Workshop - Vibration of a Cantilevered Beam (Turner's Problem)

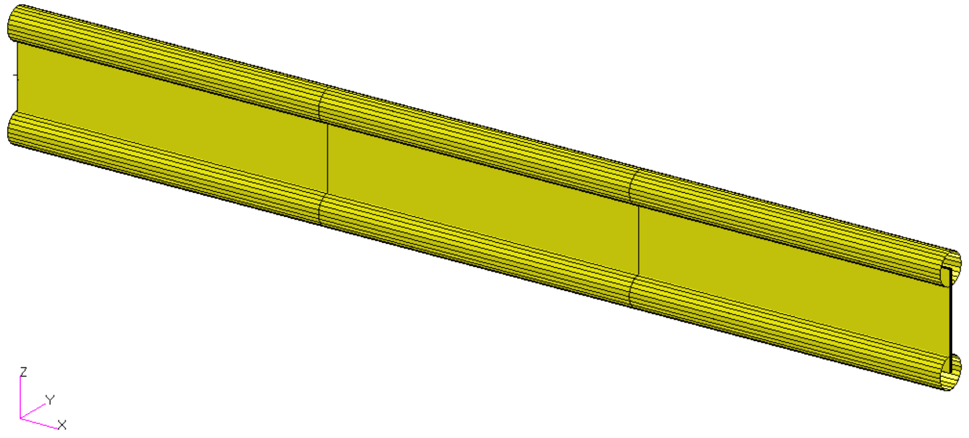
AN MSC NASTRAN SOL 200 TUTORIAL

Goal: Use Nastran SOL 200 Optimization

Minimize the weight of this structure while constraining the 1st natural frequency

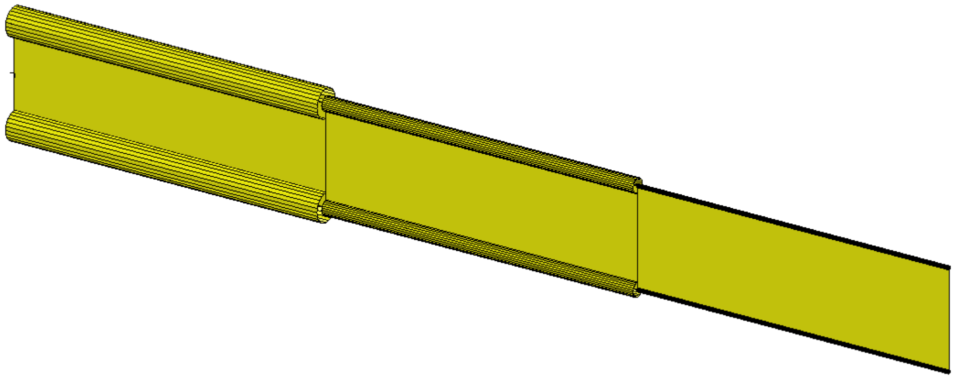
Before Optimization

- Weight: 19.2 lbs.
- 1^{st} Natural Frequency: 26 Hz



After Optimization

- Weight: 6.97 lbs.
- 1^{st} Natural Frequency: 20 Hz



MSC Nastran Design Sensitivity and Optimization User's Guide
Chapter 8 - Example Problems - Vibration of a Cantilevered Beam (Turner's Problem)

Details of the structural model

Vibration of a Cantilevered Beam (Turner's Problem)

This problem was originally published by M.J. Turner (see Reference 13.). The problem is to design a minimum weight structure while constraining the fundamental natural frequency to be at or above 20 Hz. The beam is symmetric about Z = 0 and made up of a shear web having top and bottom caps that are modeled with rod elements. Turner's original design model consisted of piecewise linear bar cross-sectional areas and web thicknesses; however, we will just approximate this as a step function model with uniform cross-sectional rod elements and uniform thickness shear elements within each of three bays.

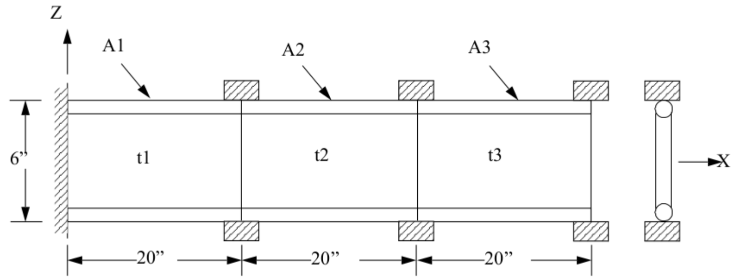
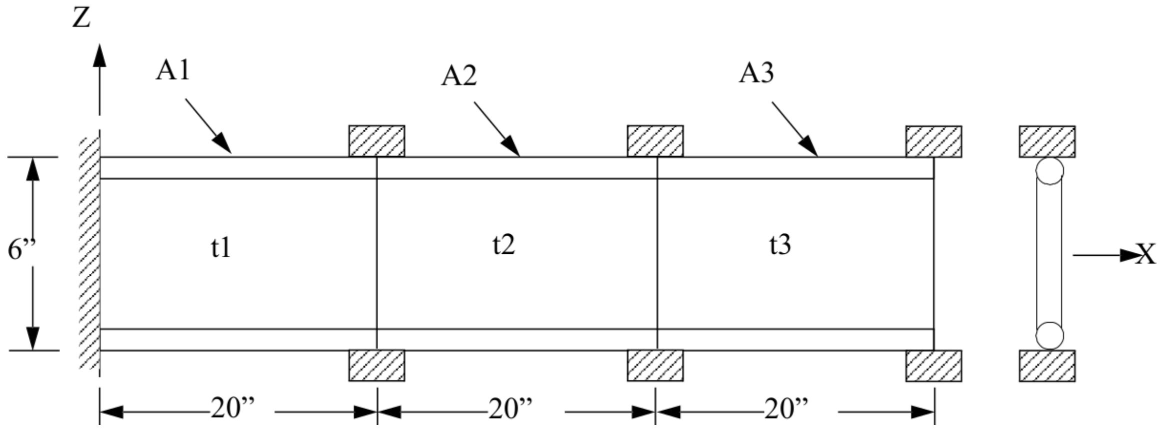
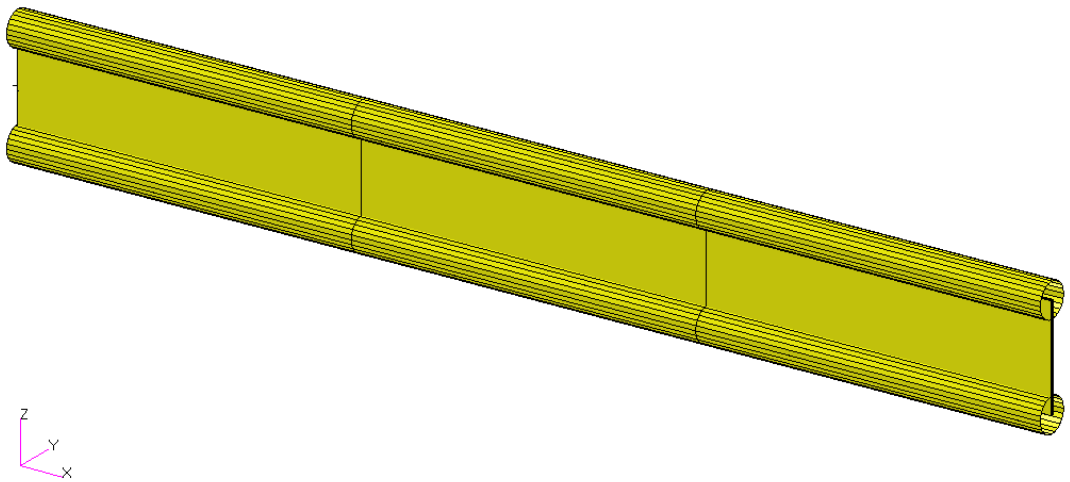


Figure 8-17 Cantilever Beam Vibration Model

MSC Nastran Design Sensitivity and Optimization User's Guide
Chapter 8 - Example Problems - Three Bar Truss





Optimization Problem Statement

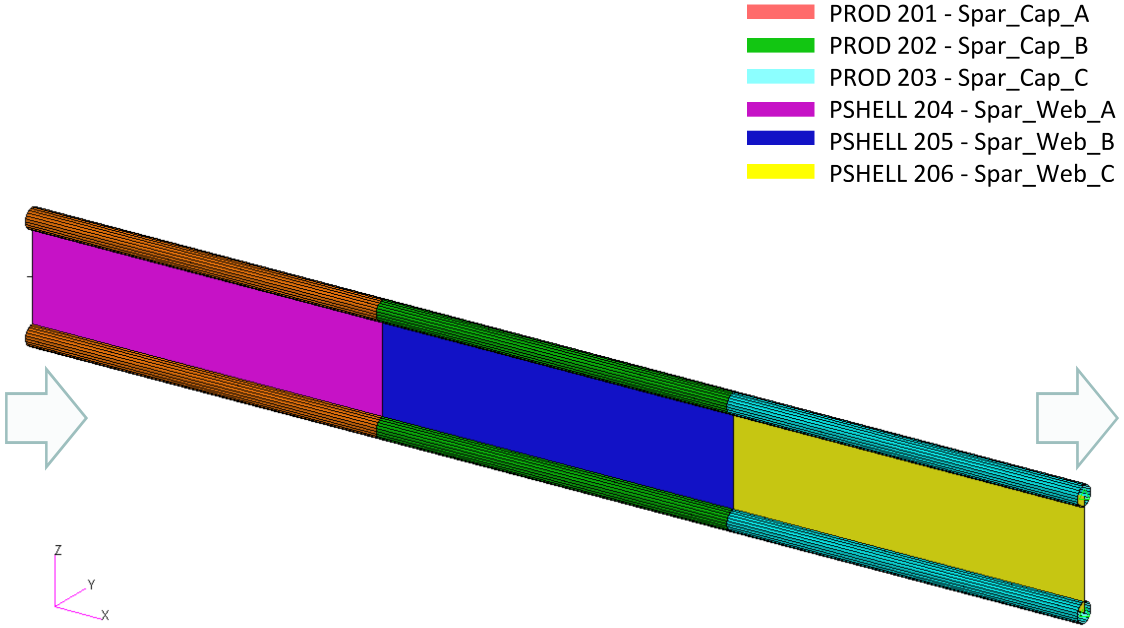
Design Variables

x1: A of PROD 201
x2: A of PROD 202
x3: A of PROD 203

.01 < x1, x2, x3 < 100.

x4: T of PSHELL 204
x5: T of PSHELL 205
x6: T of PSHELL 206

.0002 < x4, x5, x6 < 2.



Design Objective, Equation

R0: Minimize a1 - 90.

where,

a1: weight of entire structure

Design Constraints

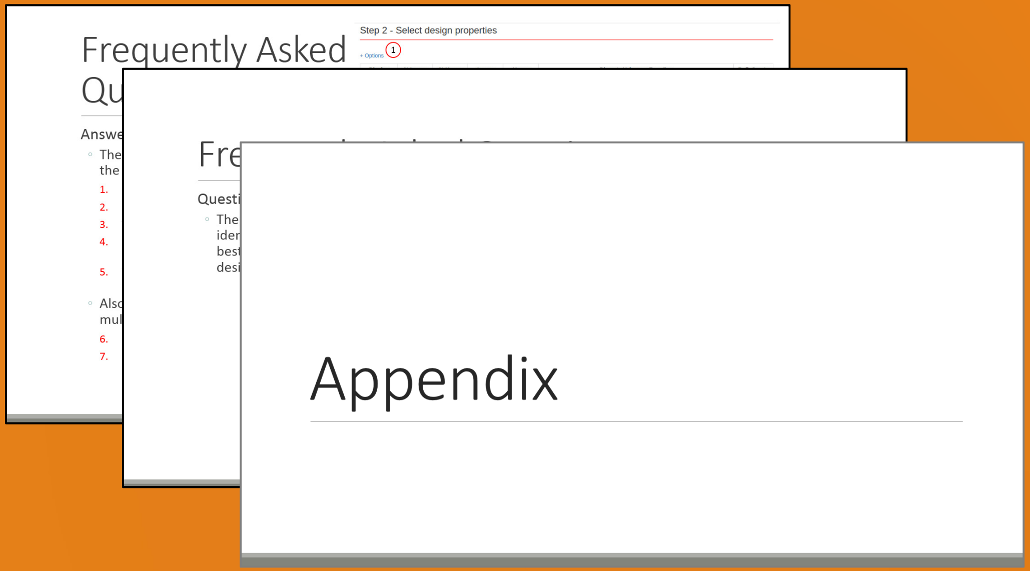
r1: 1st Natural frequency

20 Hz < r1

More Information Available in the Appendix

The Appendix includes information regarding the following:

- Frequently Asked Questions
  - There are thousands of properties that have been identified as designable. How can the properties best be sorted so the thicknesses can be set as design variables?



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 Variables
     - Design Objective
     - Design Constraints
   - Perform optimization with Nastran SOL 200
3. Plot the Optimization Results
4. Update the original model with optimized parameters

Special Topics Covered

Equation Driven Objective - MSC Nastran includes a list of quantities that can be set as objectives or constraints. In addition, custom user defined equations may be specified and be set as objectives or constraints. This tutorial details the process in defining custom equations.

Equation Objective

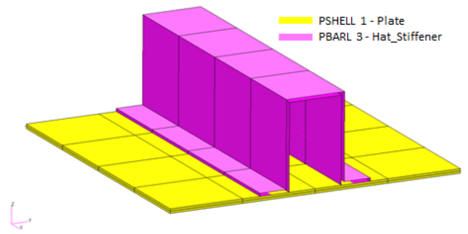
Minimize $f = a1 - 90.0$

SOL 200 Web App Capabilities

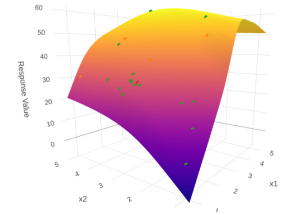
Benefits

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

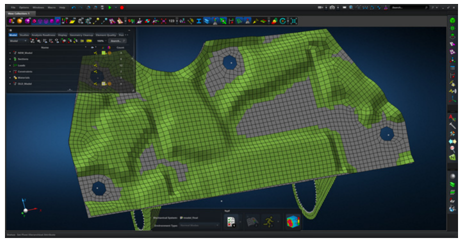
Capabilities



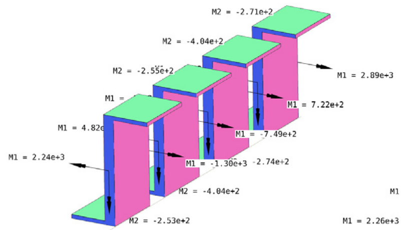
Web Apps for SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography and multi-model.



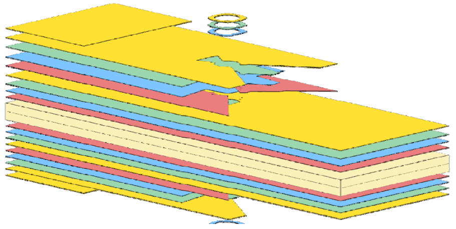
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



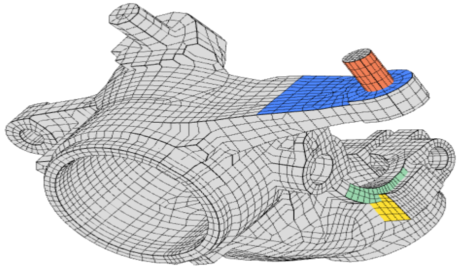
MSC Apex Post Processing Support
View the newly optimized model after an optimization



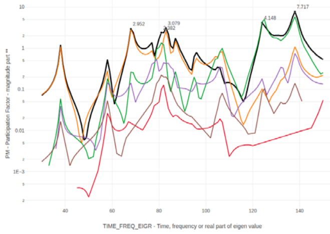
Beams Viewer Web App
Post process 1D element forces, including shear forces, moments, torque and axial forces



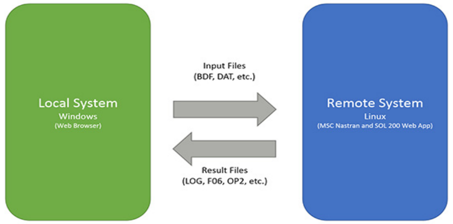
Ply Shape Optimization Web App
Spread plies optimally and generate new PCOMPG entries



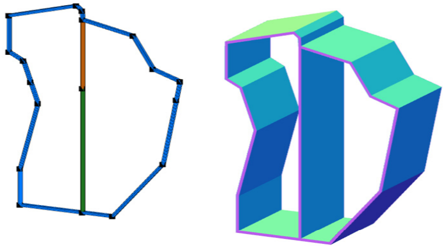
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



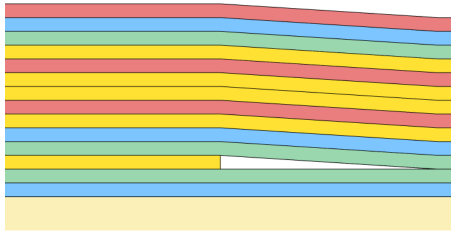
HDF5 Explorer Web App
Create XY plots using data from the H5 file



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



PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically

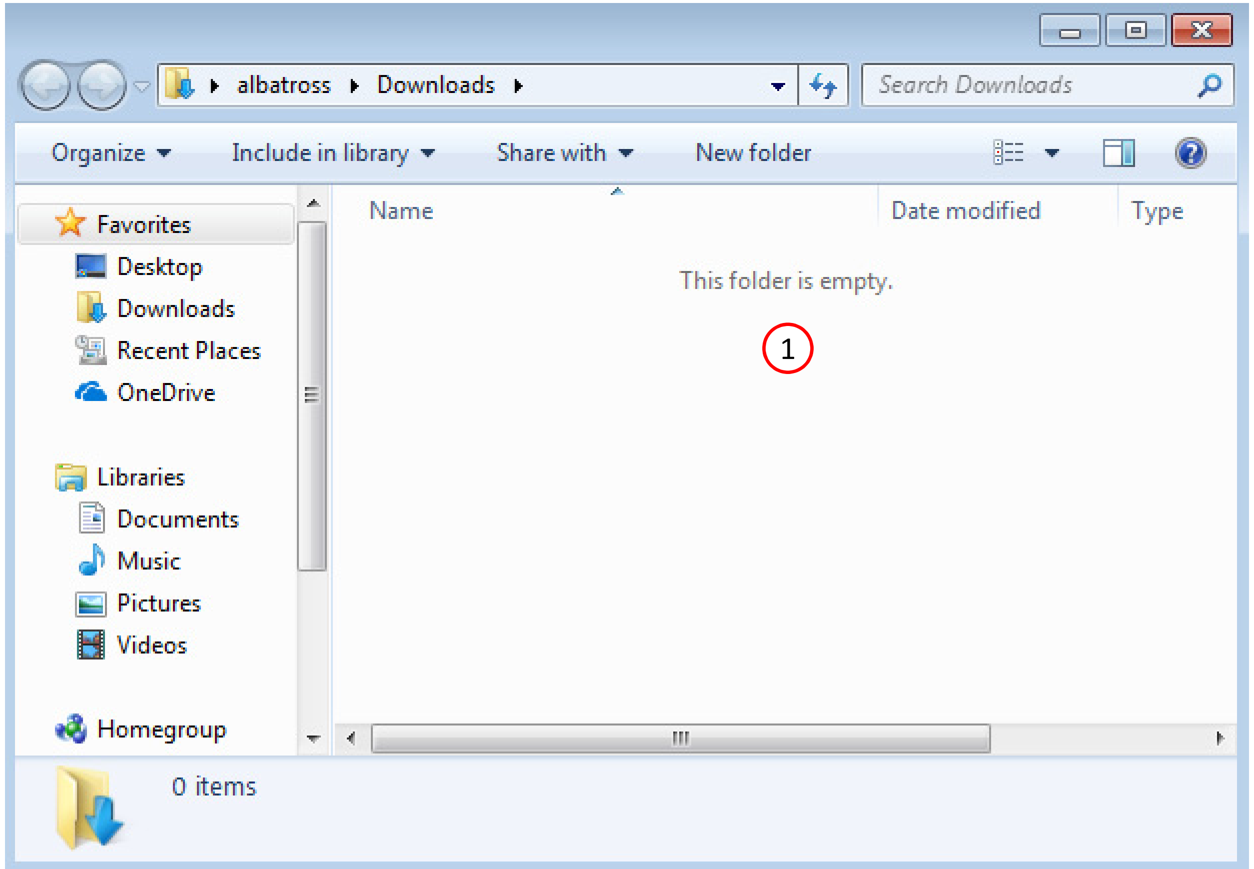


Stacking Sequence Web App
Optimize the stacking sequence of composite laminate plies

Before Starting

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

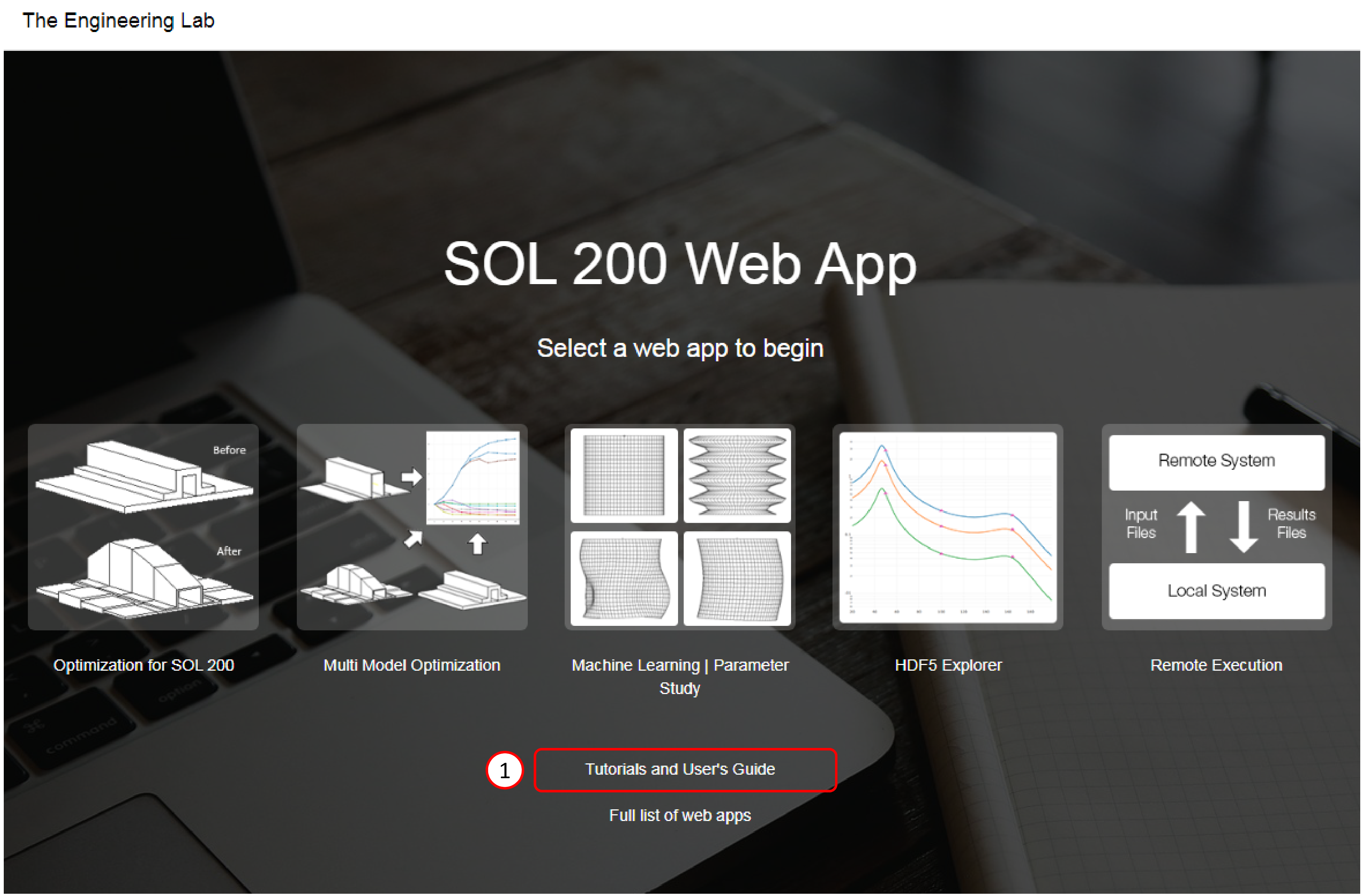
- Throughout this workshop, you will be working with multiple file types and directories such as:
  - .bdf/.dat
  - nastran_working_directory
  - .f06, .log, .pch, .h5, etc.
- To minimize confusion with files and folders, it is encouraged to start with a clean directory.



Go to the User's Guide

1. Click on the indicated link

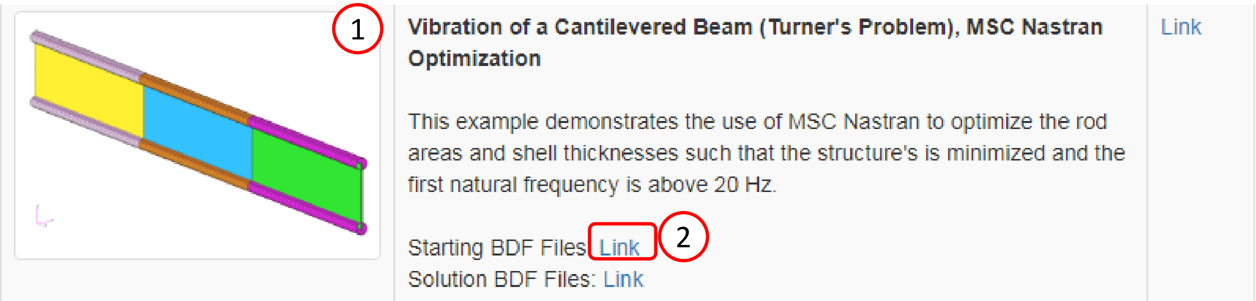
- The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.

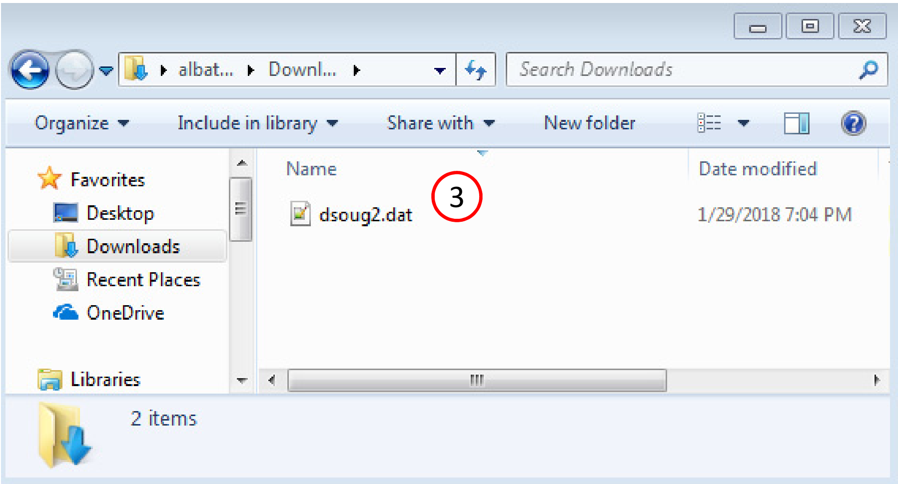


Obtain Starting Files

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

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

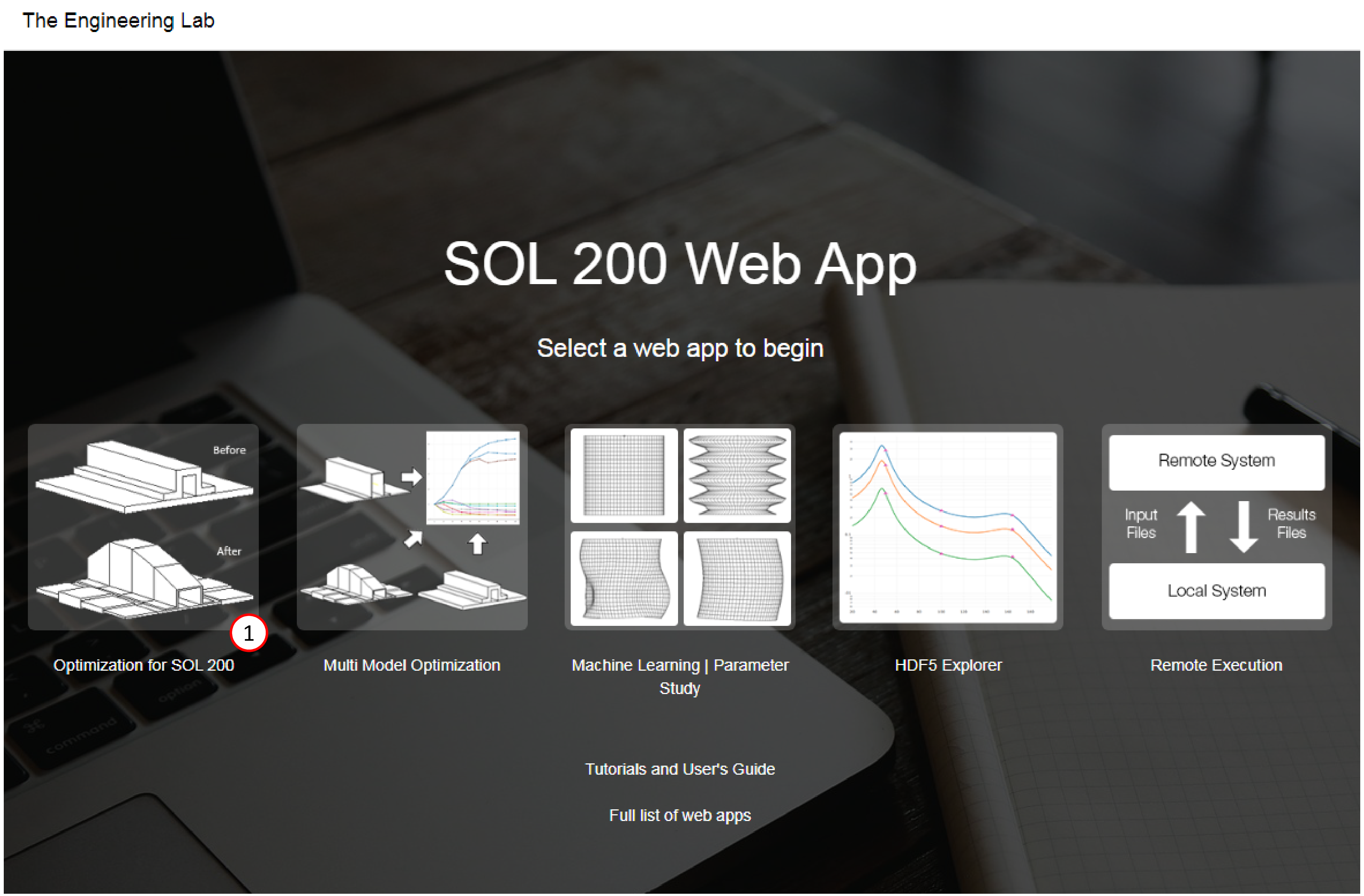




Open the Correct Page

1. Click on the indicated link

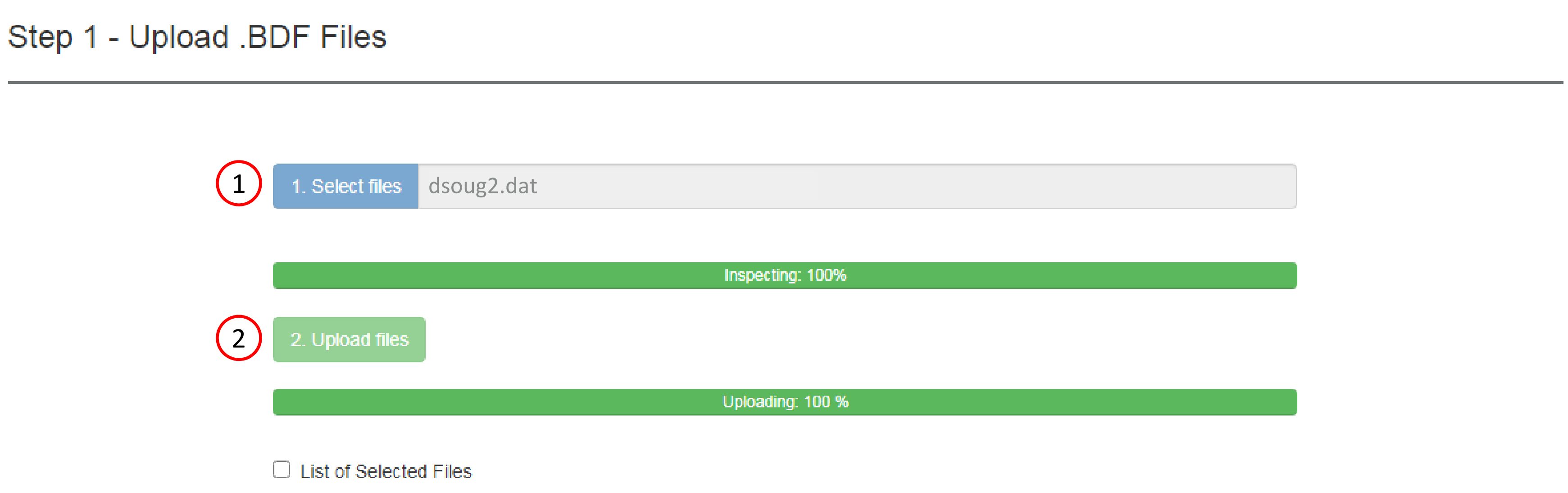
- MSC Nastran can perform many optimization types. The SOL 200 Web App includes dedicated web apps for the following:
    - Optimization for SOL 200 (Size, Topology, Topometry, Topography, Local Optimization, Sensitivity Analysis and Global Optimization)
    - Multi Model Optimization
    - Machine Learning
- 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 dsoug2.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.



Create Design Variables

1. In the search box, type ‘a’
2. Click on the plus (+) icons to set the areas as design variables
3. Specify the lower bound as .01 for design variables x1, x2, and x3
4. Specify the upper bound as 100. for design variables x1, x2, and x3

- 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 properties

+ Options

Create DVXREL1	Property	Property Description	Entry	Entry ID	Current Value
	a (1)	Search	Search	Search	Search
(2) +	A	Area of the rod	PROD	201	1.0
+	A	Area of the rod	PROD	202	1.0
+	A	Area of the rod	PROD	203	1.0

Step 2 - Adjust design variables

Delete Visible Rows

+ Options

	Label	Status	Property	Property Description	Entry	Entry ID	Initial Value	Lower Bound	Upper Bound	Allowed Discrete Values
	Search	Search	Search	Search	Search	Search	Search	S (3)	S (4)	Search
✖	x1	✔	A	Area of the rod	PROD	201	1.0	.01	100.	Examples: -2.0, 1.0, THRU, 10.0,
✖	x2	✔	A	Area of the rod	PROD	202	1.0	.01	100.	Examples: -2.0, 1.0, THRU, 10.0,
✖	x3	✔	A	Area of the rod	PROD	203	1.0	.01	100.	Examples: -2.0, 1.0, THRU, 10.0,

Create Design Variables

1. In the search box, type ‘t’
2. Click on the plus (+) icons to set the thicknesses as design variables
3. Click 10 on the pagination bar
4. Specify the lower bound as .0002 for design variables x4, x5, and x6
5. Specify the upper bound as 2.0 for design variables x4, x5, and x6

- In some instances, the optimizer will vary a positive design variable and make it negative, e.g. a thickness of .08 becomes -.01 in a weight minimization optimization. Certain properties, such as thickness or beam cross sections should never be negative. The lower bound in this example is set to .002 to avoid a negative variable during the optimization.

Step 1 - Select design properties

+ Options

Create DVXREL1	Property	Property Description	Entry	Entry ID	Current Value
	t (1)	Search	Search	Search	Search
+ (2)	T	Thickness	PSHELL	204	0.2
+	T	Thickness	PSHELL	205	0.2
+	T	Thickness	PSHELL	206	0.2

Step 2 - Adjust design variables

✖ Delete Visible Rows

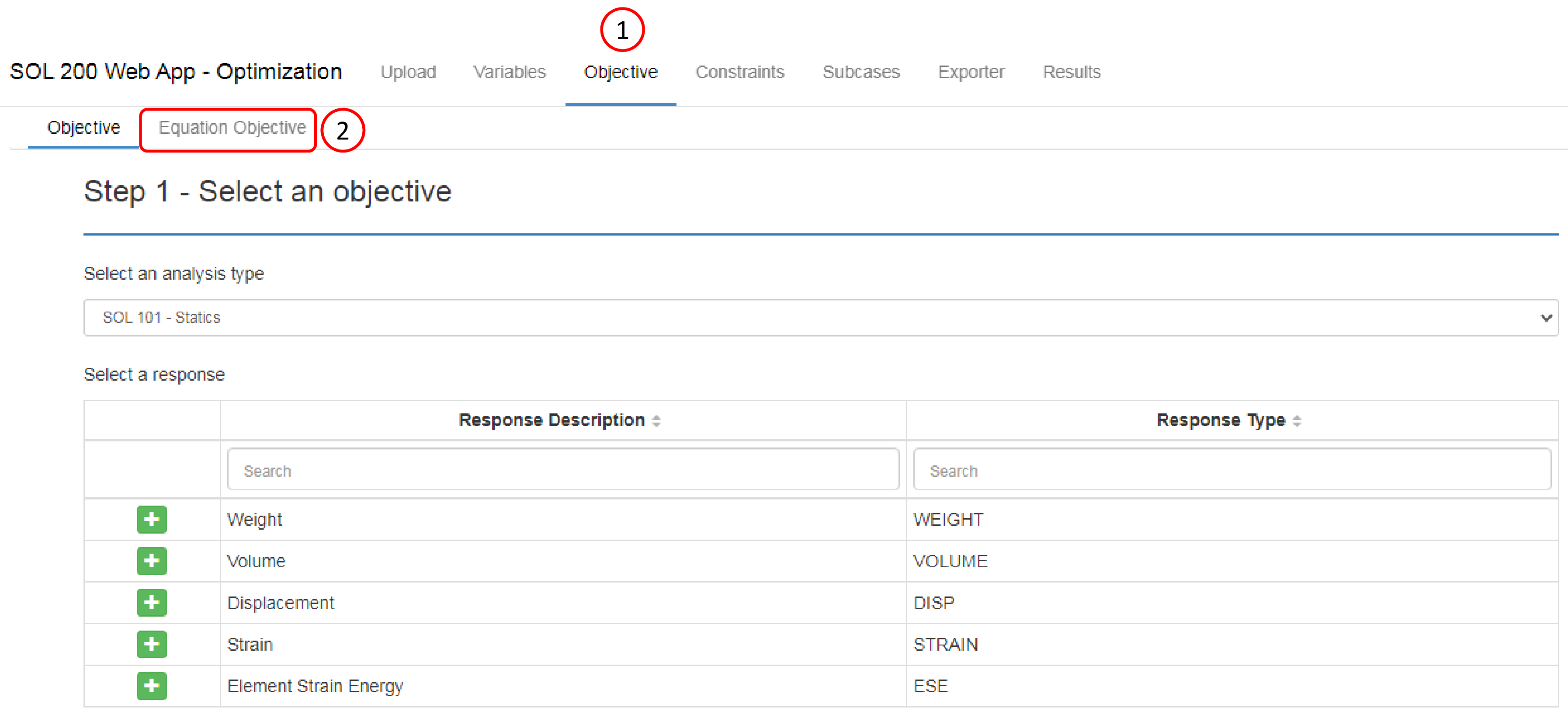
+ Options

	Label	Status	Property	Property Description	Entry	Entry ID	Initial Value	Lower Bound	Upper Bound	Allowed Discrete Values
	Search	Search	Search	Search	Search	Search	Search	Search	Search	Search
✖	x1	✔	A	Area of the rod	PROD	201	1.0	.01	100.	Examples: -2.0, 1.0, THRU, 10.0,
✖	x2	✔	A	Area of the rod	PROD	202	1.0	.01	100.	Examples: -2.0, 1.0, THRU, 10.0,
✖	x3	✔	A	Area of the rod	PROD	203	1.0	[illegible] (4)	[illegible] (5)	Examples: -2.0, 1.0, THRU, 10.0,
✖	x4	✔	T	Thickness	PSHELL	204	0.2	.0002	2.	Examples: -2.0, 1.0, THRU, 10.0,
✖	x5	✔	T	Thickness	PSHELL	205	0.2	.0002	2.	Examples: -2.0, 1.0, THRU, 10.0,
✖	x6	✔	T	Thickness	PSHELL	206	0.2	.0002	2.	Examples: -2.0, 1.0, THRU, 10.0,

(3) 5 | 10 | 20 | 30 | 40 | 50

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.

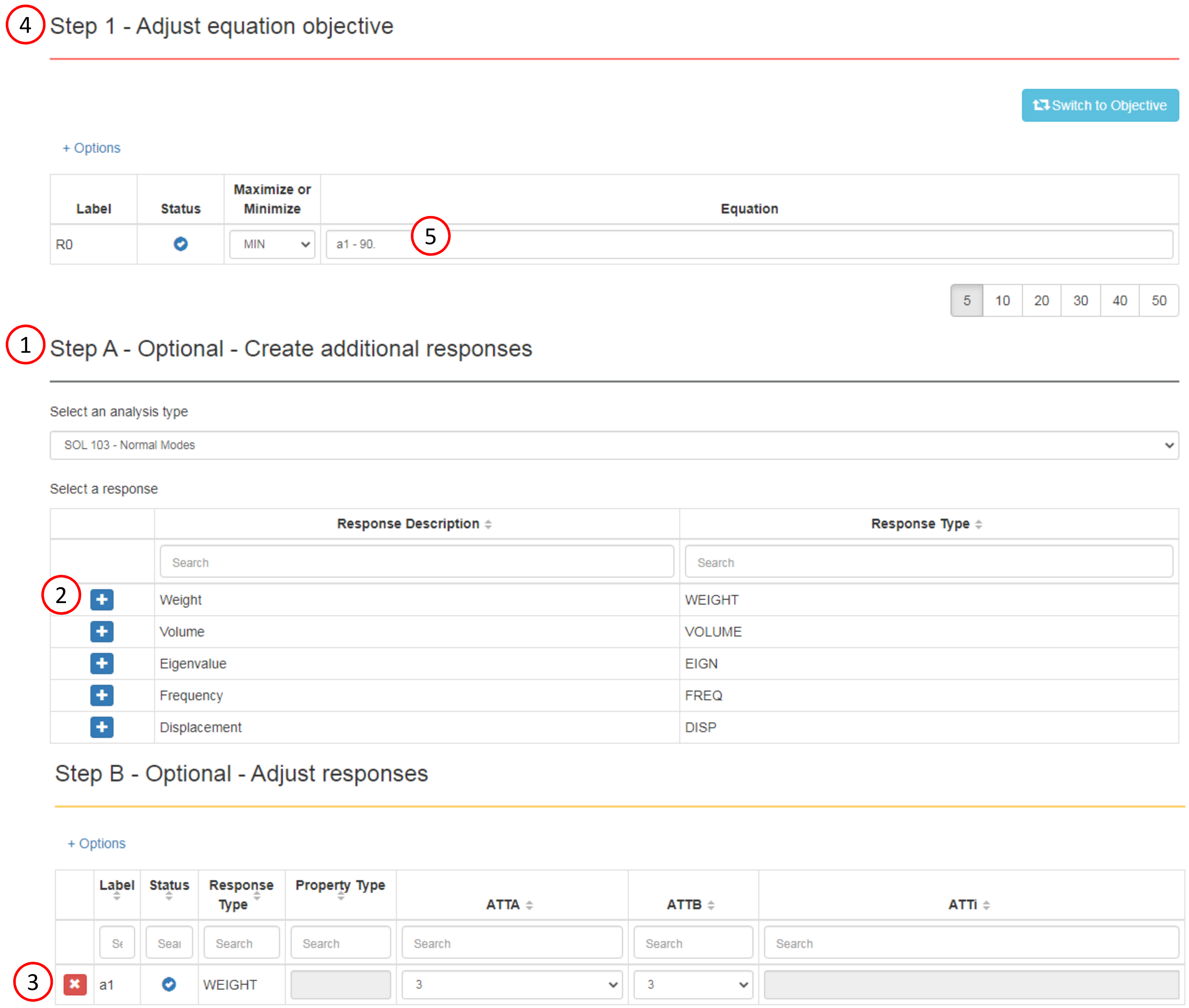
Create Design Objective

1. Scroll to section: Step A - Optional - Create additional responses
2. Click the plus (+) icon for Weight
3. A weight response a1 has been created
4. Scroll to section: Step 1 - Adjust equation objective
5. Type in this equation:

a1 - 90.0

Caution: Do not copy and paste this equation into the web app, sometimes PowerPoint will change the negative symbol from '-' to '–' and will be carried over if you copy and paste. Manually type in the equation instead.

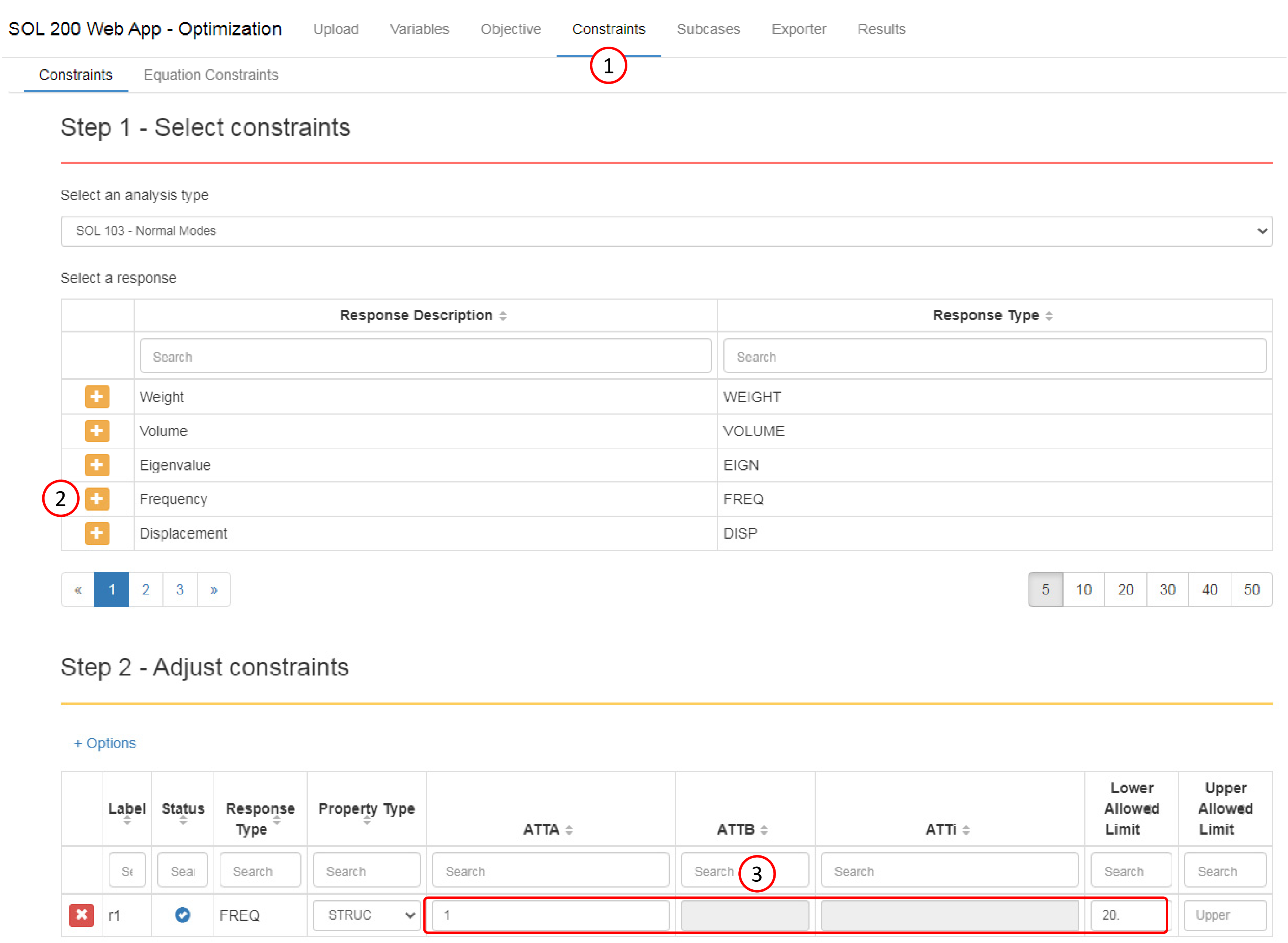
- Suppose an analysis model is 10000 units of mass. If the design variables only impact .001 units of mass, then the sensitivities computed will be too small and the optimizer will be unable to minimize the weight. To over come this, the objective is set to the weight of only the design regions (Total weight minus the weight of the non-design region OR r0 = a1 - 9999.999). With this new objective, the sensitivities are better conditioned, and the optimizer can minimize the weight.
- Alternatively, the following option augments the objective so the objective reports the change/difference in the objective instead of the original objective. For example, Before: 10000 changes to 10002 After: 0 changes to 2.
    - DOPTPRM OBJMOD 1



Create Design Constraints

1. Click Constraints
2. Click the plus (+) icon for Frequency
3. Configure the following for r1
   - ATTA: 1 (mode 1)
   - Lower Allowed Limit: 20.0

- The constraint r1 is read as follows: The natural frequency of mode 1 is to be greater than 20Hz.

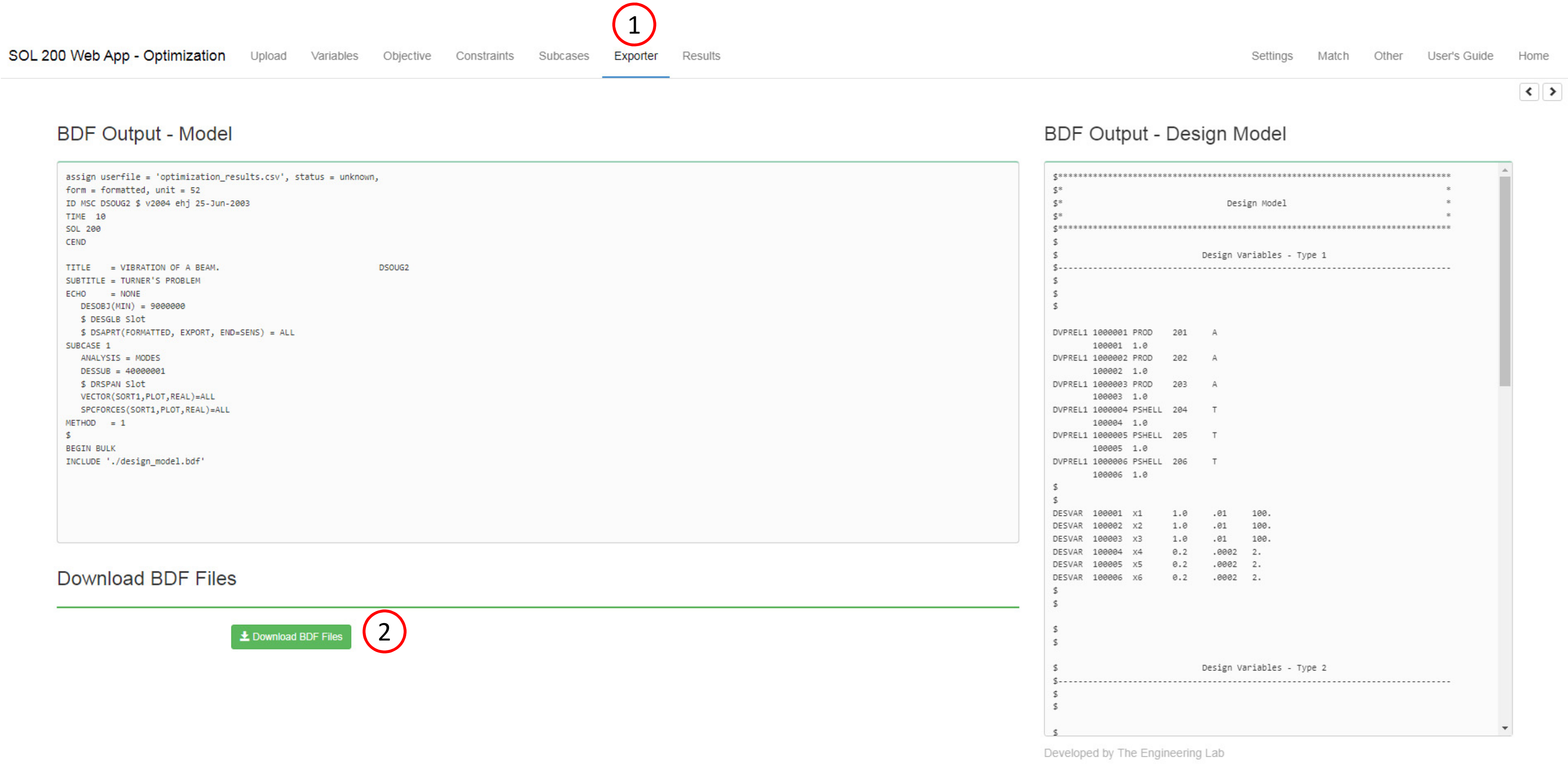


HEXAGON Technology Partner

Export New BDF Files

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

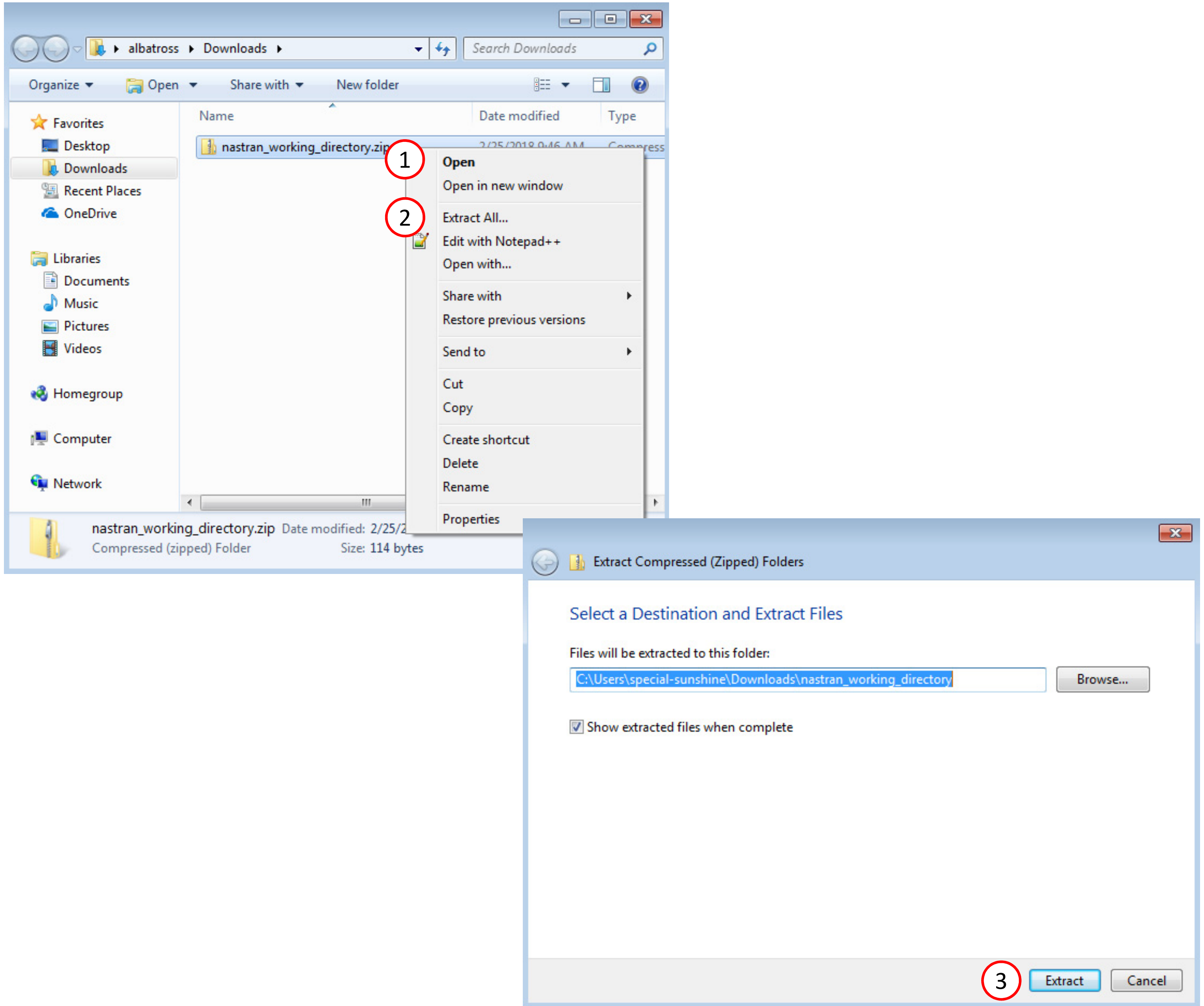
- When the download button is clicked a new file named “nastran_working_directory” is downloaded. If the file already exists in your local folder, the folder name is appended with a number, e.g. “nastran_working_directory (1).zip”



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

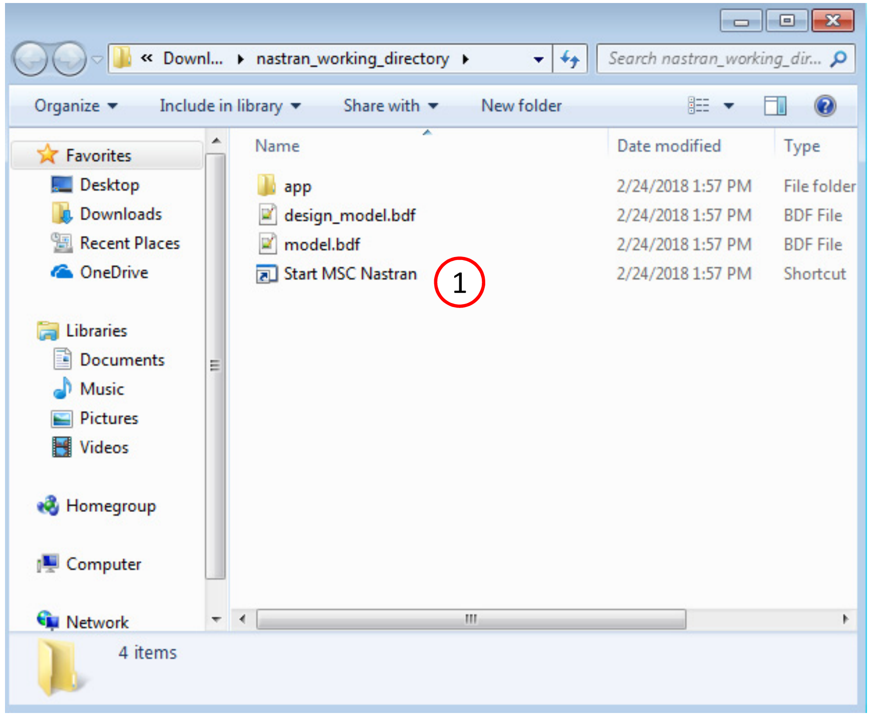
- After a successful optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the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

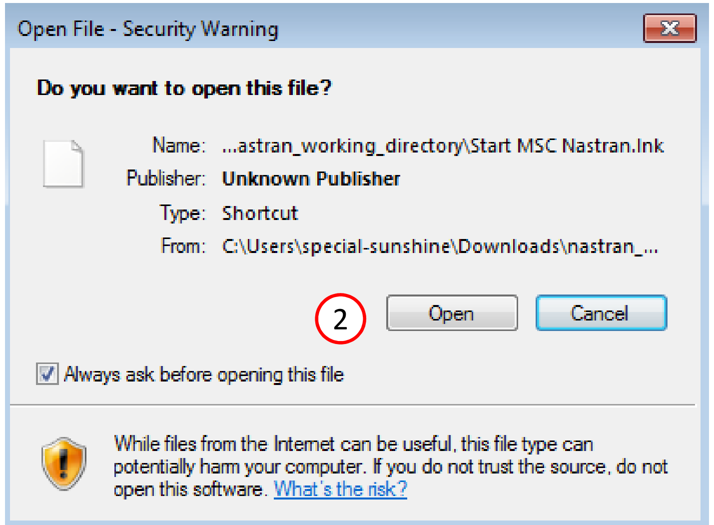
Using Linux?

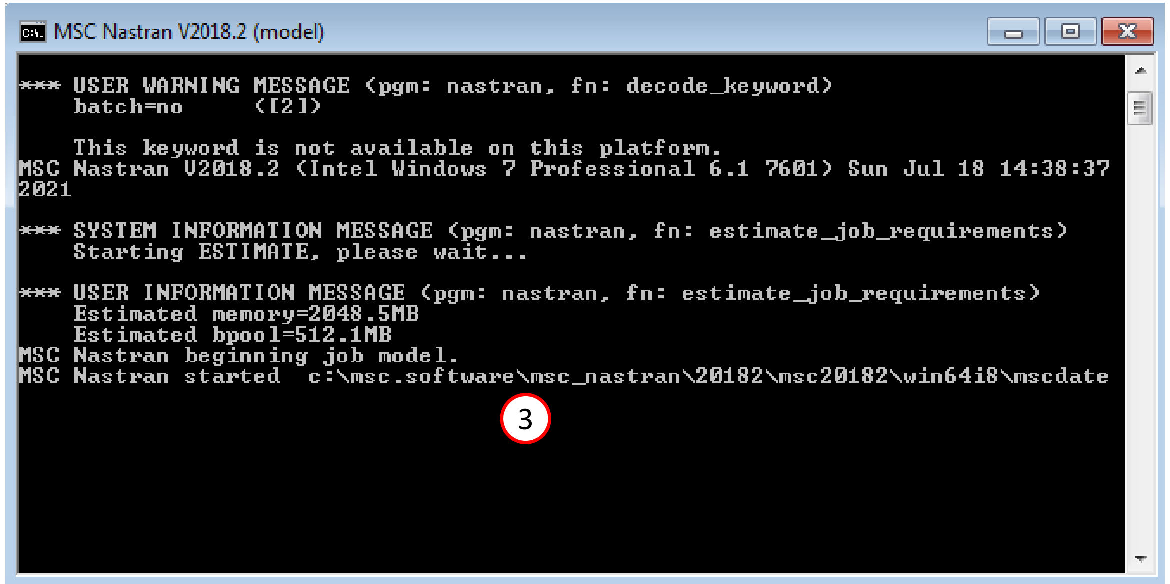
Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
   cd ./nastran_working_directory
3) Use this command to start the process
   ./Start_MSC_Nastran.sh

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, normalized constraints (not shown) and design variables can be reviewed.

- After an optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- The total weight of the structure is ~110 units of mass, but the Objective plot is reporting an initial mass of ~20. Recall earlier that the equation objective was set as follows: R0 = a1 - 90, where a1 = ~110. After evaluation, the initial objective is R0 = ~20 .

SOL 200 Web App - Local Optimization Results

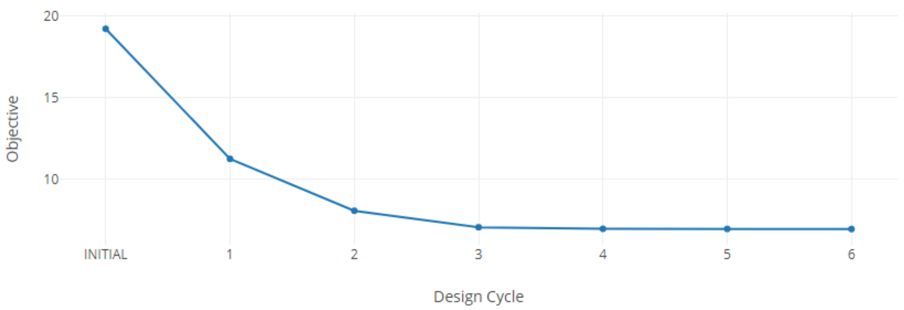
Home

Final Message in .f06

1

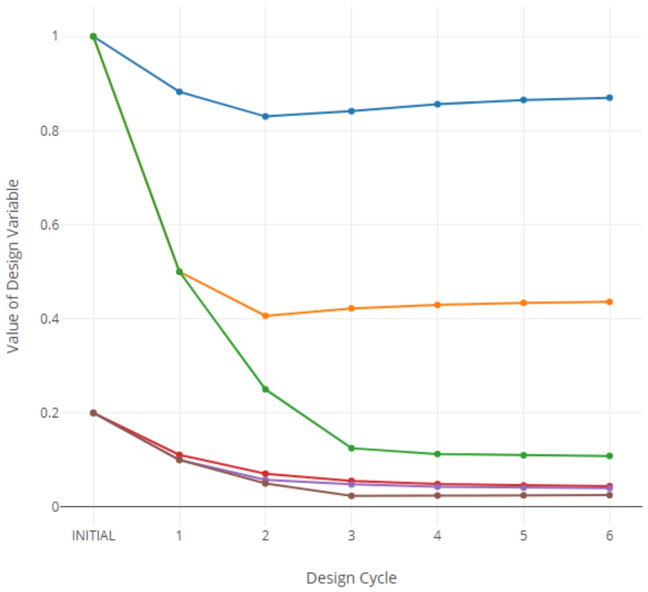
RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER = 6.

Objective



2

Design Variables



Display None | Display All

Display	Color	Label	Label Comments
☑		x1	A, Area of the rod, of PROD 201 (Spar_Cap_A)
☑		x2	A, Area of the rod, of PROD 202 (Spar_Cap_B)
☑		x3	A, Area of the rod, of PROD 203 (Spar_Cap_C)
☑		x4	T, Thickness, of PSHELL 204 (Spar_Web_A)
☑		x5	T, Thickness, of PSHELL 205 (Spar_Web_B)
☑		x6	T, Thickness, of PSHELL 206 (Spar_Web_C)

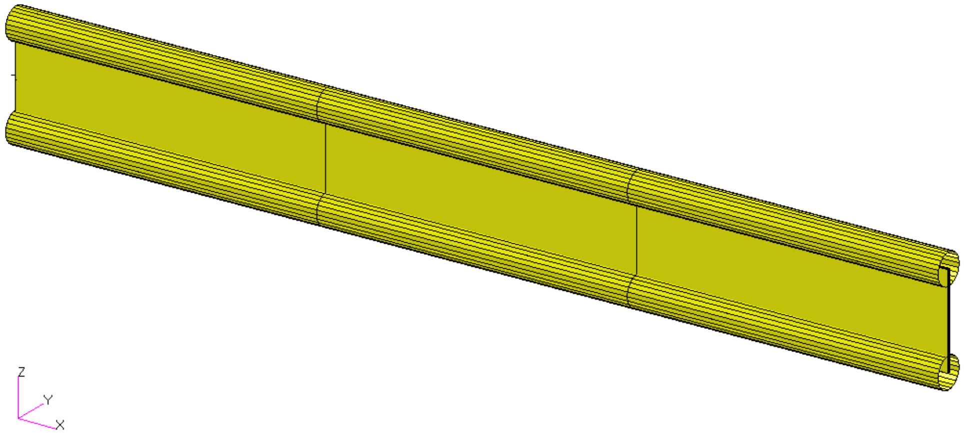
Results

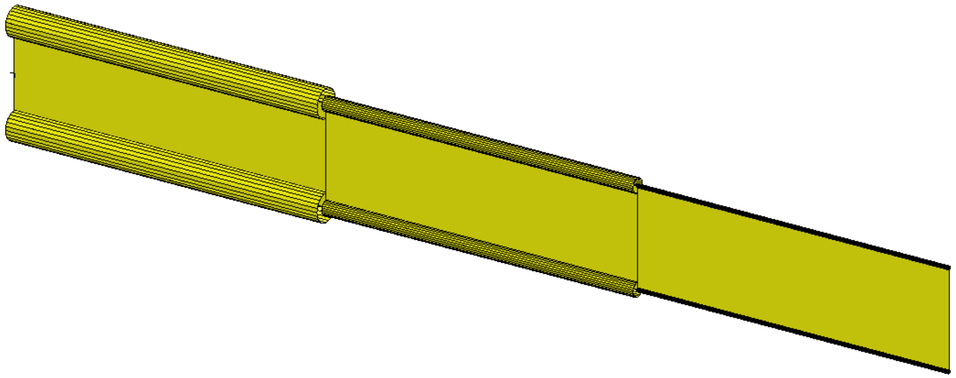
Before Optimization

- Weight: 19.2 lbs.
- 1^{st} Natural Frequency: 26 Hz

After Optimization

- Weight: 6.97 lbs.
- 1^{st} Natural Frequency: 20 Hz



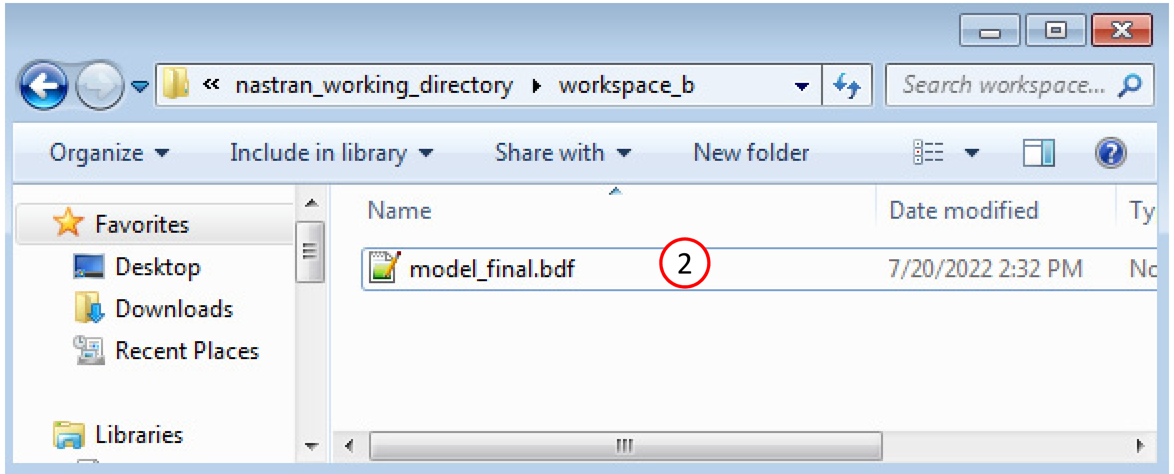


MSC Nastran Design Sensitivity and Optimization User's Guide
Chapter 8 - Example Problems - Vibration of a Cantilevered Beam (Turner's Problem)

Update the Original Model

1. The original input files, e.g. DAT, BDF, etc., contains the original values for the designed properties. These original values must be updated to use the new and optimized values.
2. A new BDF file has been created in nastran_working_directory/workspace_b/model_final.bdf.
3. The file model_final.bdf is a copy of the original input files but the original values for the designed properties have been updated to use the optimized values.

- If you were using multiple INCLUDE files, model_final.bdf is a combination of all INCLUDE files. The next few slides discuss an alternative method of using the PCH to BDF web app to update the values for the designed properties while preserving separate INCLUDE files.



Original Input Files

```
$ Elements and Element Properties for region : Spar_Cap_A
PROD     201     1       1.0     0.0
$ Elements and Element Properties for region : Spar_Cap_B
PROD     202     1       1.0     0.0
$ Elements and Element Properties for region : Spar_Cap_C
PROD     203     1       1.0     0.0
$
CQUAD4   4       204     1       2       6       5
CQUAD4   5       205     2       3       7       6
CQUAD4   6       206     3       4       8       7
$ Elements and Element Properties for region : Spar_Web_A
PSHELL   204     1       0.2
$ Elements and Element Properties for region : Spar_Web_B
PSHELL   205     1       0.2
$ Elements and Element Properties for region : Spar_Web_C
PSHELL   206     1       0.2
$
CONM2    10      2               15.0
CONM2    11      3               15.0
```

1

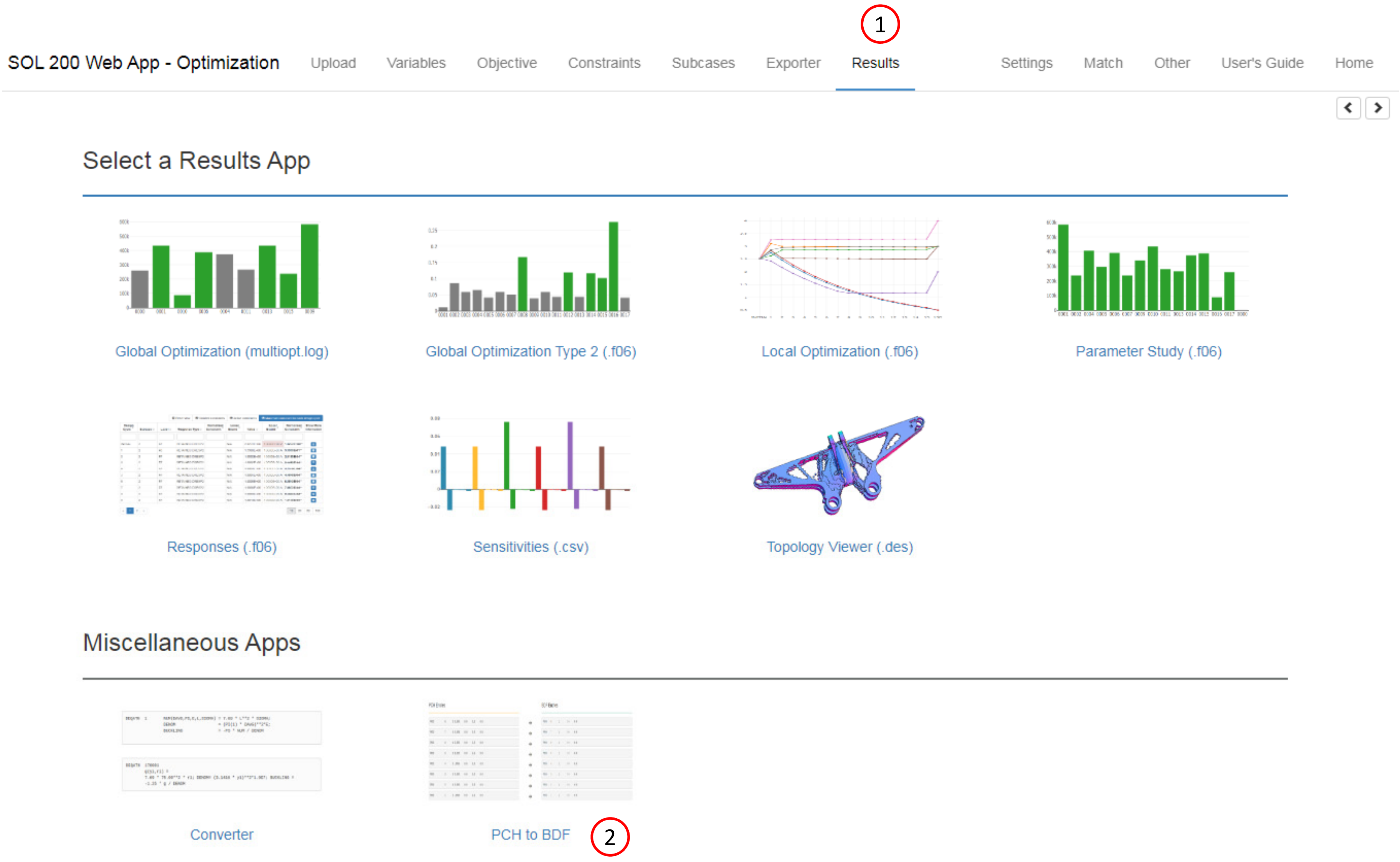
Updated BDF File (model_final.bdf)

```
$ Elements and Element Properties for region : Spar_Cap_A
PROD         201       1 .869879   0.0     0.0     0.0
$ Elements and Element Properties for region : Spar_Cap_B
PROD         202       1 .435946   0.0     0.0     0.0
$ Elements and Element Properties for region : Spar_Cap_C
PROD         203       1 .10855    0.0     0.0     0.0
$
CQUAD4   4       204       1       2       6       5
CQUAD4   5       205       2       3       7       6
CQUAD4   6       206       3       4       8       7
$ Elements and Element Properties for region : Spar_Web_A
PSHELL       204       1 .044307       0     1.0           0 .833333   0.0
                               0
$ Elements and Element Properties for region : Spar_Web_B
PSHELL       205       1 .040087       0     1.0           0 .833333   0.0
                               0
$ Elements and Element Properties for region : Spar_Web_C
PSHELL       206       1 .02526        0     1.0           0 .833333   0.0
                               0
```

3

Update the Original Model

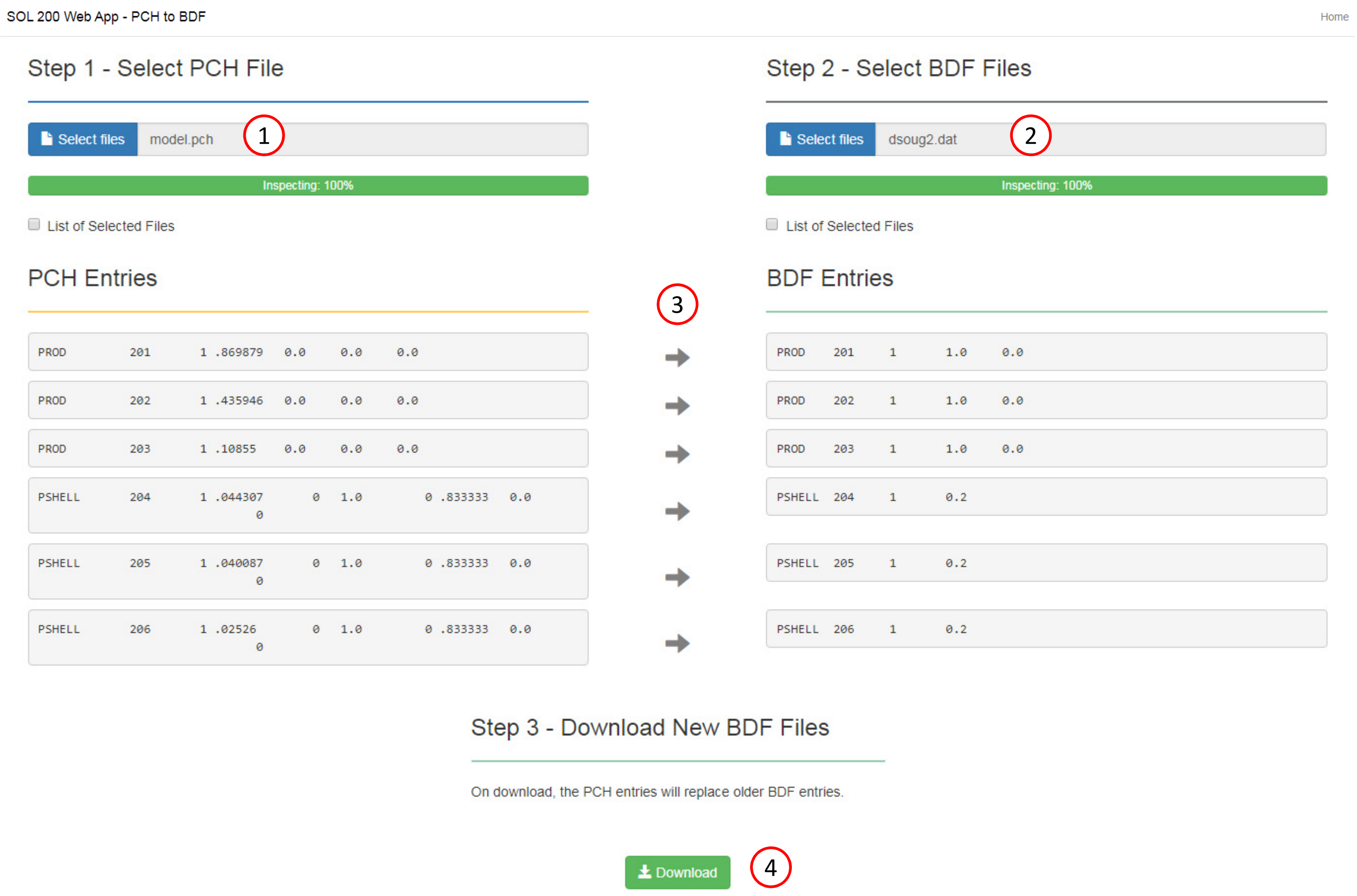
1. Click Results
2. Click PCH to BDF



Update the Original Model

The original .bdf/.dat file has old information about the properties. The properties will be updated.

1. Select the model.pch file
2. Select the original file: dsoug2.dat
3. A summary of updates that will be performed are shown
4. Click Download and a new updated BDF file is downloaded



Update the Original Model

1. Note the entries have been updated with the optimized properties

dsoug2.dat

```
GRID     3               40.0    0.0     -3.0            2456
GRID     4               60.0    0.0     -3.0            2456
GRID     5               0.0     0.0     3.0             123456
GRID     6               20.0    0.0     3.0             2456
GRID     7               40.0    0.0     3.0             2456
GRID     8               60.0    0.0     3.0             2456
$
CROD     1       201     5       6
CROD     2       202     6       7
CROD     3       203     7       8
CROD     7       201     1       2
CROD     8       202     2       3
CROD     9       203     3       4
$ Elements and Element Properties for region : Spar_Cap_A
PROD     201     1       1.0     0.0
$ Elements and Element Properties for region : Spar_Cap_B
PROD     202     1       1.0     0.0
$ Elements and Element Properties for region : Spar_Cap_C
PROD     203     1       1.0     0.0
$
CQUAD4   4       204     1       2       6       5
CQUAD4   5       205     2       3       7       6
CQUAD4   6       206     3       4       8       7
$ Elements and Element Properties for region : Spar_Web_A
PSHELL   204     1       0.2
$ Elements and Element Properties for region : Spar_Web_B
PSHELL   205     1       0.2
$ Elements and Element Properties for region : Spar_Web_C
PSHELL   206     1       0.2
$
CONM2    10      2               15.0
CONM2    11      3               15.0
CONM2    12      4               15.0
CONM2    14      6               15.0
CONM2    15      7               15.0
CONM2    16      8               15.0
$
$ Material Record : Aluminum
$ Description of Material : Date: 17-Apr-18          Time: 17:36:49
MAT1     1       1.03E7          0.3     0.1
PARAM    WTMASS  0.002588
PARAM    GRDPNT  1
ENDDATA
```

1

Original BDF/DAT File

dsoug2.dat

```
GRID     3               40.0    0.0     -3.0            2456
GRID     4               60.0    0.0     -3.0            2456
GRID     5               0.0     0.0     3.0             123456
GRID     6               20.0    0.0     3.0             2456
GRID     7               40.0    0.0     3.0             2456
GRID     8               60.0    0.0     3.0             2456
$
CROD     1       201     5       6
CROD     2       202     6       7
CROD     3       203     7       8
CROD     7       201     1       2
CROD     8       202     2       3
CROD     9       203     3       4
$ Elements and Element Properties for region : Spar_Cap_A
PROD          201       1 .869879   0.0     0.0     0.0
$ Elements and Element Properties for region : Spar_Cap_B
PROD          202       1 .435946   0.0     0.0     0.0
$ Elements and Element Properties for region : Spar_Cap_C
PROD          203       1 .10855    0.0     0.0     0.0
$
CQUAD4   4       204     1       2       6       5
CQUAD4   5       205     2       3       7       6
CQUAD4   6       206     3       4       8       7
$ Elements and Element Properties for region : Spar_Web_A
PSHELL        204       1 .044307       0   1.0          0 .833333   0.0
                                0
$ Elements and Element Properties for region : Spar_Web_B
PSHELL        205       1 .040087       0   1.0          0 .833333   0.0
                                0
$ Elements and Element Properties for region : Spar_Web_C
PSHELL        206       1 .02526        0   1.0          0 .833333   0.0
                                0
$
CONM2    10      2               15.0
CONM2    11      3               15.0
CONM2    12      4               15.0
CONM2    14      6               15.0
CONM2    15      7               15.0
CONM2    16      8               15.0
$
$ Material Record : Aluminum
$ Description of Material : Date: 17-Apr-18          Time: 17:36:49
MAT1     1       1.03E7          0.3     0.1
PARAM    WTMASS  0.002588
```

Downloaded BDF/DAT File

End of Tutorial

Appendix

Appendix Contents

- Frequently Asked Questions
  - There are thousands of properties that have been identified as designable. How can the properties best be sorted so the thicknesses can be set as design variables?

Frequently Asked Questions

Question:

- There are thousands of properties that have been identified as designable. How can the properties best be sorted so the thicknesses can be set as design variables?

Step 2 - Select design properties

+ Options

Create DVXREL1	Property	Property Description	Entry	Entry ID	Current Value
	Search	Search	Search	Search	Search
+	SB	Allowable shear stress of the bondin...	PCOMP	1	13000.
+	T1	Thickness of ply	PCOMP	1	.01
+	THETA1	Orientation angle of ply	PCOMP	1	85.
+	T2	Thickness of ply	PCOMP	1	.01
+	THETA2	Orientation angle of ply	PCOMP	1	-85.
+	T3	Thickness of ply	PCOMP	1	.01
+	THETA3	Orientation angle of ply	PCOMP	1	60.
+	T4	Thickness of ply	PCOMP	1	.01
+	THETA4	Orientation angle of ply	PCOMP	1	-60.
+	T5	Thickness of ply	PCOMP	1	.01
+	THETA5	Orientation angle of ply	PCOMP	1	60.
+	T6	Thickness of ply	PCOMP	1	.01
+	THETA6	Orientation angle of ply	PCOMP	1	-60.
+	T7	Thickness of ply	PCOMP	1	.01
+	THETA7	Orientation angle of ply	PCOMP	1	85.
+	T8	Thickness of ply	PCOMP	1	.01
+	THETA8	Orientation angle of ply	PCOMP	1	-85.
+	E1	Modulus of elasticity, 1-direction	MAT8	1	1.0701+7
+	E2	Modulus of elasticity, 2-direction	MAT8	1	543750.
+	NU12	Poisson's ratio	MAT8	1	.4

« 1 2 »

5 10 20 30 40 50

Frequently Asked Questions

Answer:

- There are search options available for the table
  1. Click on Options
  2. Click ‘Starts with’
  3. Type ‘T’ in the search box
  4. Click on Property twice to sort the table in sequential order
  5. Type into the box the number 8 to display only 8 rows
- Also, there is an option to create multiple design variables in one click
  6. Specify lower and upper bounds
  7. Click ‘Create’ and all the visible properties will be set as design variables