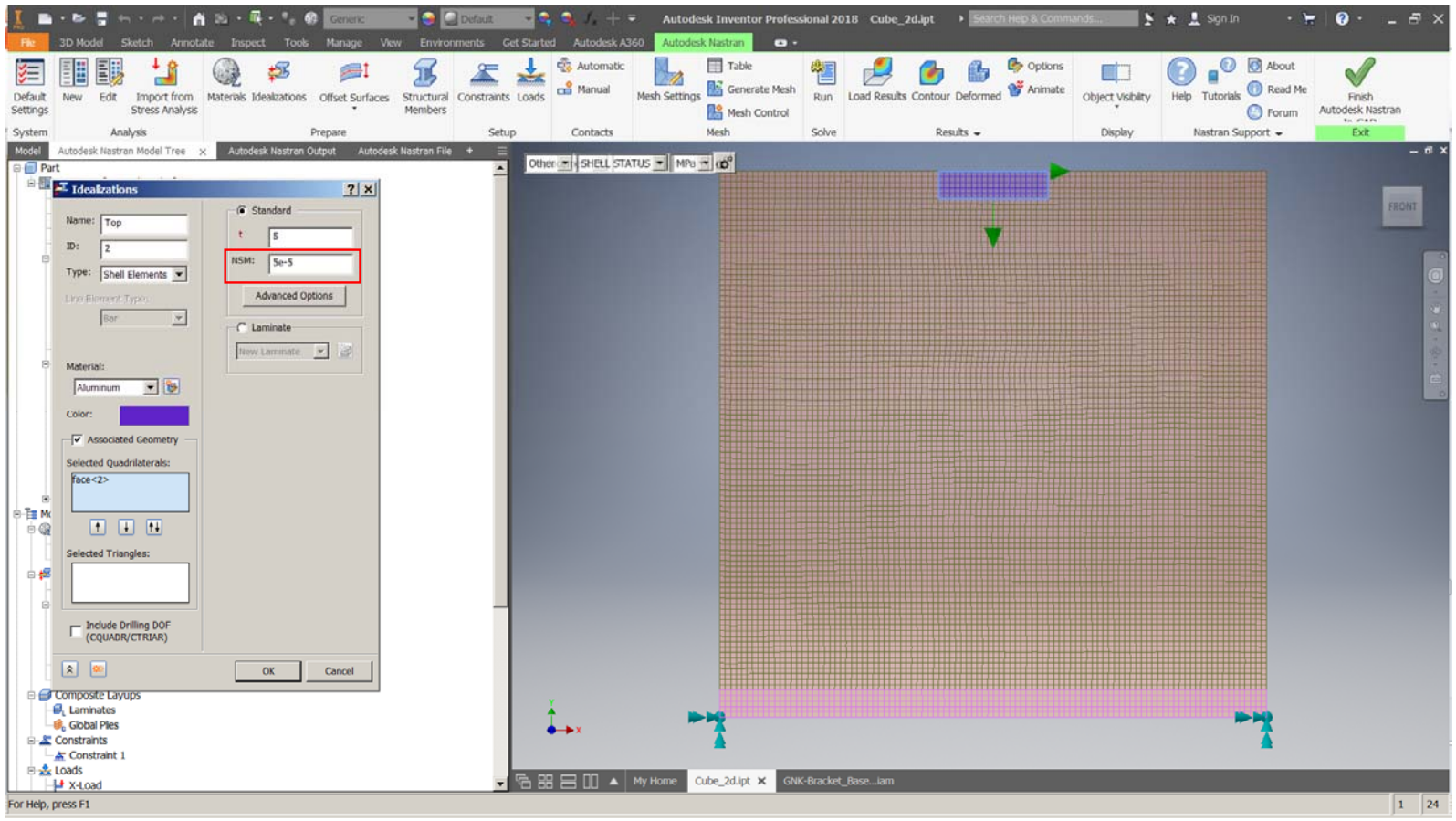


Obj: Min. VF (mass), Constraint: Disp. & Comp. Index

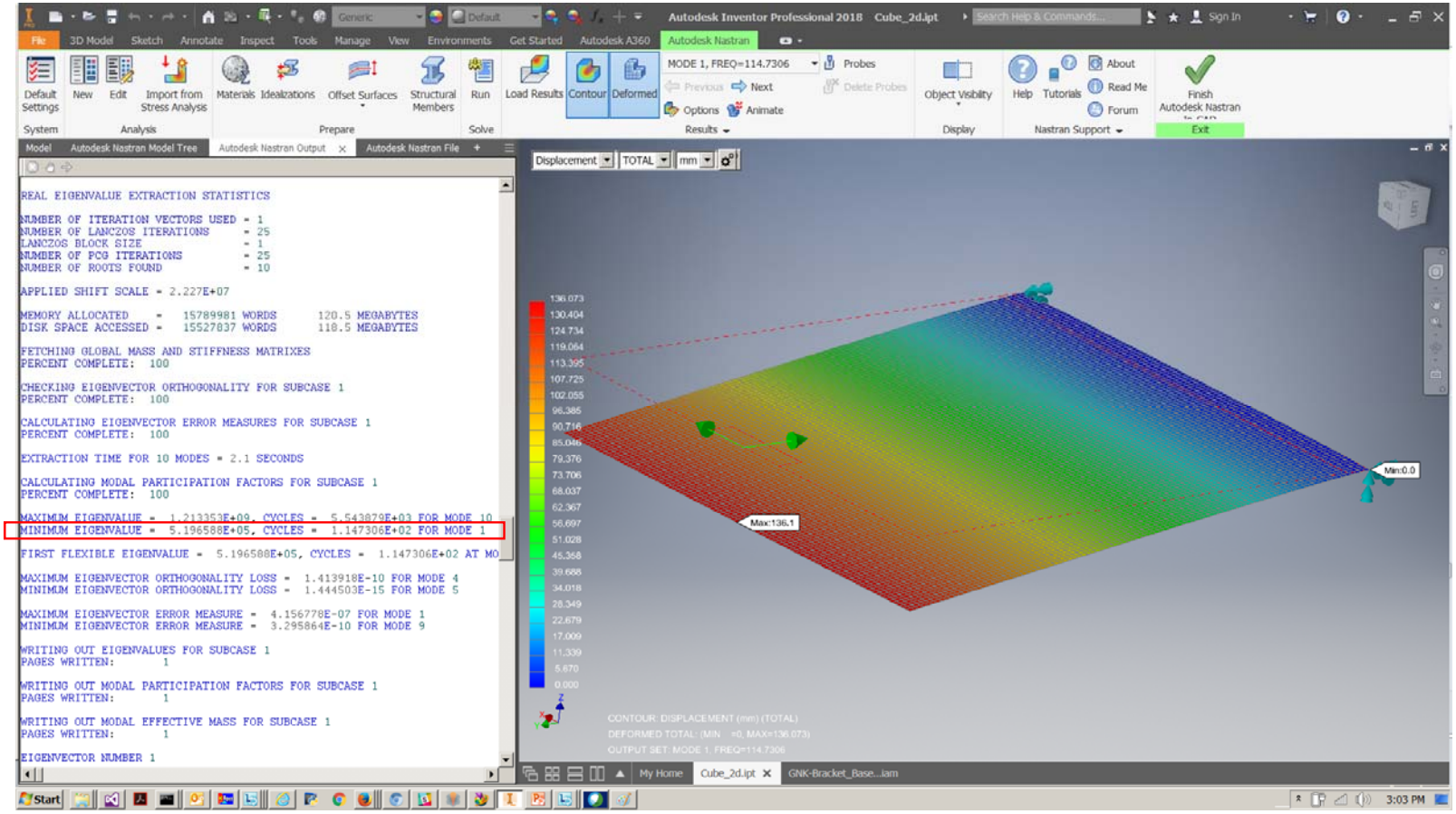
NTOPTSTRESSDIV	10
TOPTCOMPINDEX	5.
TOPTDESIGNCONSTR	0.01
TOPTDESIGNREGION	1
TOPTELEMEXTTOL	1.0E-2
TOPTELEMSYMTOL	0.9
TOPTGEN	VFDISP
TOPTMANCONSTR	SYM
TOPTMANCORD	0
TOPTMANDIR	YZ



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

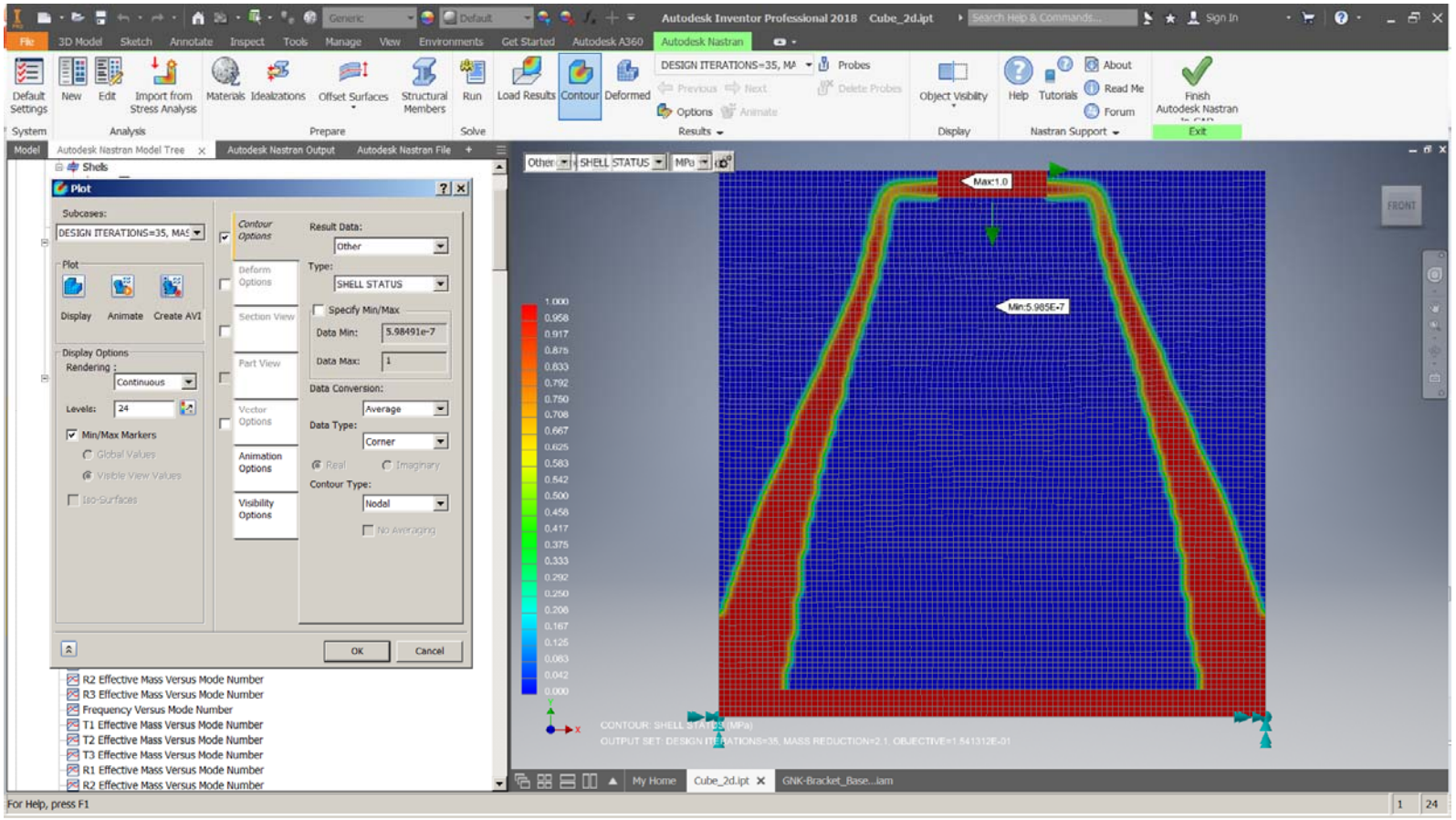


Obj: Min. VF (mass), Constraint: Frequency



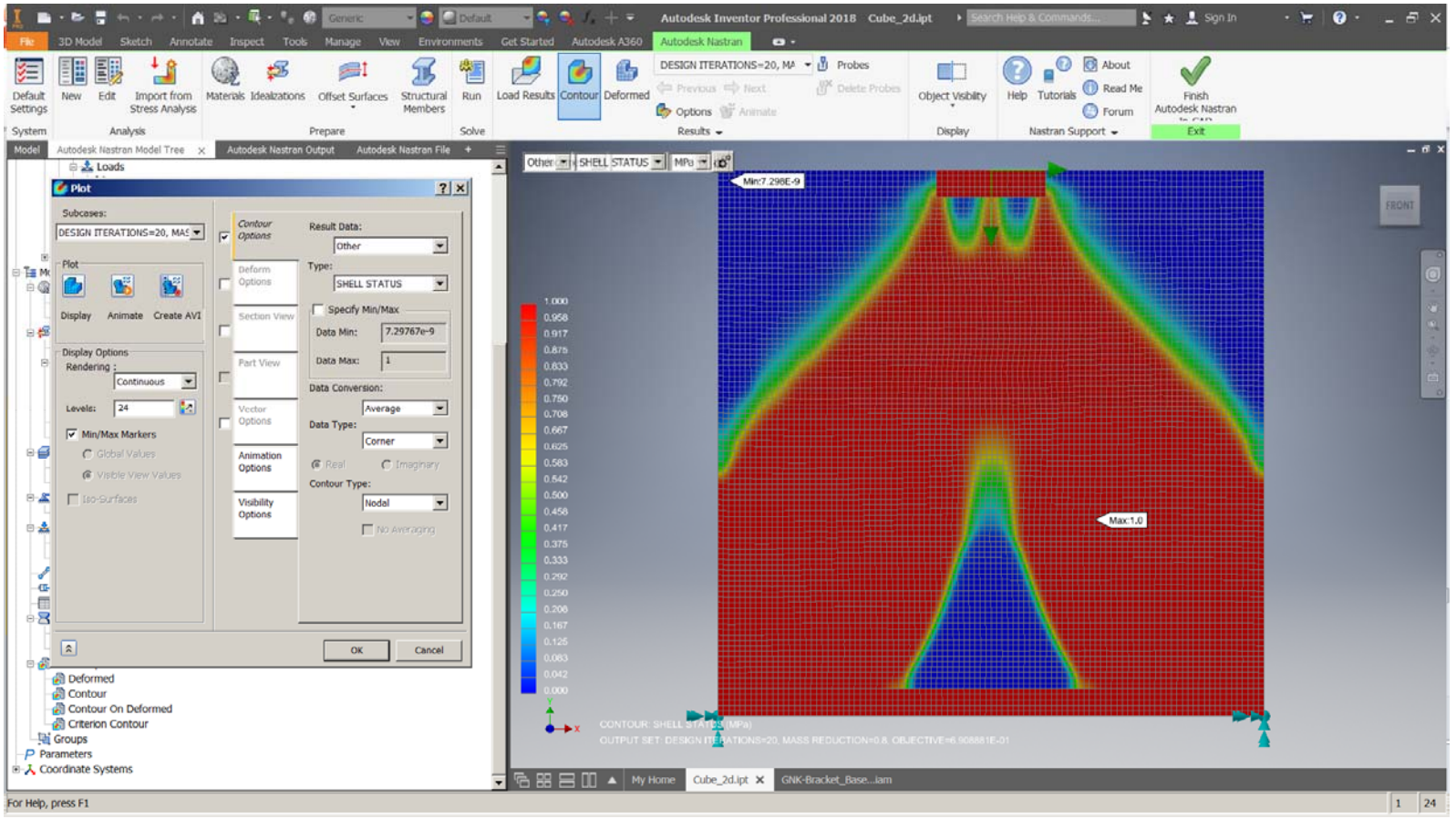
Obj: Min. VF (mass), Constraint: Frequency > 10Hz

NTOPTSTRESSDIV	10
TOPTCOMPINDEX	5.
TOPTDESIGNCONSTR	20.
TOPTDESIGNREGION	1
TOPTELEMEXTTOL	1.0E-2
TOPTELEMSYMTOL	0.9
TOPTGEN	VFFREQ
TOPTMANCONSTR	SYM
TOPTMANCORD	0
TOPTMANDIR	YZ



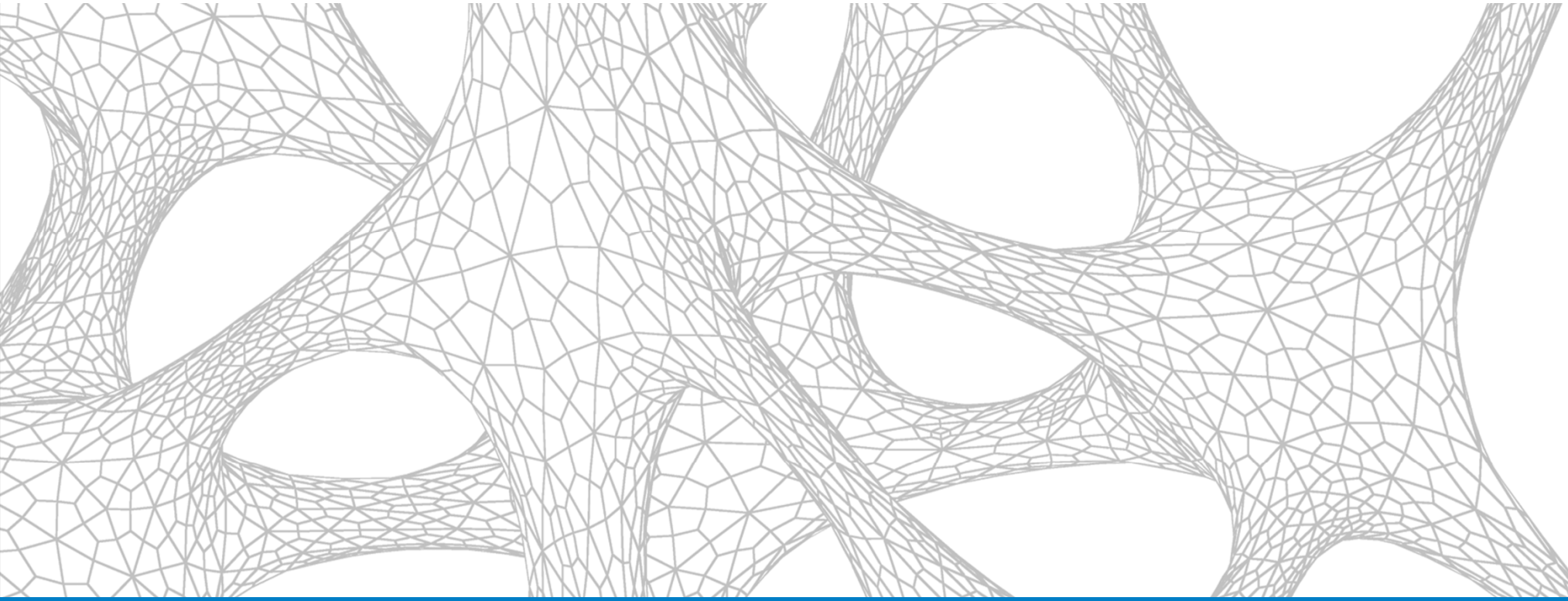
Obj: Min. VF (mass), Constraint: Frequency > 12Hz

NTOPTSTRESSDIV	10
TOPTCOMPINDEX	5.
TOPTDESIGNCONSTR	12.
TOPTDESIGNREGION	1
TOPTELEMEXTTOL	1.0E-2
TOPTELEMSYMTOL	0.9
TOPTGEN	VFFREQ
TOPTMANCONSTR	SYM
TOPTMANCORD	0
TOPTMANDIR	YZ



Commonly Used Topology Optimization Parameters

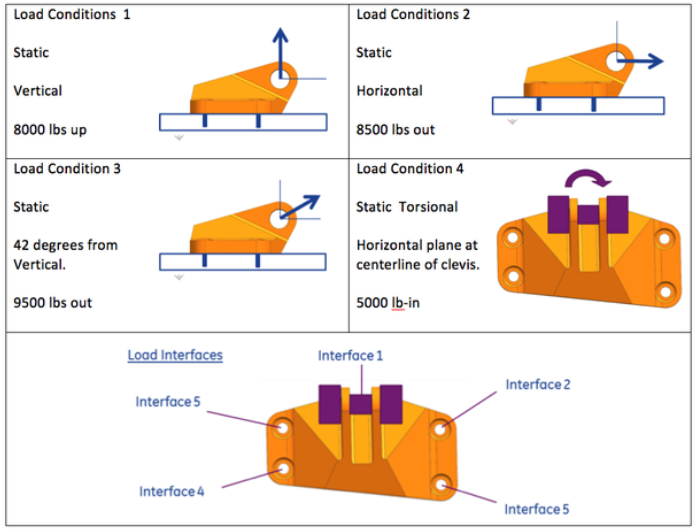
Parameter	Description	Default	Suggested Range	Remarks
MAXTOPTITER	Limits the number of design iterations	200	100 - 300	Increase when iteration limit exceeded
NTOPTSTRESSDIV	Number of stress sub-divisions	10	3 - 10	Reduce for better performance/increase for better accuracy
TOPTELEMEXTTOL	Tolerance for 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

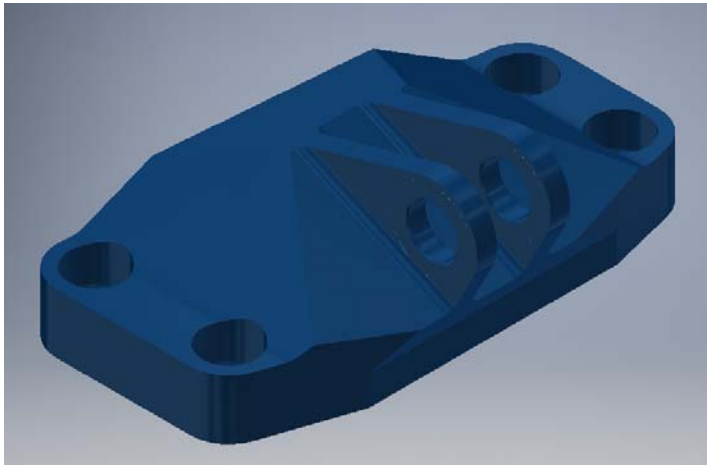


GE Bracket Challenge Problem

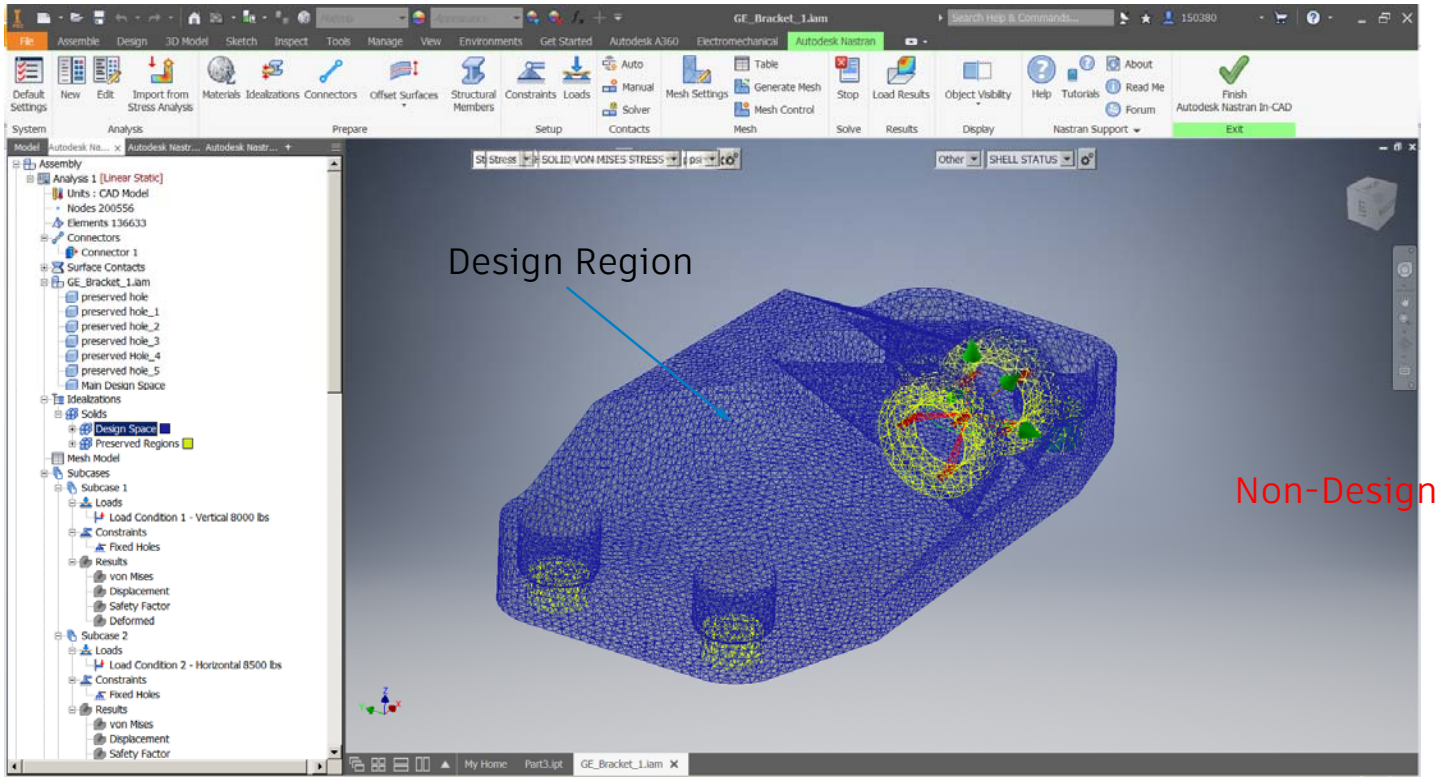
GE Bracket Challenge Problem

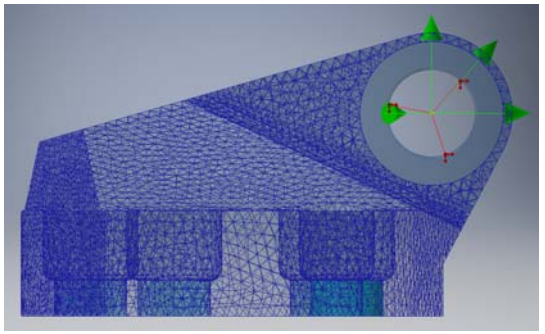
- Material: Titanium Ti-6Al-4V
- BC constraints: At inside of bolt holes
- Load conditions
  - Vertical 8000 lbs
  - Horizontal 8500 lbs
  - 42 deg 9500 lbs
  - 5000 in-lbs torque about horizontal plane
- Design constraint: Factor of Safety (FOS) = 1.2
- Manufacturing constraint: AM
- Objective: minimize mass
- Original volume: 27.58 in^3
- 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



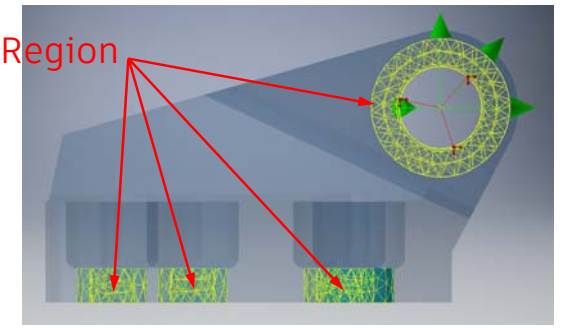


GE Demo Bracket Model

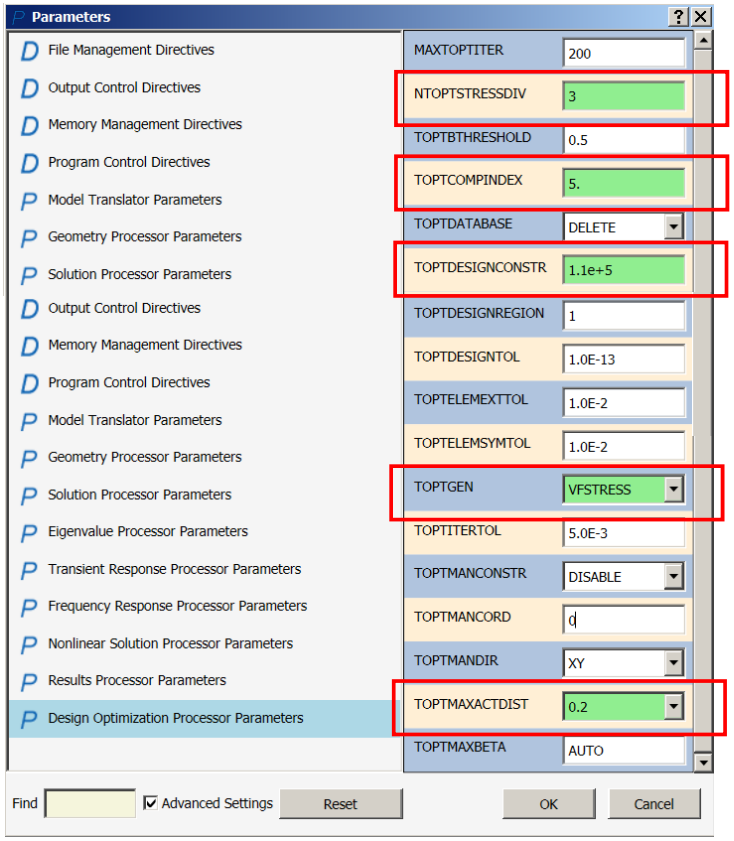




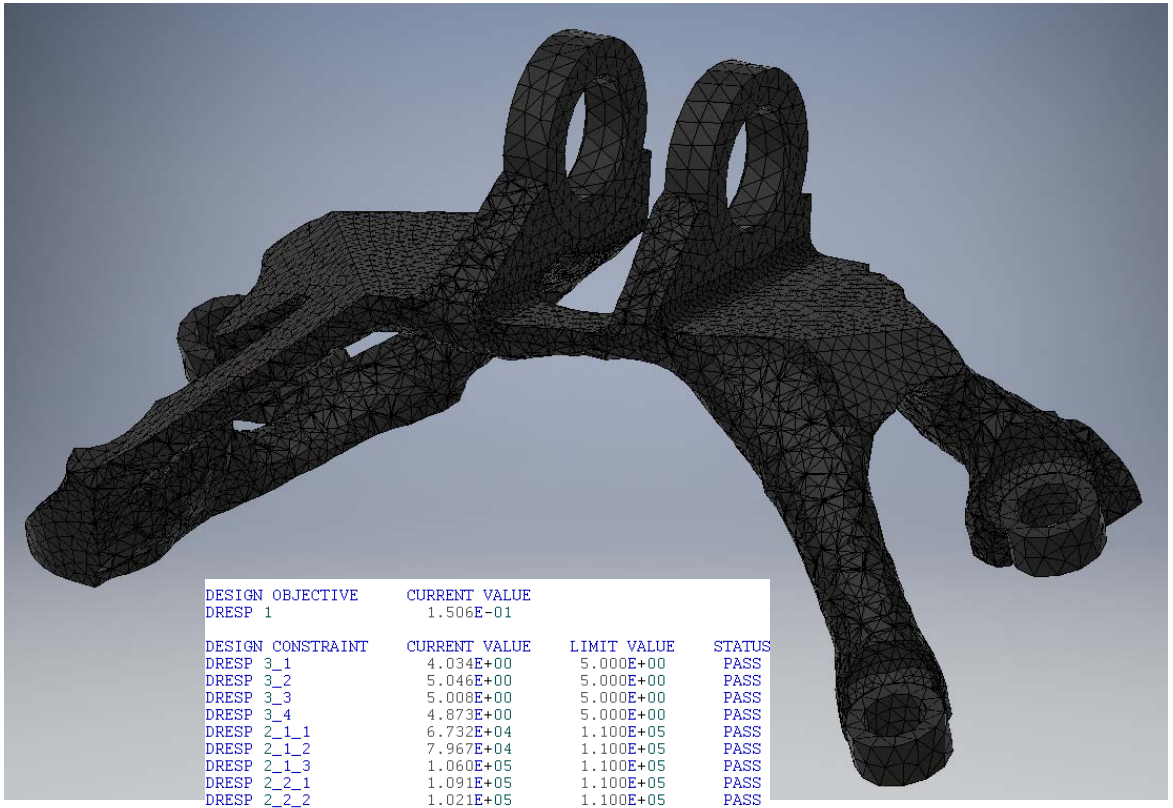
Non-Design Region

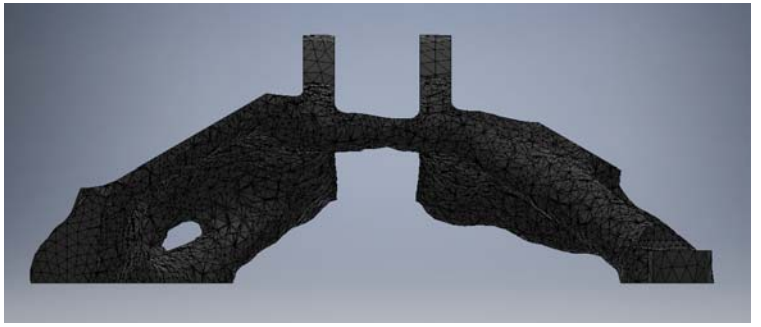


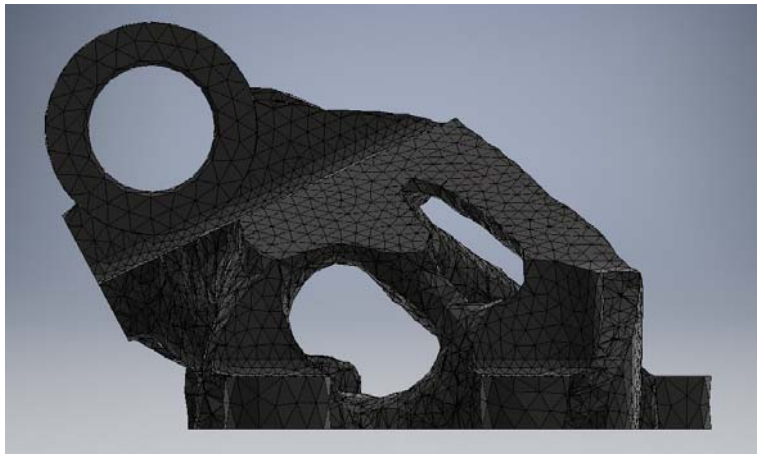
GE Demo Bracket With Stress Constraints Only



GE Demo Bracket With Stress Constraints Only





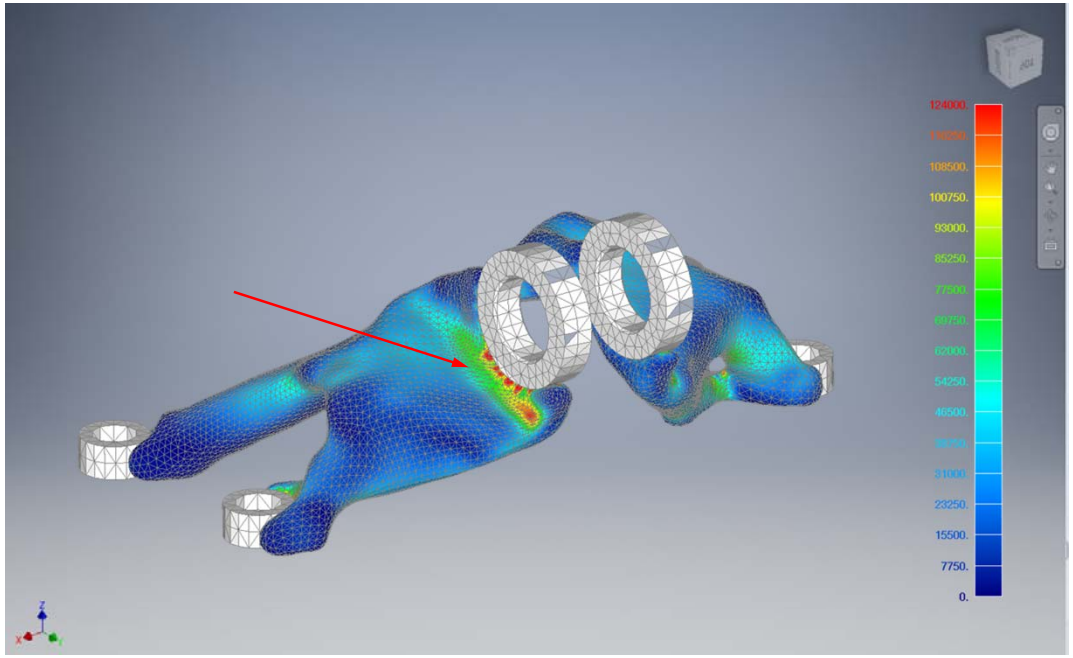


DESIGN OBJECTIVE	CURRENT VALUE		
DRESP 1	1.506E-01		
DESIGN CONSTRAINT	**CURRENT VALUE**	**LIMIT VALUE**	**STATUS**
DRESP 3_1	4.034E+00	5.000E+00	PASS
DRESP 3_2	5.046E+00	5.000E+00	PASS
DRESP 3_3	5.008E+00	5.000E+00	PASS
DRESP 3_4	4.873E+00	5.000E+00	PASS
DRESP 2_1_1	6.732E+04	1.100E+05	PASS
DRESP 2_1_2	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 in^3
- Design space weight reduction = 83%
- Total weight reduction = 80.5%

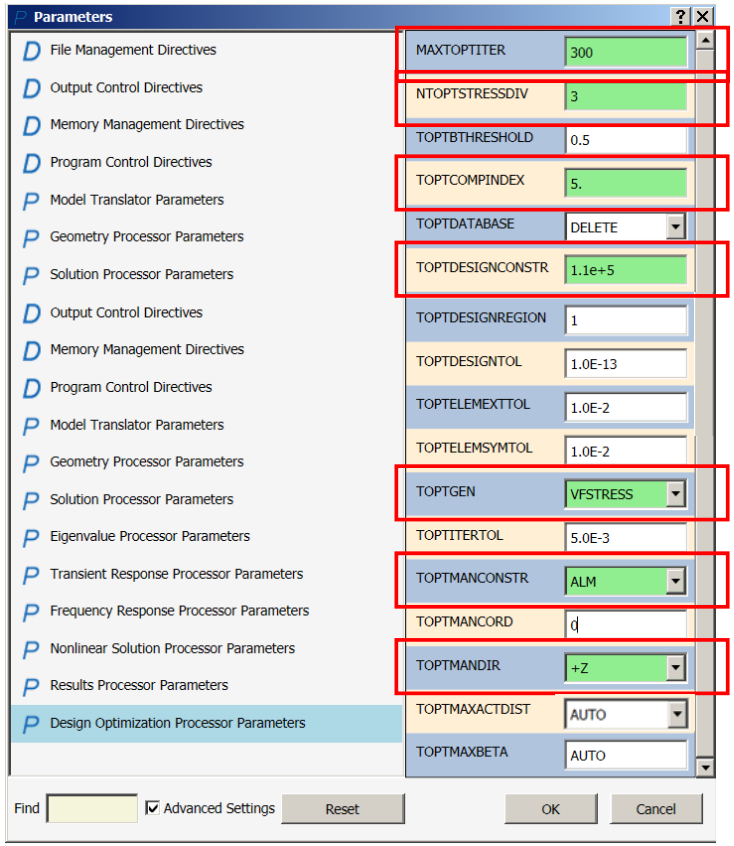
Verification Analysis



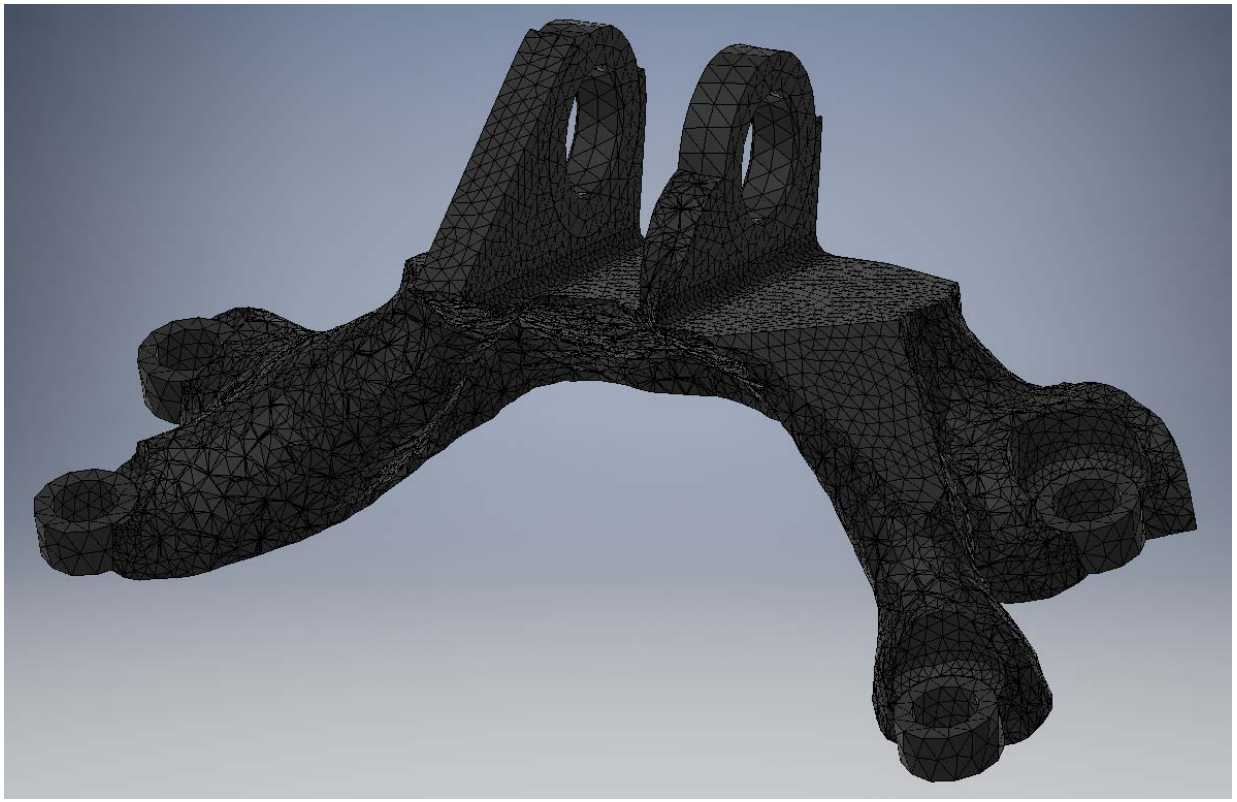
	Original Model		Stress Only	
Load Case	von Mises Stress (ksi)	FOS	von Mises Stress (ksi)	FOS
1	96.0	1.15	124.0	0.89
2	76.8	1.43	95.8	1.15
3	62.0	1.77	95.6	1.15
4	47.5	2.32	106.5	1.03

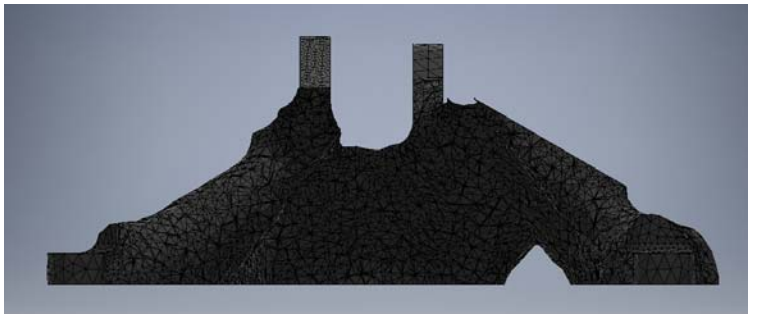
- TO models do not use corner stress data unlike the verification model shown
- Using a 20% higher stress limit is recommended to account for center stresses and variations in smoothed geometry

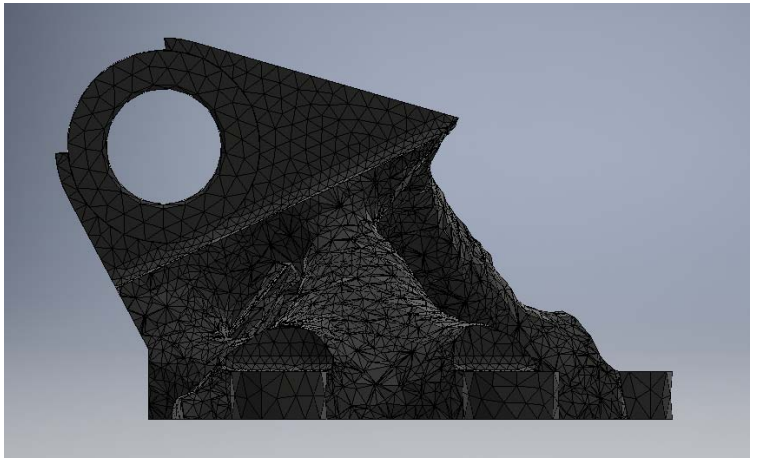
GE Demo Bracket With Stress & AM Constraints



GE Demo Bracket With Stress & AM Constraints

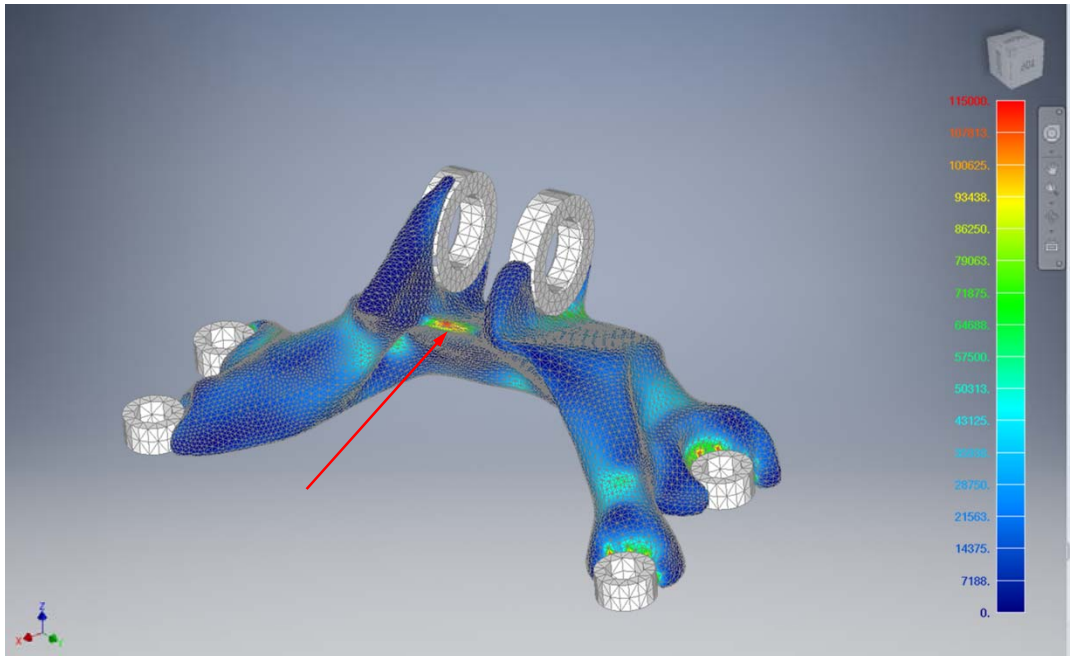






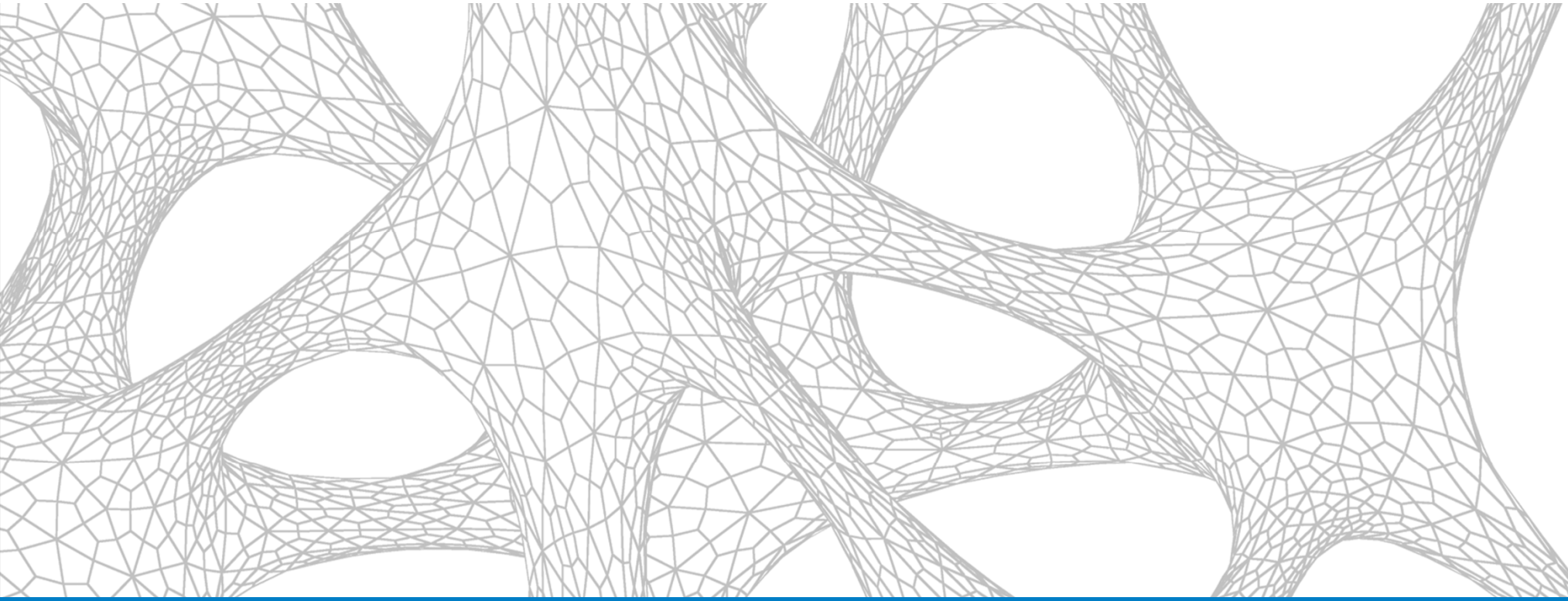
- New volume = 4.68 in^3
- Design space weight reduction = 72%
- Total weight reduction = 68.1%

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?


PRESENTATION FINISHED
ANY "QUESTIONS" LEFT?
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