

# Workshop - MSC Nastran Topology Optimization Manufacturing Constraints

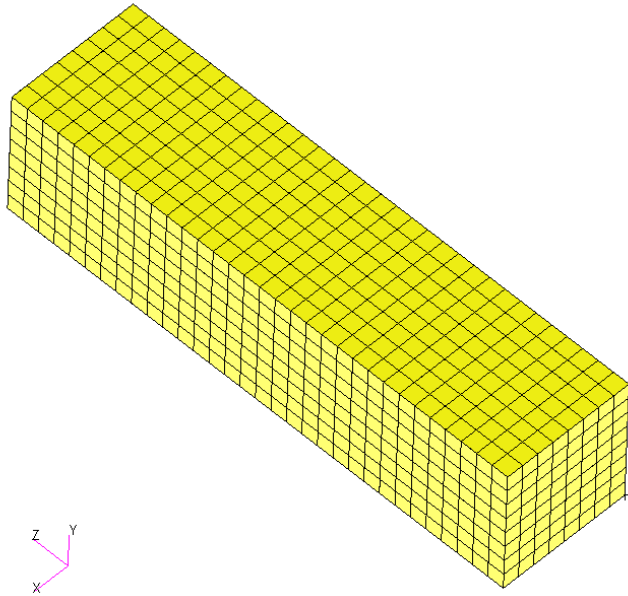
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AN MSC NASTRAN SOL 200 TUTORIAL

# Goal: Use Nastran SOL 200 Optimization

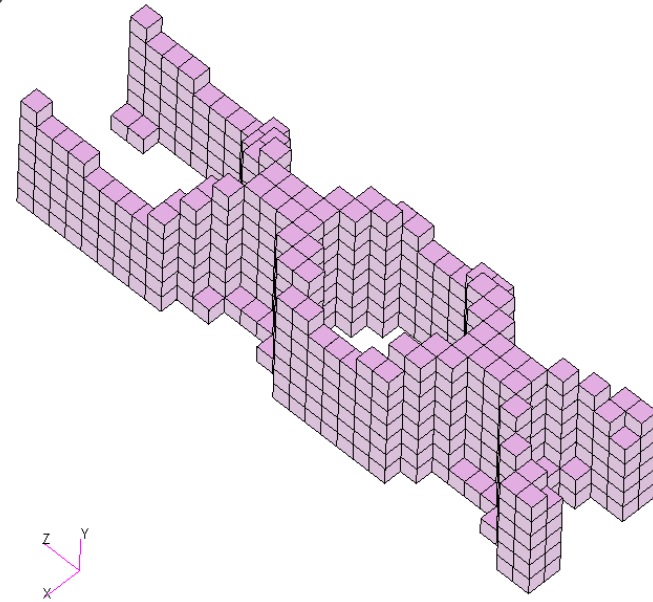
## Before Optimization

- Mass: 25.6



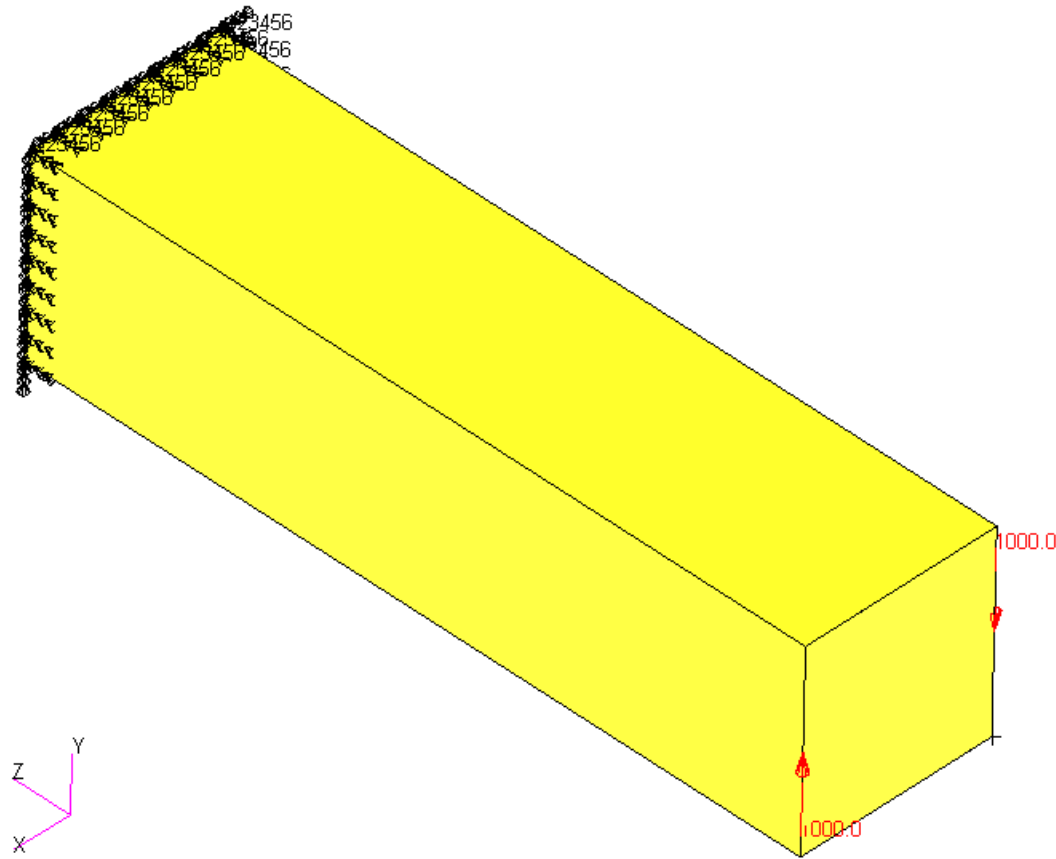
## After Optimization

- Mass: 7.7 (~70% mass reduction)
- Mirror Symmetry Constraints
- Casting Constraints



# Details of the structural model

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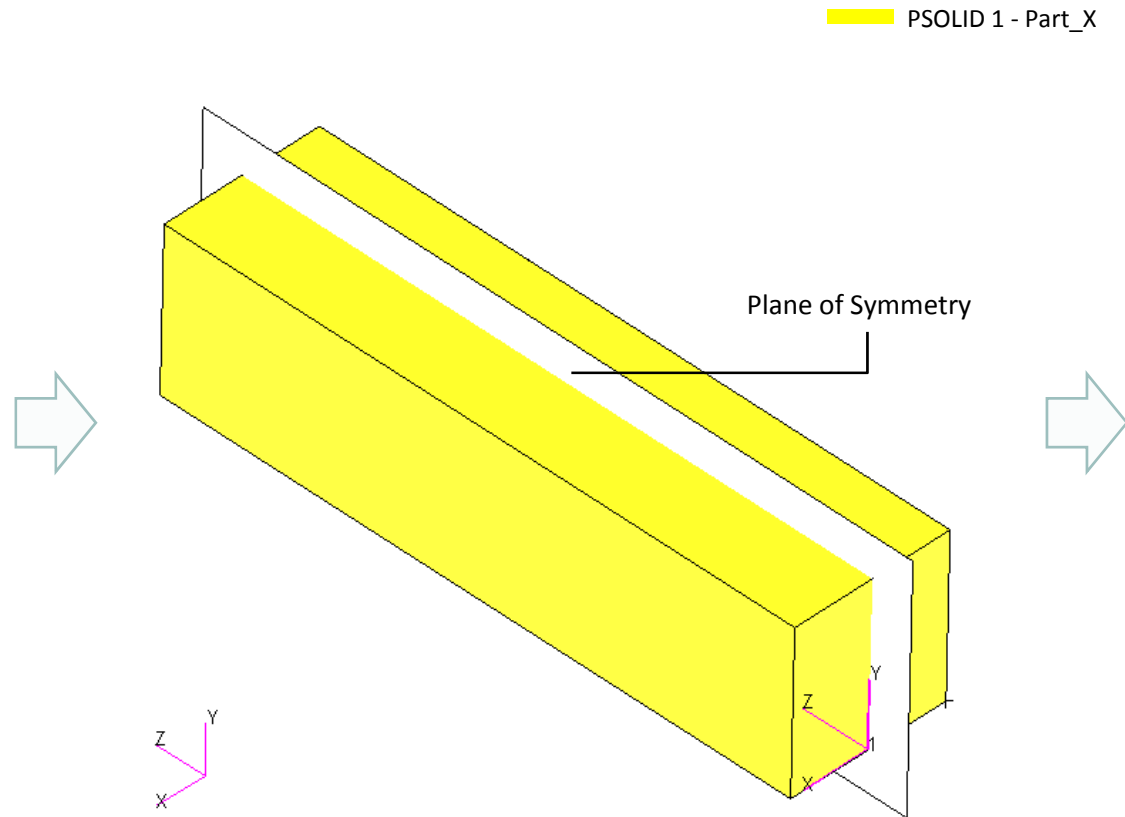
# Optimization Problem Statement

## Design Region/Variables

x1: PSOLID 1

Restrictions:

- Mirror Symmetry Constraints
  - Symmetry about the YZ plane of coordinate system 1
- Casting in Y direction of coordinate system 1, use 1 die



## Design Objective

r0: Minimize compliance

## Design Constraints

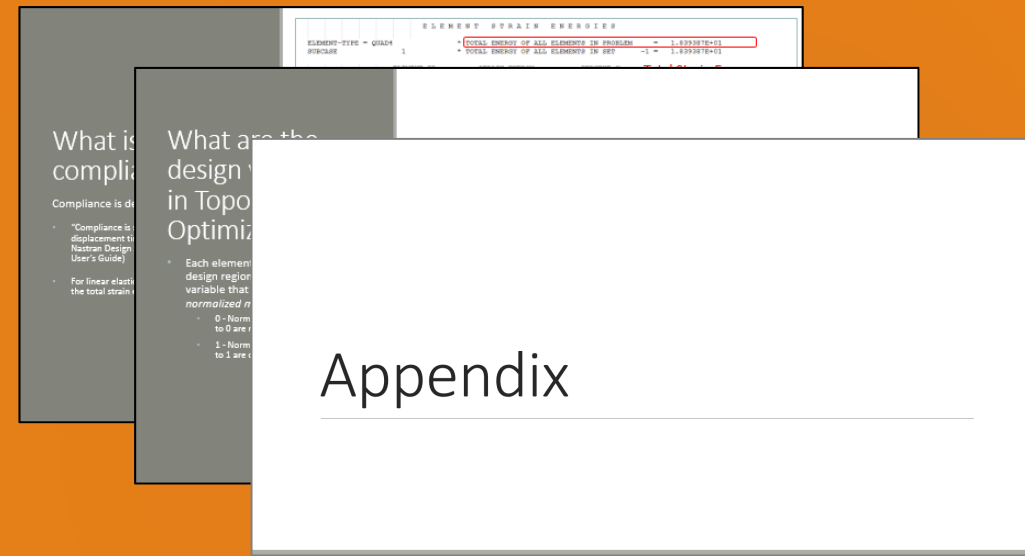
r1: Fractional mass

$r1 < .3$  (70% mass reduction)

# More Information Available in the Appendix

The Appendix includes information regarding the following:

- Frequently Asked Questions
  - What are the design variables in Topology Optimization?
  - What is FRMASS or Fractional Mass?
  - What is compliance?
  - How can non-critical elements be removed from the design?
- Topology Optimization Workflows
- Viewer Web App for Topology Optimization Post Processing



# Contact me

- Nastran SOL 200 training
- Nastran SOL 200 questions
- Structural or mechanical optimization questions
- Access to the SOL 200 Web App

christian@ the-engineering-lab.com

# Tutorial

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# Tutorial Overview

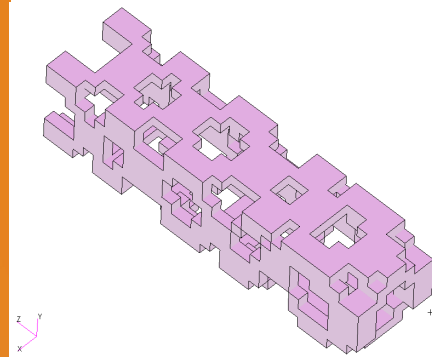
1. Start with a .bdf or .dat file
2. Use the SOL 200 Web App to:
  - Convert the .bdf file to SOL 200
    - Design Regions/Variables
    - Design Objective
    - Design Constraints
  - Perform optimization with Nastran SOL 200
3. Review optimization results
  - .f06
  - Topology Optimization and Structural Results

## Special Topics Covered

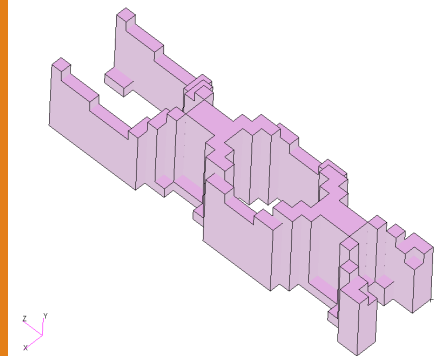
**Mirror Symmetry Constraints** - Fit the Topology Optimization solution must be symmetric, constraints may be imposed to achieve this.

**Manufacturing Constraints** - The manufacturability of Topology Optimization results is important. Options exist to produce results that can be manufactured.

Without Manufacturing Constraints, but with Symmetry



With Manufacturing Constraints and Symmetry



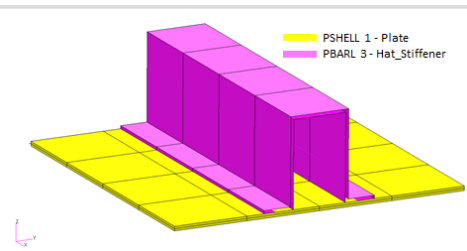


# SOL 200 Web App Capabilities

## Benefits

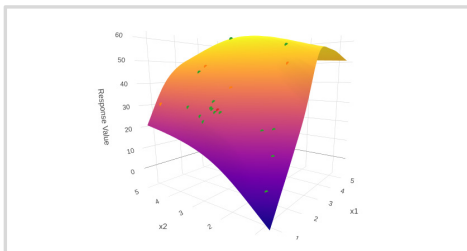
- 200+ error validations (real time)
- Web browser accessible
- Automated creation of entries (real time)
- Automatic post-processing
- 76 tutorials

## Capabilities



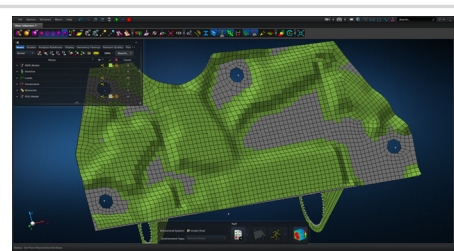
### Web Apps for SOL 200

Pre/post for MSC Nastran SOL 200.  
Support for size, topology, topometry, topography and multi-model.



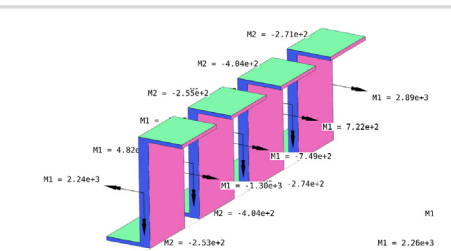
### Machine Learning Web App

Bayesian Optimization for nonlinear response optimization (SOL 400)



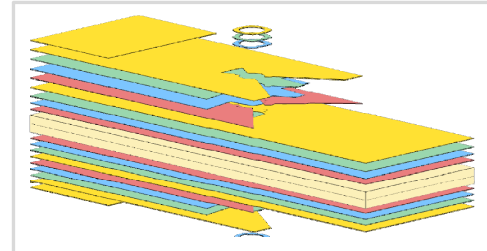
### MSC Apex Post Processing Support

View the newly optimized model after an optimization



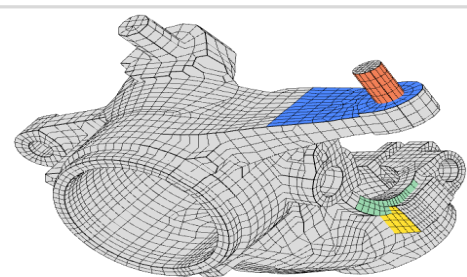
### Beams Viewer Web App

Post process 1D element forces, including shear forces, moments, torque and axial forces



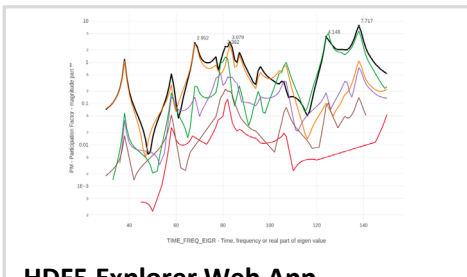
### Ply Shape Optimization Web App

Spread plies optimally and generate new PCOMPG entries



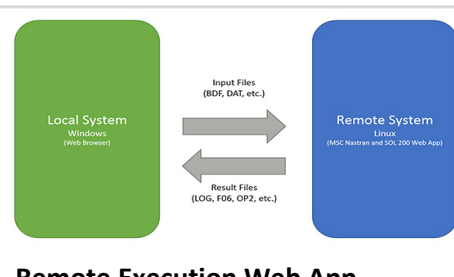
### Shape Optimization Web App

Use a web application to configure and perform shape optimization.



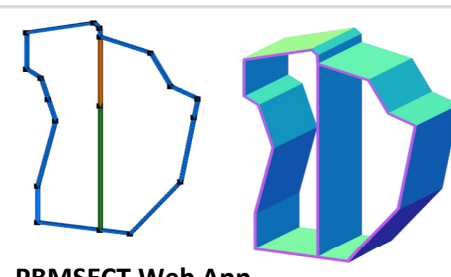
### HDF5 Explorer Web App

Create XY plots using data from the H5 file



### Remote Execution Web App

Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



### PBMSECT Web App

Generate PBMSECT and PBRSECT entries graphically



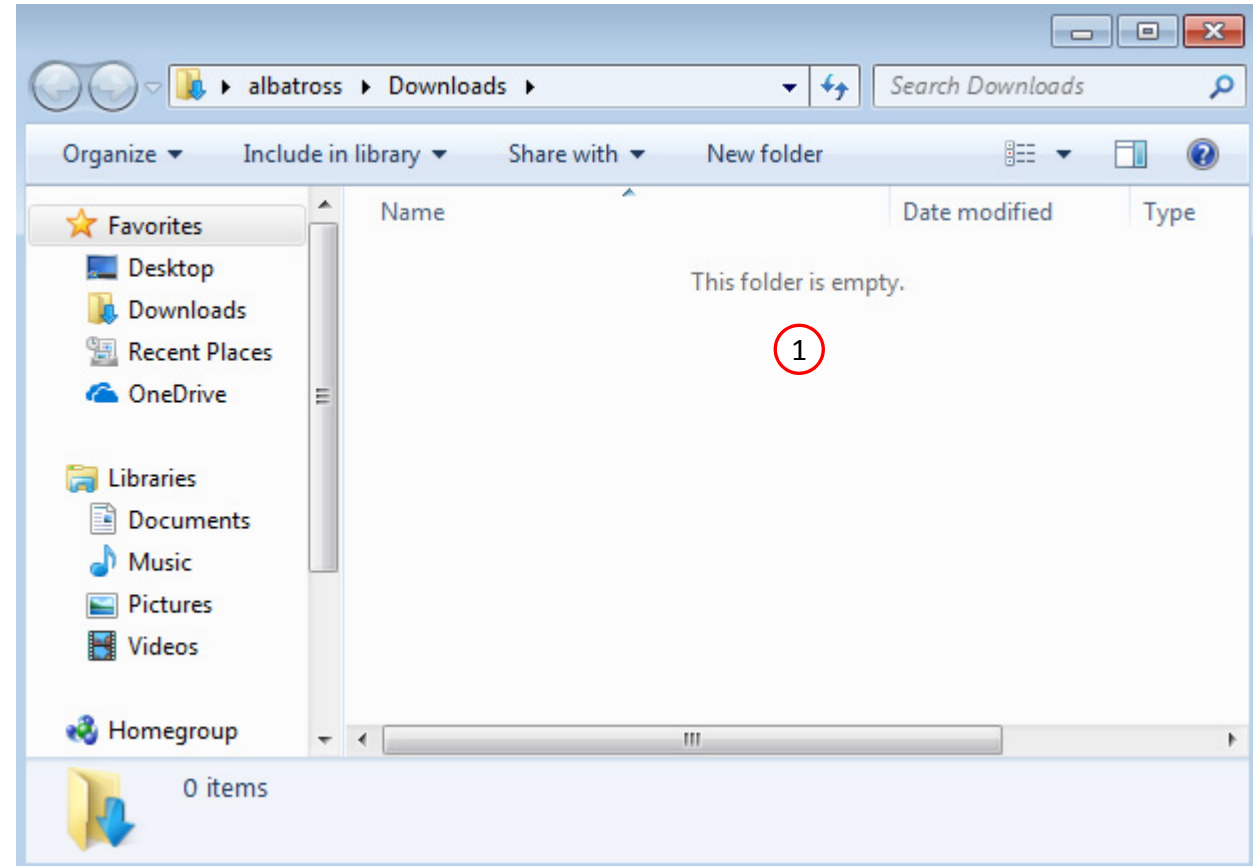
### Stacking Sequence Web App

Optimize the stacking sequence of composite laminate plies

# Before Starting

1. Ensure the Downloads directory is empty in order to prevent confusion with other files

- Throughout this workshop, you will be working with multiple file types and directories such as:
  - .bdf/.dat
  - nastran\_working\_directory
  - .f06, .log, .pch, .h5, etc.
- To minimize confusion with files and folders, it is encouraged to start with a clean directory.



# Go to the User's Guide

1. Click on the indicated link

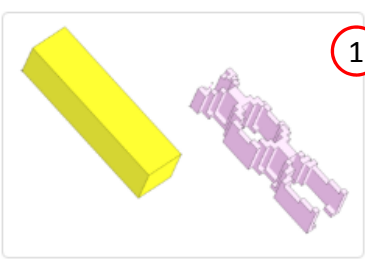
- The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.

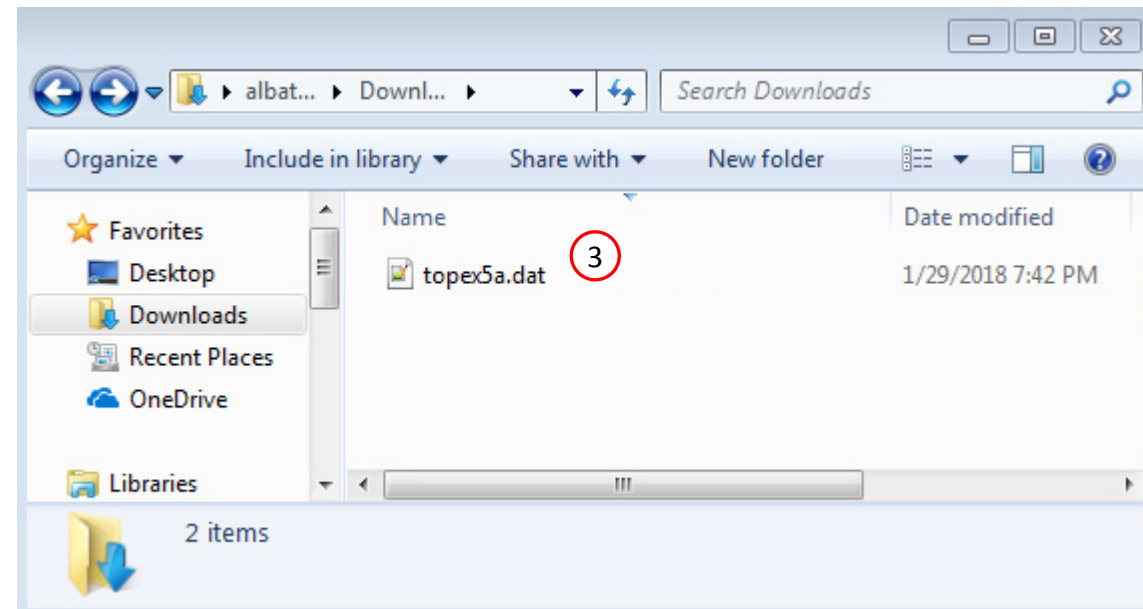


# Obtain Starting Files

1. Find the indicated example
2. Click Link
3. The starting file has been downloaded

- When starting the procedure, all the necessary BDF files must be collected together.

	<p><b>MSC Nastran Topology Optimization Manufacturing Constraints</b> <a href="#">Link</a></p> <p>A cantilever beam is composed of 3D or Hexahedral elements and a load is applied at the free end. Topology Optimization is used to identify regions of material to remove. This example discusses options to produce a symmetric design and a design that can be manufactured via casting.</p> <p>Starting BDF Files: <a href="#">Link</a> <b>2</b> Solution BDF Files: <a href="#">Link</a></p>
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# Open the Correct Page

1. Click on the indicated link

- MSC Nastran can perform many optimization types. The SOL 200 Web App includes dedicated web apps for the following:
  - Optimization for SOL 200 (Size, Topology, Topometry, Topography, Local Optimization, Sensitivity Analysis and Global Optimization)
  - Multi Model Optimization
  - Machine Learning
- The web app also features the HDF5 Explorer, a web application to extract results from the H5 file type.

SOL 200 Web App

Select a web app to begin

Optimization for SOL 200

Multi Model Optimization

Machine Learning | Parameter Study

HDF5 Explorer

Remote Execution

Tutorials and User's Guide

Full list of web apps

# Upload BDF Files

1. Click 1. Select Files and select topex5a.dat
2. Click Upload Files

- The process starts by uploading all the necessary BDF files. The BDF files can be files of your own or files found in the Tutorials section of the User's Guide.

## Step 1 - Upload .BDF Files

The screenshot shows a two-step process for uploading files. Step 1, '1. Select files', is highlighted with a red circle and shows a file named 'topex5a.dat' selected. Below it, a green progress bar indicates 'Inspecting: 100%'. Step 2, '2. Upload files', is also highlighted with a red circle and shows a green progress bar indicating 'Uploading: 100 %'. At the bottom, there is a checkbox labeled 'List of Selected Files' which is currently unchecked.

1. Select files topex5a.dat

Inspecting: 100%

2. Upload files

Uploading: 100 %

☐ List of Selected Files



# Create Design Region

1. Click Topology
2. Click on the plus (+) icons to set PSOLID 1 as a Design Region
3. Click + Options
4. Mark the checkboxes for the following:
  1. Symmetry Constraint Columns
  2. Casting Columns
5. Click the Right Arrow to expand the width of the table
6. Set the following for the design region
  - Use Symmetry Constraints: Yes
  - Coordinate System ID: 1
  - Symmetry Planes: YZ
  - Use Casting Constraints: Yes
  - Draw Direction: Y
  - Die Option: 1 - Single
  - Is the mesh aligned to ...: NO
7. Confirm the Symmetry Plane is set to YZ
8. Click the Left Arrow to restore the width of the table

- When a topology design region is set, one design variable is created for each element in the design region. Each design variable corresponds to the Normalized Material Density of that element, see the appendix for additional details.
- If PSOLID 1 has 500 elements associated and is configured as a design region, then there will be 500 design variables created.

SOL 200 Web App - Optimization    Upload    **Variables**    Objective    Constraints    Subcases    Exporter    Results    Settings    Match    Other    User's Guide    Home

Size **Topology** **1** try Topography

### Step 1 - Select design regions

+ Options

Create TOPVAR	Entry	Entry ID
	Search	Search
<b>2</b> +	PSOLID	1

5 10 20 30 40 50  
Number of Visible Rows 5

### Step 2 - Adjust TOPVAR Entries

**3** + Options **4**

☐ Entry Name ☒ Symmetry Constraint Columns ☒ Casting Columns ☐ Extrusion Columns ☐ Member Size Limit Columns ☐ Stress Limit Column

	Label	Status	Entry	Entry ID	Coordinate System ID	Use Symmetry Constraints	Symmetry Planes	Cyclic Symmetry Axis	Number of Cyclic Patterns	Use Casting Constraints	Draw Direction	Die Option	Is the mesh aligned to the draw or extrusion direction?
	Search	Search	Search	Search									
<b>6</b>	x1		PSOLID	1	1	Yes	<input checked="" type="checkbox"/> YZ	Disable	Examples: 0, 1, 2, etc.	Yes	Y	1 - Single die	NO

**7**

1	Yes	<input type="checkbox"/> XY <input checked="" type="checkbox"/> YZ <input type="checkbox"/> ZX	Disable	Examples: 0, 1, 2, etc.	Yes	Y	1 - Single die	NO
---	-----	--	---------	-------------------------	-----	---	----------------	----

**5** BDF Output - Design Model

```

$
$
$-----$
$
$ TOPVAR 300001 x1
$      SYN 1
$      CAST 1
    
```

# Create Design Objective

1. Click on Objective
2. Type 'comp' in the search box
3. Select the plus(+) icon for Compliance
4. The objective with label r0 is created.  
The objective is to minimize (MIN)

• Compliance is equal to twice the total strain energy. By minimizing the compliance/strain energy, the stiffness of the model is being maximized. See the appendix for additional details regarding compliance.

Objective

Equation Objective


1

## Step 1 - Select an objective

Select an analysis type

SOL 101 - Statics



Select a response

	Response Description ▾	Response Type ▾
	<input type="text" value="Search"/>	<input type="text" value="comp"/>
3 	Compliance (Product of displacement and the applied load)	COMP

5 10 20 30 40 50

## Step 2 - Adjust objective

+ Options

	Label	Status	Response Type	Maximize or Minimize	Property Type	ATTA	ATTB	ATTI
	r0		COMP	4 MIN ▾				



# Create Design Constraints

1. Click Constraints
2. Type 'frmass' in the search box
3. Select the plus(+) icon for Fractional Mass
4. Configure the following for r1
  - Upper Allowed Limit: .3
    - (Retain 30% of the material / 70% mass reduction)

- The fractional mass constraint r1 is set for a target of .3. The optimizer will vary the design variables, normalized material densities, to produce a design that is less than or equal to 30% of the original mass.

## Step 1 - Select constraints

Select an analysis type

SOL 101 - Statics



Select a response

	Response Description	Response Type
	Search	frmass
3	 Fractional Mass	FRMASS

5 10 20 30 40 50

## Step 2 - Adjust constraints

+ Options

	Label	Status	Response Type	Property Type	ATTA	ATTB	ATTi	Lower Allowed Limit	Upper Allowed Limit
	St	Seal	Search	Search	Search	Search	Search	Search	Search
	r1		FRMASS				Blank or Property ID (PID)	Lower	4 .3

# Configure Optimization Settings

1. Click Settings
2. Set DESMAX to 100

- This example has been previously performed with a DESMAX value of 50, but the optimization ended with RUN TERMINATED DUE TO MAXIMUM NUMBER OF DESIGN CYCLES.
- A DESMAX value of 100 is used instead to allow for additional design cycles with the goal of obtaining convergence.

1

## Optimization Settings

Parameter ▾	Description ▾	Configure ▾
Search	Search	Search
APRCOD	Approximation method to be used	<input type="checkbox"/> 2 - Mixed Method ▾
CONV1	Relative criterion to detect convergence	<input type="checkbox"/> Enter a positive real number
CONV2	Absolute criterion to detect convergence	<input type="checkbox"/> Enter a positive real number
DELX	Fractional change allowed in each design variable during any optimization cycle	<input type="checkbox"/> Enter a positive real number
DESMAX	Maximum number of design cycles to be performed	<input checked="" type="checkbox"/> 100 2
DISBEG	Design cycle number for discrete variable processing initiation	<input type="checkbox"/> Enter a positive integer
GMAX	Maximum constraint violation allowed at the converged optimum	<input type="checkbox"/> Enter a positive real number
P1	Print items, e.g. objective, design variables, at every n-th design cycle to the .f06 file	<input checked="" type="checkbox"/> 1
P2	Items to be printed to the .f06 file	<input checked="" type="checkbox"/> 12 - Print constraints and response ▾
TCHECK	Topology Checkerboarding	<input type="checkbox"/> -1 - Automatic selection (Default) ▾
TDMIN	Minimum diameter of members in topology optimization	<input type="checkbox"/> Enter a positive real number
TREGION	Trust Region	<input type="checkbox"/> 1 - Trust Region On ▾

# Export New BDF Files

1. Click on Exporter
2. Click on Download BDF Files

- When the download button is clicked a new file named "nastran\_working\_directory" is downloaded. If the file already exists in your local folder, the folder name is appended with a number, e.g. "nastran\_working\_directory (1).zip"

SOL 200 Web App - Optimization

UploadVariablesObjectiveConstraintsSubcasesExporterResults

SettingsMatchOtherUser's GuideHome

BDF Output - Model

```
assign userfile = 'optimization_results.csv', status = unknown,  
form = formatted, unit = S2  
$ Topology Opt with one die Casting/Symmetry Constraint XMY  
SOL 200  
CEND  
  
SEALL = ALL  
SUPER = ALL  
TITLE = MSC.Nastran job created on 04-Feb-05 at 10:52:01  
ECHO = NONE  
$ Direct Text Input for Global Case Control Data  
DESOBJ(MIN) = 8000000  
DESLB = 40000000  
$ OSAPRT(FORMATTED, EXPORT, END=SENS) = ALL  
SUBCASE 1  
ANALYSIS = STATICS  
$ DESSUB Slot  
$ DRSPAN Slot  
$ Subcase name : Default  
SUBTITLE=Default  
SPC = 2  
LOAD = 2  
DISPLACEMENT(PLOT,SORT1,REAL)=ALL  
ESE(THRESH,.99)=ALL  
STRESS(PLOT,SORT1,REAL,VONMISES,BILIN)=ALL  
$ Direct Text Input for this Subcase  
BEGIN BULK  
INCLUDE './design_model.bdf'
```

BDF Output - Design Model

```
$  
$  
$              Design Model          $  
$  
$-----$  
$              Design Regions/variables      $  
$-----$  
$  
TOPVAR    300001   x1     PSOLID                1  
           SYM       1         YZ  
           CAST      1        Y      1      NO  
  
$  
$              Design Objective            $  
$-----$  
$  
DRESP1    8000000 r0      COMP  
  
$  
$              Design Constraints          $  
$-----$  
$  
DRESP1    8000001 r1      FRMASS  
  
$  
$  
DCONSTR    30001    8000001      .3  
  
$  
$              Design Equation Constraints      $  
$-----$  
$  
$  
$  
$  
$  
$
```

Download BDF Files

Download BDF Files

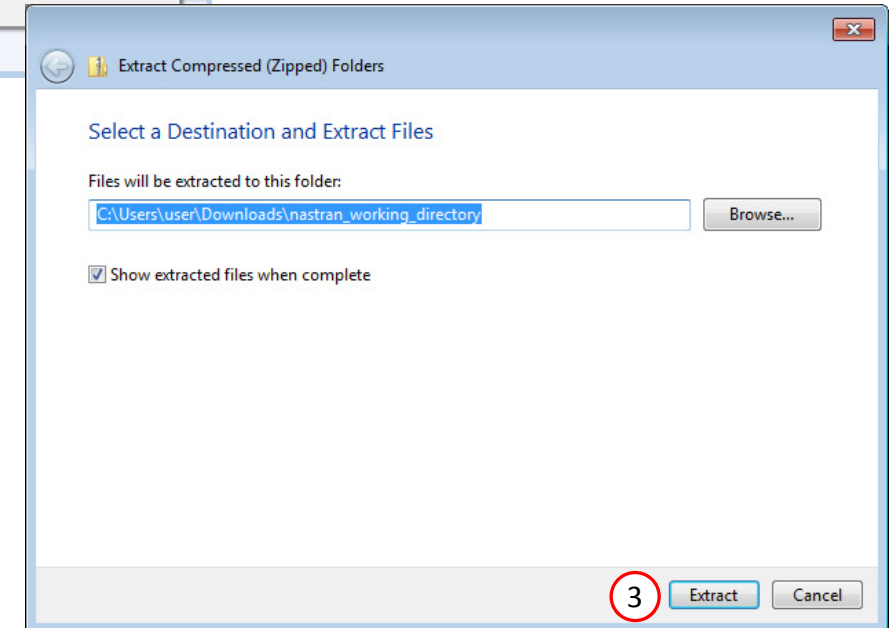
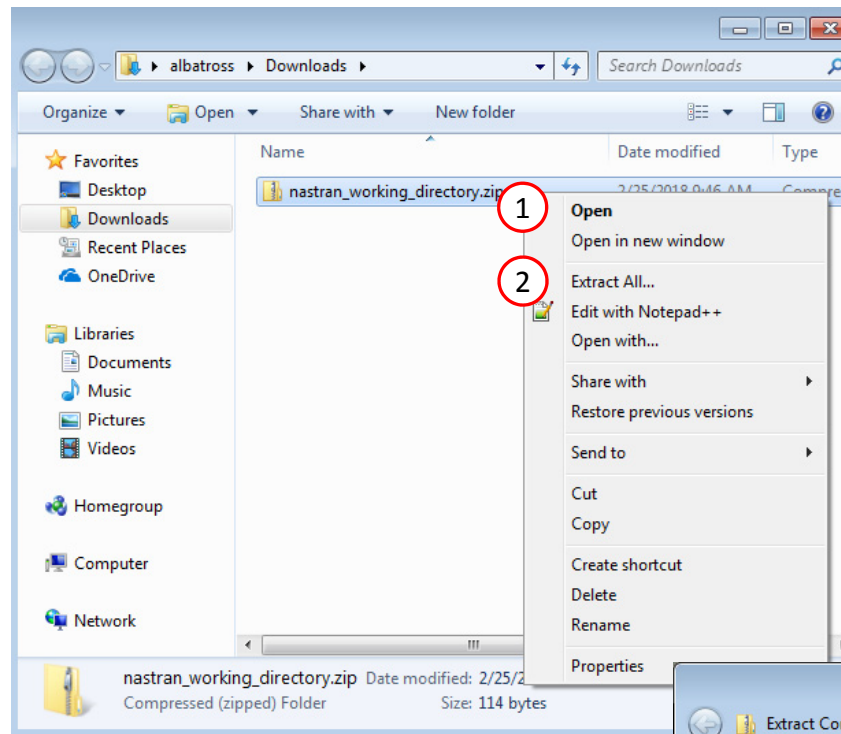
2

Developed by The Engineering Lab

# Perform the Optimization with Nastran SOL 200

1. A new .zip file has been downloaded
2. Right click on the file
3. Click Extract All
4. Click Extract on the following window

- Always extract the contents of the ZIP file to a new, empty folder.



# Perform the Optimization with Nastran SOL 200

1. Inside of the new folder, double click on Start MSC Nastran
2. Click Open, Run or Allow Access on any subsequent windows
3. MSC Nastran will now start

- After a successful optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- One can run the Nastran job on a remote machine as follows:
  - 1) Copy the BDF files and the INCLUDE files to a remote machine.
  - 2) Run the MSC Nastran job on the remote machine.
  - 3) After completion, copy the BDF, F06, LOG, H5 files to the local machine.
  - 4) Click "Start MSC Nastran" to display the results.

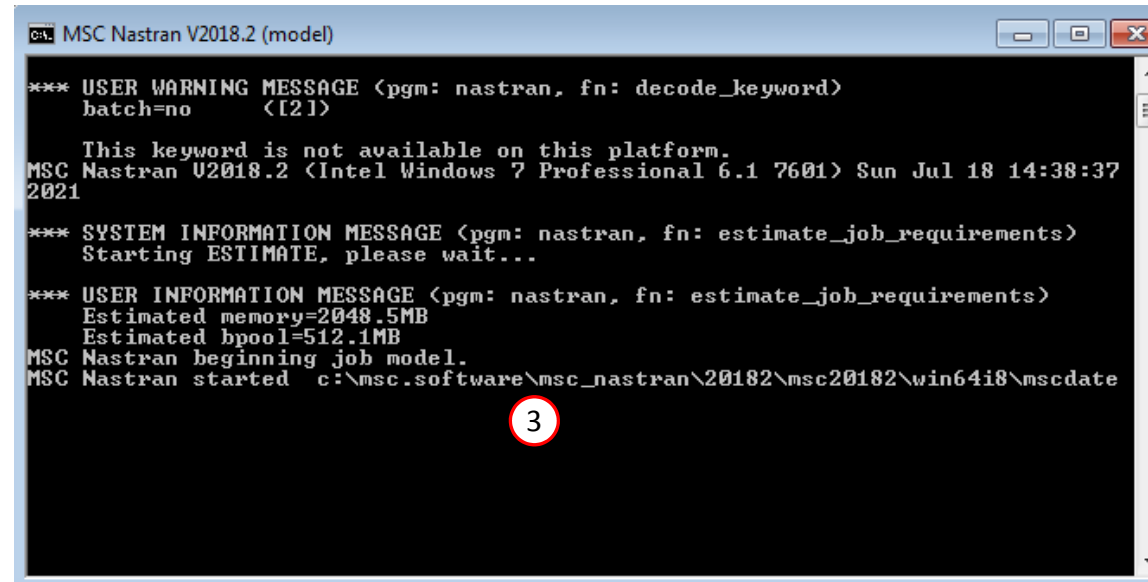
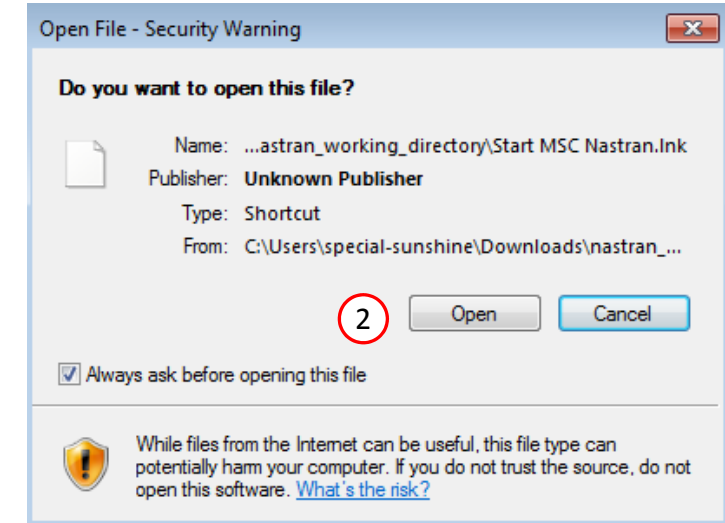
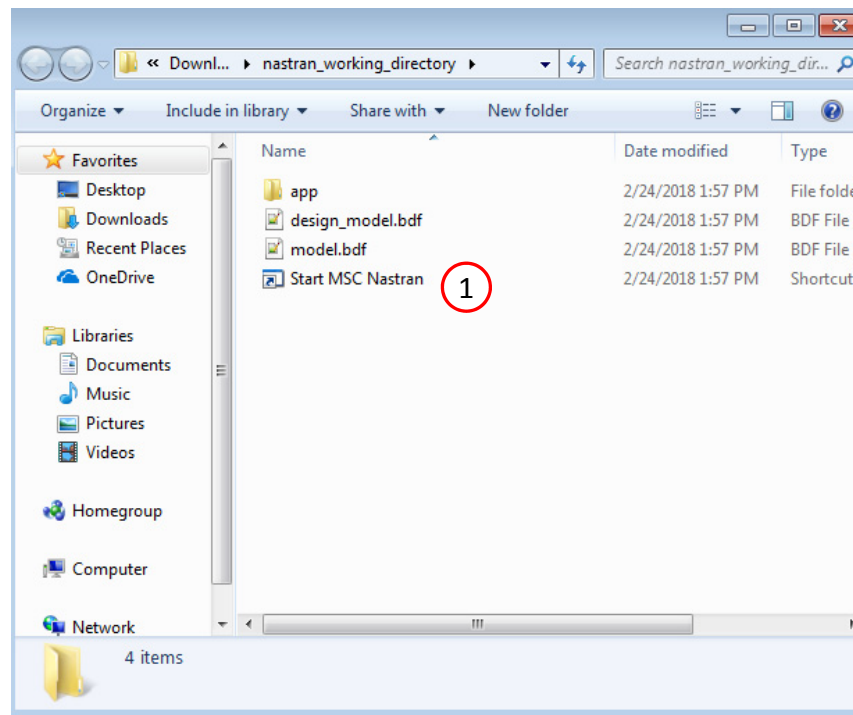
## Using Linux?

Follow these instructions:

- 1) Open Terminal
- 2) Navigate to the nastran\_working\_directory  
`cd ./nastran_working_directory`
- 3) Use this command to start the process  
`./Start_MSC_Nastran.sh`

In some instances, execute permission must be granted to the directory. Use this command. This command assumes you are one folder level up.

```
sudo chmod -R u+x ./nastran_working_directory
```



# Status

1. While MSC Nastran is running, a status page will show the current state of MSC Nastran

- The status of the MSC Nastran job is reported on the Status page. Note that Windows 7 users will experience a delay in the status updates. All other users of Windows 10 and Red Hat Linux will see immediate status updates.

## SOL 200 Web App - Status

 Python

 MSC Nastran

### Status

Name	Status of Job	Design Cycle	RUN TERMINATED DUE TO
model.bdf	Running	None	

# Review Optimization Results

After MSC Nastran is finished, the results will be automatically uploaded.

1. Ensure the messages shown have green checkmarks. This is indication of success. Any red icons indicate challenges.
2. The final value of objective and normalized constraints can be reviewed.

- After an optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.

## Final Message in .f06

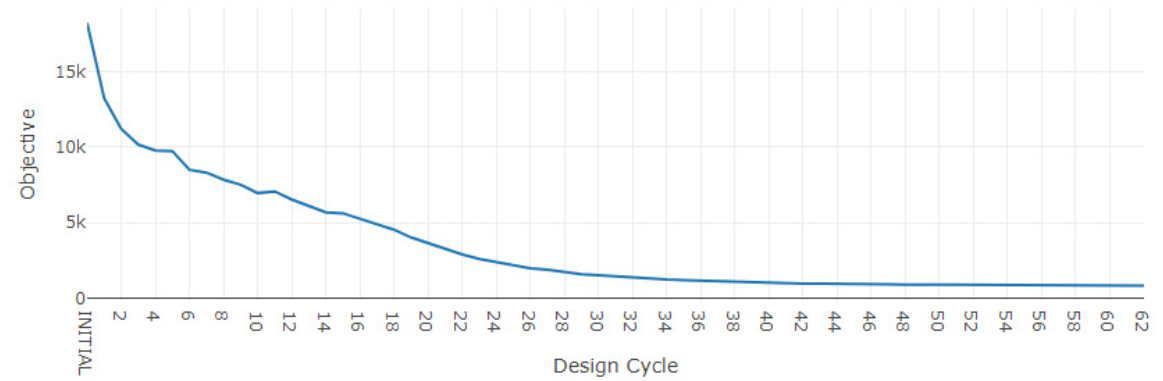
1



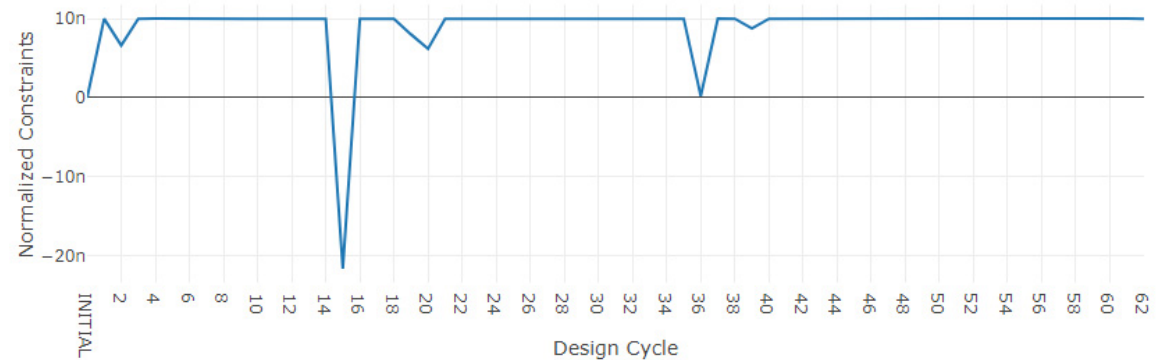
RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER = 62.

## Objective

2



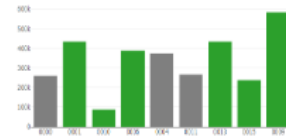
## Normalized Constraints



# Review Optimization Results

1. Return to the Optimization web app
2. Go to the Results section
3. Click Topology Viewer

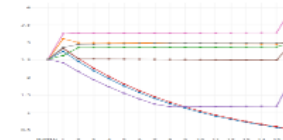
## Select a Results App



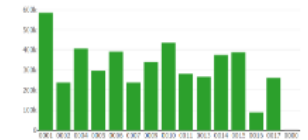
Global Optimization (multiplt.log)



Global Optimization Type 2 (.f06)

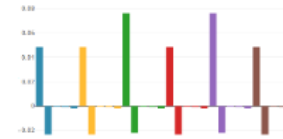


Local Optimization (.f06)

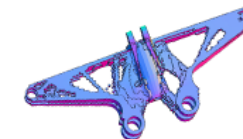


Parameter Study (.f06)

Responses (.f06)



Sensitivities (.csv)



Topology Viewer (.des) 3

## Miscellaneous Apps

Converter

PCH to BDF

- The Topology Viewer is capable of displaying topology results and is accessed from the Results section of the Optimization web app. The appendix has additional information regarding capabilities of the Topology Viewer.



# Review Optimization Results

1. Click Upload BDF
2. Click 1. Select files
3. Navigate to directory nastran\_working\_directory
4. Select the model.bdf and design\_model.bdf files.
5. Click Open
6. Click 2. Upload files
7. The model is displayed

- During file upload, reading and parsing process, the web app does not report the reading progress for large files. Know that the web app parses files at a rate of 10MB every 25 seconds.

The image is a composite of three parts illustrating a workflow:

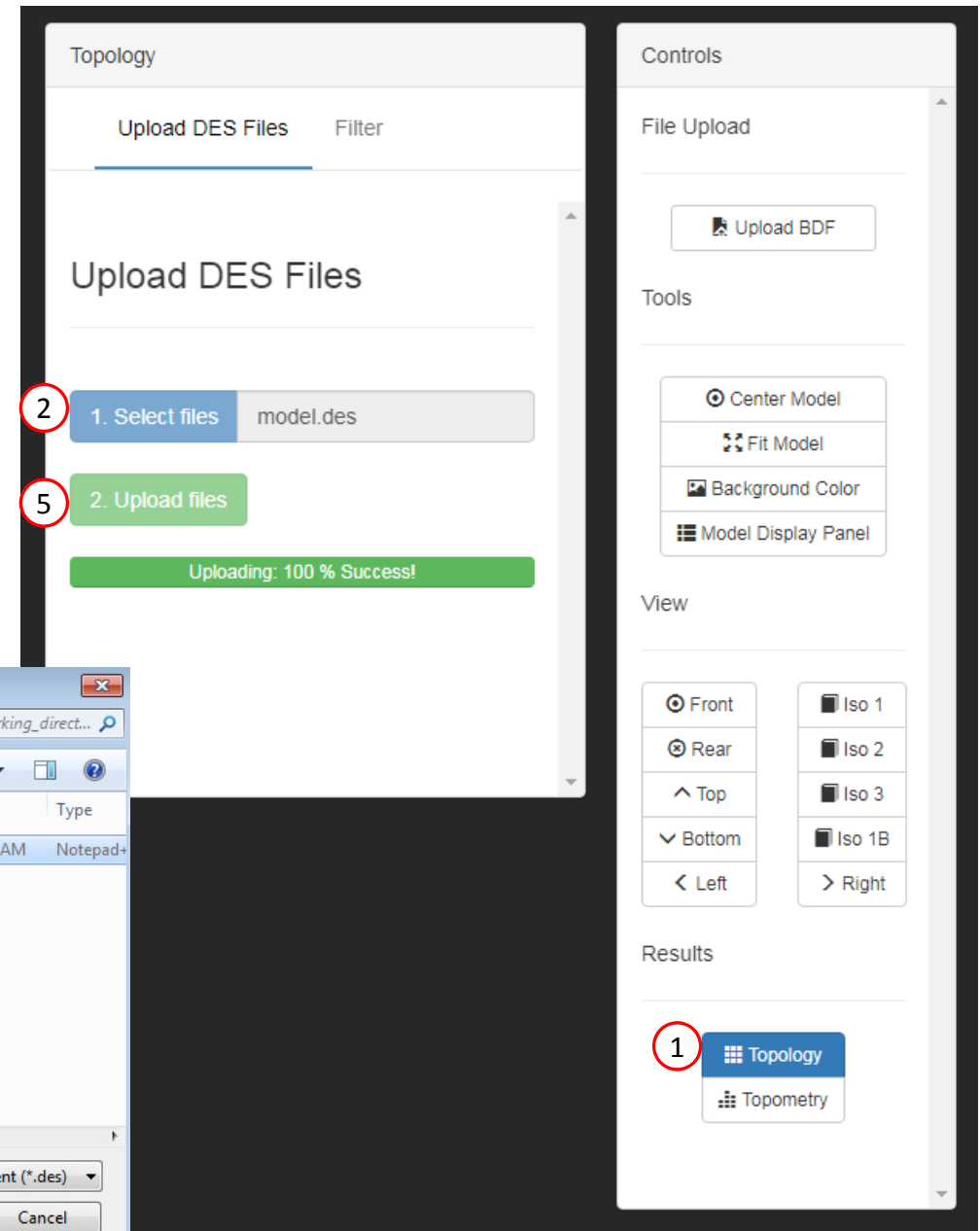
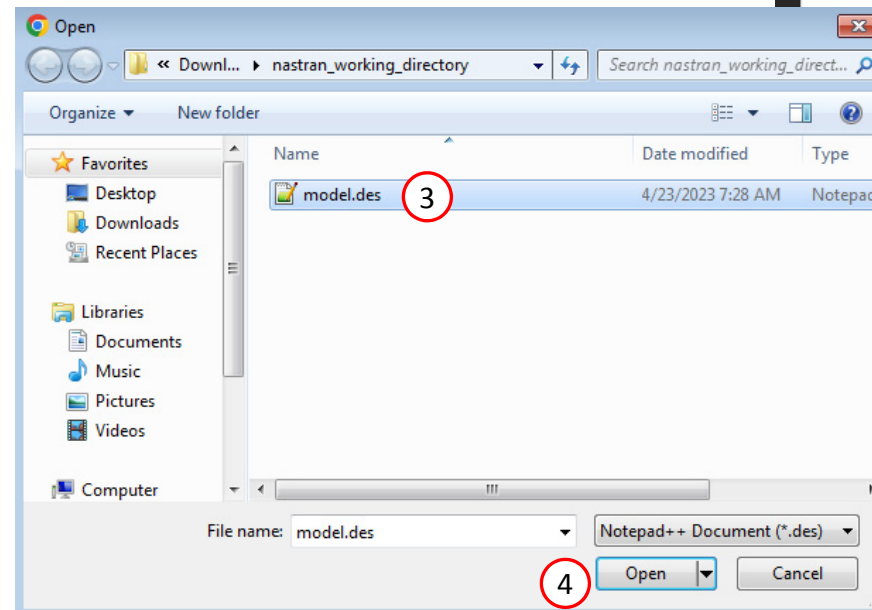
- Top Left:** A screenshot of a web application's 'File Upload' section. It shows a 'BDF' file type, a 'Select Directory' button, and two progress bars. The first bar, labeled '1. Select files' and '2 files selected', is at 100% inspection. The second bar, labeled '2. Upload files', is at 100% uploading. A checkbox for 'List of Selected Files' is visible.
- Top Right:** A sidebar of the web application with a 'Controls' panel. The 'File Upload' section has a button labeled '1' with a file icon and 'Upload BDF'. Below it, the 'Tools' panel includes buttons for 'Center Model', 'Fit Model', 'Background Color', and 'Model Display Panel'. The 'View' panel shows orientation options like 'Front', 'Rear', 'Top', 'Bottom', 'Left', 'Right' and isometric views 'Iso 1', 'Iso 2', 'Iso 3', 'Iso 1B'.
- Bottom Left:** A 3D model of a red hexagonal prism, labeled with a red circle '7'.
- Bottom Right:** A screenshot of a Windows File Explorer window. The address bar shows the path 'nastran\_working\_directo...'. The file list shows three items: 'app' (File folder), 'design\_model.bdf' (BDF File), and 'model.bdf' (BDF File). The 'design\_model.bdf' file is selected, labeled with a red circle '4'. The 'Open' button is labeled with a red circle '5'.

# Review Optimization Results

1. Click Topology
2. Click 1. Select files
3. Select the model.des file
4. Click Open
5. Click 2. Upload files

The results of the topology optimization are now accessible within the Viewer web app.

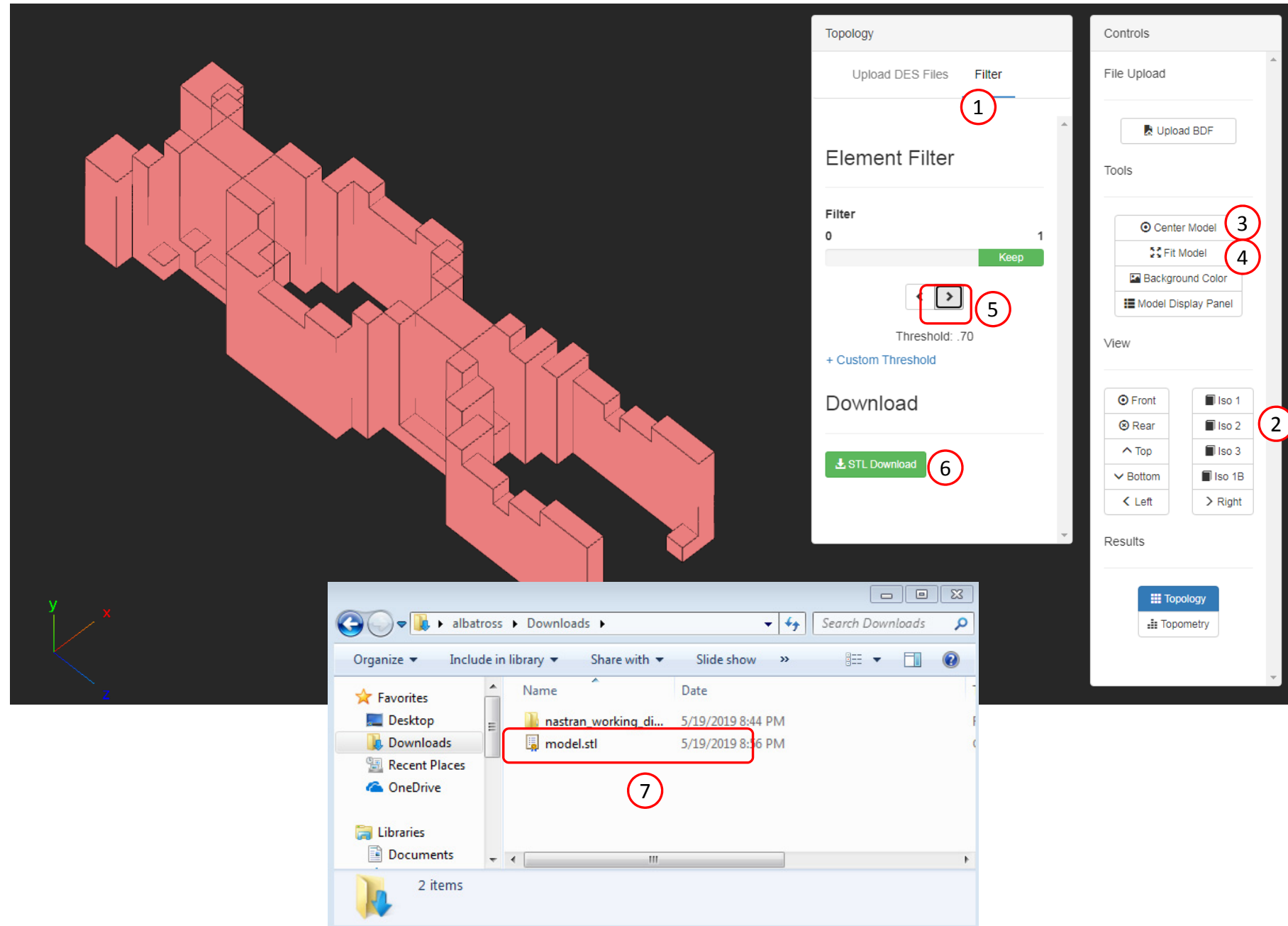
- When the DES file is uploaded, the topology results are automatically displayed. By default, elements with a normalized material density greater than a threshold of .3 are displayed. The threshold can be modified.



# Review Optimization Results

1. Click Filter
2. Click Iso 2
3. Click Center Model
4. Click Fit Model
5. Click the right arrow to remove elements below the threshold value
6. Click STL Download
7. The displayed model has been downloaded to an STL file and may be imported to separate CAD package or FEA pre processor

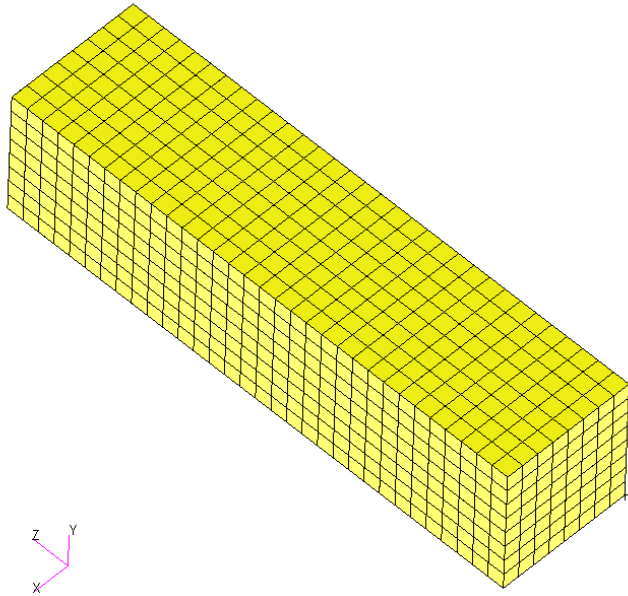
- A normalized material density (NMD) close to 1 indicates the element is very important and should be kept in the design. It is not recommended to go beyond a threshold of .7 since very critical elements would be removed. Elements with an NMD close to 0 are not critical and can be removed.
- Common thresholds to use are typically in the range of .3 to .7



# Results

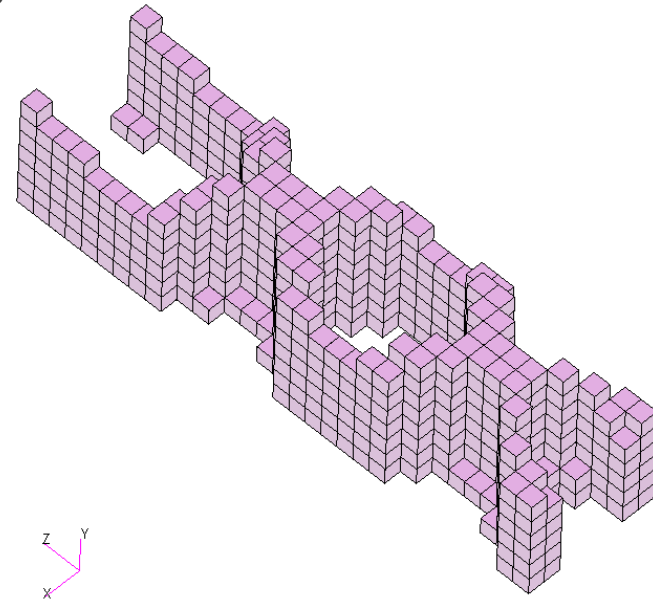
## Before Optimization

- Mass: 25.6



## After Optimization

- Mass: 7.7 (~70% mass reduction)
- Mirror Symmetry Constraints
- Casting



End of Tutorial

# Appendix

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# Appendix Contents

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- Frequently Asked Questions
  - What are the design variables in Topology Optimization?
  - What is FRMASS or Fractional Mass?
  - What is compliance?
  - How can non-critical elements be removed from the design?
- Topology Optimization Workflows
- Viewer Web App for Topology Optimization Post Processing

# What are the design variables in Topology Optimization?

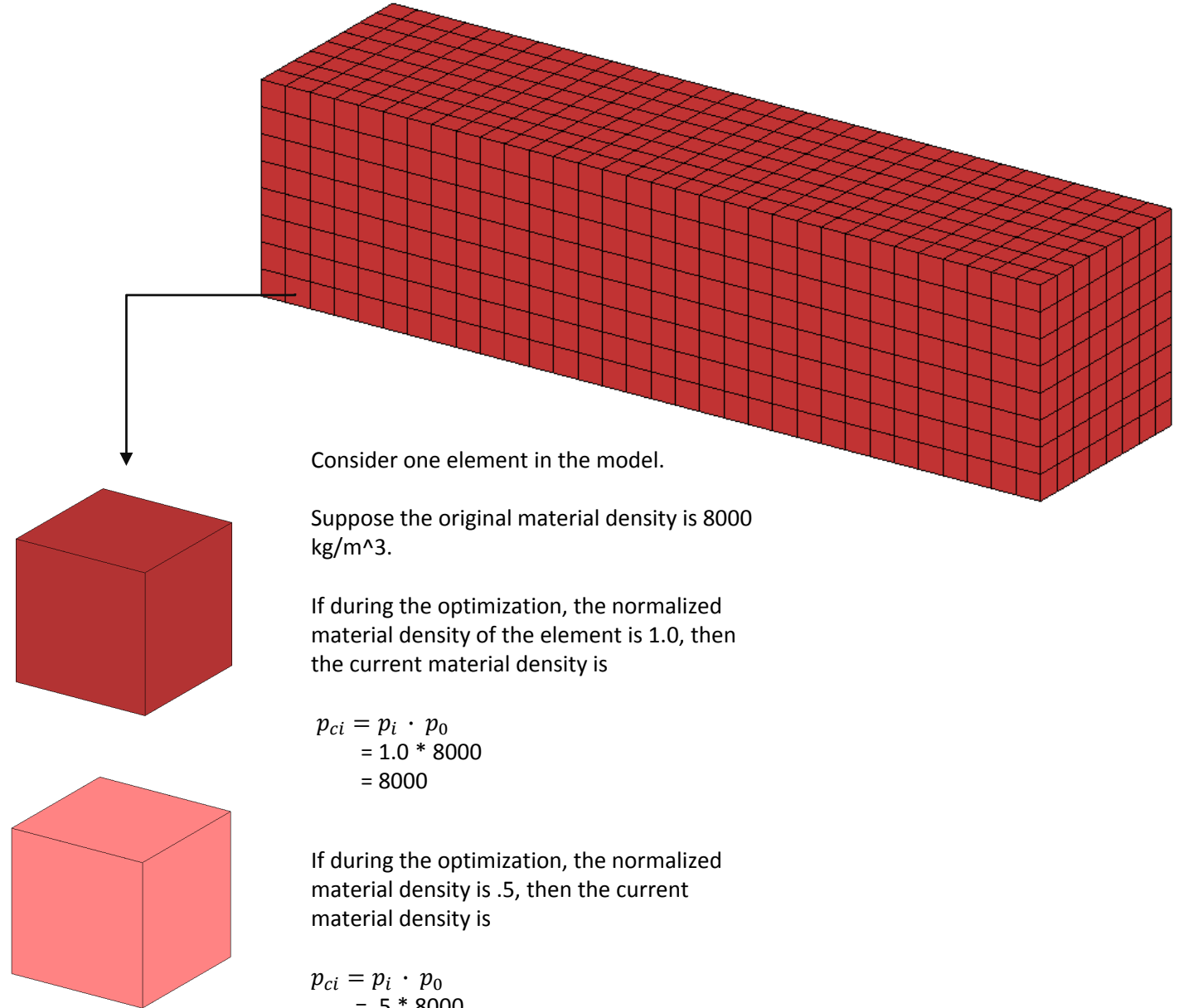
The design variables in a topology optimization are normalized material densities ( $p_i$ ) of each element.

$$p_i = \frac{p_{ci}}{p_0}$$

$p_{ci}$  : The current material density of element  $i$

$p_0$  : The original material density

$p_i$  : The normalized material density of element  $i$





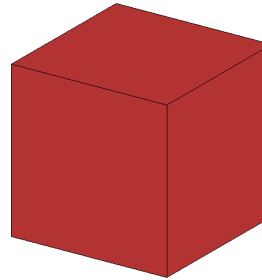
# What are the design variables in Topology Optimization?

The design variables or normalized material densities can vary between 0 and 1.

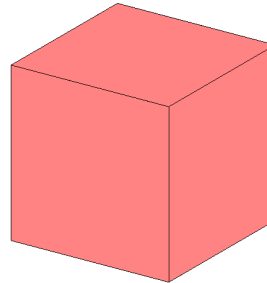
- 1 - Normalized density values close to 1 are critical to the design
- 0 - Normalized density values close to 0 are not critical to the design

It should be noted that during the optimization, elements are never removed. Instead, the normalized material density values are used to determine which elements should be kept or removed.

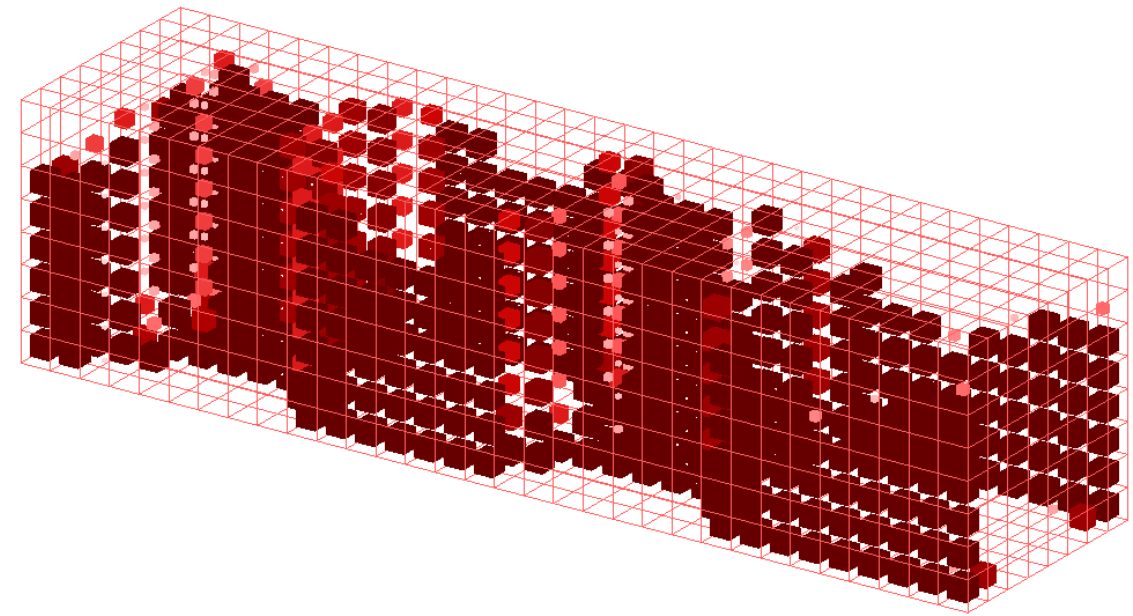
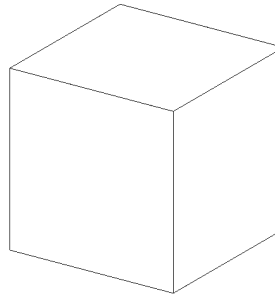
$p_i = 1.0$



$p_i = .50$



$p_i = 0.0$



During the optimization, the normalized material density of each element is allowed to vary between 0 and 1 ( $0 < p_i \leq 1$ )

# What is FRMASS or Fractional Mass?

Since the design variables or normalized material densities can range between 0 and 1, the final mass will be some fraction of the original mass. This is known as the fractional mass or FRMASS.

$$\text{FRMASS} = \frac{\sum p_i \cdot p_0 \cdot v_i}{\sum p_0 \cdot v_i}$$

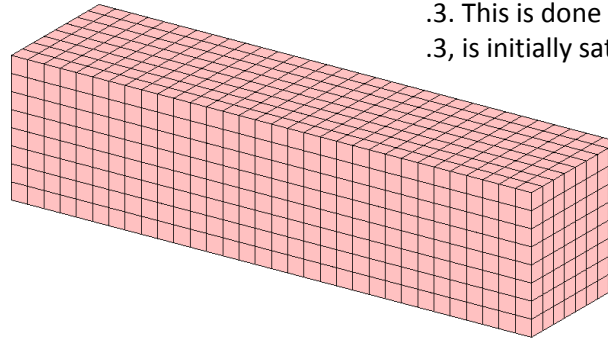
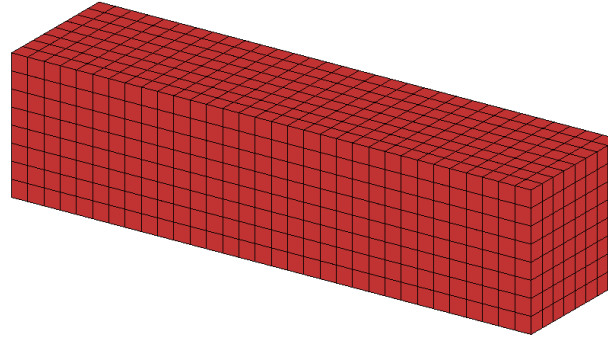
$p_0$  : The original material density

$p_i$  : The normalized material density of the element

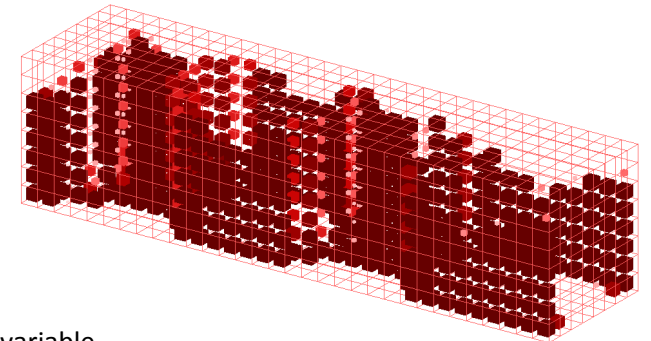
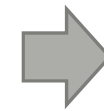
$v_i$  : Volume of element

0) Suppose this is the optimization problem statement:

- Objective: Minimize compliance
- Constraint: FRMASS < .3



1) Prior to the optimization start, each material density is reduced from 1.0 to .3, and as a result, the fractional mass (FRMASS) is reduced from 1.0 to .3. This is done so the design constraint, FRMASS < .3, is initially satisfied.



2) During the optimization, each variable (normalized material density) is allowed to range between 0 and 1.0, but the constraint that the FRMASS < .3 should ultimately be satisfied.

# What is compliance?

Compliance is defined in many ways

- “Compliance is simply the product of the displacement times the applied load” (MSC Nastran Design Sensitivity and Optimization User’s Guide)
- For linear elastic solids, the work is twice the total strain energy

E L E M E N T   S T R A I N   E N E R G I E S				
ELEMENT-TYPE = HEXA		* TOTAL ENERGY OF ALL ELEMENTS IN PROBLEM	=	9.111034E+03
SUBCASE	1	* TOTAL ENERGY OF ALL ELEMENTS IN SET	-1 =	9.111034E+03
ELEMENT-ID	STRAIN-ENERGY	PERCENT OF TC	Total Strain Energy	
25	8.059148E+02	8.8455		
32	8.059148E+02	8.8455		6.447318E+03
33	8.059148E+02	8.8455		6.447318E+03
40	8.059148E+02	8.8455		6.447318E+03
TYPE = HEXA	SUBTOTAL	9.111034E+03	100.0000	

***** SUMMARY OF DESIGN CYCLE HISTORY *****				
(HARD CONVERGENCE ACHIEVED)				
NUMBER OF FINITE ELEMENT ANALYSES COMPLETED			56	
NUMBER OF OPTIMIZATIONS W.R.T. APPROXIMATE MODELS			55	
OBJECTIVE AND MAXIMUM CONSTRAINT HISTORY				
CYCLE NUMBER	OBJECTIVE FROM APPROXIMATE OPTIMIZATION	OBJECTIVE FROM EXACT ANALYSIS	FRACTIONAL ERROR OF APPROXIMATION	MAXIMUM VALUE OF CONSTRAINT
INITIAL		1.822207E+04		-4.625929E-15
1	5.076533E+03	1.321111E+04	6.163140E-01	9.999972E-09
2	5.721454E+03	1.120000E+04	4.893855E-01	6.604279E-09
3	4.220301E+03	1.016538E+04	-5.848357E-01	1.000032E-08
4	3.996396E+03	9.769504E+03	-5.909315E-01	9.983010E-09

# What is compliance? Continued

The .f06 file reports the value of compliance and strain energy. **The following applies if and only if minimizing the compliance is the design objective.**

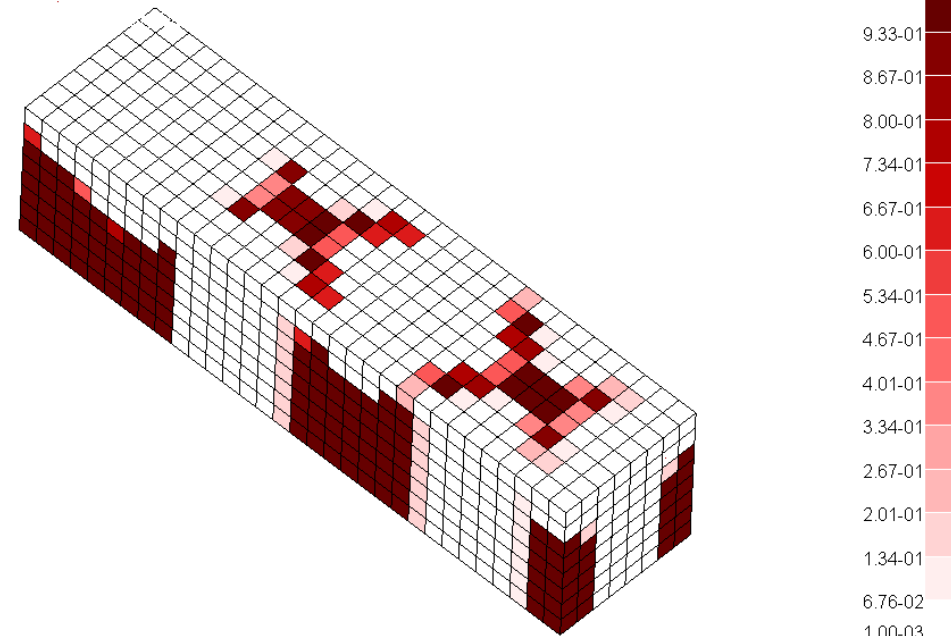
1. Make sure this statement is in the Case Control Section of the .bdf file.  
*ESE(THRESH=.99)=ALL*
2. Search the .f06 file for the initial design's  
*ELEMENT STRAIN ENERGIES*
3. Note the value of *TOTAL ENERGY OF ALL ELEMENTS IN PROBLEM*
4. Search the .f06 for the  
*SUMMARY OF DESIGN CYCLE HISTORY*
5. Note the value for OBJECTIVE FROM EXACT ANALYSIS for the INITIAL cycle number
6. The Compliance of 1.8222E4 is twice the TOTAL STRAIN ENERGY of 9.11E3.

E L E M E N T   S T R A I N   E N E R G I E S				
ELEMENT-TYPE = HEXA		* TOTAL ENERGY OF ALL ELEMENTS IN PROBLEM	=	9.111034E+03
SUBCASE	1	* TOTAL ENERGY OF ALL ELEMENTS IN SET	-1 =	9.111034E+03
	ELEMENT-ID	STRAIN-ENERGY	PERCENT OF TOTAL	STRAIN-ENERGY-DENSITY
	25	8.059148E+02	8.8455	6.447318E+03
	32	8.059148E+02	8.8455	6.447318E+03
	33	8.059148E+02	8.8455	6.447318E+03
	40	8.059148E+02	8.8455	6.447318E+03
TYPE = HEXA	SUBTOTAL	9.111034E+03	100.0000	

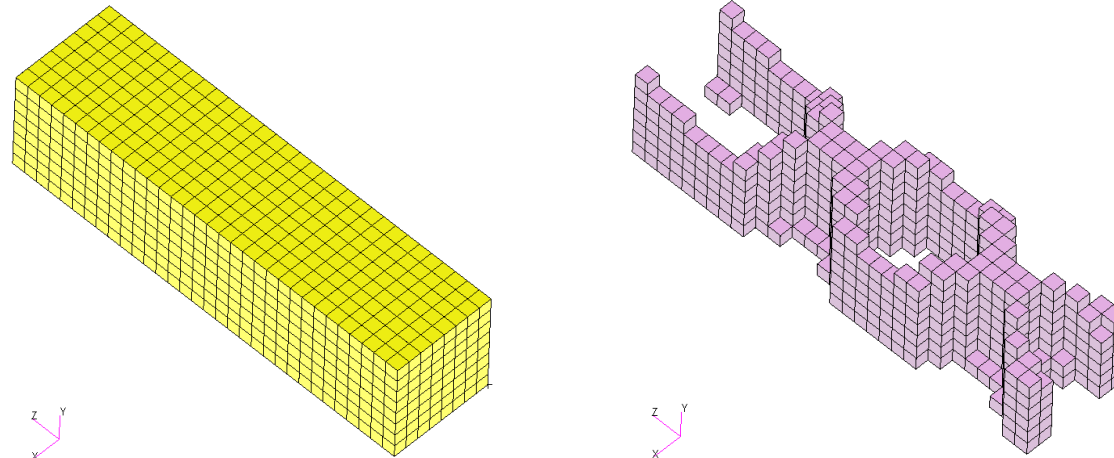
***** S U M M A R Y   O F   D E S I G N   C Y C L E   H I S T O R Y *****				
(HARD CONVERGENCE ACHIEVED)				
NUMBER OF FINITE ELEMENT ANALYSES COMPLETED			56	
NUMBER OF OPTIMIZATIONS W.R.T. APPROXIMATE MODELS			55	
OBJECTIVE AND MAXIMUM CONSTRAINT HISTORY				
CYCLE NUMBER	OBJECTIVE FROM APPROXIMATE OPTIMIZATION	OBJECTIVE FROM EXACT ANALYSIS	FRACTIONAL ERROR OF APPROXIMATION	MAXIMUM VALUE OF CONSTRAINT
INITIAL		1.822207E+04		-4.625929E-15
1	5.076533E+03	1.323096E+04	-6.163140E-01	9.999972E-09
2	5.721454E+03	1.120504E+04	-4.893855E-01	6.604279E-09
3	4.220301E+03	1.016538E+04	-5.848357E-01	1.000032E-08
4	3.996396E+03	9.769504E+03	-5.909315E-01	9.983010E-09

# How can non-critical elements be removed from the design?

- Use the threshold to suppress non-critical elements
- The threshold means: *'Keep every element that has a normalized density greater than the threshold'*
- Recall from before:
  - 0 - Normalized density values close to 0 are not critical to the design
  - 1 - Normalized density values close to 1 are critical to the design



The normalized densities are plotted for each element. Note that all the elements are present.



Action:

Object:

Select Result Case

DESIGN CYCLE: 55, topex5a.des

Threshold:

☐ Fringe

Target Entity

Entire Model

Group Name

HIGH\_DENS\_GRP4

# Topology Optimization Workflows

There are 2 common optimization problem statements for topology optimization

---

## METHOD A

### Objective:

- Minimize Compliance

### Constraint:

- FRMASS < Upper Bound

### Comments:

- Multiple optimizations at different bounds for FRMASS are necessary. The best solution is selected from the multiple optimizations.

## METHOD B

### Objective:

- Minimize FRMASS

### Constraint:

- Von Mises Stress < Upper Bound

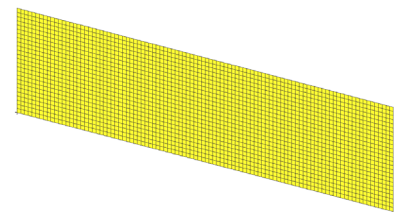
# Traditional Topology Optimization

Objective: Minimize Compliance (Maximize Stiffness)

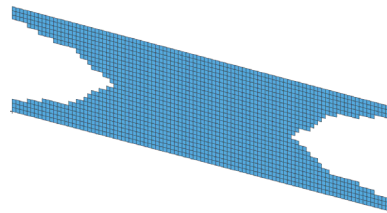
Constraint: Fractional Mass < .## (Target Mass)

---

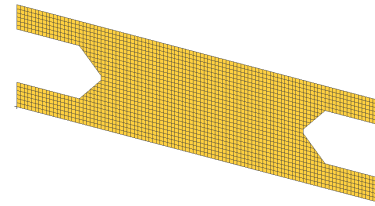
Original Design



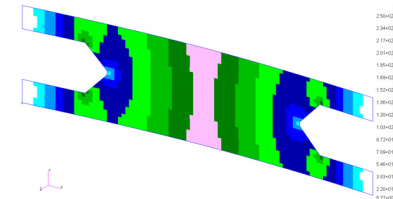
Mass: 9.737 grams



FRMASS < .75  
Mass: 7.186 g  
Optimization B



Mass: 7.739 g



Max von Mises: 150 MPa  
Max Displacement : 2.78 mm

1<sup>st</sup> natural Frequency: 111 Hz



# Traditional Topology Optimization

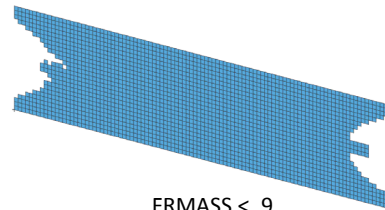
Objective: Minimize Compliance (Maximize Stiffness)

Constraint: Fractional Mass < .## (Target Mass)

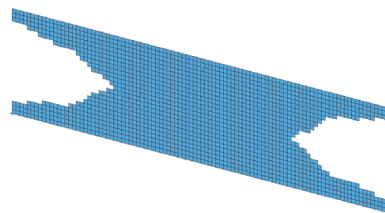
Original Design

Mass: 9.737 grams

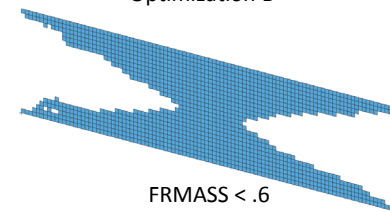
Topology Solution



FRMASS < .9  
Mass: 8.756 g  
Optimization A

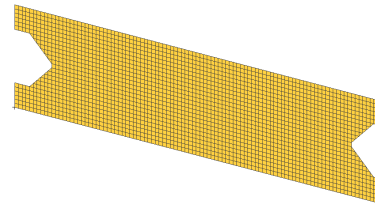


FRMASS < .75  
Mass: 7.186 g  
Optimization B

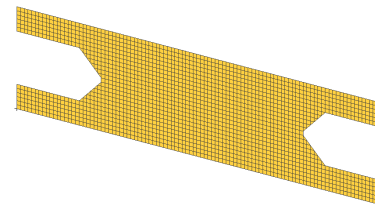


FRMASS < .6  
Mass: 5.718 g  
Optimization C

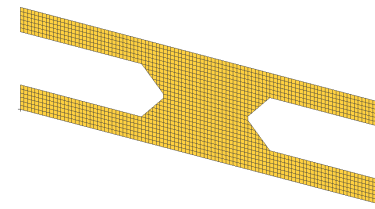
Refined Design



Mass: 9.094 g

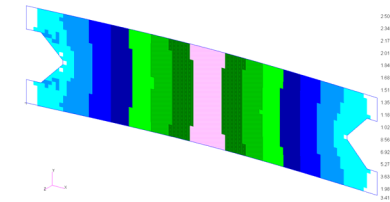


Mass: 7.739 g



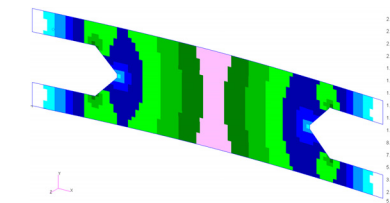
Mass: 6.119 g

Verification



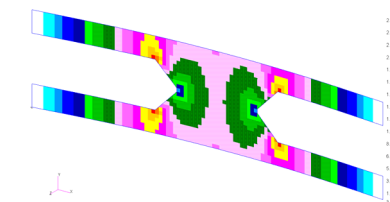
Max von Mises: 150 MPa  
Max Displacement: 2.52 mm

1<sup>st</sup> natural Frequency: 114 Hz



Max von Mises: 150 MPa  
Max Displacement : 2.78 mm

1<sup>st</sup> natural Frequency: 111 Hz



Max von Mises: 250 MPa  
Max Displacement : 3.57 mm

1<sup>st</sup> natural Frequency: 109 Hz

Best Solution: Optimization B  
led to a valid and light weight  
design

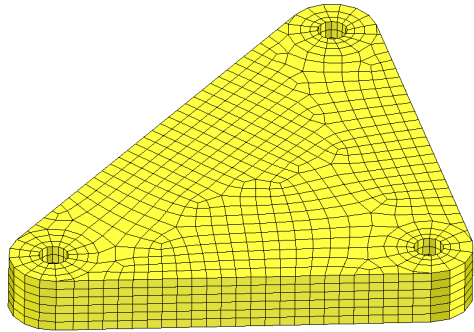


# Latest Topology Optimization

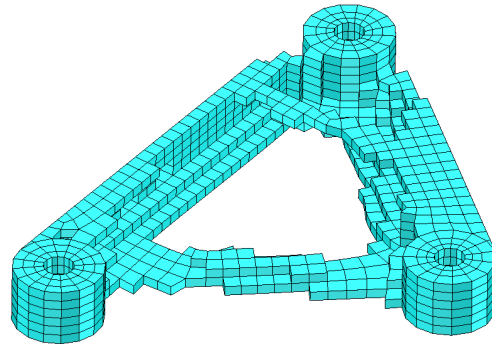
Objective: Minimize Fractional Mass (Minimize Mass)

Constraint: Stress Constraint

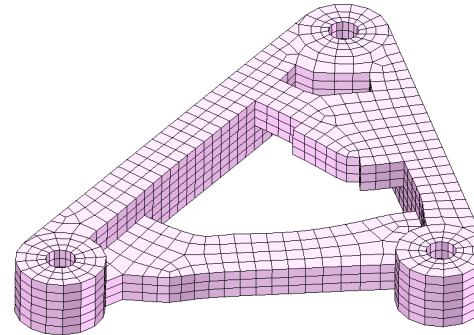
Original Design



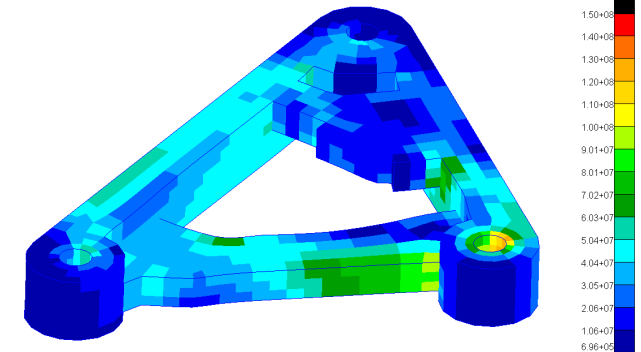
Topology Solution



Refined Design



Verification



# Viewer Web App for Topology Optimization Post Processing

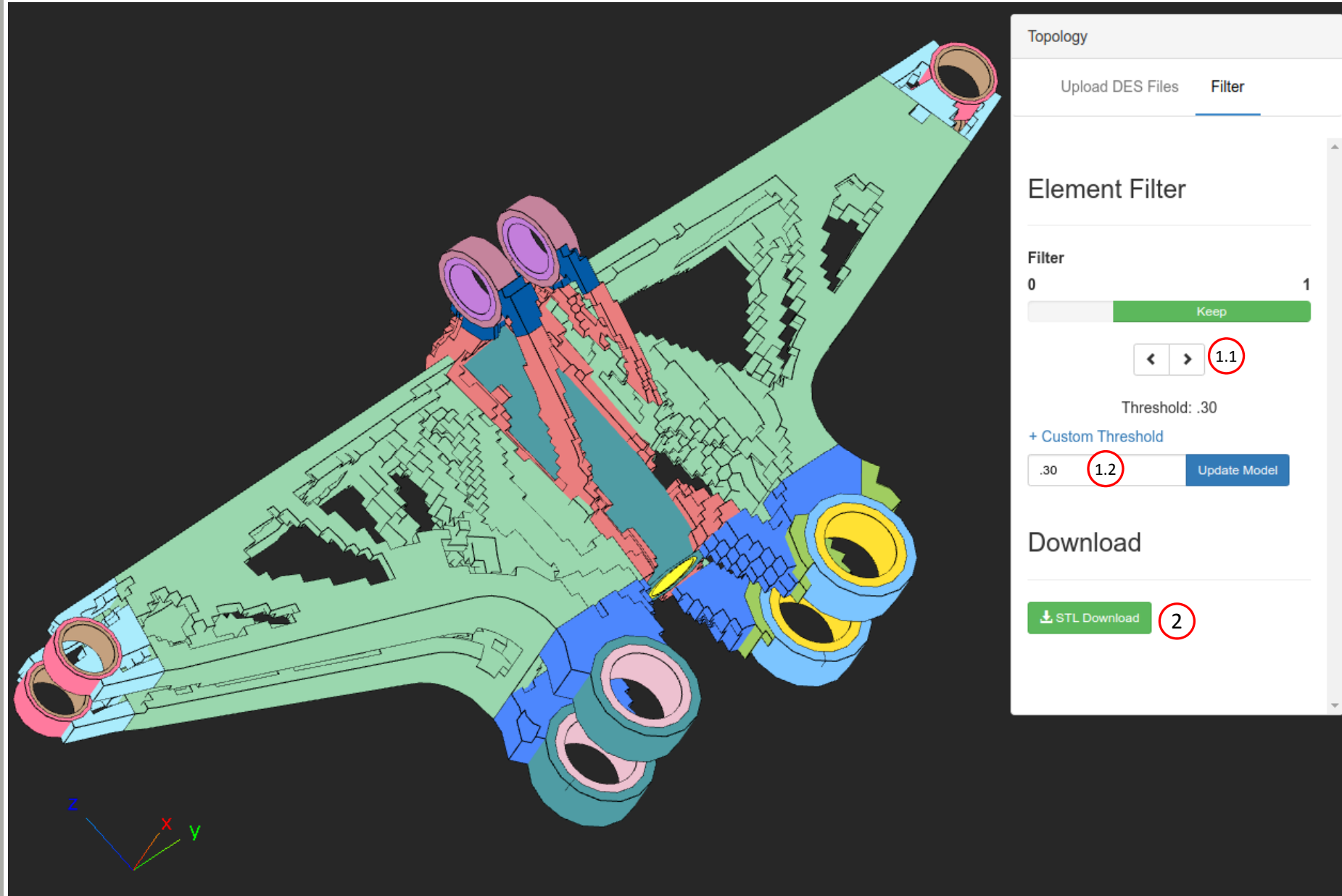
---

# Review Optimization Results

The Viewer web app supports post processing topology optimization results.

Filtering of topology optimization results is controlled by one of 2 different ways:

1. The arrows can be used to move the threshold to values of 1.0, .3, .4, .5, .6 and .7
2. If a specific threshold is necessary, do the following:
  1. Click Custom Threshold
  2. Supply the custom threshold
  3. Click Update Model
1. STL Download – This downloads an STL file containing the model as displayed. This is useful for moving the topology results to a CAD package or FEA pre processor



# Viewer

## Supported Capabilities

---

### Supported Element Types

- CTRIA3
- CTRIA6
- CTRIAR
- CQUAD4
- CQUAD8
- CQUADR
- CQUAD4
- CQUAD8
- CQUADR
- CHEXA
- CTETRA
- CPENTA
- All other elements are not supported

### Coordinate Systems Supported

- Only the basic coordinate system (CID=0) is supported for GRIDs. This is a rectangular Cartesian system and is also known as the default coordinate system.
- All other coordinate systems are not supported. This includes cylindrical, spherical and other cartesian systems (CID=1, 2, 3...).

### STL Download/Export is Supported

### Performance

- When uploading BDF or DES files, there are many operations performed, e.g. reading, parsing, and displaying data. This is the first release of the Topology Viewer and future improvements to performance will be made. At the time of writing this, the viewer is capable of fully parsing and displaying 10MB of BDF files every 25 seconds. The viewer does not provide a progress bar regarding the parsing process, so it was best to document here the expected parsing rate.