Workshop - Uncertainty Quantification - 10 Bar Truss with MSC Nastran

AN MSC NASTRAN UNCERTAINTY QUANTIFICATION TUTORIAL

Questions? Email: christian@ the-engineering-lab.com

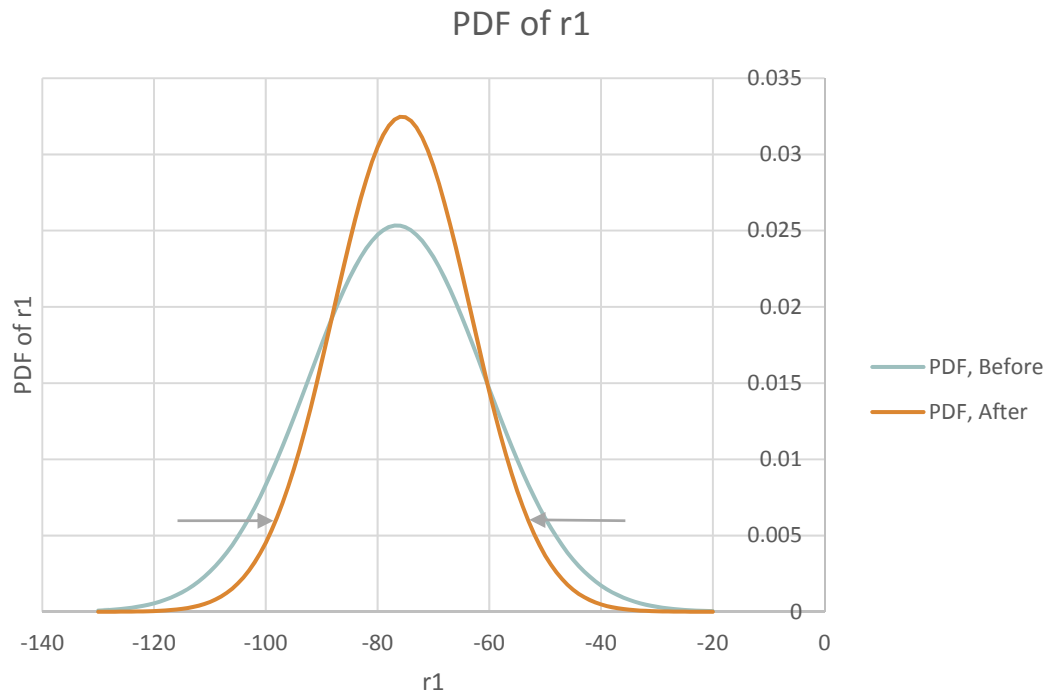
Goal: Use Uncertainty Quantification to Reduce Variance of Response r1

Before

- r1 Standard Deviation: 1.5740647557e+01

After

- r1 Standard Deviation: 1.2281104131e+01



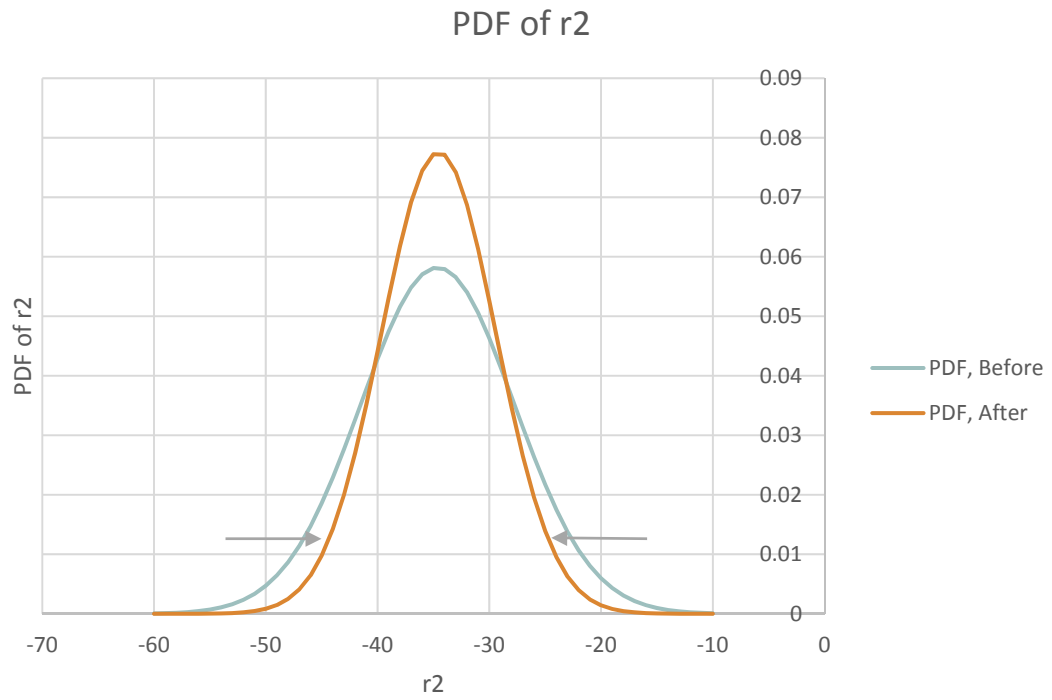
Goal: Use Uncertainty Quantification to Reduce Variance of Response r2

Before

- r2 Standard Deviation: 6.8557433340e+00

After

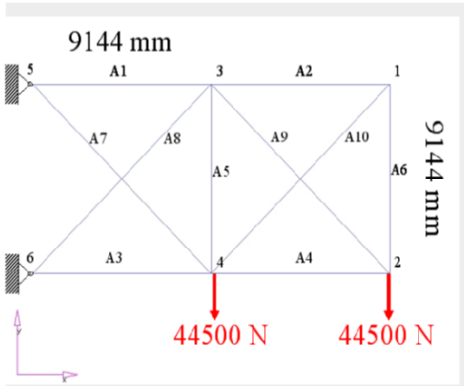
- r2 Standard Deviation: 5.1436271240e+00

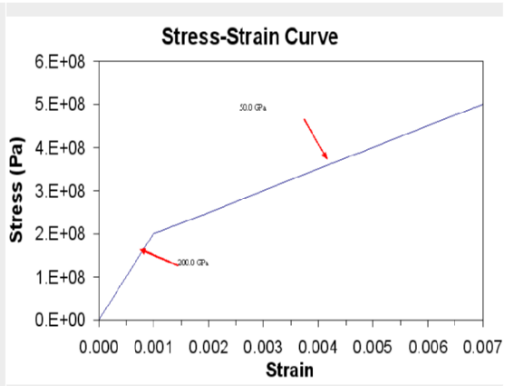


Details of the Structural Model

Examples

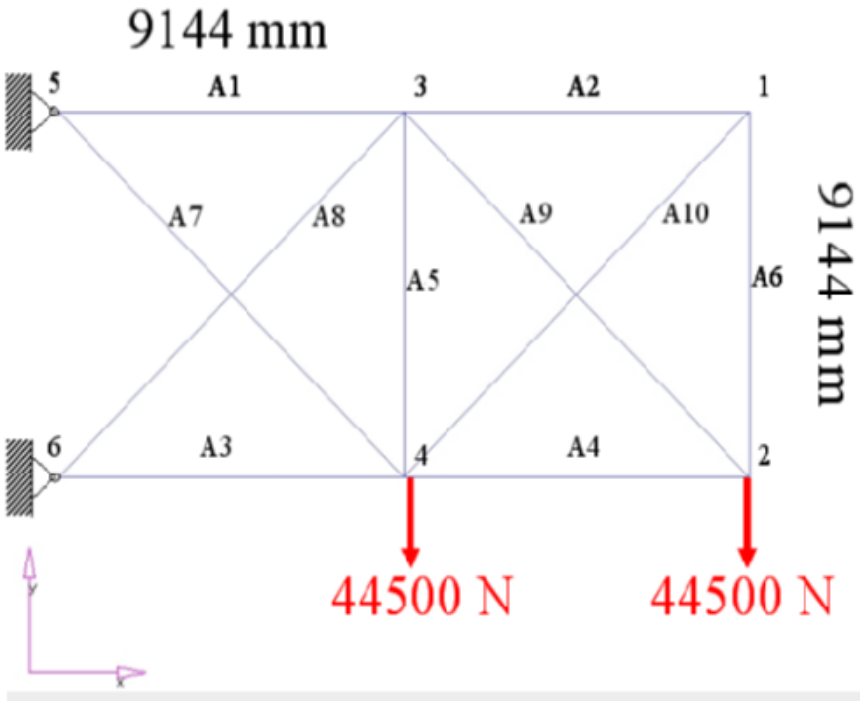
Example 1 10 Bar Truss (test library problem: deslo.dat)





(cross sectional areas)	
Find:	
Minimize:	Weight
	$\lvert\sigma_j\rvert \le 220 MPa \quad (j = 1,...,10)$
	$\lvert\delta_{all}\rvert \le 100.0 mm$ (both x and y directions of all nodes)
	$78.5 mm^2 \le X_i \le 2826.0 mm^2 \quad (i = 1,...,10)$

MSC Nastran Design Sensitivity and Optimization User's Guide
Chapter 8 – Special Topics - Optimization of Nonlinear Structural Responses



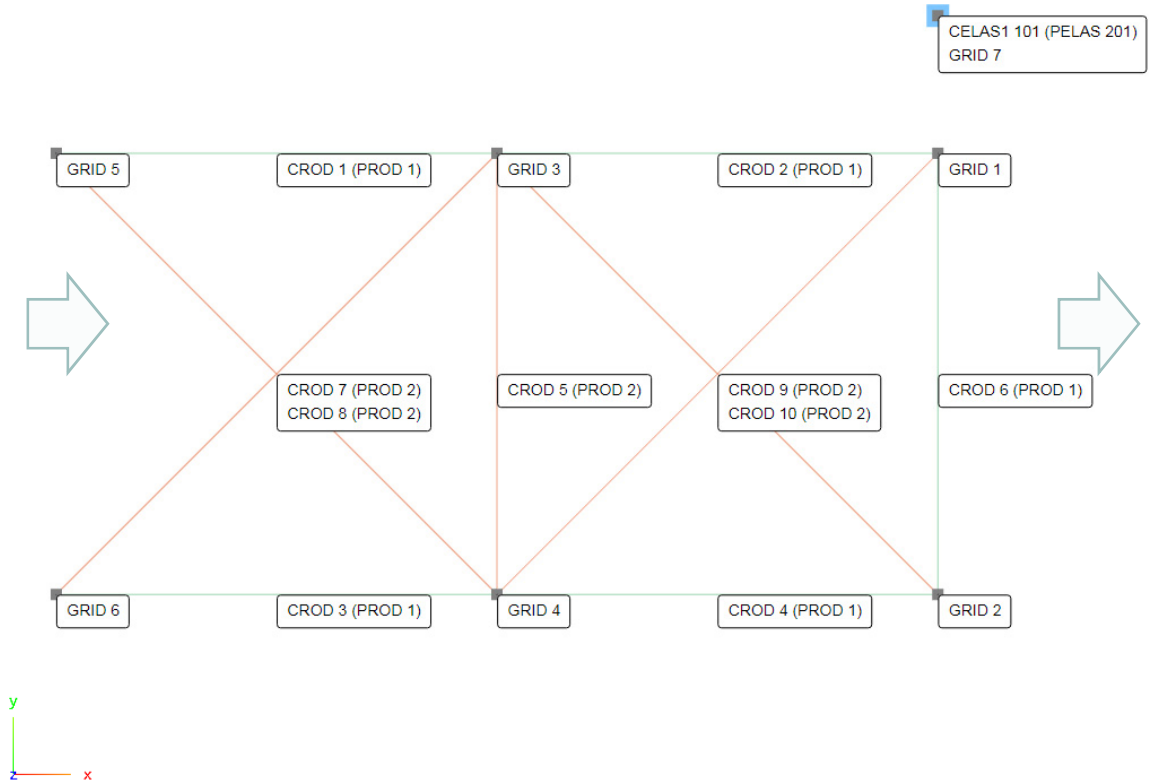
Problem Statement

Note that responses r1 and r2 are dependent on parameters x1, x2, x3, x4 and are expected to have non-zero correlation coefficients. Response r3 is dependent on no parameter and is expected to have zero or nearly zero correlation coefficients. Similarly, since parameter x5 is not used by any element, parameter x5 has no influence on any response and will have zero or nearly zero correlation coefficients.

Parameters

x1: Young's Modulus (E) of MAT1 1
x2: Load Scale Factor (S1) on LOAD 2
x3: Area (A) of PROD 1
x4: Area (A) of PROD 2
x5: Area (A) of PROD 3
Unused property, dummy parameter

Parameter	Distribution	Mean	Standard Deviation
x1	Lognormal	2.E5	20000.
x2	Lognormal	4.45E4	4450.
x3	Lognormal	300.0	60.0
x4	Lognormal	300.0	60.0
x5	Lognormal	300.0	60.0



Responses

r1: Displacement, y component, of grid 2

r2: Displacement, y component, of grid 4

r3: Displacement, y component, of grid 7

Quantities of Interest (QoI)

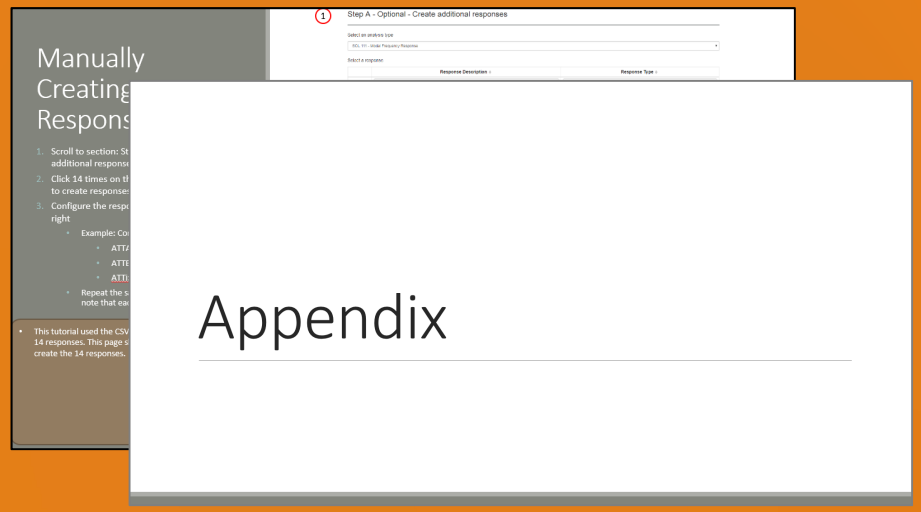
Mean and standard deviations of responses

Correlation coefficients between inputs (parameters) and outputs (responses)

More Information Available in the Appendix

The Appendix includes information regarding the following:

- What is a projection?
- What is Pearson correlation coefficient?
- What is Spearman's correlation coefficient?
- What is skewness?
- What is kurtosis?
- What is a 95% confidence interval?



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 and .h5 file
2. Use the SOL 200 Web App to:
   - Configure an Uncertainty Quantification Task
     - Parameters
     - Responses
     - Samples
   - Perform Uncertainty Quantification
3. Display Uncertainty Quantification Results

Special Topics Covered

Uncertainty Quantification - There are many methods available to perform uncertainty quantification. This exercise details the sampling method for uncertainty quantification. The goal is to reduce the variance of outputs due to uncertain inputs. The Latin hypercube sampling method is used to generate samples. Quantities of interest include the mean, standard deviation and correlation coefficients.

SOL 200 Web App Capabilities

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

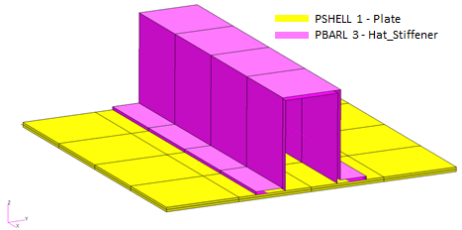
Compatibility

- 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.

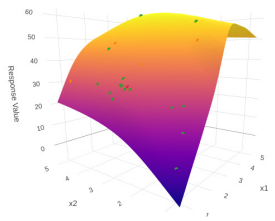
Benefits

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

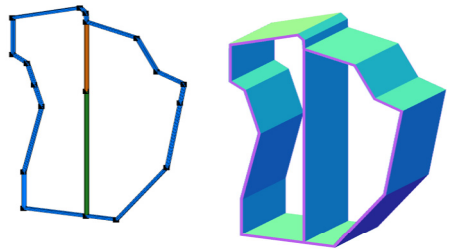
Web Apps



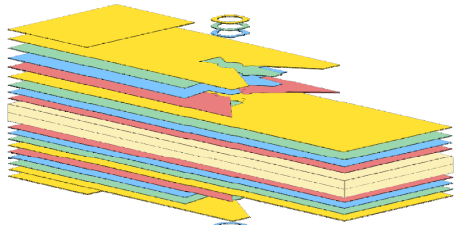
Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography, multi-model optimization.



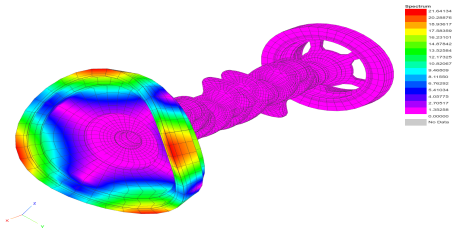
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



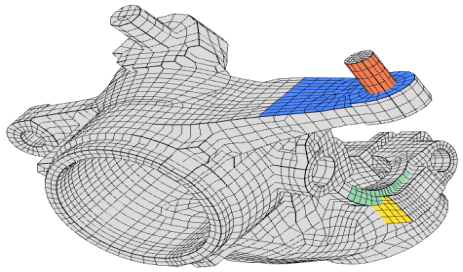
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



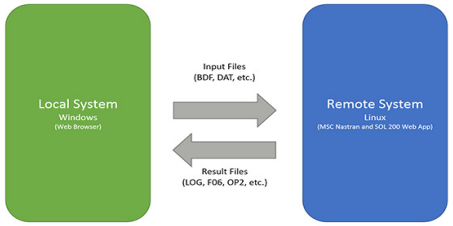
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries



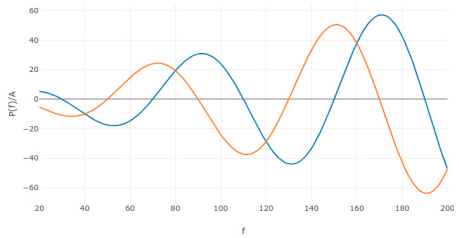
Post-processor Web App
View MSC Nastran results in a web browser on Windows and Linux



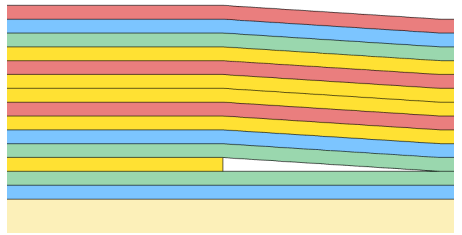
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



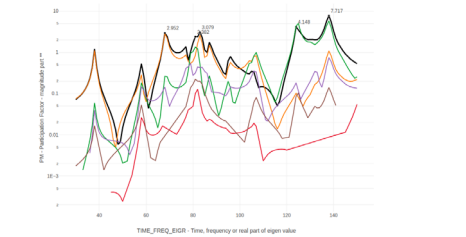
Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



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



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

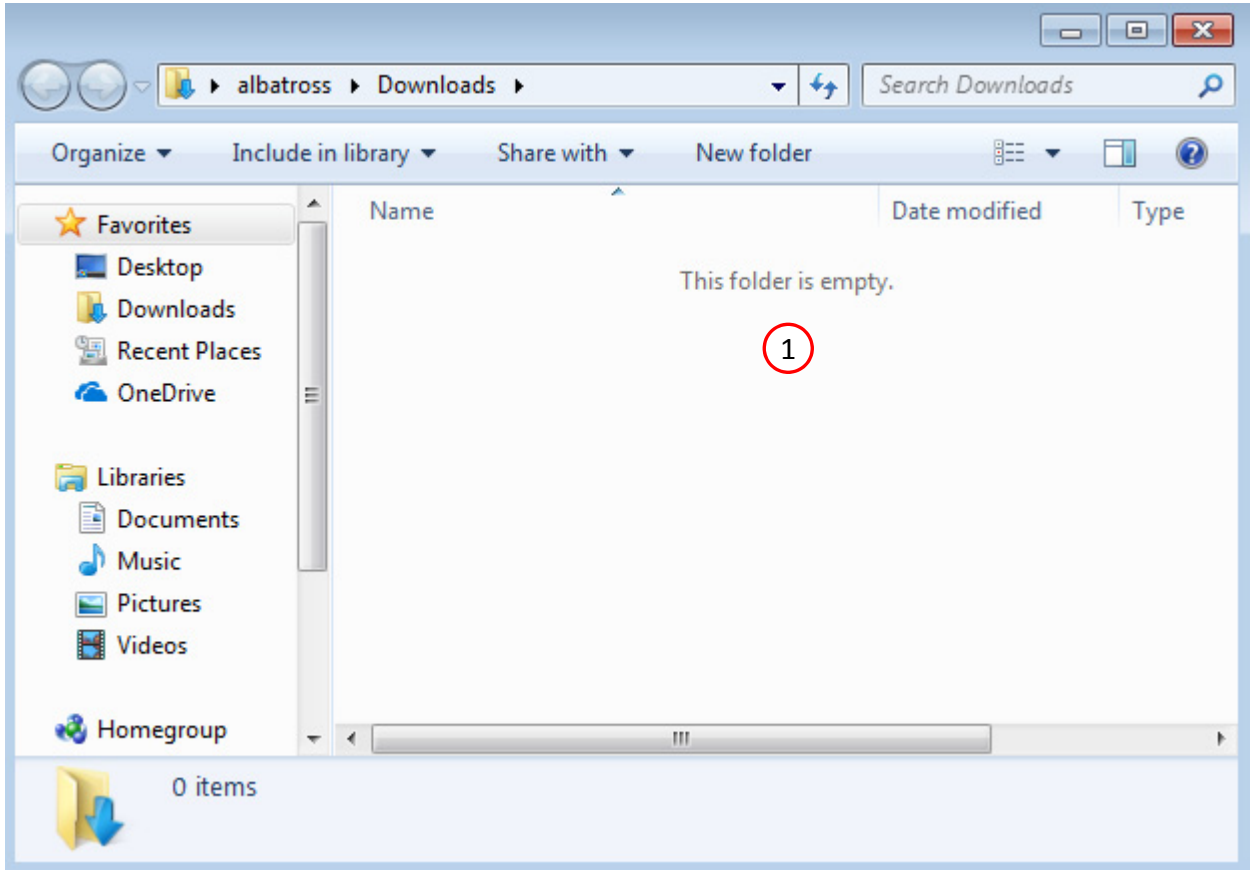


HDF5 Explorer Web App
Create graphs (XY plots) using data from the H5 file

Part A – Initial Sampling

Before Starting

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



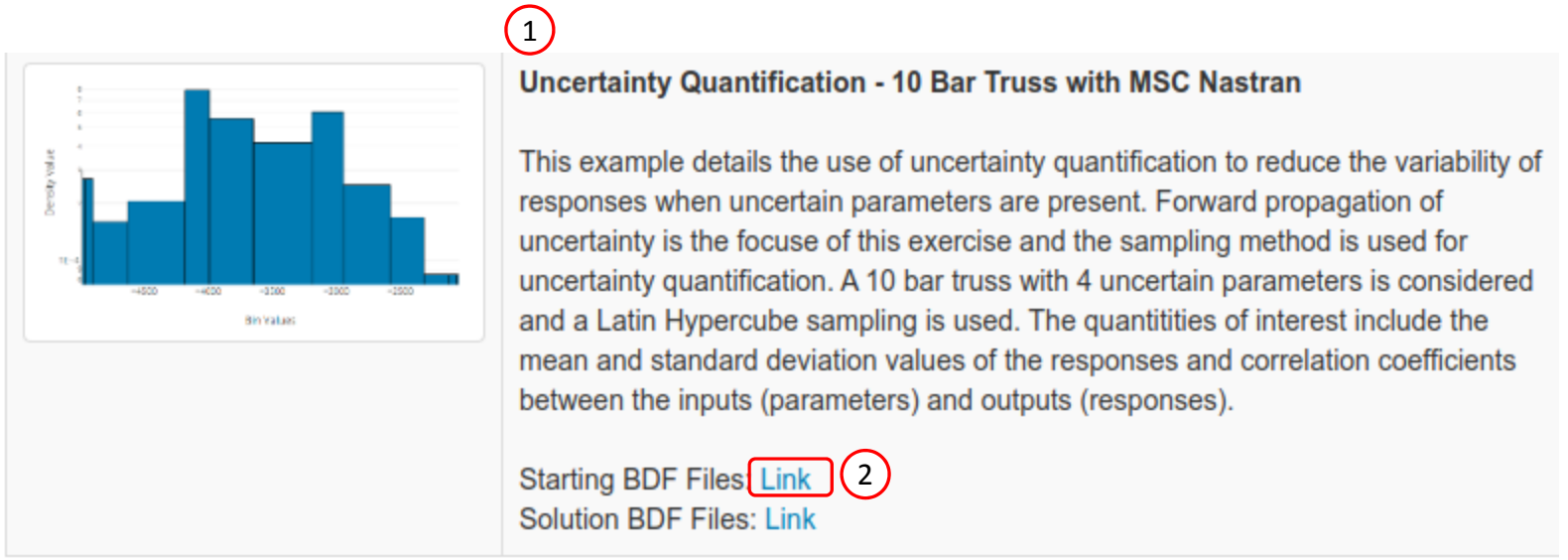
Go to the User's Guide

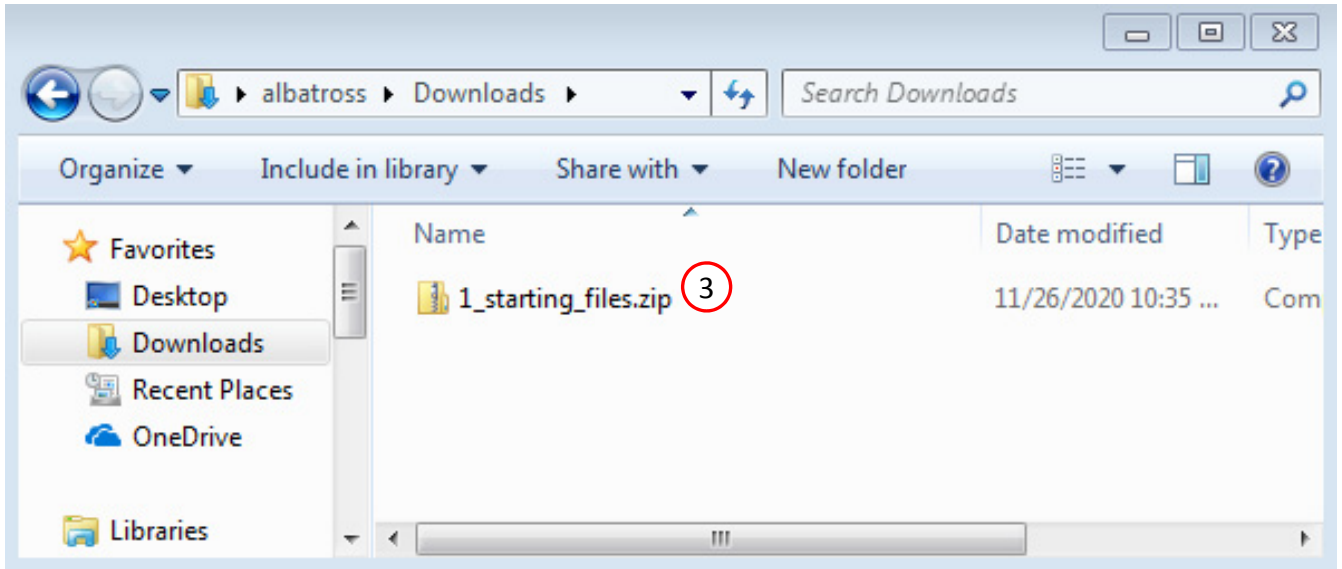
1. Click on the indicated link

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

Obtain Starting Files

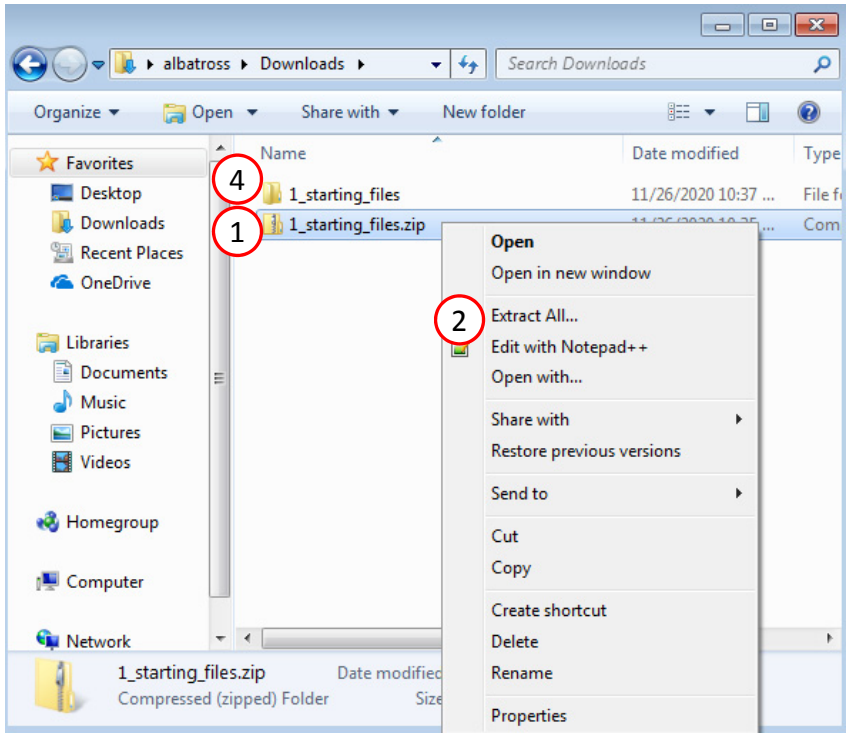
1. Find the indicated example
2. Click Link
3. The starting file has been downloaded

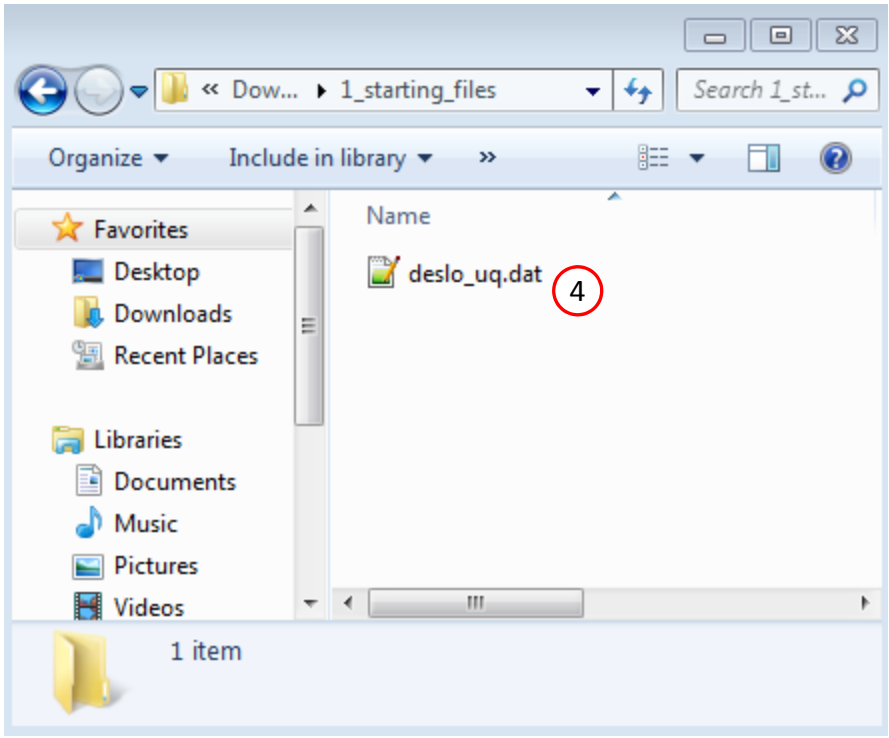


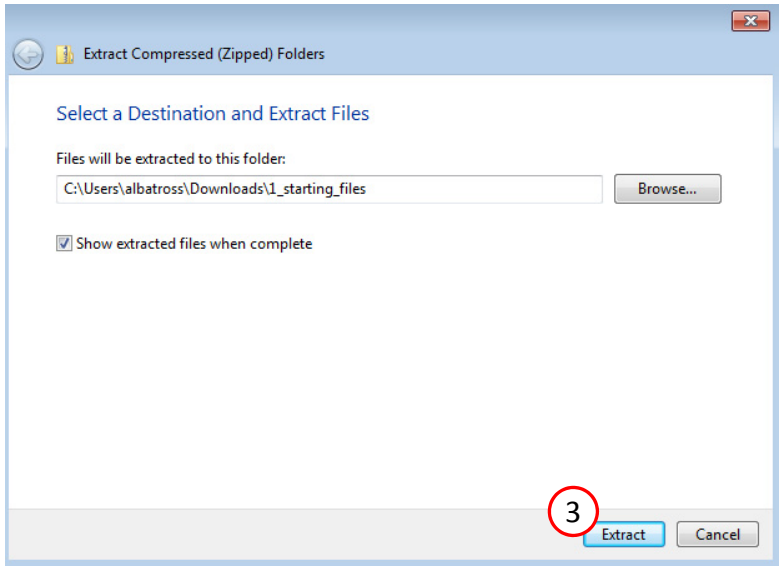


Obtain Starting Files

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



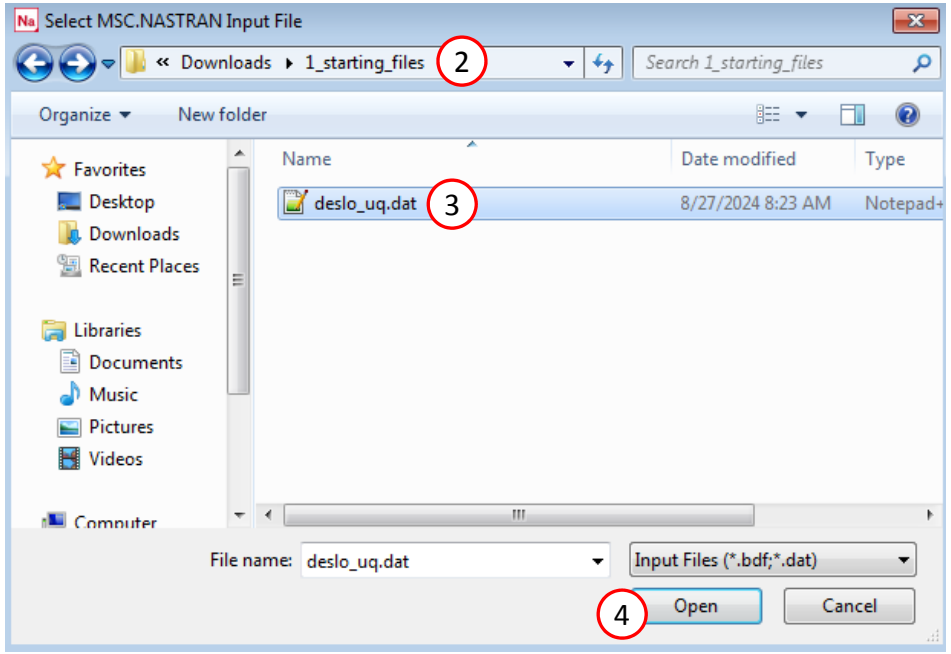


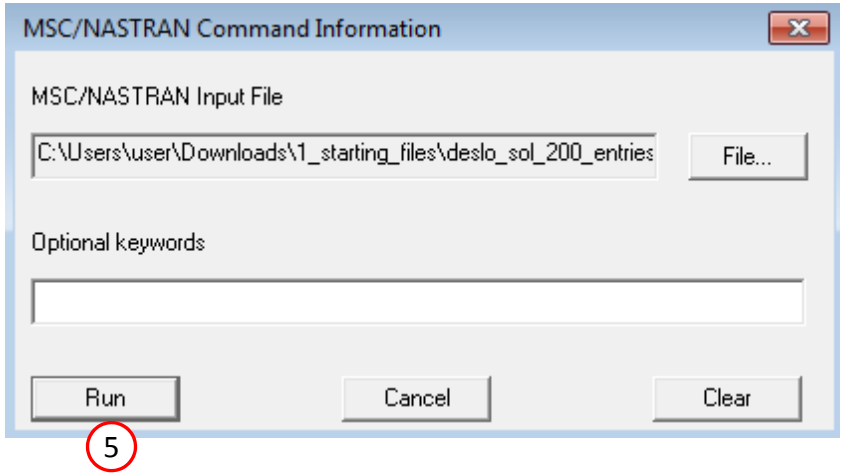


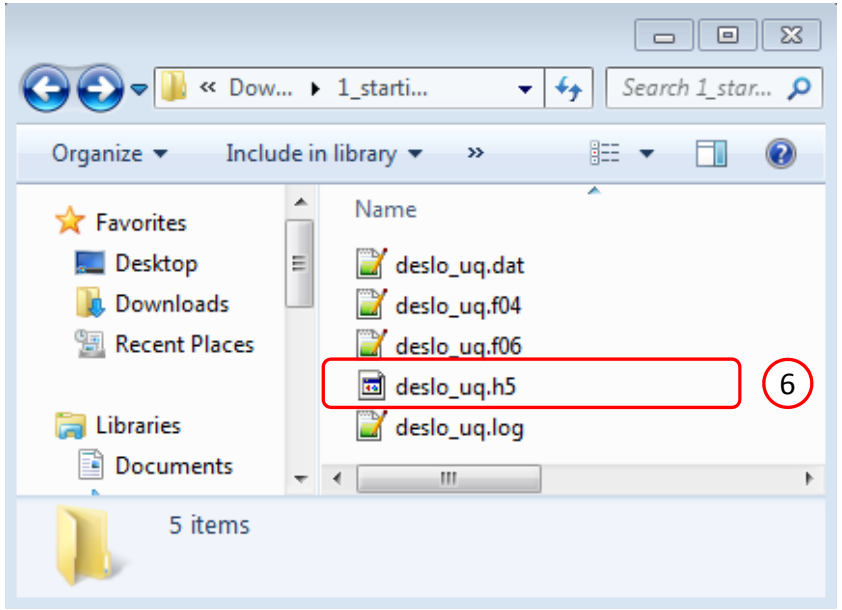
Create the Starting H5 File

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
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.

Open the Correct Page

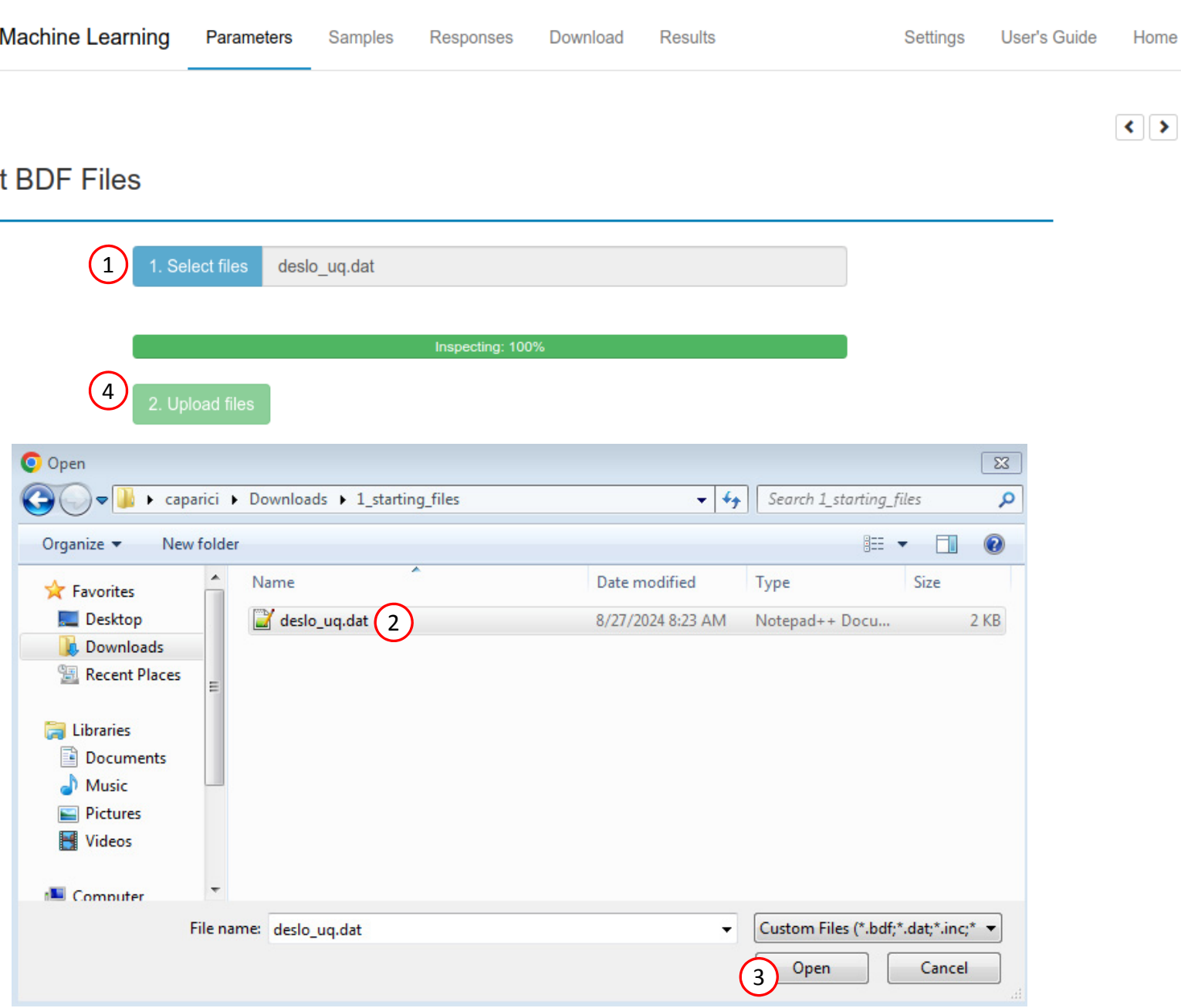
1. Click on the indicated link

- 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.

Select BDF Files

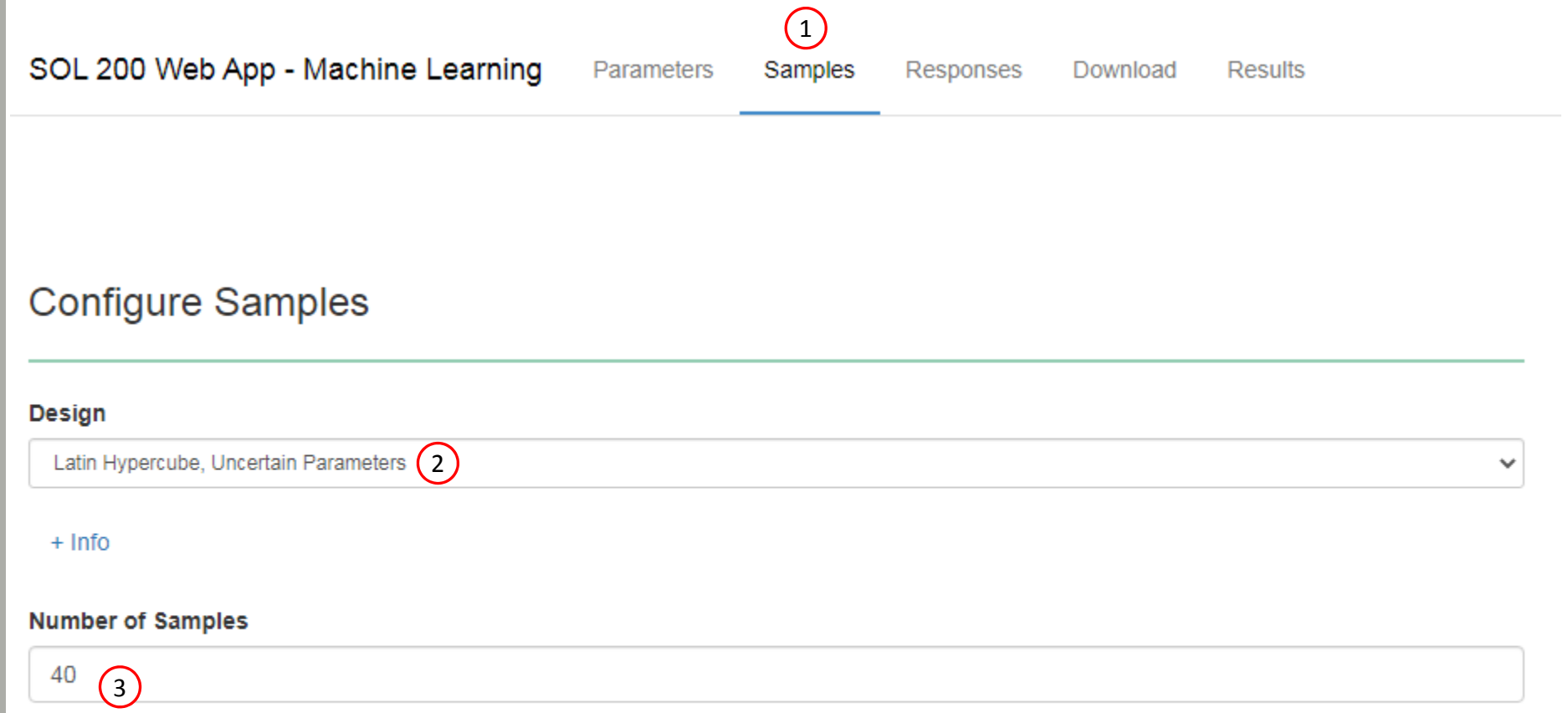
1. Click Select files
2. Select the indicated file
3. Click Open
4. Click Upload files

- 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.



Samples

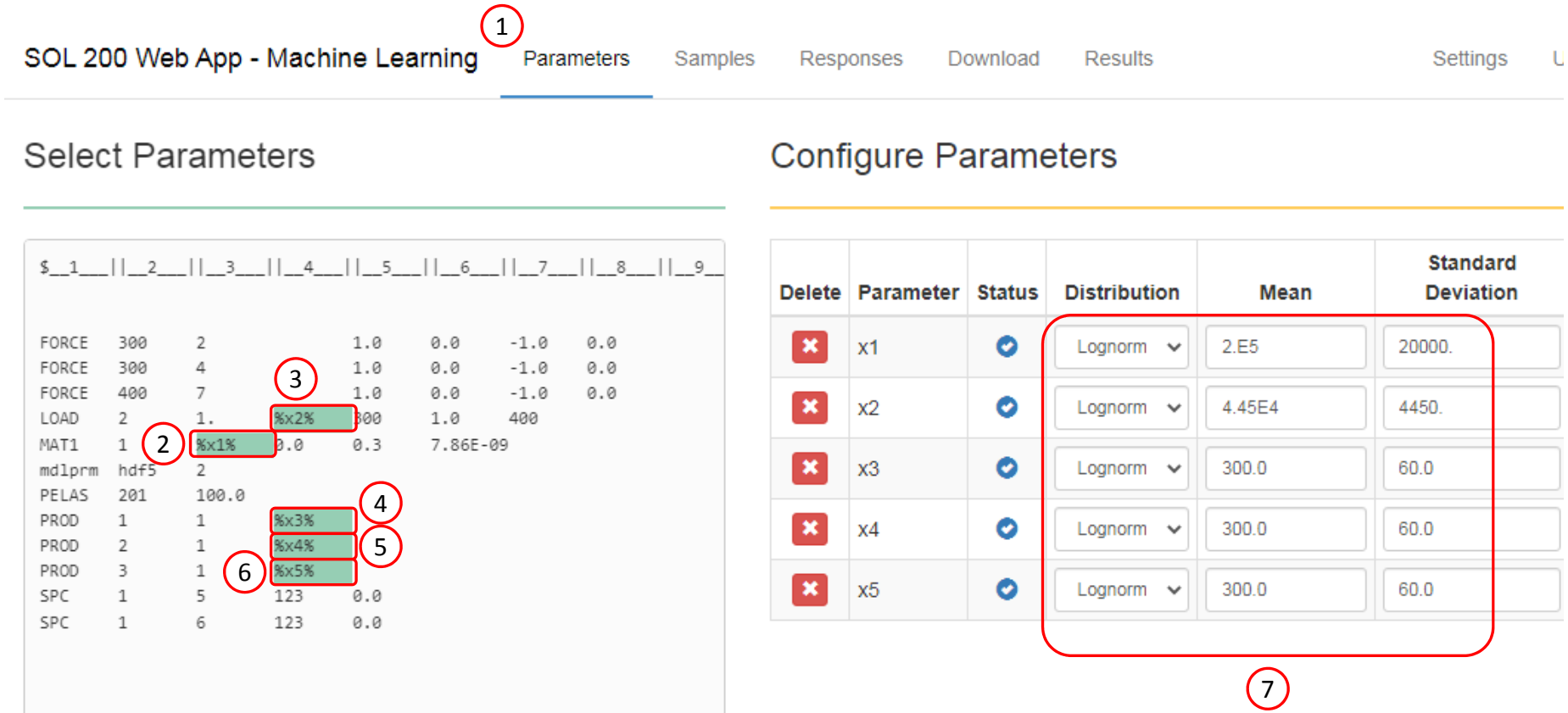
1. Click Samples
2. Set Design to Latin Hypercube, Uncertain Parameters
3. Set Number of Samples to 40



Parameters

1. Click Parameters
2. Click the indicated field to create parameter x1
3. Click the indicated field to create parameter x2
4. Click the indicated field to create parameter x3
5. Click the indicated field to create parameter x4
6. Click the indicated field to create parameter x5
7. Modify the distribution, mean and standard deviation to match the values in the table below

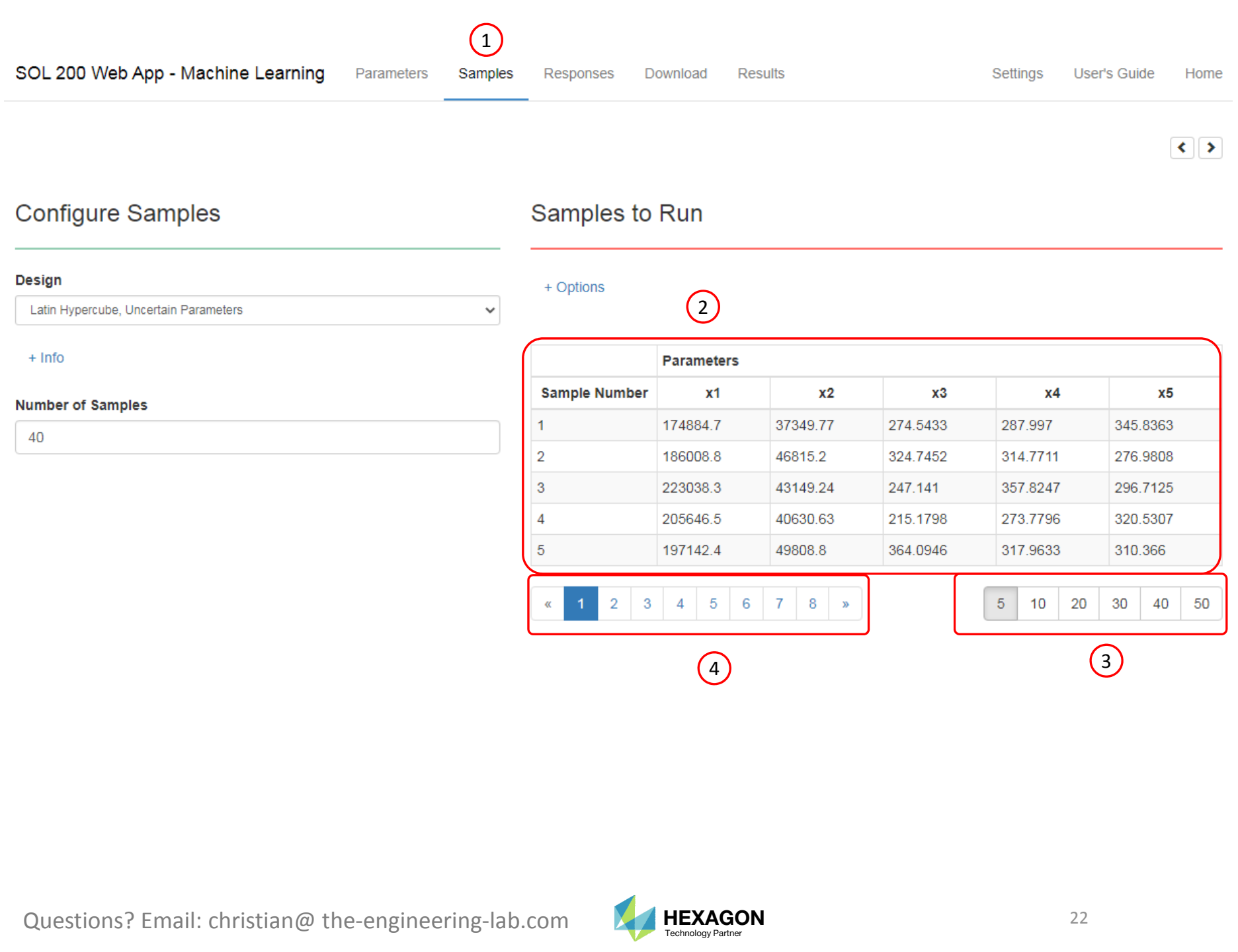
Parameter	Distribution	Mean	Standard Deviation
x1	Lognormal	2.E5	20000.
x2	Lognormal	4.45E4	4450.
x3	Lognormal	300.0	60.0
x4	Lognormal	300.0	60.0
x5	Lognormal	300.0	60.0



Samples

Inspect the samples.

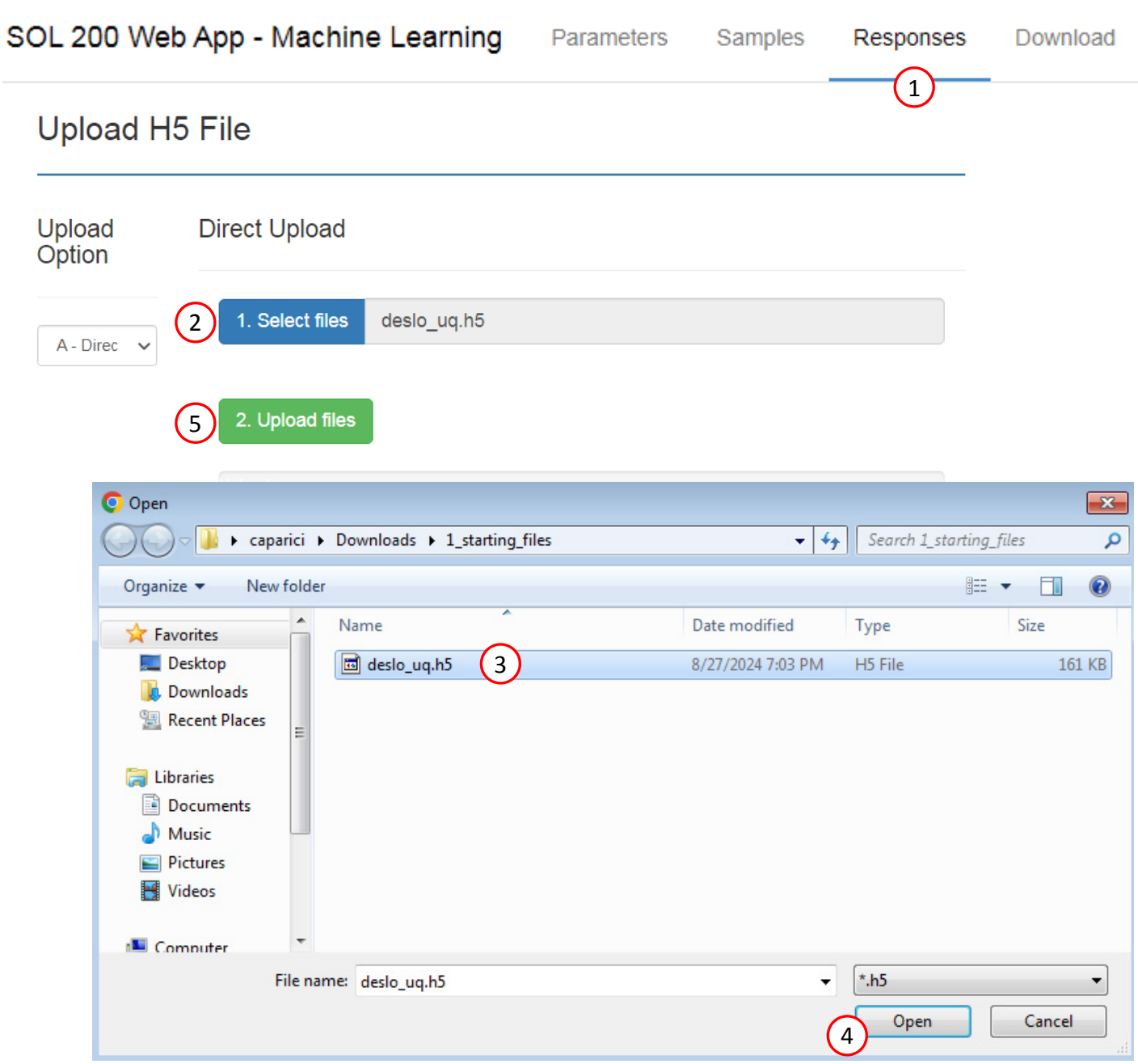
1. Click Samples
2. 40 samples have been generated
   - The samples are randomly selected, so different values should be expected
3. Only 5 rows are displayed. The indicated controls maybe used to display 5, 10, 20, 30, 40 or 50 rows.
4. The indicated controls maybe used to view different rows of the table.



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.

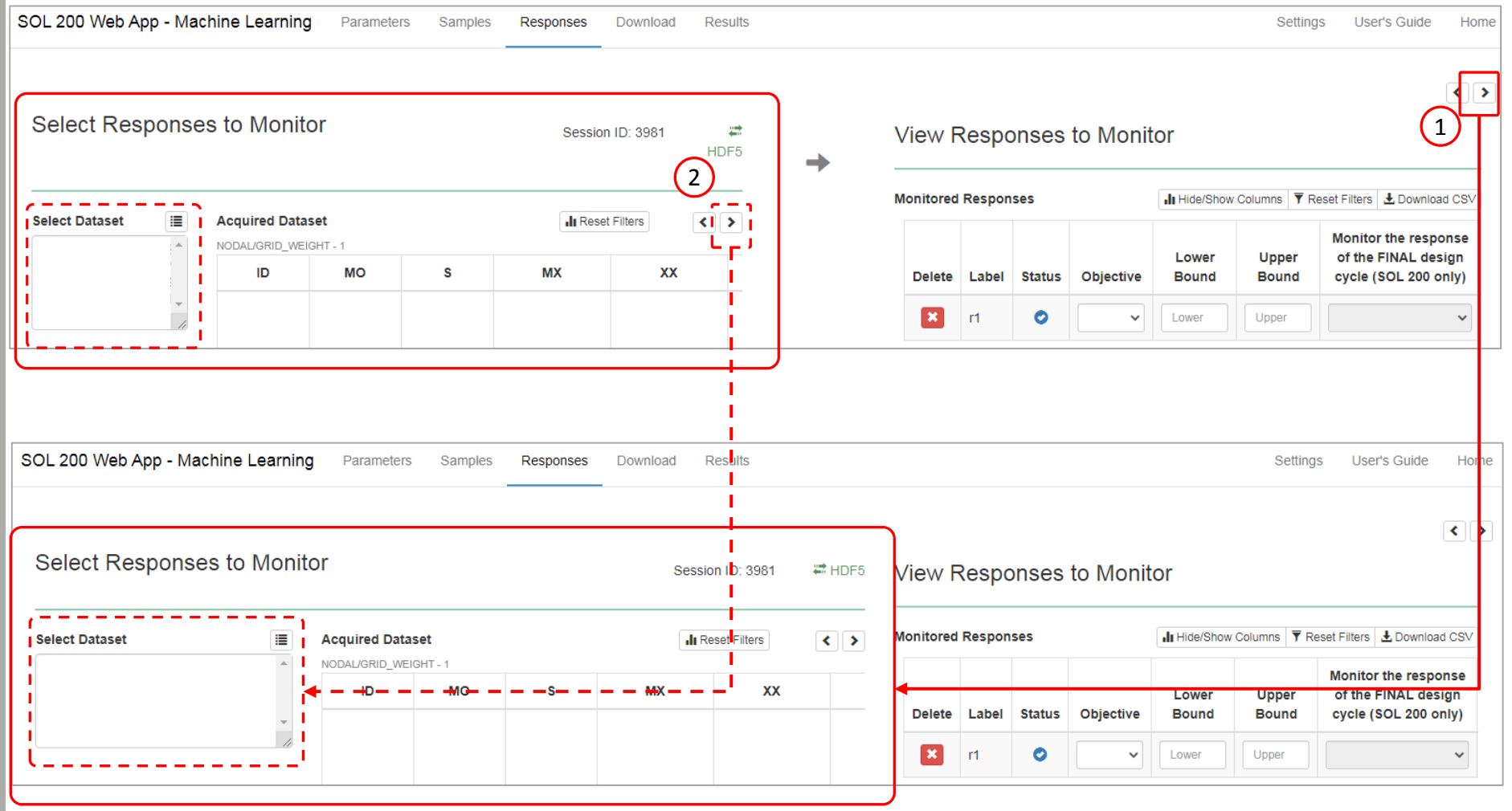


Adjust the Column Width

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

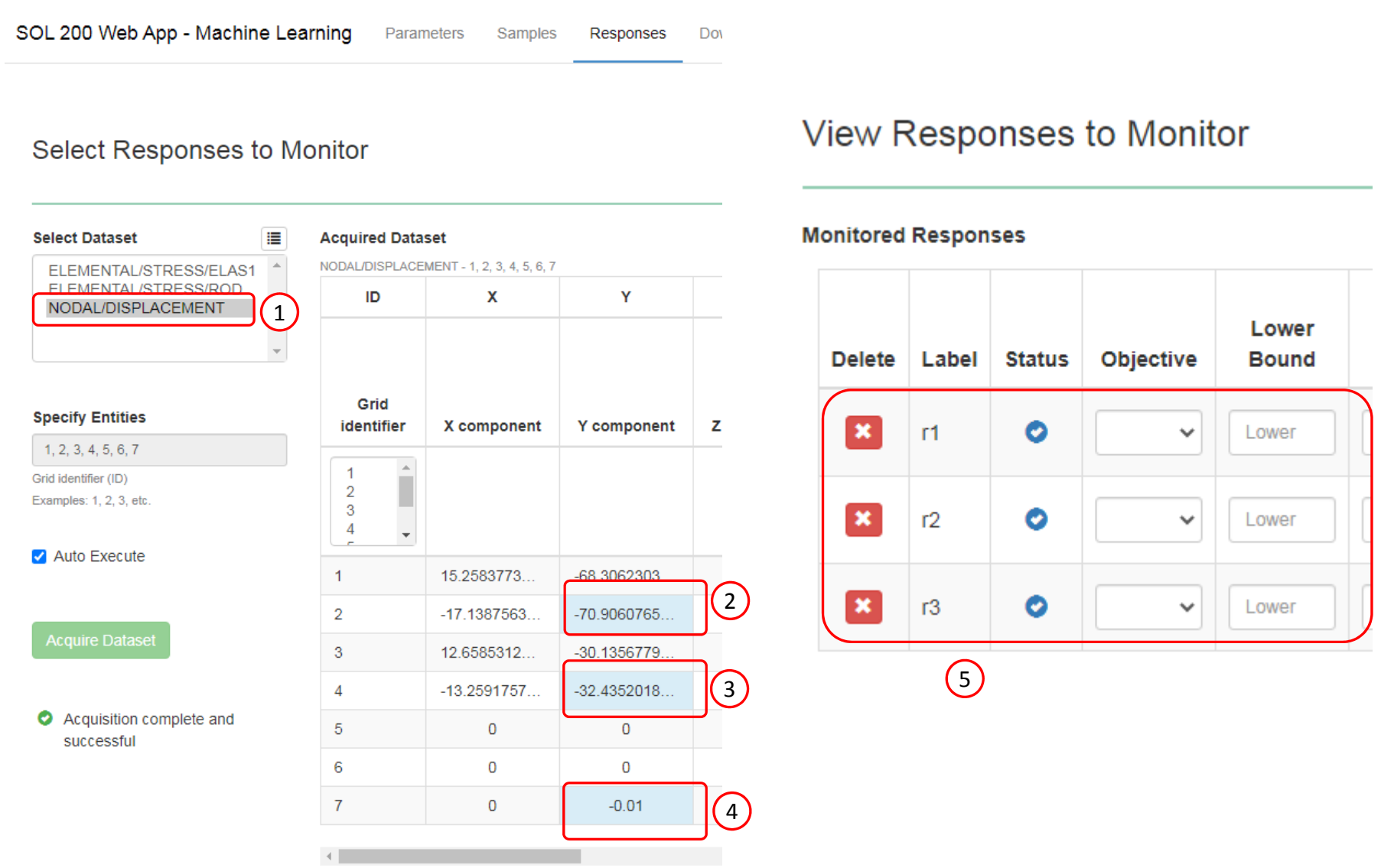
- IMPORTANT! This image is not meant to match exactly what you see in your view. The text in this image is expected to be different from your view. The purpose of this page and image is to demonstrate how to increase the width of the indicated sections.



Select Responses

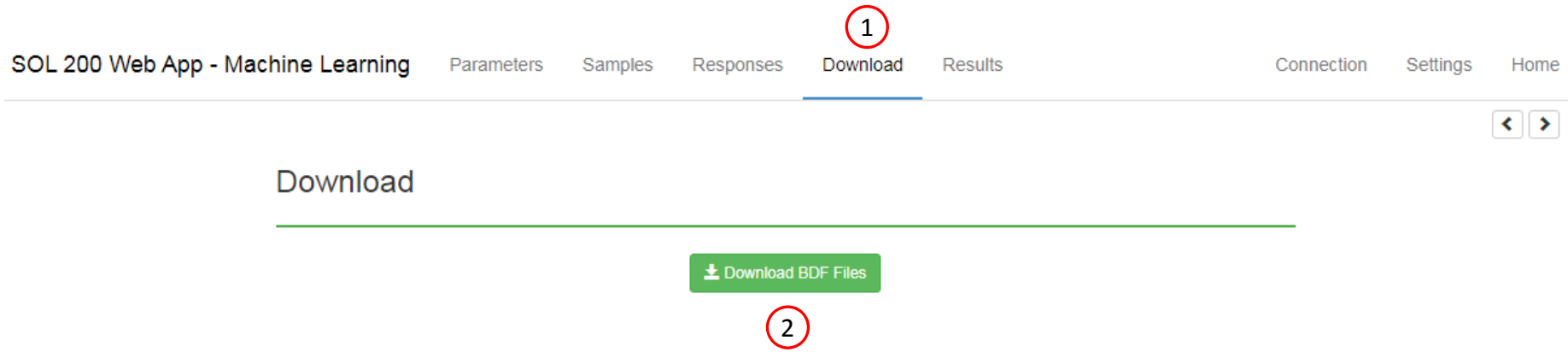
1. Select the following dataset: NODAL/DISPLACEMENT
2. Select the indicated cell
3. Select the indicated cell
4. Select the indicated cell
5. The newly created Response to Monitor is listed as r1, r2, r3

- The column ID lists the grid ID for each row. The y-component of displacement for grids 2, 4 and 7 are set as responses for the uncertainty quantification.



Download

1. Click Download
2. Click Download BDF Files

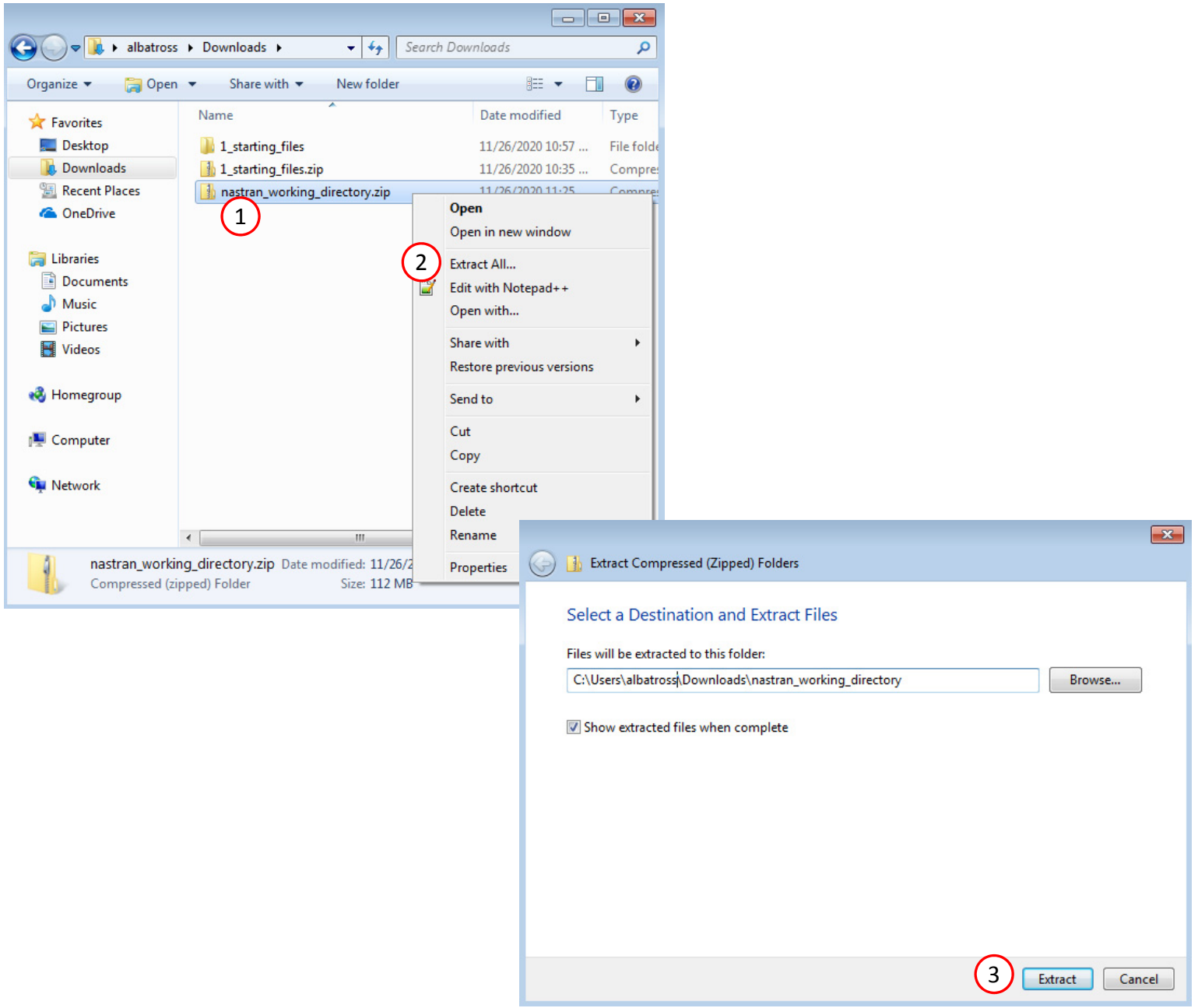


Start MSC Nastran

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

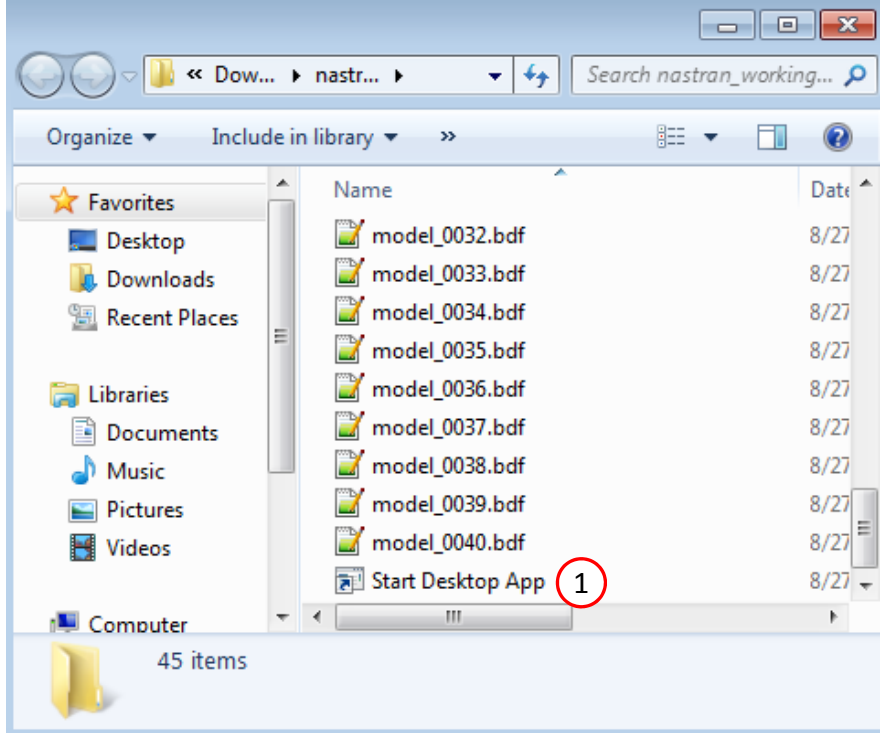
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the remote machine. 3) After completion, copy the BDF, F06, LOG, H5 files to the local machine. 4) Click "Start Desktop App" to display the results.

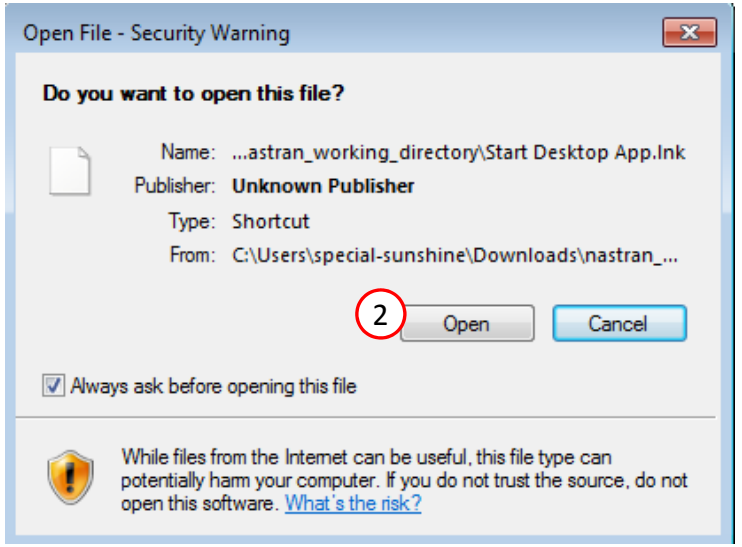
Using Linux?

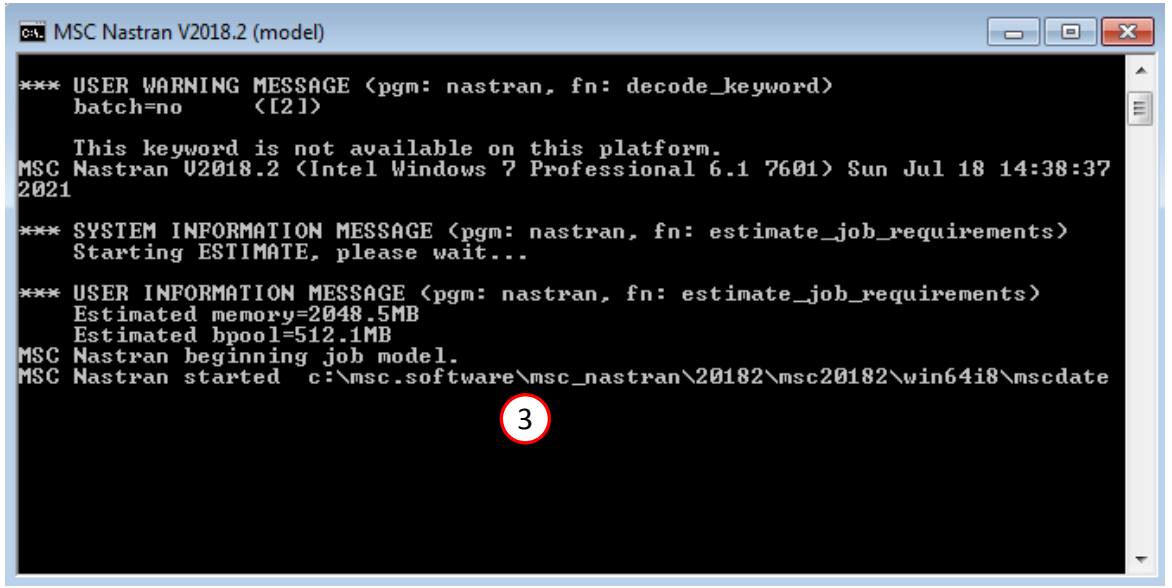
Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
   cd ./nastran_working_directory
3) Use this command to start the process
   ./Start_MSC_Nastran.sh

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

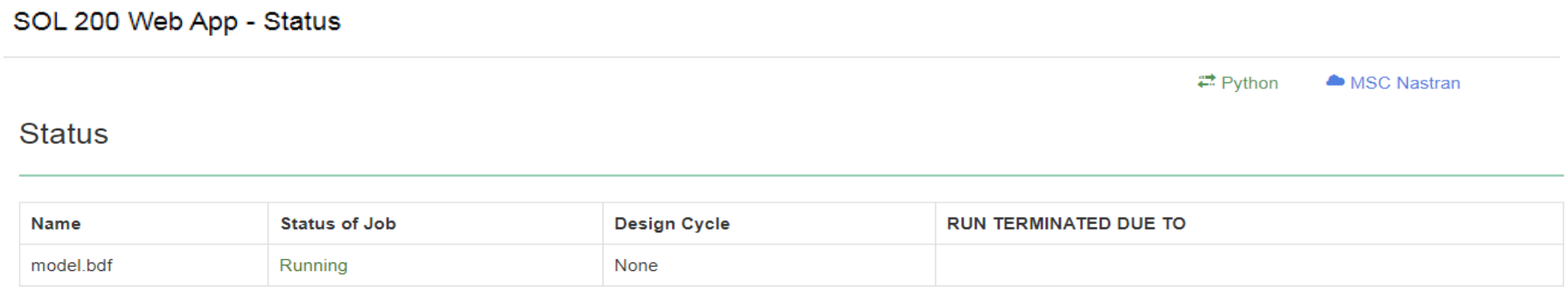






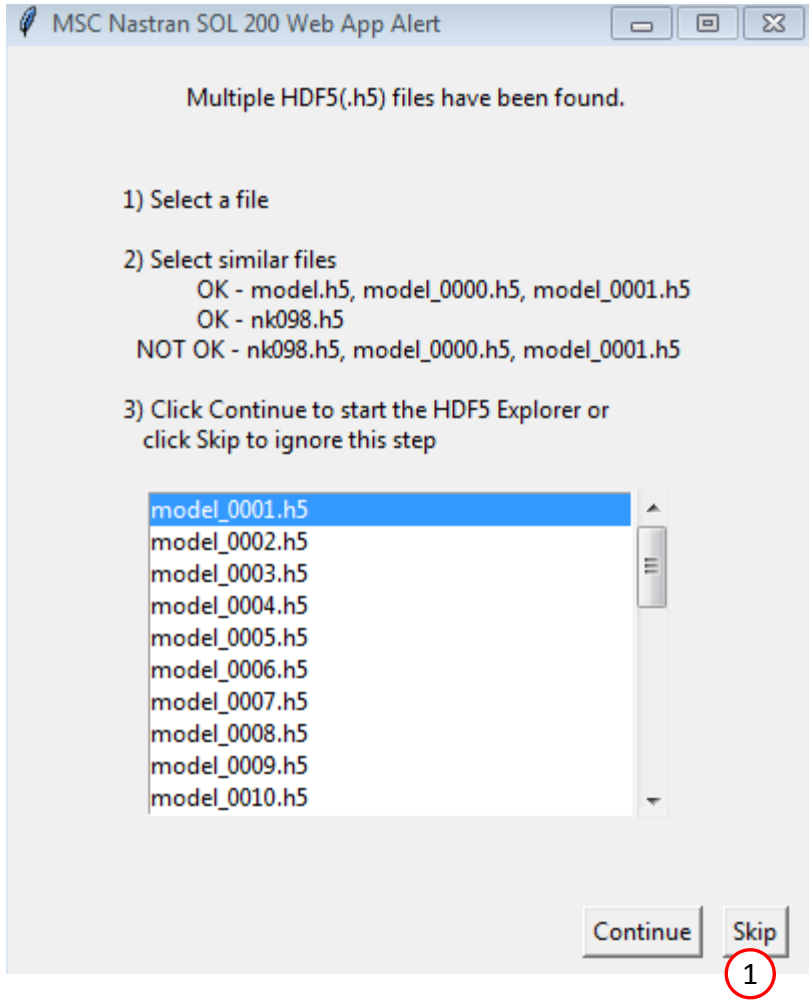
Status

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



Machine Learning Results

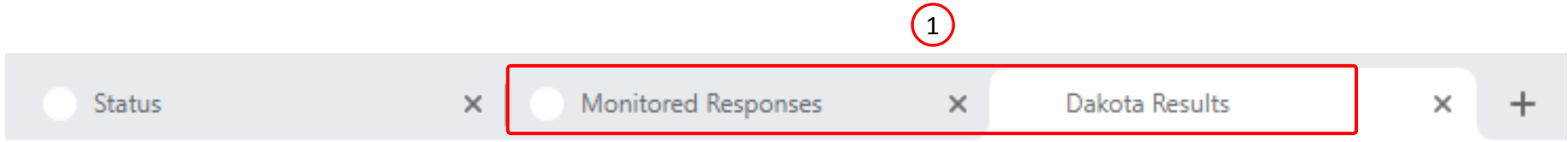
1. After the process is complete, you will be asked to start the HDF5 Explorer. You can click Skip to skip opening the HDF5 Explorer.



Results

After each MSC Nastran analysis is complete, multiple web apps are automatically opened to display the results.

1. Use the tabs to switch between each web app
2. A description of each web app is given in the table.



2

Name of Web App	Purpose	Description
Monitored Responses	• The response value from each sample can be compared.	• After each MSC Nastran analysis, the response values are extracted from the H5 file and contained in a file named app_monitored_responses.csv. The Monitored Responses web app is used to create a bar chart of the values contained in this CSV file.
Dakota Results	• This web app displays the results of a Dakota study.	• After the responses for all samples are acquired, Sandia Dakota is executed to determine the statistics.

Review Results

1. The Monitored Responses web app is opened
2. The r1, r2 and r3 responses correspond to the y component of displacement at grids 2, 4 and 7, respectively.

A. The table titled Monitored Response can be interacted with. Each column in the table contains filters. Once a filter is modified, the Bar Chart will instantly update.
B. Additional functions include the ability to highlight the MAX and MIN bars, download a CSV file and reset the filters.

Review Results

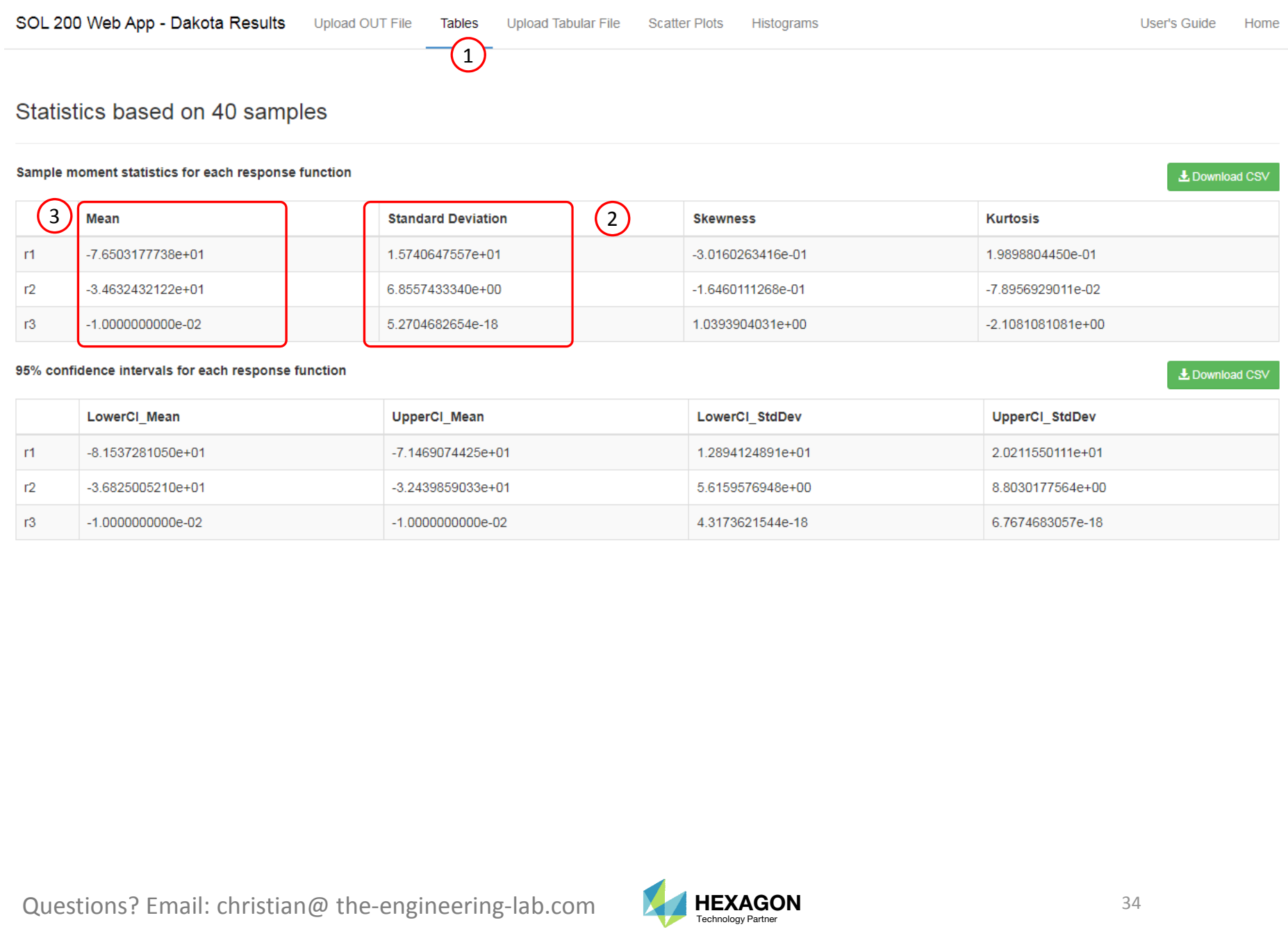
1. In the background, Sandia Dakota was executed to determine the quantities of interest, e.g. mean, standard deviation, etc. The results are contained in the OUT file.

File: workspace_d/dakota.out (1)

```
<<<<< Function evaluation summary (UQ_I): 0 total (0 new, 0 duplicate)
------------------------------------------------------------------------
Statistics based on 40 samples:

Sample moment statistics for each response function:
                          Mean           Std Dev          Skewness          Kurtosis
            r1 -7.6503177738e+01  1.5740647557e+01 -3.0160263416e-01  1.9898804450e-01
            r2 -3.4632432122e+01  6.8557433340e+00 -1.6460111268e-01 -7.8956929011e-02
            r3 -1.0000000000e-02  5.2704682654e-18  1.0393904031e+00 -2.1081081081e+00

95% confidence intervals for each response function:
                    LowerCI_Mean      UpperCI_Mean    LowerCI_StdDev    UpperCI_StdDev
            r1 -8.1537281050e+01 -7.1469074425e+01  1.2894124891e+01  2.0211550111e+01
            r2 -3.6825005210e+01 -3.2439859033e+01  5.6159576948e+00  8.8030177564e+00
            r3 -1.0000000000e-02 -1.0000000000e-02  4.3173621544e-18  6.7674683057e-18

[…]
Simple Correlation Matrix among all inputs and outputs:
                         x1           x2           x3           x4           x5           r1           r2           r3
          x1  1.00000e+00
          x2 -1.10512e-01  1.00000e+00
          x3  1.54094e-01  1.69421e-01  1.00000e+00
          x4  1.89505e-01  3.46524e-01  2.64909e-01  1.00000e+00
          x5  2.22206e-01 -2.01454e-01 -6.08376e-02 -2.87279e-01  1.00000e+00
          r1  6.51560e-01 -3.11070e-01  6.56974e-01  3.76223e-01  5.31302e-02  1.00000e+00
          r2  6.81976e-01 -2.85070e-01  5.14679e-01  5.51336e-01 -2.56422e-03  9.63153e-01  1.00000e+00
          r3  1.31839e-15 -7.16441e-16  6.31439e-16 -9.47159e-16 -2.73739e-15 -4.38885e-16  1.24206e-15  1.00000e+00

Partial Correlation Matrix between input and output:
                         r1           r2           r3
          x1  8.60024e-01  8.85721e-01  2.31708e-15
          x2 -8.60492e-01 -8.86258e-01 -4.23496e-16
          x3  9.12323e-01  8.45796e-01  7.48632e-16
          x4  6.98539e-01  8.85942e-01 -2.27173e-15
          x5 -8.90610e-02 -1.36330e-01 -3.76261e-15
```

Review Results

1. Click Tables
2. Note the standard deviation. The goal in this exercise is to reduce the variance, or standard deviation. These standard deviation values will be used for future comparison.
3. The mean values based on 40 samples are displayed.



Review Results

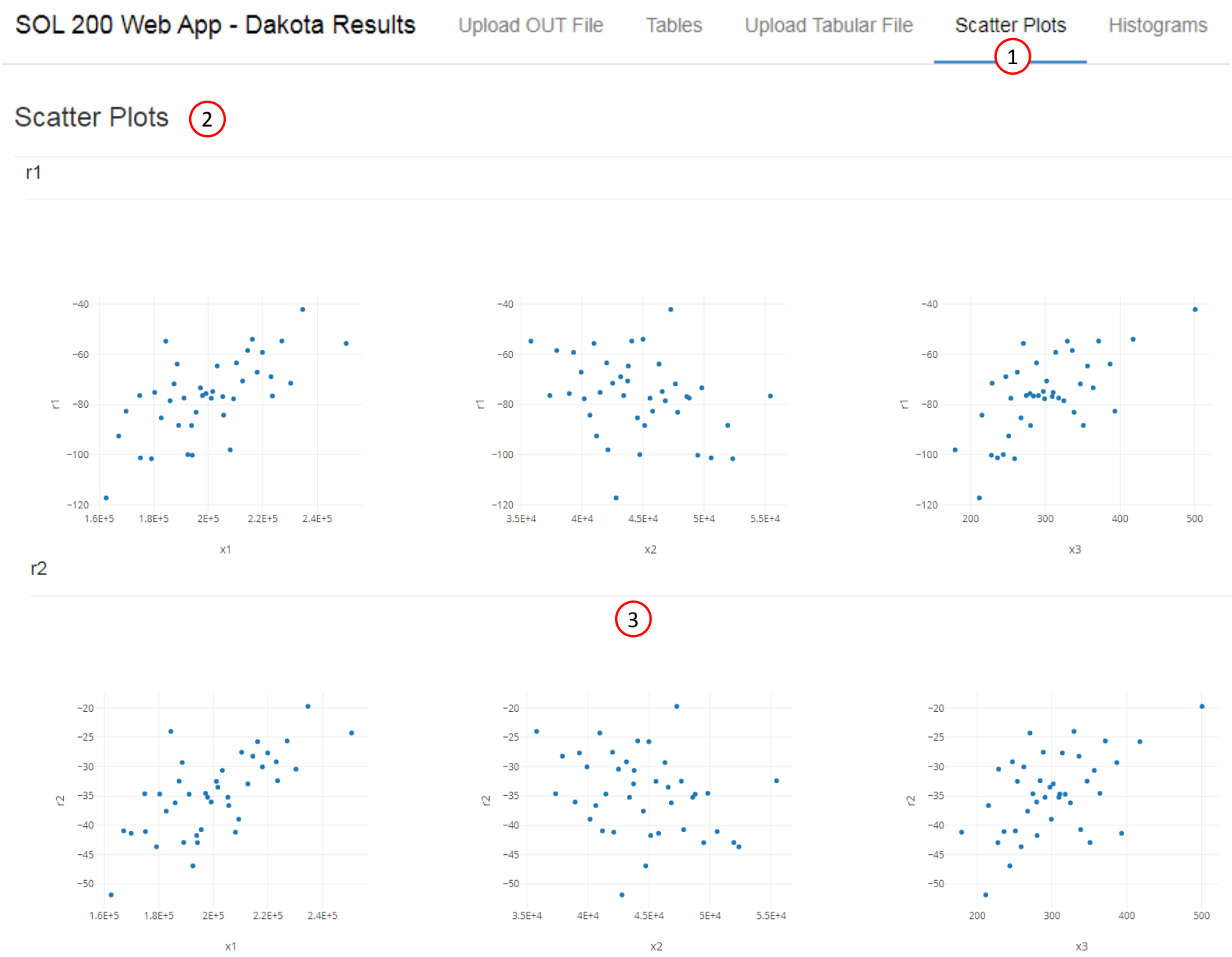
1. Click Histograms
2. The mean and standard deviation values from the previous page are used to build a probability density function (PDF) assuming the response has a normal distribution. The PDF is plotted as the orange plot/trace.
3. The horizontal axis represents the response level.
4. The vertical axis represents the count or frequency.
5. The vertical axis to the right represents the probability density value and is colored orange.

If the blue bars align to the PDF plot, the response's distribution is normal. If the bars do not align, the distribution is not normal.

Review Results

1. Click Scatter Plots
2. Scroll to section Scatter Plots
3. Projections for each variable are displayed as scatter plots.

- To keep this exercise brief, not all the plots are discussed or displayed. Plots for variables x4 and x5 are not displayed in this exercise, but will be visible in the web app.
- Refer to the Appendix for an explanation of what is a projection.

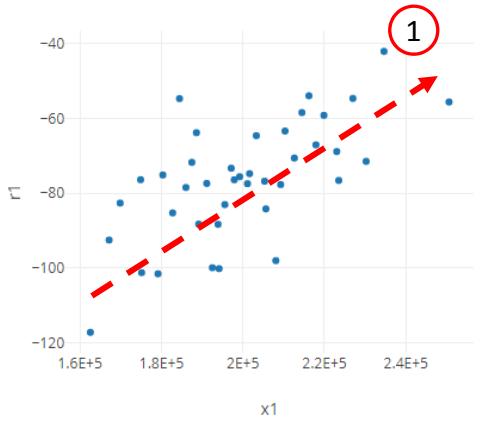


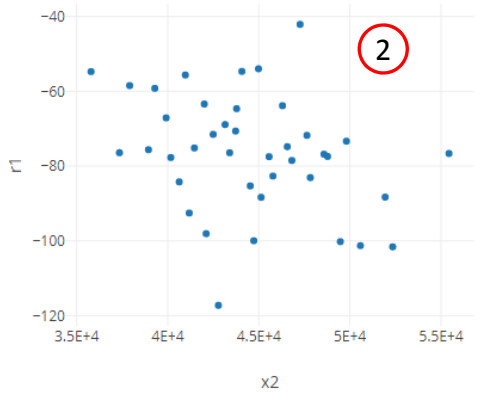
Review Results

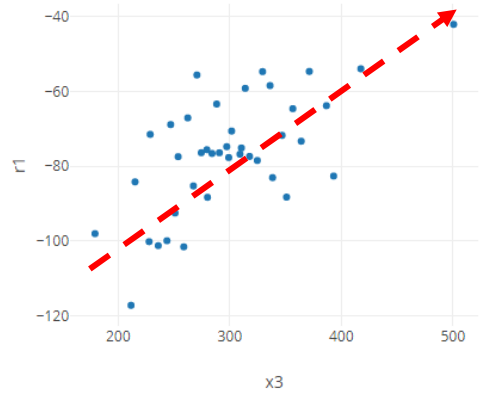
Notice some of the following trends.

1. For response r1 across x1,
   - The relationship appears linear
2. For response r1 across x2,
   - There is no clear relationship, linear or nonlinear, that may be defined

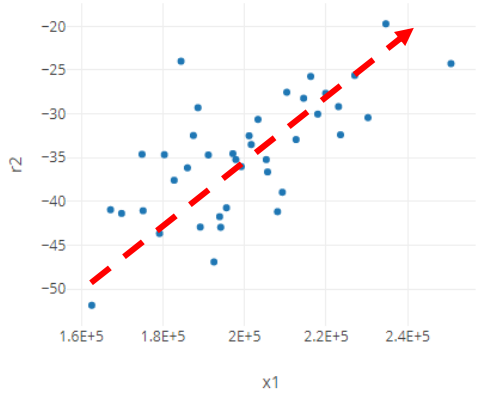
r1

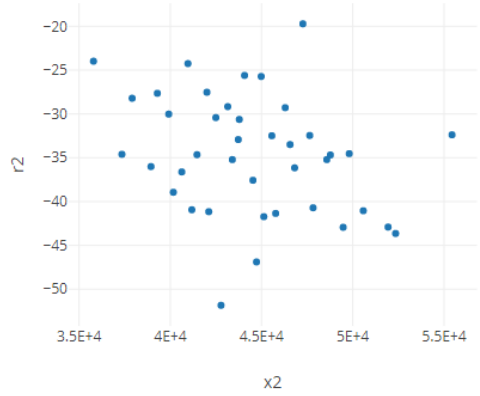


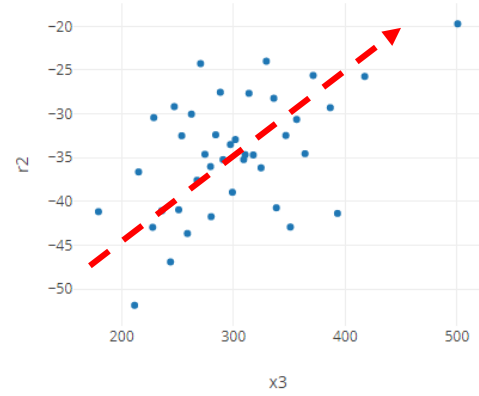




r2



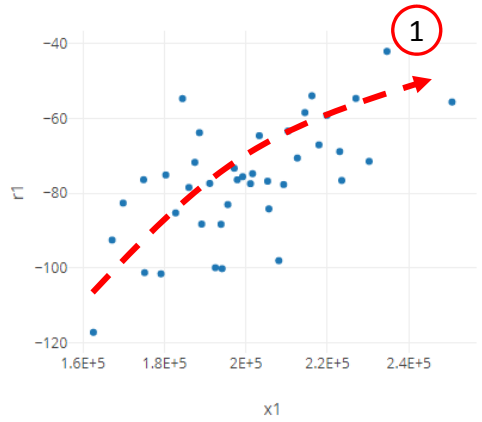


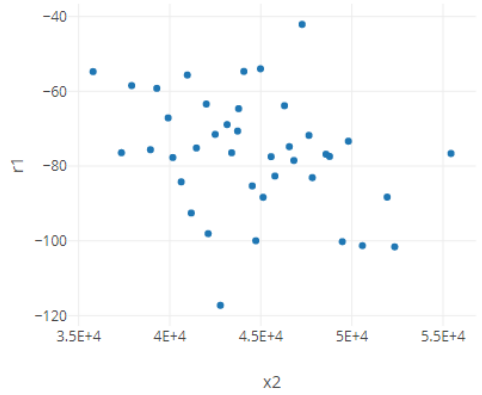


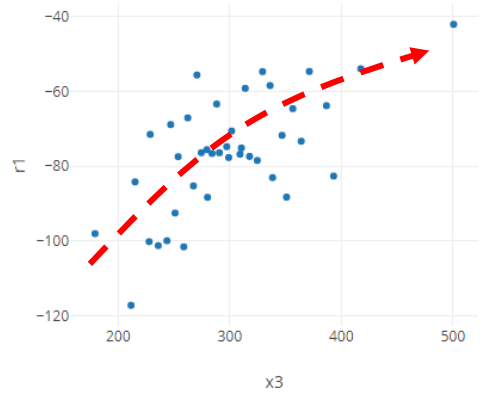
Review Results

1. Alternatively, a nonlinear relationship may be defined for some

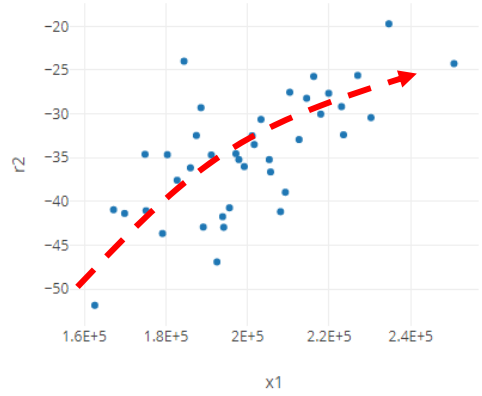
r1

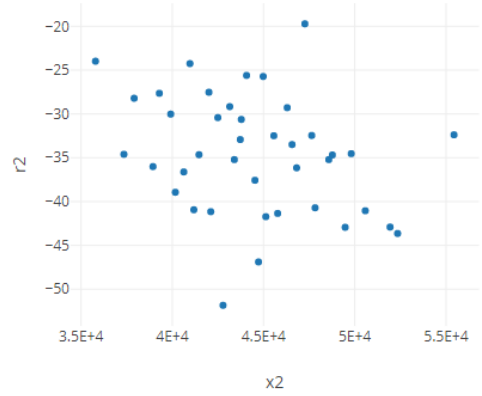


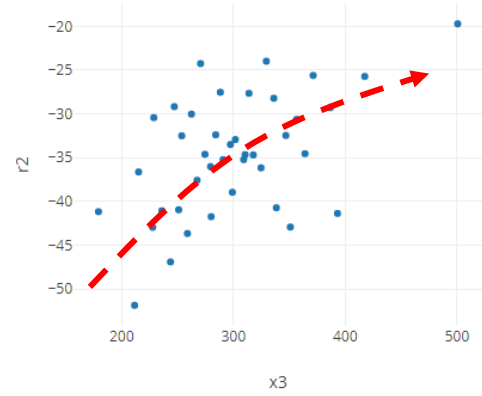




r2







Correlation Coefficients

Dakota outputs 2 types of correlation coefficients.

Pearson Correlation Coefficient

- Simple Correlation Matrix
- Partial Correlation Matrix

Spearman's Correlation Coefficient

- Simple Rank Correlation Matrix
- Partial Rank Correlation Matrix

File: workspace_d/dakota.out

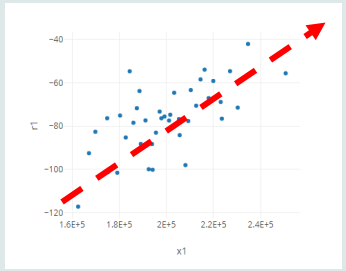
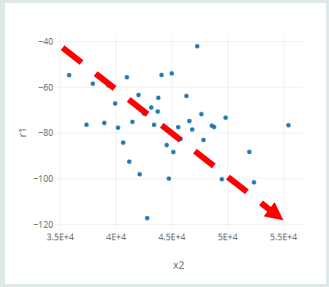
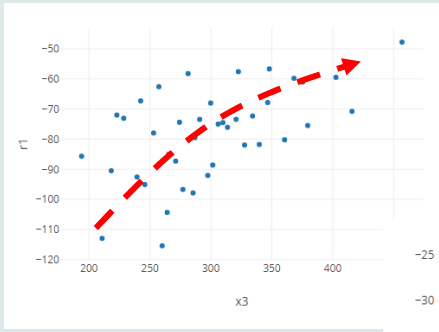
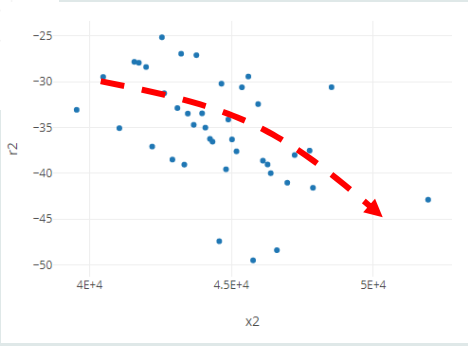
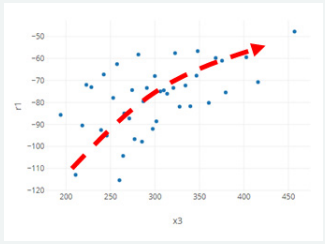
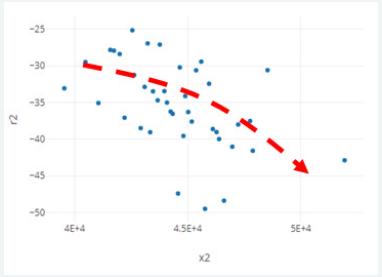
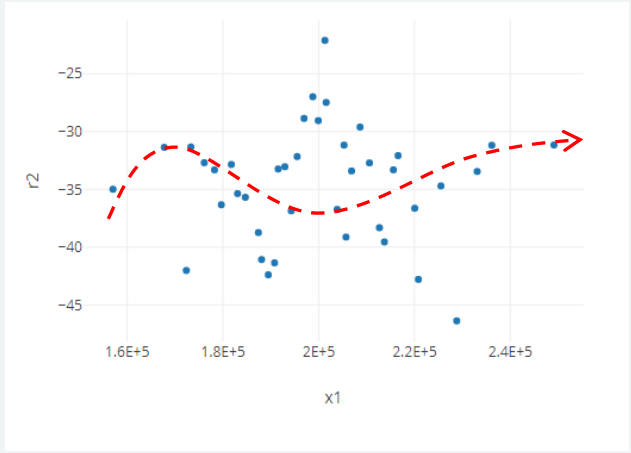
```
<<<<< Function evaluation summary (UQ_I): 0 total (0 new, 0 duplicate)
------------------------------------------------------------------------
Statistics based on 40 samples:

[…]

Simple Correlation Matrix among all inputs and outputs:
                        x1           x2           x3           x4           x5           r1           r2           r3
          x1  1.00000e+00
          x2 -1.10512e-01  1.00000e+00
          x3  1.54094e-01  1.69421e-01  1.00000e+00
          x4  1.89505e-01  3.46524e-01  2.64909e-01  1.00000e+00
          x5  2.22206e-01 -2.01454e-01 -6.08376e-02 -2.87279e-01  1.00000e+00
          r1  6.51560e-01 -3.11070e-01  6.56974e-01  3.76223e-01  5.31302e-02  1.000
          r2  6.81976e-01 -2.85070e-01  5.14679e-01  5.51336e-01 -2.56422e-03  9.631
          r3  1.31839e-15 -7.16441e-16  6.31439e-16 -9.47159e-16 -2.73739e-15  4.388                +00

Partial Correlation Matrix between input and output:
                        r1           r2           r3
          x1  8.60024e-01  8.85721e-01  2.31708e-15
          x2 -8.60492e-01 -8.86258e-01 -4.23496e-16
          x3  9.12323e-01  8.45796e-01  7.48632e-16
          x4  6.98539e-01  8.85942e-01 -2.27173e-15
          x5 -8.90610e-02 -1.36330e-01 -3.76261e-15

Simple Rank Correlation Matrix among all inputs and outputs:
                        x1           x2           x3           x4           x5           r1           r2           r3
          x1  1.00000e+00
          x2 -1.84053e-01  1.00000e+00
          x3  7.80488e-02  2.15947e-01  1.00000e+00
          x4  1.43527e-01  3.45403e-01  1.41651e-01  1.00000e+00
          x5  2.27955e-01 -2.03752e-01 -1.14447e-01 -1.91370e-01  1.00000e+00
          r1  6.17448e-01 -3.45591e-01  5.66229e-01  3.81051e-01  7.42964e-02  1.000
          r2  6.40713e-01 -3.08818e-01  4.32083e-01  5.53659e-01  5.83490e-02  9.604
          r3     -nan(ind)    -nan(ind)    -nan(ind)    -nan(ind)    -nan(ind)    -na                nd)

Partial Rank Correlation Matrix between input and output:
                        r1           r2           r3
          x1  8.34799e-01  8.92312e-01    -nan(ind)
          x2 -8.90863e-01 -9.26446e-01    -nan(ind)
          x3  9.18583e-01  9.06256e-01    -nan(ind)
          x4  8.43935e-01  9.45226e-01    -nan(ind)
          x5  8.27180e-02  1.12182e-01    -nan(ind)
```

Pearson Correlation Coefficients

Spearman's Correlation Coefficients

Correlation Coefficients

1. Use the Pearson type when the relationship is linear. The coefficient is positive if the linear relationship is increasing, else it is negative if decreasing.
2. Do NOT use the Pearson type if the relationship is nonlinear.
3. Use the Spearman's type when the relationship is nonlinear AND monotonic. Monotonic is when the relationship is always increasing OR decreasing, but not both together.
4. Do NOT use the Spearman's type when the relationship is both increasing and decreasing.

	Pearson	Spearman's
OK	 1 	 3 
NOT OK	 2 	 4

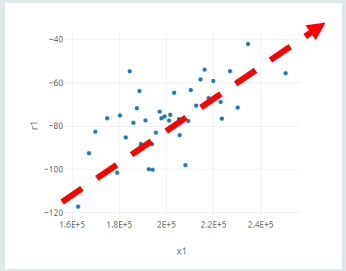
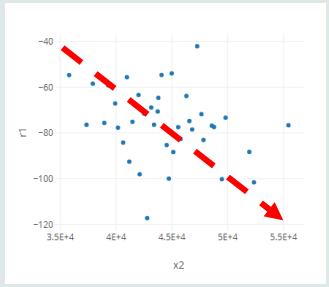
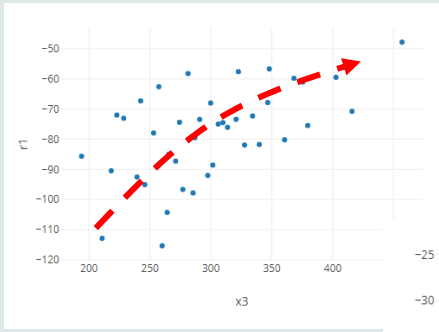
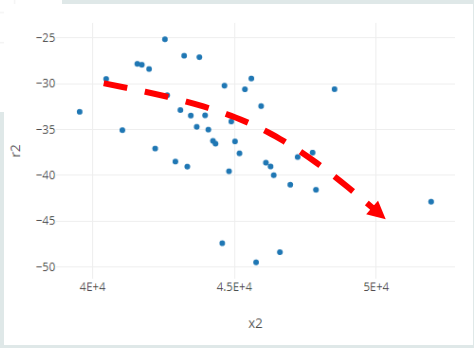
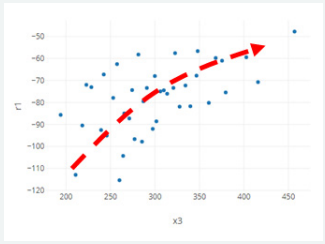
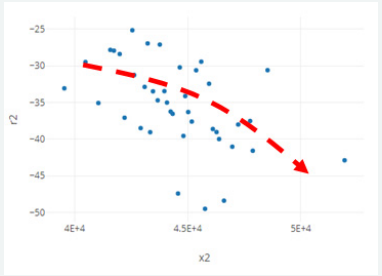
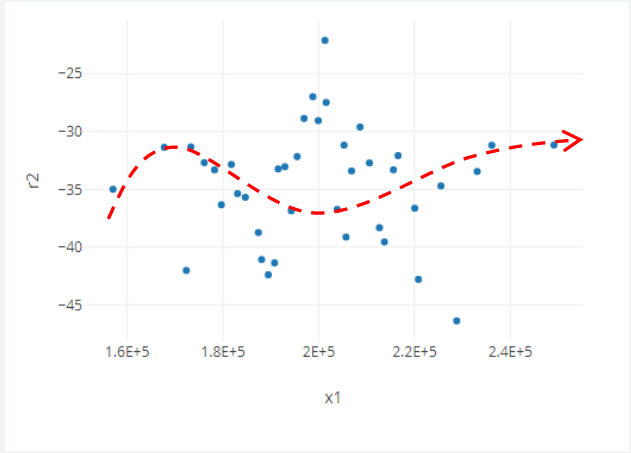
Correlation Coefficients

Decision logic:

Is the relationship linear?

- Yes – Use Pearson
  - Is there only one parameter?
    - Yes – Use Simple Correlation Matrix
    - No – Use Partial Correlation Matrix
- No – Is the relationship nonlinear AND monotonic?
  - Yes – Use Spearman's
    - Is there only one parameter?
      - Yes – Use Simple Rank Correlation Matrix
      - No – Use Partial Rank Correlation Matrix
  - No – Do not consider correlation coefficients

It was previously shown the scatter plots suggest a linear relationship between outputs and inputs, so Pearson correlation coefficients are inspected. Since there are 5 parameters involved, the table titled Partial Correlation Matrix is used.

	Pearson	Spearman's
OK	 	 
NOT OK	 	

Review Results

The Pearson correlation coefficients are inspected. The goal is to identify 2 parameters that are strongly correlated to the responses. Once these parameters are identified, these parameters will be adjusted to reduce the variance.

1. Navigate to section Simple Correlation Matrix among all inputs and outputs
2. A response is strongly correlated to a parameter if its coefficient is close to 1.0. Many practitioners will define "strongly correlated" differently. For this exercise, a strong correlation is any coefficient that is greater than 0.9. If the coefficient is negative, use the absolute value.
3. As a preferred alternative, use the partial correlation coefficients. Navigate to section Partial Correlation Matrix between input and output.
4. For response r1, parameter x3 has a strong influence on response r1.
5. For response r2, parameter x4 has a modest influence on response r2.
6. Alternatively, parameter x2 has a stronger influence on response r2. Parameter x2 corresponds to the load factor and is more difficult to control in practice. Since x3 and x4 are both cross section areas, and may be controlled through better manufacturing procedures, these parameters are selected for further adjustment.

Simple Correlation Matrix among all inputs and outputs (1)

Download CSV

	x1	x2	x3	x4	x5	r1	r2	r3
x1	1.00000e+00							
x2	-1.10512e-01	1.00000e+00						
x3	1.54094e-01	1.69421e-01	1.00000e+00					
x4	1.89505e-01	3.46524e-01	2.64909e-01	1.00000e+00				
x5	2.22206e-01	-2.01454e-01	-6.08376e-02	-2.87279e-01	1.00000e+00			
r1	6.51560e-01	-3.11070e-01	6.56974e-01	3.76223e-01	5.31302e-02	1.00000e+00		
r2	6.81976e-01	-2.85070e-01	5.14679e-01	5.51336e-01	-2.56422e-03	9.63153e-01	1.00000e+00	
r3	1.31839e-15	-7.16441e-16	6.31439e-16	-9.47159e-16	-2.73739e-15	-4.38885e-16	1.38951e-15	1.00000e+00

(2)

Partial Correlation Matrix between input and output (3)

Download CSV

	r1	r2	r3
x1	8.60024e-01	8.85721e-01	2.31708e-15
x2	-8.60492e-01	-8.86258e-01	-4.23496e-16
x3	9.12323e-01	8.45796e-01	7.48632e-16
x4	6.98539e-01	8.85942e-01	-2.27173e-15
x5	-8.90610e-02	-1.36330e-01	-3.76261e-15

(4) (5) (6)

Review Results

1. Recall that parameter x5 is a dummy parameter and has no influence on the responses. Their correlation coefficients are zero or nearly zero.
2. Similarly, response r3 is also a dummy response and is not influenced by any parameter. Its correlation coefficients are zero or nearly zero.
3. The same statements may be said for the partial correlation coefficients.

Simple Correlation Matrix among all inputs and outputs

Download CSV

	x1	x2	x3	x4	x5	r1	r2	r3
x1	1.00000e+00							
x2	-1.10512e-01	1.00000e+00						
x3	1.54094e-01	1.69421e-01	1.00000e+00					
x4	1.89505e-01	3.46524e-01	2.64909e-01	1.00000e+00				
x5	2.22206e-01	-2.01454e-01	-6.08376e-02	-2.87279e-01	1.00000e+00			
r1	6.51560e-01	-3.11070e-01	6.56974e-01	3.76223e-01	5.31302e-02	1.00000e+00		
r2	6.81976e-01	-2.85070e-01	5.14679e-01	5.51336e-01	-2.56422e-03	9.63153e-01	1.00000e+00	
r3	1.31839e-15	-7.16441e-16	6.31439e-16	-9.47159e-16	-2.73739e-15	-4.38885e-16	1.38951e-15	1.00000e+00

(2) (1)

Partial Correlation Matrix between input and output

Download CSV

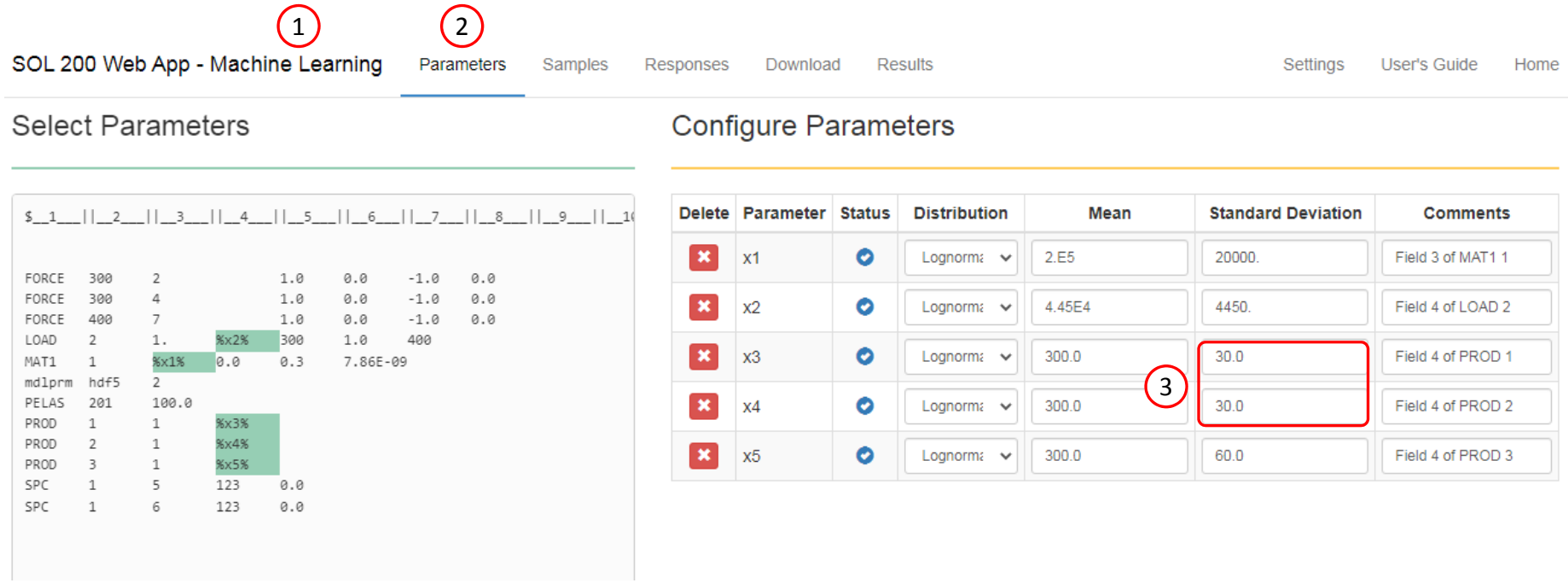
	r1	r2	r3
x1	8.60024e-01	8.85721e-01	2.31708e-15
x2	-8.60492e-01	-8.86258e-01	-4.23496e-16
x3	9.12323e-01	8.45796e-01	7.48632e-16
x4	6.98539e-01	8.85942e-01	-2.27173e-15
x5	-8.90610e-02	-1.36330e-01	-3.76261e-15

(3)

Part B – Secondary Sampling

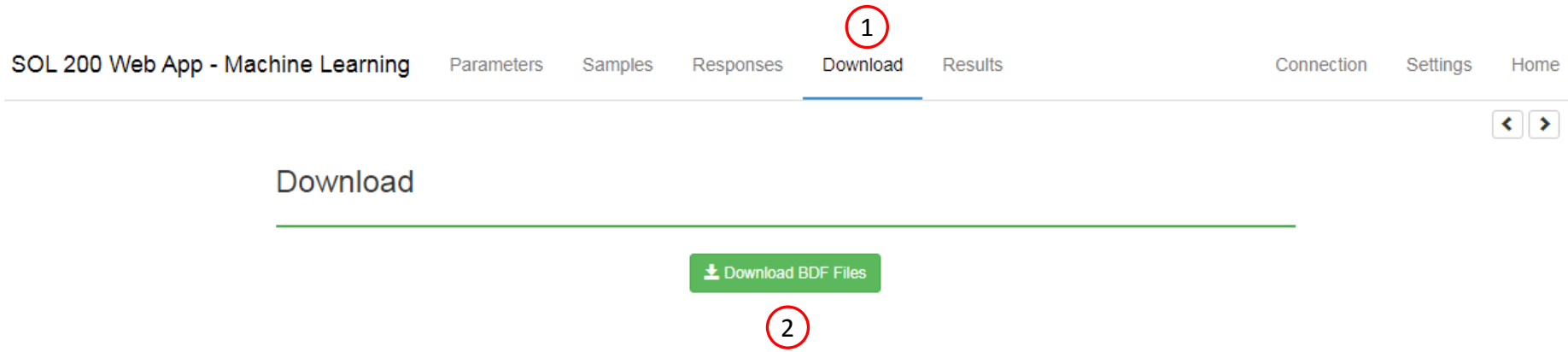
Parameters

1. Return to the Machine Learning web app
2. Click Parameters
3. Set the standard deviation of parameters x3 and x4 to 30.0
    - Parameters x3 and x4 were previously identified as having a strong correlation to the responses and are ideal parameters to adjust with the goal of reducing the variance of the responses. The original standard deviation of 60.0 was halved to 30.0 in an attempt to reduce the response's variance. Since parameters x3 and x4 correspond to cross sectional areas, reducing the standard deviation of these parameters may be achieved by improving the manufacturing process of the truss members .



Download

1. Click Download
2. Click Download BDF Files

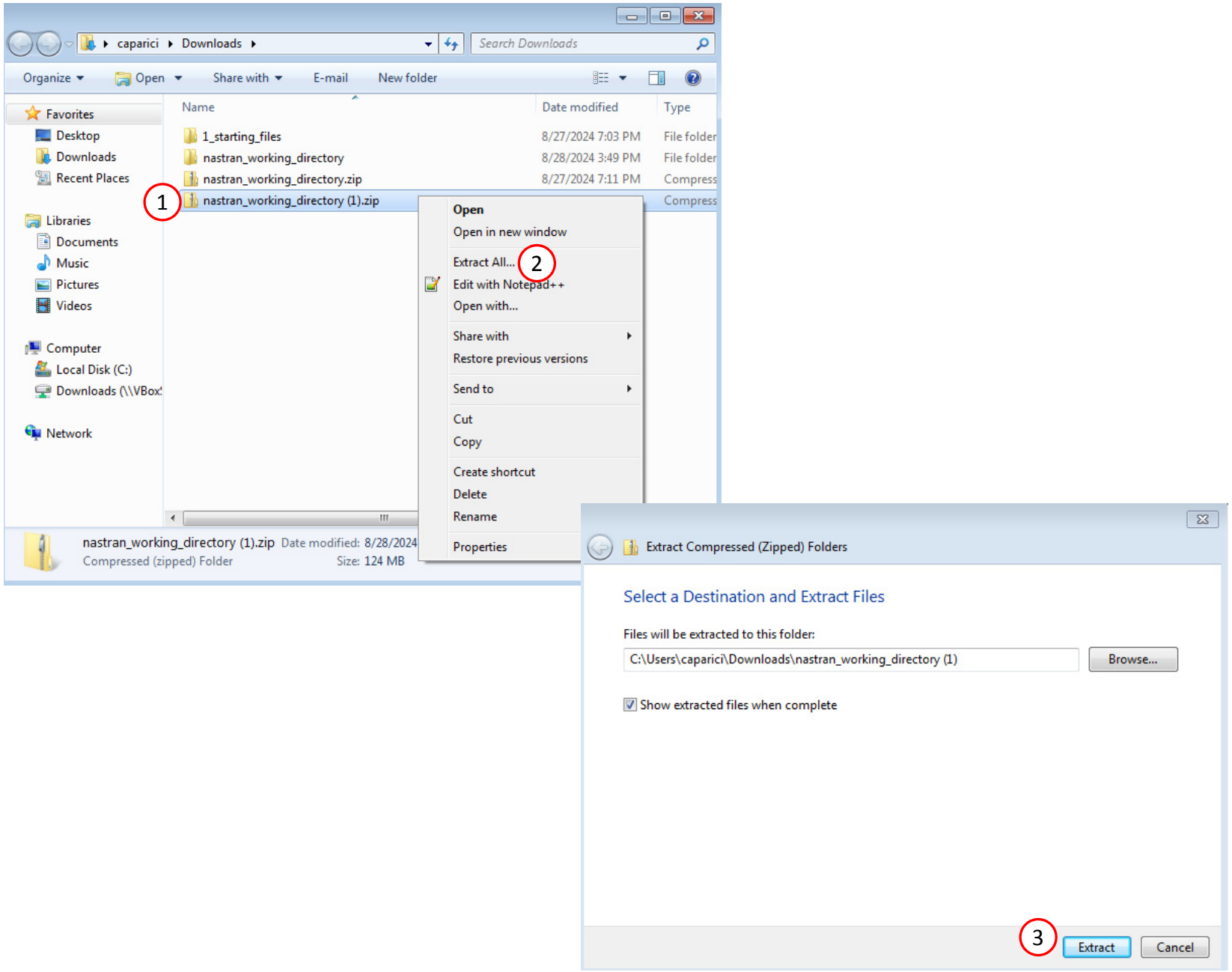


Start MSC Nastran

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

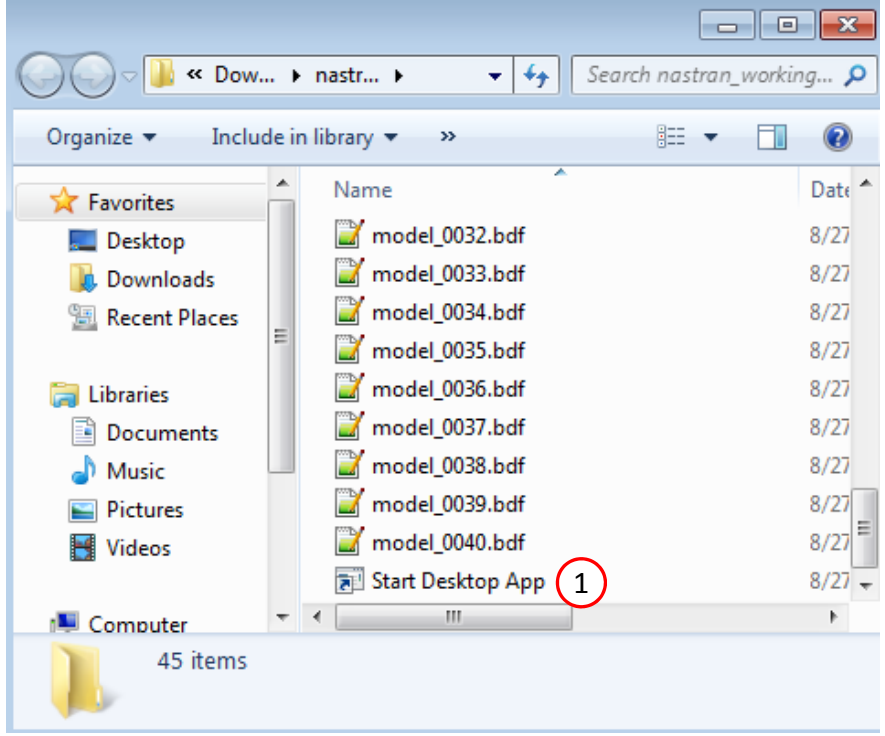
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the remote machine. 3) After completion, copy the BDF, F06, LOG, H5 files to the local machine. 4) Click "Start Desktop App" to display the results.

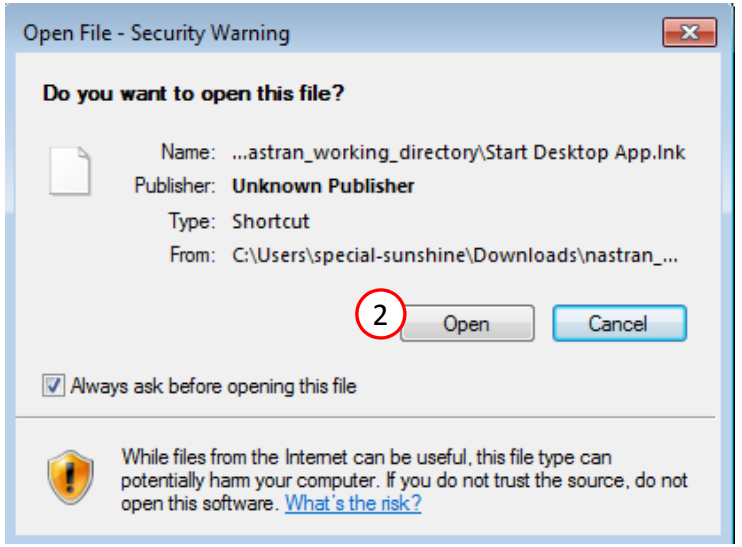
Using Linux?

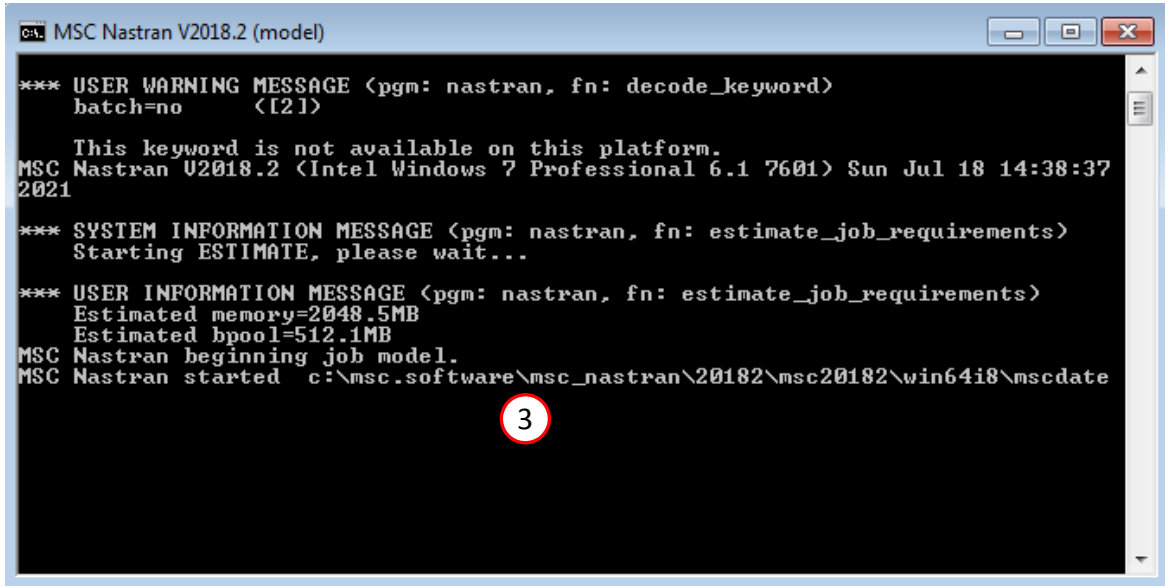
Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
   cd ./nastran_working_directory
3) Use this command to start the process
   ./Start_MSC_Nastran.sh

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

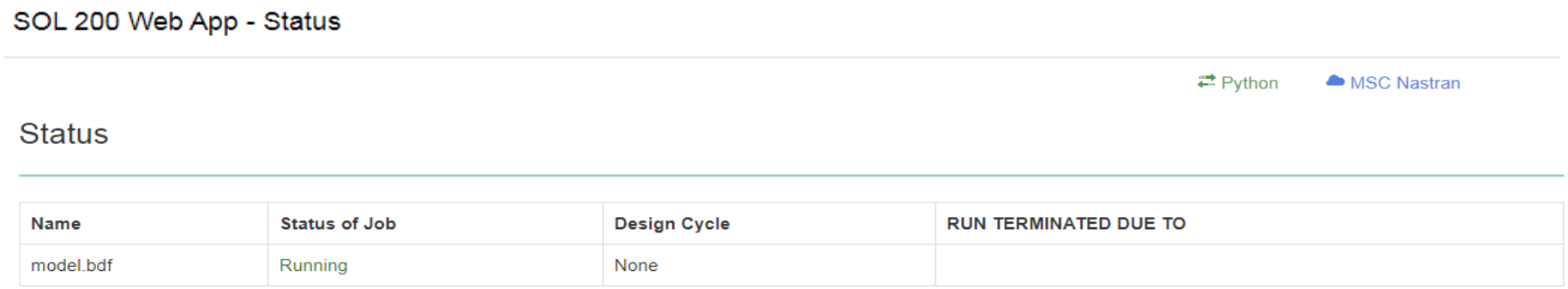






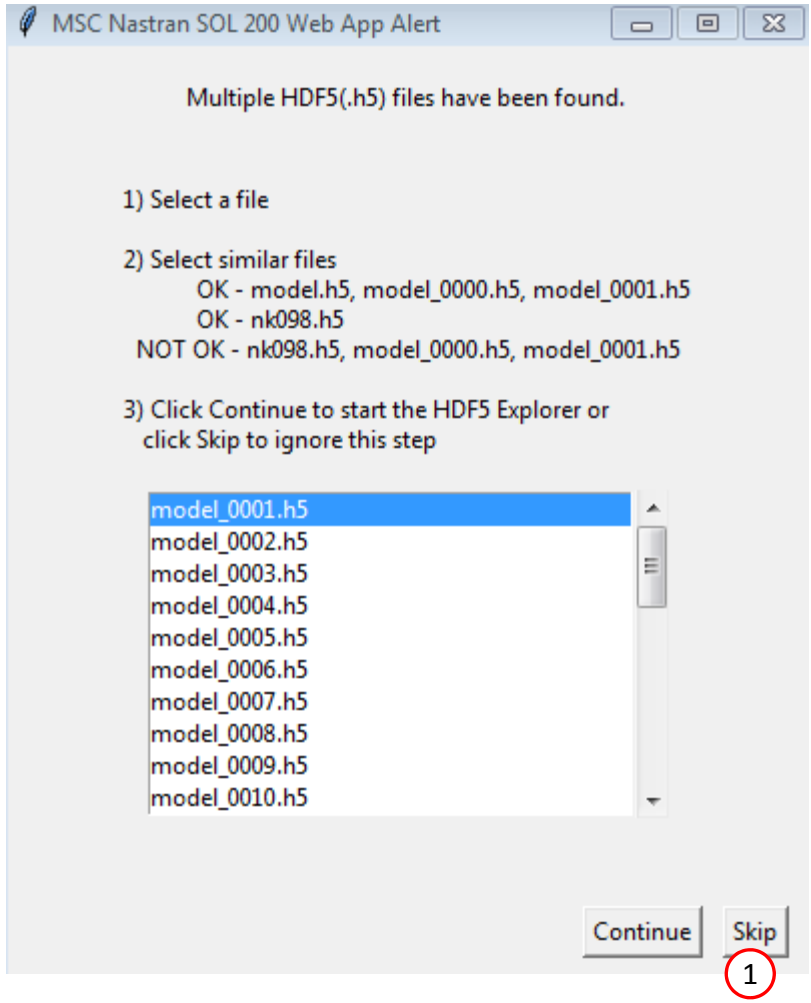
Status

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



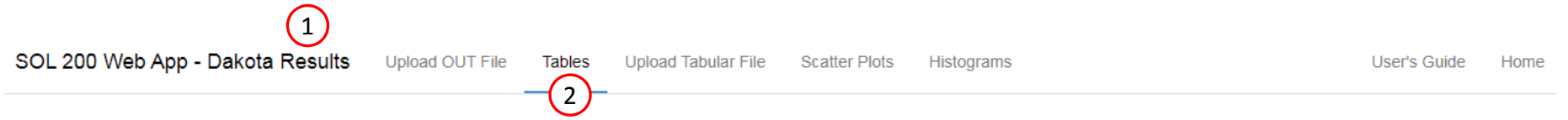
Machine Learning Results

1. After the process is complete, you will be asked to start the HDF5 Explorer. You can click Skip to skip opening the HDF5 Explorer.



Review Results

1. Refer to the Dakota Results web app
2. Click Tables
3. Note the new standard deviation values. In the next part, a comparison is performed between the original and new standard deviations.



Statistics based on 40 samples

Sample moment statistics for each response function

Download CSV

3

	Mean	Standard Deviation	Skewness	Kurtosis
r1	-7.5622608233e+01	1.2281104131e+01	-7.2542475037e-01	2.9380181403e-01
r2	-3.4533539421e+01	5.1436271240e+00	-6.1549999809e-01	3.9912244651e-02
r3	-1.0000000000e-02	5.2704682654e-18	1.0393904031e+00	-2.1081081081e+00

95% confidence intervals for each response function

Download CSV

	LowerCI_Mean	UpperCI_Mean	LowerCI_StdDev	UpperCI_StdDev
r1	-7.9550295882e+01	-7.1694920585e+01	1.0060201773e+01	1.5769373570e+01
r2	-3.6178551181e+01	-3.2888527660e+01	4.2134588358e+00	6.6045997785e+00
r3	-1.0000000000e-02	-1.0000000000e-02	4.3173621544e-18	6.7674683057e-18

Part C – Comparison of Results

Review Results

- Recall the goal was to reduce the variance or standard deviation of the responses r1 and r2. The standard deviations of the responses from parts A and B are record in the shown table.

	Initial Uncertainty Quantification (Part A)	Final Uncertainty Quantification (Part B)
r1	1.5740647557e+01	1.2281104131e+01
r2	6.8557433340e+00	5.1436271240e+00

Review Results

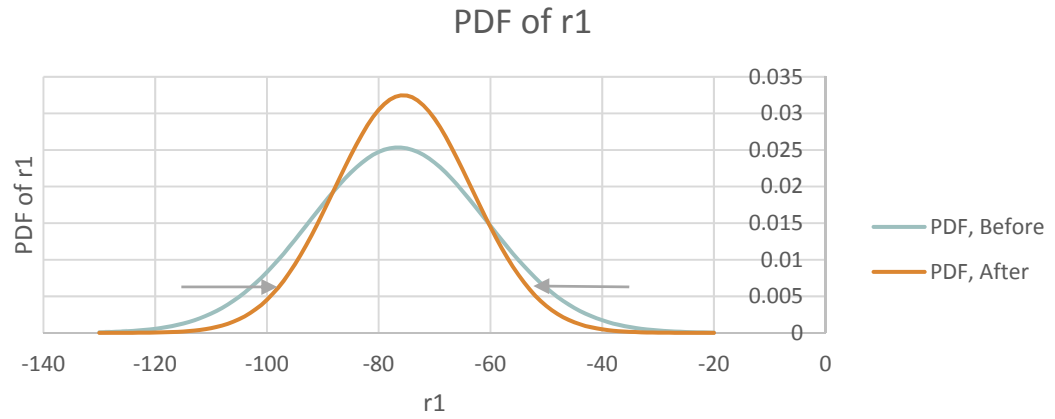
- Assuming a normal distribution for both responses, a probability density function is plotted for both responses by using the means and standard deviations from parts A and B.
- The standard deviations have been reduced for both responses r1 and r2, indicating the variances of the responses has been successfully reduced.
- The PDF plots also indicate the variance of the responses has been successfully reduced.
- When this exercise is repeated, the values are expected to be different since the sampling is random. Regardless of the randomization, reducing the variance should be achievable when this exercise is repeated and the procedure is followed.

Before

- r1 Standard Deviation: 1.5740647557e+01

After

- r1 Standard Deviation: 1.2281104131e+01

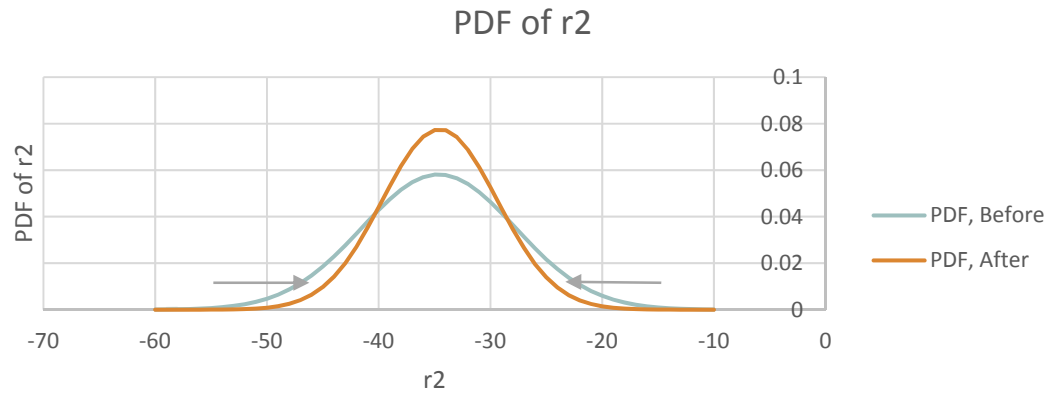


Before

- r2 Standard Deviation: 6.8557433340e+00

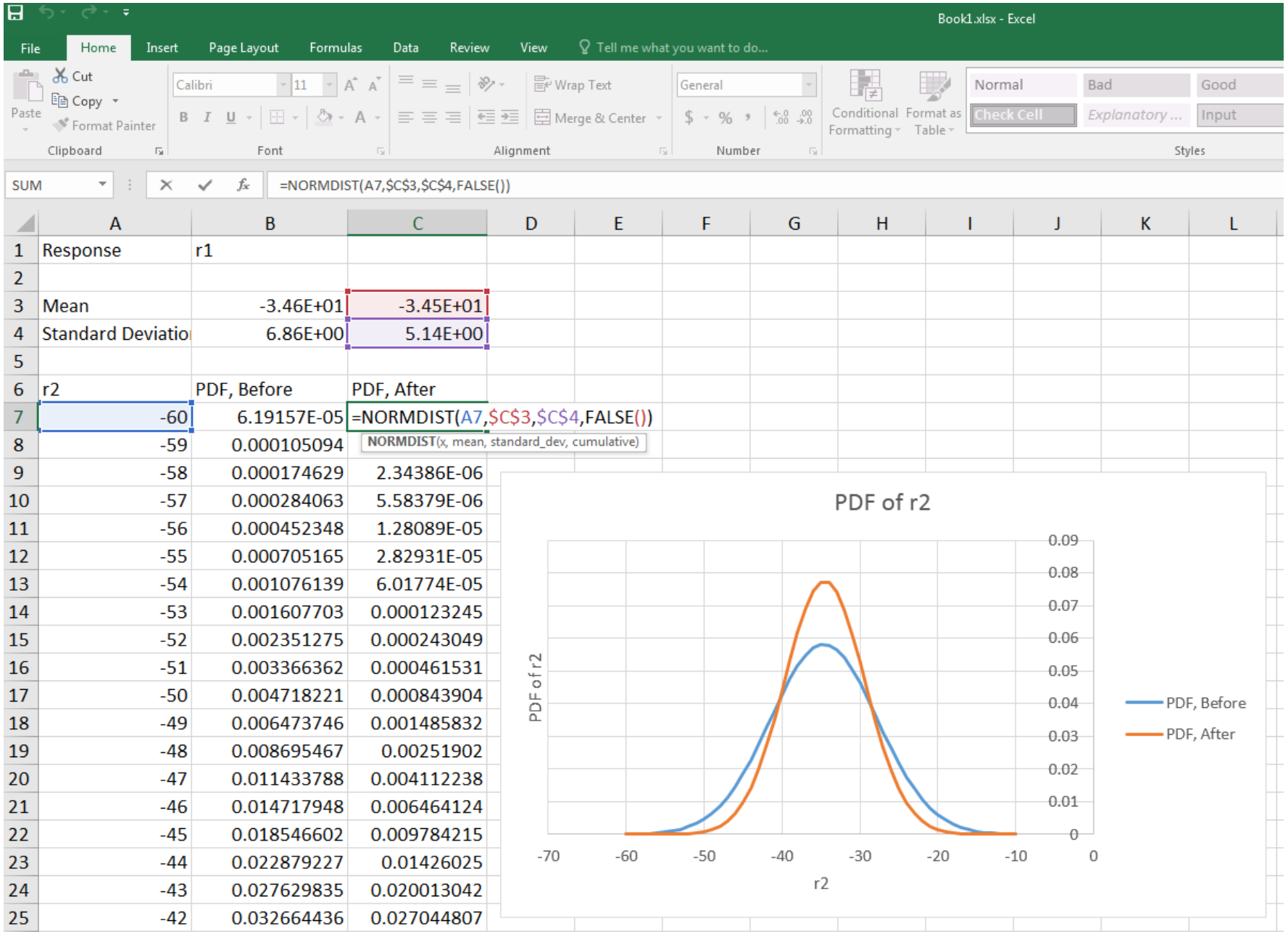
After

- r2 Standard Deviation: 5.1436271240e+00



Excel

- Since the mean and standard deviation were determined, Excel may be used to create probability density function (PDF) plots for each response. Then, comparisons may be made between the original and new PDFs.



	A	B	C
1	Response	r1	
2			
3	Mean	-3.46E+01	-3.45E+01
4	Standard Deviatio	6.86E+00	5.14E+00
5			
6	r2	PDF, Before	PDF, After
7	-60	6.19157E-05	=NORMDIST(A7,C3,C4,FALSE())
8	-59	0.000105094	
9	-58	0.000174629	2.34386E-06
10	-57	0.000284063	5.58379E-06
11	-56	0.000452348	1.28089E-05
12	-55	0.000705165	2.82931E-05
13	-54	0.001076139	6.01774E-05
14	-53	0.001607703	0.000123245
15	-52	0.002351275	0.000243049
16	-51	0.003366362	0.000461531
17	-50	0.004718221	0.000843904
18	-49	0.006473746	0.001485832
19	-48	0.008695467	0.00251902
20	-47	0.011433788	0.004112238
21	-46	0.014717948	0.006464124
22	-45	0.018546602	0.009784215
23	-44	0.022879227	0.01426025
24	-43	0.027629835	0.020013042
25	-42	0.032664436	0.027044807

End of Tutorial

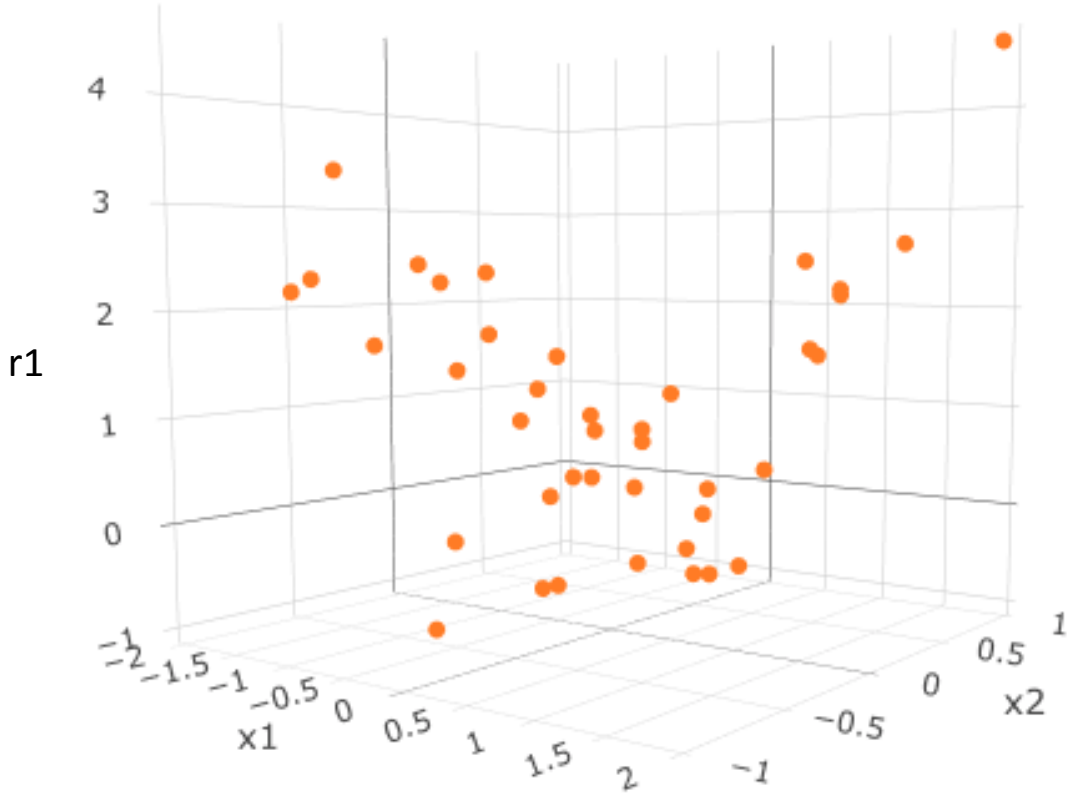
Appendix

Appendix Contents

- What is a projection?
- What is Pearson correlation coefficient?
- What is Spearman's correlation coefficient?
- What is skewness?
- What is kurtosis?
- What is a 95% confidence interval?

What is a projection?

- Consider a response that is dependent on multiple parameters. In the example on the right, the response is dependent on 2 parameters x1 and x2.



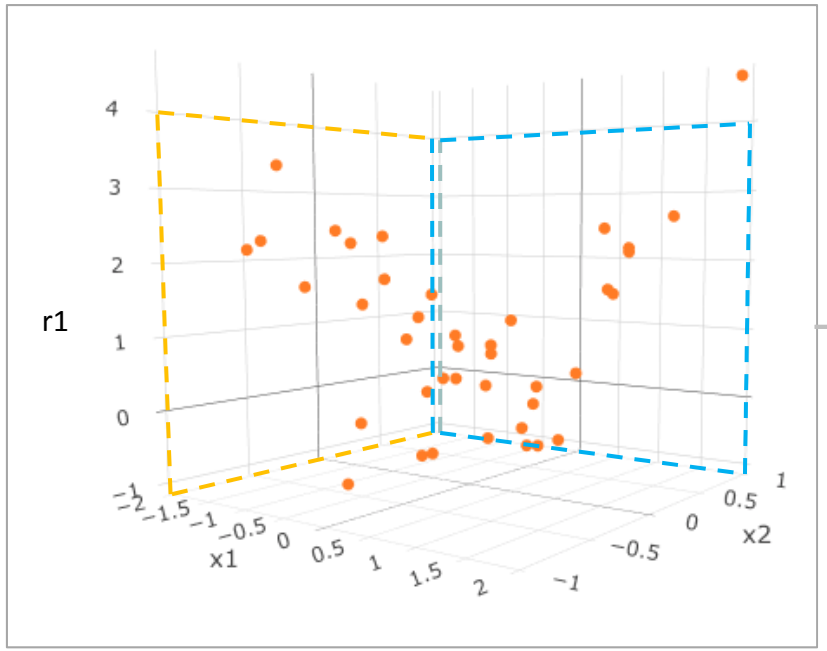
What is a projection?

An orthogonal projection is when N dimensional data is projected onto a 2D plane.

1. For the indicated plot, the 3D data is visualized on the x1, r1 plane.
2. For the indicated plot, the 3D data is visualized on the x2, r1 plane.

sample	x1	~~x2~~	r1
0	1.93	~~0.97~~	4.63
1	-1.09	~~0.38~~	1.44
2	0.71	~~-0.30~~	0.98
3	-0.69	~~0.33~~	0.84

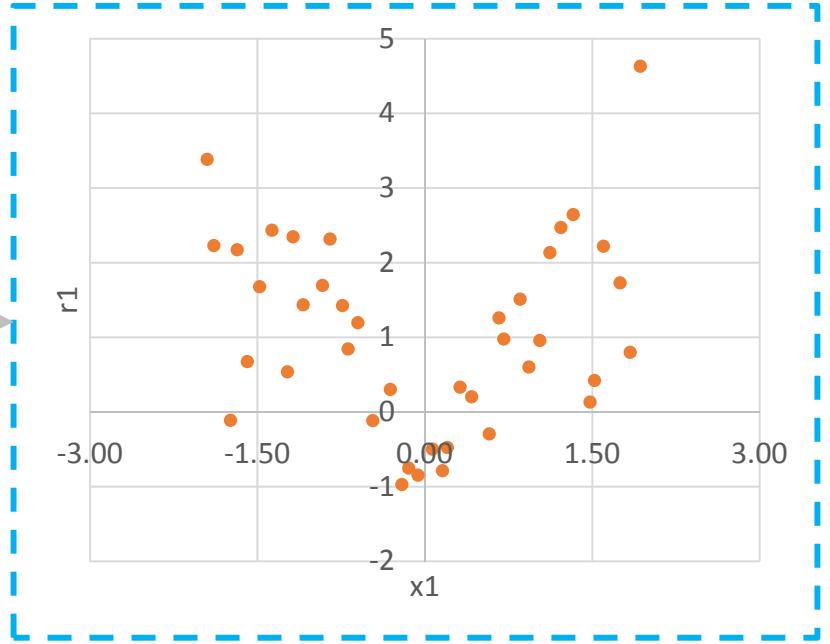
(x1, x2, r1) => (x1, r1)



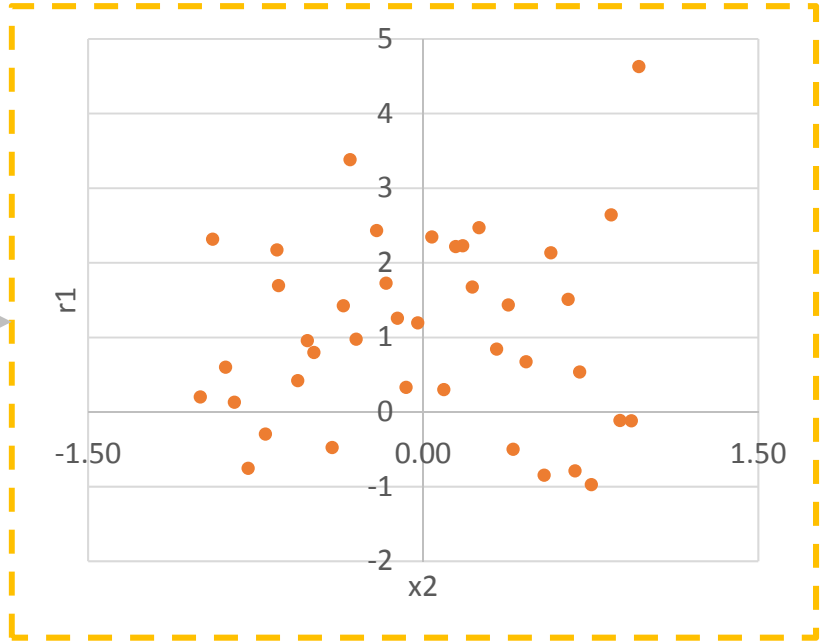
(x1, x2, r1) => (x2, r1)

sample	~~x1~~	x2	r1
0	~~1.93~~	0.97	4.63
1	~~-1.09~~	0.38	1.44
2	~~0.71~~	-0.30	0.98
3	~~-0.69~~	0.33	0.84

1



2



What is Pearson Correlation Coefficient?

- Dakota lists Pearson correlation coefficients under the table titled *Simple Correlation Matrix among all inputs and outputs.*
- Another form of Pearson correlation coefficients are listed in the table titled *Partial Correlation Matrix between input and output .*

Visit

https://www.scribbr.com/statistics/pearson-correlation-coefficient/#visualize

What is Spearman's Correlation Coefficient?

- Dakota lists Spearman's correlation coefficients under the table titled *Simple Rank Correlation Matrix among all inputs and outputs.*
- Another form of Spearman's correlation coefficients are listed in the table titled *Partial Rank Correlation Matrix between input and output.*

Visit

https://www.scribbr.com/statistics/correlation-coefficient/#spearmans-rho

What is Skewness?

Visit

https://www.scribbr.com/statistics/skewness/

What is Kurtosis?

Visit

https://www.scribbr.com/statistics/kurtosis/

What is a confidence interval?

A confidence interval is NOT a probability or chance.

NOT OK

- There is a 95% probability the quantity of interest is within the interval.
- There is a 95% chance the quantity of interest is within the interval.

A confidence interval is confidence.

OK

- There is 95% CONFIDENCE the quantity of interest is within the interval.
- After repeated sampling, 95% of confidence intervals will contain the true quantity of interest.

Visit

https://en.wikipedia.org/wiki/Confidence_interval