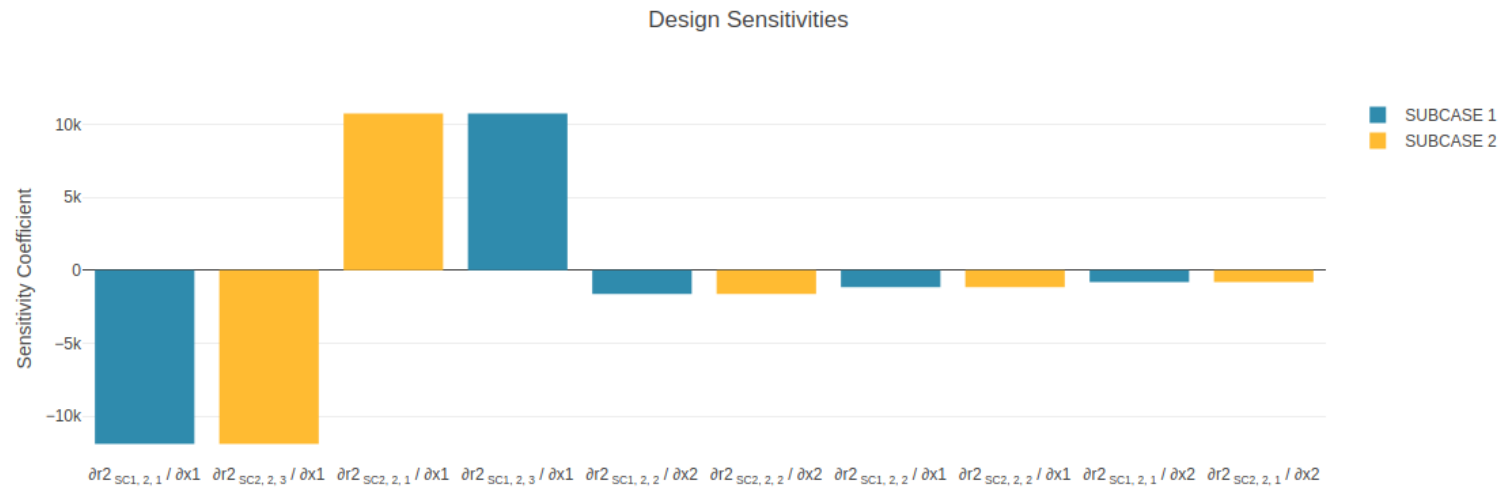


Workshop - Structural Optimization of a 3 Bar Truss, Sensitivity Analysis

AN MSC NASTRAN SOL 200 TUTORIAL

Goal: Perform a Sensitivity Analysis

Sensitivities



Select a response

r0
r1
r2

Select a design variable

x1
x2

Select a SUBCASE

All Subcases
SUBCASE 1
SUBCASE 2

Details of the Structural Model

Three-Bar Truss

A common task in design optimization is to reduce the mass of a structure subjected to several load conditions. Figure 8-1 shows a simple three-bar truss that must be built to withstand two separate loading conditions. Note that these two loads subject the outer truss members to both compressive as well as tensile loads. Due to the loading symmetry, we expect the design to be symmetric as well. As an exercise, we'll show how to enforce this symmetry using design variable linking.

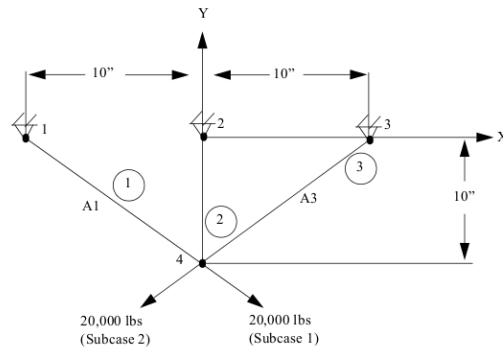
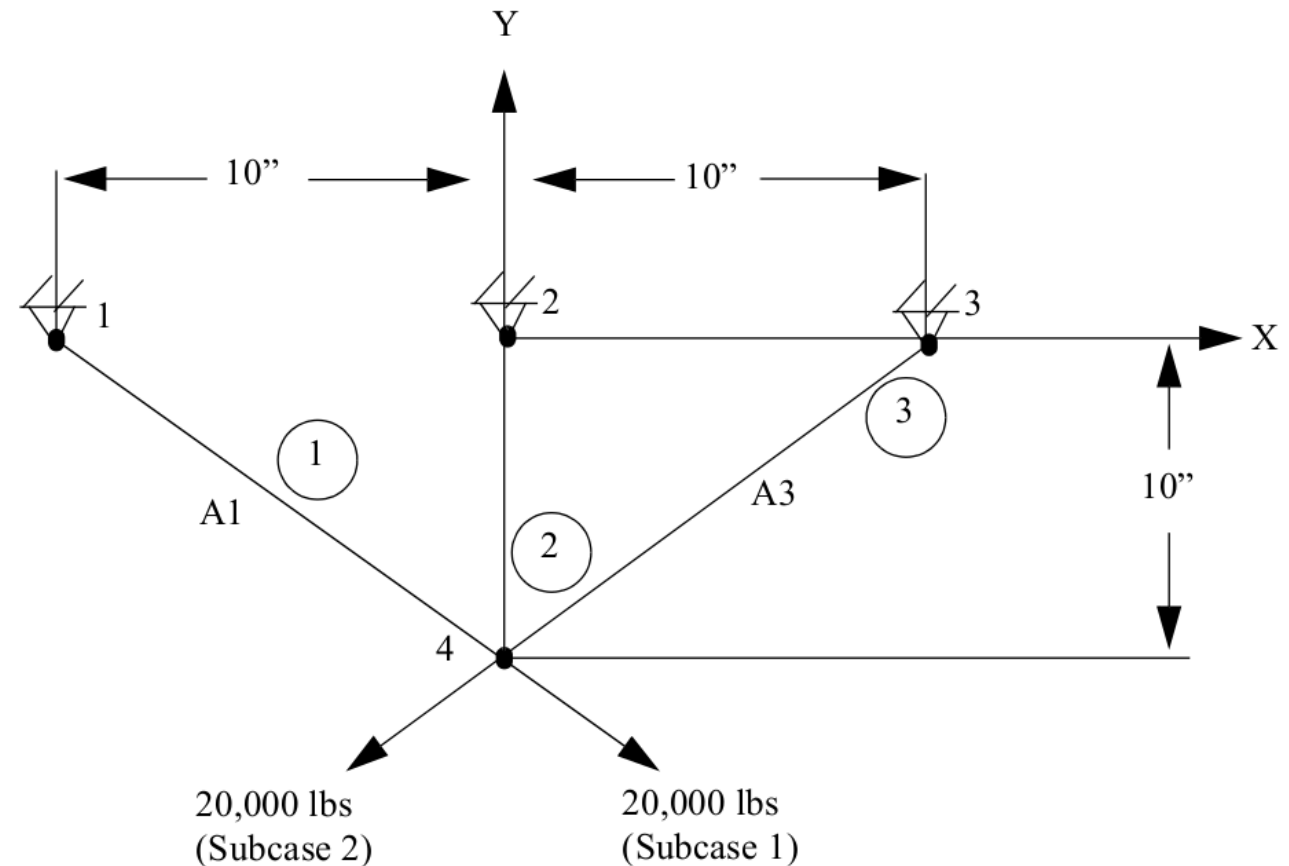


Figure 8-1 Three-Bar Truss

An important, but often overlooked consideration is that the optimization capability in MSC Nastran is multidisciplinary. That is, the final optimal design is the result of a simultaneous consideration of all analysis disciplines across all subcases. In this case, the optimal three-bar truss design will satisfy the load requirements for both static subcases, which is to be expected. (If, for example, a normal modes or buckling subcase were to be added, the resultant design would have to not only satisfy the static strength requirements, but also constraints on eigenvalues. As an exercise you may wish to try adding an eigenvalue constraint.)

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



Optimization Problem Statement

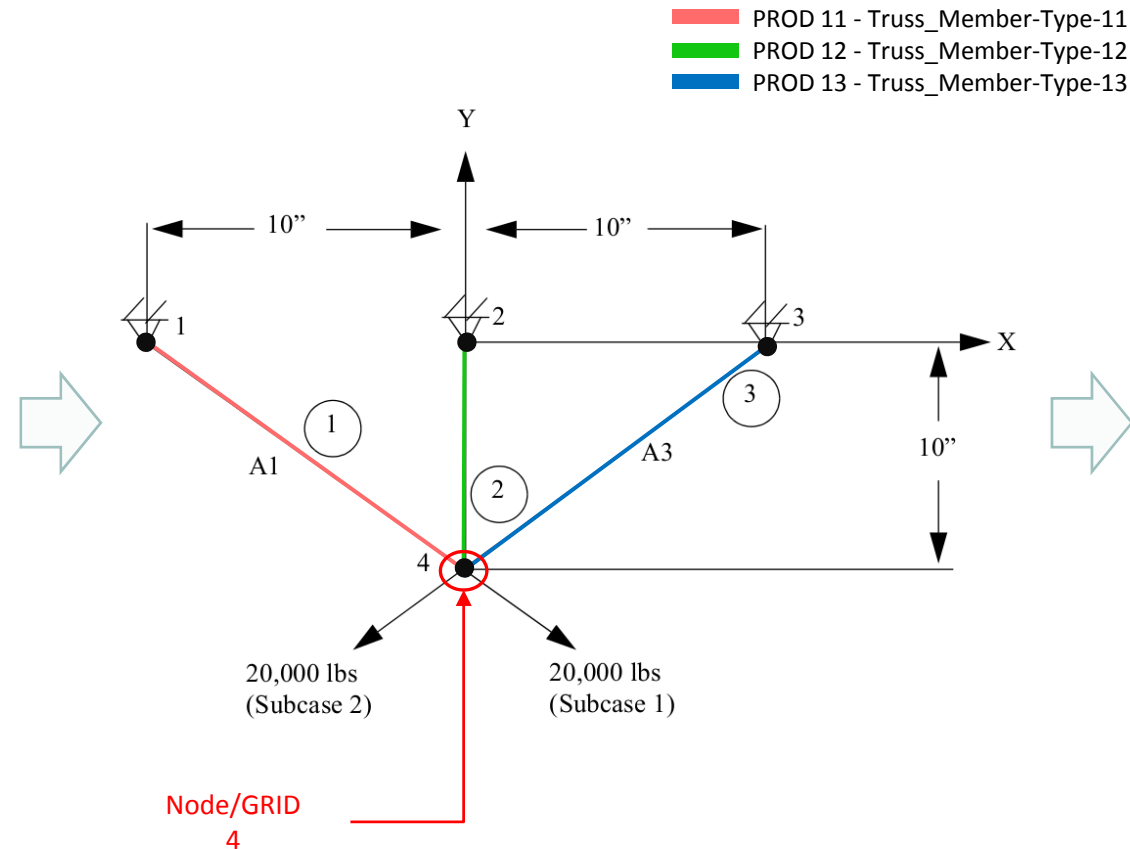
Design Variables

x1: A of PROD 11
x2: A of PROD 12
x3: A of PROD 13

$$.1 < x1, x2, x3 < 100.$$

Variable Link

$$x3 = x1$$



Design Objective

r0: Minimize weight

Design Constraints

r1: Axial stress of elements related to
PROD 11, 12, 13

$$-15000 < r1 < 20000$$

r2: x and y component of displacement for
node 4

$$-.2 < r2 < .2$$

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

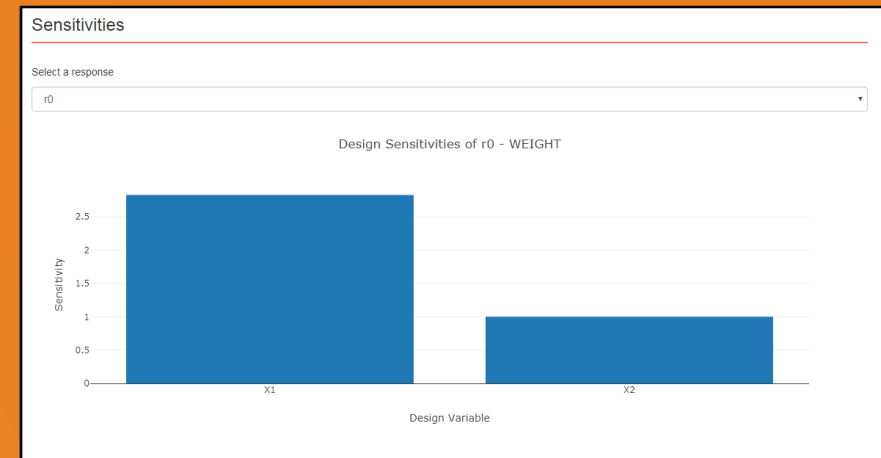
Tutorial

Tutorial Overview

1. Start with a .bdf or .dat file
2. Use the SOL 200 Web App to:
 - Import a previously created SOL 200 BDF files
 - Set the web app to perform a sensitivity analysis
 - Perform sensitivity analysis with Nastran SOL 200
3. Plot the Sensitivities

Special Topics Covered

Automatic Plots - After a sensitivity analysis is complete and result files are created, the sensitivities may be automatically plotted by the Nastran Web App. This tutorial describes how to create these plots.

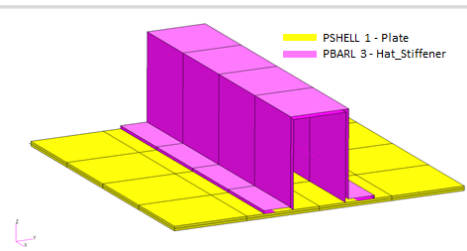


SOL 200 Web App Capabilities

Benefits

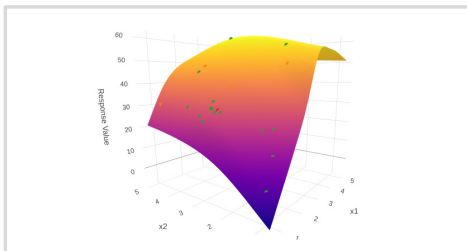
- 200+ error validations (real time)
- Web browser accessible
- Automated creation of entries (real time)
- Automatic post-processing
- 76 tutorials

Capabilities



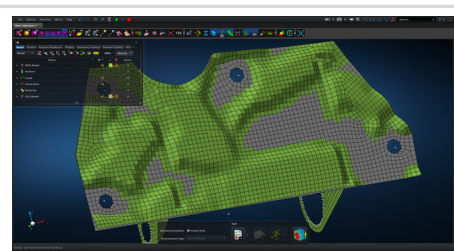
Web Apps for SOL 200

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



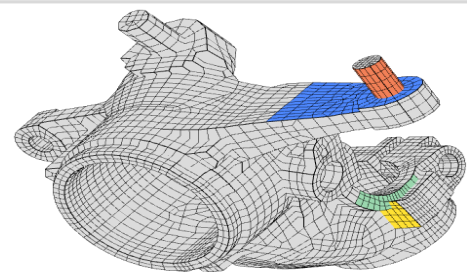
Machine Learning Web App

Bayesian Optimization for nonlinear response optimization (SOL 400)



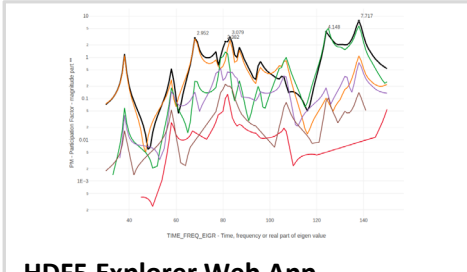
MSC Apex Post Processing Support

View the newly optimized model after an optimization



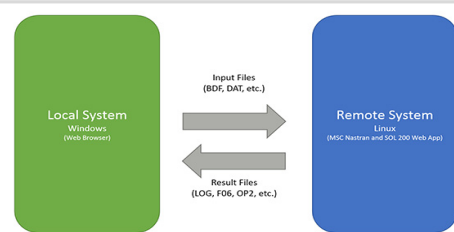
Shape Optimization Web App

Use a web application to configure and perform shape optimization.



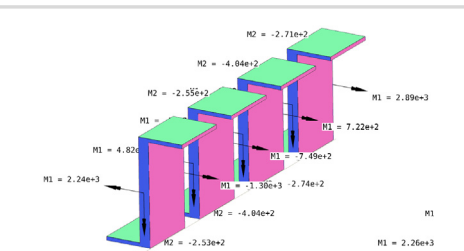
HDF5 Explorer Web App

Create XY plots using data from the H5 file



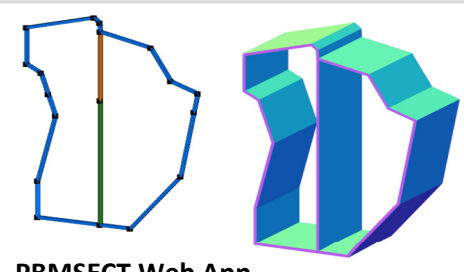
Remote Execution Web App

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



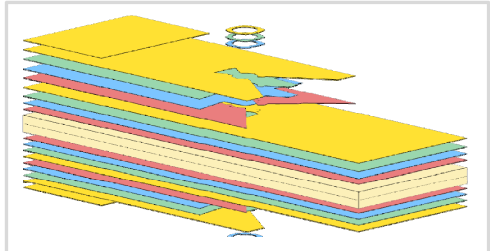
Beams Viewer Web App

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



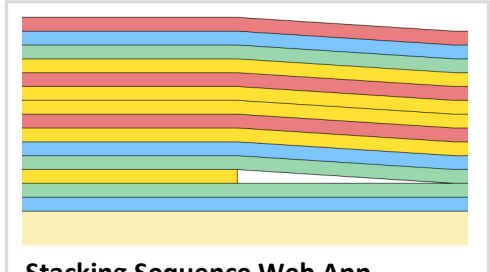
PBMSECT Web App

Generate PBMSECT and PBRSECT entries graphically



Ply Shape Optimization Web App

Spread plies optimally and generate new PCOMPG entries



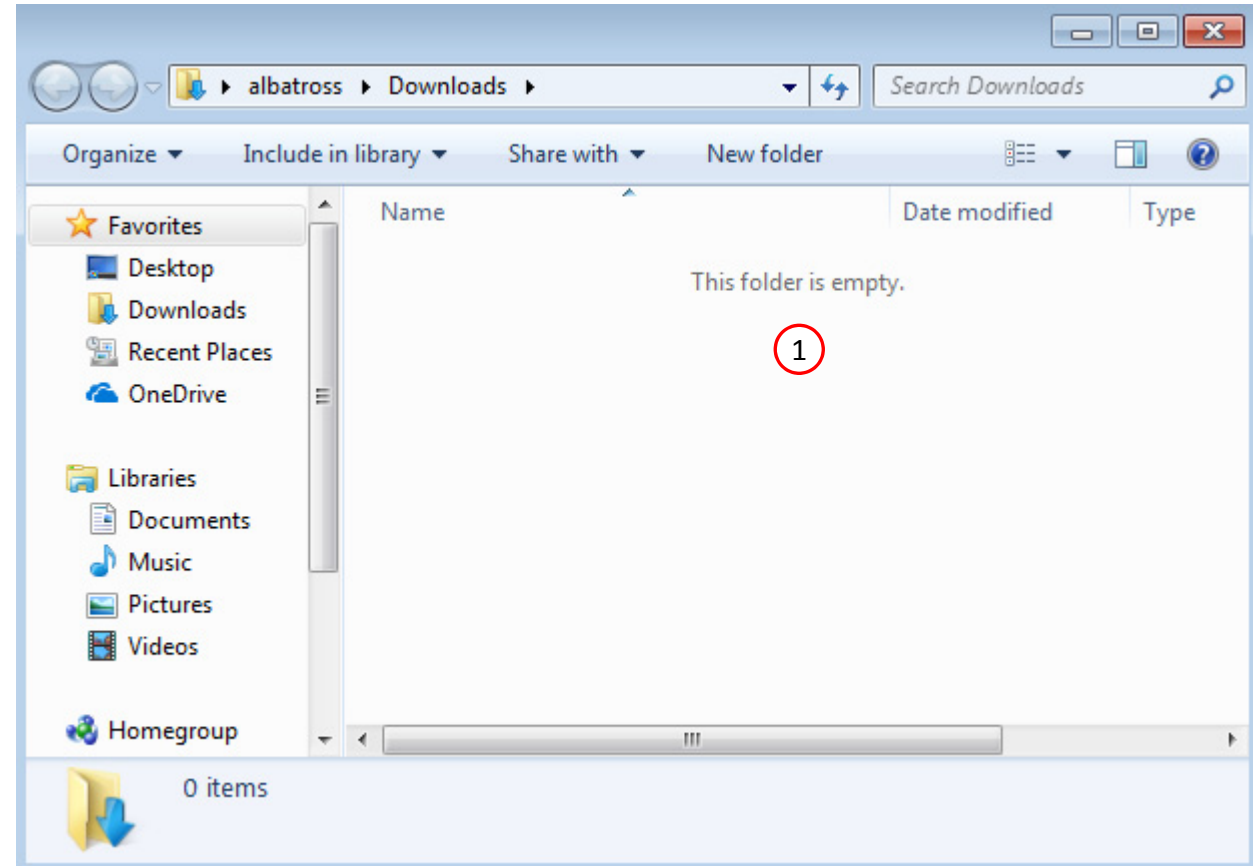
Stacking Sequence Web App

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

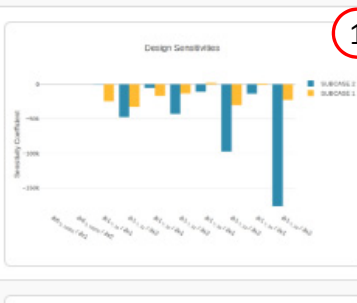
- The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.

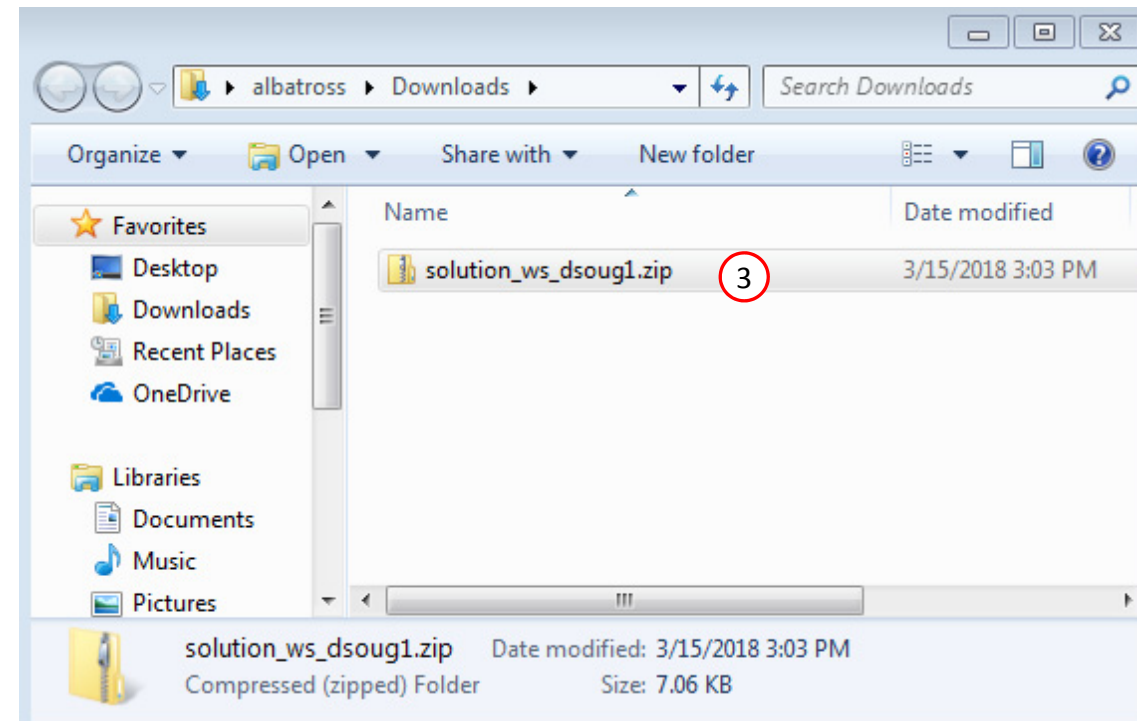


Obtain Starting Files

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.

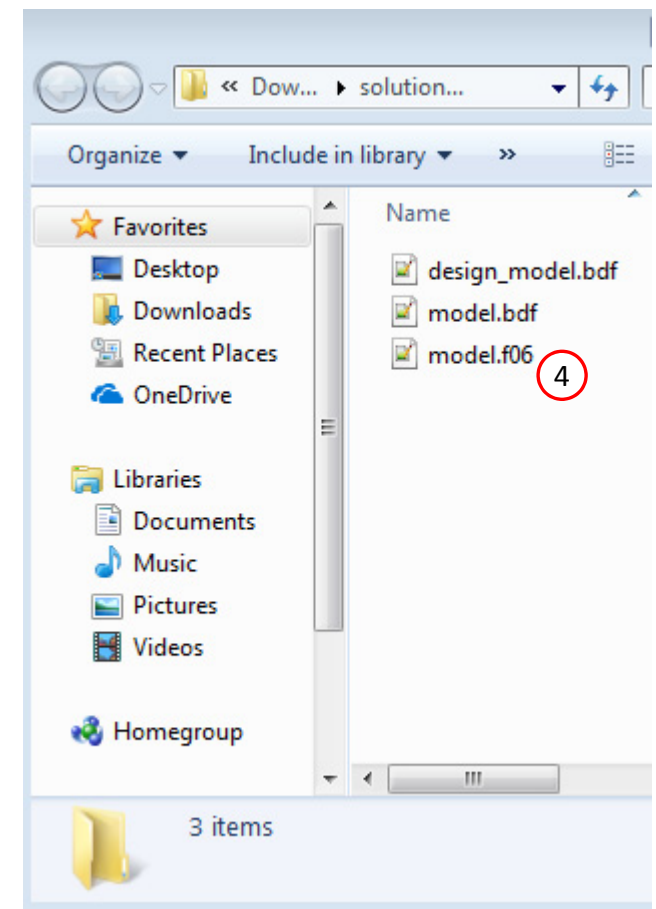
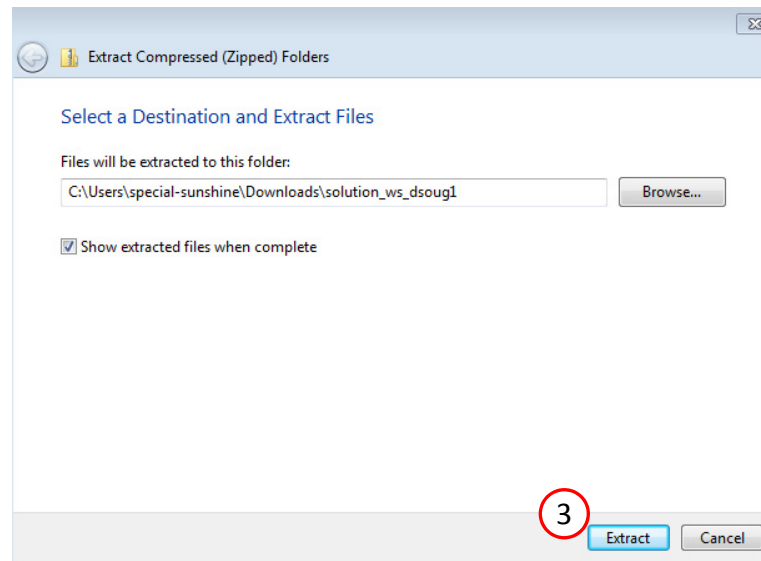
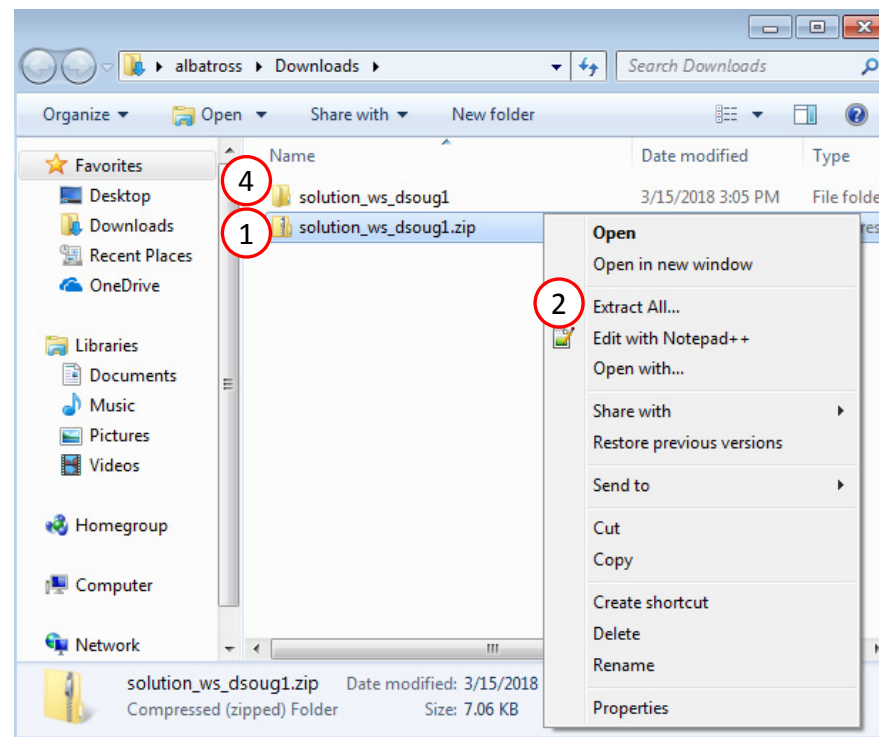
	<p>1 Sensitivity Analysis of a 3 Bar Truss - MSC Nastran Optimization</p> <p>A structural optimization was previously performed on a 3 bar truss. In this tutorial, the process to perform a sensitivity analysis is detailed.</p> <p>Starting BDF Files: Link 2</p> <p>Solution BDF Files: Link</p>
<p>Vibration of a Cantilevered Beam (Turner's Problem) MSC Nastran Link</p>	



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.



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.
- HDF5 Explorer**: Shows a line graph with multiple colored curves.
- 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 model.bdf and design_model.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 two-step process for uploading files. Step 1, '1. Select files', is highlighted with a blue bar and shows '2 files selected'. Below it is a green progress bar labeled 'Inspecting: 100%'. Step 2, '2. Upload files', is highlighted with a green bar. Below it is another green progress bar labeled 'Uploading: 100 %'. At the bottom, there is a checkbox labeled 'List of Selected Files' which is currently unchecked.

1. Select files 2 files selected

Inspecting: 100%

2. Upload files

Uploading: 100 %

☐ List of Selected Files

1. Previously created SOL 200 BDF files have been imported to the web app and may be modified.

- 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.

15

Configure Settings

1. At the top right hand corner, click on Settings
2. Mark the checkbox labeled Perform Sensitivity Analysis

- Sensitivity analysis computes the gradients or partial derivatives of responses with respect to design variables. For example, if the sensitivity of weight with respect to x_1 is -200., then a change of 1.0 in x_1 yields a change of -200 in the weight.

1

Optimization Settings

Parameter ▾	Description ▾	Configure ▾
Search	Search	Search
APRCOD	Approximation method to be used	<input type="checkbox"/> 2 - Mixed Method ▾
CONV1	Relative criterion to detect convergence	<input type="checkbox"/> Enter a positive real number
CONV2	Absolute criterion to detect convergence	<input type="checkbox"/> Enter a positive real number
DELX	Fractional change allowed in each design variable during any optimization cycle	<input type="checkbox"/> Enter a positive real number
DESMAX	Maximum number of design cycles to be performed	<input checked="" type="checkbox"/> 20
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"/> 15 - Print objective, design variab ▾

Optimization Type

- ☐ Perform Local Optimization
- ☒ Perform Sensitivity Analysis 2
- ☐ Perform Global Optimization
- ☐ Perform Global Optimization Type 2
- ☐ Perform Parameter Study

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

UploadVariablesObjectiveConstraintsSubcasesExporterResults

SettingsMatchOtherUser's GuideHome

1

BDF Output - Model

```
assign userfile = 'optimization_results.csv', status = unknown,
form = formatted, unit = SI
$_1_|$_2_|$_3_|$_4_|$_5_|$_6_|$_7_|$_8_|$_9_|$_10_|
ID MSC DSOUG1 $ V2004 ehj 25-Jun-2003
TIME 10 $
SOL 200
CEND

TITLE = SYMMETRIC THREE BAR TRUSS DESIGN OPTIMIZATION - DSOUG1
SUBTITLE = BASELINE - 2 CROSS SECTIONAL AREAS AS DESIGN VARIABLES
$ Result Output
ECHO = NONE
SPC = 100
DISPLACEMENT(SORT1,REAL)=ALL
SPCFORCES(SORT1,REAL)=ALL
STRESS(SORT1,REAL,VONMISES,BILIN)=ALL
$ Subcases
DESOBJ(MIN) = 8000000
DSAPRT(FORMATTED, EXPORT, END=SENS) = ALL
$ DESGLB Slot
SUBCASE 1
ANALYSIS = STATICS
DESSUB = 40000001
$ DRSPAN Slot
LABEL = LOAD CONDITION 1
LOAD = 300
SUBCASE 2
ANALYSIS = STATICS
DESSUB = 40000001
```

BDF Output - Design Model

```
$*****
$*                                     *
$*                               Design Model *
$*                                     *
$*****
$
$----- Design Variables - Type 1 -----
$
$
$
$
DVPREL1 1000001 PROD 11 A
100001 1.0
DVPREL1 1000002 PROD 12 A
100002 1.0
DVPREL1 1000003 PROD 13 A
100003 1.0
$
$
DESVAR 100001 x1 1.0 .01 100.
DESVAR 100002 x2 2.0 .01 100.
DESVAR 100003 x3 1.0 .01 100.
$
$
$
$
DLINK 1 100003 100001 1.0
$
$----- Design Variables - Type 2 -----
$
$
$
$
$
$----- Design Objective -----
$
$
DRESPI 8000000 r0 WEIGHT 3 3
```

Download BDF Files

Download BDF Files

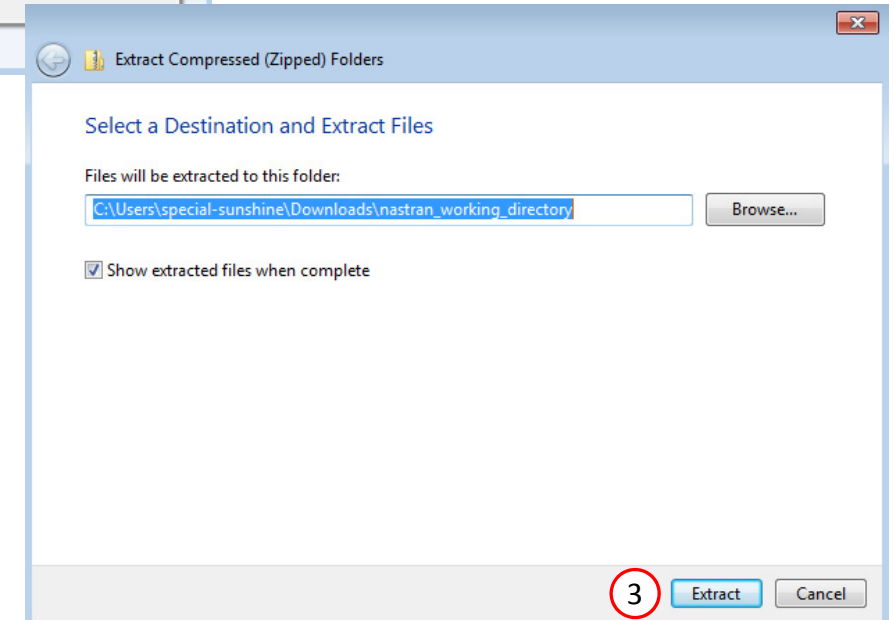
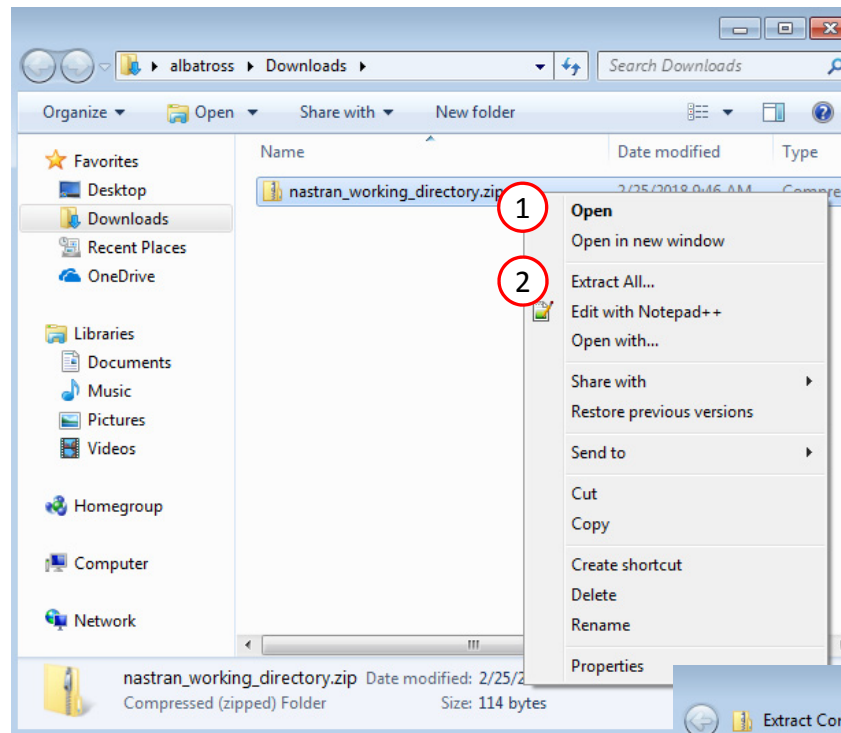
2

Developed by The Engineering Lab

Perform the Optimization with Nastran SOL 200

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

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



Perform the Optimization with Nastran SOL 200

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

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

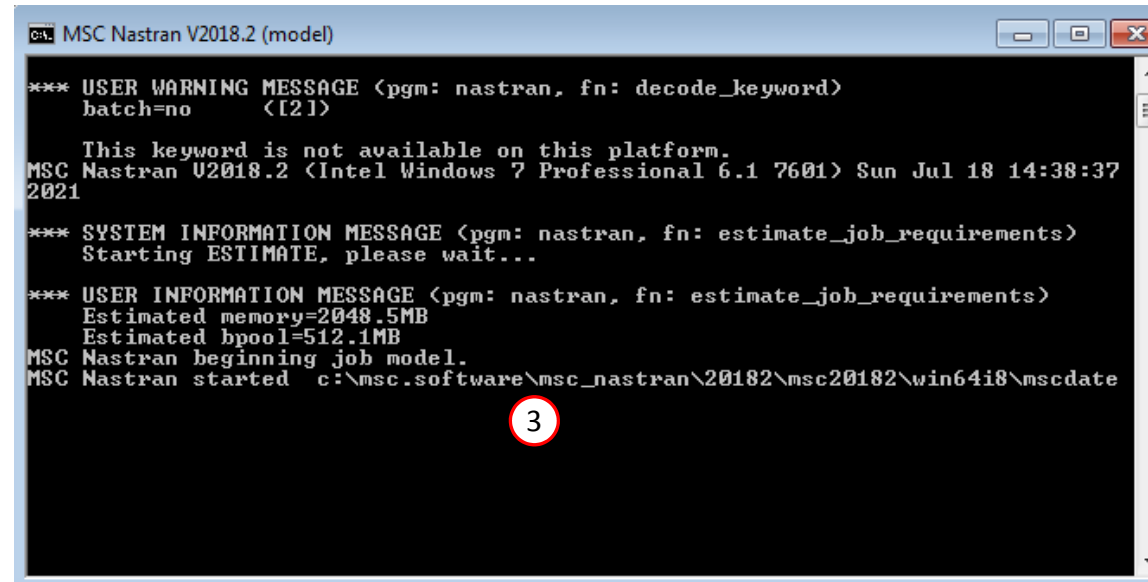
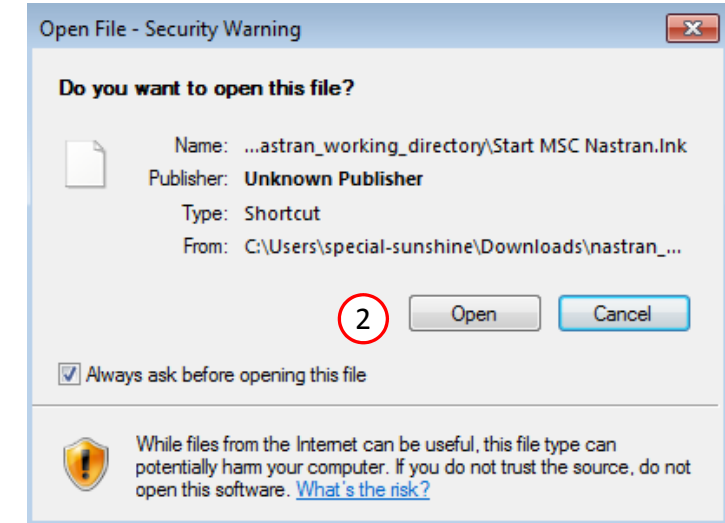
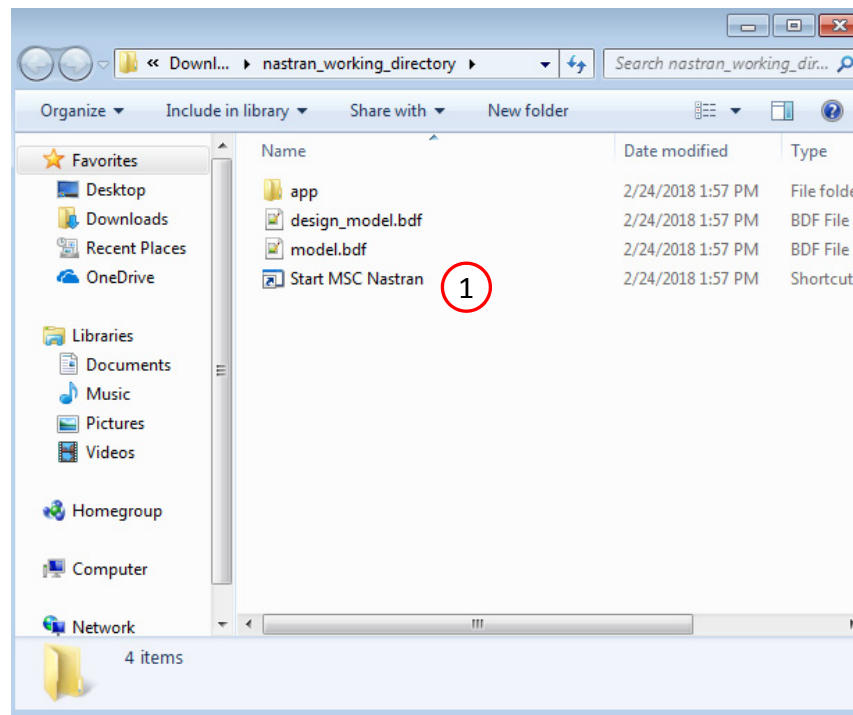
Using Linux?

Follow these instructions:

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

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

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



Status

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

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

SOL 200 Web App - Status

 Python  MSC Nastran

Status

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

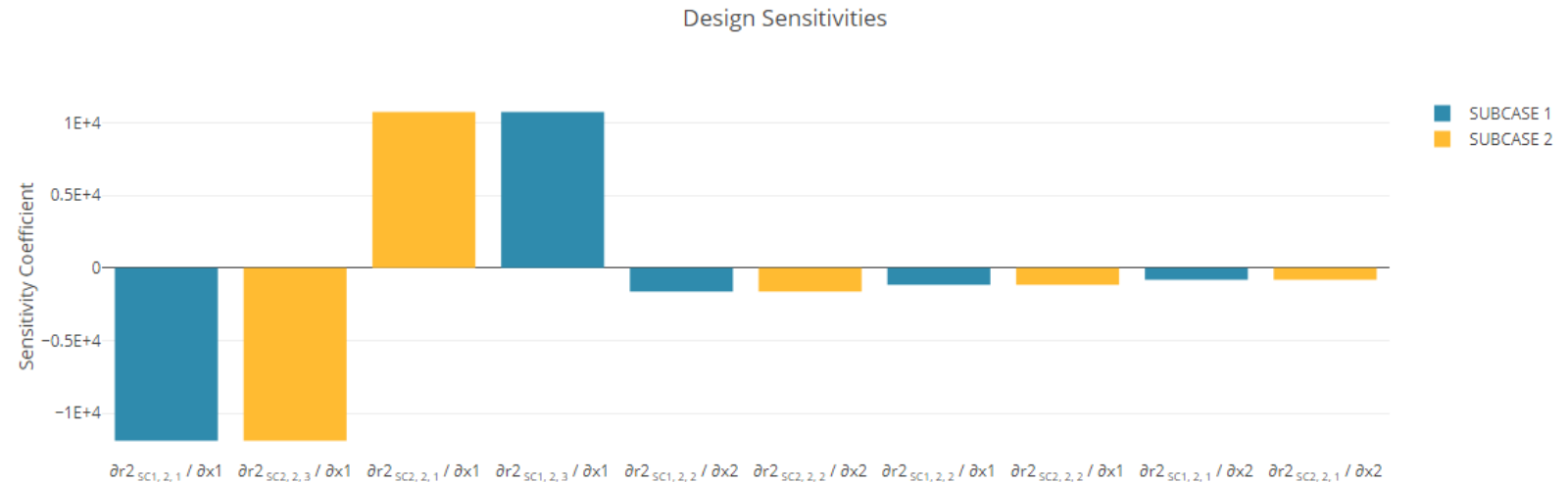
Review Optimization Results

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

1. Select any of the options to dynamically plot different sensitivities

- The sensitivities are labeled in the following form:
 $\partial r_{2, SC1, 2, 1} / \partial x_1$
- This is read as the sensitivity of r2 with respect to x1, for subcase 1, component 2 (axial stress) of element 1.
- This sensitivity is negative, so a unit change in x1 will produce a -11893 change in $r_{2, SC1, 2, 1}$.

Sensitivities



Select a response

r0
r1
r2

Select a design variable

x1
x2

Select a SUBCASE

Global Responses
SUBCASE 1
SUBCASE 2

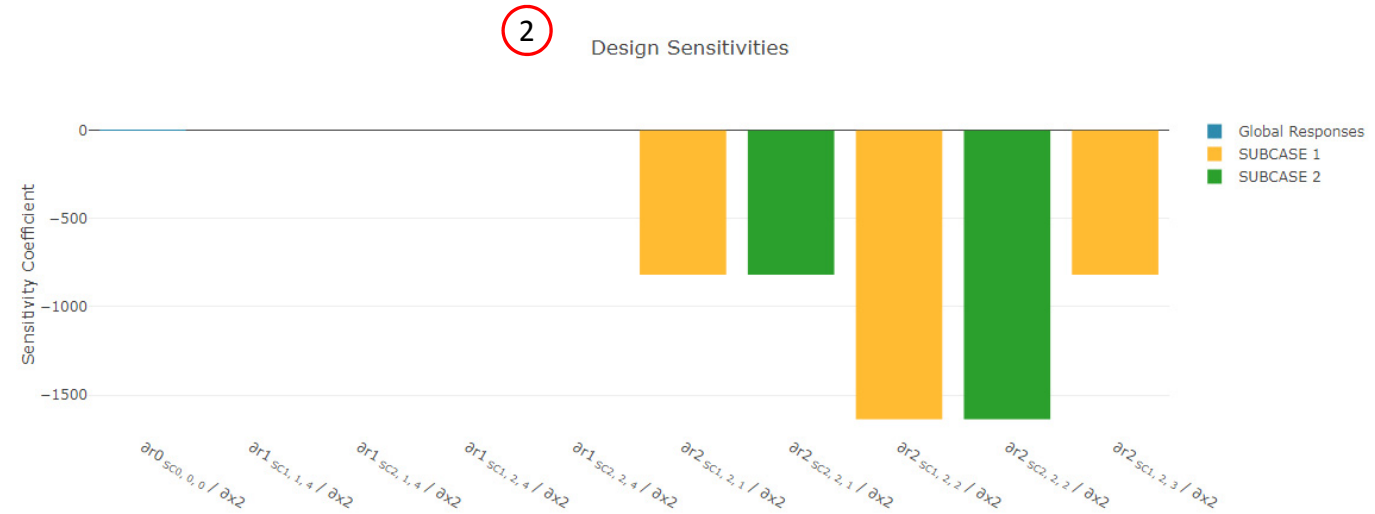
1

Review Optimization Results

1. Click the column headers to sort the table
2. Note the sensitivities are immediately updated automatically

- The data displayed in the table is immediately plotted in the Bar Charts. This example has 22 sensitivity values. The table shows only 10 sensitivities, so the Bar Chart displays only 10 sensitivities.

Sensitivities



Sensitivity Table

Response	Response Type	1 Variable	Component ID	Element/Grid ID	Subcase	Response Value	Frequency / Time	Sensitivity	Sensitivity Coefficient	Absolute Value of Sensitivity Coefficient
r0	WEIGHT	x2	0	0	0	4.8284E+00	0.0000E+00	$\partial r0_{SC0,0,0} / \partial x2$	1	1
r1	DISP	x2	1	4	1	2.2627E-02	0.0000E+00	$\partial r1_{SC1,1,4} / \partial x2$	0	0
r1	DISP	x2	1	4	2	-2.2627E-02	0.0000E+00	$\partial r1_{SC2,1,4} / \partial x2$	0	0
r1	DISP	x2	2	4	1	-4.4328E-03	0.0000E+00	$\partial r1_{SC1,2,4} / \partial x2$	0.0016375	0.0016375
r1	DISP	x2	2	4	2	-4.4328E-03	0.0000E+00	$\partial r1_{SC2,2,4} / \partial x2$	0.0016375	0.0016375
r2	STRESS	x2	2	1	1	1.3530E+04	0.0000E+00	$\partial r2_{SC1,2,1} / \partial x2$	-818.73	818.73
r2	STRESS	x2	2	1	2	-9.0973E+03	0.0000E+00	$\partial r2_{SC2,2,1} / \partial x2$	-818.73	818.73
r2	STRESS	x2	2	2	1	4.4328E+03	0.0000E+00	$\partial r2_{SC1,2,2} / \partial x2$	-1637.5	1637.5
r2	STRESS	x2	2	2	2	4.4328E+03	0.0000E+00	$\partial r2_{SC2,2,2} / \partial x2$	-1637.5	1637.5
r2	STRESS	x2	2	3	1	-9.0973E+03	0.0000E+00	$\partial r2_{SC1,2,3} / \partial x2$	-818.73	818.73

End of Tutorial