Workshop – Optimization Under Uncertainty - 3 Bar Truss, Part 1 of 2

AN UNCERTAINTY QUANTIFICATION AND OPTIMIZATION UNDER UNCERTAINTY TUTORIAL WITH SANDIA DAKOTA AND MSC NASTRAN

Goal: Decide UQ Method

- Optimization under uncertainty (OUU) is significantly more costly than a traditional optimization involving deterministic inputs and outputs. Part of the cost is due to the number of black box function runs that are necessary to perform the uncertainty quantification (UQ) and determine the tail probabilities.
- Sampling alone is the simplest but one of the costliest methods for UQ. The *mean value first-order second-moment* (MVFOSM) method is one of the least expensive UQ methods, but is limited to responses that are linear or nearly linear, response distributions that are normal (Gaussian) and assumes gradients are available. Efficient OUU depends on carefully selecting the least costly and accurate UQ method.
- The goal of this exercise is to detail a procedure to do the following:
  - Determine if the response distributions are normal
  - Decide the UQ method to use in a future OUU
  - Configure an MSC Nastran SOL 200 optimization assuming the inputs and outputs are deterministic
  - Determine an ideal starting point for a future OUU
  - Identify critical constraints to consider in a future OUU
  - Prepare MSC Nastran bulk data files (BDF) for future OUU configuration

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

Tutorial Overview

1. Start with bulk data files
2. Use the SOL 200 Web App to:
   - Confirm the responses have near normal (Gaussian) distributions
   - Configure the bulk data files to output sensitivities/gradients

Special Topics Covered

Uncertainty Quantification (UQ) Method Selection - Sandia Dakota supports multiple UQ methods, each with a different level of computational cost, e.g. polynomial chaos, stochastic collocation, etc. Many of these UQ methods are limited by the curse of dimensionality, so problems with 1-10 variables, or parameters, are practical and larger problems are impractical. For large structural systems, there is a need to consider problems involving dozens or hundreds of variables and constraints. The *mean value first-order second-moment* (MVFOSM) method is one of the least computationally expensive UQ methods and requires only one black box function evaluation to compute the responses and gradients and derive the mean, standard deviation and tail probabilities for each response. The MVFOSM method does not apply to every response and is limited to responses with normal distributions and responses where gradients are available. This tutorial details a process to qualify problems for the MVFOSM method. If the MVFOSM method may be used, it will significantly reduce the computational cost for UQ and OUU.

SOL 200 Web App Capabilities

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

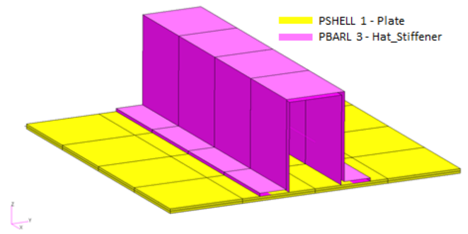
Compatibility

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

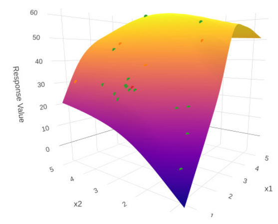
Benefits

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

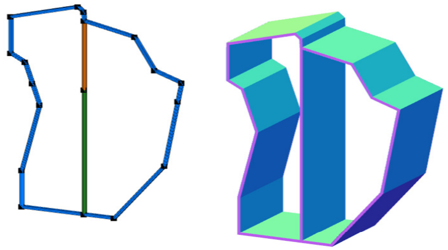
Web Apps



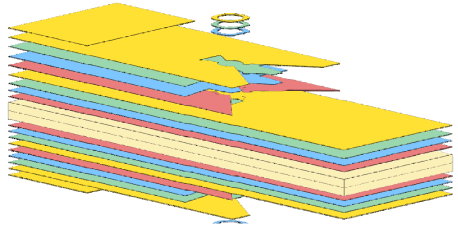
Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography, multi-model optimization.



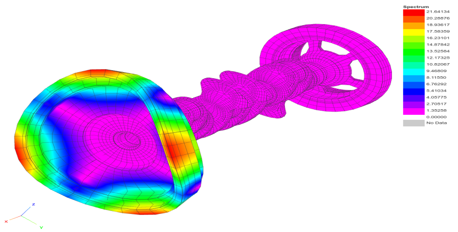
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



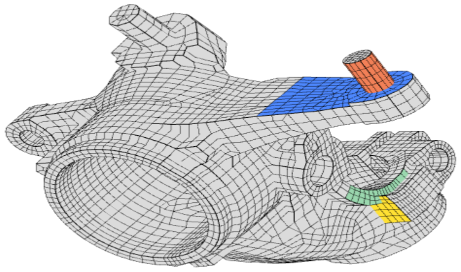
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



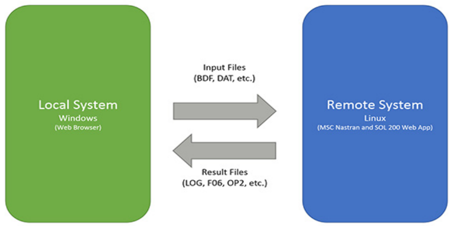
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries



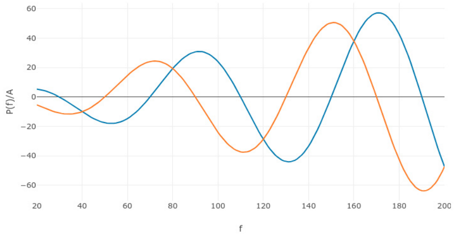
Post-processor Web App
View MSC Nastran results in a web browser on Windows and Linux



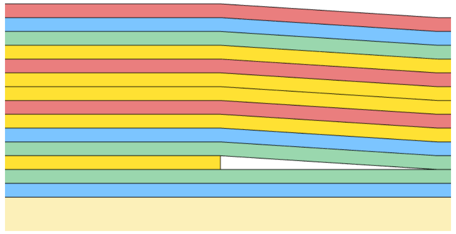
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



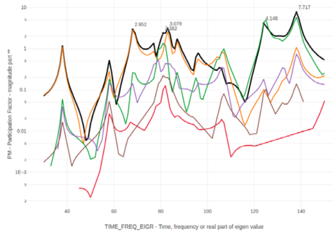
Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



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



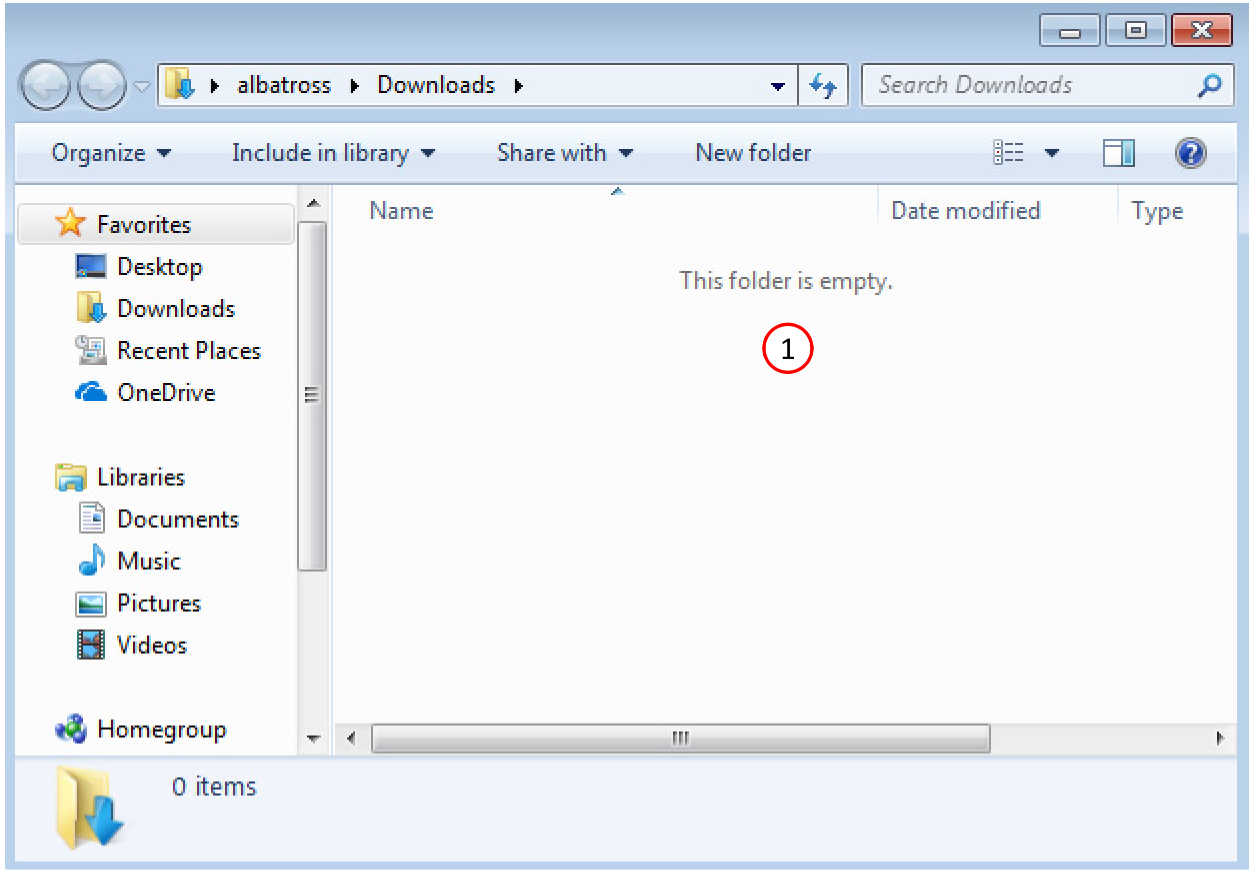
Stacking Sequence Web App
Optimize the stacking sequence of composite laminate plies



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

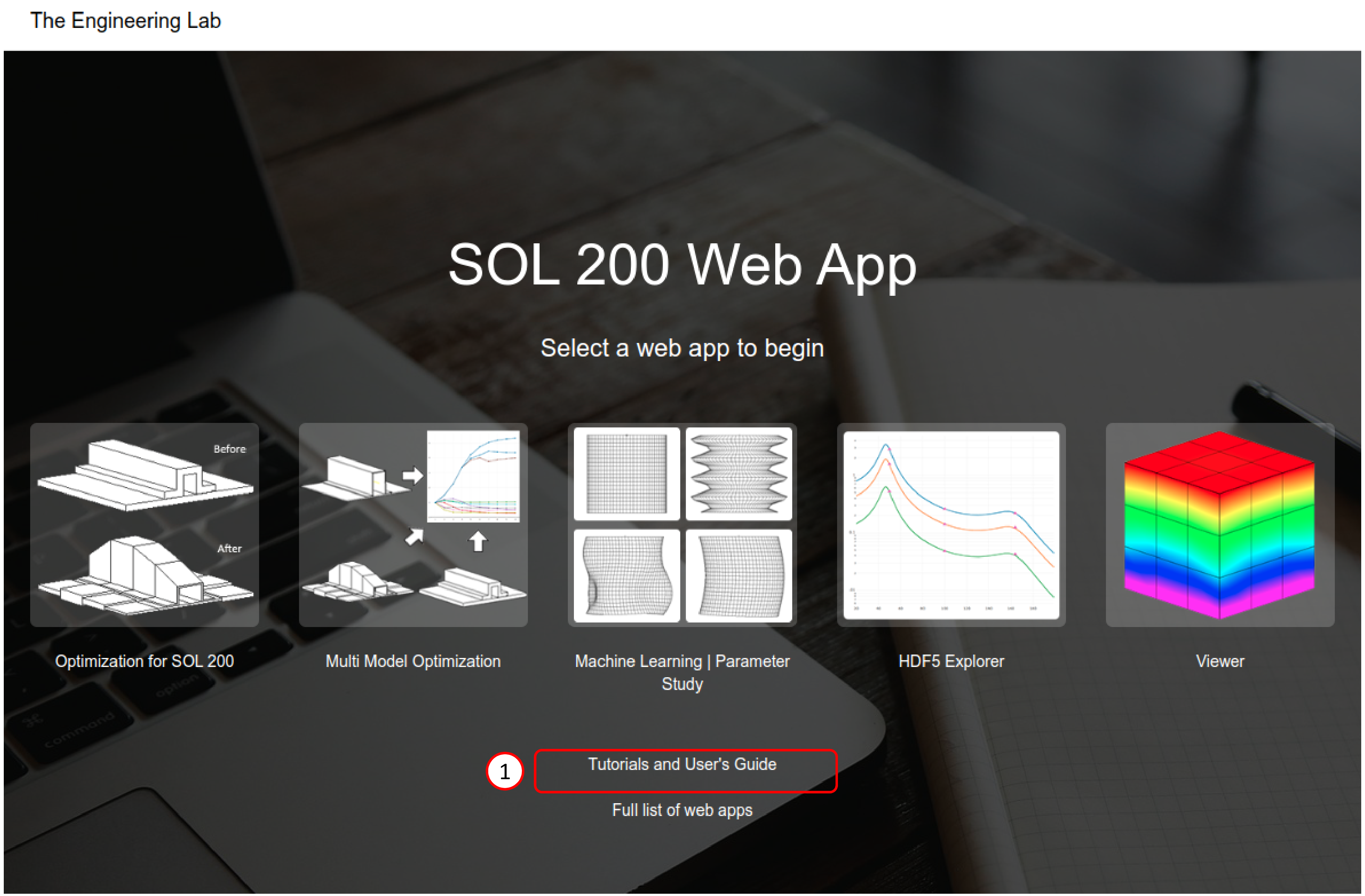
Before Starting

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



Go to the User's Guide

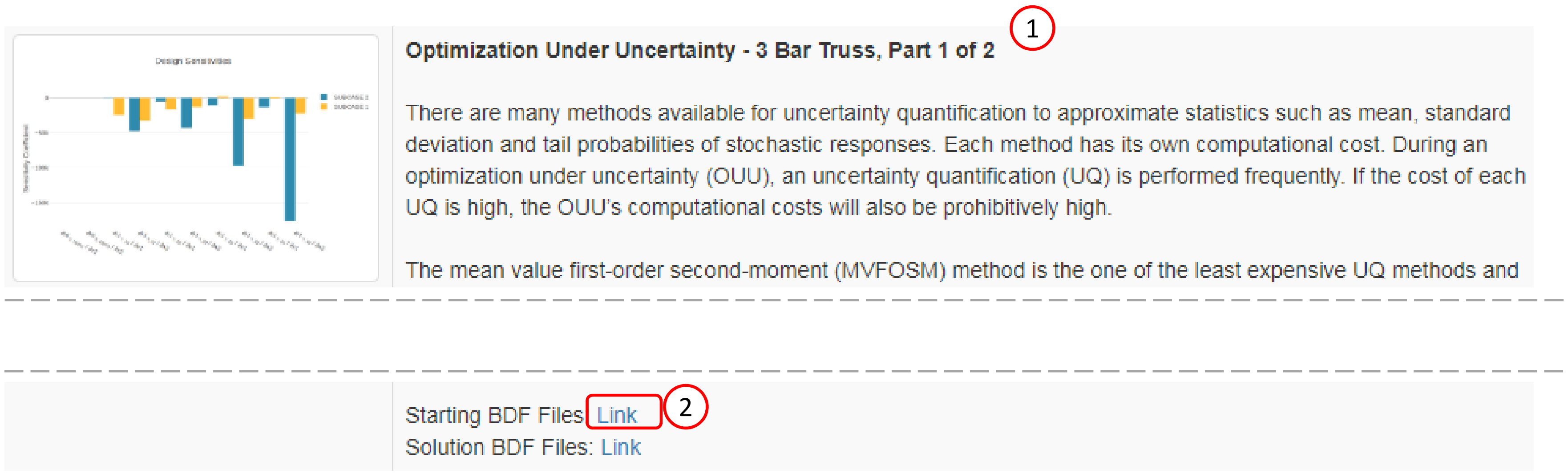
1. Click on the indicated link

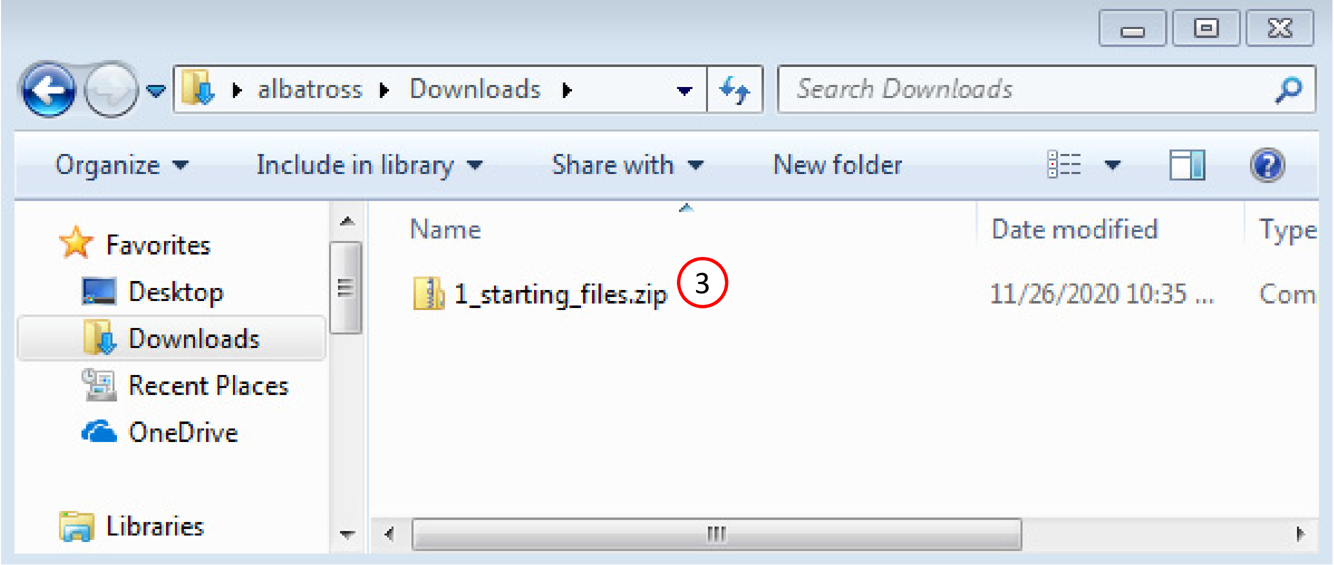


- The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.

Obtain Starting Files

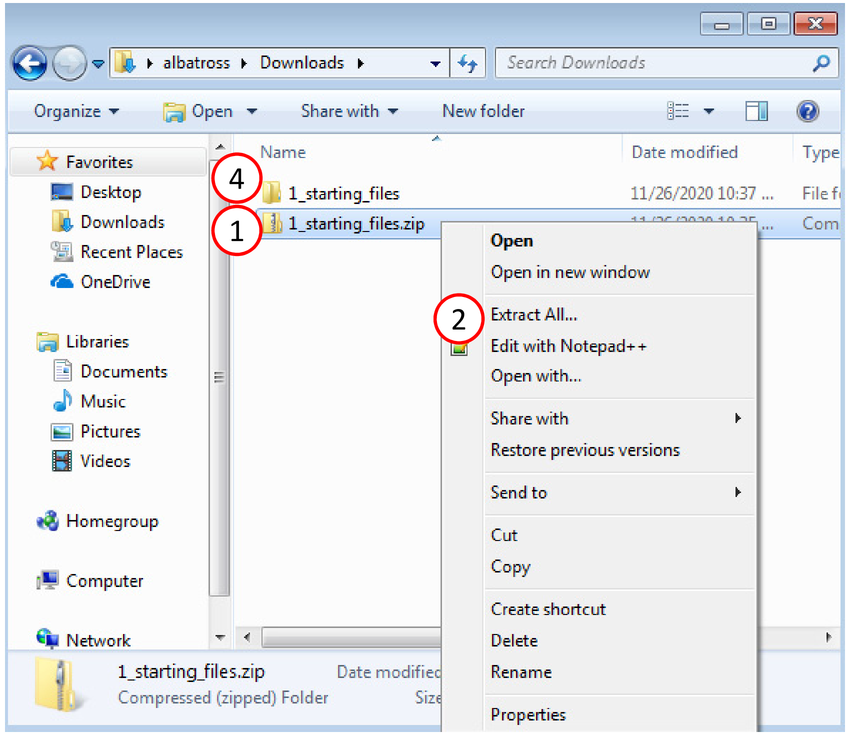
1. Find the indicated example
2. Click Link
3. The starting file has been downloaded

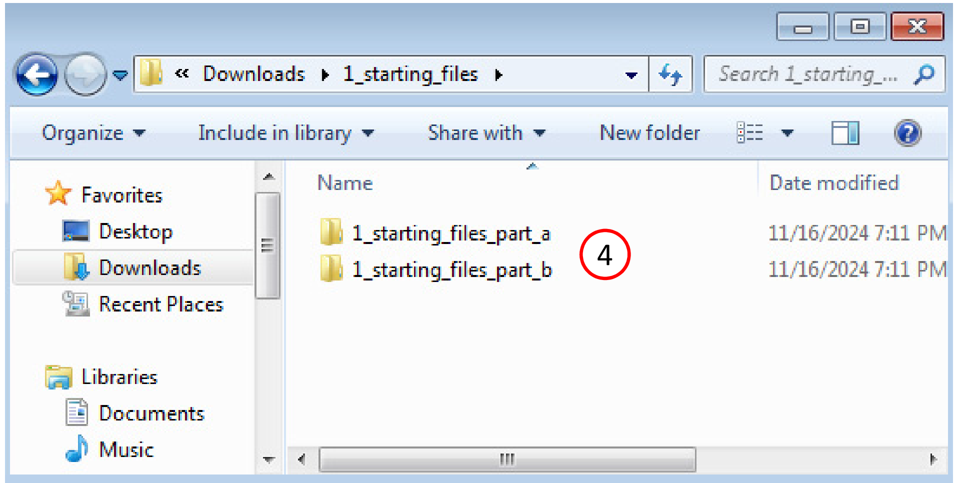


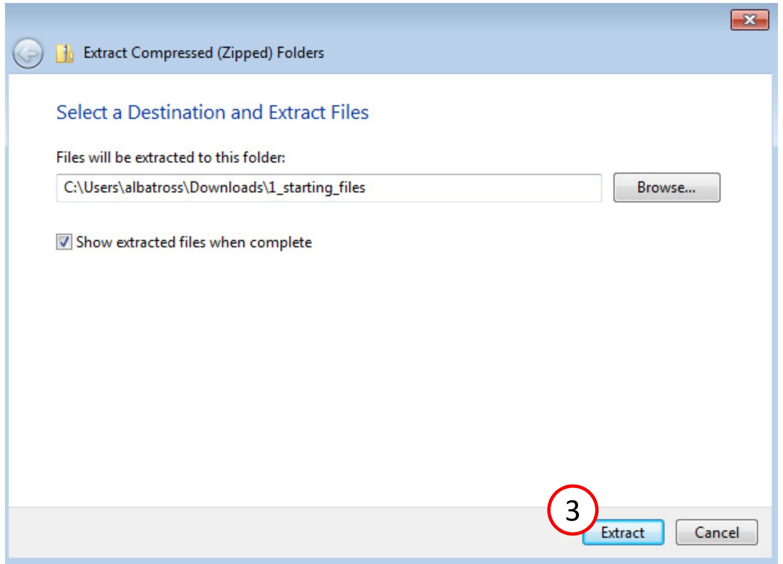


Obtain Starting Files

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



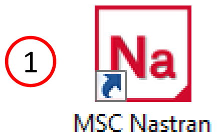


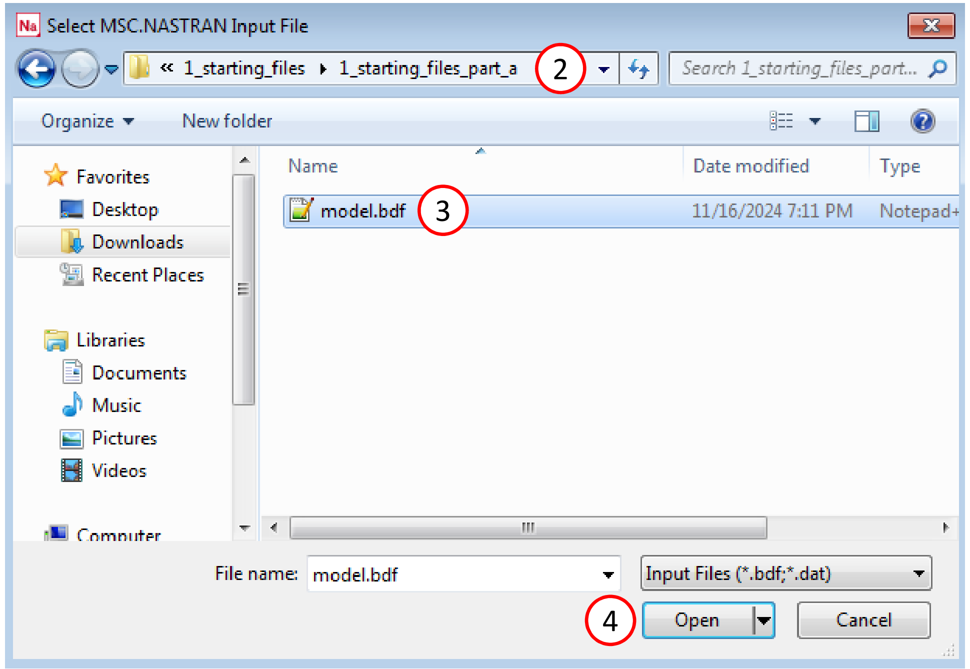


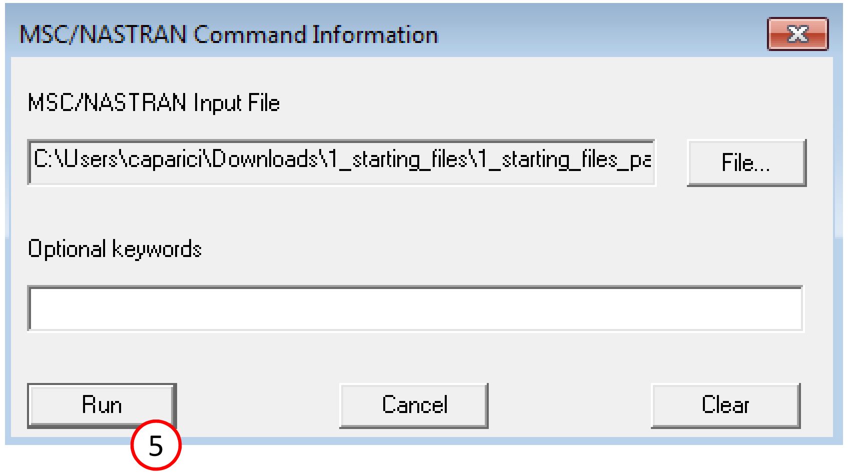
Create the Starting H5 File

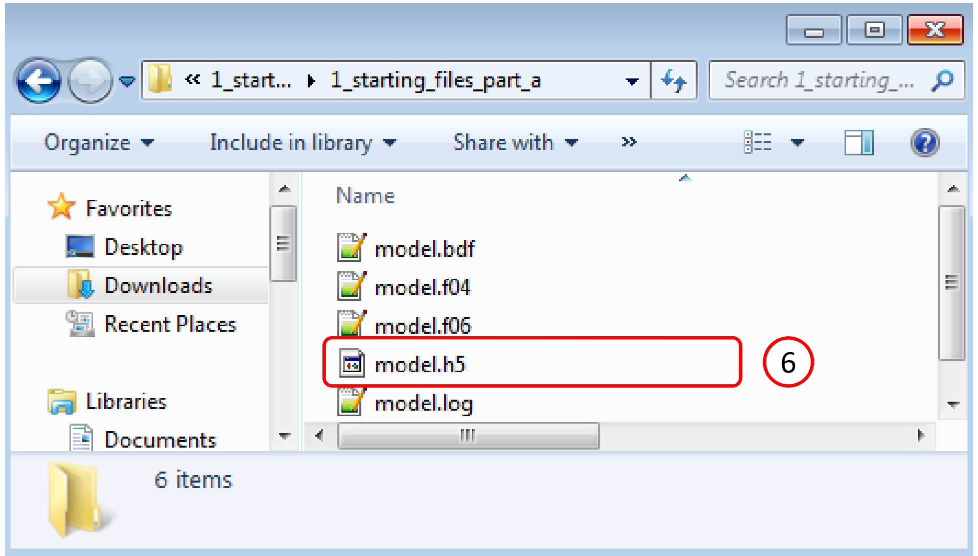
A starting H5 file must be created. This H5 file will be used to configure the responses later on.

1. Double click the MSC Nastran desktop shortcut
2. Navigate to the directory named 1_starting_files_part_a
3. Select the indicated file
4. Click Open
5. Click Run
6. The starting H5 file is created









Use the same MSC Nastran version throughout this exercise

The following applies if you have multiple versions of MSC Nastran installed.

To ensure compatibility, use the same MSC Nastran version throughout this exercise.
For example, scenario 1 is OK but scenario 2 is NOT OK.

- Scenario 1 - OK
  - MSC Nastran 2021 is used to create the starting H5 file.
  - MSC Nastran 2021 is used for each run during Machine Learning or Parameter study.
- Scenario 2 – NOT OK
  - MSC Nastran 2018.2 is used to create the starting H5 file.
  - MSC Nastran 2021 is used for each run during Machine Learning or Parameter study.

Using the same MSC Nastran version is critical for consistent response extraction from the H5 file. A response configured for Nastran version X may not match in Nastran version Y, which leads to unsuccessful response extraction from the H5 files. The goal is to make sure all H5 files generated are from the same MSC Nastran version.

Part A – Uncertainty Quantification and Confirming Responses Are Normal (Gaussian)

Motivation

Part A - In part A, the response distributions were confirmed to have near normal distributions. Also, the responses are supported by MSC Nastran SOL 200, so the SOL 200 procedure is used in part B to output the gradients. Since the distributions are normal and gradients are available, the MVFOSM method may be used for UQ or OUU.

Part B - In part B, the MSC Nastran bulk data file of the 3-bar truss is prepared to output gradients for use in a future OUU.

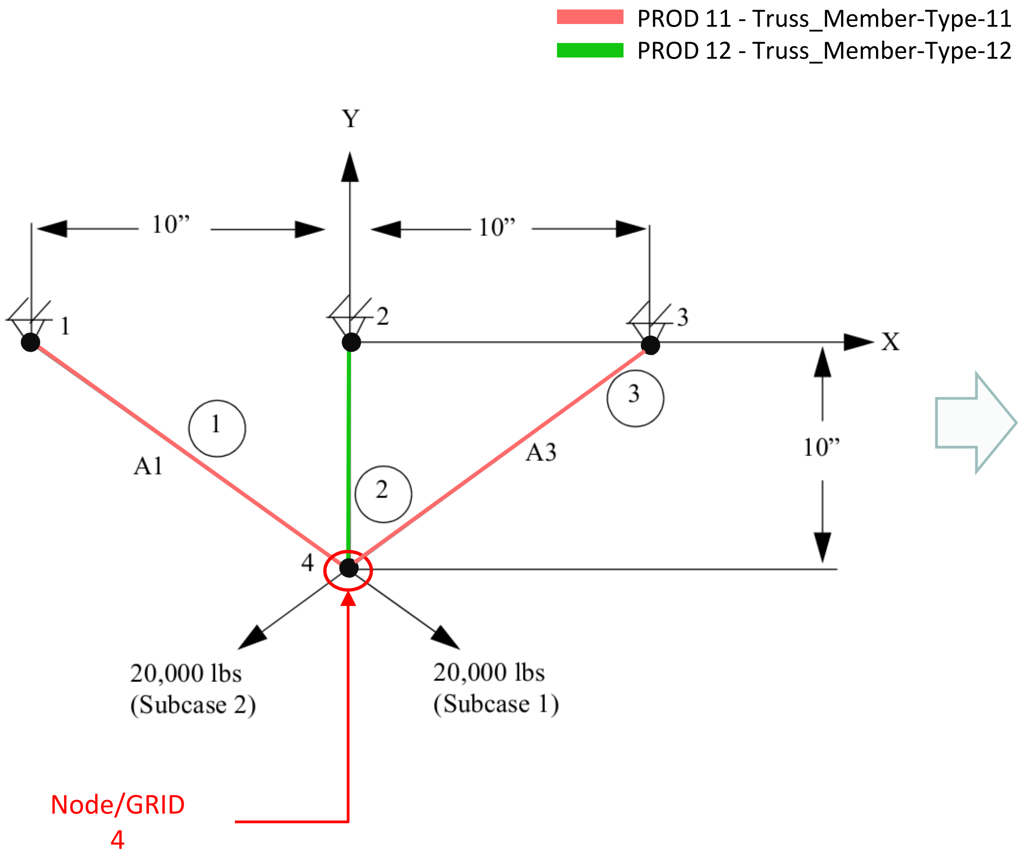
- An MSC Nastran SOL 200 optimization was performed to determine a starting point for a future OUU.
- The bulk data files of the 3-bar truss are configured for a sensitivity analysis, which will output gradients necessary in a future UQ or OUU.
  - The bounds on the DESVAR entries are removed.
  - The procedure is changed from a local optimization to a sensitivity analysis.
  - The DSCREEN entries are modified to output at gradients for at most 100 responses for each response type.
  - A test run is performed to ensure the bulk data files are free from errors and sensitivities/gradients are output.

Uncertainty Quantification Problem Statement

Design Variables

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

Variable	Mean	Standard Deviation	Distribution
x1	1.0	0.04	Lognormal
x2	2.0	0.04	Lognormal



Responses

r1: Mass
r2: Stress in element 1, subcase 1
r3: Stress in element 2, subcase 1
r4: Stress in element 3, subcase 1
r5: Stress in element 1, subcase 2
r6: Stress in element 2, subcase 2
r7: Stress in element 3, subcase 2
r8: Displacement, x-component, at node 4, subcase 1
r9: Displacement, y-component, at node 4, subcase 1
r10: Displacement, x-component, at node 4, subcase 2
r11: Displacement, y-component, at node 4, subcase 2

Quantities of interest

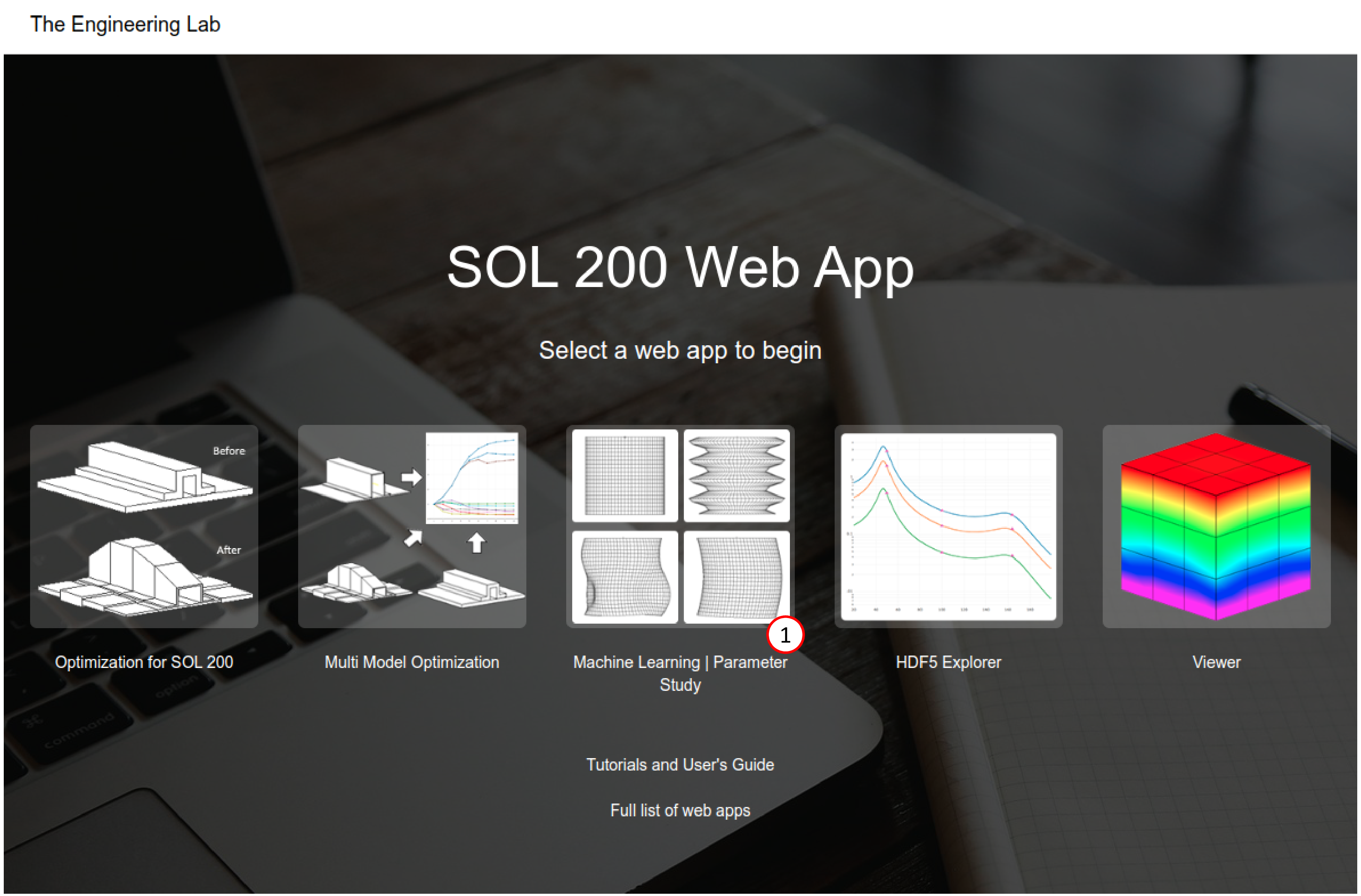
r1: Mean and standard deviation (2 quantities)

r2, r3, r4, r5, r6, r7: Mean, standard deviation, and probabilities of exceeding the bounds of -20,000 < ri < 20,000

r8, r9, r10, r11: Mean, standard deviation, and probabilities of exceeding the bounds of -0.2 < ri< 0.2

Open the Correct Page

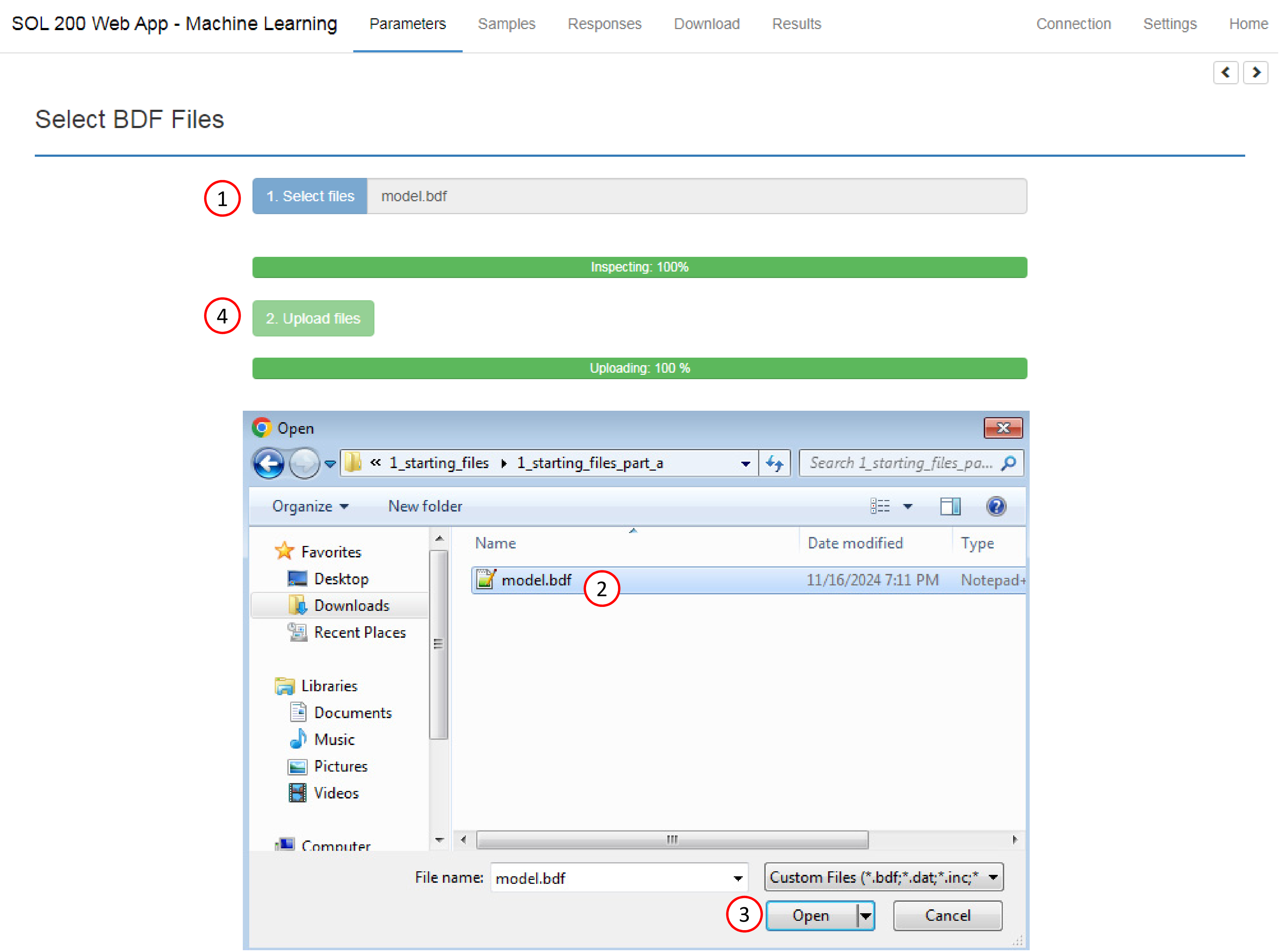
1. Click on the indicated link



Select BDF Files

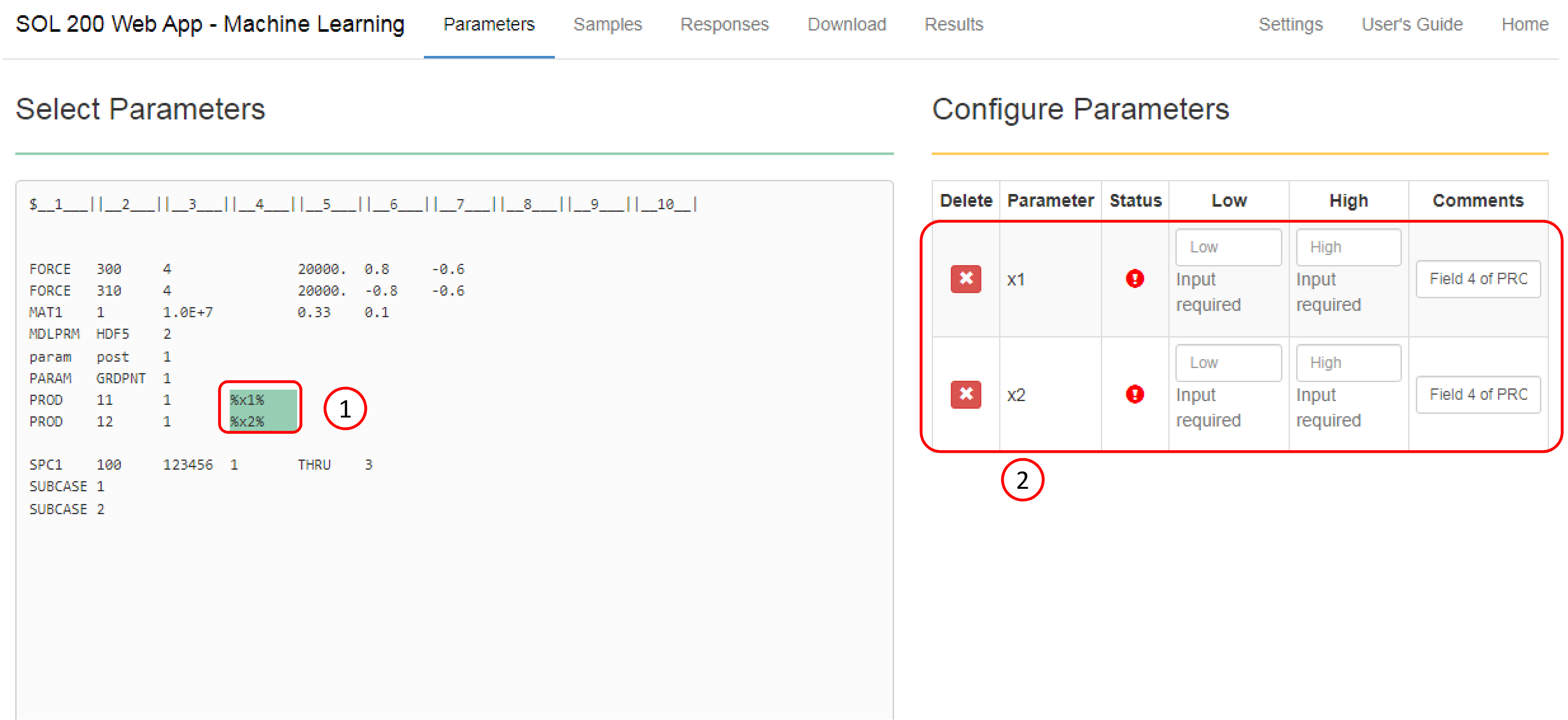
1. Click Select files
2. Select the indicated file
3. Click Open
4. Click Upload files

- When starting the procedure, all the necessary BDF, or DAT, files must be collected and uploaded together. Relevant INCLUDE files must also be collected and uploaded.



Parameters

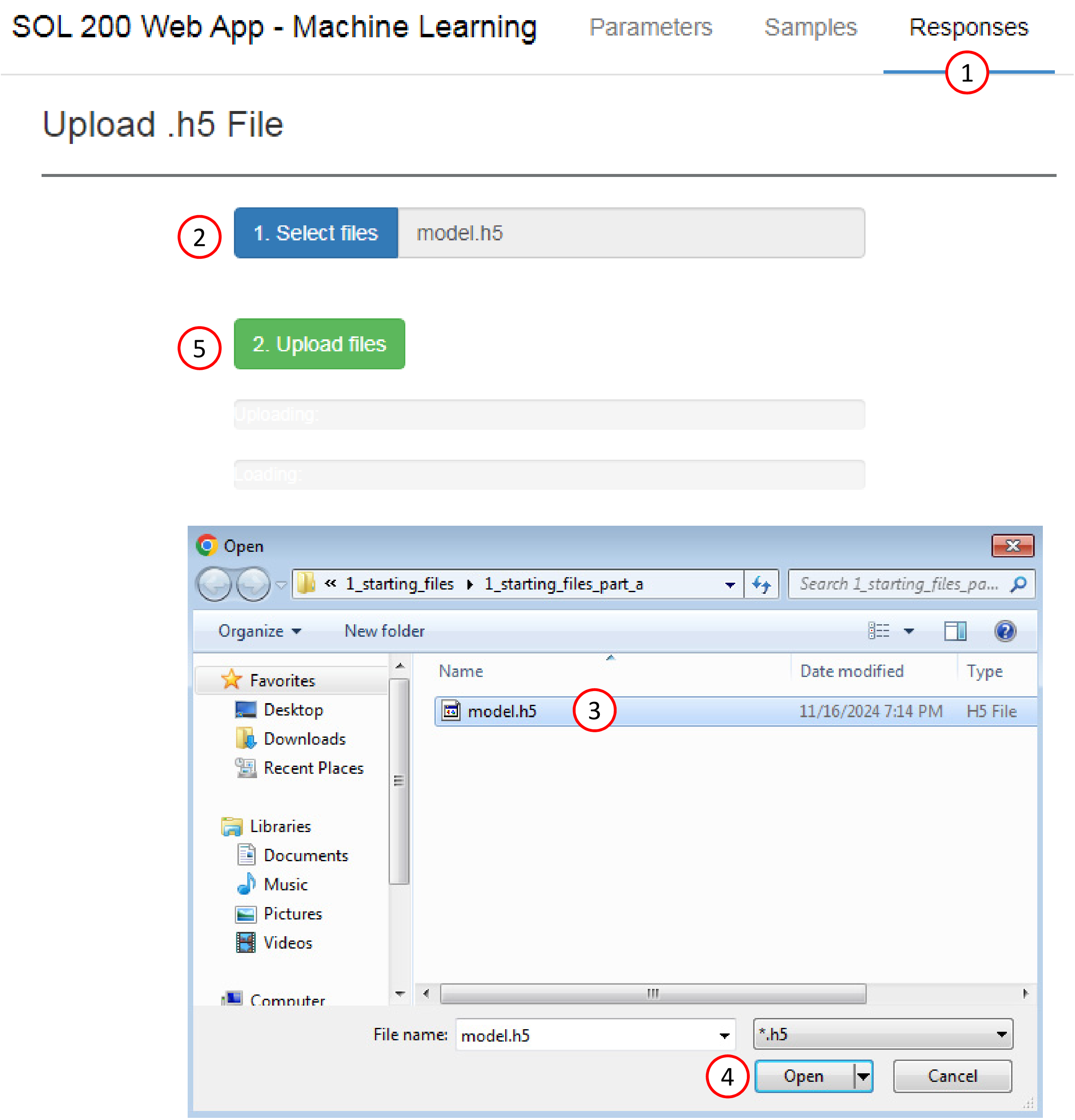
1. Set the following fields as parameters
   - x1: Initial value, field 4, of DESVAR 100001
   - x2: Initial value, field 4, of DESVAR 100002
2. Two new variables should be listed



Responses

1. Click Responses
2. Click Select files
3. Select the indicated file
4. Click Open
5. Click Upload files

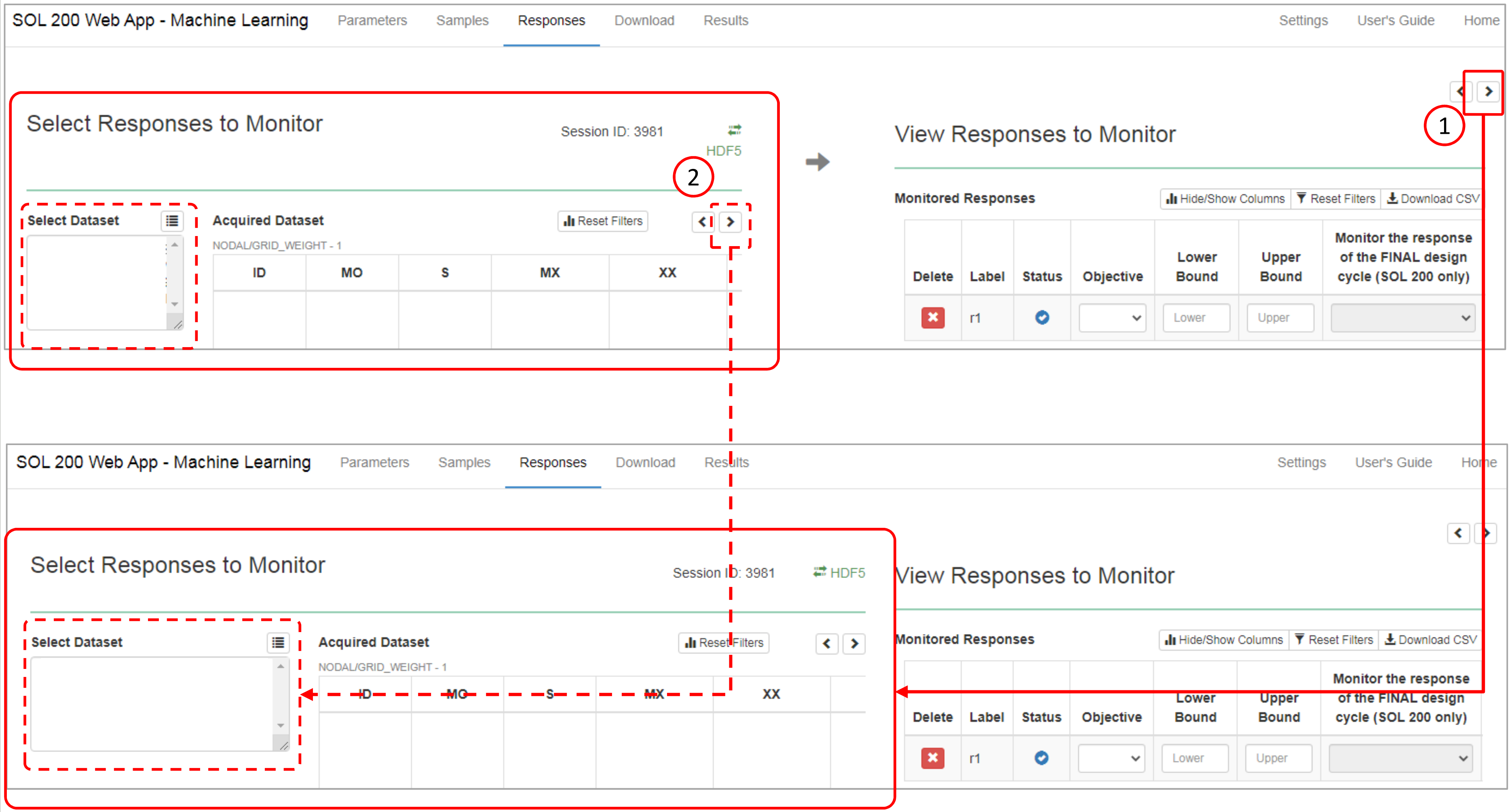
- On this page, the H5 file is uploaded to the web app.



Adjust the Column Width

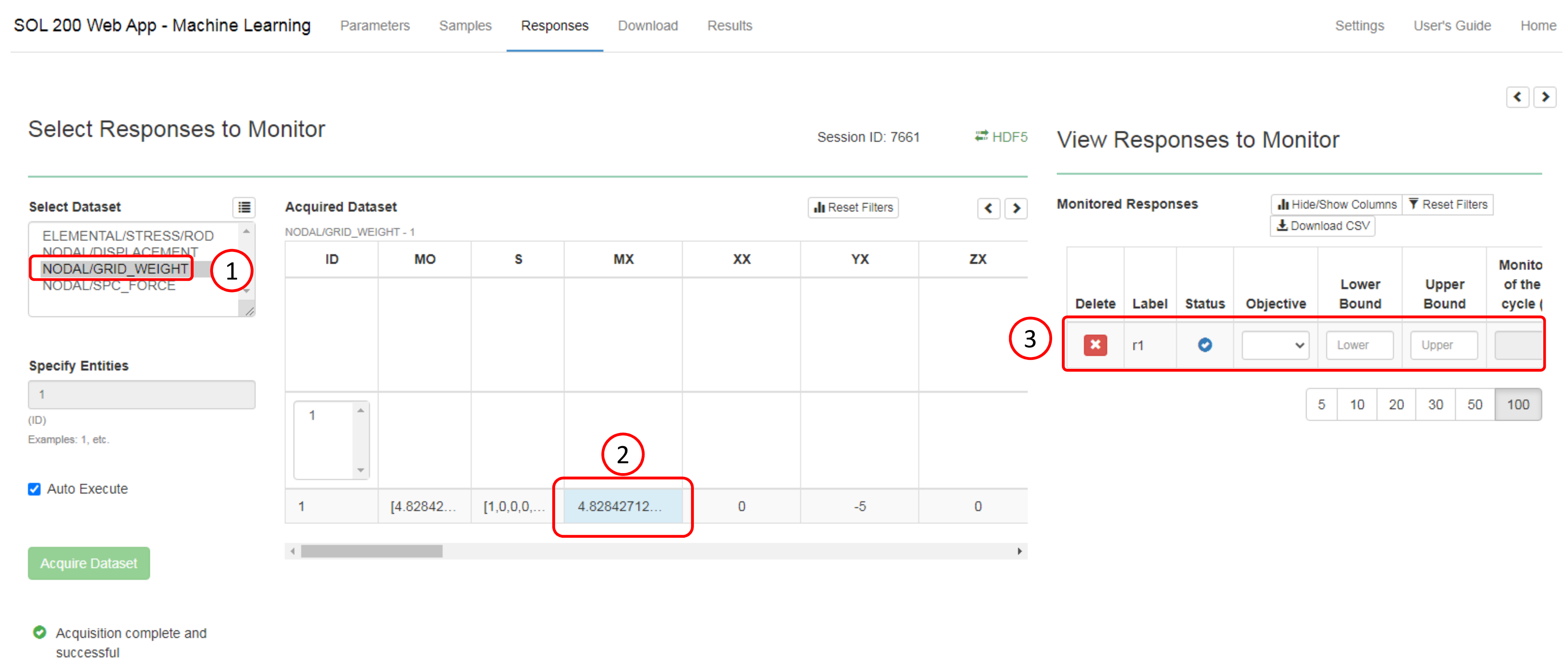
1. Optional - Use at your liking the buttons at the top right hand corner to adjust the width of the left and right columns
2. Optional – Use the indicated buttons to adjust the width of the column Select Dataset

- IMPORTANT! This image is not meant to match exactly what you see in your view. The text in this image is expected to be different from your view. The purpose of this page and image is to demonstrate how to increase the width of the indicated sections.



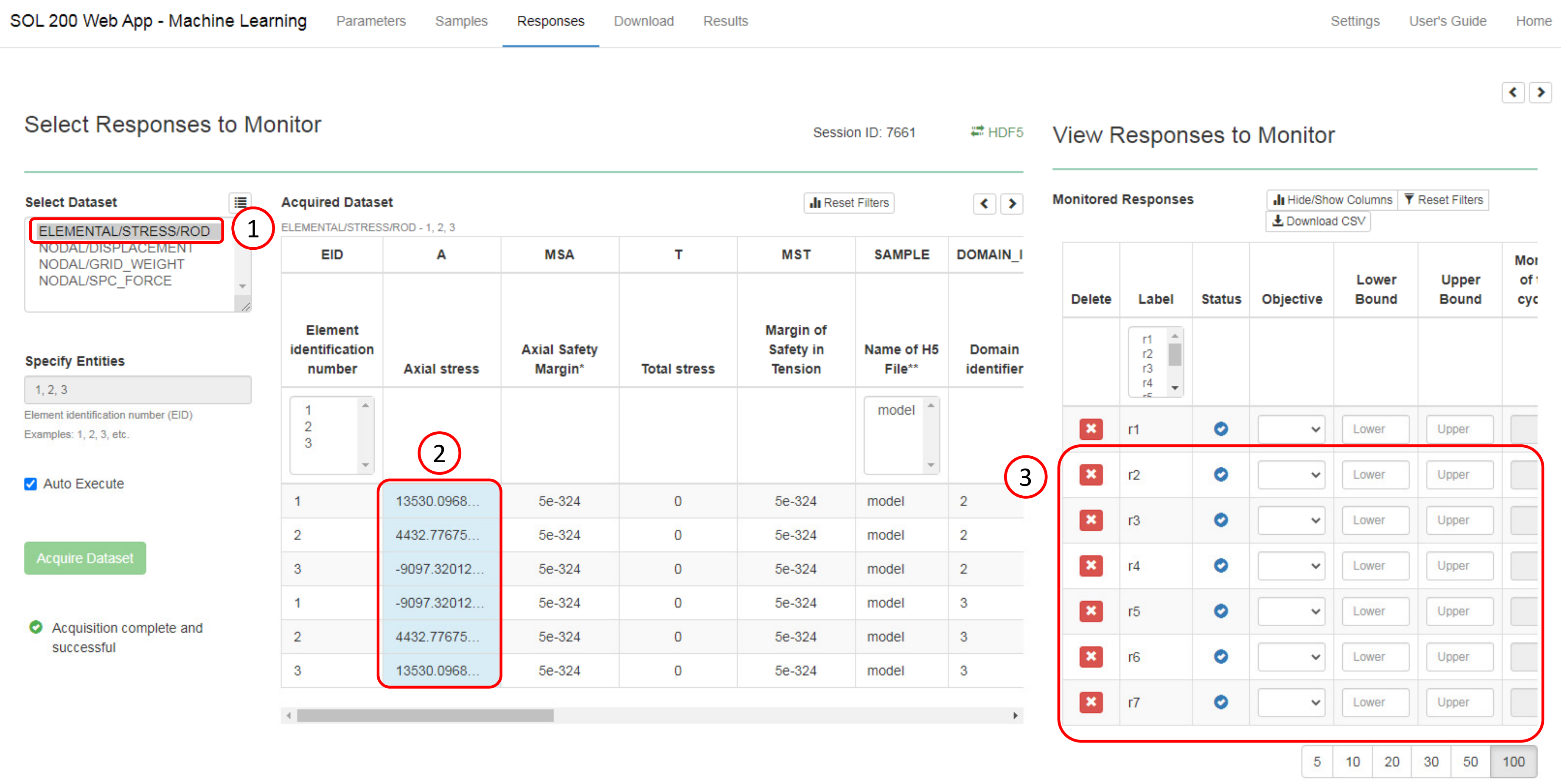
Select Responses

1. Select the following dataset: NODAL/GRID_WEIGHT
2. Select the indicated cell
3. The following responses have been created: r1



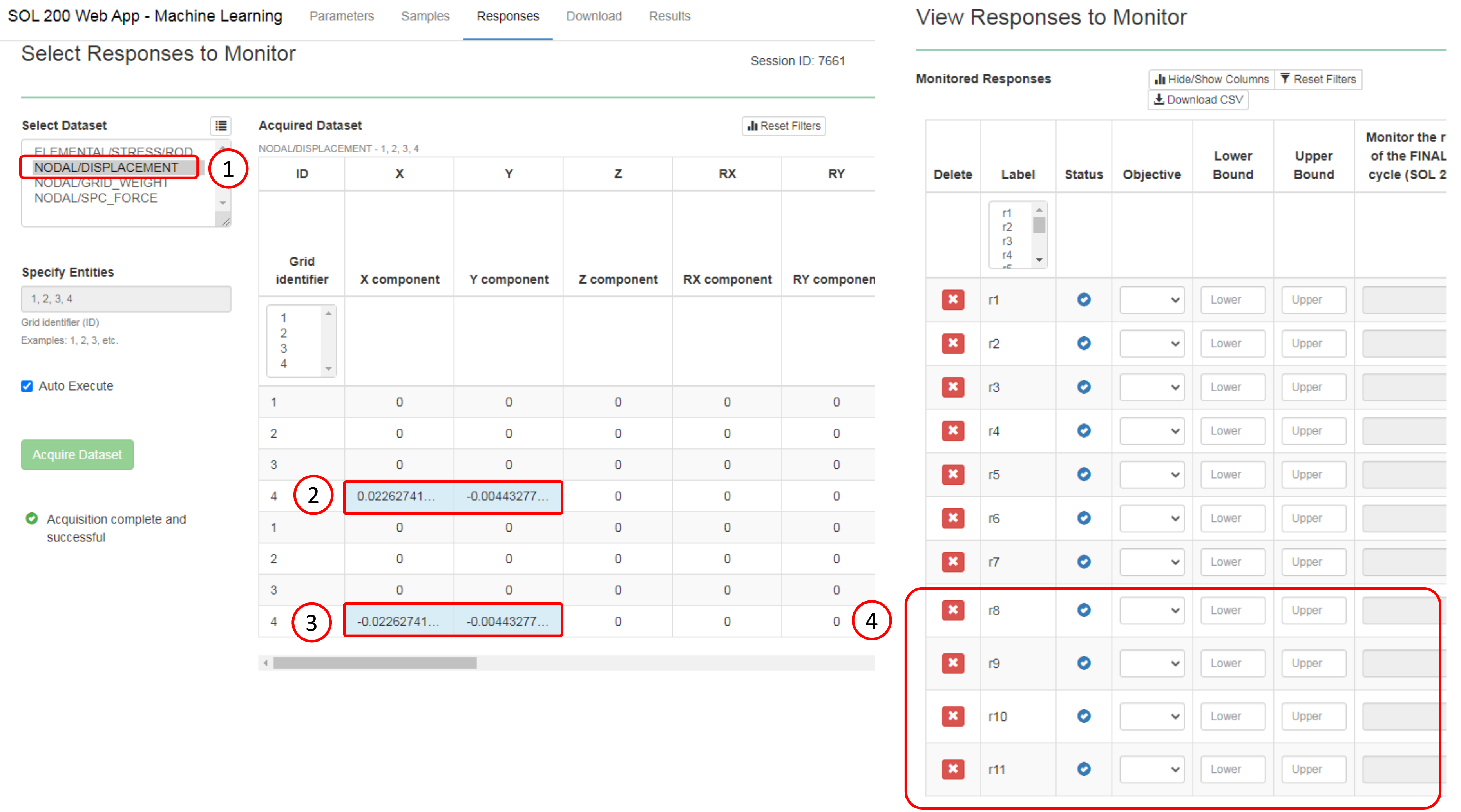
Select Responses

1. Select the following dataset: ELEMENTAL/STRESS/ROD
2. Select the indicated cells
3. The following responses have been created: r2, r3, r4, r5, r6, r7



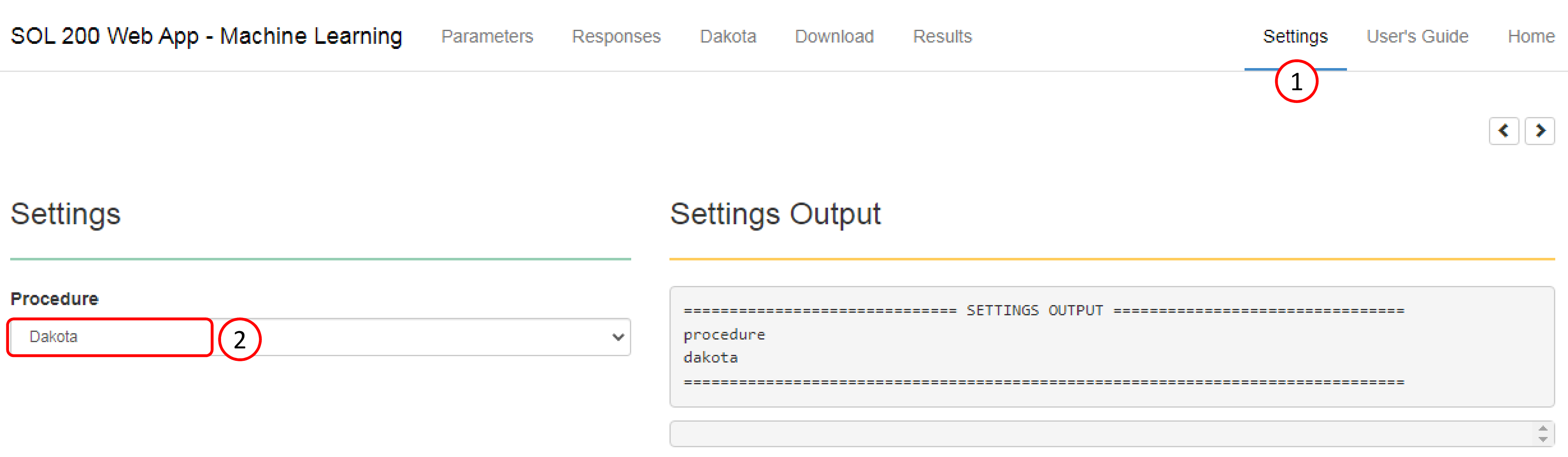
Select Responses

1. Select the following dataset: NODAL/DISPLACEMENT
2. Select the indicated cells
3. The following responses have been created: r8, r9, r10, r11



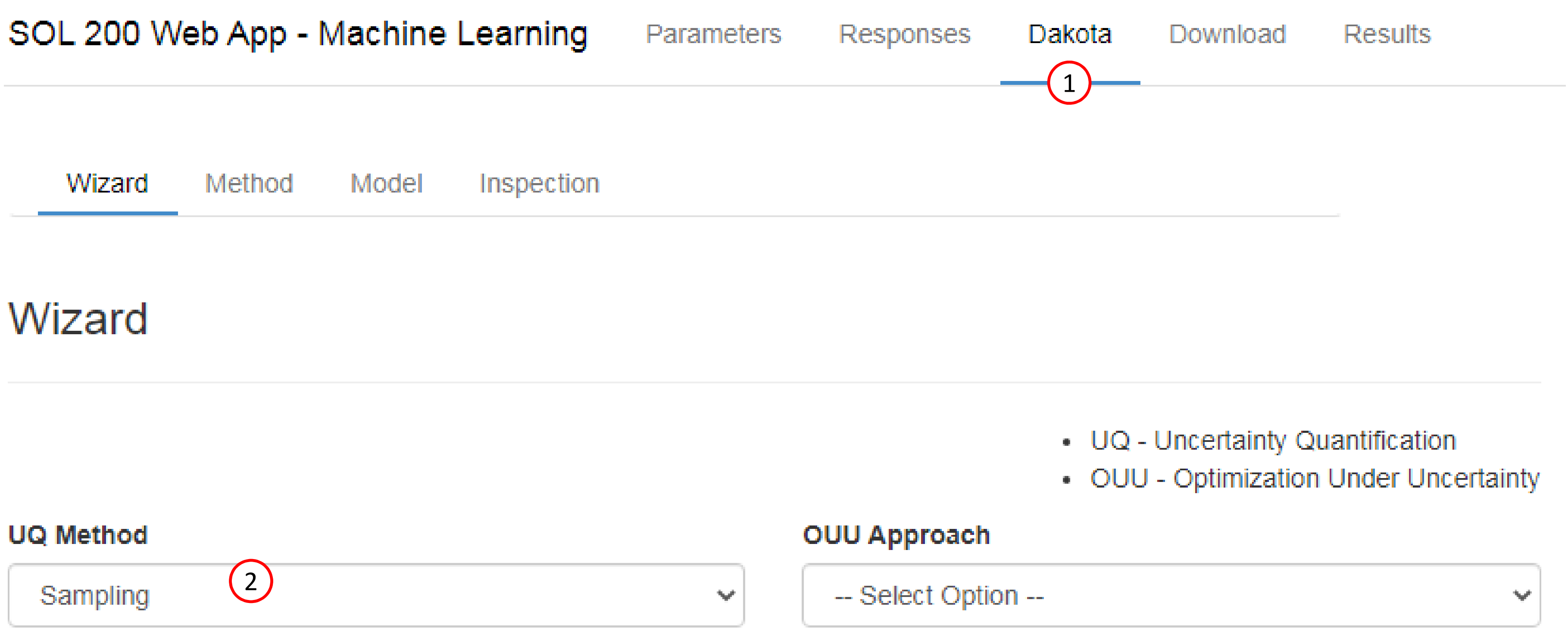
Settings

1. Click Settings
2. Set Procedure to Dakota



Dakota

1. Click Dakota
2. Set UQ Method to Sampling



Dakota - Uncertainty Quantification (UQ)

1. Scroll to section Uncertainty Quantification
2. Set both distributions to Lognormal Uncertain
3. Set both standard deviations to 0.04
4. For this example, bounds are not used. Ensure the bounds are blank.

- Variables that are normally distributed allow for negative values. This is problematic if the variable should always be positive. In this example, the cross sectional area is varied and should always be positive, else if the area is negative, the FEA solver will fail. A lognormal distribution allows for only positive values. The variables in this exercise are configured as having a lognormal distribution.
- The standard deviation is often determined via testing or provided by the supplier or manufacturer.
- In this exercise, bounds are not provided for the uncertain variables. If bounds are provided, the final LHS considers points only within the bounds.

Uncertainty Quantification (1)

Configure UQ Variables

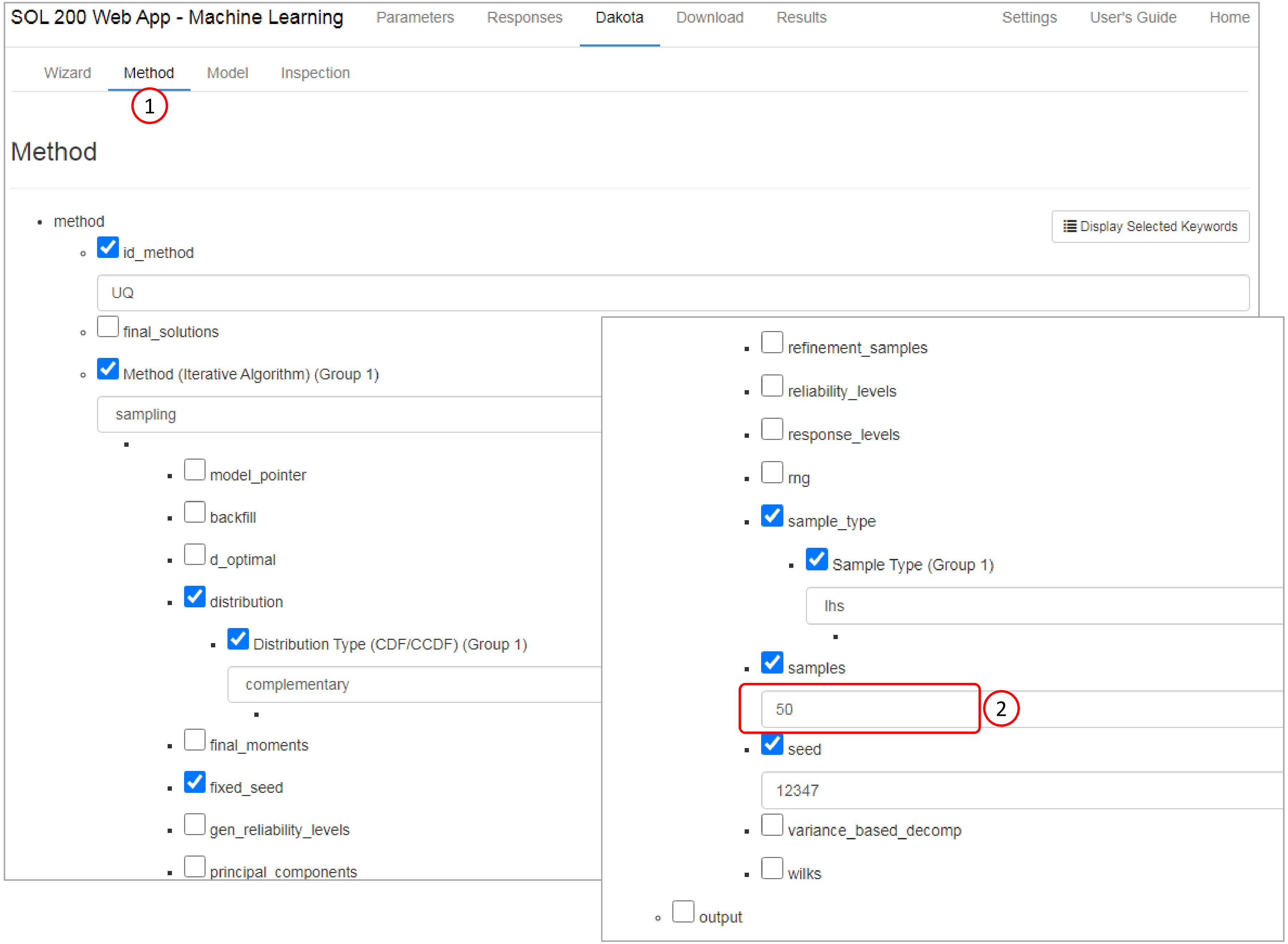
Reset Table

Delete	Descriptor	Status	Distribution	Mean	Standard Deviation	Initial Value	Lower Bound	Upper Bound	Description
✖	x1	✔	Lognorı	1.0	0.04		UQ Lo\	UQ Up|	Field 4 of P
✖	x2	✔	Lognorı	2.0	0.04		UQ Lo\	UQ Up|	Field 4 of P

(2) (3) (4)

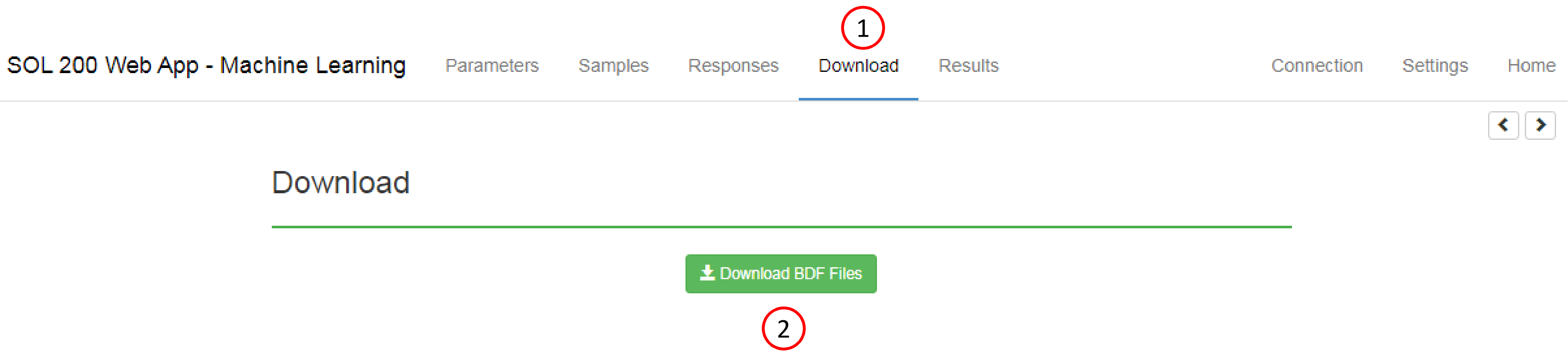
Uncertainty Quantification

1. Click Method
2. Set the keyword samples to 50
   - The uncertainty quantification will use 50 MSC Nastran runs



Download

1. Click Download
2. Click Download BDF Files

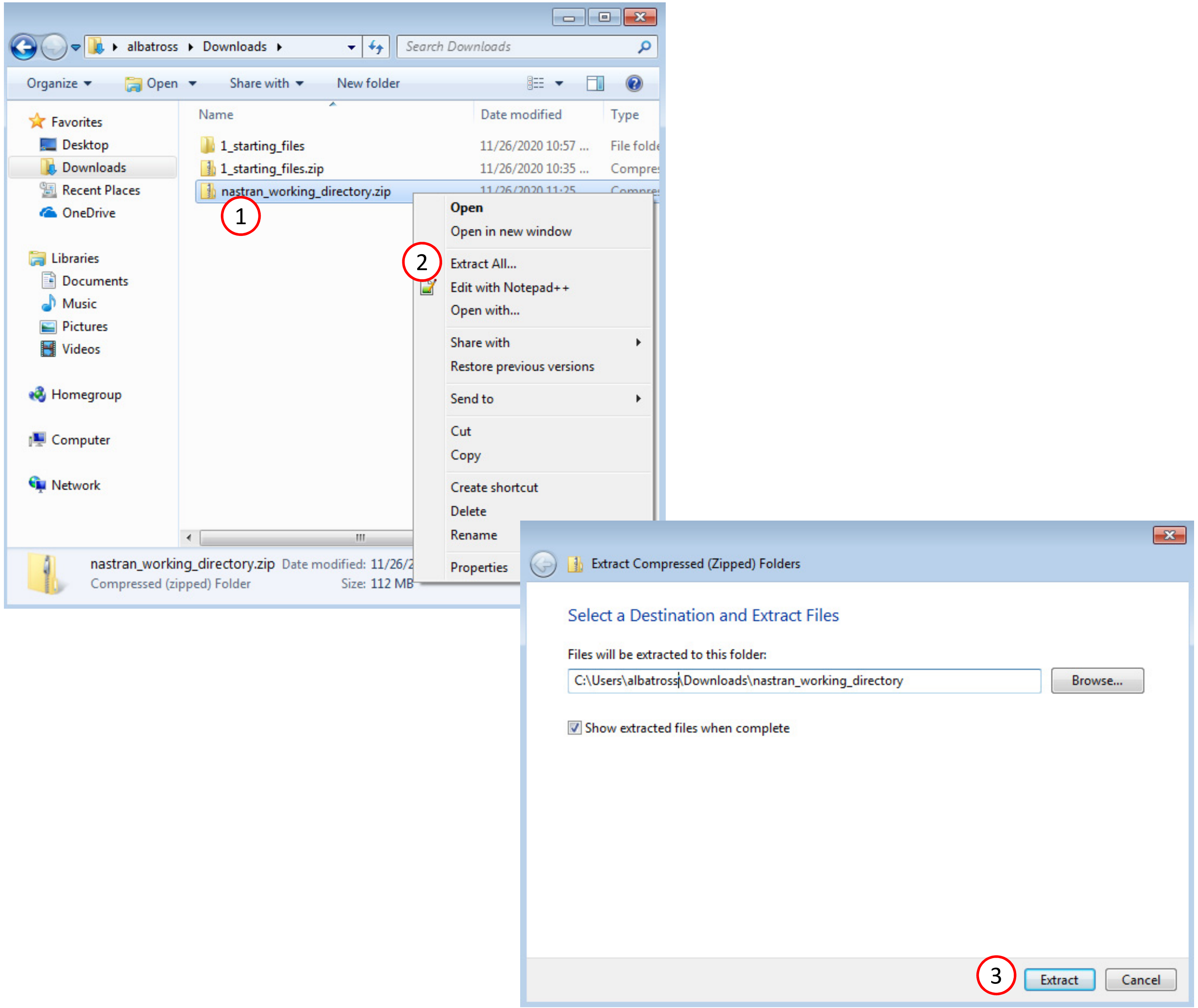


Start MSC Nastran

A new .zip file has been downloaded

1. Right click on the file
2. Click Extract All
3. Click Extract on the following window

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



Start Desktop App

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

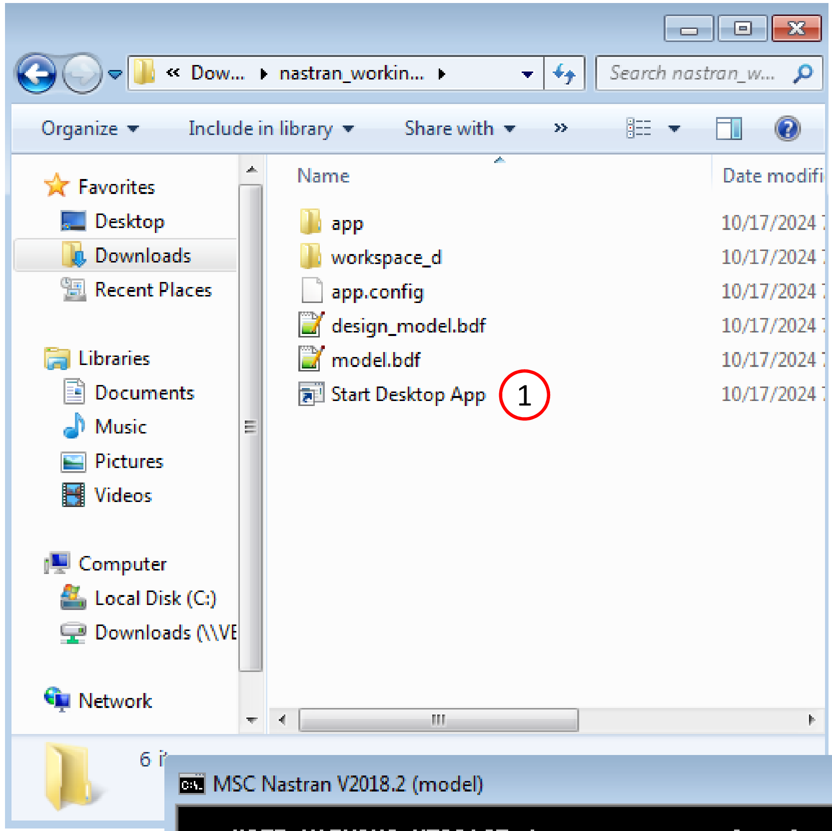
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the remote machine. 3) After completion, copy the BDF, F06, LOG, H5 files to the local machine. 4) Click “Start Desktop App” to display the results.

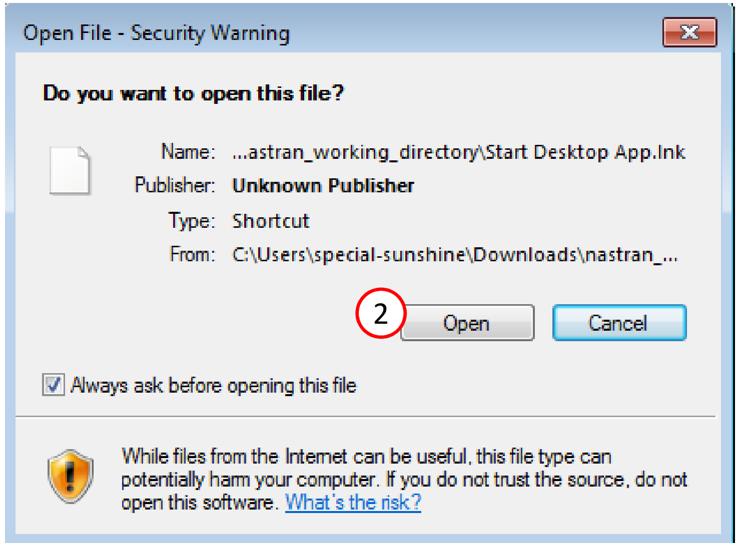
Using Linux?

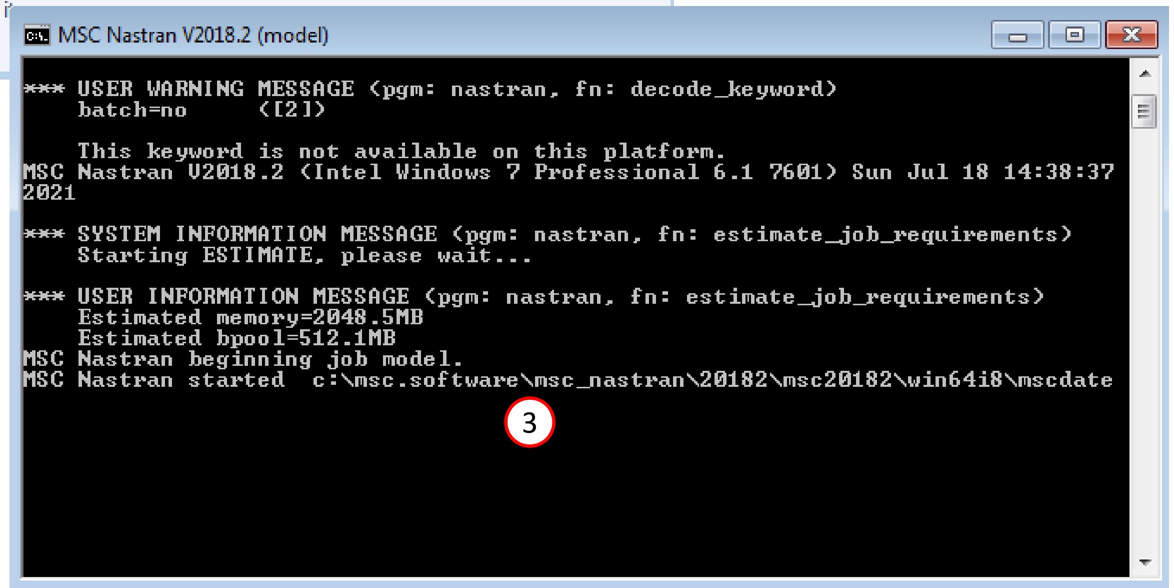
Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
   cd ./nastran_working_directory
3) Use this command to start the process
   ./Start_MSC_Nastran.sh

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

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

SOL 200 Web App - Status

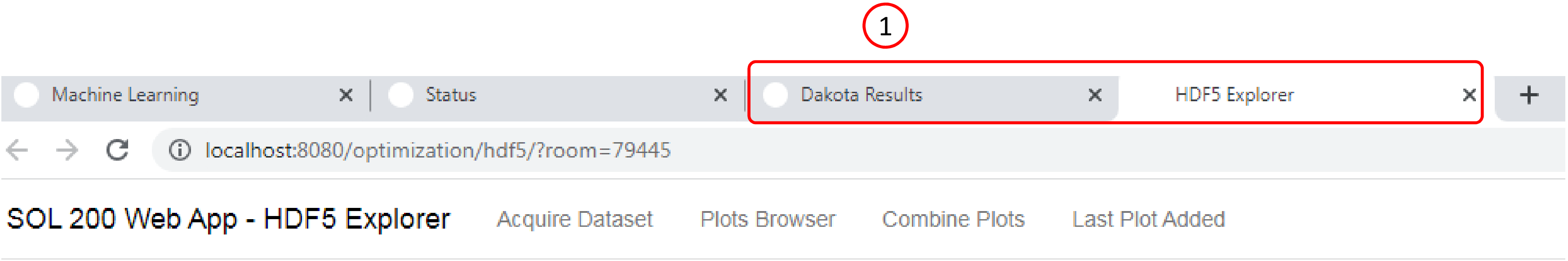
Python MSC Nastran

Status

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

UQ Completion

1. The UQ is complete when the indicated web apps are opened.



UQ Results

1. The results of the uncertainty quantification are found in file dakota.out. Note that the mean, standard deviation, skewness and kurtosis for each responses is listed.
2. Select the window or tab that displays the Dakota Results web app. This web app displays some of the results found in the Dakota output file dakota.out.
3. Click Tables
4. The same results found in the file dakota.out are displayed in the web app
5. The skewness is a measure of the distribution's symmetry. A normal distribution has a skewness of zero, i.e. the distribution is symmetric. If the skewness is reasonably small, the distribution is very close to a normal distribution. From experience, skewness values within the range of -0.5 to +0.5 are indication of a near normal distribution.

2

SOL 200 Web App - Dakota Results | Upload OUT File | Tables | Upload Tabular File | Scatter Plots | Histograms | User's Guide | Home

3

Statistics based on 50 samples

Sample moment statistics for each response function

5

Download CSV

4

	Mean	Standard Deviation	Skewness	Kurtosis
r1	4.8279590943e+00	1.1754839330e-01	5.3215577792e-02	-4.1072200142e-01
r2	1.3550873230e+04	4.7109459188e+02	1.5126416459e-01	-2.7255138682e-01
r3	4.4340359141e+03	7.8657599827e+01	-9.4060255845e-02	-7.1675181810e-01
r4	-9.1168373160e+03	4.2713590041e+02	-1.5808602311e-01	-2.5354362937e-01
r5	-9.1168373160e+03	4.2713590041e+02	-1.5808602311e-01	-2.5354362937e-01
r6	4.4340359141e+03	7.8657599827e+01	-9.4060255845e-02	-7.1675181810e-01
r7	1.3550873230e+04	4.7109459188e+02	1.5126416459e-01	-2.7255138682e-01
r8	2.2667710546e-02	8.9585901001e-04	1.5733778402e-01	-2.5950843535e-01
r9	-4.4340359141e-03	7.8657599827e-05	9.4060255845e-02	-7.1675181810e-01
r10	-2.2667710546e-02	8.9585901001e-04	-1.5733778402e-01	-2.5950843535e-01
r11	-4.4340359141e-03	7.8657599827e-05	9.4060255845e-02	-7.1675181810e-01

1

File: dakota.out

```
<<<<< Function evaluation summary (UQ_I): 50 total (50 new, 0 duplicate)
---------------------------------------------------------------------
Statistics based on 50 samples:

Sample moment statistics for each response function:
                            Mean           Std Dev          Skewness          Kurtosis
          r1  4.8279590943e+00  1.1754839330e-01  5.3215577792e-02 -4.1072200142e-01
          r2  1.3550873230e+04  4.7109459188e+02  1.5126416459e-01 -2.7255138682e-01
          r3  4.4340359141e+03  7.8657599827e+01 -9.4060255845e-02 -7.1675181810e-01
```

UQ Results

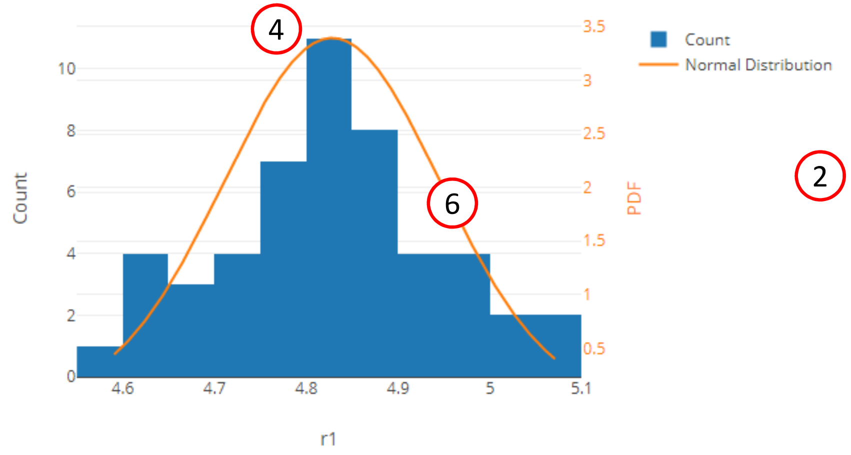
1. Click Histograms
2. A histogram for each response is displayed
3. Recall the skewness for each response
4. For response r1, the skewness is 0.0532 and is very small, indicating the response's distribution is nearly symmetric and is a near normal distribution.
5. For response r2, the skewness is 0.151. This skewness value is deemed reasonably small, so the distribution is considered a near normal distribution.
6. The probability density functions (PDF), colored in orange, are built using a normal distribution with the mean and standard deviation given in the Dakota results file. The orange plot is NOT the response's true distribution and is used for comparison only. The blue bars of the histogram represent the true distribution of the response. If the histogram and PDF plot align, this is indication the response's distribution is nearly normal.

There are 2 methods for deeming a response's distribution is nearly normal: the skewness values are small and comparing the histogram with a PDF of a normal distribution.

SOL 200 Web App - Dakota Results | Upload OUT File | Tables | Upload Tabular File | Scatter Plots | Histograms (1) | User's Guide | Home

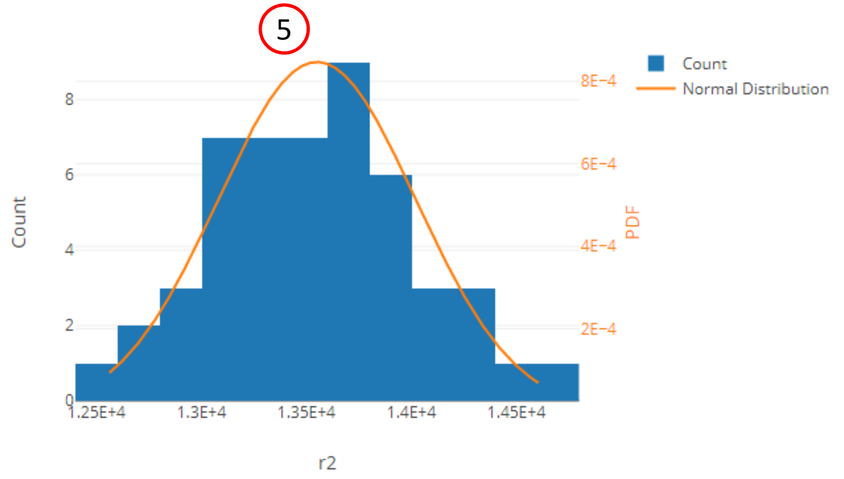
Histograms

r1



2

r2

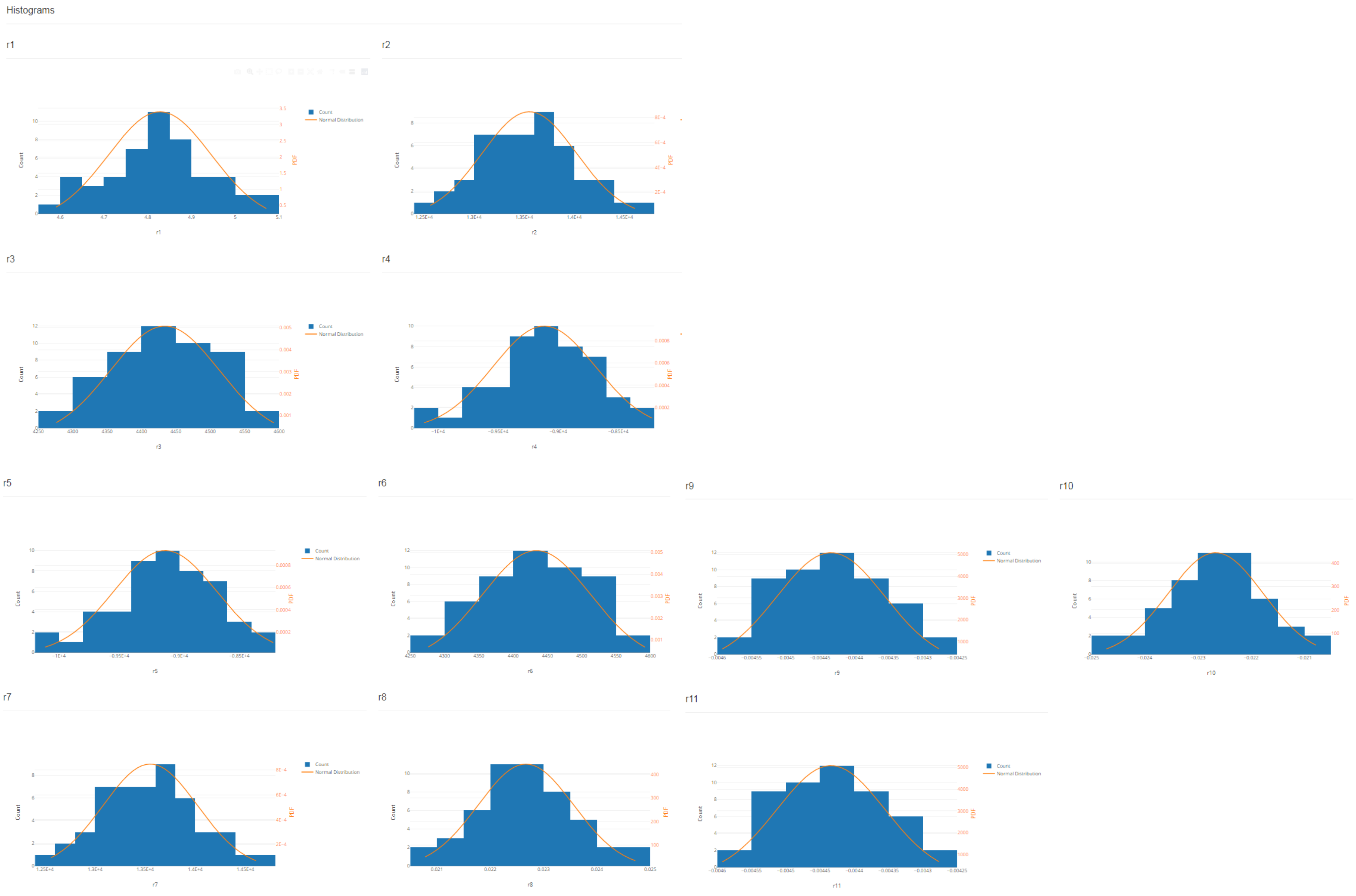


Sample moment statistics for each response function

	Mean	Standard Deviation	Skewness
r1	4.8279590943e+00	1.1754839330e-01	(3) 5.3215577792e-02
r2	1.3550873230e+04	4.7109459188e+02	1.5126416459e-01
r3	4.4340359141e+03	7.8657599827e+01	-9.4060255845e-02

UQ Results

1. Inspection of the other skewness values and histograms indicates the response distributions are nearly normal. This is evidence the MVFOSM method is appropriate for estimating tail probabilities for each response.



Examples of Non-normal Distributions

The examples shown on this page are for responses from other structural models and not the 3-bar truss.

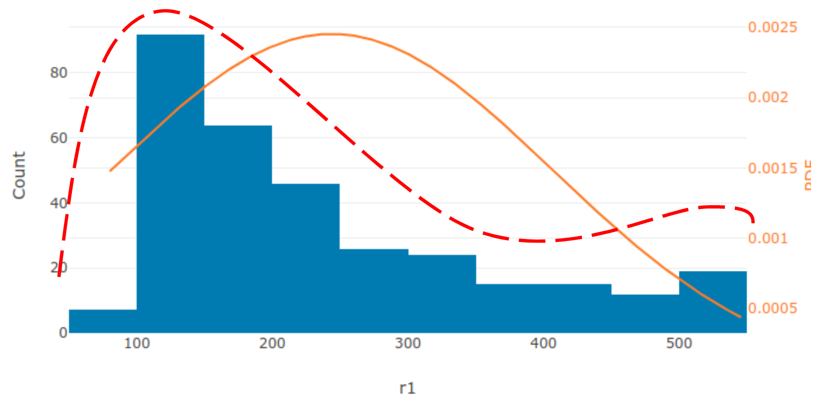
1. For example 1, the response's skewness value is 1.0035985638e+00. This is a significantly large skewness value and indicates the distribution is highly asymmetric. A look at the histogram confirms the distribution is asymmetric. The orange plot which is the PDF for a normal distribution does not align to the histogram. Also, Microsoft PowerPoint was used to superimpose a possible PDF that better aligns to the histogram, refer to the red dashed line/plot. The actual distribution is likely a bi-modal distribution, not a normal distribution.

2. For example 2, the response's skewness value is -7.0504626153e+00. This is a significantly large skewness value and indicates the distribution is highly asymmetric. A look at the histogram confirms the distribution is asymmetric. The orange plot which is the PDF for a normal distribution does not align to the histogram. Also, Microsoft PowerPoint was used to superimpose a possible PDF that better aligns to the histogram, refer to the red dashed line/plot.

The MVFOSM method is unsuitable for estimating the tail probabilities for both of these responses since they are not normally distributed. This is evident by both the large skewness values and the deviations of the histograms (blue bars) from the PDF of normal distributions (orange plots).

Example 1 (1)

r1

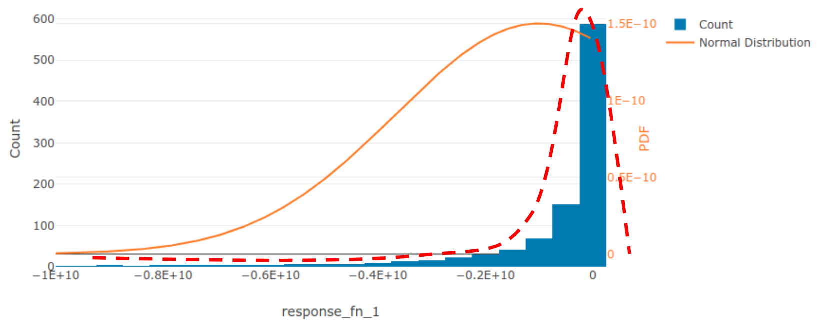


Sample moment statistics for each response function

	Mean	Standard Deviation	Skewness
r1	2.3679716926e+02	1.2345130386e+02	1.0035985638e+00

Example 2 (2)

response_fn_1



Sample moment statistics for each response function

	Mean	Standard Deviation	Skewness
response_fn_1	-1.0069781265e+09	2.6608285336e+09	-7.0504626153e+00

Can MVFOSM be used for uncertainty quantification?

- For the MVFOSM method to yield good approximations of tail probabilities, the response's distributions must be normal or nearly normal. Also, gradients must be available.
  - As confirmed in the previous steps, the response distributions are nearly normal.
  - Also, the weight, displacement and stress responses are response types supported by MSC Nastran SOL 200. Since MSC Nastran SOL 200 outputs sensitivities/gradients, gradients are available for the responses of interest.
- The answer to the original question is as follows: Yes, the MVFOSM method may be used for UQ and OUU.
- If the answer is no, then one of the other UQ methods available in Sandia Dakota should be considered, e.g. polynomial chaos, stochastic collocation, etc. Also, the other UQ methods are greatly limited by the curse of dimensionality, so problems within 1-10 parameters are practical. Problems with more than 10 parameters may require up to thousands of FEA runs and are impractical. The true cost will vary depending on the UQ method and number of parameters and responses.
- The MVFOSM method is significantly less computationally expensive and can address higher dimension problems, so take advantage of the MVFOSM method when possible. In a separate tutorial, a UQ and OUU involving +50 parameters is optimized with approximately 300 FEA runs. While some might call this costly, it is actually not considering other UQ methods during OUU might require +5,000 FEA runs.

Another Comment

Does the MVFOSM method work well for nonlinear response functions? It depends.

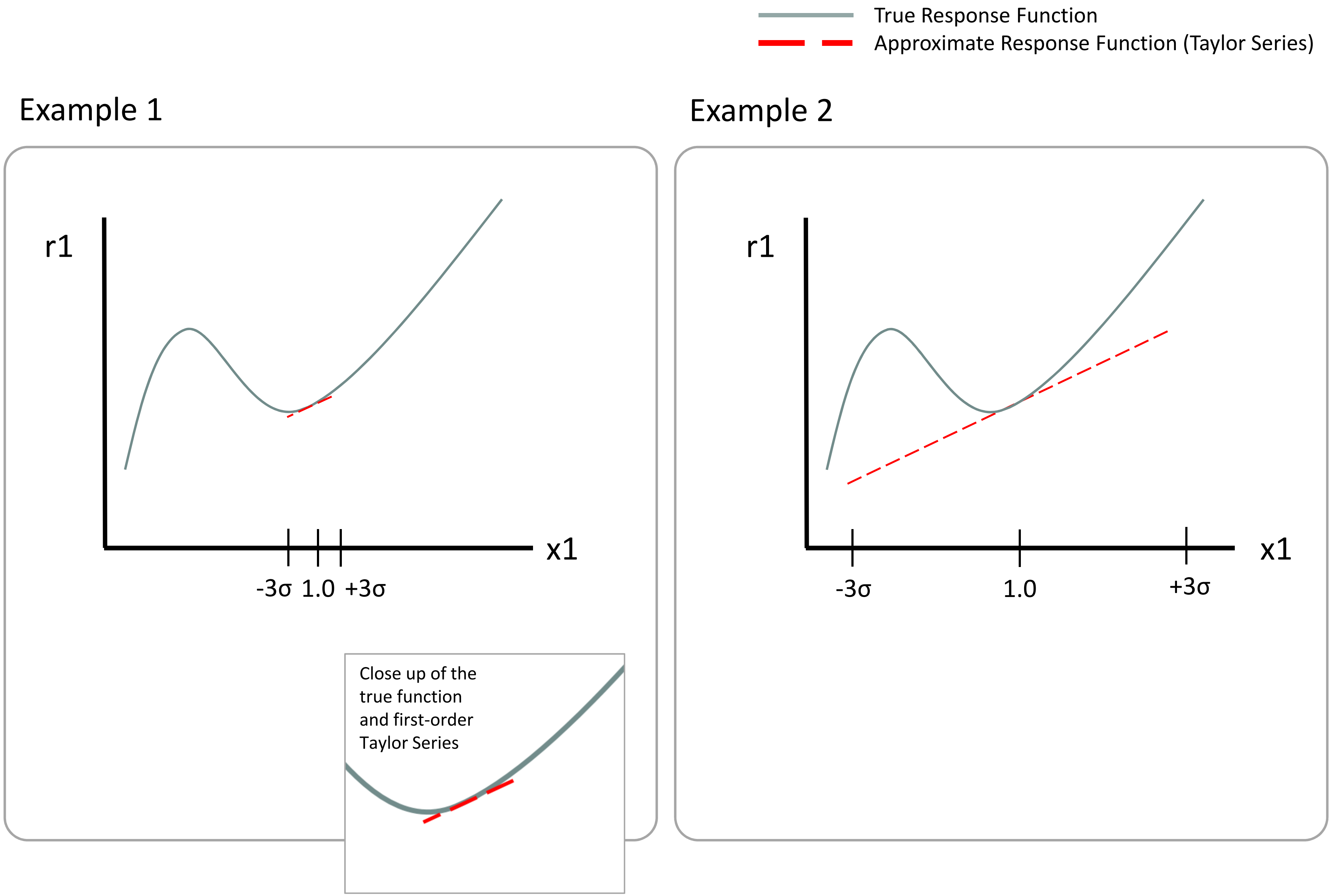
Consider 2 examples.

- In example 1, the x1 variable's mean is 1.0 and the standard deviation is 0.01.
- In example 2, the x1 variable's mean is 1.0 and the standard deviation is 0.1. Note the standard deviation is significantly larger.

The MVFOSM method is based on the assumption the response function can be approximated with a first-order Taylor series that includes gradients. It is from the first-order Taylor series that the mean and standard deviation are approximated.

1. In example 1, since the variable's standard deviation is small enough, the first-order Taylor series is fairly accurate in approximating the true response function. While the response function is globally nonlinear, UQ using the MVFOSM method is expected to yield accurate tail probabilities in the local region, or the region within 3 standard deviations.
2. In example 2, if the standard deviations are large enough, the first-order Taylor series poorly approximates the true response function. If the MVFOSM method is used when the variable's standard deviations are large, MVFOSM is expected to yield inaccurate tail probabilities.

To answer the original question, MVFOSM works well when the variable's standard deviations are small enough such that a first-order Taylor series can approximate the true response function.



Part B – Preparing MSC Nastran Bulk Data Files for Optimization Under Uncertainty

Motivation

Part A - In part A, the response distributions were confirmed to have near normal distributions. Also, the responses are supported by MSC Nastran SOL 200, so the SOL 200 procedure is used in part B to output the gradients. Since the distributions are normal and gradients are available, the MVFOSM method may be used for UQ or OUU.

Part B - In part B, the MSC Nastran bulk data file of the 3-bar truss is prepared to output gradients for use in a future OUU.

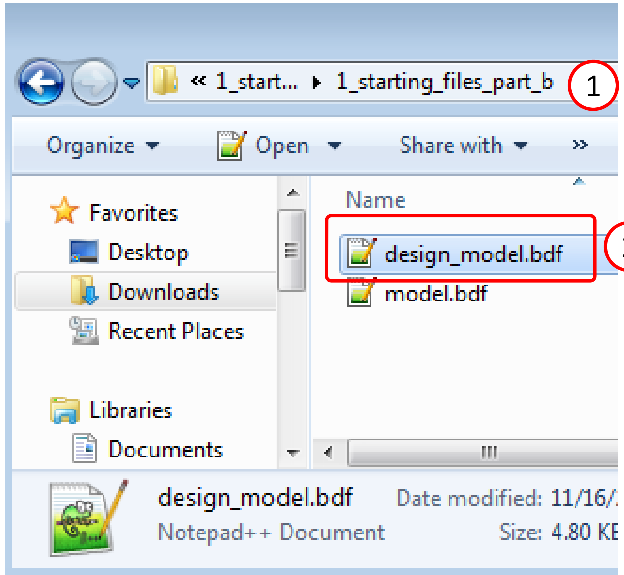
- An MSC Nastran SOL 200 optimization was performed to determine a starting point for a future OUU.
- The bulk data files of the 3-bar truss are configured for a sensitivity analysis, which will output gradients necessary in a future UQ or OUU.
  - The bounds on the DESVAR entries are removed.
  - The procedure is changed from a local optimization to a sensitivity analysis.
  - The DSCREEN entries are modified to output at gradients for at most 100 responses for each response type.
  - A test run is performed to ensure the bulk data files are free from errors and sensitivities/gradients are output.

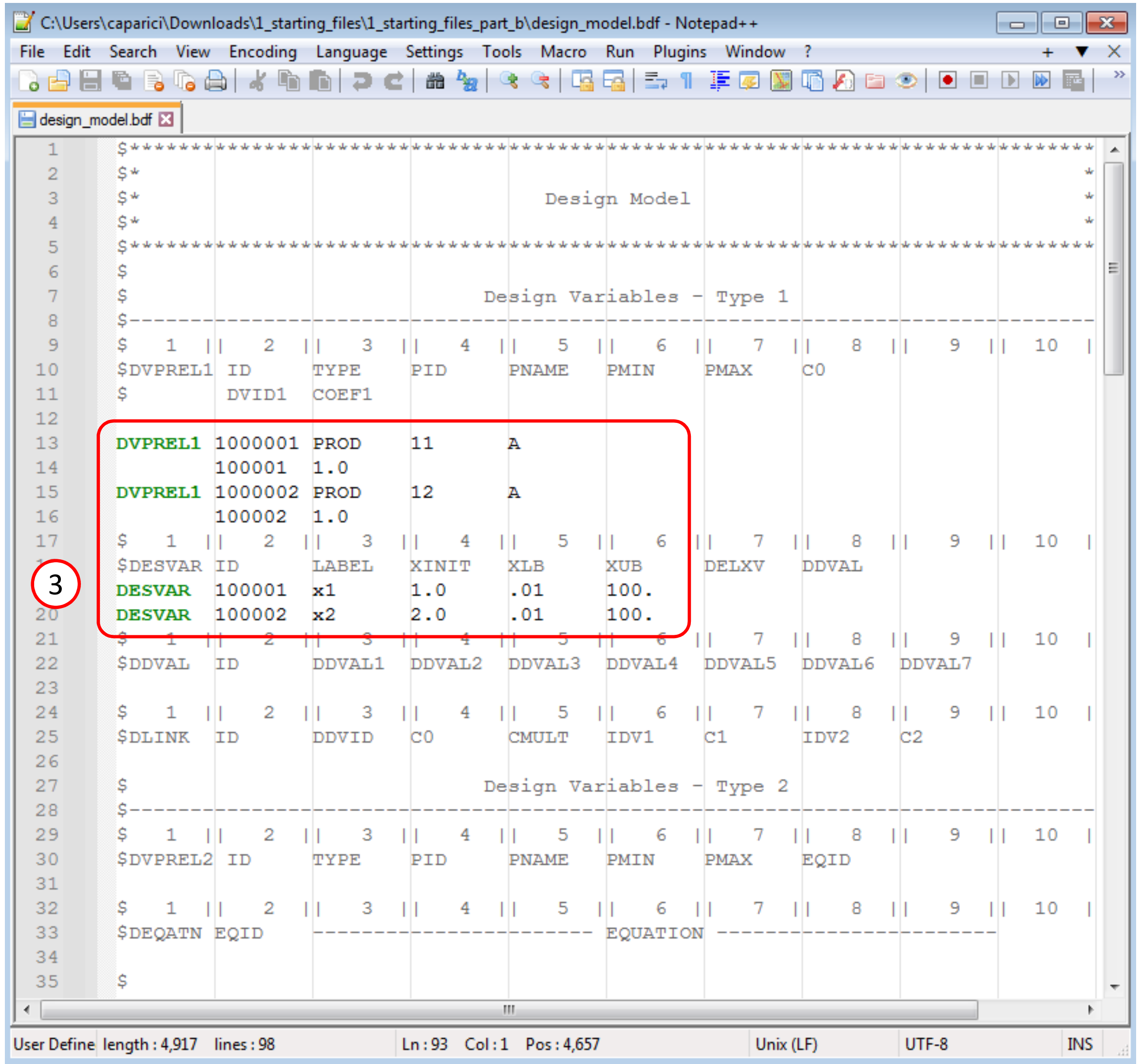
Note

Since the MVFOSM method may be used, gradients must be available. MSC Nastran SOL 200 has a sensitivity analysis capability that outputs gradients. The bulk data files must be configured for MSC Nastran SOL 200. Variables, objective and constraints must be defined via entries DESVAR, DVPREL1, DRESP1, DCONSTR, etc. This has already been done.

1. Navigate to directory 1_starting_files_part_b
2. Open file design_model.bdf in a text editor
3. Inspection of the file shows entries for SOL 200 have already been configured., including entries for the variables, objective and constraints.

Configuring bulk data files for MSC Nastran SOL 200 has been extensively detailed in various tutorials found in the User's Guide. New users to MSC Nastran SOL 200 are referred to the extensive set of tutorials found in the User's Guide.





Optimization Problem Statement

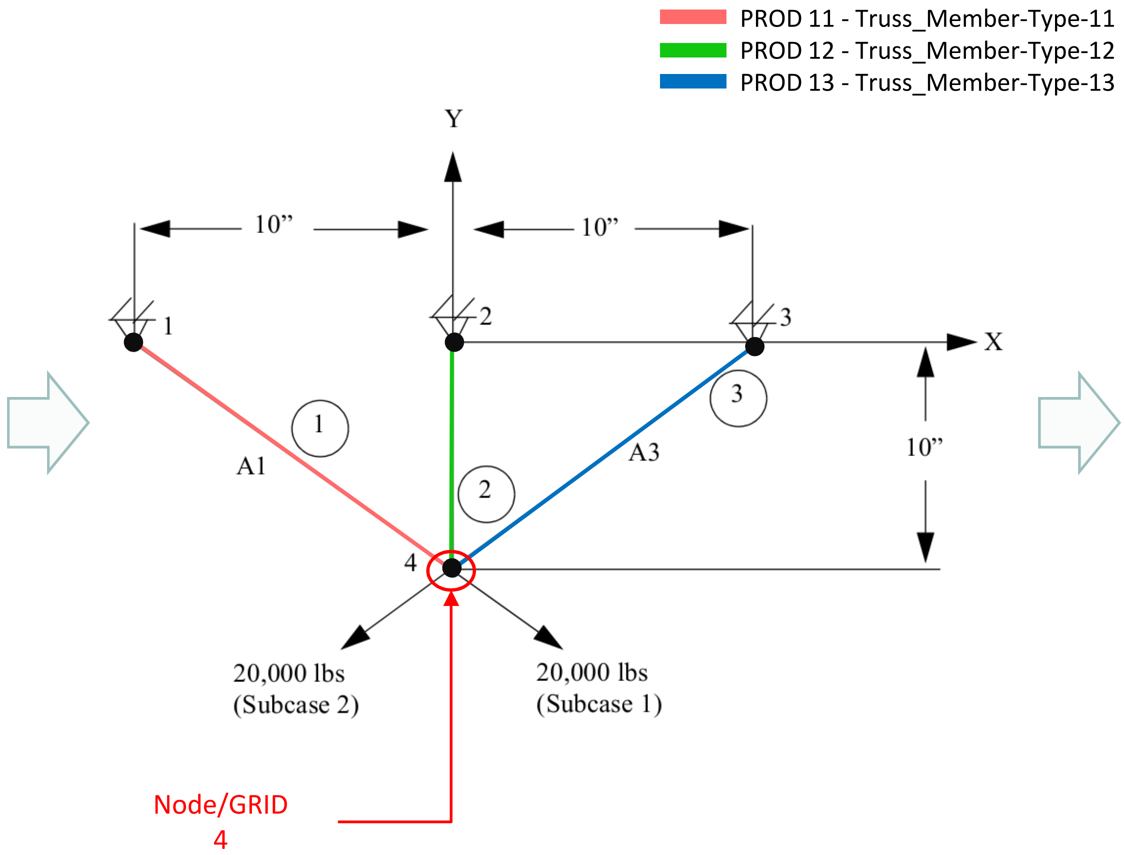
Design Variables

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

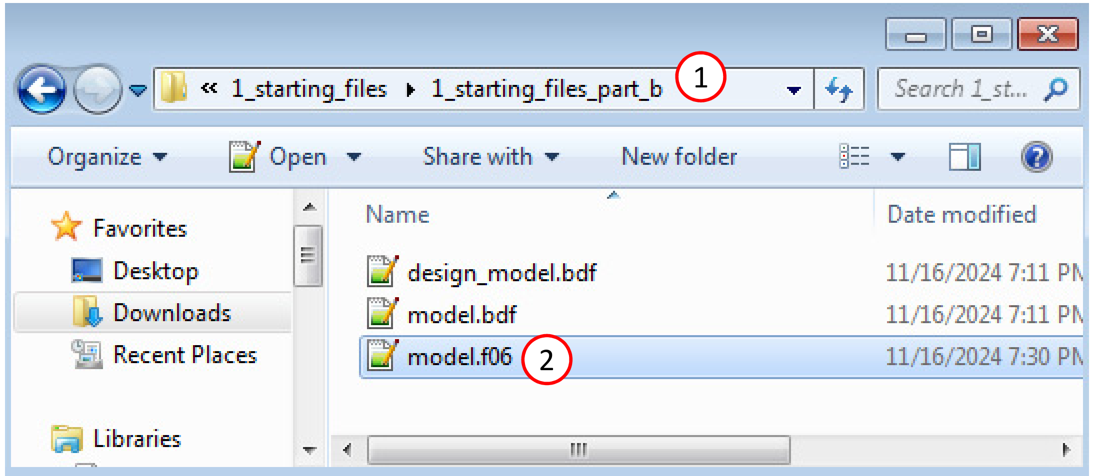
-15000 < r1 < 20000

r2: x and y component of displacement for node 4

-.2 < r2 < .2

Inspection of Optimization Results for Deterministic Responses

1. Navigate to directory 1_starting_files_part_b
2. Open file model.f06 in a text editor
3. MSC Nastran SOL 200 was used to perform an optimization with deterministic inputs and outputs. The optimization solution will be used as the initial point for a future OUU. The rationale is that the optimal solution for an OUU is near the optimal solution of an optimization with deterministic responses and will reduce the amount of search the optimizer requires to find the optimal OUU solution. Record the optimal solution x1 and x2 for future use.




```
DESIGN VARIABLE HISTORY
-----------------------------------------------------------------------------------------------------------------------------------
 INTERNAL |    EXTERNAL   |                |
  DV. ID. |     DV. ID.   |      LABEL     |   INITIAL     :       1       :       2       :       3       :       4       :       5       :
-----------------------------------------------------------------------------------------------------------------------------------
        1 |      100001   |   X1           |   1.0000E+00 :   7.1191E-01 :   7.7981E-01 :   7.9873E-01 :   8.1395E-01 :   8.2430E-01 :
        2 |      100002   |   X2           |   2.0000E+00 :   1.0000E+00 :   6.1771E-01 :   4.7517E-01 :   4.0784E-01 :   3.7203E-01 :
-----------------------------------------------------------------------------------------------------------------------------------
 INTERNAL |    EXTERNAL   |                |
  DV. ID. |     DV. ID.   |      LABEL     |       6       :       7       :       8       :       9       :      10       :      11       :
-----------------------------------------------------------------------------------------------------------------------------------
        1 |      100001   |   X1           |   8.3571E-01 :   8.3724E-01 :
        2 |      100002   |   X2           |   3.3435E-01 :   3.2830E-01 :
*** USER INFORMATION MESSAGE 6464 (DOM12E)
    RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER =         7.
```

3

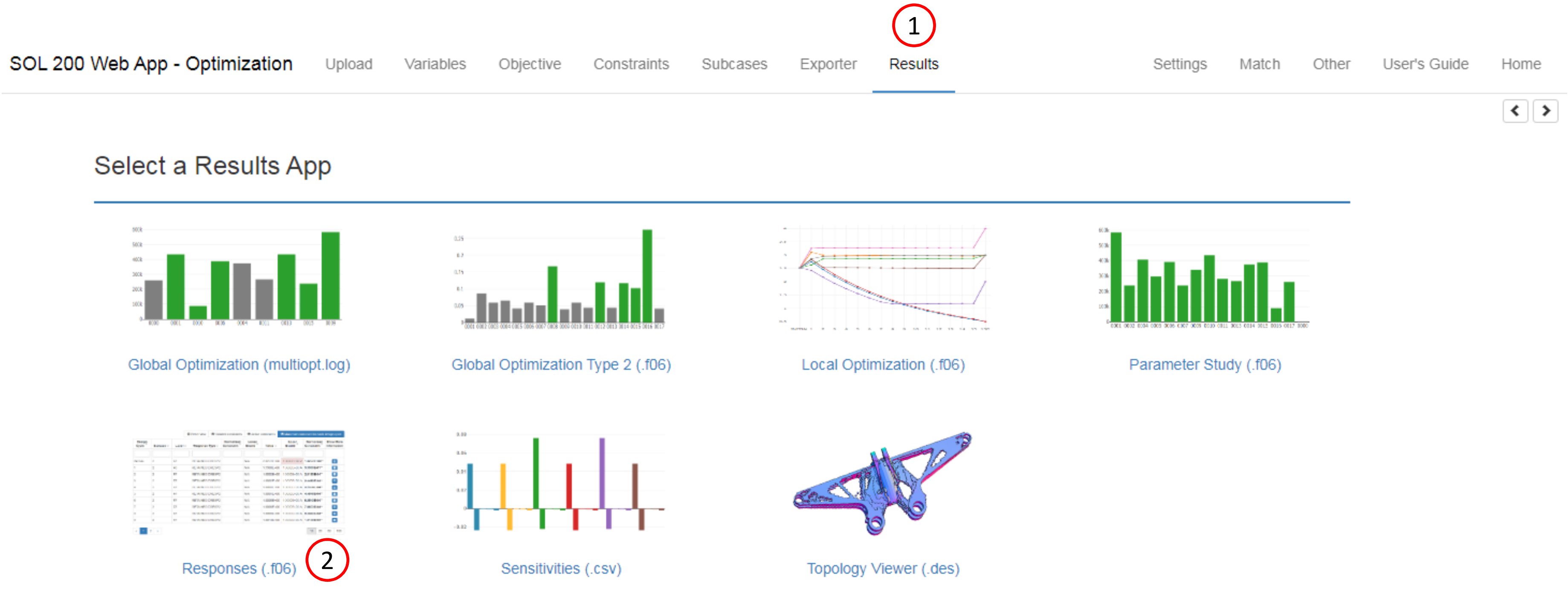
Open the Correct Page

1. Click on the indicated link

The Engineering Lab

Open the Responses App

1. Click Results.
2. Click Responses(.f06).



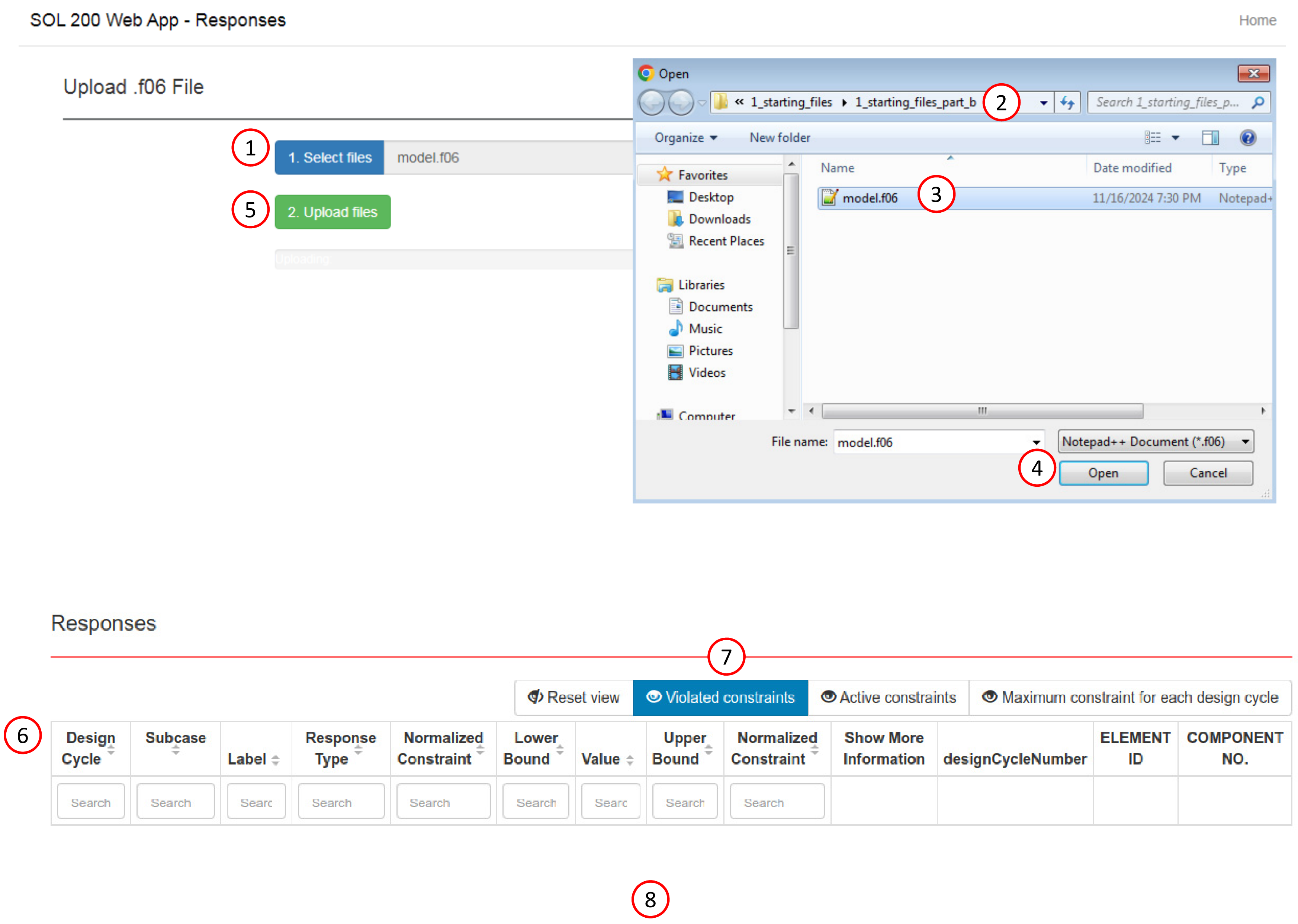
- The Results section contains links to numerous other web application designed for specific applications. For example, if sensitivity analysis is performed, the Sensitivities App can display the results.

Responses During Optimization

The goal is to identify which responses are critical during the optimization. A response is critical if its constraints are violated or active during the optimization. The same responses will be critical during an OUU.

A new page is open to the Responses web app.

1. Click Select files
2. Navigate to directory 1_starting_files_part_b
3. Select file model.f06
4. Click Open
5. Click Upload files
6. The responses considered during the optimization and listed in the .f06 file are shown in the table
7. Click Violated constraints
8. Note there are no violated constraints during the optimization, so the table is empty



Screening Responses and Constraints for OUU

1. Click Active constraints
2. Click the indicated button to display at most 25 rows in the table
3. The active constraints correspond to stress responses from subcase 1 and 2
4. Click on the indicated blue button to display additional columns
5. The active constraints also correspond to elements 1 and 3.

The displacement responses and constraints are neither violated or active during optimization and are likely not to exceed constraints on probabilities of failure during OUU. Constraints on displacement responses will not be considered in a future OUU.

While there are 3 elements in the 3-bar truss, only stress responses from elements 1 and 3 will be considered in a future OUU. The axial stress from element 2 is not considered since this axial stress was neither active or violated during the optimization.

Responses

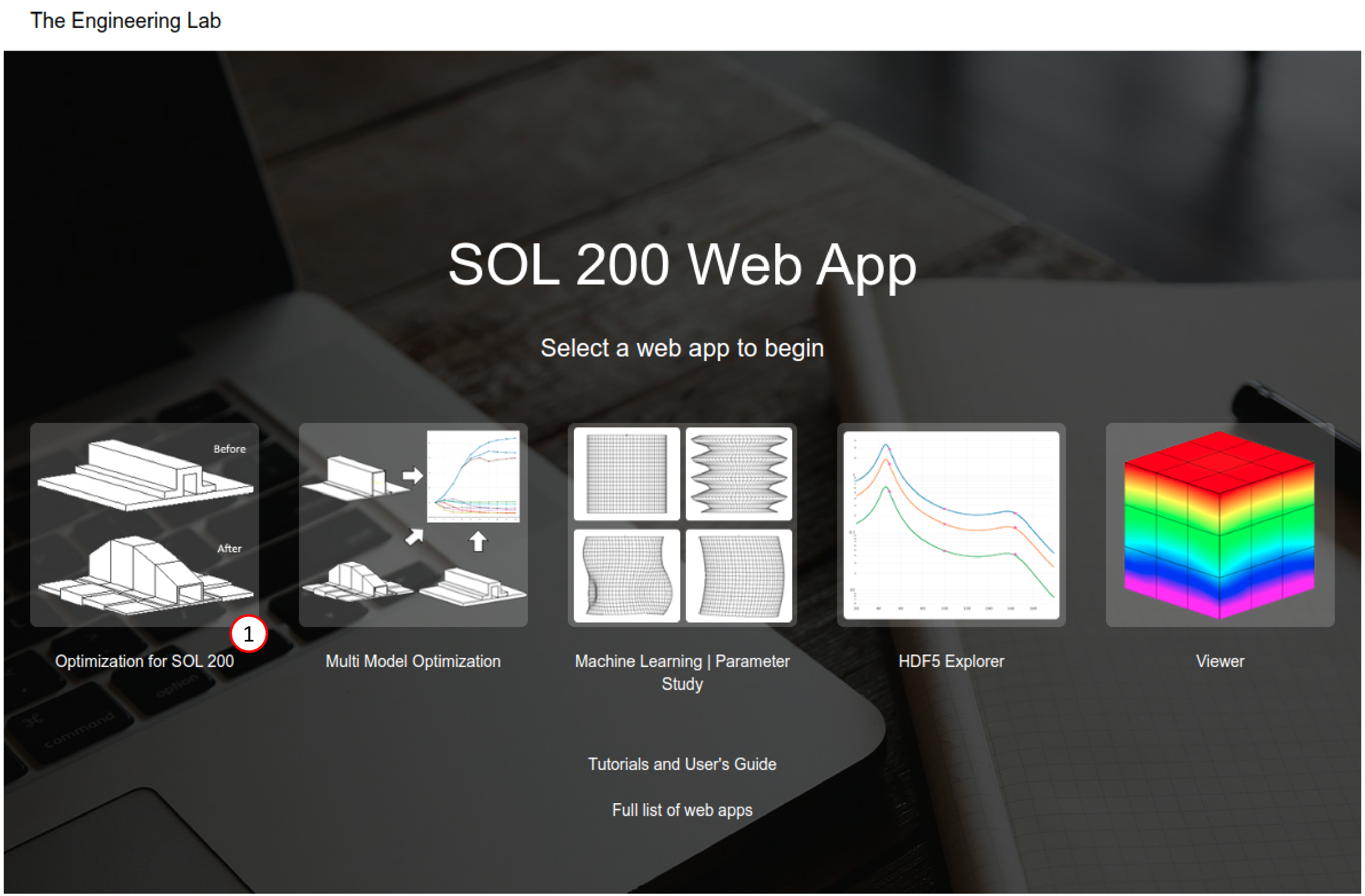
Reset view | Violated constraints | Active constraints | Maximum constraint for each design cycle

Design Cycle	Subcase	Label	Response Type	Normalized Constraint	Lower Bound	Value	Upper Bound	Normalized Constraint	Show More Information	designCycleNumber	ELEMENT ID	COMPONENT NO.
1	1	r2	STRESS		N/A	1.9883E+04	2.0000E+04 A	**-5.8502E-03****		1	1	2
1	2	r2	STRESS		N/A	1.9883E+04	2.0000E+04 A	**-5.8502E-03****		1	3	2
2	1	r2	STRESS		N/A	1.9640E+04	2.0000E+04 A	**-1.7978E-02****		2	1	2
2	2	r2	STRESS		N/A	1.9640E+04	2.0000E+04 A	**-1.7978E-02****		2	3	2
3	1	r2	STRESS		N/A	1.9934E+04	2.0000E+04 A	**-3.2965E-03****		3	1	2
3	2	r2	STRESS		N/A	1.9934E+04	2.0000E+04 A	**-3.2965E-03****		3	3	2
4	1	r2	STRESS		N/A	2.0001E+04	2.0000E+04 A	**5.1584E-05****		4	1	2
4	2	r2	STRESS		N/A	2.0001E+04	2.0000E+04 A	**5.1584E-05****		4	3	2
5	1	r2	STRESS		N/A	2.0009E+04	2.0000E+04 A	**4.2618E-04****		5	1	2
5	2	r2	STRESS		N/A	2.0009E+04	2.0000E+04 A	**4.2618E-04****		5	3	2
6	1	r2	STRESS		N/A	2.0022E+04	2.0000E+04 A	**1.1166E-03****		6	1	2
6	2	r2	STRESS		N/A	2.0022E+04	2.0000E+04 A	**1.1166E-03****		6	3	2
FINAL - 7	1	r2	STRESS		N/A	2.0033E+04	2.0000E+04 A	**1.6263E-03****		7	1	2
FINAL - 7	2	r2	STRESS		N/A	2.0033E+04	2.0000E+04 A	**1.6263E-03****		7	3	2

10 | 25 | 50 | 100

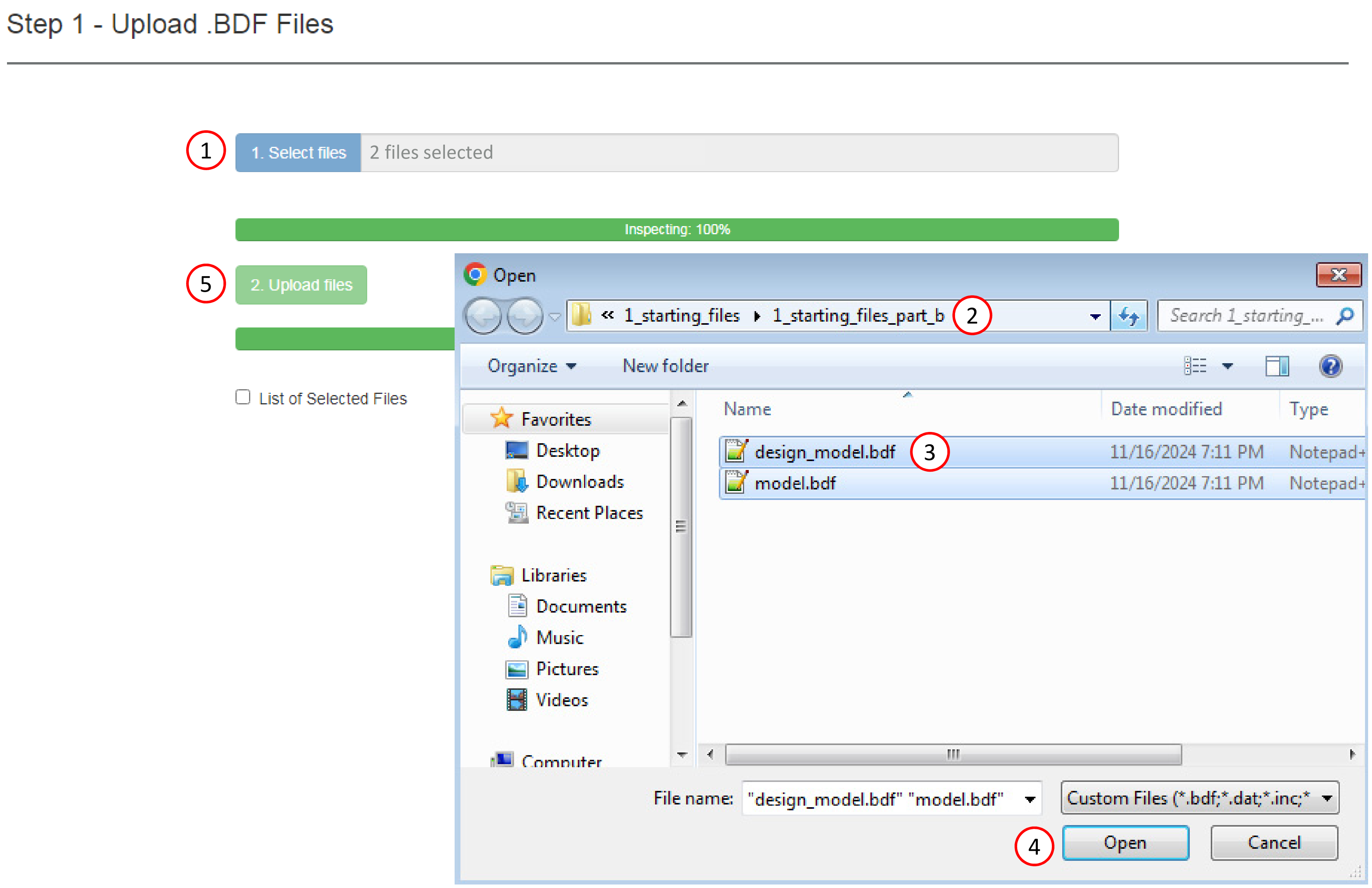
Open the Correct Page

1. Click on the indicated link



Upload BDF Files

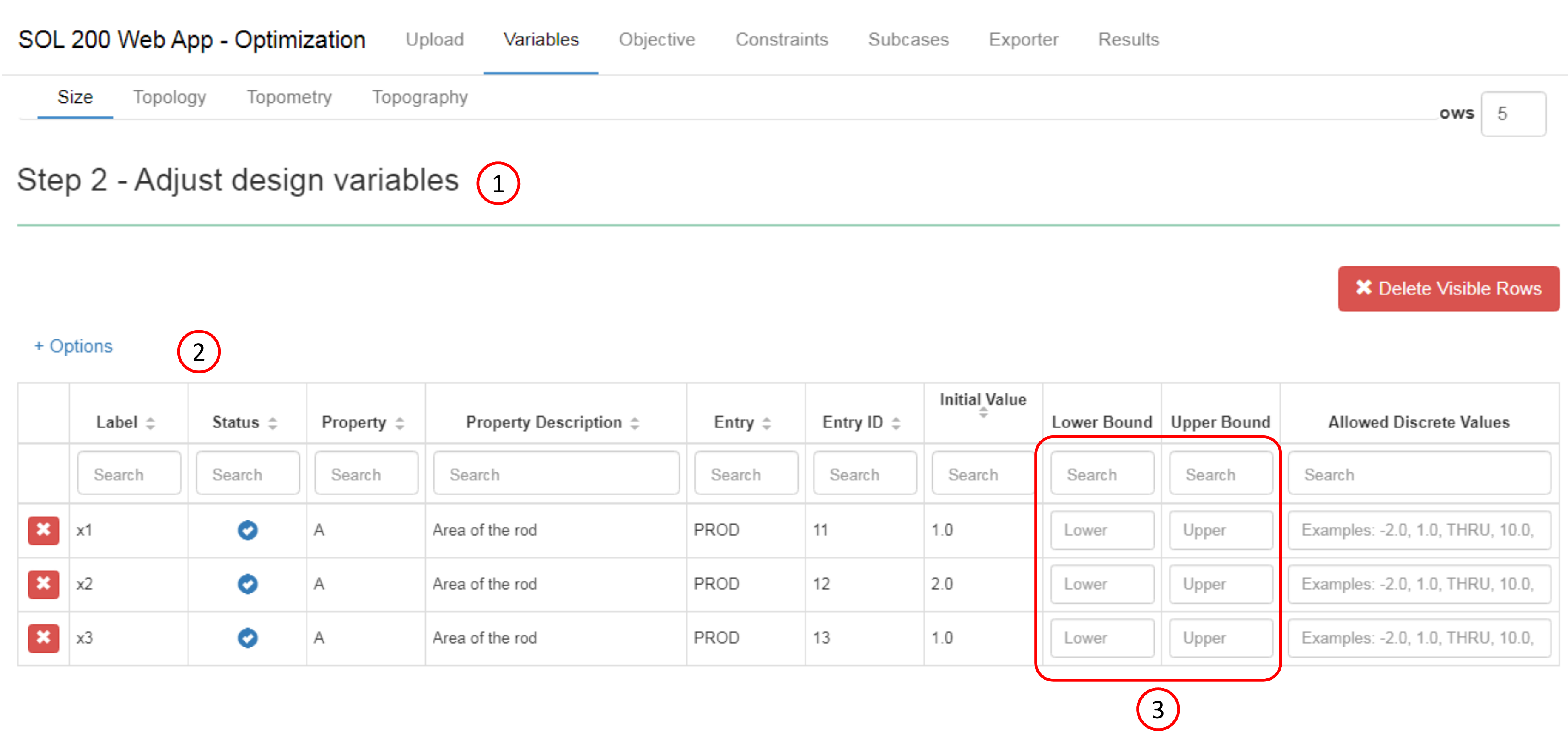
1. Click Select Files
2. Navigate to directory 1_starting_files_part_b
3. Select model.bdf and design_model.bdf
4. Click Open
5. Click Upload Files



Modify Variables

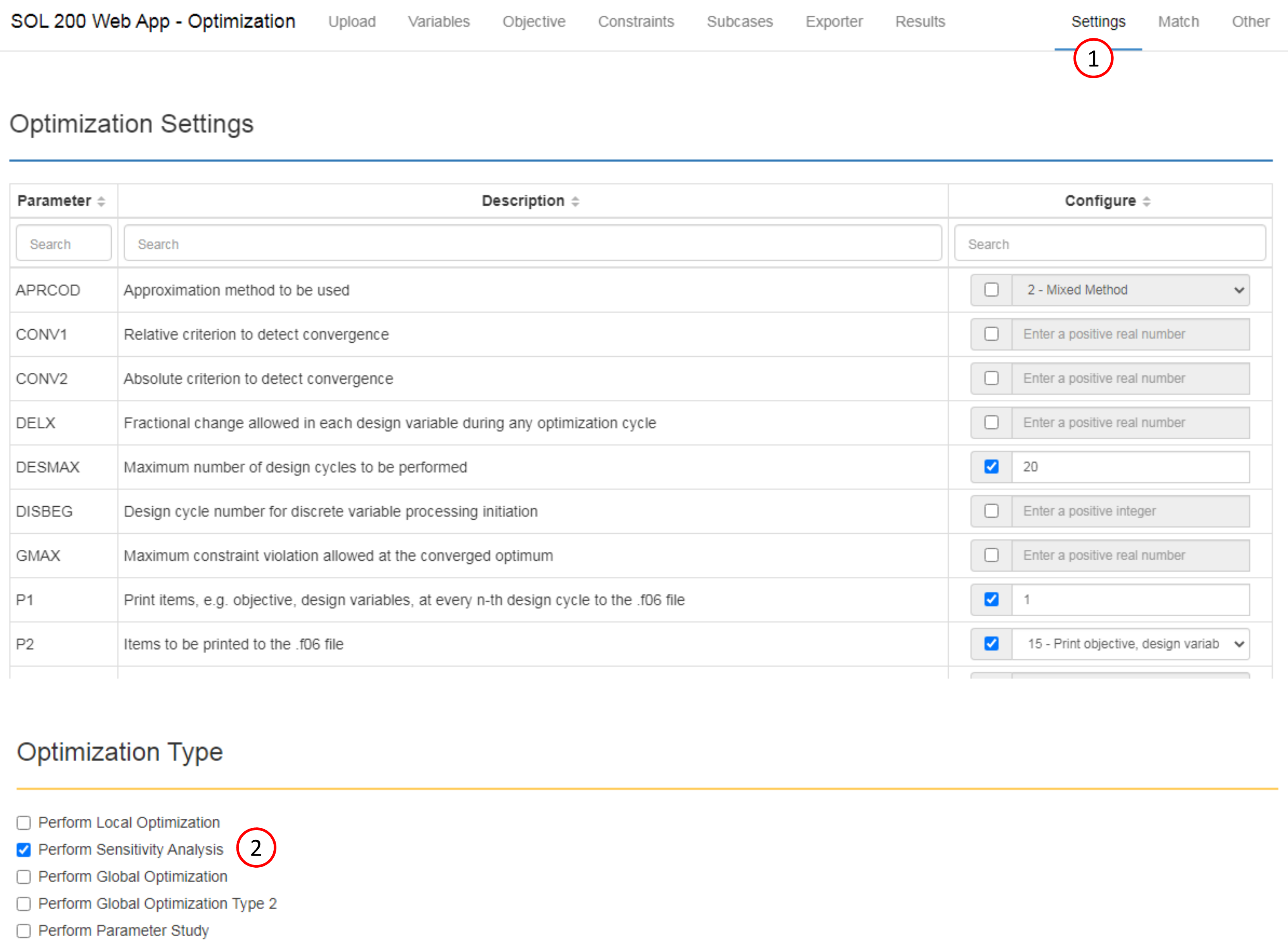
1. Navigate to section Step 2 – Adjust design variables
2. The design variables configured in a separate tutorial are now available for modification
3. Remove all the bounds from each variable

- The DESVAR bounds may conflict with the bounds configured for OUU. For example, if the OUU variable x1_mean is configured between -10 and +10, but the DESVAR entry is configured to have bounds between -5 and +5, when the OUU optimizer submits a variable value x1_mean=+8, the MSC Nastran run will fail because +8 exceeds the bounds on the DESVAR entry. It is for this reason, that the bounds on DESVAR entries should be removed prior to configuring an OUU. Quick reminder that part B is meant to configure bulk data files to output gradients, a formal OUU configuration comes in a future tutorial.



Configure Settings

1. Click Settings
2. Mark the checkbox labeled Perform Sensitivity Analysis

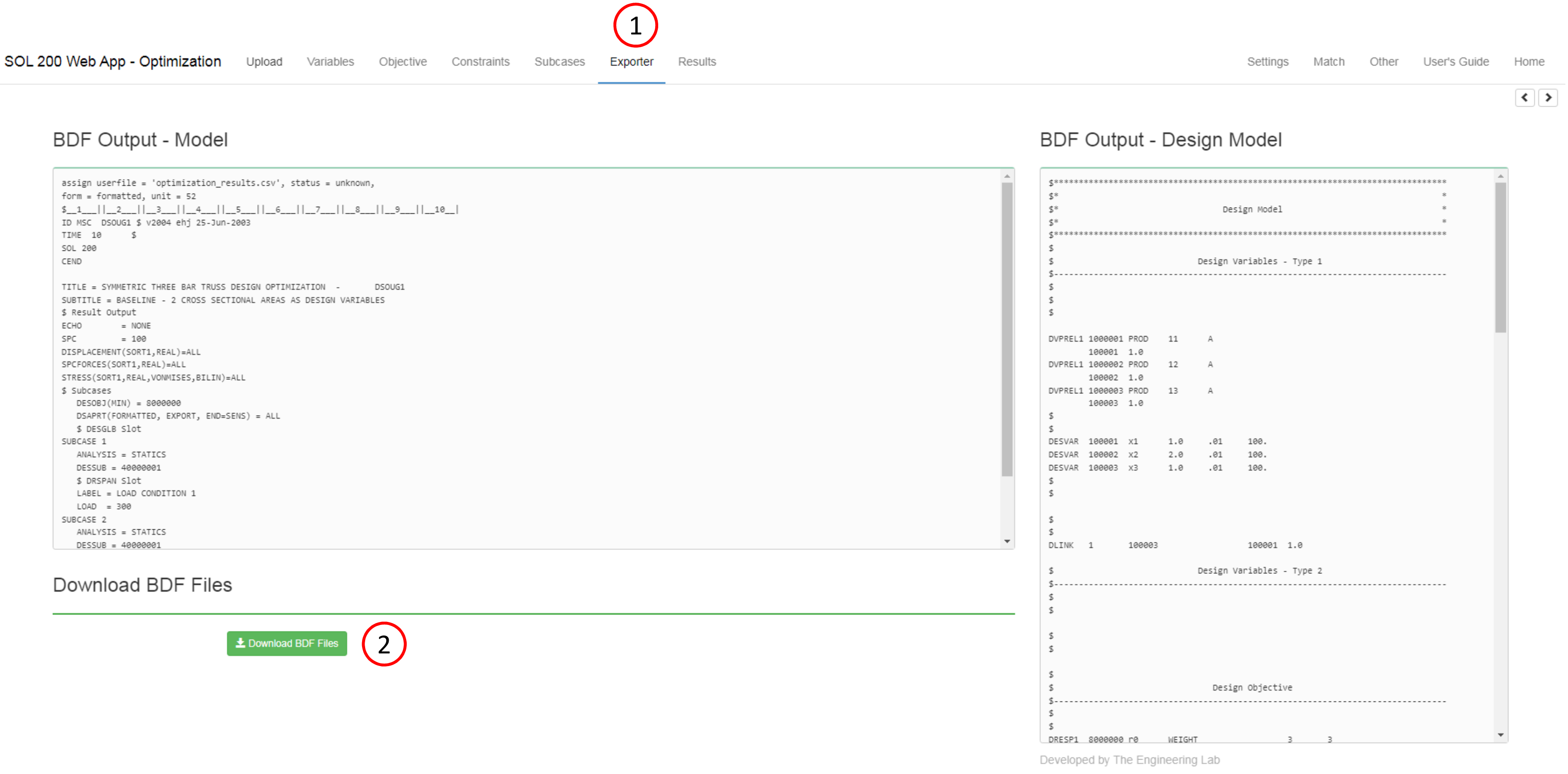


- Sensitivity analysis computes the gradients or partial derivatives of responses with respect to design variables. For example, if the sensitivity of weight with respect to x1 is -200., then a change of 1.0 in x1 yields a change of -200 in the weight.

Export New BDF Files

1. Click Exporter
2. Click 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”

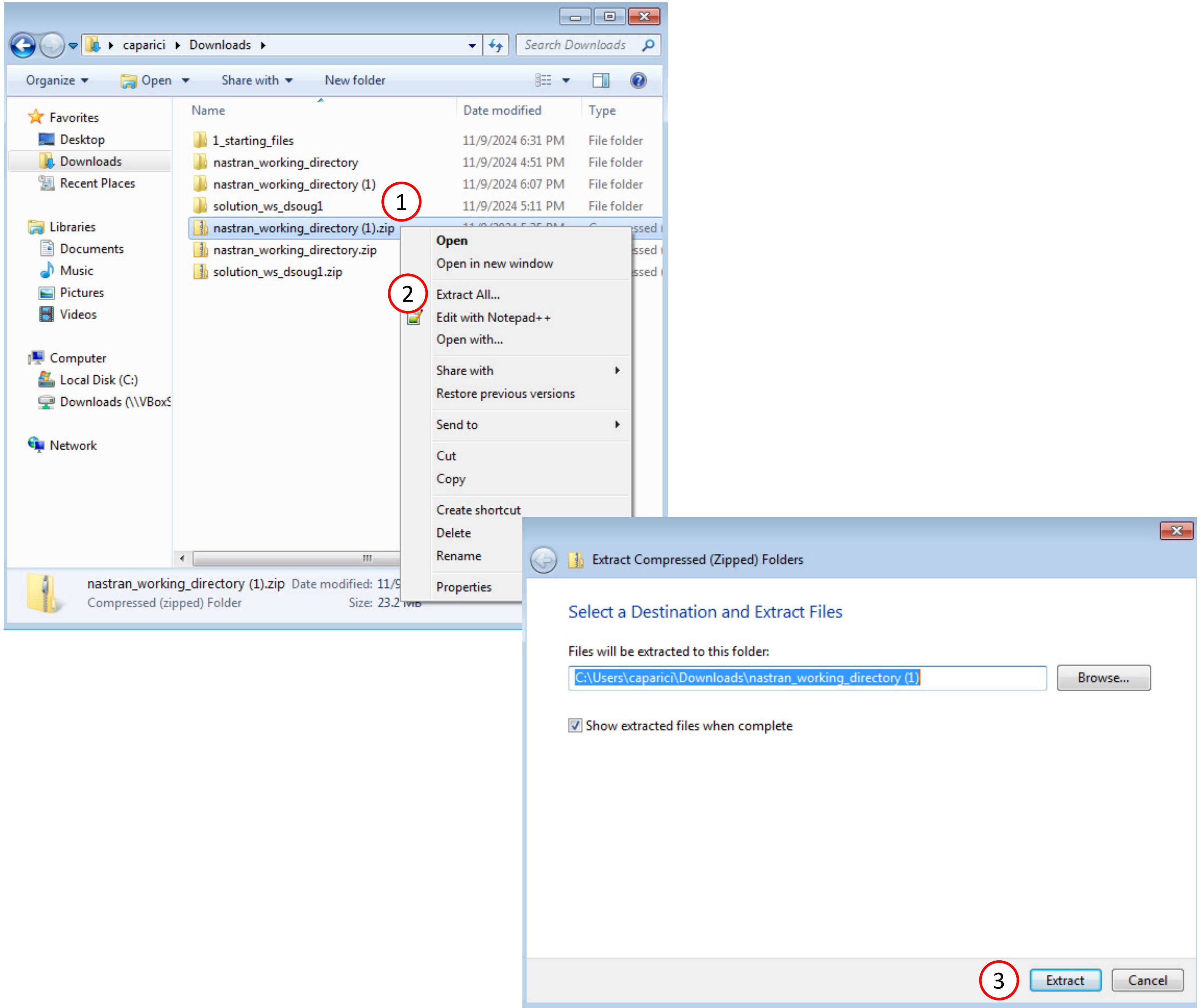


Perform the Optimization with Nastran SOL 200

A new .zip file has been downloaded

1. Right click on the file
2. Click Extract All
3. Click Extract on the following window

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



Update the DSCREEN entries

MSC Nastran SOL 200 will output a finite number of sensitivities or gradients. This is controlled by the DSCREEN entry. When the BDF files are downloaded from the Size web app, the DSCREEN entries are configured to output gradients for at most 10 responses for each response type. For OUU problems that involve hundreds of responses, you will need gradients for more than 10 responses.

1. Open the file design_model.bdf in Notepad++
2. Use CTRL+ALT and the left mouse button to select only the values 10 for each row simultaneously.
3. Replace each value 10 with the value 100. Now gradients will be available for up to 100 responses for each response type.
4. Save any edits made to the text file (not shown)

While a future OUU is only considering the responses from elements 1 and 3 (2 responses), this step is not necessary since the DSCREEN entry is already configured to output gradients for at most 10 responses. But this step will be required for OUU with hundreds of responses and constraints, so it was worth mentioning.

Before

(1)

```
$
$    Design Constraint Screening
$---------------------------------------
$
DSCREEN WEIGHT  -10000. 10
DSCREEN VOLUME  -10000. 10
DSCREEN EIGN    -10000. 10
DSCREEN CEIG    -10000. 10
DSCREEN FREQ    -10000. 10
DSCREEN LAMA    -10000. 10
DSCREEN DISP    -10000. 10
DSCREEN STRAIN  -10000. 10
DSCREEN ESE     -10000. 10
DSCREEN STRESS  -10000. 10
DSCREEN FORCE   -10000. 10
DSCREEN FATIGUE -10000. 10
DSCREEN FRFTG   -10000. 10
DSCREEN SPCFORCE-10000. 10
DSCREEN CSTRAIN -10000. 10
DSCREEN CSTRESS -10000. 10
DSCREEN CFAILURE-10000. 10
DSCREEN CSTRAT  -10000. 10
DSCREEN TOTSE   -10000. 10
[…]
DSCREEN STMOND1 -10000. 10
DSCREEN MONPNT3 -10000. 10
DSCREEN AEMONP1 -10000. 10
DSCREEN AEMOND1 -10000. 10
DSCREEN TRIM    -10000. 10
DSCREEN STABDER -10000. 10
DSCREEN FLUTTER -10000. 10
DSCREEN DIVERG  -10000. 10
DSCREEN WMPID   -10000. 10
DSCREEN EQUA    -10000. 10
```

(2)

After

```
$
$    Design Constraint Screening
$---------------------------------------
$
DSCREEN WEIGHT  -10000. 100
DSCREEN VOLUME  -10000. 100
DSCREEN EIGN    -10000. 100
DSCREEN CEIG    -10000. 100
DSCREEN FREQ    -10000. 100
DSCREEN LAMA    -10000. 100
DSCREEN DISP    -10000. 100
DSCREEN STRAIN  -10000. 100
DSCREEN ESE     -10000. 100
DSCREEN STRESS  -10000. 100
DSCREEN FORCE   -10000. 100
DSCREEN FATIGUE -10000. 100
DSCREEN FRFTG   -10000. 100
DSCREEN SPCFORCE-10000. 100
DSCREEN CSTRAIN -10000. 100
DSCREEN CSTRESS -10000. 100
DSCREEN CFAILURE-10000. 100
DSCREEN CSTRAT  -10000. 100
DSCREEN TOTSE   -10000. 100
[…]
DSCREEN STMOND1 -10000. 100
DSCREEN MONPNT3 -10000. 100
DSCREEN AEMONP1 -10000. 100
DSCREEN AEMOND1 -10000. 100
DSCREEN TRIM    -10000. 100
DSCREEN STABDER -10000. 100
DSCREEN FLUTTER -10000. 100
DSCREEN DIVERG  -10000. 100
DSCREEN WMPID   -10000. 100
DSCREEN EQUA    -10000. 100
```

(3)

Sensitivity Analysis Only

1. Open file model.bdf in a text editor. Note the DSPART case control command is present and is configured for a sensitivity analysis only (END=SENS). MSC Nastran SOL 200 is NOT used to perform an optimization. MSC Nastran SOL 200 is only used to output gradients for use in a future OUU.

```
DESOBJ(MIN) = 8000000
DSAPRT(FORMATTED, EXPORT, END=SENS) = ALL
$ DESGLB Slot
```

(1)

Ensure H5 Output is Enabled

1. Inspection of file design_model.bdf shows H5 output is enabled. No modifications are necessary.

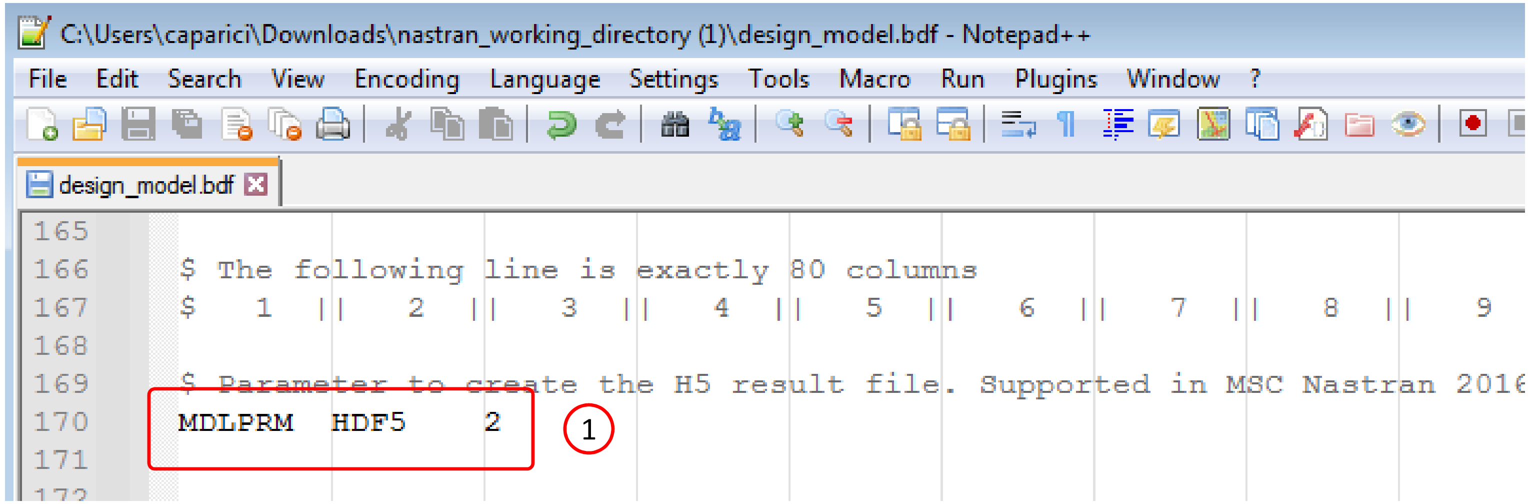
The response values and gradients will be stored in the H5 file and will be accessed during the uncertainty quantification or optimization under uncertainty.

A. If H5 output is not enabled, H5 output may be enabled with the following instructions.

Add one of the following entries to the bulk data files.

MDLPRM,HDF5,2

HDF5OUT



(A)

Option 1

```
MDLPRM   HDF5     2
```

Option 2

```
HDF5OUT
```

Next Step

A test sensitivity analysis is performed to ensure the bulk data files run with no error.

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

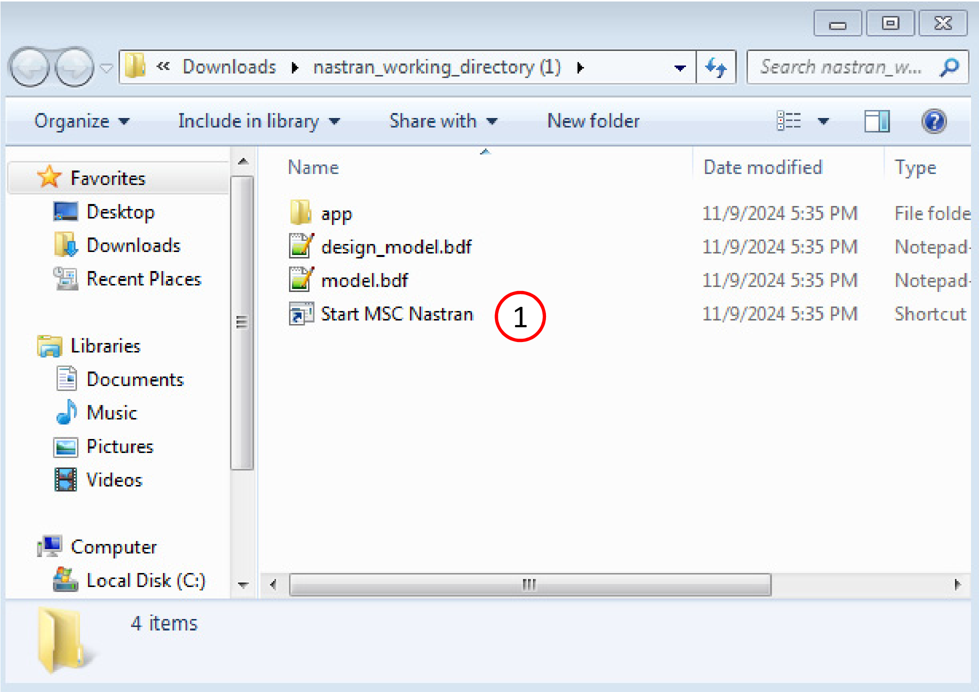
- After a successful run, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the remote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

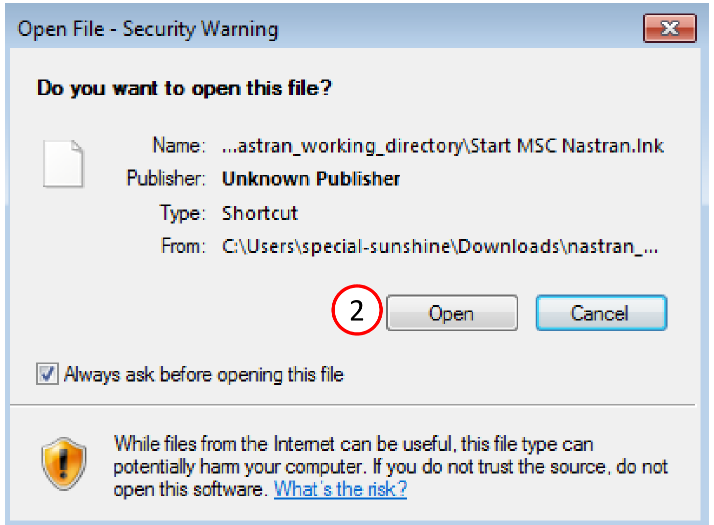
Using Linux?

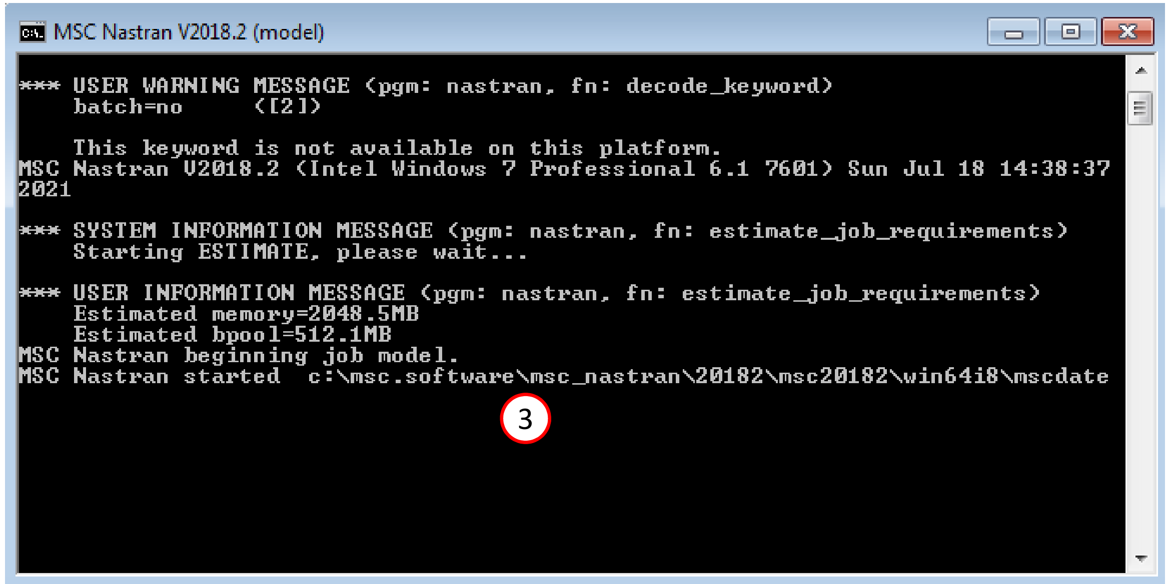
Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
cd ./nastran_working_directory
3) Use this command to start the process
./Start_MSC_Nastran.sh

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

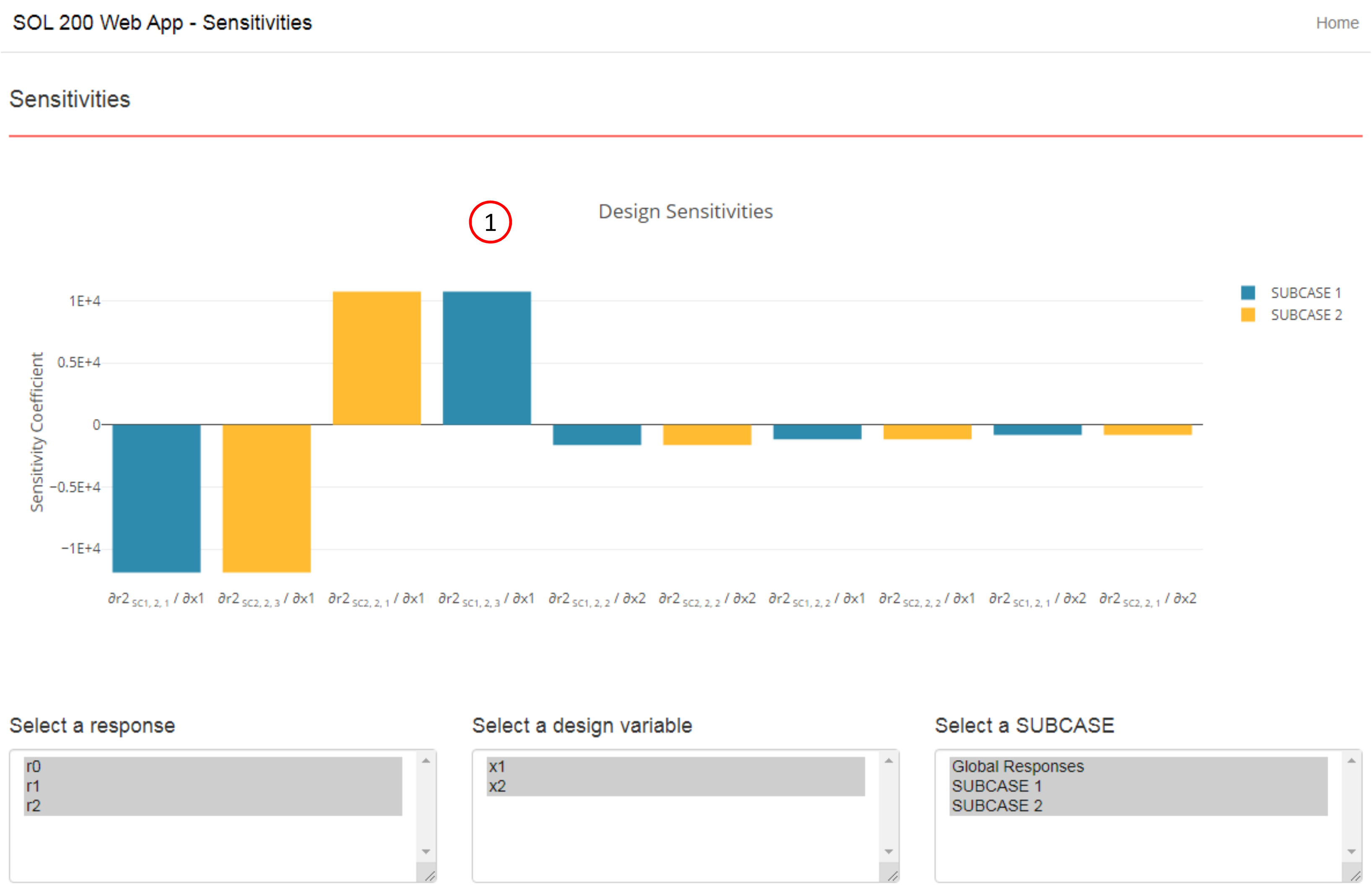
Status

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

Review Optimization Results

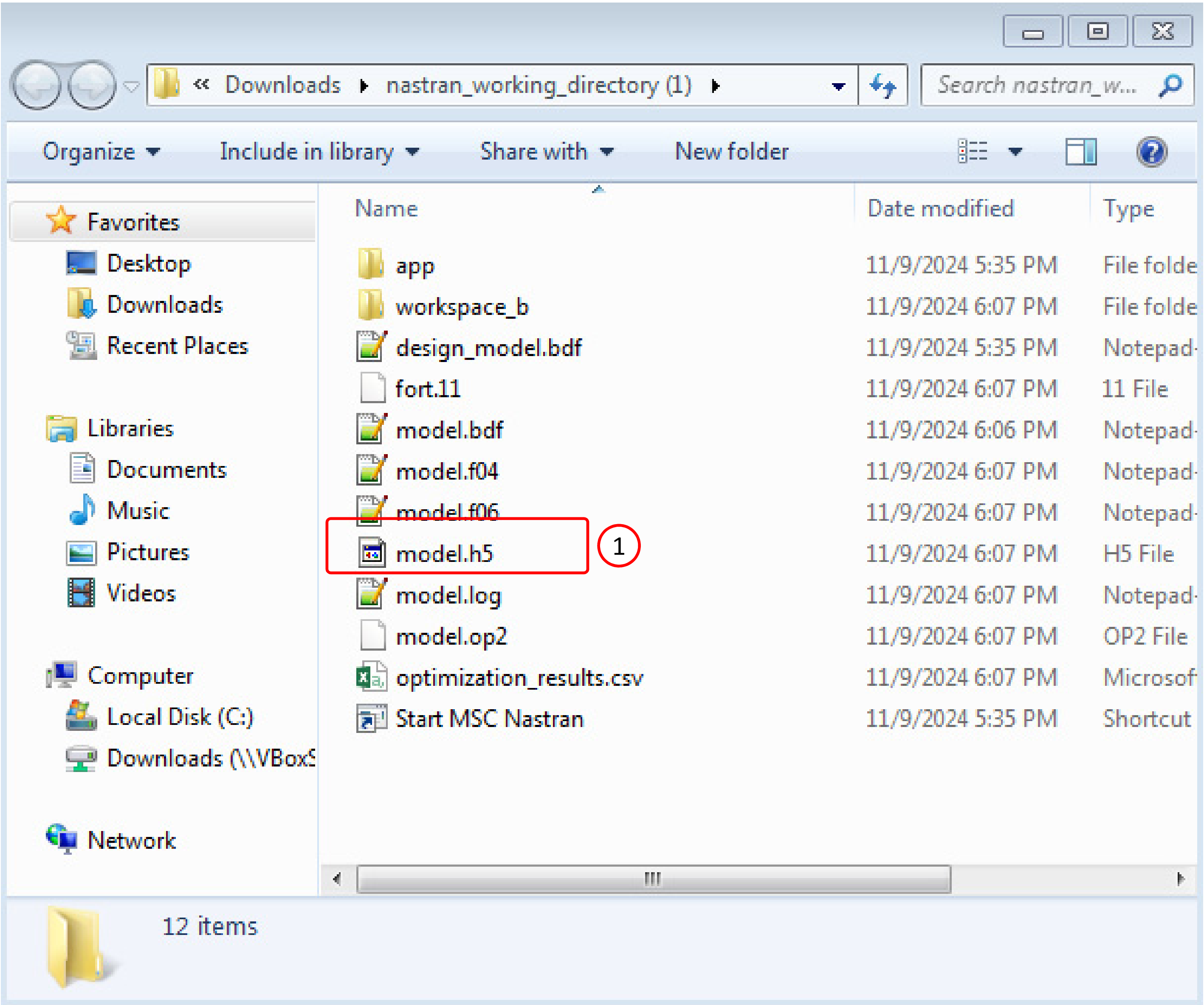
After MSC Nastran is successfully complete, the results will be automatically uploaded.

1. If bar charts are displayed, such as the one shown, the sensitivity analysis has been a success. The bulk data files are now configured to output sensitivities for use in a future UQ or OUU.



Confirm the H5 is Present

1. As stated earlier, it is essential the H5 file is available. The UQ or OUU procedures will depend on the presence of the H5 file to acquire the necessary responses and gradients.



Summary

Part A - In part A, the response distributions were confirmed to have near normal distributions. Also, the responses are supported by MSC Nastran SOL 200, so the SOL 200 procedure is used in part B to output the gradients. Since the distributions are normal and gradients are available, the MVFOSM method may be used for UQ or OUU.

Part B - In part B, the MSC Nastran bulk data file of the 3-bar truss is prepared to output gradients for use in a future OUU.

- An MSC Nastran SOL 200 optimization was performed to determine a starting point for a future OUU.
- The bulk data files of the 3-bar truss are configured for a sensitivity analysis, which will output gradients necessary in a future UQ or OUU.
  - The bounds on the DESVAR entries are removed.
  - The procedure is changed from a local optimization to a sensitivity analysis.
  - The DSCREEN entries are modified to output at gradients for at most 100 responses for each response type.
  - A test run is performed to ensure the bulk data files are free from errors and sensitivities/gradients are output.

End of Tutorial