

# MSC Nastran Topology Optimization - Multidiscipline - Static Loading and Natural Frequency

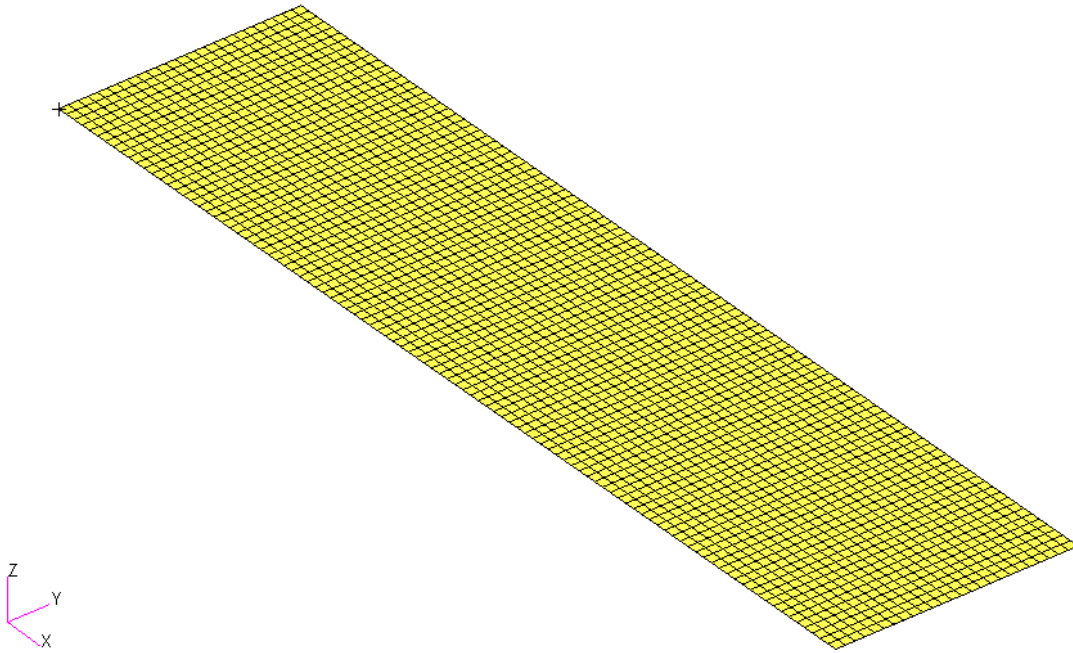
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AN MSC NASTRAN SOL 200 TUTORIAL

# Goal: Use Nastran SOL 200 Optimization

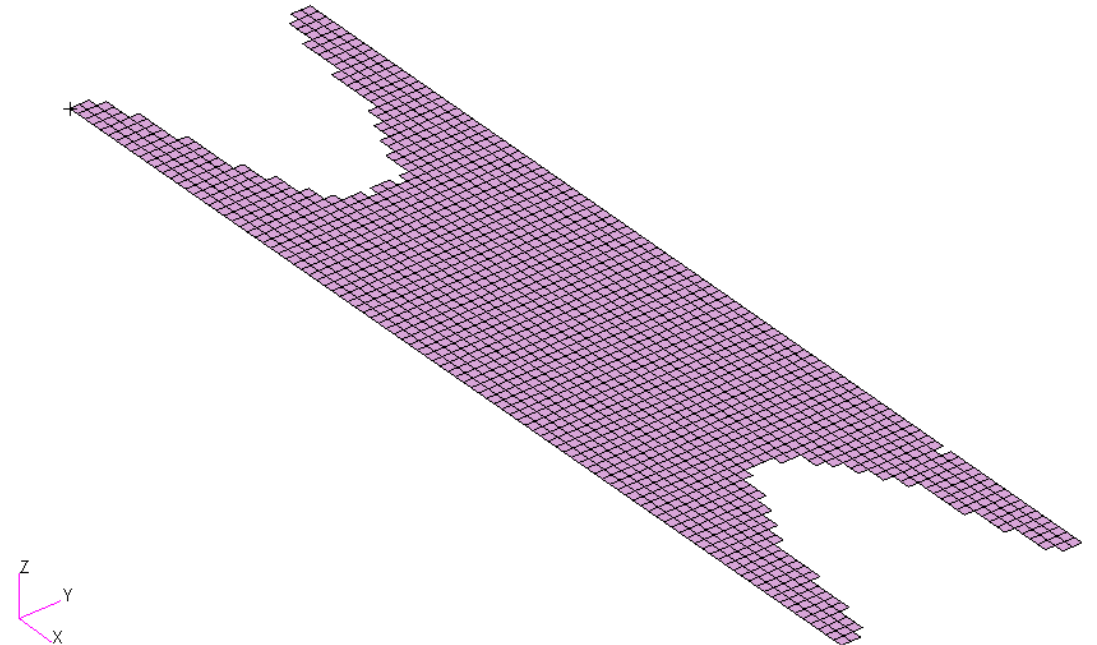
## Before Optimization

- Mass:  $9.73\text{E-}06$



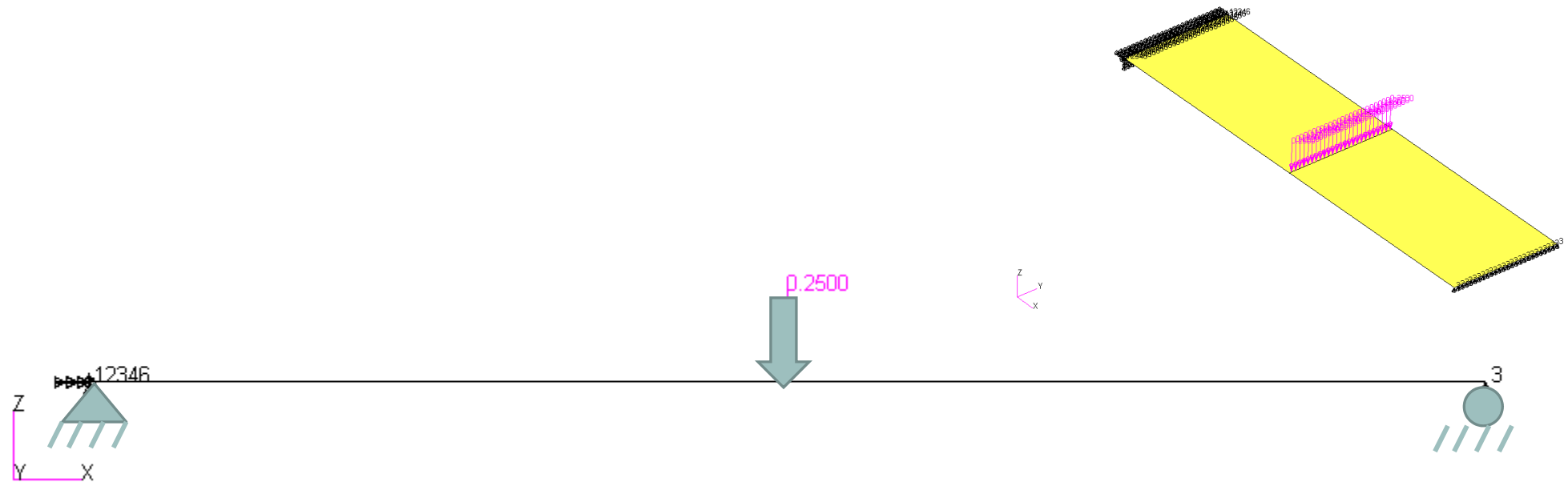
## After Optimization

- Mass:  $7.05\text{E-}06$  (~25% mass reduction)
- Maximize stiffness
- Maximize first natural frequency



# Details of the structural model

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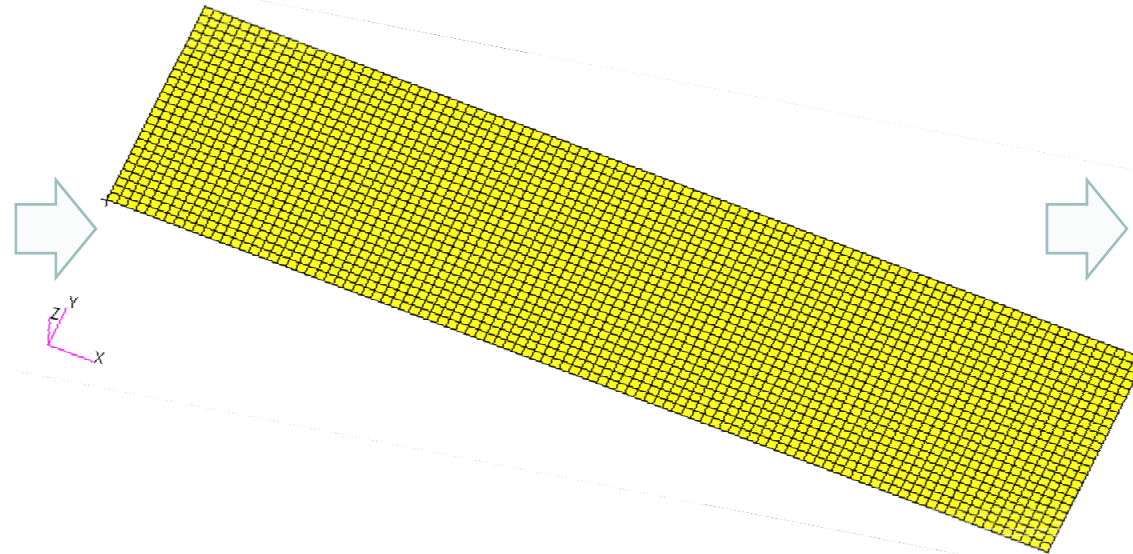


# Optimization Problem Statement

## Design Region/Variables

x1: PSHELL 1

PSHELL 1 - Plate



## Design Equation Objective

R0: Minimize the sum of normalized compliance and normalized natural frequency

$$R0 = \frac{a1}{36.7} + \frac{86.4}{a2}$$

a1: Compliance of SUBCASE 1

a2: Natural frequency of mode 1 of SUBCASE 2

## Design Constraints

r1: Fractional mass

$$r1 < .75 \quad (25\% \text{ mass reduction})$$

r2: The z component of displacement at node 714

$$-5.0 < r2$$

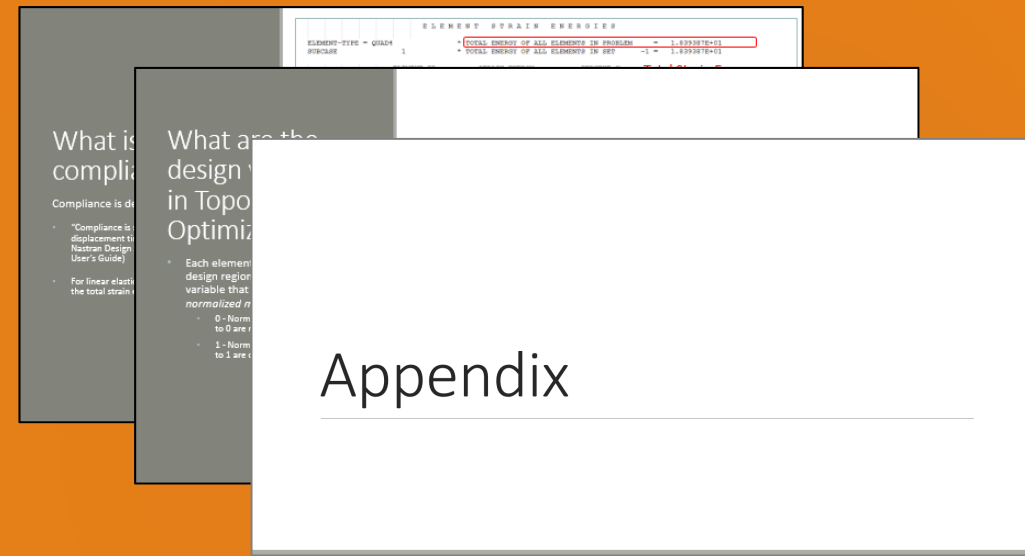
r3: The natural frequency of mode 1

$$20 < r3$$

# 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

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# 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

**Multidiscipline Optimization** - This example is optimizing for static analysis and normal modes analysis.

**Equation Objective with SUBCASE spanning responses** - The Equation Objective defined in this example is dependent on responses from multiple SUBCASEs. The a1 response comes from SUBCASE 1 and a2 comes from SUBCASE 2. The use of DRSPAN enables the specification of which SUBCASEs produces the necessary values.

$$R0 = \frac{a1}{36.7} + \frac{86.4}{a2}$$

### Step 4 - Configure DRSPAN for Synthetic Objective and Constraints

Label ▾	Configure SUBCASEs of Equation Inputs
<input type="text"/>	
R0	R0 ( a1 <sub>SUBCASE 1</sub> , a2 <sub>SUBCASE 2</sub> )

Not Set

SUBCASE 1

SUBCASE 2

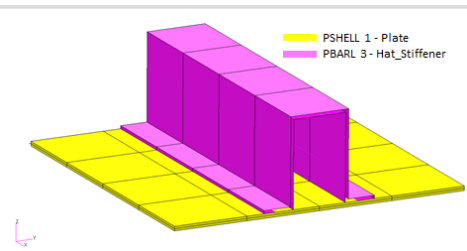


# SOL 200 Web App Capabilities

## Benefits

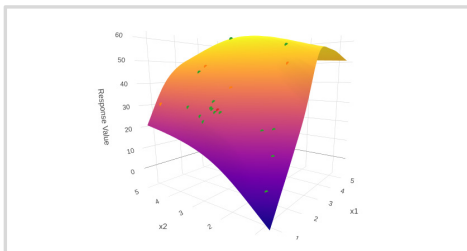
- 200+ error validations (real time)
- Web browser accessible
- Automated creation of entries (real time)
- Automatic post-processing
- 76 tutorials

## Capabilities



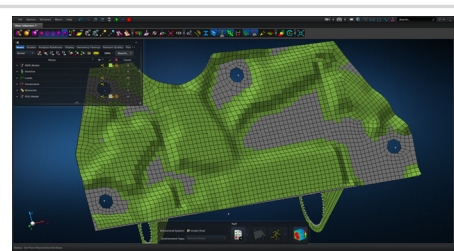
### Web Apps for SOL 200

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



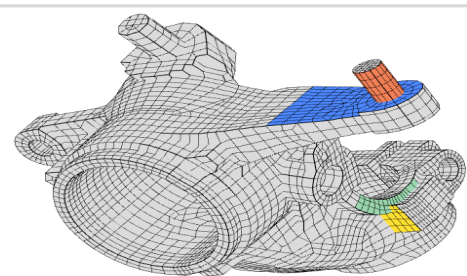
### Machine Learning Web App

Bayesian Optimization for nonlinear response optimization (SOL 400)



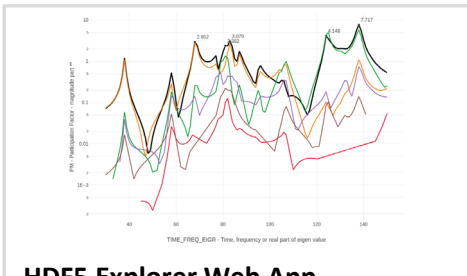
### MSC Apex Post Processing Support

View the newly optimized model after an optimization



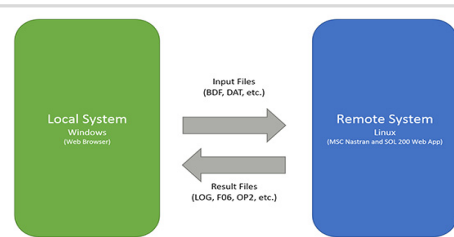
### Shape Optimization Web App

Use a web application to configure and perform shape optimization.



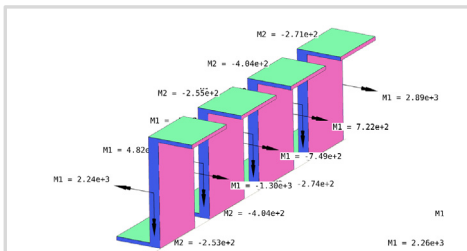
### HDF5 Explorer Web App

Create XY plots using data from the H5 file



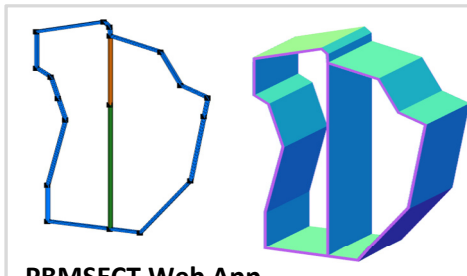
### Remote Execution Web App

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



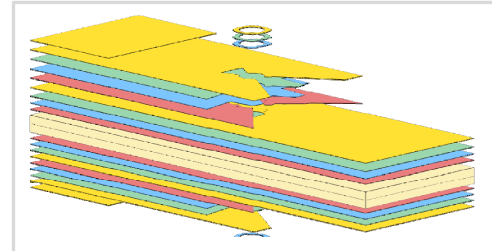
### Beams Viewer Web App

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



### PBMSECT Web App

Generate PBMSECT and PBRSECT entries graphically



### Ply Shape Optimization Web App

Spread plies optimally and generate new PCOMPG entries



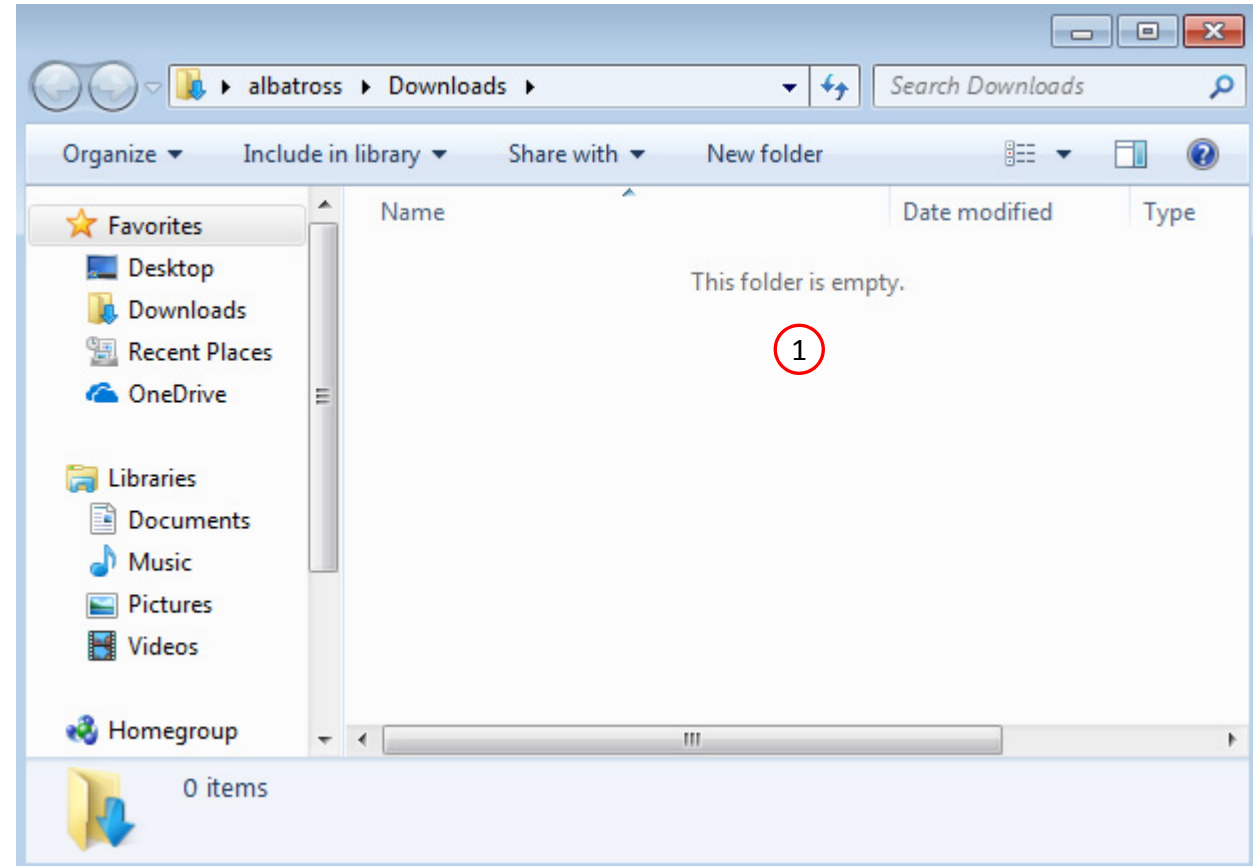
### Stacking Sequence Web App

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

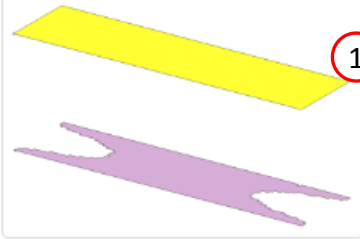
- The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.



# 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.



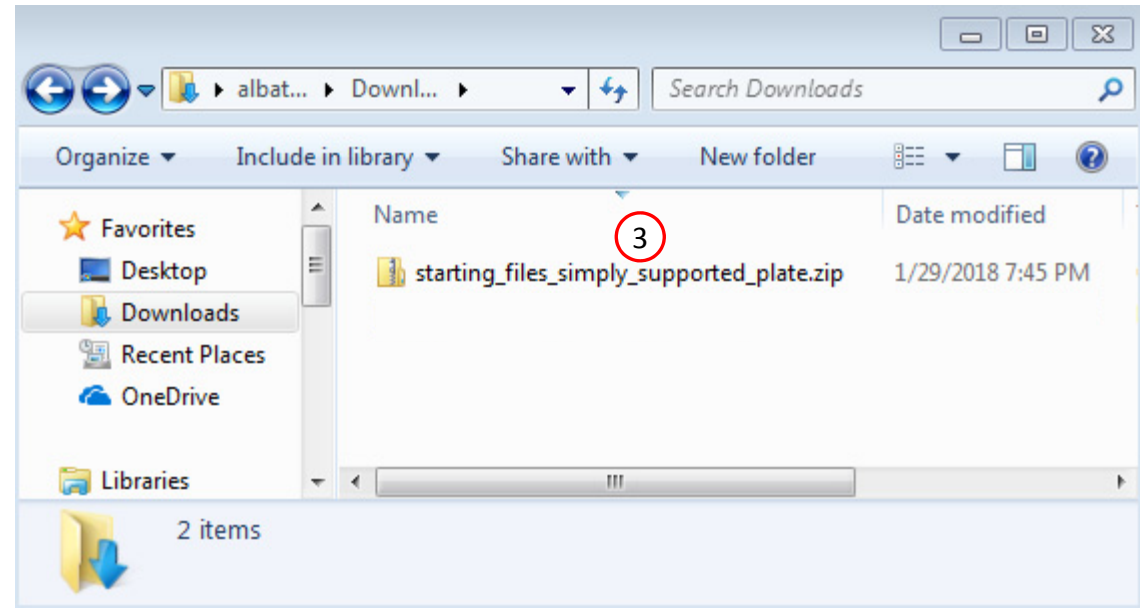
**1**

### MSC Nastran Topology Optimization - Multidiscipline - Static Loading and Natural Frequency

A cantilevered plate is composed of 2D finite elements and a load is applied at the midspan. The MSC Nastran Topology Optimization capability is used to determine which portions of the plate should be kept in order to satisfy weight, stiffness and first natural frequency targets. This example also showcases the ability to optimize for multiple analysis types, e.g. static and normal modes analysis.

Starting BDF Files: [Link](#) **2**  
Solution BDF Files: [Link](#)

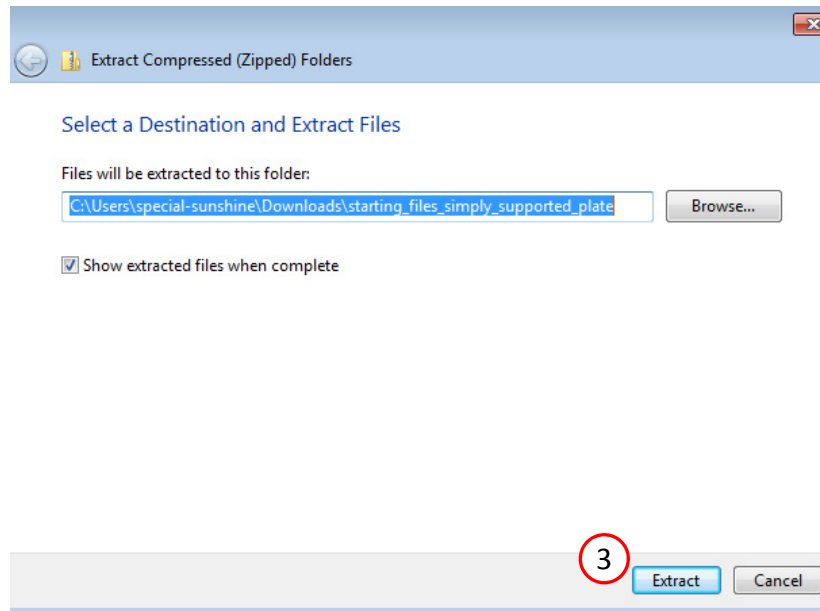
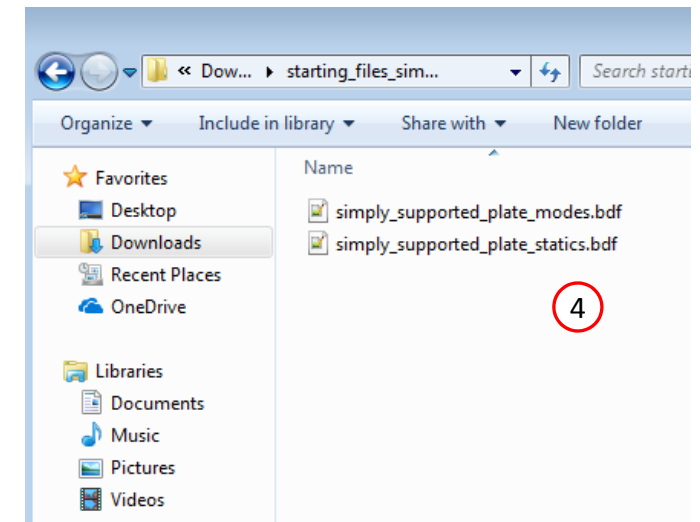
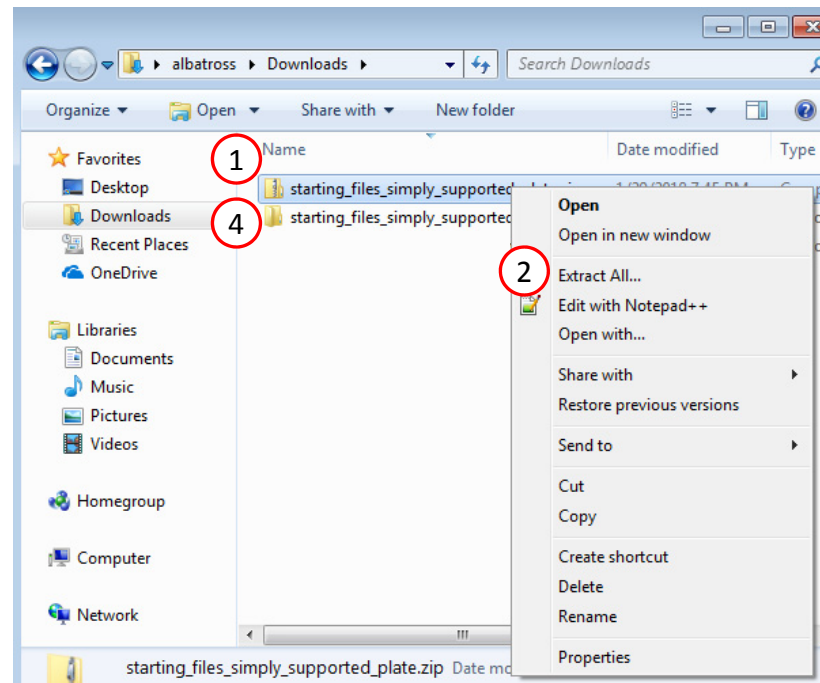
[Link](#)



# Obtain Starting Files

1. Right click on the zip file
2. Select Extract All...
3. Click Extract
4. The starting files are now available in a folder

- This example is using a previously created design model. The design model is a model that has been converted to SOL 200 and contains bulk data entries describing the optimization problem statement, e.g. variables, objective and constraints.





# Merge the BDF files

There are two separate BDF files. Both files contain the simply supported plate. One BDF file is configured to perform a Linear Static analysis. The second BDF file is configured to perform a Normal Modes Analysis. To perform an optimization for both static and normal modes analysis, the files must be combined.

1. Open *simply\_supported\_plate\_modes.bdf*. Take SUBCASE 1 and move it to *simply\_supported\_plate\_statics.bdf*. Rename SUBCASE 1 to SUBCASE 2 to avoid duplicate SUBCASEs.
2. Take the line with EIGRL at the beginning and move it to *simply\_supported\_plate\_statics.bdf*
3. Save *simply\_supported\_plate\_statics.bdf* as *simply\_supported\_plate\_combined.bdf* (Not shown)

- In this tutorial a Multidisciplinary Optimization is performed. This is done by:

1. Merging the BDF files
2. Adding different ANALYSIS commands to each SUBCASE.

```
1 $ MSC.Nastran input file created on September 07, 2017 at 13:28:54 by
2 $ Patran 2017.0.2
3 $ Direct Text Input for Nastran System Cell Section
4 $ Direct Text Input for File Management Section
5 $ Direct Text Input for Executive Control
6 $ Linear Static Analysis, Database
7 SOL 101
8 CEND
9 $ Direct Text Input for Global Case Control Data
10 TITLE = MSC.Nastran job created on 07-Sep-17 at 13:07:10
11 ECHO = NONE
12 SUBCASE 1
13 $ Subcase name : Default
14 SUBTITLE=Default
15 SPC = 2
16 LOAD = 2
17 DISPLACEMENT(PLOT, SORT1, REAL)=ALL
18 SPCFORCES(PLOT, SORT1, REAL)=ALL
19 STRESS(PLOT, SORT1, REAL, VONMISES, BILIN)=ALL
20 ESE(THRESH=.90)=ALL
21 SUBCASE 2
22 SUBTITLE=Default
23 METHOD = 1
24 SPC = 2
25 VECTOR(PLOT, SORT1, REAL)=ALL
26 SPCFORCES(PLOT, SORT1, REAL)=ALL
27 BEGIN BULK
28 $ Direct Text Input for Bulk Data
29 PARAM POST 0
30 PARAM PRTMAXIM YES
31 EIGRL 1 3 0 MASS
32 $ Elements and Element Properties for region : prop
33 PSHELL 1 1 .5 1 1
34 $ Pset: "prop" will be imported as: "pshell.1"
35 CQUAD4 1 1 2 53 52
```

```
1 $ MSC.Nastran input file created on September 07, 2017 at 13:29:54 by
2 $ Patran 2017.0.2
3 $ Direct Text Input for Nastran System Cell Section
4 $ Direct Text Input for File Management Section
5 $ Direct Text Input for Executive Control
6 $ Normal Modes Analysis, Database
7 SOL 103
8 CEND
9 $ Direct Text Input for Global Case Control Data
10 TITLE = MSC.Nastran job created on 07-Sep-17 at 13:07:10
11 ECHO = NONE
12 $ Using Nastran default values for DEVEEC
13 SUBCASE 1
14 SUBTITLE=Default
15 METHOD = 1
16 SPC = 2
17 VECTOR(PLOT, SORT1, REAL)=ALL
18 SPCFORCES(PLOT, SORT1, REAL)=ALL
19 $ Direct Text Input for this Subcase
20 BEGIN BULK
21 $ Direct Text Input for Bulk Data
22 PARAM POST 0
23 PARAM PRTMAXIM YES
24 EIGRL 1 3 0 MASS
25 $ Elements and Element Properties for region : prop
26 PSHELL 1 1 .5 1 1
27 $ Pset: "prop" will be imported as: "pshell.1"
28 CQUAD4 1 1 2 53 52
29 CQUAD4 2 1 2 3 54 53
30 CQUAD4 3 1 3 4 55 54
31 CQUAD4 4 1 4 5 56 55
32 CQUAD4 5 1 5 6 57 56
33 CQUAD4 6 1 6 7 58 57
34 CQUAD4 7 1 7 8 59 58
35 CQUAD4 8 1 8 9 60 59
36 CQUAD4 9 1 9 10 61 60
37 CQUAD4 10 1 10 11 62 61
```

EIGRL	1	3	0	MASS	
PSHELL	1	1	.5	1	1
CQUAD4	1	1	2	53	52
CQUAD4	2	1	3	54	53
CQUAD4	3	1	4	55	54
CQUAD4	4	1	5	56	55
CQUAD4	5	1	6	57	56
CQUAD4	6	1	7	58	57
CQUAD4	7	1	8	59	58
CQUAD4	8	1	9	60	59
CQUAD4	9	1	10	61	60
CQUAD4	10	1	10	62	61

# 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.

The screenshot displays the SOL 200 Web App interface. At the top, it says "SOL 200 Web App" and "Select a web app to begin". Below this, there are five main categories of web apps, each with a representative image:

- Optimization for SOL 200**: Shows a 3D model of a mechanical part with "Before" and "After" states. A red circle with the number "1" is placed over this icon.
- Multi Model Optimization**: Shows a 3D model and a line graph.
- Machine Learning | Parameter Study**: Shows four small plots representing different data sets or models.
- HDF5 Explorer**: Shows a line graph with multiple data series.
- Remote Execution**: Shows a diagram of data flow between a "Remote System" and a "Local System", with "Input Files" going up and "Results Files" going down.

At the bottom of the interface, there are two links: "Tutorials and User's Guide" and "Full list of web apps".

# Upload BDF Files

1. Click 1. Select Files and select simply\_supported\_plate\_combined.bdf
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 web interface for uploading BDF files. It consists of two main steps, each with a button and a progress bar.

**Step 1:** A button labeled "1. Select files" is followed by a text input field containing the filename "simply\_supported\_plate\_combined.bdf". Below this is a green progress bar labeled "Inspecting: 100%".

**Step 2:** A button labeled "2. Upload files" is followed by a green progress bar labeled "Uploading: 100 %".

Below the progress bars, there is a checkbox labeled "List of Selected Files" which is currently unchecked.



# Create Design Region

1. Click Topology
2. Click on the plus (+) icons to set PSHELL 1 as a Design Region
3. The Design Region is displayed in the next table. Any element associated with PSHELL 1 will be allowed to change during the optimization.

- In traditional Size optimization, individual design variables are created. It is slightly different for Topology optimization. When a design region is set, each element in the design region has a design variable created for it. Each design variable corresponds to the Normalized Material Density of that element, see the appendix for additional details.
- If PSHELL 1 has 500 elements associated and is configured as a design region, then there will be 500 design variables created.
- Each step has hidden functionality for advanced users. The visibility is controlled by clicking [+ Options](#).
- If the property entry, e.g. PSHELL, was given a name in Patran, e.g. Car Door, the name can be shown by marking the checkbox titled Entry Name.

## Step 1 - Select design regions



[+ Options](#)

Create TOPVAR	Entry ↕	Entry ID ↕
	<input type="text" value="Search"/>	<input type="text" value="Search"/>
<b>2</b> 	PSHELL	1

5 10 20 30 40 50  
Number of Visible Rows 5

## Step 2 - Adjust TOPVAR Entries

[+ Options](#)

	Label ↕	Status ↕	Entry ↕	Entry ID ↕
	<input type="text" value="Search"/>	<input type="text" value="Search"/>	<input type="text" value="Search"/>	<input type="text" value="Search"/>
	x1 <b>3</b>		PSHELL	1

# Create Design Objective

1. Click on Objective
2. Click on Equation Objective

- There are 2 methods of setting an objective.
  - Method 1 – Select a objective from a given list of responses, e.g. Weight, Volume, etc.
  - Method 2 – Create an equation.
- This example uses Method 2 for the objective.

## 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="Search"/>
	Weight	WEIGHT
	Volume	VOLUME
	Displacement	DISP
	Strain	STRAIN
	Element Strain Energy	ESE

# Create Design Objective

1. Scroll down to section Step A - Optional - Create additional responses
2. Ensure the analysis type is set to SOL 101 - Statics
3. Type in 'comp' to the search box
4. Click the plus (+) icon to set compliance as a response type
5. Set the analysis type as SOL 103 - Normal Modes
6. Clear the search box.
7. Click the plus (+) icon to set Frequency as a response type

- This example performs a multidisciplinary optimization for statics and modes. The objective will be a combination of compliance and natural frequency. The responses necessary for compliance and natural frequency are created on this page.

## 1 Step A - Optional - Create additional responses

Select an analysis type

SOL 101 - Statics 2

Select a response

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

## Step A - Optional - Create additional responses

Select an analysis type

SOL 103 - Normal Modes 5

Select a response

	Response Description ⇅	Response Type ⇅
	<input type="text" value="Search"/>	<input 6="" type="text" value="Search"/>
+ 7	Weight	WEIGHT
+	Volume	VOLUME
+	Eigenvalue	EIGN
+	Frequency	FREQ
+	Displacement	DISP

« 1 2 3 »

5 10 20 30 40 50

# Create Design Objective

1. Scroll to section Step B - Optional - Adjust responses
2. For response a2, ensure ATTA is set to 1 which represents mode 1

- a1 is read as the compliance. Compliance is twice the total strain energy. Refer to the Appendix for more information about compliance.
- a2 is the natural frequency for mode 1.

## 1 Step B - Optional - Adjust responses

+ Options

	Label	Status	Response Type	Property Type	ATTA	ATTB	ATTi
	St	Seal	Search	Search	Search	Search	Search
✖	a1	✓	COMP				
✖	a2	✓	FREQ	STRUC	1		

2

# Create Design Objective

1. Scroll to section Step 1 - Adjust equation objective
2. Type this equation into the box
  - $a1 / 1.0 + 2.0 / a2$
3. The values 1.0 and 2.0 will be replaced later in this tutorial

- The objective is a combination of a1 and a2. The objective must be conditioned properly such that if one response is larger than the other, e.g.  $a1=.01$  and  $a2 = 2000000$ , a change in the smaller of the 2 is still detected by the optimizer. This is addressed by normalizing both a1 and a2. For now, it is not known which values are necessary to normalize a1 or a2, so values 1 and 2 are used for now.

## Step 1 - Adjust equation objective ①

↕ Switch to Objective

+ Options

Label	Status	Maximize or Minimize	Equation
R0	✓	MIN	$a1 / 1.0 + 2.0 / a2$

②

$a1 / 1.0 + 2.0 / a2$

# Create Design Constraints

1. Click Constraints
2. Set the analysis type to SOL 101 - Statics
3. Type in 'fr' to the search box
4. Select the plus(+) icon for Fractional Mass
5. Clear the search box.
6. Select the plus(+) icon for Displacement

SOL 200 Web App - Optimization
Upload
Variables
Objective
Constraints
Subcases
Exporter
Results

Constraints
Equation Constraints

Step 1 - Select constraints

Select an analysis type

2
SOL 101 - Statics

Select a response

	Response Description ▾	Response Type ▾
	Search	fr 3
4 +	Fractional Mass	FRMASS

Step 1 - Select constraints

Select an analysis type

SOL 101 - Statics

Select a response

	Response Description ▾	Response Type ▾
	Search	Search 5
+	Weight	WEIGHT
+	Volume	VOLUME
6 +	Displacement	DISP
+	Strain	STRAIN
+	Element Strain Energy	ESE

# Create Design Constraints

1. Set the analysis type to SOL 103 - Modes
2. Select the plus(+) icon for Frequency

- Topology optimization works best when working with a small number of responses, e.g. Compliance, Fractional Mass, a single von Mises stress.
- In this tutorial a single displacement is constrained. The number of constraints should be kept to a minimum. For example, constraining multiple displacements at various nodes is not advised.

SOL 200 Web App - Optimization   Upload   Variables   Objective   **Constraints**   Subcases   Exporter   Results






**Constraints**   Equation Constraints

### Step 1 - Select constraints

Select an analysis type

1

Select a response

	Response Description ▾	Response Type ▾
	<input type="text" value="Search"/>	<input type="text" value="Search"/>
	Weight	WEIGHT
	Volume	VOLUME
	Eigenvalue	EIGN
2 	Frequency	FREQ
	Displacement	DISP

# Create Design Constraints

1. Configure the following for r1
  - Upper Allowed Limit: .75
2. Configure the following for r2
  - ATTA: 3 (3 - T3 or Z component)
  - ATTi: 714 (node 714)
  - Lower Allowed Limit: -5.0
3. Configure the following for r3
  - ATTA: 1 (mode 1)
  - Lower Allowed Limit: 20.

- Constraints r1 and r2 will be assigned to the statics subcase. Constraint r3 will be assigned to the modes subcase.

## 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	-- Select Pr			Blank or Property ID (PID)	Lower 1	.75
✕	r2	☑	DISP	2	3 - T3 (Rectangular z, Cylindrical z		714	-5.	Upper
✕	r3	☑	FREQ	STRUC	3			20.	Upper

5 10 20 30 40 50



# Assign Constraints to Load Cases (SUBCASES)

1. Click Subcases
2. Mark the checkbox
3. Mark the checkbox
4. Set the analysis type as Normal Modes for SUBCASE 2
5. Mark the checkbox

- r1 or FRMASS constraint has been assigned to Global Constraints
- r2 or DISP constraint has been assigned to SUBCASE 1, the statics subcase
- r3 or FREQ constraint has been assigned to SUBCASE 2, the modes subcase

1

## Step 1 - Assign constraints to subcases

Display Columns

Global Constraints  
SUBCASE 1  
SUBCASE 2

☐ Uncheck visible boxes

☒ Check visible boxes

+ Options

	Status	Label	Response Type	Analysis Type	Description	Global Constraints	SUBCASE 1	SUBCASE 2
		<input type="text" value="Search"/>	<input type="text" value="Search"/>	<input type="text" value="Search"/>	<input type="text" value="Search"/>			
						Analysis Types →	Statics	Normal Modes
	<input checked="" type="checkbox"/>	r1	FRMASS		Fractional mass	<input checked="" type="checkbox"/>		
	<input checked="" type="checkbox"/>	r2	DISP	STATICS	Item code null component(s) of displacement at grid		<input checked="" type="checkbox"/>	
	<input checked="" type="checkbox"/>	r3	FREQ	MODES	Natural frequency of mode			<input checked="" type="checkbox"/>

# Configure DRSPAN

The Equation Objective is in terms of a1 and a2, where a1 is a statics response and a2 is a normal modes response. The DRSPAN functionality in Nastran is used to specify which SUBCASE generates a1 and a2.

1. Find this section: Step B - Optional - Configure DRSPAN for equation objective and constraints
2. Set a1 to SUBCASE 1
3. Set a2 to SUBCASE 2

- Some responses, e.g. stress, strain, frequency, etc., are subcases dependent. The Equation Objective is composed of subcase dependent responses Compliance and Frequency. If there are numerous subcases, the optimizer must be told which subcases the responses originate from. This is done via the DRSPAN command and is configured on this page.

## Step 1 - Assign constraints to subcases

Display Columns

Global Constraints  
SUBCASE 1  
SUBCASE 2

☐ Uncheck visible boxes

☒ Check visible boxes

+ Options

Status ▾	Label ▾	Response Type ▾	Analysis Type ▾	Description	Global Constraints ▾	SUBCASE 1 ▾	SUBCASE 2 ▾
	Search	Search	Search	Search			

☐ Step A - Optional - Assign objective to subcase

Select the subcase that generates the objective response

Above All Subcases ▾

① ☐ Step B - Optional - Configure DRSPAN for equation objective and constraints

+ Info

Label ▾	Status ▾	Configure SUBCASEs of Equation Inputs	
Search	Search	2	3
R0	<input checked="" type="checkbox"/>	R0 ( a1 SUBCASE 1 a2 SUBCASE 2 )	

# Configure Optimization Settings

1. Click Settings
2. Set DESMAX to 1

- Recall that the Equation Objective is composed of a1 and a2 and the goal is to find values that normalize both a1 and a2. This is done by obtaining the current or initial values of a1 and a2. In the event the values are not known, you can perform an optimization for only one design cycle. The initial values are then available as shown on the following pages.

1

## Optimization Settings

Parameter ▾	Description ▾	Configure ▾
<input type="text" value="Search"/>	<input type="text" value="Search"/>	<input type="text" value="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"/> 1 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 ▾

1. Click on Exporter
2. Click on Download 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
Upload Variables Objective Constraints Subcases **Exporter** Results
Settings Match Other User's Guide Home

---

### BDF Output - Model

```

assign userfile = 'optimization_results.csv', status = unknown,
form = formatted, unit = 52
$ MSC.Nastran input file created on September 07, 2017 at 13:28:54 by
$ Patran 2017.0.2
$ Direct Text Input for Nastran System Cell Section
$ Direct Text Input for File Management Section
$ Direct Text Input for Executive Control
$ Linear Static Analysis, Database
SOL 200
CEND

SET 30001 = 6000001
SET 30002 = 6000002
$ Direct Text Input for Global Case Control Data
TITLE = MSC.Nastran job created on 07-Sep-17 at 13:07:10
ECHO = NONE
DESOBJ(MIN) = 9000000
DESGLB = 40000000
$ DSAPRT(FORMATTED, EXPORT, END=SENS) = ALL
SUBCASE 1
ANALYSIS = STATICS
DESSUB = 40000001
DRSPAN = 30001
$ Subcase name : Default
SUBTITLE=Default
SPC = 2
LOAD = 2
DISPLACEMENT(PLOT,SORT1,REAL)=ALL
SPCFORCES(PLOT,SORT1,REAL)=ALL
        
```

### BDF Output - Design Model

```

*****
$*                                     *
$*                               Design Model                                *
$*                                     *
$*****
$
$                               Design Regions/Variables                    $
$-----
$
$
TOPVAR   300001    X1          PSHELL                                  1

$
$
$                               Design Equation Objective                     $
$-----
$
$
DRESP2   9000000    R0          170000
         DRESP1   6000001    6000002

$
$
DEQATH   170000
         g(a1,a2) =
         a1 / 1.0 + 2.0 / a2

$
$                               Supporting Responses                         $
$-----
$
$
DRESP1   6000001    a1          COMP                                     1
DRESP1   6000002    a2          FREQ      STRUC

$
$                               Design Constraints                           $
$-----
$
$
DRESP1   8000001    r1          FRMASS                                    3              714
DRESP1   8000002    r2          DISP
DRESP1   8000003    r3          FREQ      STRUC                            1

$
$
        
```

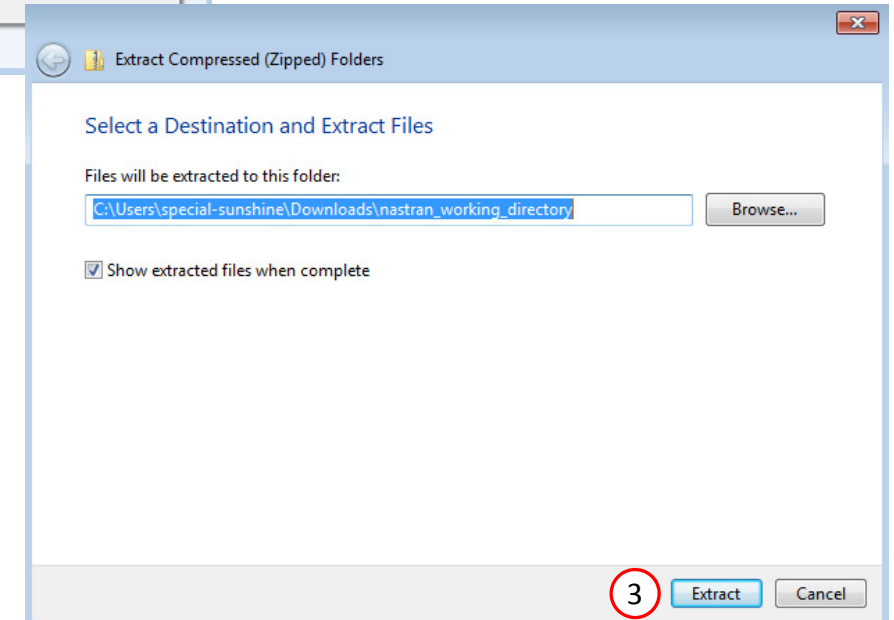
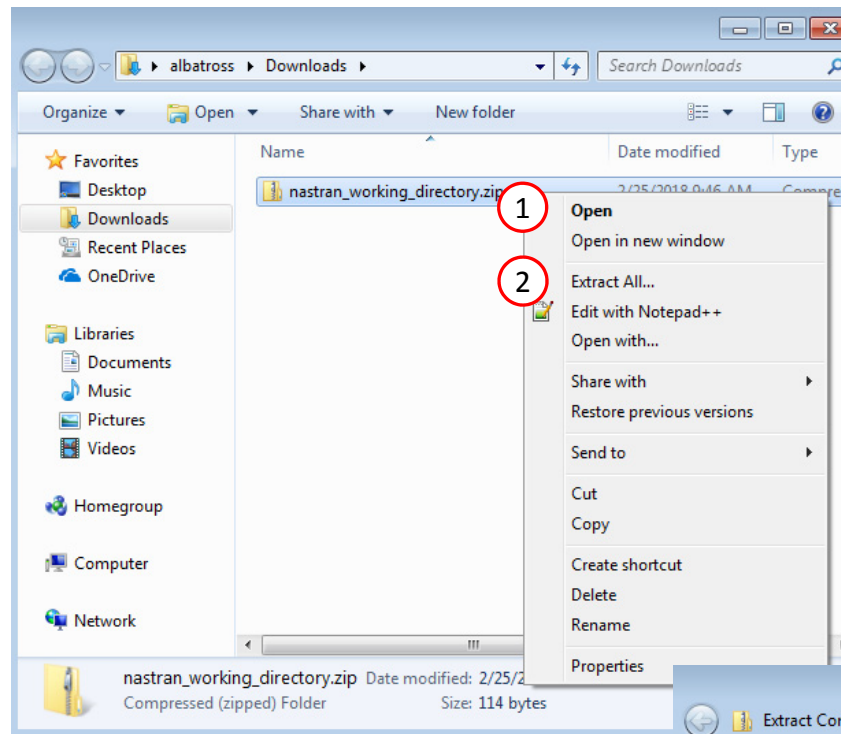
Download BDF Files

2

# 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.

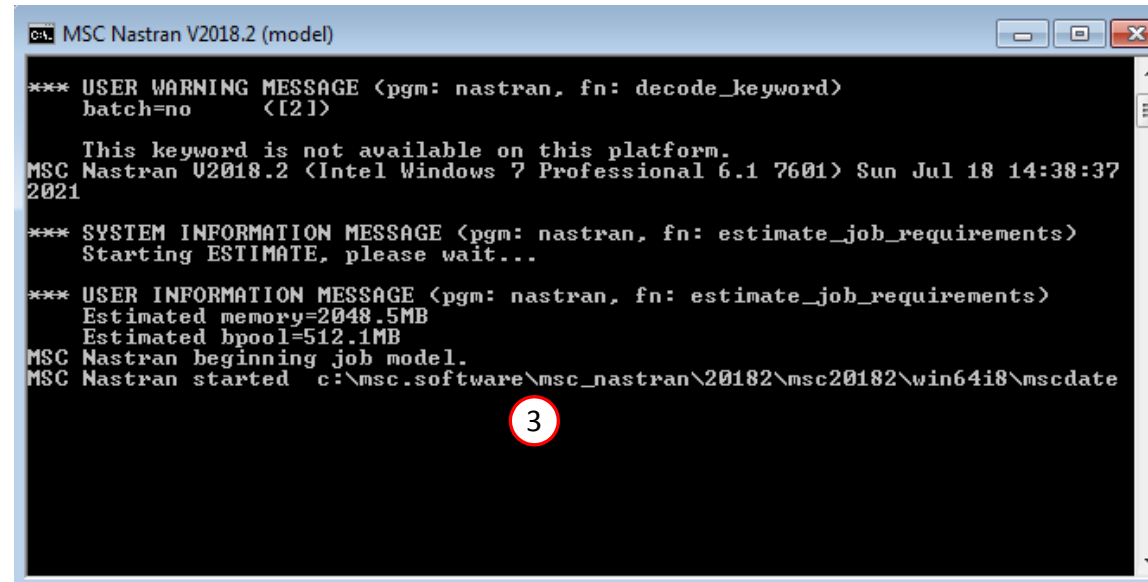
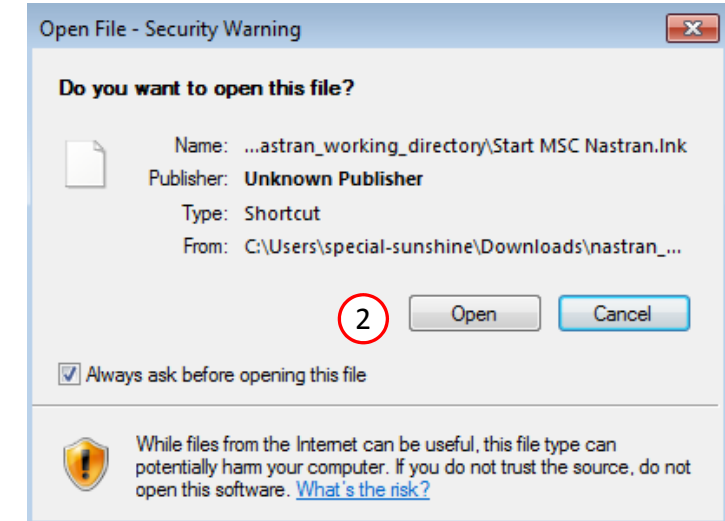
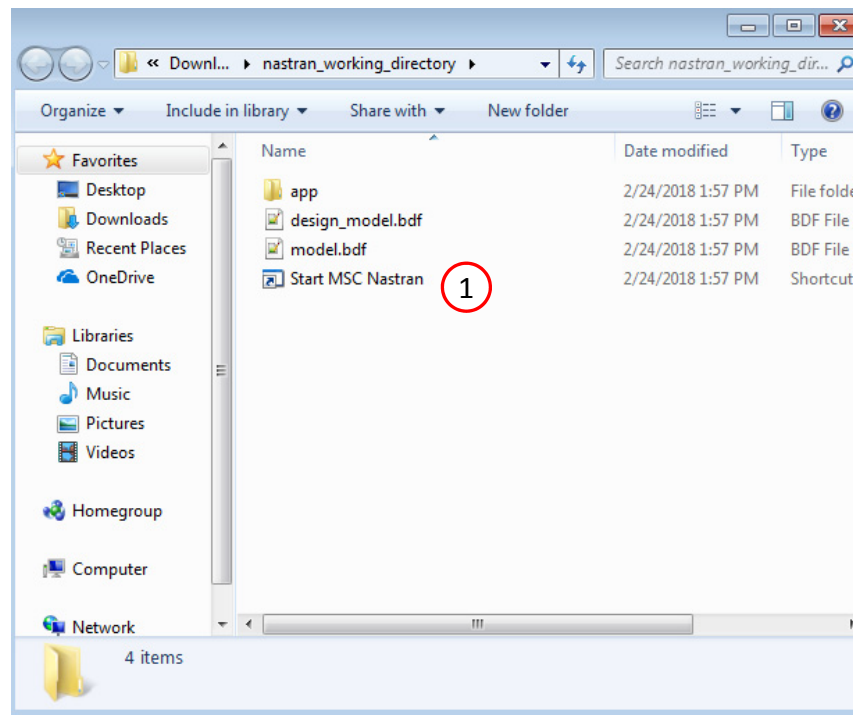
## Using Linux?

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

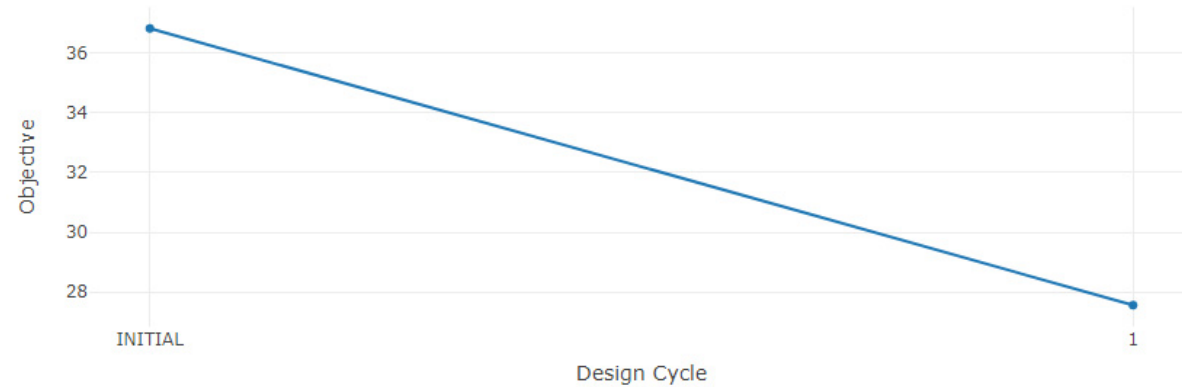
1. After MSC Nastran is successfully complete, the results will be automatically uploaded.
2. The final value of objective and normalized constraints can be reviewed.

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

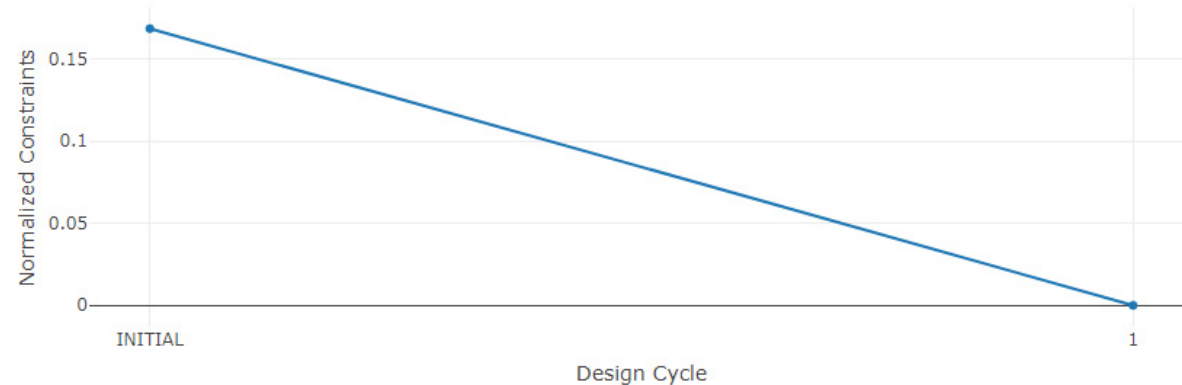
## Final Message in .f06

RUN TERMINATED DUE TO MAXIMUM NUMBER OF DESIGN CYCLES = 1.

## Objective



## Normalized Constraints





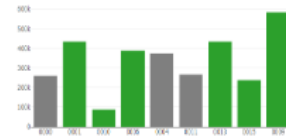
# Obtain quantities from .f06

The previous optimization was done only for one design cycle. The intent was to obtain two quantities a1 and a2, the compliance and 1<sup>st</sup> natural frequency, respectively.

1. Go to the Results section
2. Click on the Responses link

- Recall that the initial values for a1 and a2 must be obtained. These initial values are contained in the F06 file. The Responses app is opened and will be used to extract the initial values for a1 and a2.

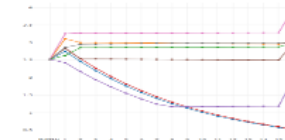
## Select a Results App



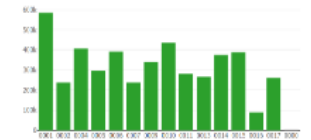
Global Optimization (multiplt.log)



Global Optimization Type 2 (.f06)



Local Optimization (.f06)

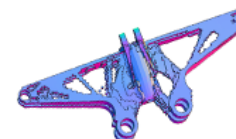


Parameter Study (.f06)

**2** Responses (.f06)



Sensitivities (.csv)



Topology Viewer (.des)

## Miscellaneous Apps

Converter

PCH to BDF

# Obtain quantities from .f06

1. Select the file named model.f06
2. Click Upload files
3. In the search box's Label column, type 'a'
4. In the search box's Design Cycle column, type 'INITIAL'
5. The values for a1 and a2 are now visible and will be used in the next slide

- The search boxes are used to display the values for a1 and a2. The Equation Objective is currently set to  $R0 = a1 / 1.0 + 2.0 / a2$ . The initial values will be used to replace 1.0 and 2.0.

Upload .f06 File

1. Select files model.f06

2. Upload files

Uploading

Responses

Reset view Violated constraints Active constraints Maximum constraint for each design cycle									
Design Cycle	Subcase	Label	Response Type	Normalized Constraint	Lower Bound	Value	Upper Bound	Normalized Constraint	Show More Information
INITIAL	Search	a	Search	Search	Search	Search	Search	Search	
INITIAL	1	a1	COMPLIANCE		N/A	3.6788E+01	N/A		
INITIAL	2	a2	NORMAL MODE		N/A	8.6430E+01	N/A		

# Responses in Design Model

1. The previous table extracted values from the section titled *Responses in Design Model*
2. The value of a1 is visible
3. The value of a2 is visible

- As a side note, the values reported in the Responses app are values found in the F06 file, section RESPONSES IN DESIGN MODEL.

```

*****
*          INITIAL ANALYSIS          *
*****

***** ANALYSIS RESULTS BASED ON THE INITIAL DESIGN *****
MSC.NASTRAN JOB CREATED ON 07-SEP-17 AT 13:07:10          SEPTEMBER 7, 2017 MSC Nastran 4/ 5/1
                                                                SUBCJ

1 |-----|
  | RESPONSES IN DESIGN MODEL |-----|

      (N/A - BOUND NOT ACTIVE OR AVAILABLE)
      (** VIOLATED RESPONSES MARKED WITH V **)
      (** ACTIVE RESPONSES MARKED WITH A **)

      INITIAL ANALYSIS SUBCASE = 1

      ----- DISPLACEMENT RESPONSES -----

      INTERNAL  DRESP1  RESPONSE  GRID  COMPONENT  LOWER  VALUE  UPPER
      ID        ID      LABEL    ID      NO.      BOUND                BOUND
      -----
      1          8000002  R2        714         3  -5.0000E+00 V  -5.8426E+00  N/A

      ----- COMPLIANCE RESPONSES -----

      INTERNAL  DRESP1  RESPONSE  LOWER  VALUE  UPPER
      ID        ID      LABEL    BOUND                BOUND
      -----
      2          6000001  A1                N/A  3.6788E+01  N/A

      ----- FRACTIONAL MASS RESPONSES -----

      INTERNAL  DRESP1  RESPONSE  TOPVAR/TOMVAR  LOWER  VALUE  UPPER
      ID        ID      LABEL    ID              BOUND                BOUND
      -----
      3          8000001  R1          0                N/A  7.5000E-01  7.5000E-01 A

      INITIAL ANALYSIS SUBCASE = 2

      ----- NORMAL MODE RESPONSES -----

      INTERNAL  DRESP1  RESPONSE  MODE  LOWER  VALUE  UPPER
      ID        ID      LABEL    NO.    BOUND                BOUND
      -----
      4          6000002  A2          1        N/A  8.6430E+01  N/A
  
```

# Update Design Objective

The previous values, 3.6788E+01 and 8.6430E+01, from the .f06 file will be used to update the Design Objective.

1. Go back to the web app and click on Objective
2. Update the equation so it reads:
  - $a1 / 3.6788E1 + 8.6430E1 / a2$

- The reader may realize that a2 is the denominator in its normalized term. This is done for the following reason. The goal is to minimize compliance, but to maximize the natural frequency, note the paradox in goals, i.e. minimization and maximization. This paradox is resolved by inverting the a2 term and placing a2 in the denominator. As the natural frequency a2 value is increased or maximized, the term " $8.6430E1 / a2$ " goes to 0.

SOL 200 Web App - Optimization 1 Upload Variables Objective Constraints Subcases Exporter Results

Objective Equation Objective

## Step 1 - Adjust equation objective

+ Options

Label	Status	Maximize or Minimize	Equation
R0		MIN	<span>2</span> $a1 / 3.6788E1 + 8.6430E1 / a2$

$$a1 / 3.6788E1 + 8.6430E1 / a2$$

# Configure Optimization Settings

1. Click Settings
2. Set DESMAX to 50

- Previously, the topology optimization was limited to only 1 design cycle. The max is changed to 100 to allow for a normal topology optimization.

1

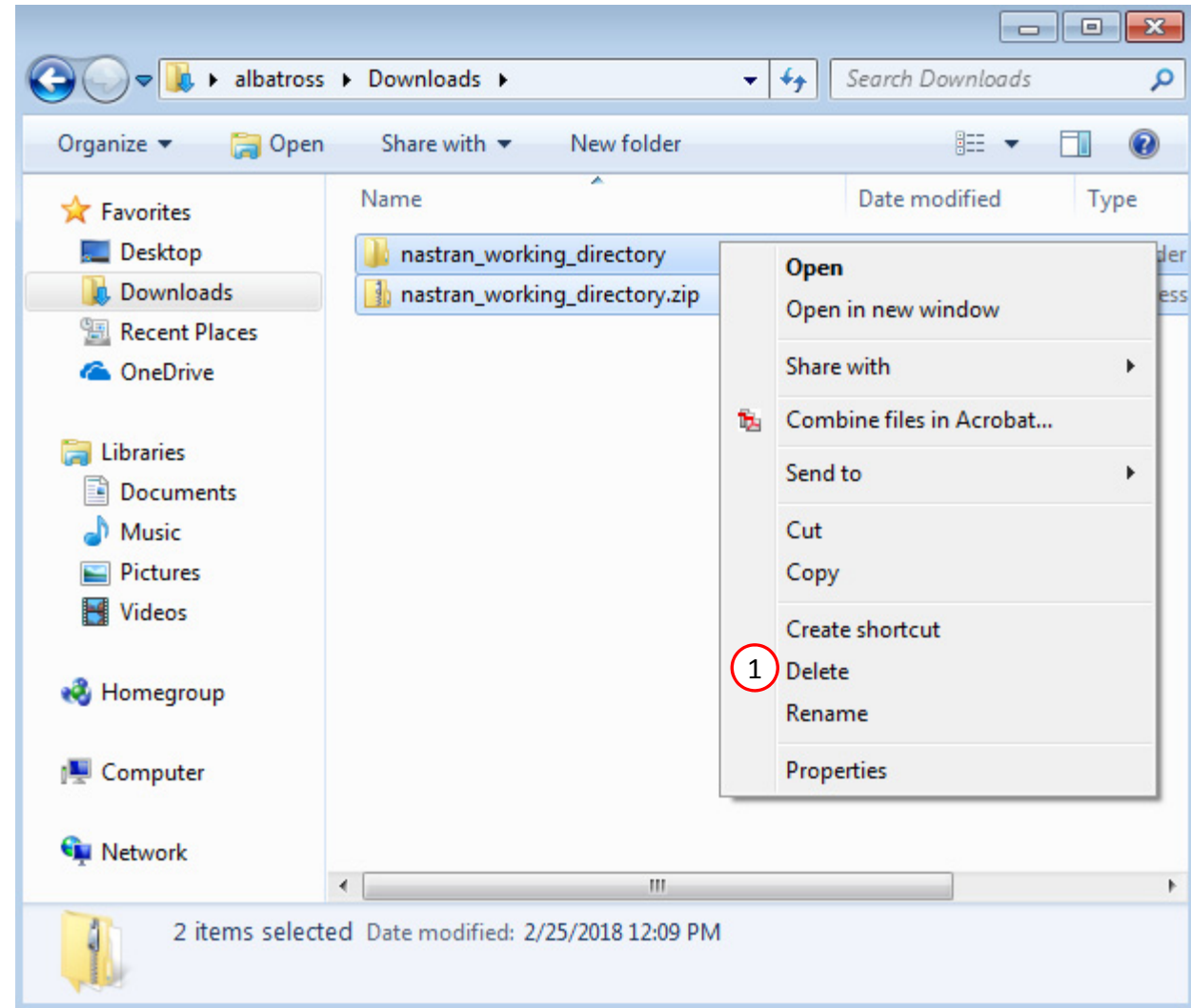
## Optimization Settings

Parameter ↕	Description ↕	Configure ↕
<input type="text" value="Search"/>	<input type="text" value="Search"/>	<input type="text" value="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"/> 50 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 respons ▼
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 ▼

# Delete old files

1. Select old files and delete them. New files will be downloaded in the next step.

- Deleting the files is optional, but is encouraged to avoid confusion with other files and folders.



# 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

Upload

Variables

Objective

Constraints

Subcases

**1** Exporter

Results

Settings

Match

Other

User's Guide

Home

BDF Output - Model

```
assign userfile = 'optimization_results.csv', status = unknown,
form = formatted, unit = 52
$ MSC.Nastran input file created on September 07, 2017 at 13:28:54 by
$ Patran 2017.0.2
$ Direct Text Input for Nastran System Cell Section
$ Direct Text Input for File Management Section
$ Direct Text Input for Executive Control
$ Linear Static Analysis, Database
SOL 200
CEND

SET 30001 = 6000001
SET 30002 = 6000002
$ Direct Text Input for Global Case Control Data
TITLE = MSC.Nastran job created on 07-Sep-17 at 13:07:10
ECHO = NONE
DESOBJ(MIN) = 9000000
DESLB = 40000000
$ DSAPRT(FORMATTED, EXPORT, END=SENS) = ALL
SUBCASE 1
ANALYSIS = STATICS
DESSUB = 40000001
DRSPAN = 30001
$ Subcase name : Default
SUBTITLE=Default
SPC = 2
LOAD = 2
DISPLACEMENT(PLOT, SORT1, REAL)=ALL
SPCFORCES(PLOT, SORT1, REAL)=ALL
```

BDF Output - Design Model

```
$*****
$*
$*                               *
$*                               *
$*                               *
$*****
$
$-----
$                               Design Regions/Variables
$-----
$
$
TOPVAR 300001 X1 PSHELL 1

$
$-----
$                               Design Equation Objective
$-----
$
$
DRESP2 9000000 R0 170000
DRESP1 6000001 6000002

$
$
DEQATN 170000
g(a1,a2) =
a1 / 1.0 + 2.0 / a2

$-----
$                               Supporting Responses
$-----
$
$
DRESP1 6000001 a1 COMP STRUC 1
DRESP1 6000002 a2 FREQ STRUC 1

$
$-----
$                               Design Constraints
$-----
$
$
DRESP1 0000001 r1 FRMSS 3 714
DRESP1 0000002 r2 DISP
DRESP1 0000003 r3 FREQ STRUC 1

$
$
```

Download BDF Files

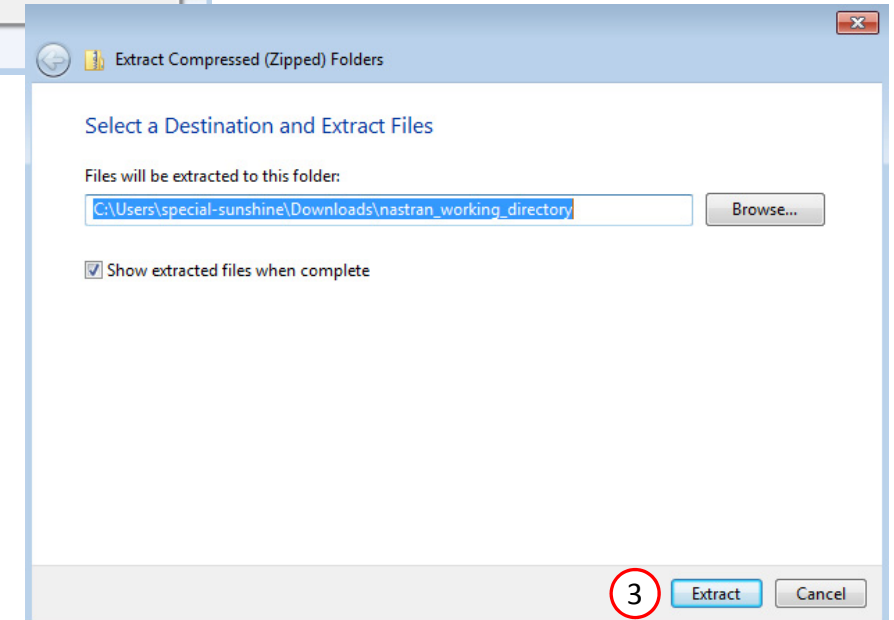
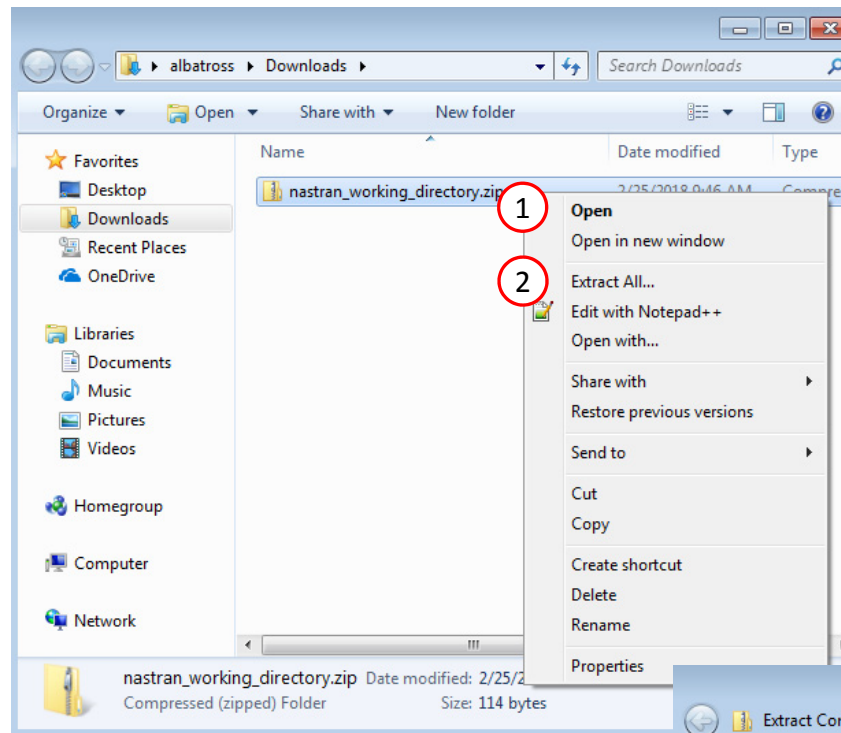
Download BDF Files

**2**

# 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.

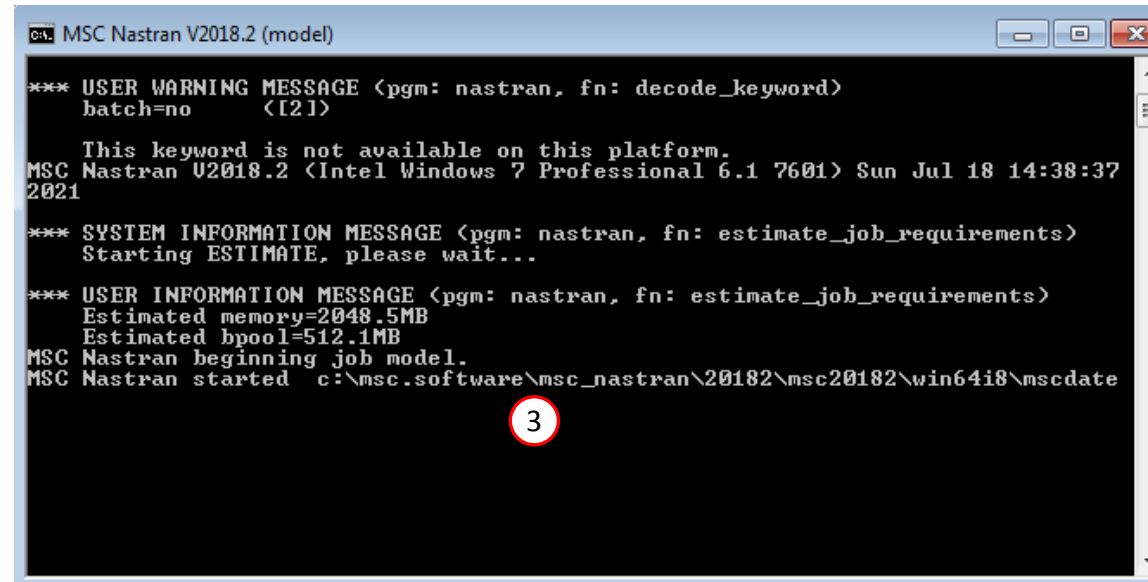
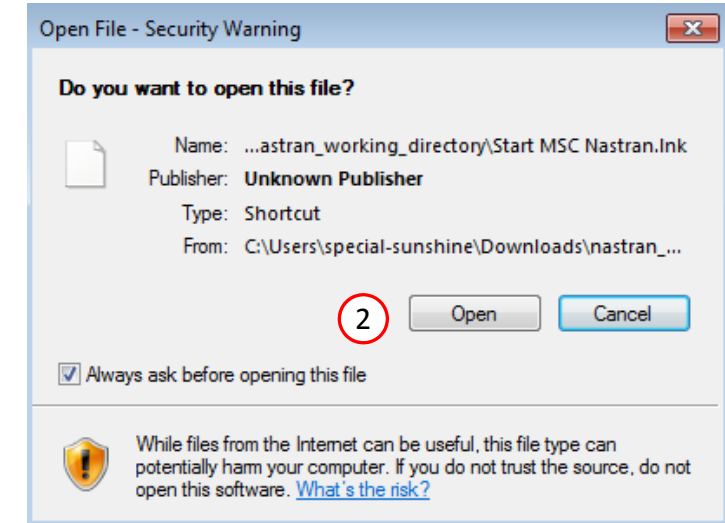
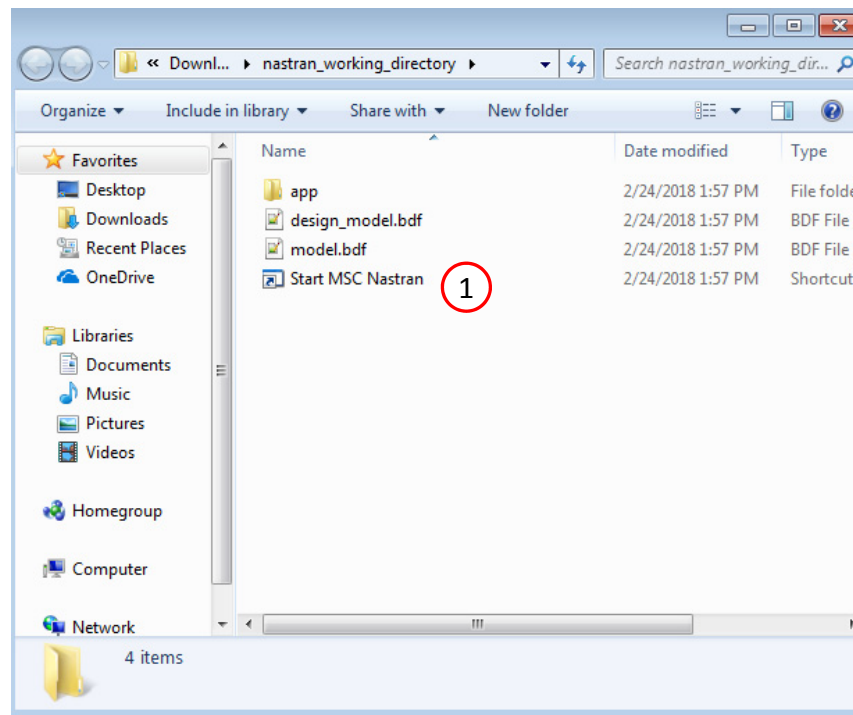
## Using Linux?

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.
- Note that initial value of the objective is 2.0. The Equation Objective has been configured such that the a1 and a2 terms are normalized or 1.0 each. For the initial design, R0 evaluates as follows:

$$R0 = a1 / 3.6788E1 + 8.6430E1 / a2$$

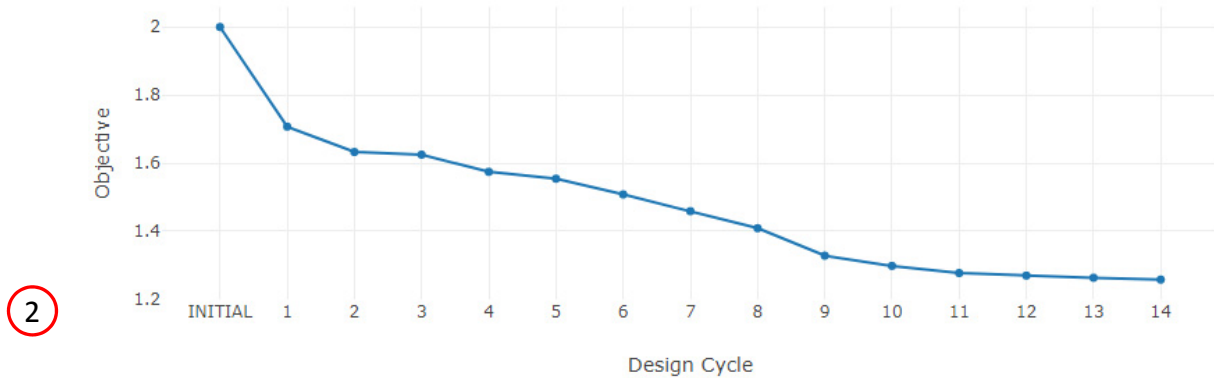
$$= 3.6788E1 / 3.6788E1 + 8.6430E1 / 8.6430E1$$

$$= 2.0$$

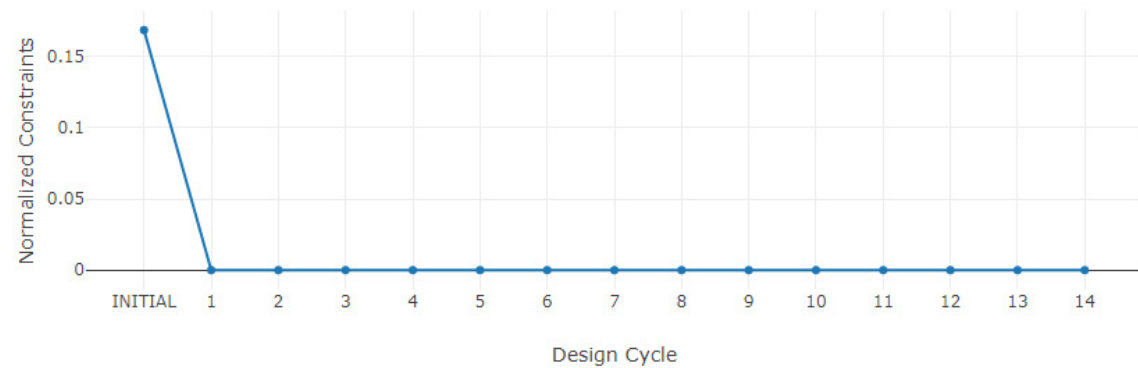
## Final Message in .f06

1  RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER = 14.

## Objective



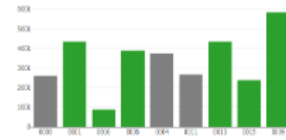
## Normalized Constraints



# Review Optimization Results

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

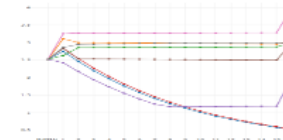
## Select a Results App



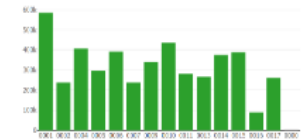
Global Optimization (multiplt.log)



Global Optimization Type 2 (.f06)

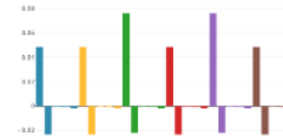


Local Optimization (.f06)

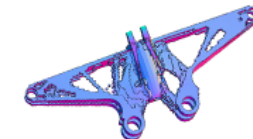


Parameter Study (.f06)

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.

The image is a composite of three screenshots illustrating the workflow of a web application for file upload and model display.

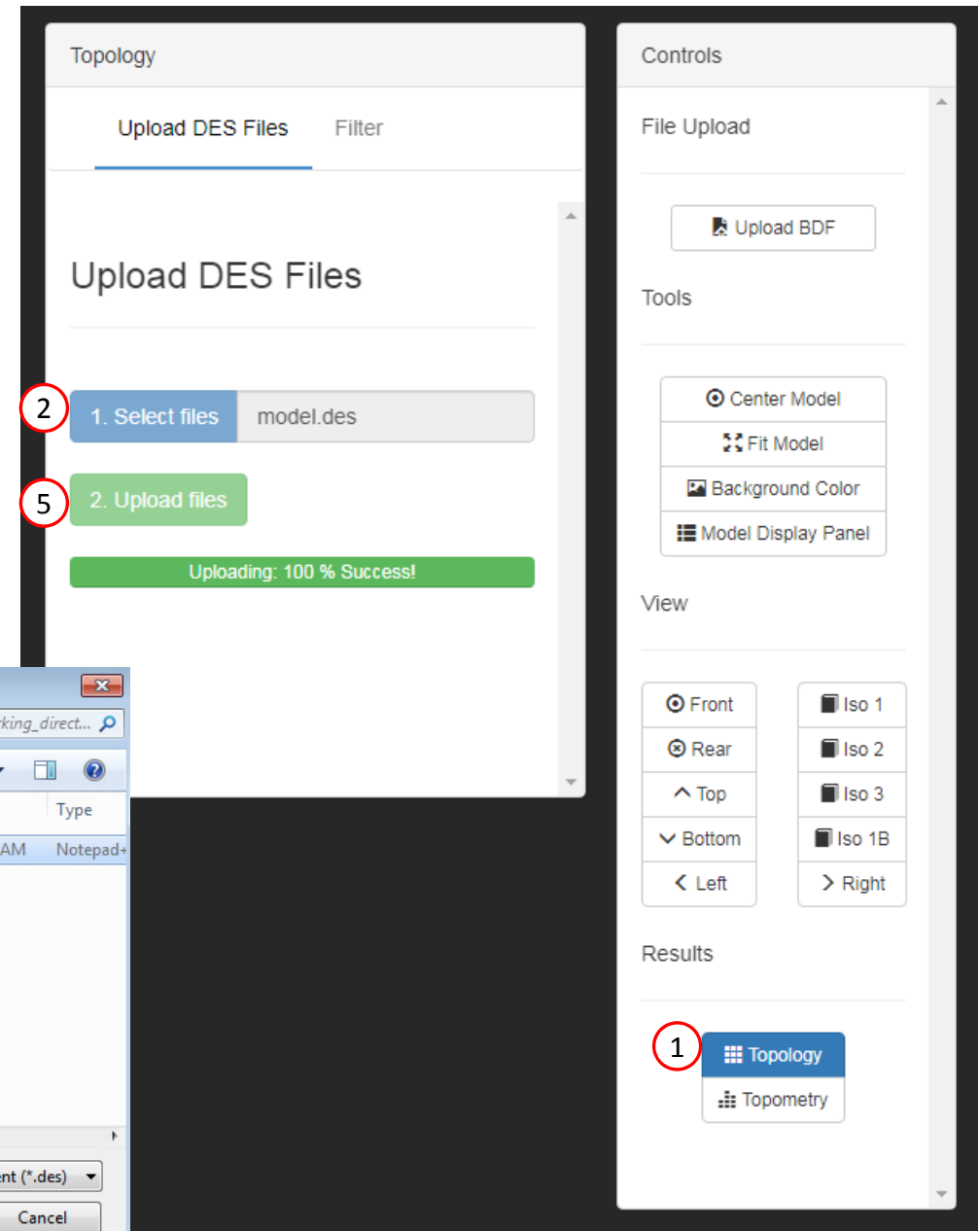
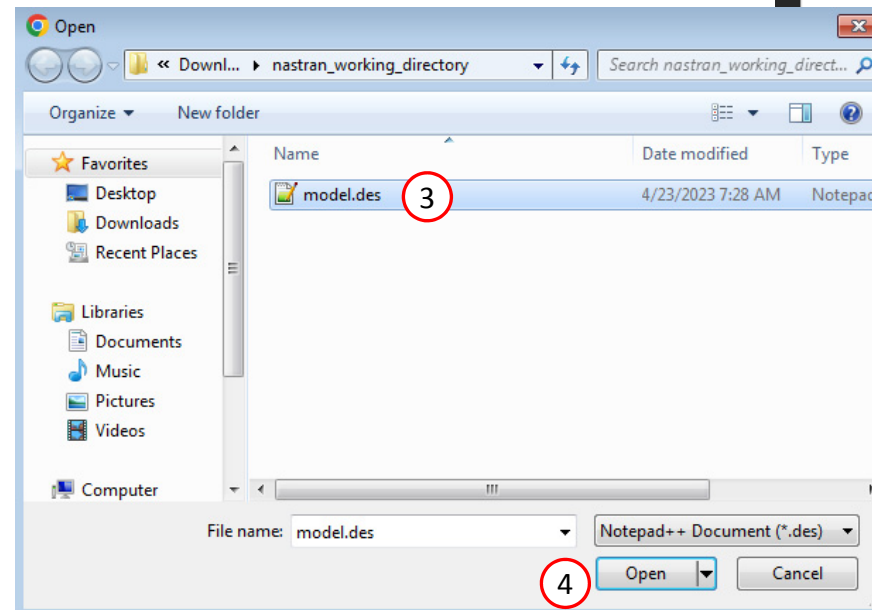
- Top Screenshot (File Upload Interface):** Shows a web interface titled "File Upload". It has a "BDF" label and a "Select Directory" button. A progress bar shows "1. Select files" with "2 files selected". Below it, a green bar indicates "Inspecting: 100%". Another green bar shows "2. Upload files" with "Uploading: 100 %". A checkbox "List of Selected Files" is at the bottom. Red circles with numbers 2 and 6 highlight the "1. Select files" and "2. Upload files" buttons respectively.
- Bottom-Left Screenshot (3D Model):** Shows a 3D model of a red, wing-like structure on a black background. A red circle with the number 7 highlights the model.
- Bottom-Right Screenshot (File Explorer):** Shows a Windows File Explorer window titled "Open". The address bar shows the path "nastran\_working\_directo...". The file list contains "app" (File folder), "design\_model.bdf" (BDF File), and "model.bdf" (BDF File). The "design\_model.bdf" and "model.bdf" files are selected. Red circles with numbers 3, 4, and 5 highlight the address bar, the selected files, and the "Open" button respectively.

# 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.

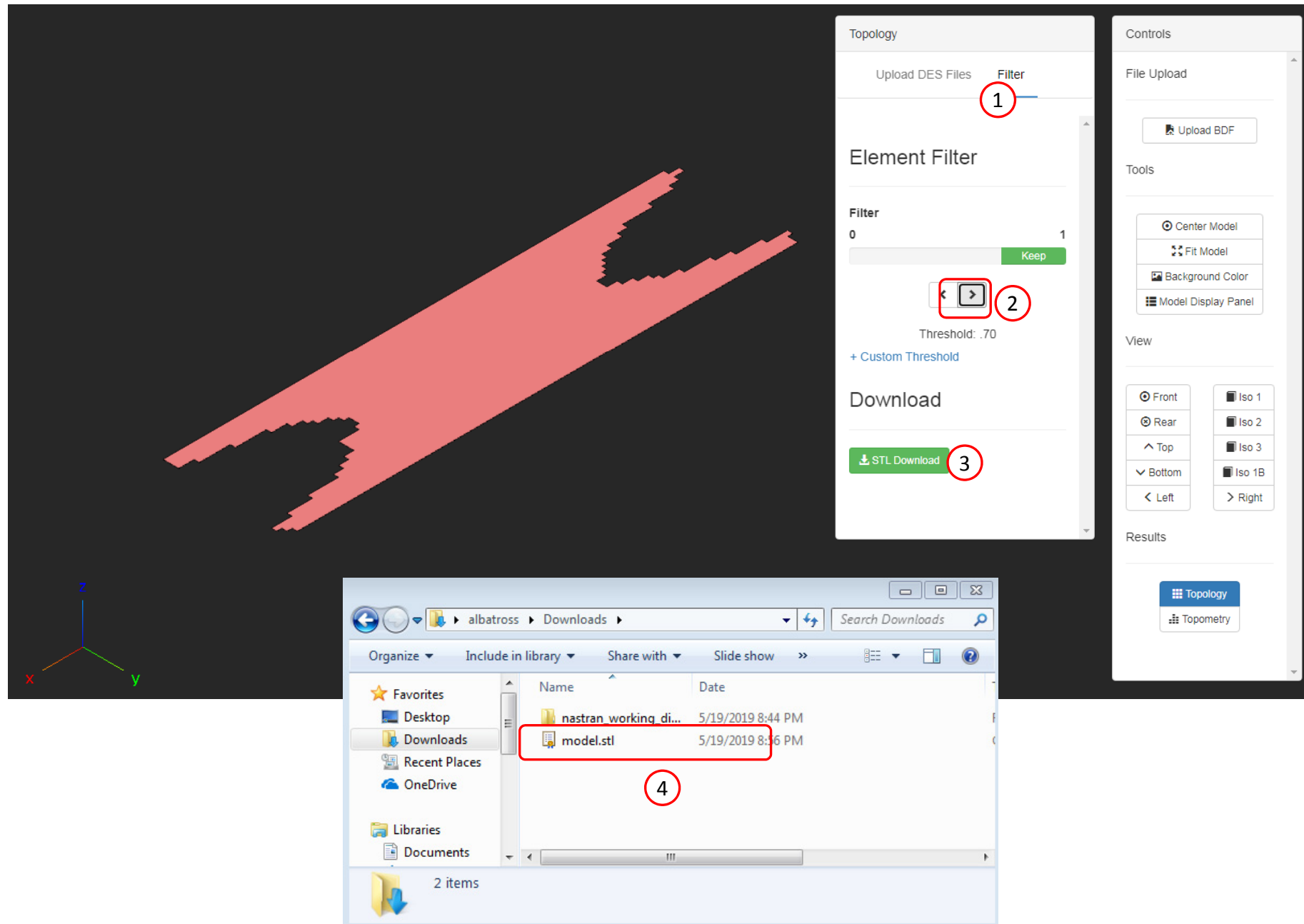
- When the DES file is uploaded, the topology results are automatically displayed. By default, elements with a normalized material density greater than a threshold of .3 are displayed. The threshold can be modified.



# Review Optimization Results

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

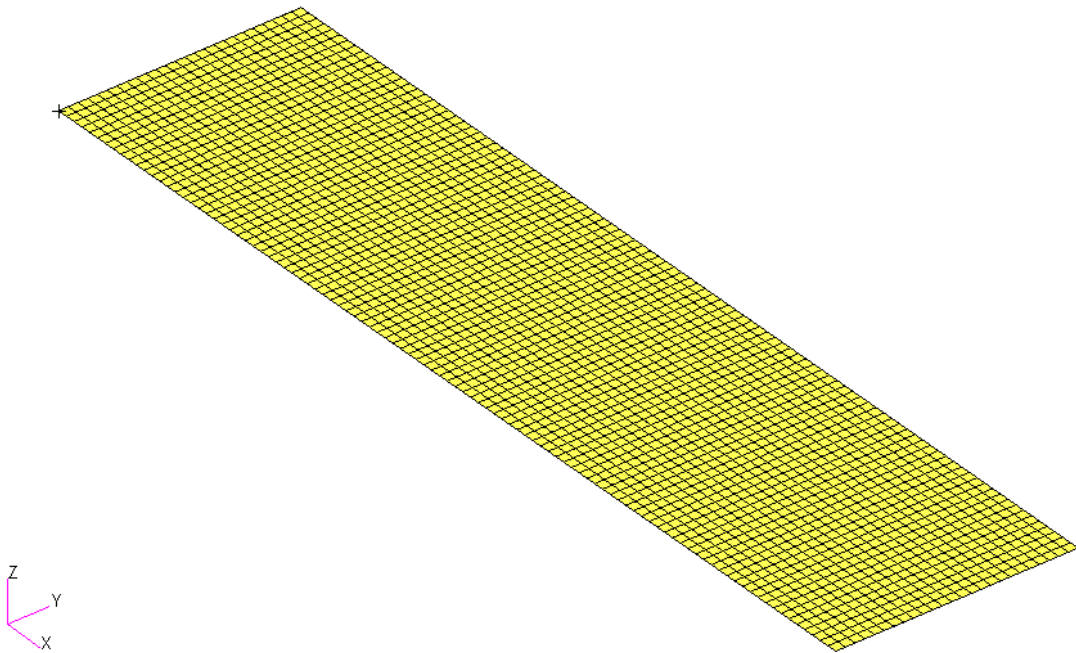
- A normalized material density (NMD) close to 1 indicates the element is very important and should be kept in the design. It is not recommended to go beyond a threshold of .7 since very critical elements would be removed. Elements with an NMD close to 0 are not critical and can be removed.
- Common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



# Results

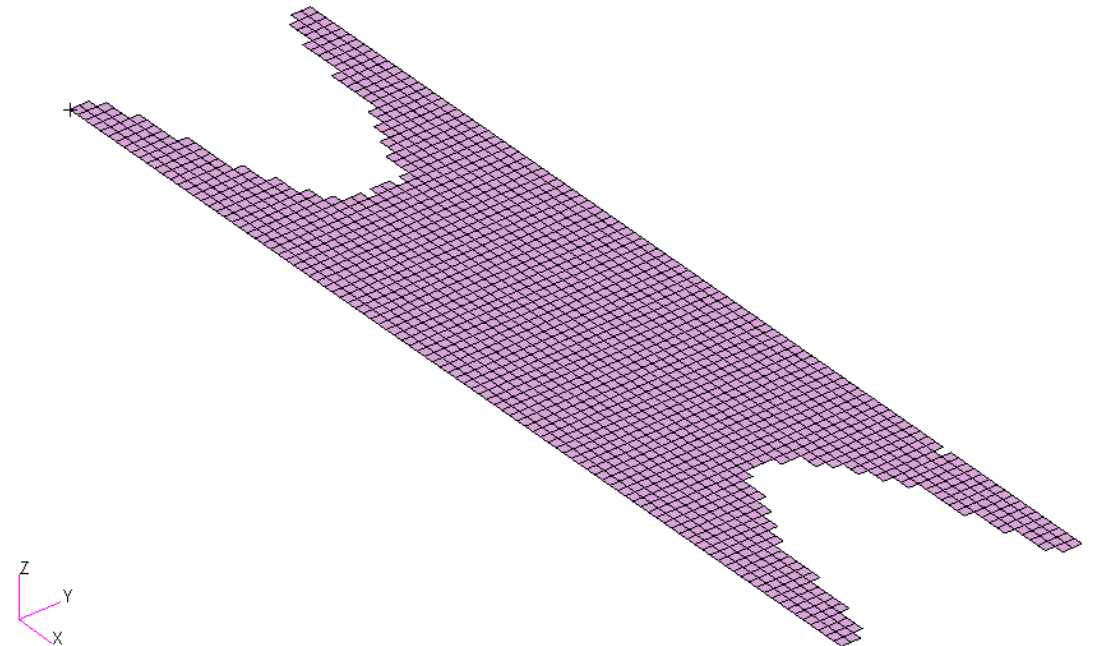
## Before Optimization

- Mass:  $9.73\text{E-}06$



## After Optimization

- Mass:  $7.05\text{E-}06$  (~25% mass reduction)
- Maximize stiffness
- Maximize first natural frequency





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?

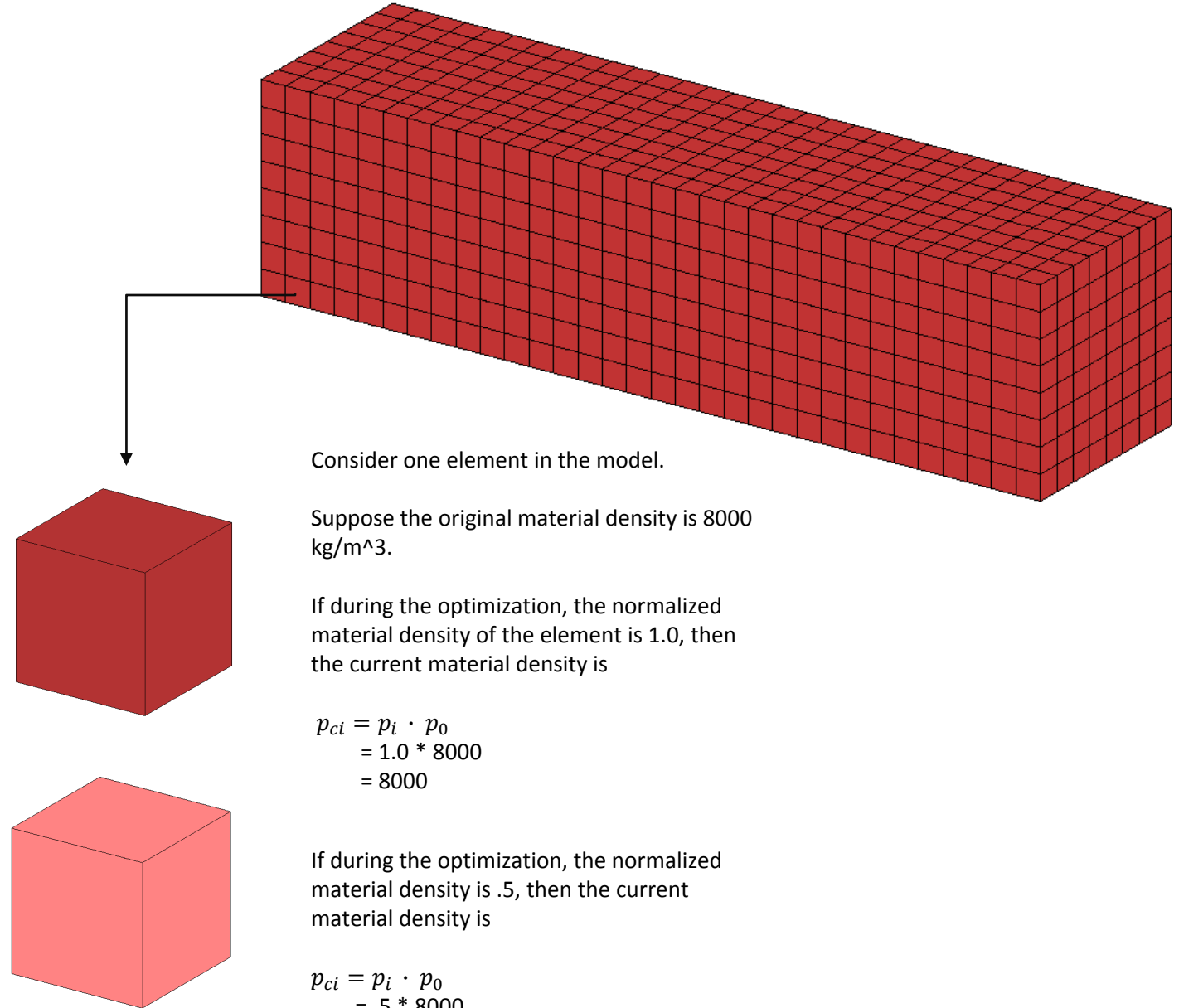
The design variables in a topology optimization are normalized material densities ( $p_i$ ) of each element.

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

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

$p_0$  : The original material density

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



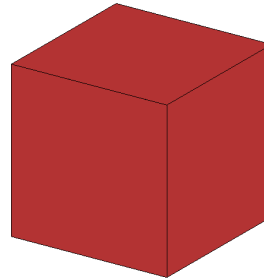
# What are the design variables in Topology Optimization?

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

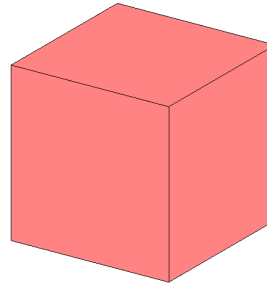
- 1 - Normalized density values close to 1 are critical to the design
- 0 - Normalized density values close to 0 are not critical to the design

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.

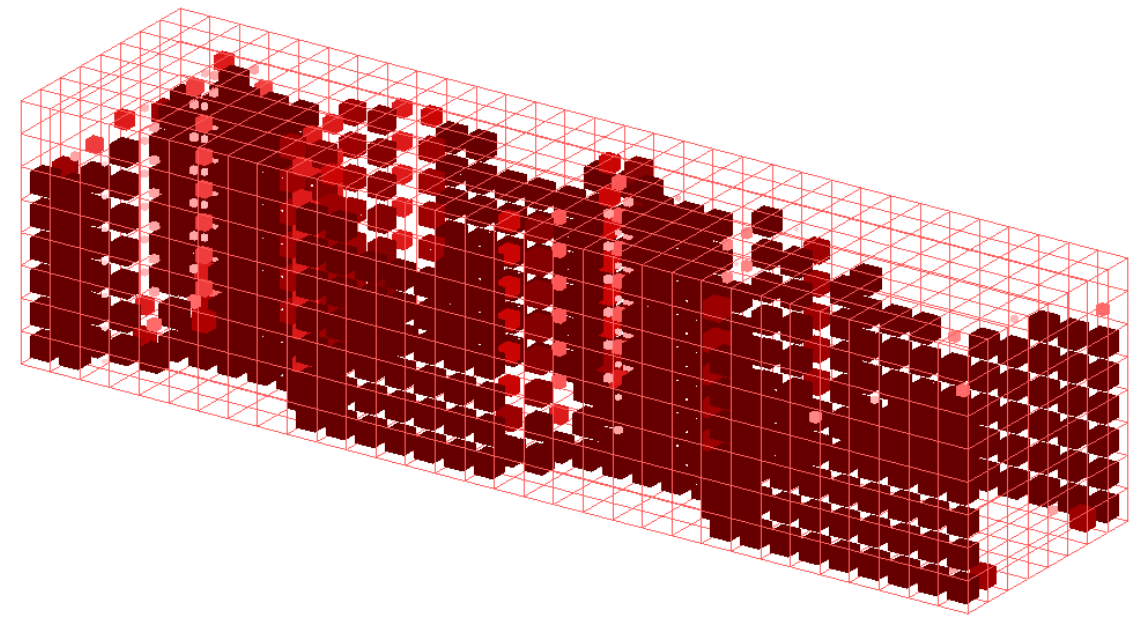
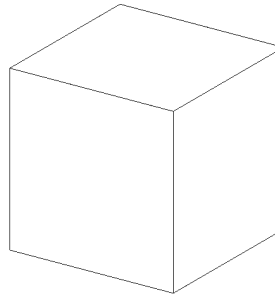
$p_i = 1.0$



$p_i = .50$



$p_i = 0.0$



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.

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

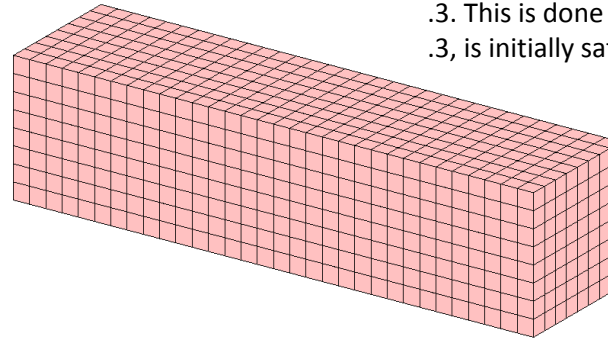
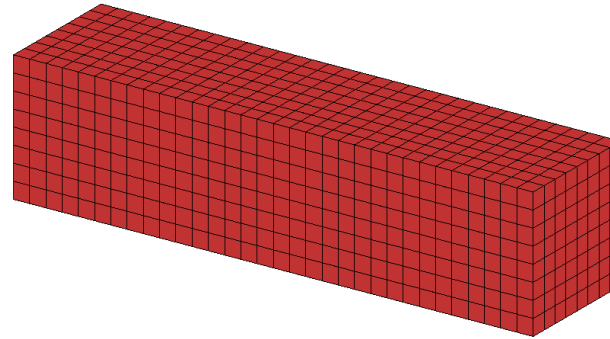
$p_0$  : The original material density

$p_i$  : The normalized material density of the element

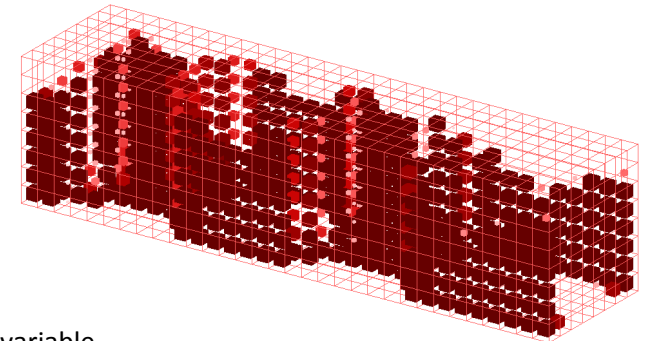
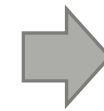
$v_i$  : Volume of element

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.

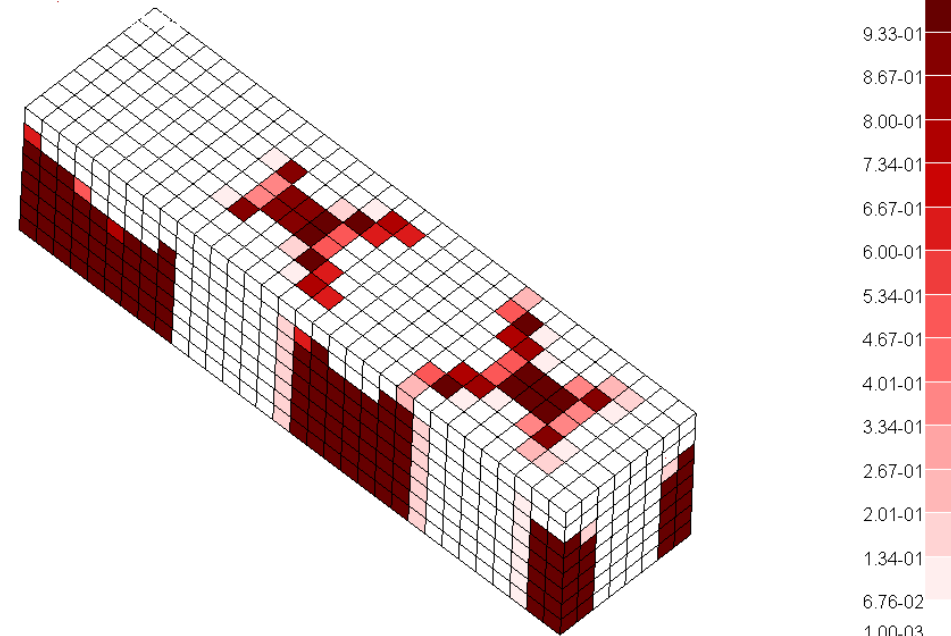
E L E M E N T   S T R A I N   E N E R G I E S				
ELEMENT-TYPE = HEXA		* TOTAL ENERGY OF ALL ELEMENTS IN PROBLEM	=	9.111034E+03
SUBCASE	1	* TOTAL ENERGY OF ALL ELEMENTS IN SET	-1 =	9.111034E+03
	ELEMENT-ID	STRAIN-ENERGY	PERCENT OF TOTAL	STRAIN-ENERGY-DENSITY
	25	8.059148E+02	8.8455	6.447318E+03
	32	8.059148E+02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

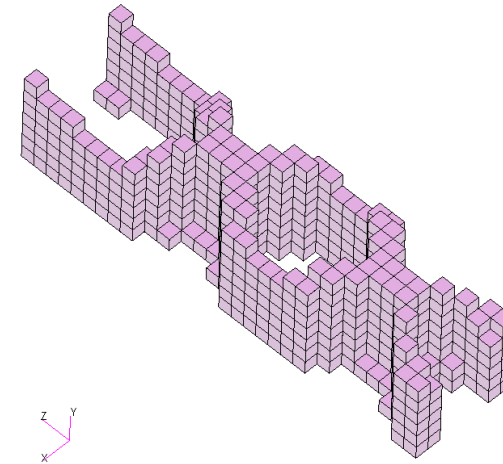
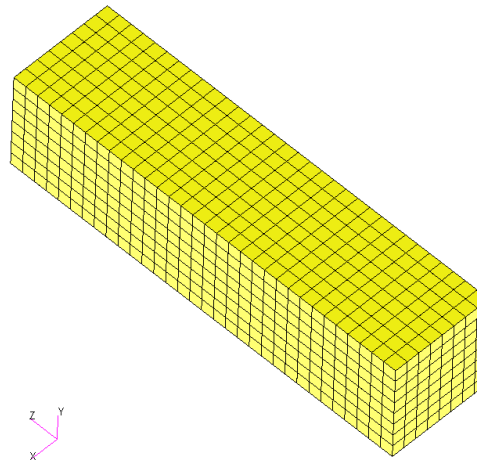


# How can non-critical elements be removed from the design?

- 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

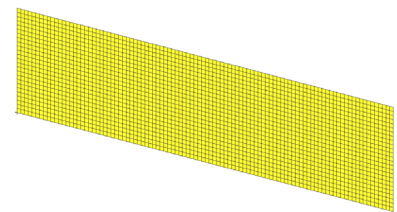
# Traditional Topology Optimization

Objective: Minimize Compliance (Maximize Stiffness)

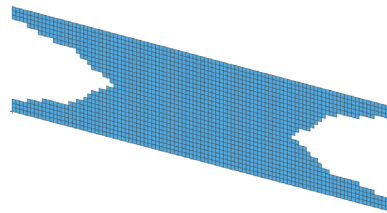
Constraint: Fractional Mass < .## (Target Mass)

---

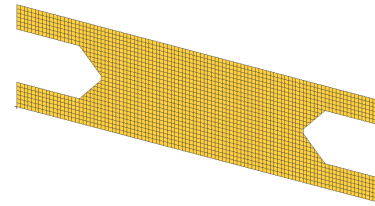
Original Design



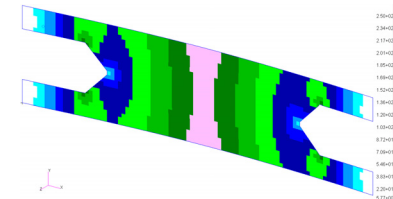
Mass: 9.737 grams



FRMASS < .75  
Mass: 7.186 g  
Optimization B



Mass: 7.739 g



Max von Misses: 150 MPa  
Max Displacement : 2.78 mm

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

# Traditional Topology Optimization

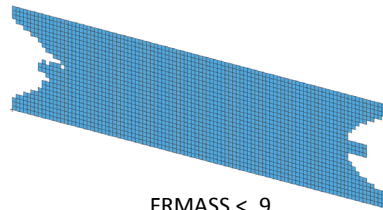
Objective: Minimize Compliance (Maximize Stiffness)

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

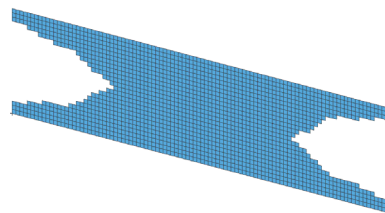
Original Design

Mass: 9.737 grams

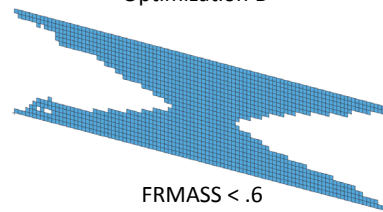
Topology Solution



FRMASS < .9  
Mass: 8.756 g  
Optimization A

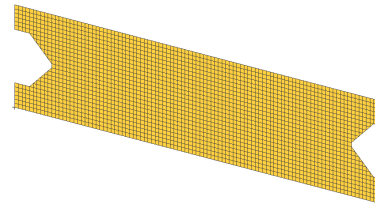


FRMASS < .75  
Mass: 7.186 g  
Optimization B

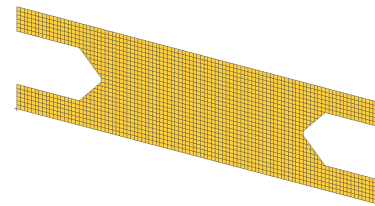


FRMASS < .6  
Mass: 5.718 g  
Optimization C

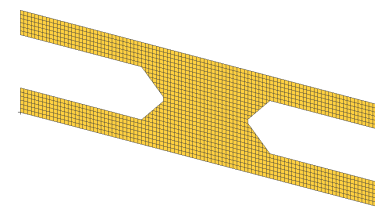
Refined Design



Mass: 9.094 g

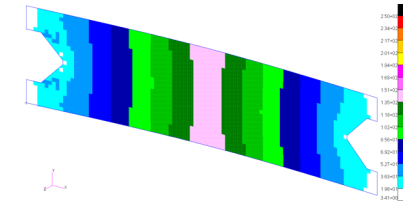


Mass: 7.739 g



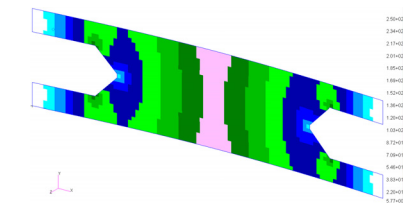
Mass: 6.119 g

Verification



Max von Misses: 150 MPa  
Max Displacement: 2.52 mm

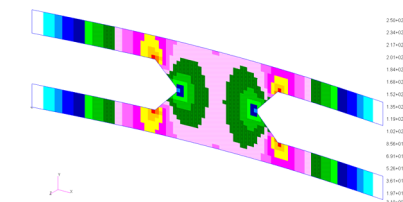
1<sup>st</sup> natural Frequency: 114 Hz



Max von Misses: 150 MPa  
Max Displacement : 2.78 mm

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

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



Max von Misses: 250 MPa  
Max Displacement : 3.57 mm

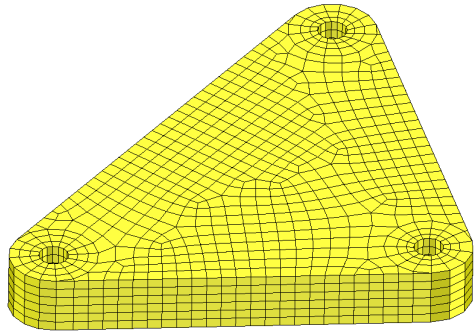
1<sup>st</sup> natural Frequency: 109 Hz

# Latest Topology Optimization

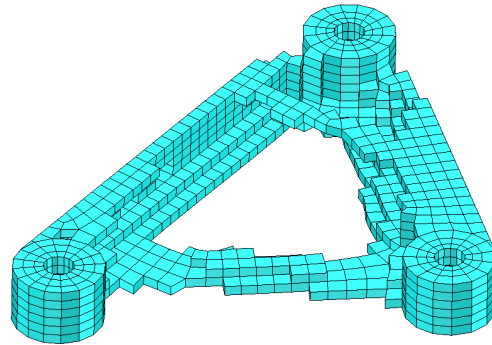
Objective: Minimize Fractional Mass (Minimize Mass)

Constraint: Stress Constraint

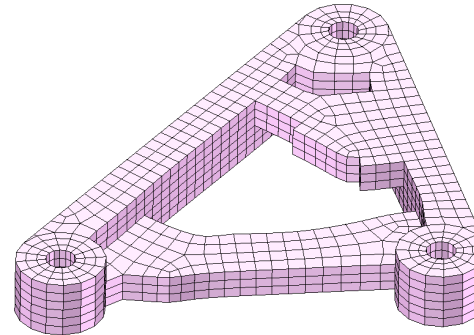
Original Design



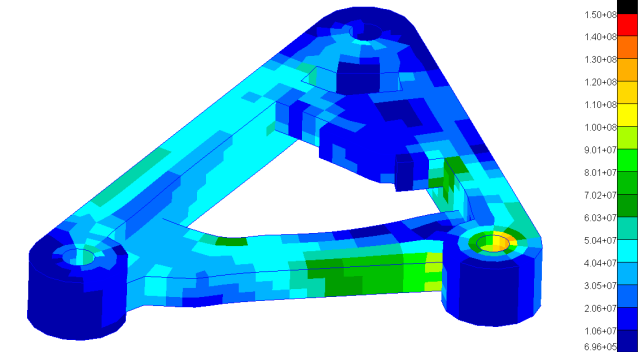
Topology Solution



Refined Design



Verification



# Viewer Web App for Topology Optimization Post Processing

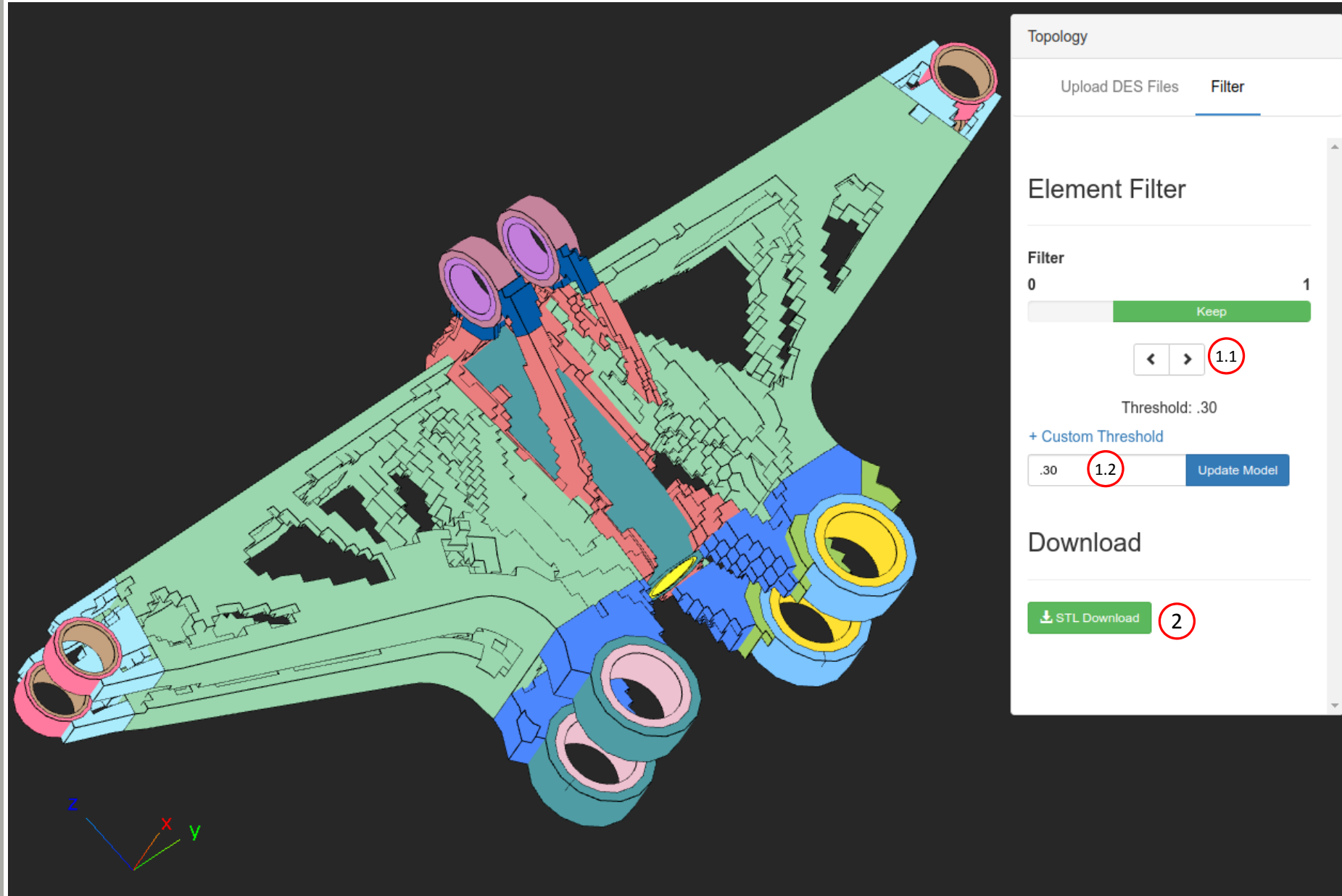
---

# 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

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### 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.