

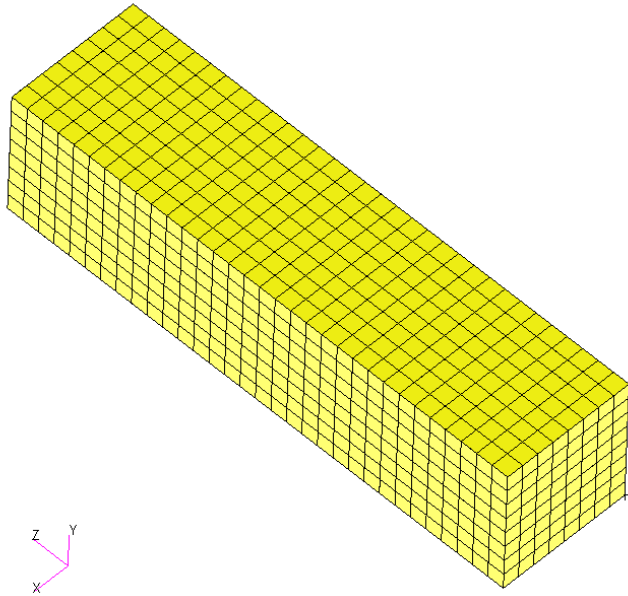
Workshop - MSC Nastran Topology Optimization Manufacturing Constraints

AN MSC NASTRAN SOL 200 TUTORIAL

Goal: Use Nastran SOL 200 Optimization

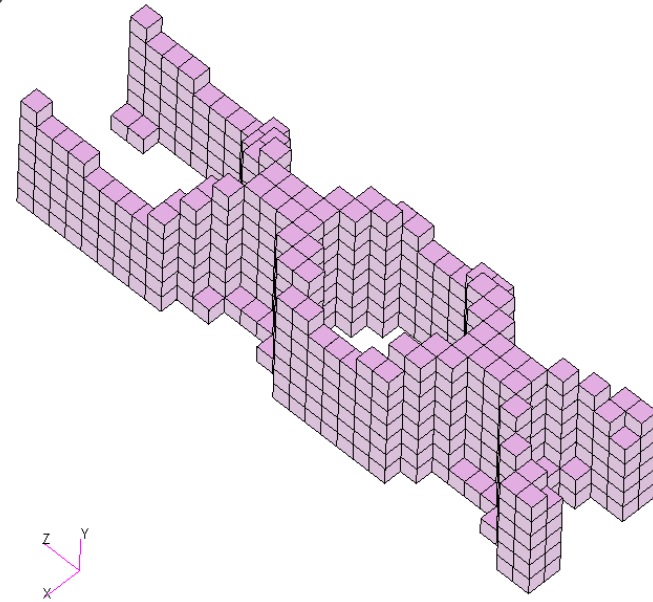
Before Optimization

- Mass: 25.6

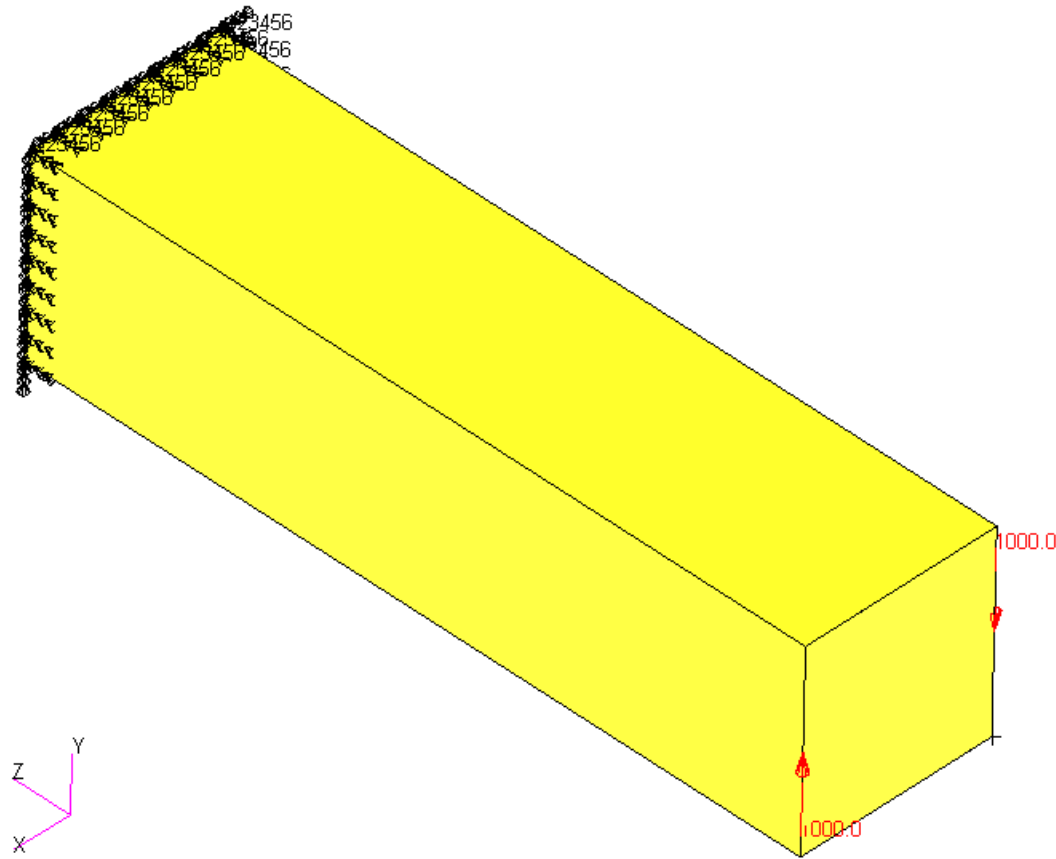


After Optimization

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



Details of the structural model



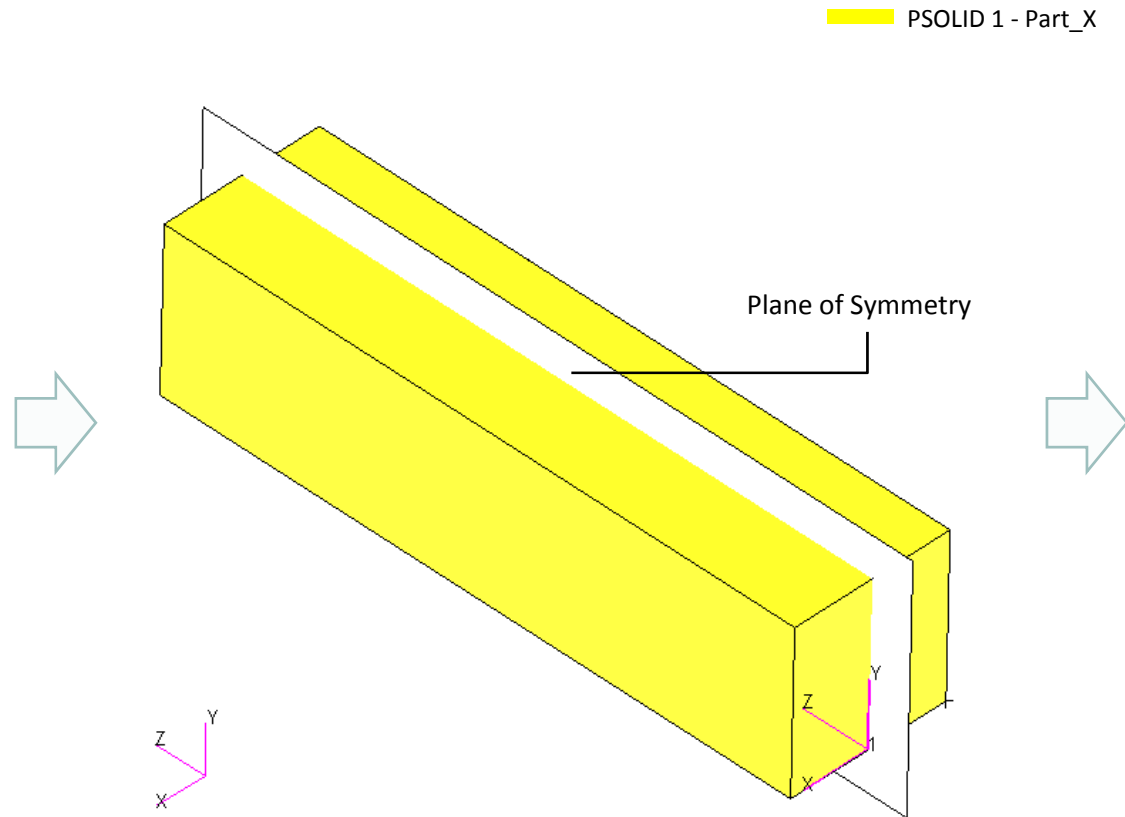
Optimization Problem Statement

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

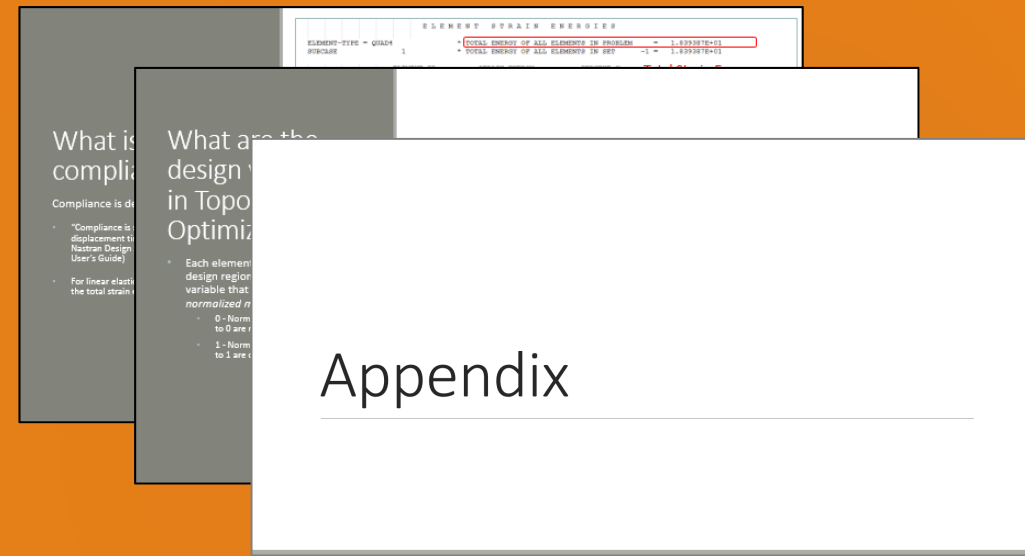
r1: Fractional mass

$r1 < .3$ (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

Tutorial Overview

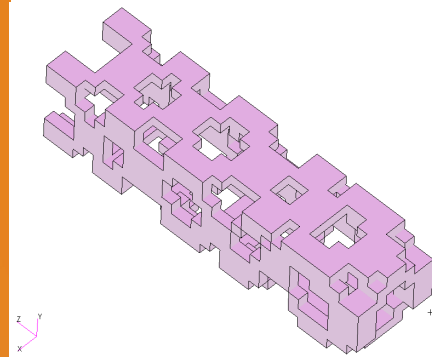
1. Start with a .bdf or .dat file
2. Use the SOL 200 Web App to:
 - Convert the .bdf file to SOL 200
 - Design Regions/Variables
 - Design Objective
 - Design Constraints
 - Perform optimization with Nastran SOL 200
3. Review optimization results
 - .f06
 - Topology Optimization and Structural Results

Special Topics Covered

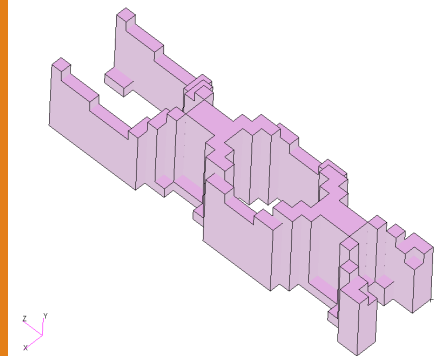
Mirror Symmetry Constraints - Fit the Topology Optimization solution must be symmetric, constraints may be imposed to achieve this.

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

The Post-processor Web App and HDF5 Explorer are free to MSC Nastran users.

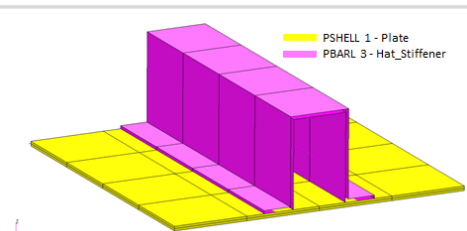
Compatibility

- Google Chrome, Mozilla Firefox or Microsoft Edge
- Windows and Red Hat Linux
- Installable on a company laptop, workstation or server. All data remains within your company.

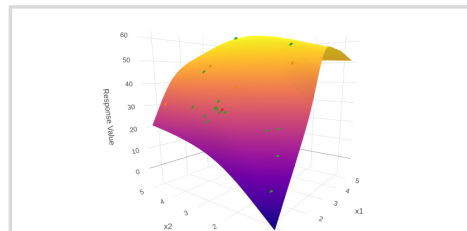
Web Apps

Benefits

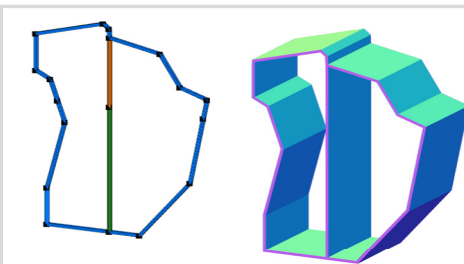
- REAL TIME error detection. 200+ error validations.
- REAL TIME creation of bulk data entries.
- Web browser accessible
- Free Post-processor web apps
- +80 tutorials



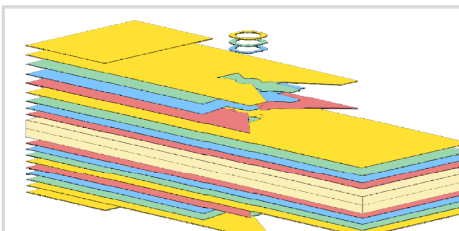
Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200.
Support for size, topology, topometry, topography, multi-model optimization.



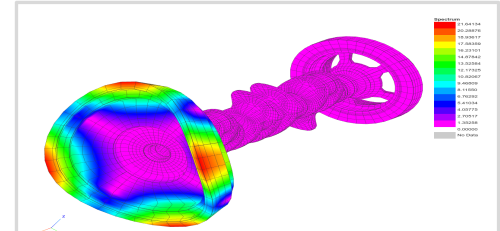
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



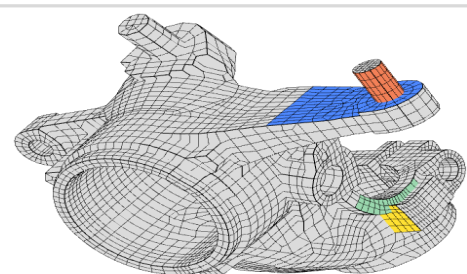
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



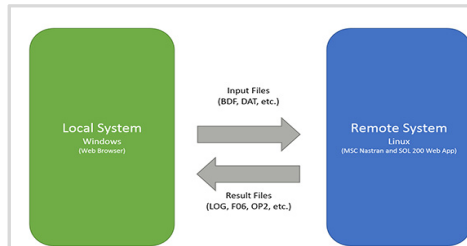
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries



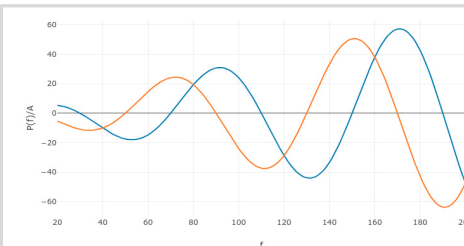
Post-processor Web App
View MSC Nastran results in a web browser on Windows and Linux



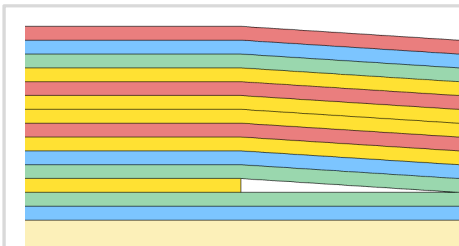
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



Dynamic Loads Web App
Generate RLOAD1, RLOAD2 and DLOAD entries graphically



Stacking Sequence Web App
Optimize the stacking sequence of composite laminate plies

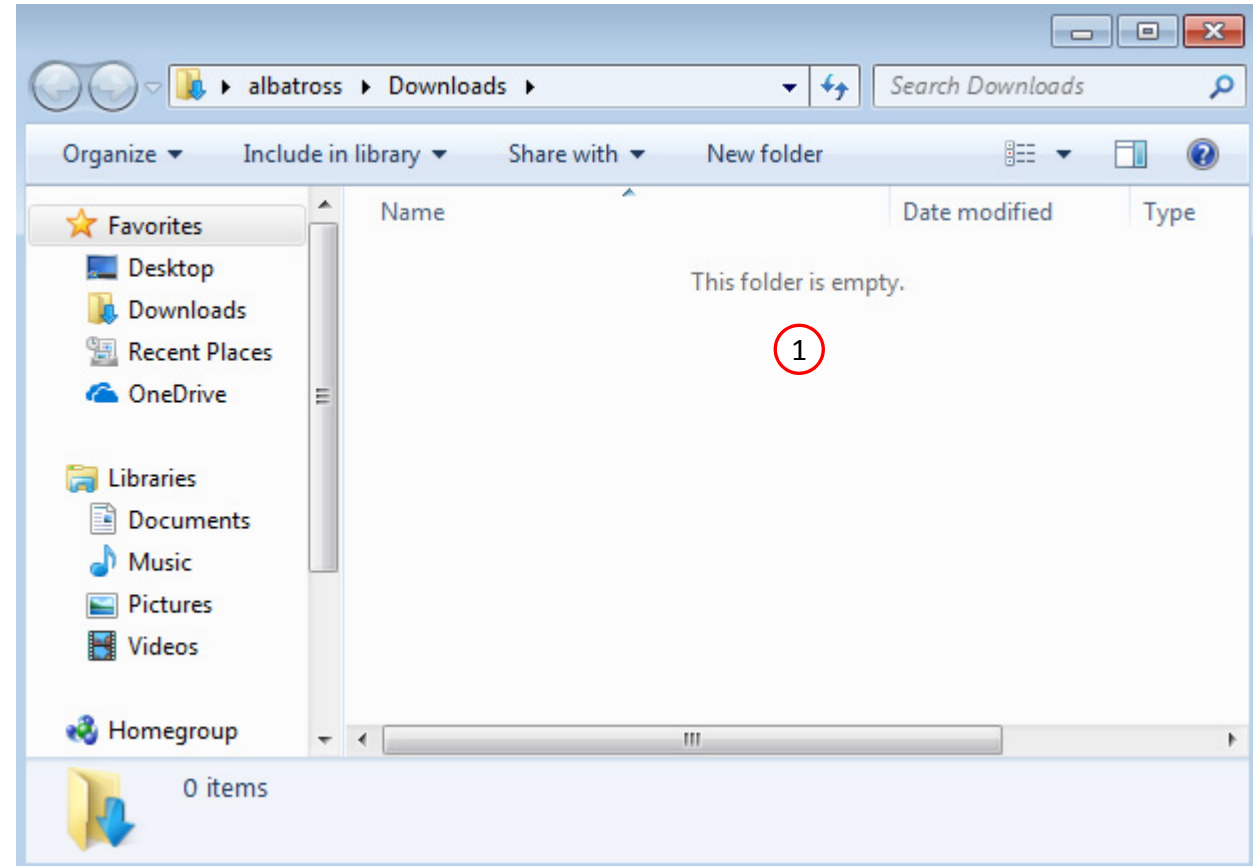


HDF5 Explorer Web App
Create graphs (XY plots) using data from the H5 file

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

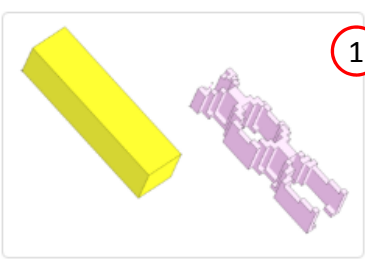
- The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.

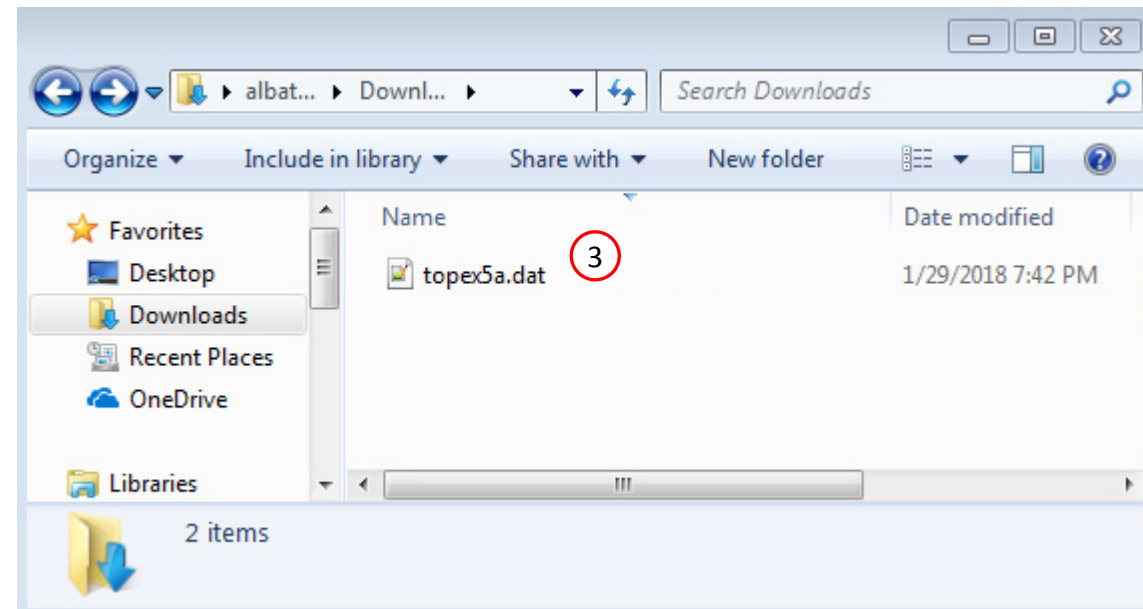


Obtain Starting Files

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.

 <div data-bbox="1299 185 1350 235">1</div>	<h3>MSC Nastran Topology Optimization Manufacturing Constraints</h3> <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: Link <div data-bbox="1605 378 1656 428">2</div> Solution BDF Files: Link</p>	Link
---	--	----------------------



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.



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 topology variable is created for each element in the design region. Each topology variable controls the density and stiffness for the respective 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
2 +	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									
6	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
---	-----	--	---------	-------------------------	-----	---	----------------	----

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, topology variable values, 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	.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
CEMD

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 Regions/variables
$-----
$
$
TOPVAR    300001   x1      PSOLID                1
          SVM      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

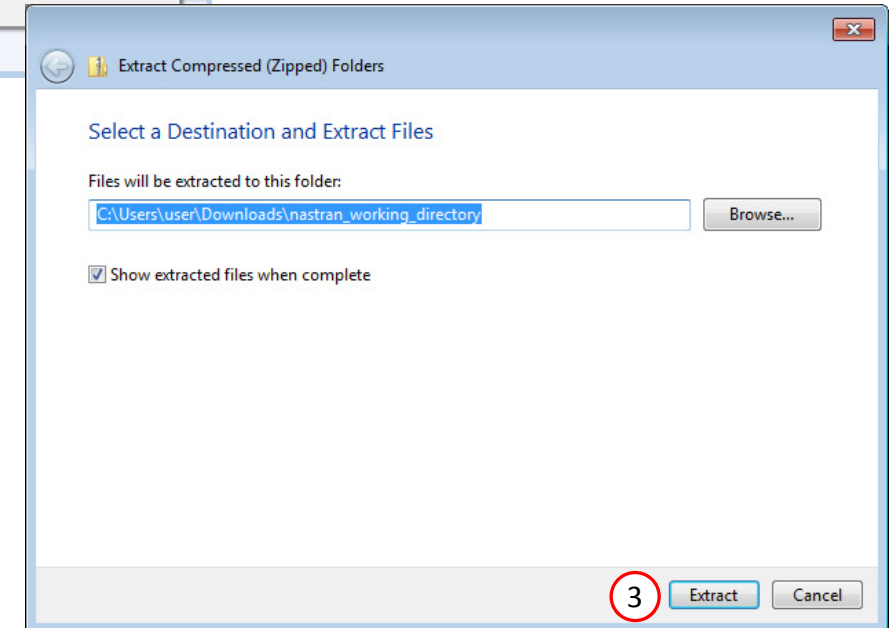
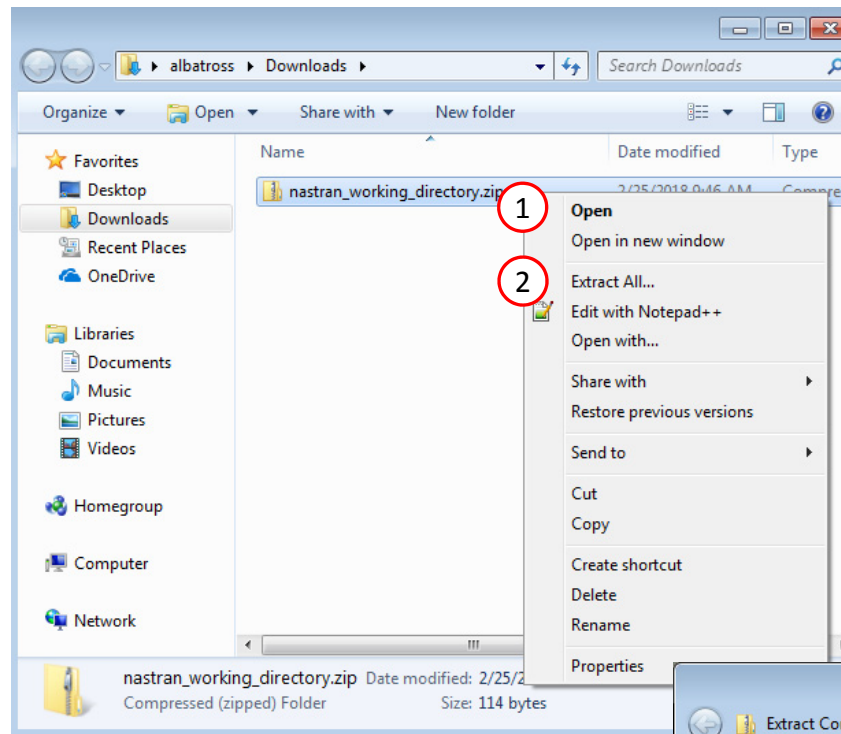
2

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.

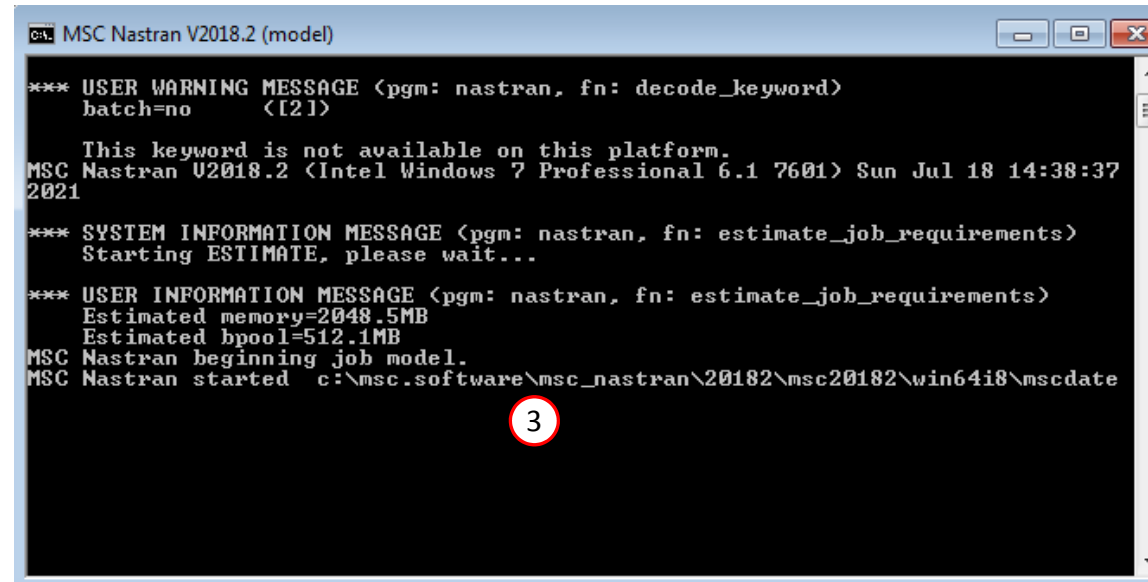
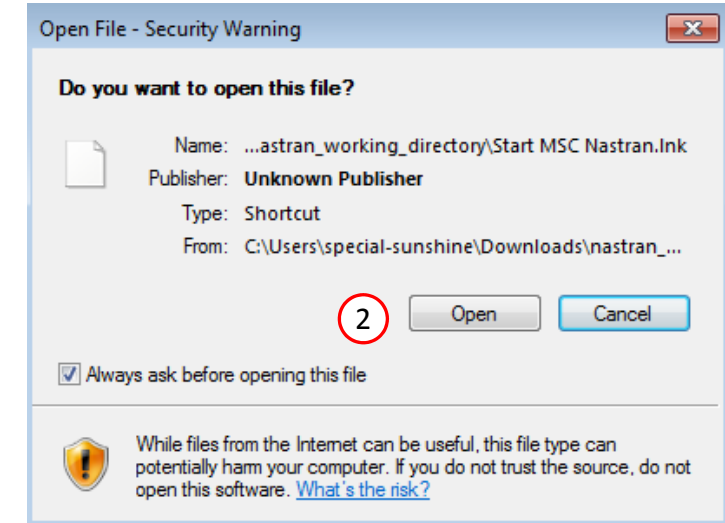
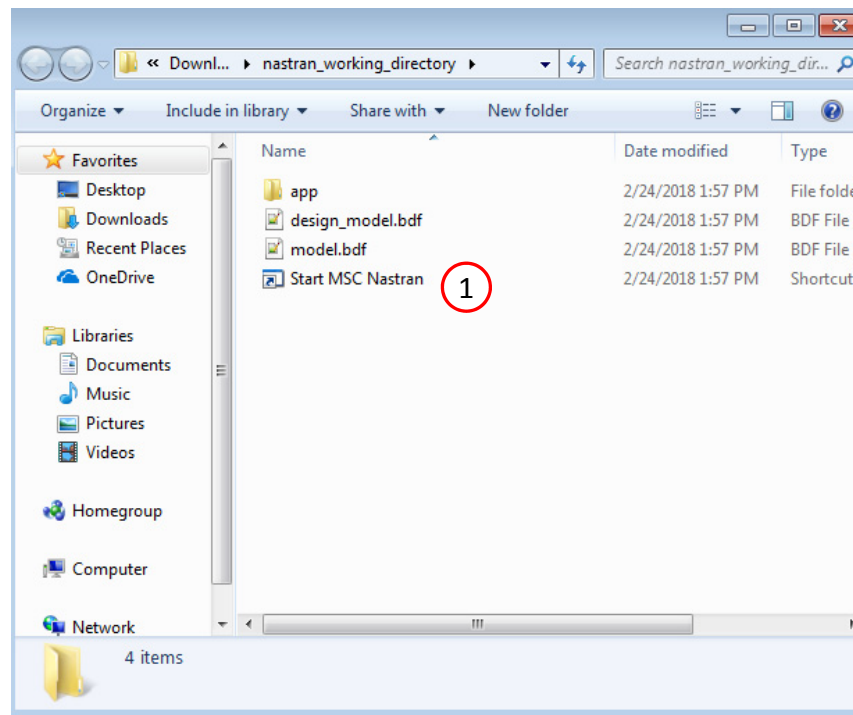
Using Linux?

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

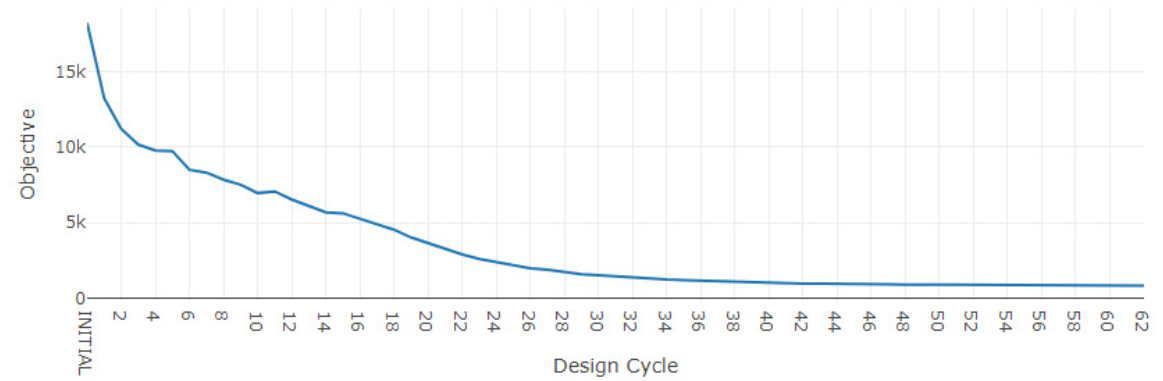
1



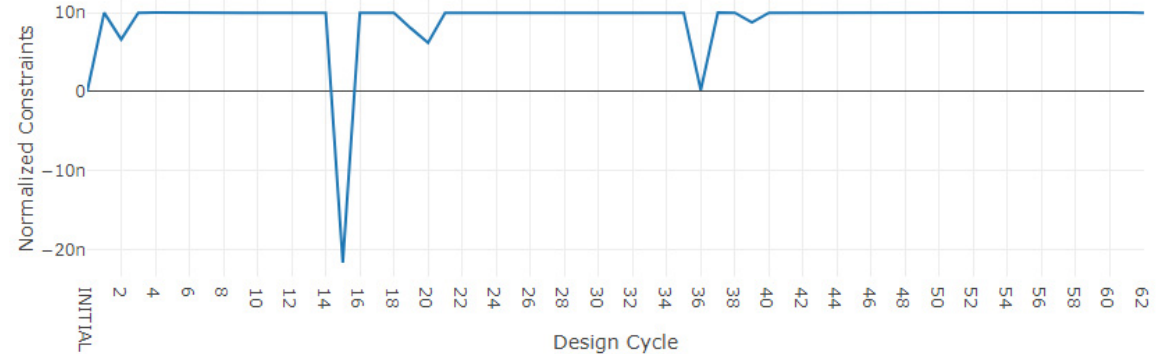
RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER = 62.

Objective

2



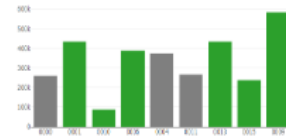
Normalized Constraints



Review Optimization Results

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

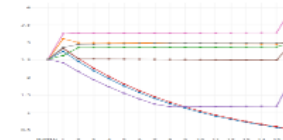
Select a Results App



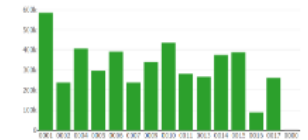
Global Optimization (multiplt.log)



Global Optimization Type 2 (.f06)

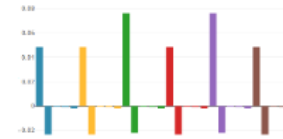


Local Optimization (.f06)

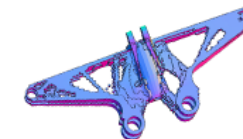


Parameter Study (.f06)

Responses (.f06)



Sensitivities (.csv)



Topology Viewer (.des) 3

Miscellaneous Apps

Converter

PCH to BDF

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

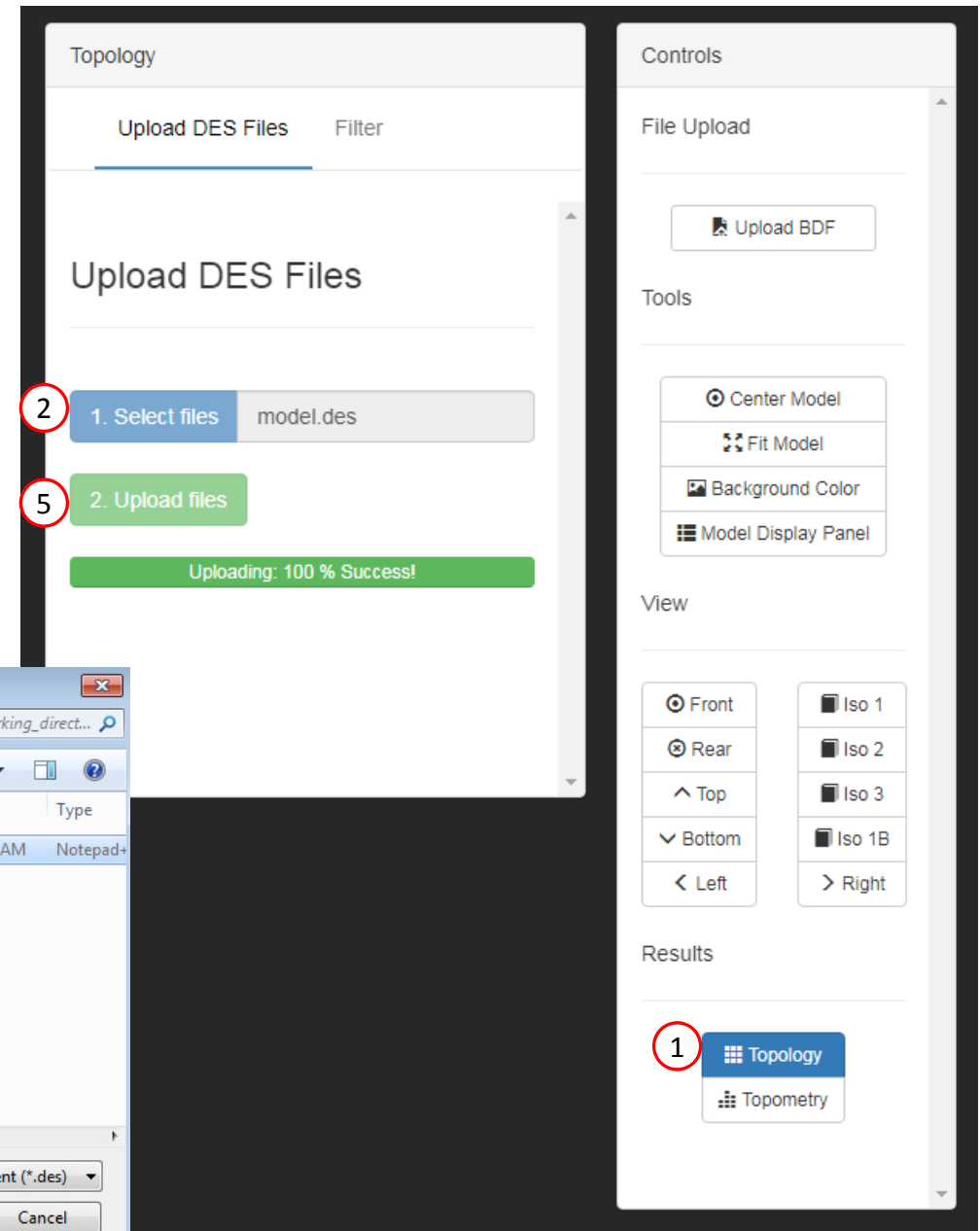
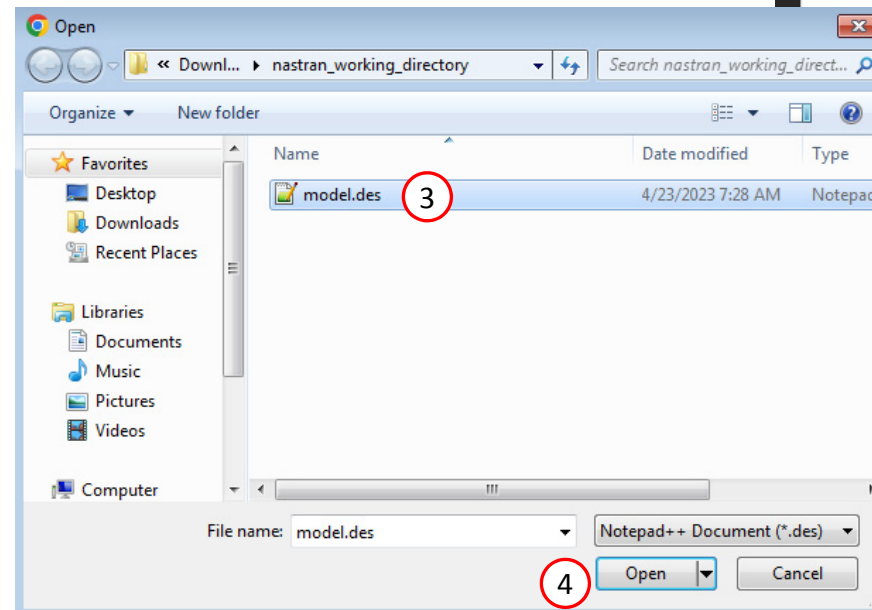
- During file upload, reading and parsing process, the web app does not report the reading progress for large files. Know that the web app parses files at a rate of 10MB every 25 seconds.

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.

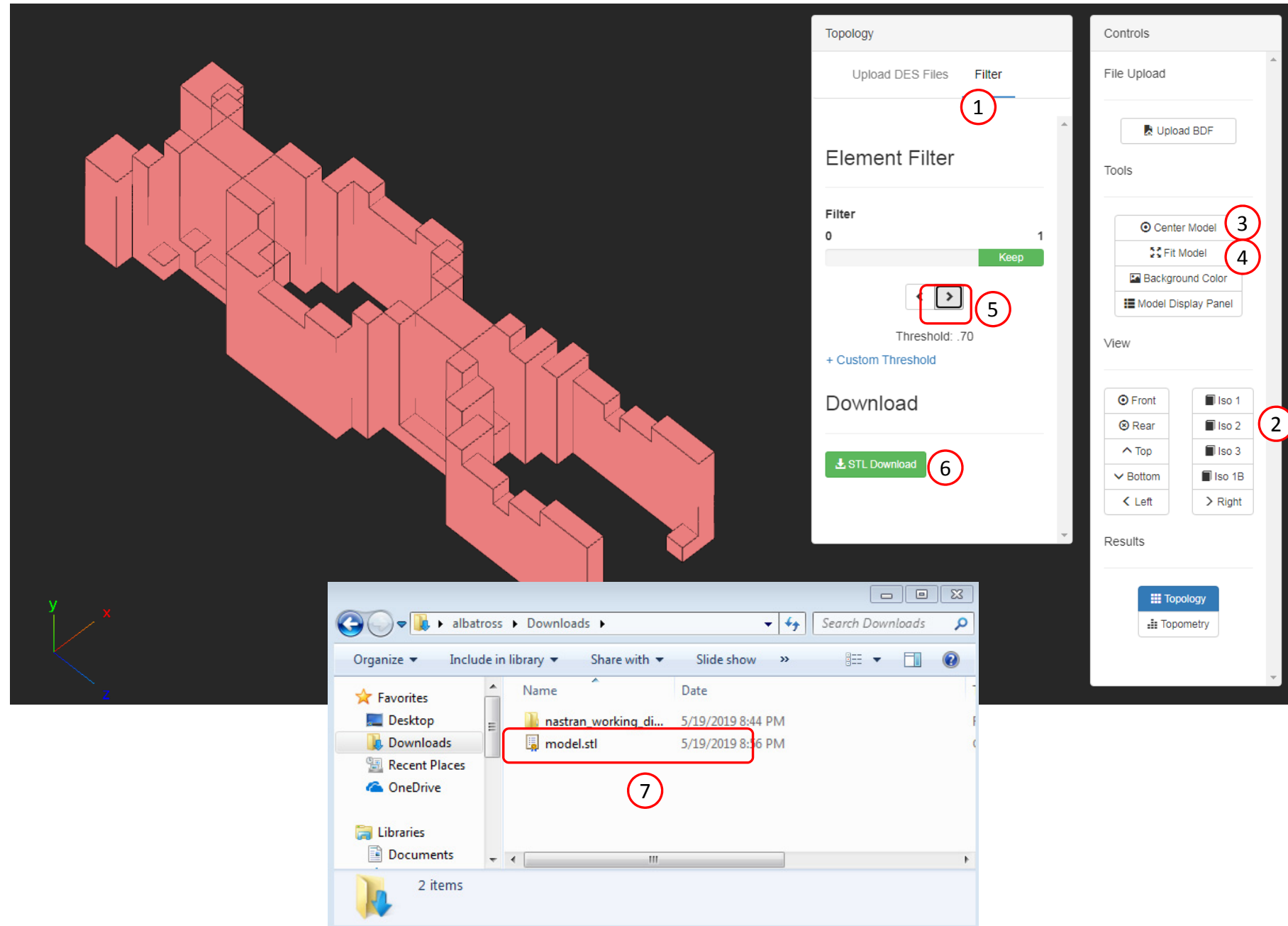
- When the DES file is uploaded, the topology results are automatically displayed. By default, elements with a topology variable value greater than a threshold of .3 are displayed. The threshold can be modified.



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

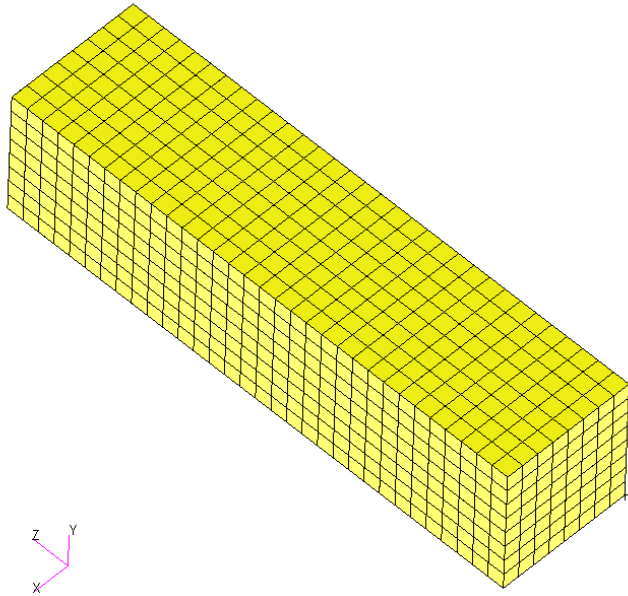
- A topology variable value close to 1 indicates the element is very important and should be kept in the design. It is not recommended to go beyond a threshold of .7 since very critical elements would be removed. Elements with an topology variable value close to 0 are not critical and can be removed.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



Results

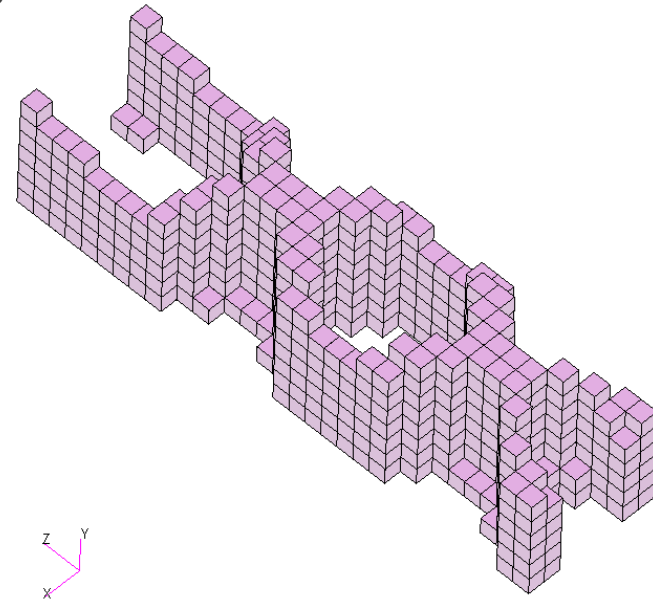
Before Optimization

- Mass: 25.6



After Optimization

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



End of Tutorial

Appendix

Appendix Contents

- 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?

Consider the following topology optimization workflow.

1. A topology design region is selected.
 - 1 material
 - 2048 elements
2. At the start of an optimization, each element is assigned its own material (stiffness and density).
 - 2048 materials
 - 2048 elements
3. During the optimization, each element is given a topology variable x_i , where i is the element ID.
 - 2048 topology variables

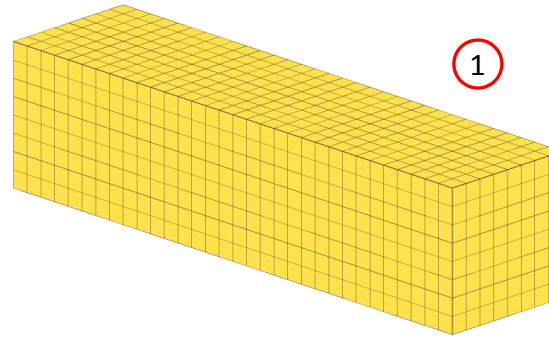
The topology variable x_i controls the material density and stiffness of element i via these expressions.

- $p_i = p_0 \cdot x_i$
- $E_i = E_0 \cdot x_i^{\text{Penalty}}$

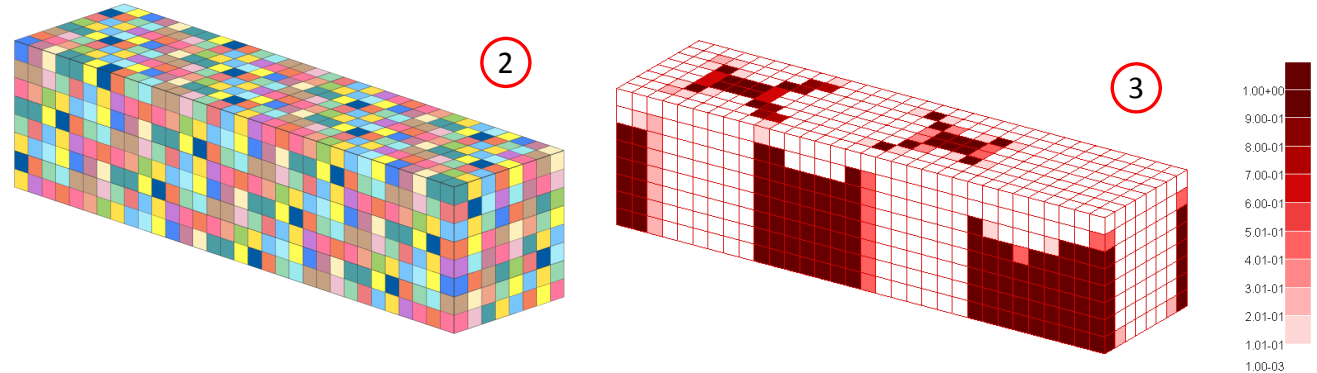
The penalty term ranges between 2-5 and is 3 by default. The topology variable varies between 0 and 1.

4. After the topology optimization, the user must decide which elements to keep.
 - During the topology optimization, elements are not automatically removed. It is up to the user to decide which elements to keep after the optimization.

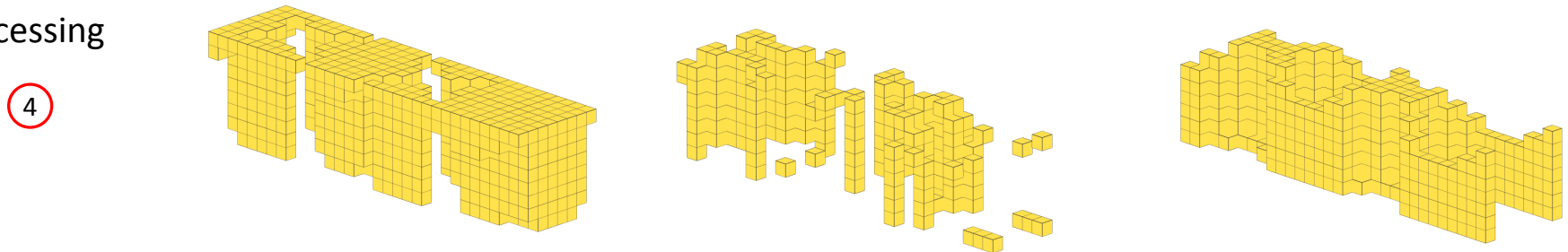
Topology Design Region



Topology Optimization



Results Post-processing



What are the design variables in Topology Optimization?

Many practitioners suggest keeping elements whose topology variable is in the range of 0.3 and 1.0, but do not explain the reasoning behind this suggestion.

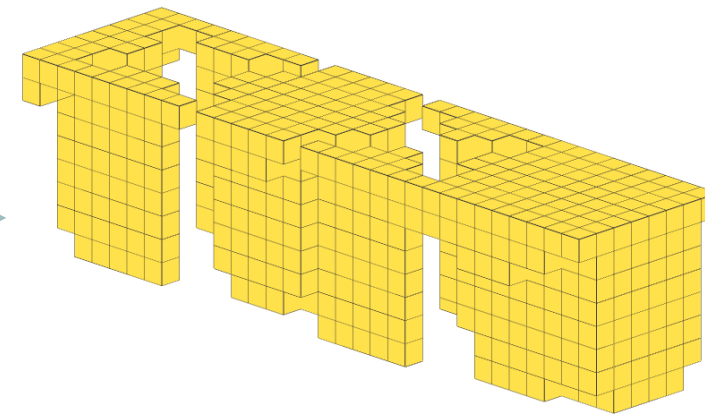
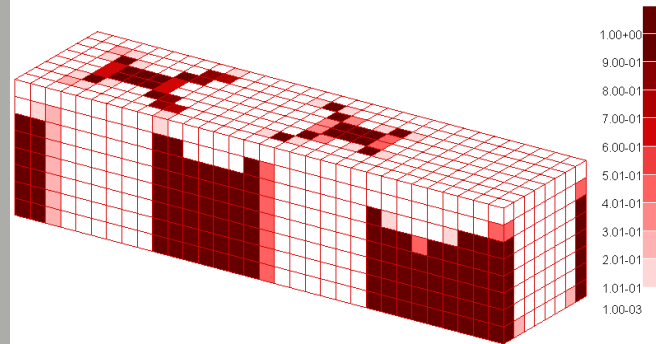
The following is an attempt to explain the suggestion.

Suppose the original stiffness of the material is $E_0 = 200E9 \text{ Pa}$.

- If $x_i=0.3$, then
 - $E_i = 200E9 \text{ Pa} * 0.3^3 = 5.4E9 \text{ Pa}$ (5.4 GPa)
 - A topology variable value of $x_i=0.3$ yields a stiffness on the range of wood.
- If $x_i=.0056$, then
 - $E_i = 200E9 \text{ Pa} * .0056^3 = 3.5123E4 \text{ Pa}$ (35.123 kPa)
 - A topology variable value of $x_i=.0056$ yields a stiffness on the range of gelatin dessert, such as Jello.

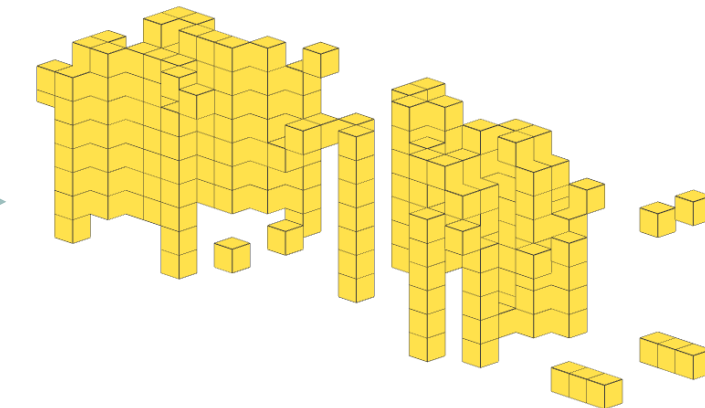
Elements with a stiffness equivalent to Jello are negligible and may be removed from the design. Elements with a stiffness equivalent to wood are also candidates for removal. Those who use topology optimization long enough will find the suggestion of keeping elements between 0.3 and 1.0 is not absolute. With trial and error, some will find that ranges of 0.5 to 1.0 or 0.4 to 1.0 will also sometimes work. Given that the best range is often unknown, this makes topology optimization a *black art*.

Topology Optimization Results



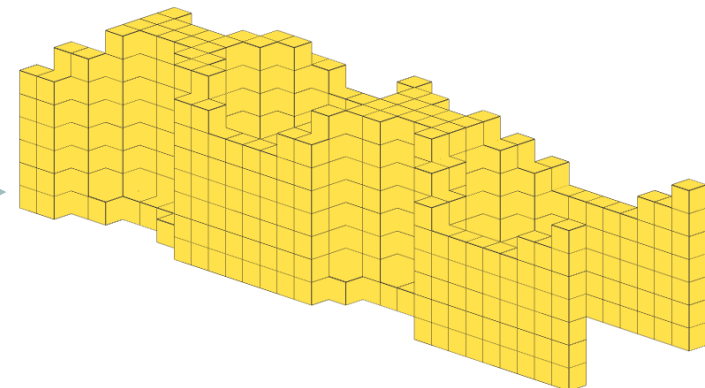
Elements in range:
 $0 < x_i \leq .0056$
 $0 < E_i \leq 3.5123E4 \text{ Pa}$
Range: Jello

Do not keep



Elements in range:
 $.0056 < x_i \leq 0.3$
 $3.5123E4 < E_i \leq 5.4E9 \text{ Pa}$
Range: Wood

Do not keep



Elements in range:
 $0.3 < x_i \leq 1.0$
 $5.4E9 \text{ Pa} < E_i \leq 200E9 \text{ Pa}$

Keep

What is FRMASS or Fractional Mass?

Since the topology variables 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.

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

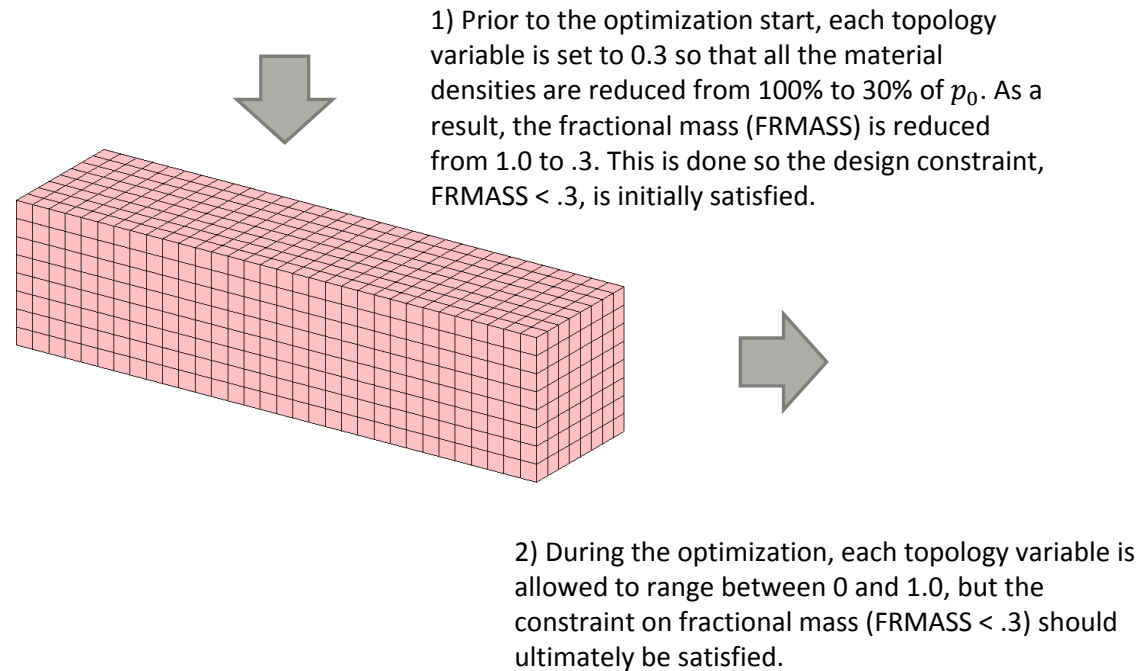
p_0 : The original material density

p_i : The optimized material density of the element ($p_i = p_0 \cdot x_i$)

v_i : Volume of element

0) Suppose this is the optimization problem statement:

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



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.

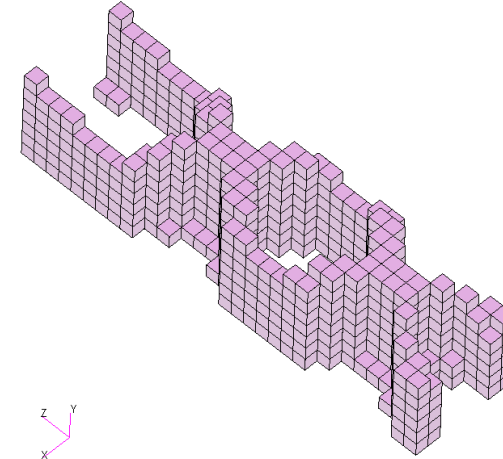
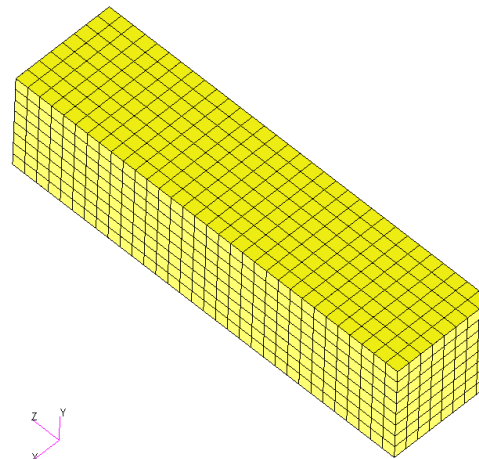
1. Make sure this statement is in the Case Control Section of the .bdf file.
ESE(THRESH=.99)=ALL
2. Search the .f06 file for the initial design's
ELEMENT STRAIN ENERGIES
3. Note the value of *TOTAL ENERGY OF ALL ELEMENTS IN PROBLEM*
4. Search the .f06 for the
SUMMARY OF DESIGN CYCLE HISTORY
5. Note the 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	

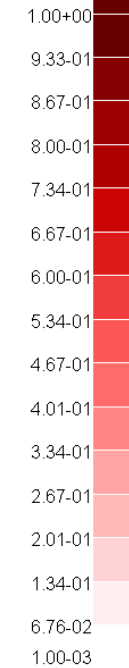
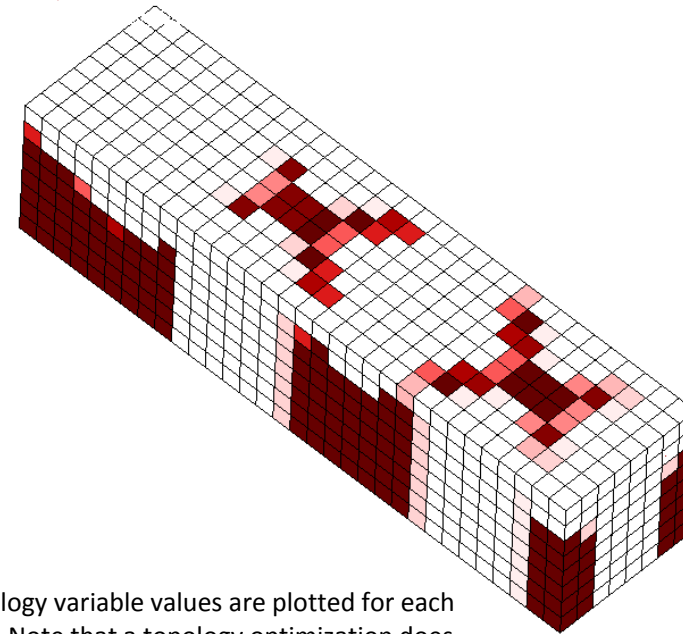
***** S U M M A R Y O F D E S I G N C Y C L E H I S T O R Y *****				
(HARD CONVERGENCE ACHIEVED)				
NUMBER OF FINITE ELEMENT ANALYSES COMPLETED			56	
NUMBER OF OPTIMIZATIONS W.R.T. APPROXIMATE MODELS			55	
OBJECTIVE AND MAXIMUM CONSTRAINT HISTORY				
CYCLE NUMBER	OBJECTIVE FROM APPROXIMATE OPTIMIZATION	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 topology variable value greater than the threshold'*
- Recall from before:
 - 0 - Topology variable values close to 0 are not critical to the design
 - 1 - Topology variable values close to 1 are critical to the design



The topology variable values are plotted for each element. Note that a topology optimization does not automatically remove elements. It is up to the user to manually decide which elements to keep.



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
 - Minimize average compliance when multiple load cases are involved.

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:

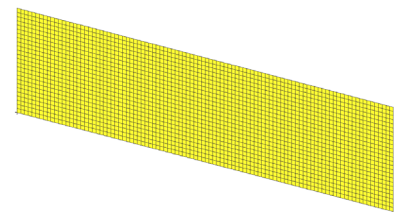
- Von Mises Stress < Upper Bound

Traditional Topology Optimization

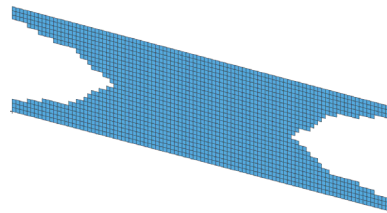
Objective: Minimize Compliance (Maximize Stiffness)

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

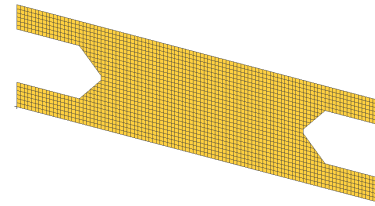
Original Design



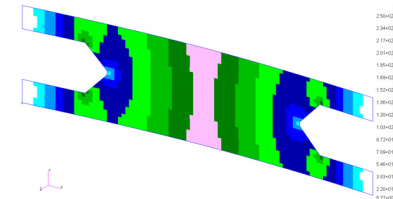
Mass: 9.737 grams



FRMASS < .75
Mass: 7.186 g
Optimization B



Mass: 7.739 g



Max von Mises: 150 MPa
Max Displacement : 2.78 mm

1st natural Frequency: 111 Hz

Traditional Topology Optimization

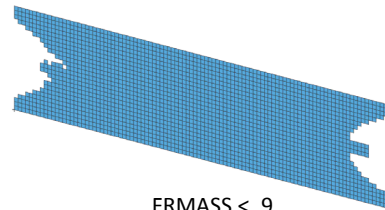
Objective: Minimize Compliance (Maximize Stiffness)

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

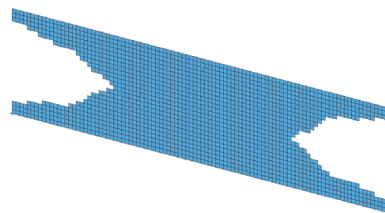
Original Design

Mass: 9.737 grams

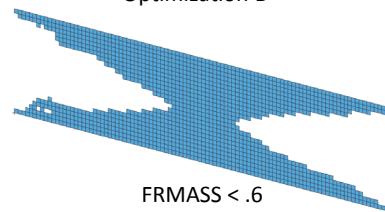
Topology Solution



FRMASS < .9
Mass: 8.756 g
Optimization A

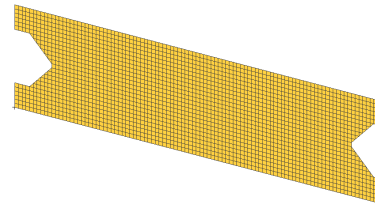


FRMASS < .75
Mass: 7.186 g
Optimization B

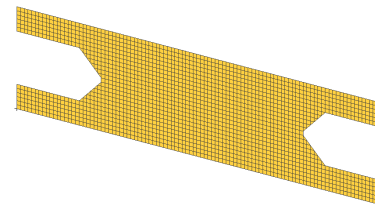


FRMASS < .6
Mass: 5.718 g
Optimization C

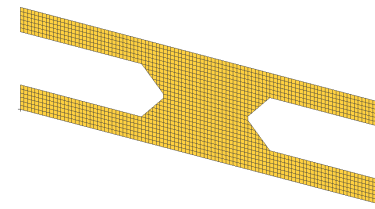
Refined Design



Mass: 9.094 g

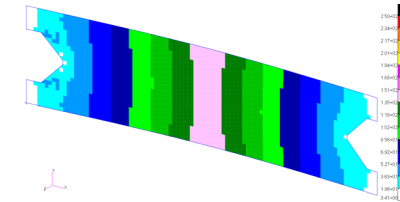


Mass: 7.739 g



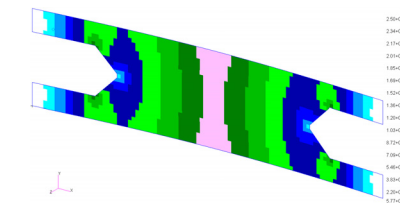
Mass: 6.119 g

Verification



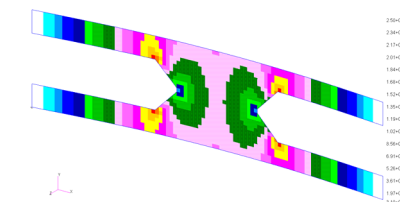
Max von Mises: 150 MPa
Max Displacement: 2.52 mm

1st natural Frequency: 114 Hz



Max von Mises: 150 MPa
Max Displacement : 2.78 mm

1st natural Frequency: 111 Hz



Max von Mises: 250 MPa
Max Displacement : 3.57 mm

1st natural Frequency: 109 Hz

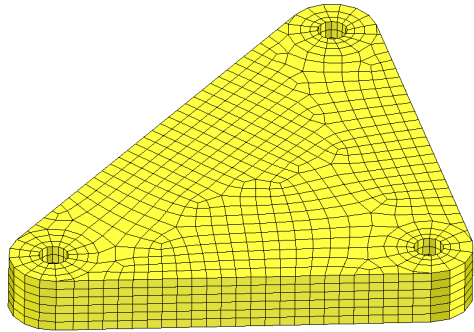
Best Solution: Optimization B
led to a valid and light weight
design

Latest Topology Optimization

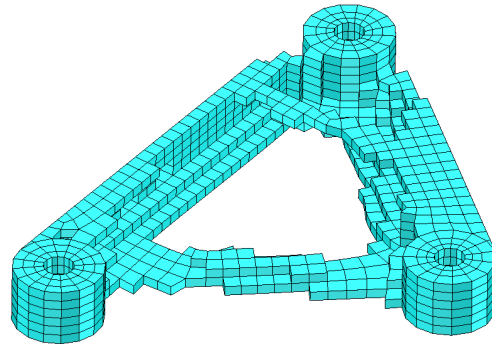
Objective: Minimize Fractional Mass (Minimize Mass)

Constraint: Stress Constraint

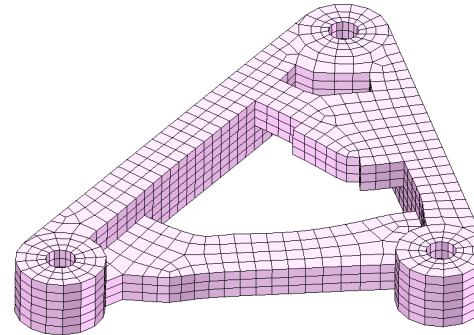
Original Design



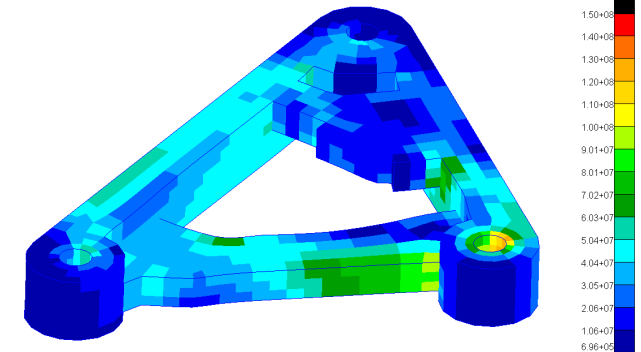
Topology Solution



Refined Design



Verification



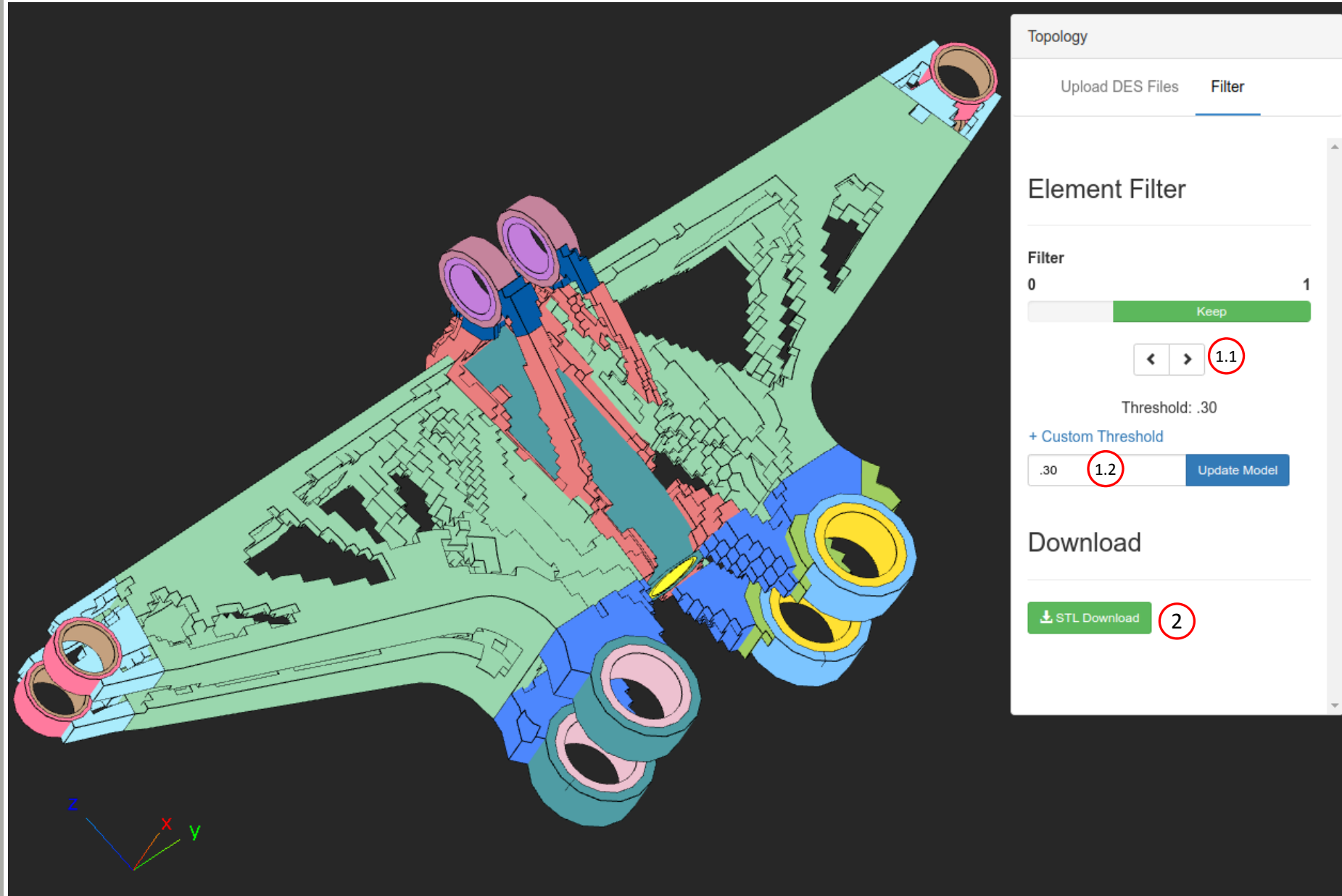
Viewer Web App for Topology Optimization Post Processing

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 for Post-processing Topology Optimization Results

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

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 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.