

Workshop - Uncertainty Quantification - 10 Bar Truss with MSC Nastran

AN MSC NASTRAN UNCERTAINTY QUANTIFICATION TUTORIAL

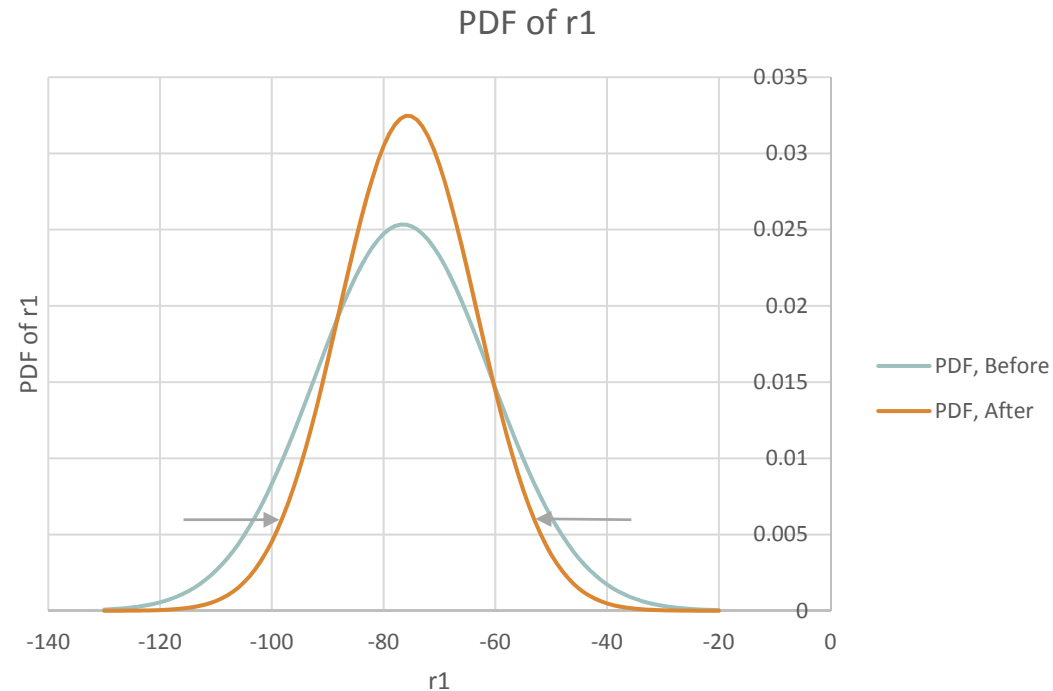
Goal: Use Uncertainty Quantification to Reduce Variance of Response r_1

Before

- r_1 Standard Deviation: $1.5740647557e+01$

After

- r_1 Standard Deviation: $1.2281104131e+01$



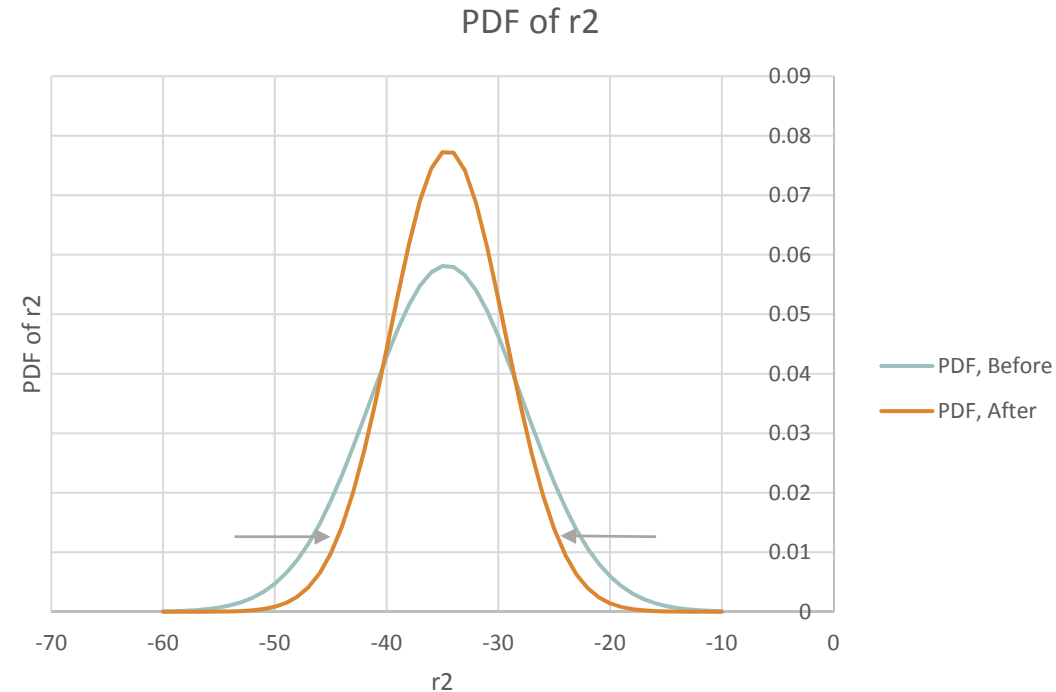
Goal: Use Uncertainty Quantification to Reduce Variance of Response r_2

Before

- r_2 Standard Deviation: $6.8557433340e+00$

After

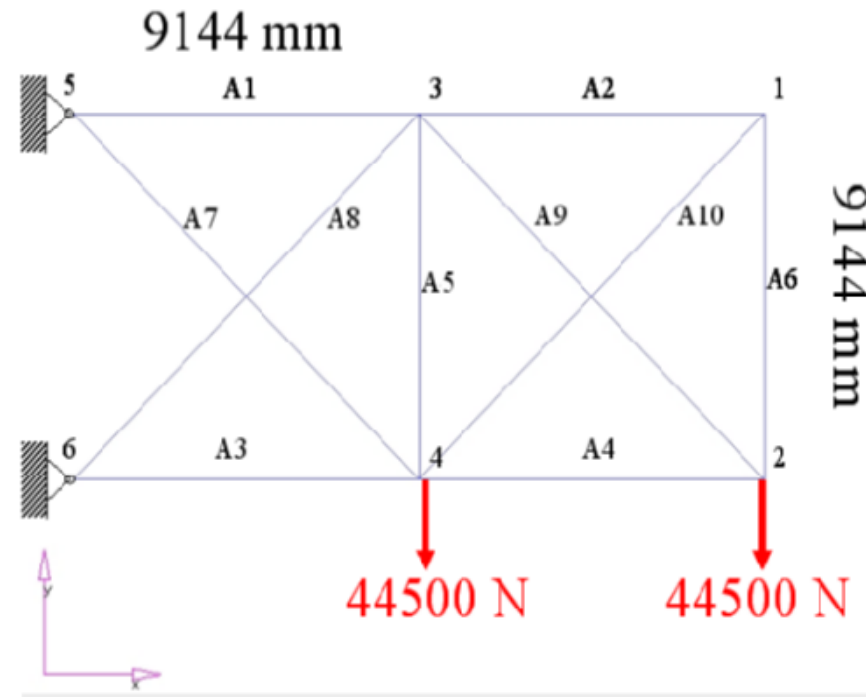
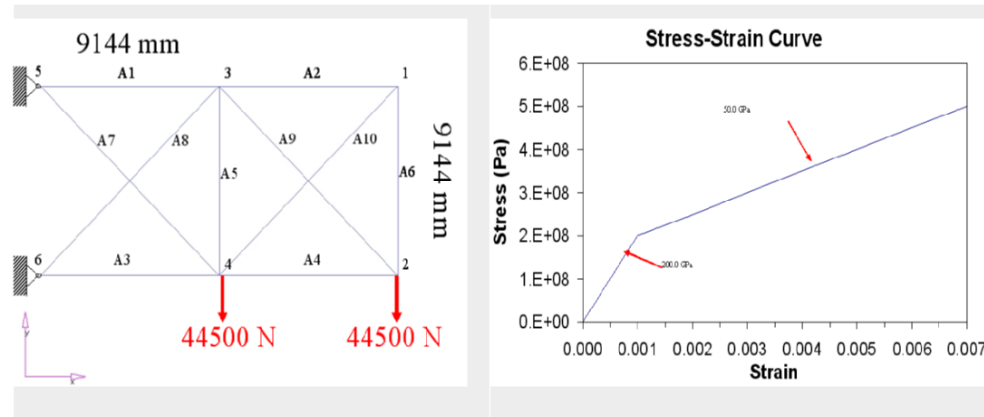
- r_2 Standard Deviation: $5.1436271240e+00$



Details of the Structural Model

Examples

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



(cross sectional areas)

Find:

Minimize:

Weight

$$|\sigma_j| \leq 220 \text{ MPa} \quad (j = 1, \dots, 10)$$

$$|\delta_{all}| \leq 100.0 \text{ mm} \quad (\text{both } x \text{ and } y \text{ directions of all nodes})$$

$$78.5 \text{ mm}^2 \leq X_i \leq 2826.0 \text{ mm}^2 \quad (i = 1, \dots, 10)$$

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

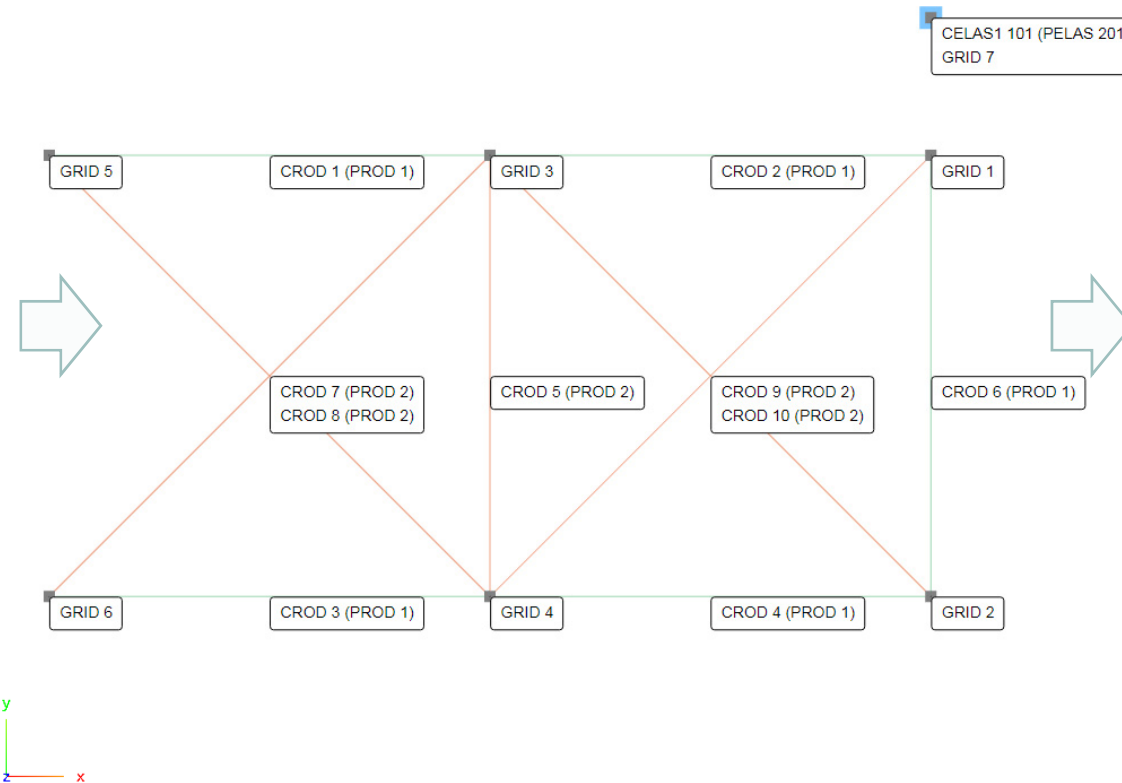
Problem Statement

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

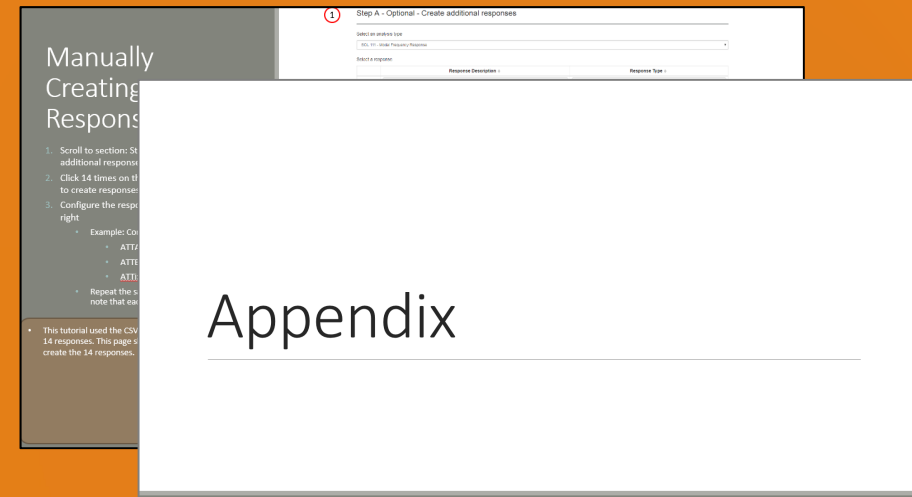
Quantities of Interest (QoI)

- 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.

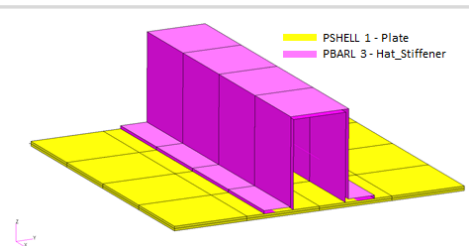
Compatibility

- 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.

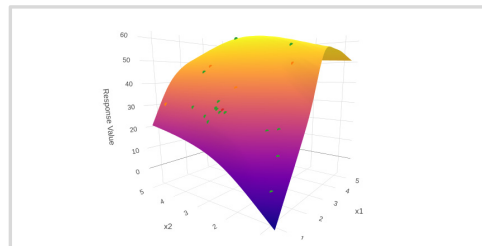
Benefits

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

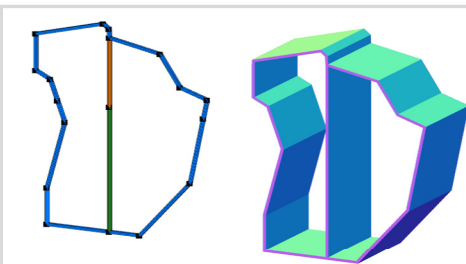
Web Apps



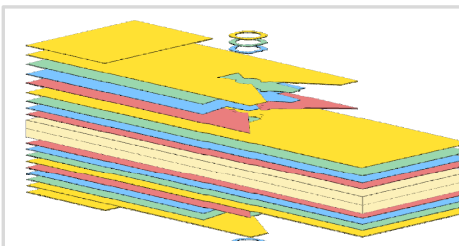
Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200.
Support for size, topology, topometry, topography, multi-model optimization.



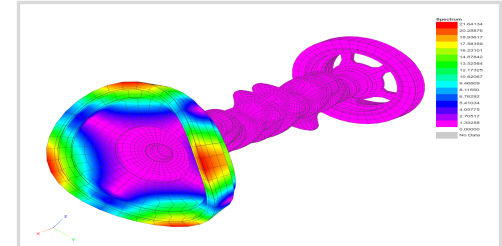
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



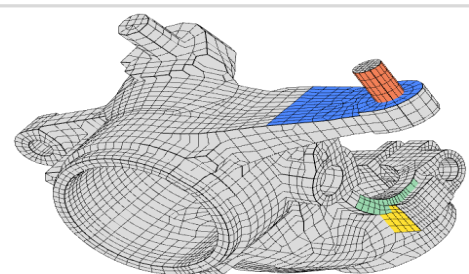
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



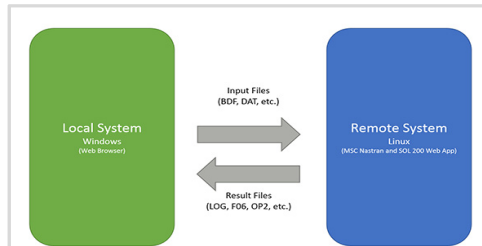
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries



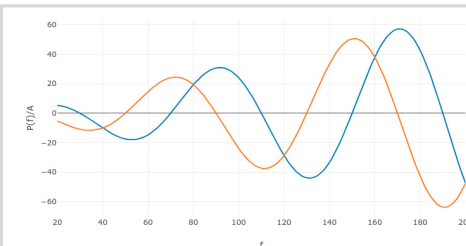
Post-processor Web App
View MSC Nastran results in a web browser on Windows and Linux



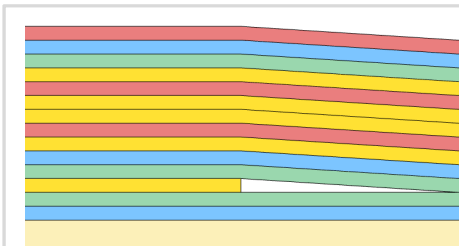
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



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

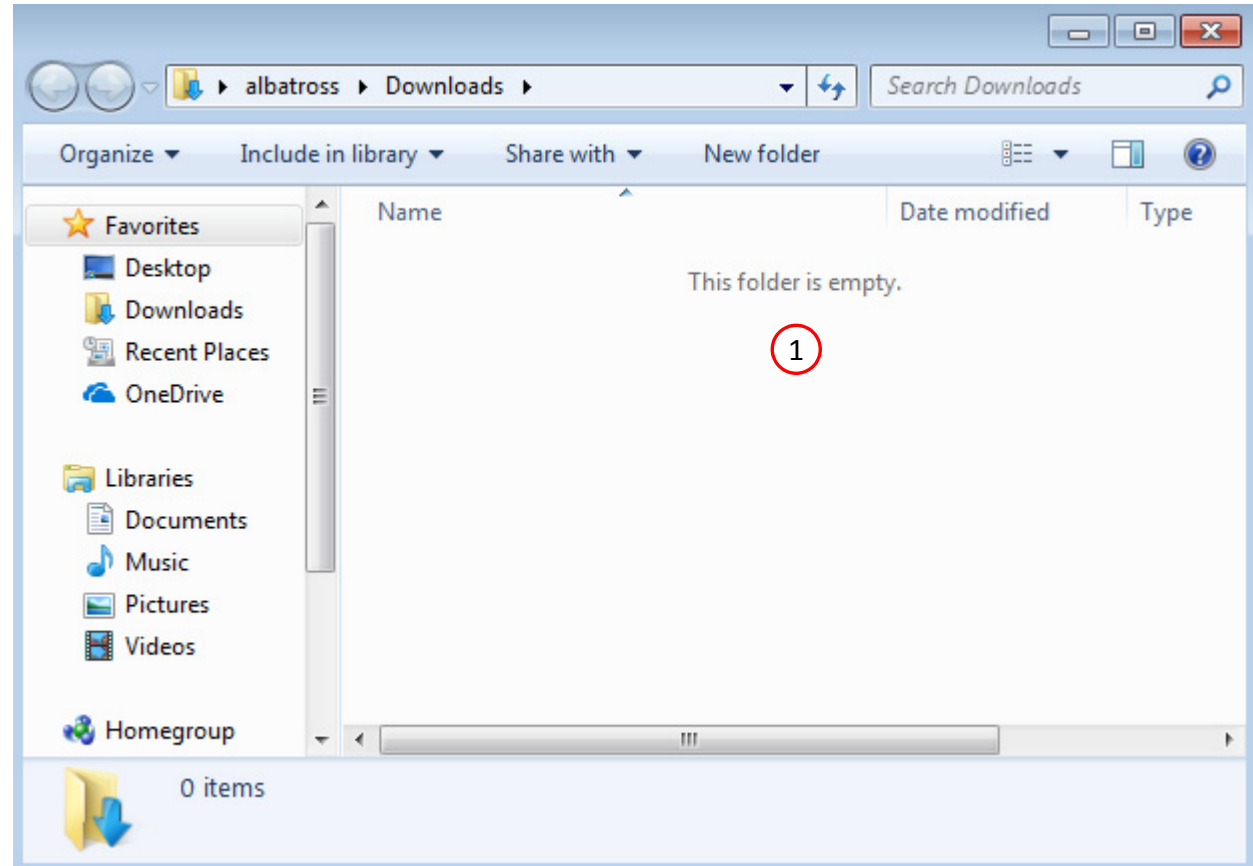


HDF5 Explorer Web App
Create graphs (XY plots) using data from the H5 file

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.

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

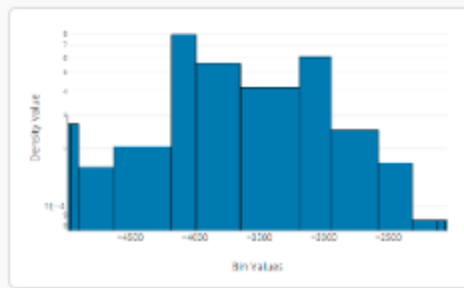
- Optimization for SOL 200:** Shows a 3D model of a mechanical part in two states, labeled "Before" and "After", illustrating the results of an optimization process.
- Multi Model Optimization:** Shows a 3D model of a part with arrows pointing to a graph showing multiple optimization curves.
- Machine Learning | Parameter Study:** Shows four different mesh deformation or stress distribution visualizations.
- HDF5 Explorer:** Shows a line graph with multiple data series plotted against a parameter.
- Viewer:** Shows a 3D cube with a color gradient from red to blue, representing a field of values.

At the bottom of the interface, there is a navigation bar with two items:

- Tutorials and User's Guide:** This item is highlighted with a red box and a circled "1", indicating it is the selected option.
- Full list of web apps:** A link to view all available applications.

Obtain Starting Files

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

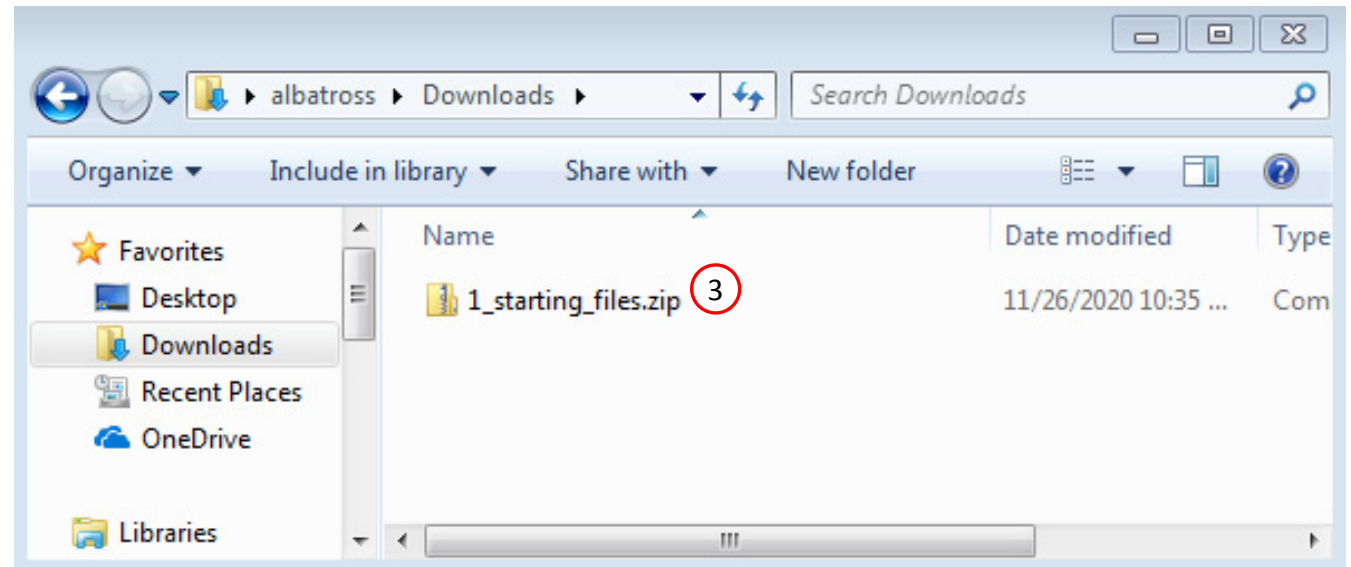


1

Uncertainty Quantification - 10 Bar Truss with MSC Nastran

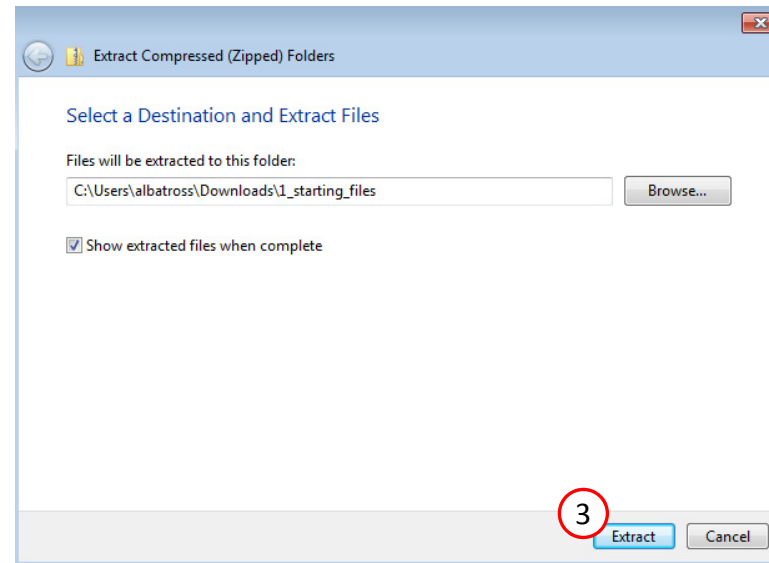
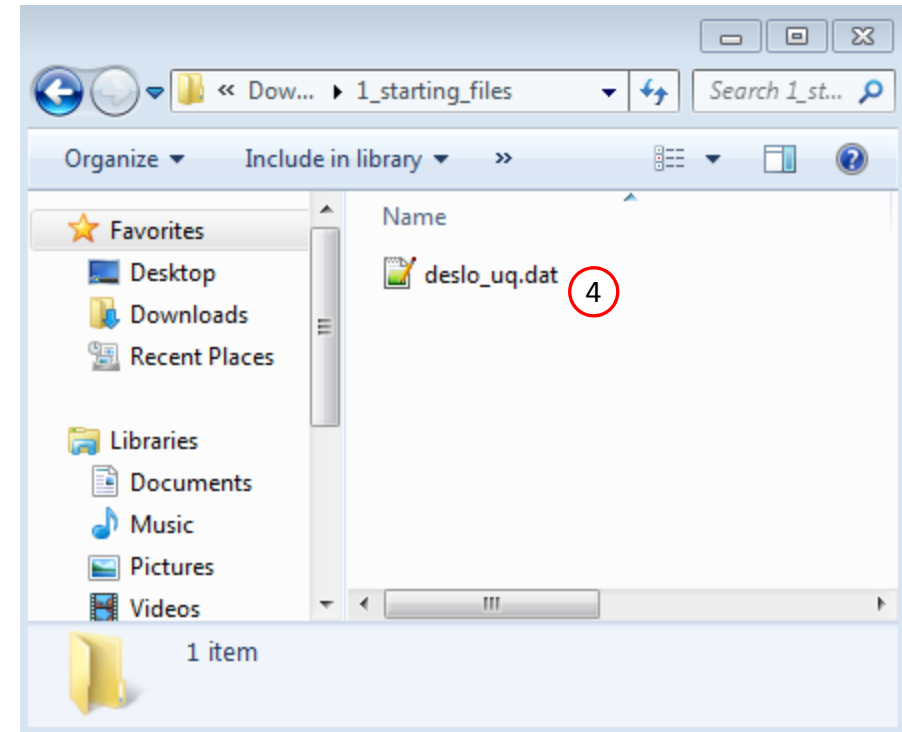
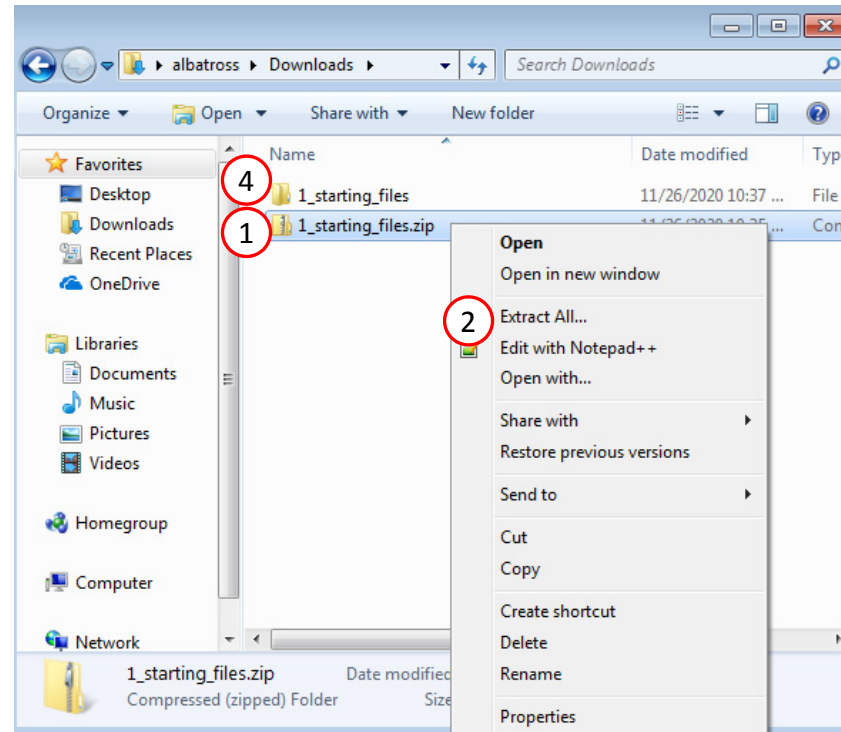
This example details the use of uncertainty quantification to reduce the variability of responses when uncertain parameters are present. Forward propagation of uncertainty is the focus of this exercise and the sampling method is used for uncertainty quantification. A 10 bar truss with 4 uncertain parameters is considered and a Latin Hypercube sampling is used. The quantities of interest include the mean and standard deviation values of the responses and correlation coefficients between the inputs (parameters) and outputs (responses).

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



Obtain Starting Files

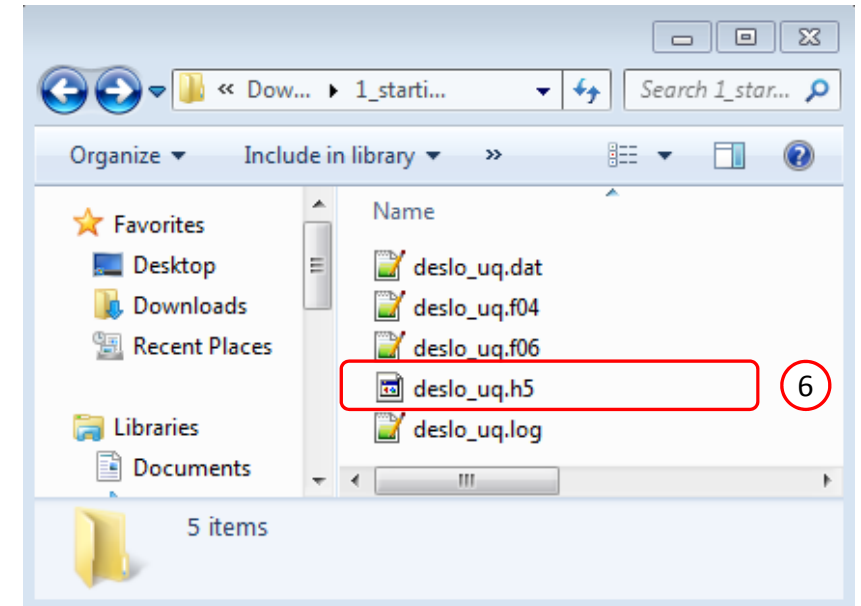
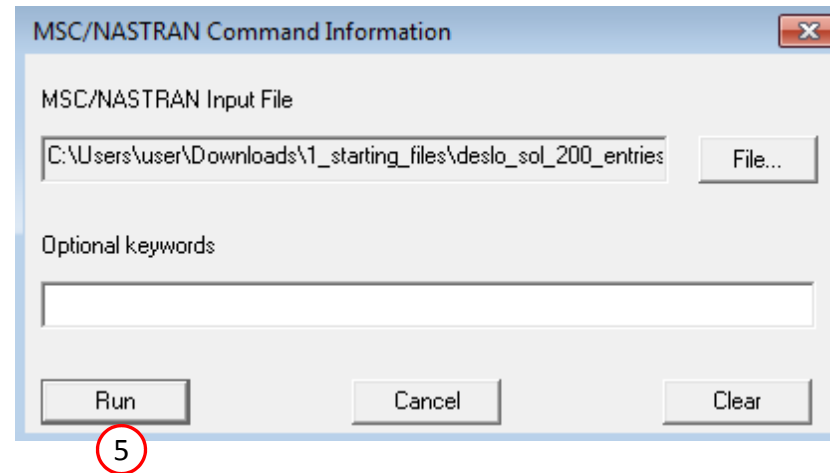
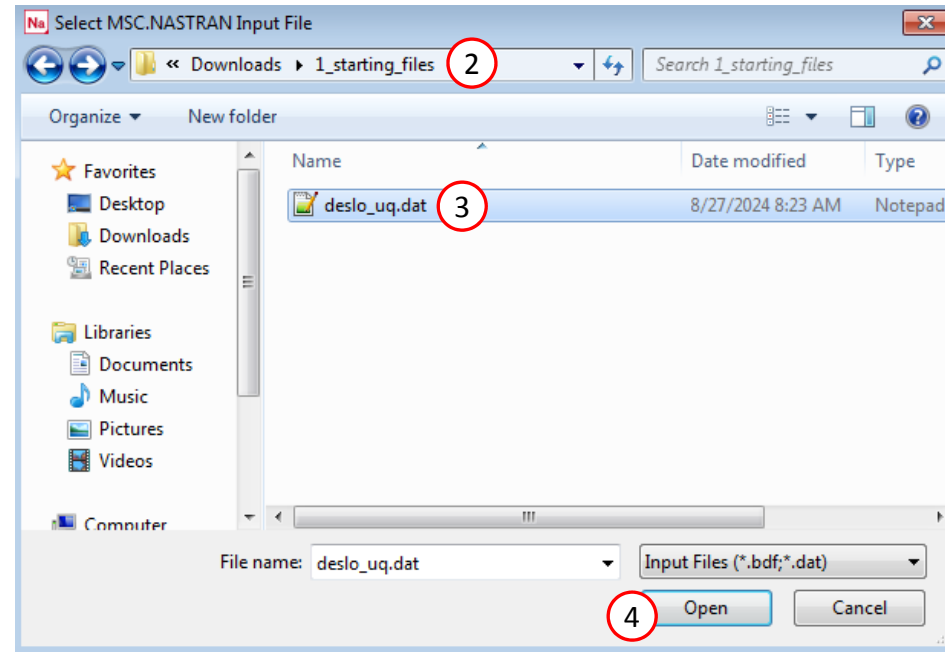
1. Right click on the zip file
2. Select Extract All...
3. Click Extract
4. The starting files are now available in a folder



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.

The screenshot displays the SOL 200 Web App interface with the following elements:

- Header:** "SOL 200 Web App" and "Select a web app to begin".
- Navigation Links:** "Tutorials and User's Guide" and "Full list of web apps".
- Web App Tiles:**
 - Optimization for SOL 200:** Shows "Before" and "After" 3D models of a mechanical part.
 - Multi Model Optimization:** Shows a 3D model and a line graph with multiple curves.
 - Machine Learning | Parameter Study:** Shows four 2D mesh deformation plots. A red circle with the number "1" is overlaid on this tile.
 - HDF5 Explorer:** Shows a line graph with multiple curves.
 - Viewer:** Shows a 3D cube with a color gradient from red to blue.

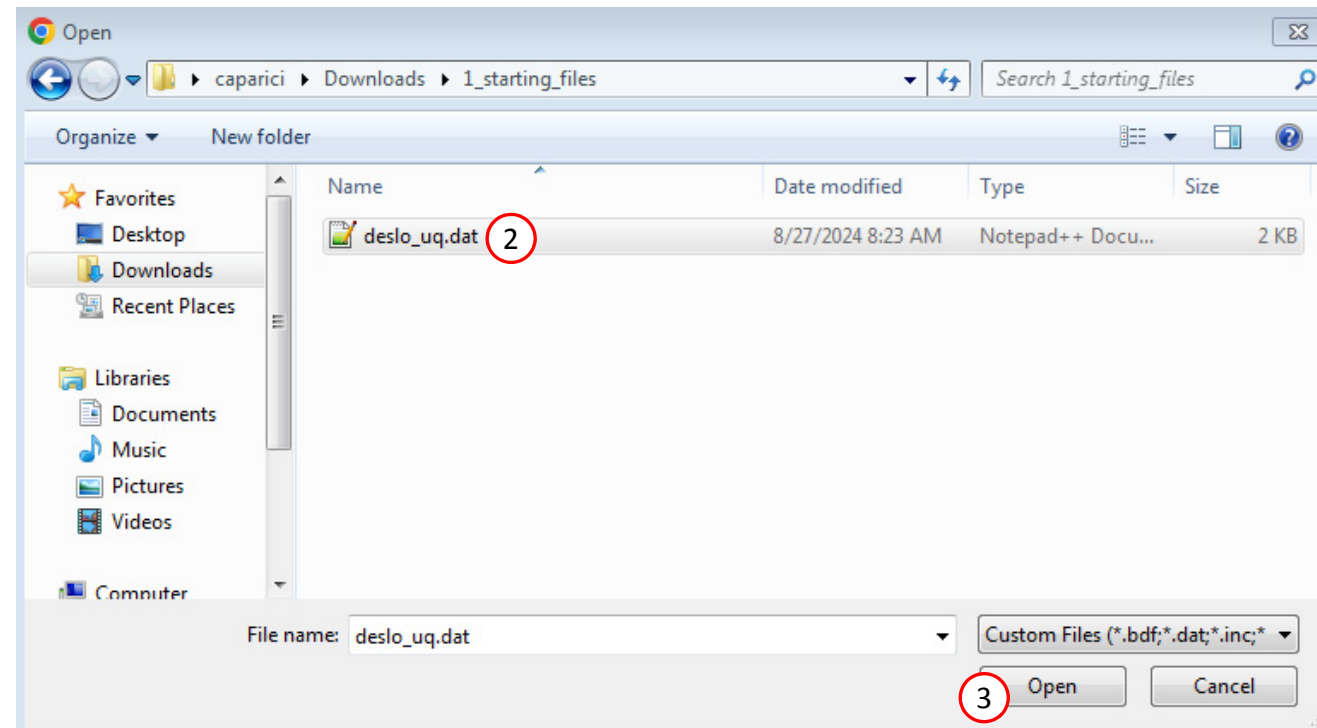


Select BDF Files

1. Select files deslo_uq.dat

Inspecting: 100%

2. Upload files



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

Configure Samples

Design

Latin Hypercube, Uncertain Parameters **2**

[+ Info](#)

Number of Samples

40 **3**

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

Select Parameters

\$ _1_ _2_ _3_ _4_ _5_ _6_ _7_ _8_ _9_							
FORCE	300	2		1.0	0.0	-1.0	0.0
FORCE	300	4	3	1.0	0.0	-1.0	0.0
FORCE	400	7		1.0	0.0	-1.0	0.0
LOAD	2	1.	%x2%	300	1.0	400	
MAT1	1	2	%x1%	0.0	0.3	7.86E-09	
mdlprm	hdf5	2					
PELAS	201	100.0					
PROD	1	1	%x3%				
PROD	2	1	%x4%				
PROD	3	1	%x5%				
SPC	1	5	6	123	0.0		
SPC	1	6		123	0.0		

Configure Parameters

Delete	Parameter	Status	Distribution	Mean	Standard Deviation
✖	x1	✔	Lognorm ▼	2.E5	20000.
✖	x2	✔	Lognorm ▼	4.45E4	4450.
✖	x3	✔	Lognorm ▼	300.0	60.0
✖	x4	✔	Lognorm ▼	300.0	60.0
✖	x5	✔	Lognorm ▼	300.0	60.0

7

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.

SOL 200 Web App - Machine Learning Parameters **Samples** Responses Download Results Settings User's Guide Home

Configure Samples

Design
Latin Hypercube, Uncertain Parameters

+ Info

Number of Samples
40

Samples to Run

+ Options

Sample Number	x1	x2	x3	x4	x5
1	174884.7	37349.77	274.5433	287.997	345.8363
2	186008.8	46815.2	324.7452	314.7711	276.9808
3	223038.3	43149.24	247.141	357.8247	296.7125
4	205646.5	40630.63	215.1798	273.7796	320.5307
5	197142.4	49808.8	364.0946	317.9633	310.366

« 1 2 3 4 5 6 7 8 »

5 10 20 30 40 50

1

Upload H5 File

Upload Option Direct Upload

A - Direc

2

1. Select files deslo_uq.h5

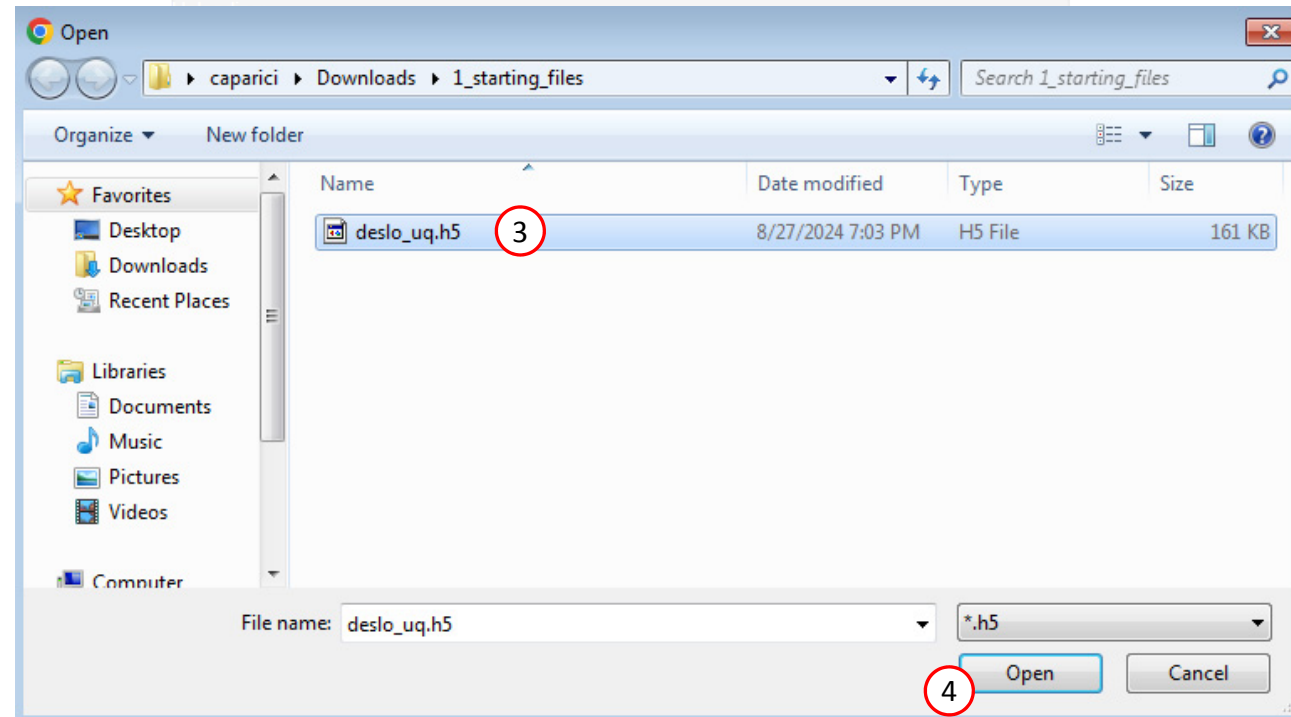
5

2. Upload files

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.

SOL 200 Web App - Machine Learning Parameters Samples Responses Download Results Settings User's Guide Home

Select Responses to Monitor Session ID: 3981 HDF5

Select Dataset Acquired Dataset NODAL/GRID_WEIGHT - 1 Reset Filters

ID	MO	S	MX	XX

View Responses to Monitor

Monitored Responses Hide/Show Columns Reset Filters Download CSV

Delete	Label	Status	Objective	Lower Bound	Upper Bound	Monitor the response of the FINAL design cycle (SOL 200 only)
<input type="checkbox"/>	r1	<input checked="" type="checkbox"/>		Lower	Upper	

SOL 200 Web App - Machine Learning Parameters Samples Responses Download Results Settings User's Guide Home

Select Responses to Monitor Session ID: 3981 HDF5

Select Dataset Acquired Dataset NODAL/GRID_WEIGHT - 1 Reset Filters

ID	MO	S	MX	XX

View Responses to Monitor

Monitored Responses Hide/Show Columns Reset Filters Download CSV

Delete	Label	Status	Objective	Lower Bound	Upper Bound	Monitor the response of the FINAL design cycle (SOL 200 only)
<input type="checkbox"/>	r1	<input checked="" type="checkbox"/>		Lower	Upper	

Download

1. Click Download
2. Click Download BDF Files

Download

 Download BDF Files

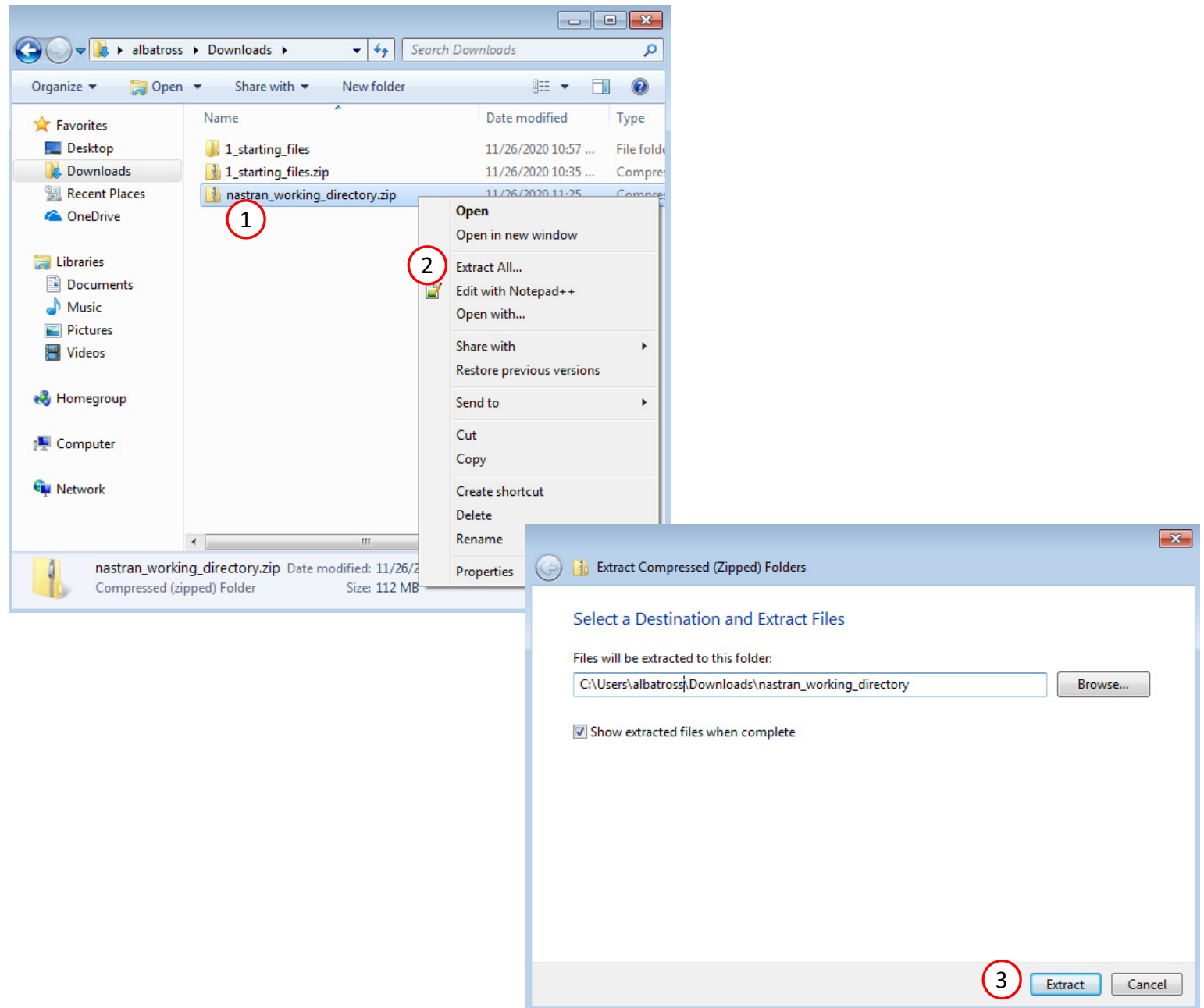
2

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.

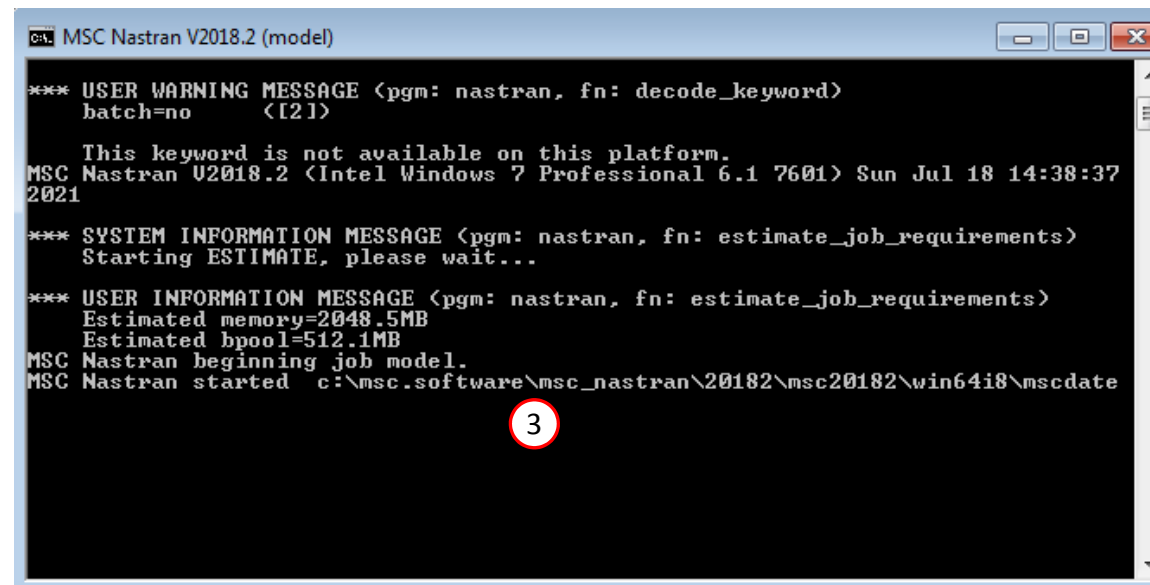
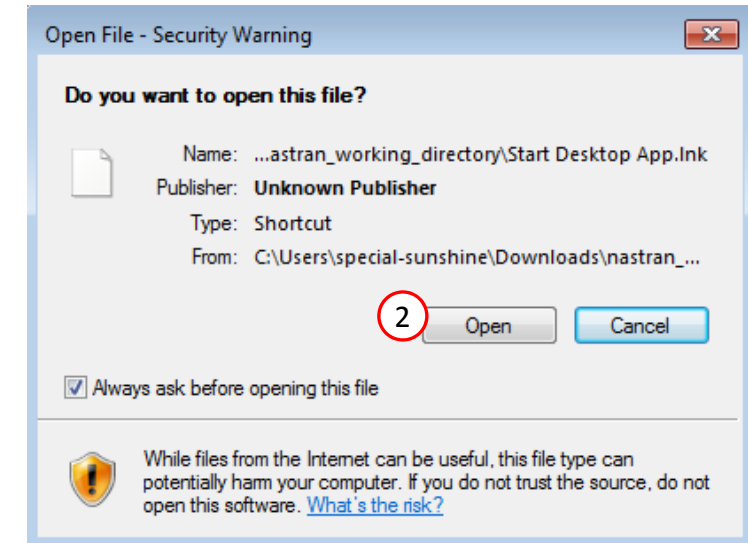
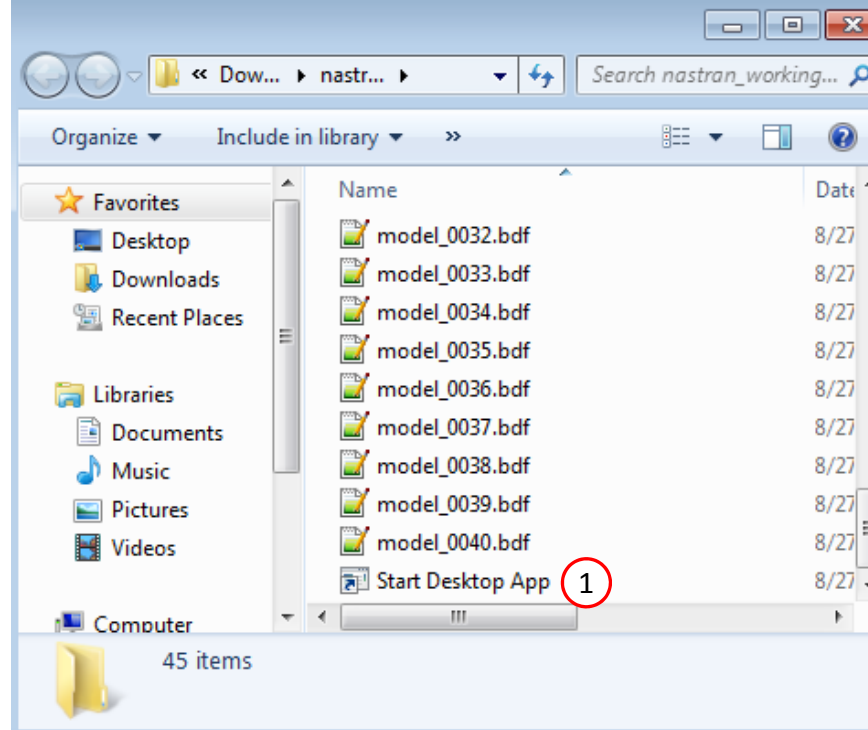
Using Linux?

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

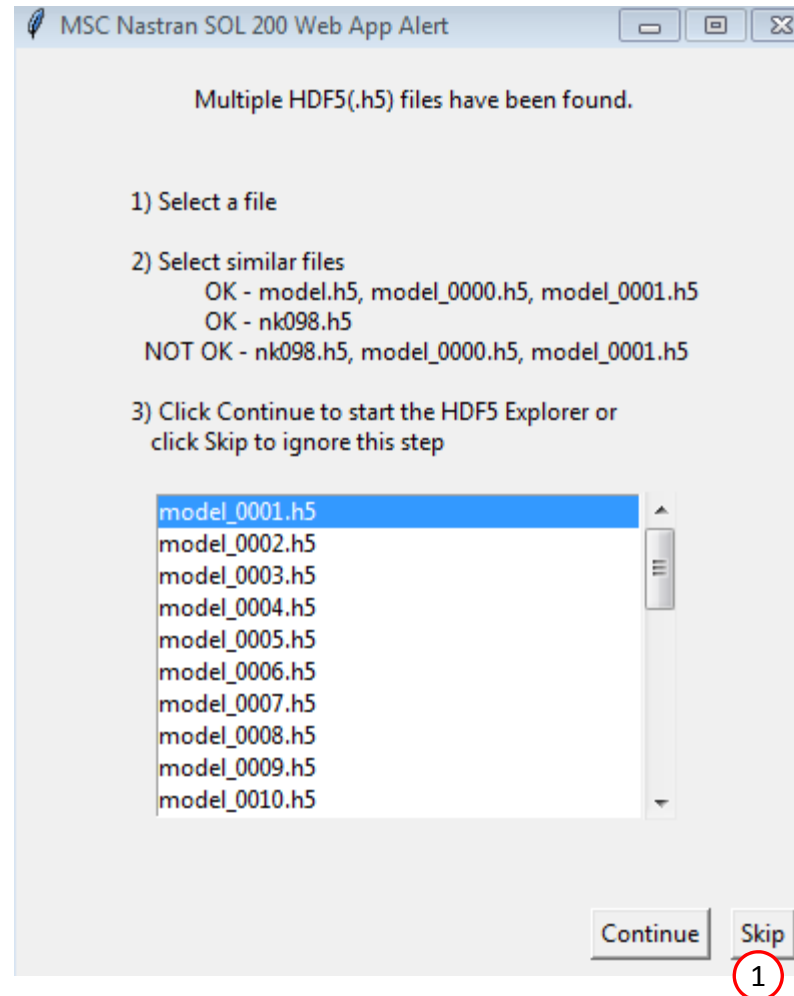
 MSC Nastran

Status

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

Machine Learning Results

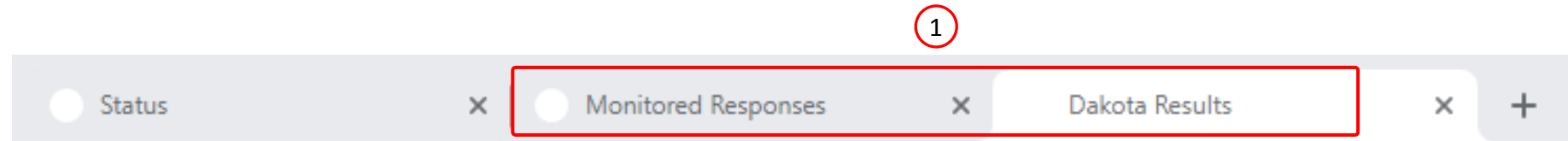
1. After the process is complete, you will be asked to start the HDF5 Explorer. You can click Skip to skip opening the HDF5 Explorer.



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.

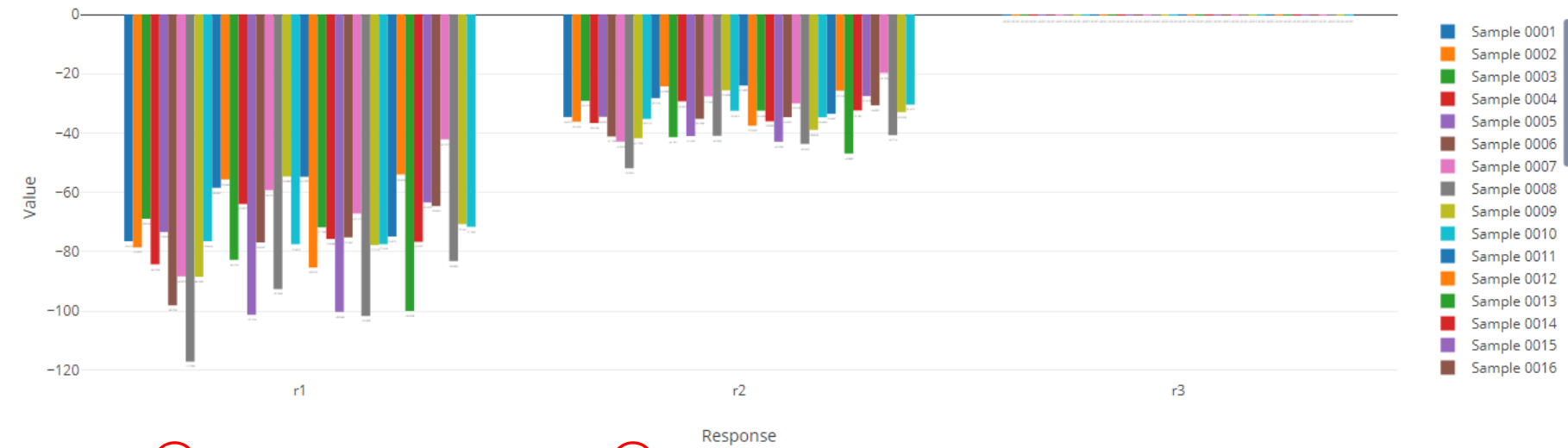


2

Name of Web App	Purpose	Description
Monitored Responses	<ul style="list-style-type: none">• The response value from each sample can be compared.	<ul style="list-style-type: none">• After each MSC Nastran analysis, the response values are extracted from the H5 file and contained in a file named <code>app_monitored_responses.csv</code>. The Monitored Responses web app is used to create a bar chart of the values contained in this CSV file.
Dakota Results	<ul style="list-style-type: none">• This web app displays the results of a Dakota study.	<ul style="list-style-type: none">• 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

B

Monitored Responses					Monitored Responses from Each Sample				
Label	Dataset Name	Field	Field Description	Current Value	0001	0002	0003	0004	
r1 r2 r3	NODAL/DISPLACEMENT	Y	Y component						
r1	NODAL/DISPLACEMENT	Y	Y component	-70.9060765290356	-76.42735491111817	-78.50731533683063	-68.90564041084161	-84.23063204367745	-73.:
r2	NODAL/DISPLACEMENT	Y	Y component	-32.435201821223686	-34.60718799959459	-36.15139708944005	-29.167511862165235	-36.61959885618245	-34.:
r3	NODAL/DISPLACEMENT	Y	Y component	-0.01	-0.01	-0.01	-0.01	-0.01	-0.0

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.

2


```

<<<<< 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. 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.

1

Statistics based on 40 samples

Sample moment statistics for each response function

Download CSV

	3 Mean	Standard Deviation	2 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

Download CSV

	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

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.

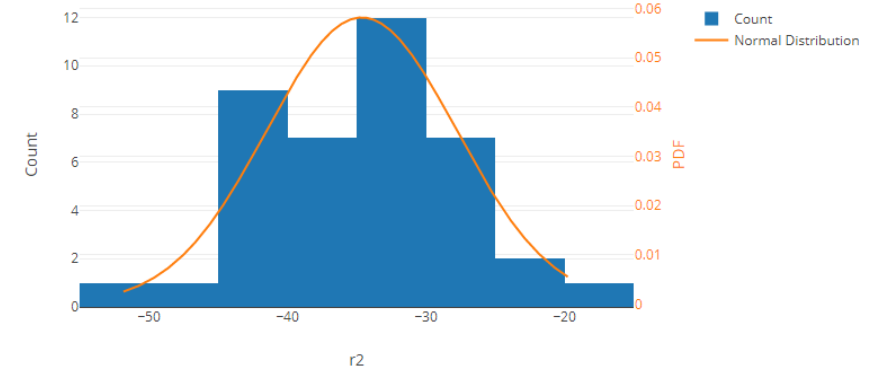
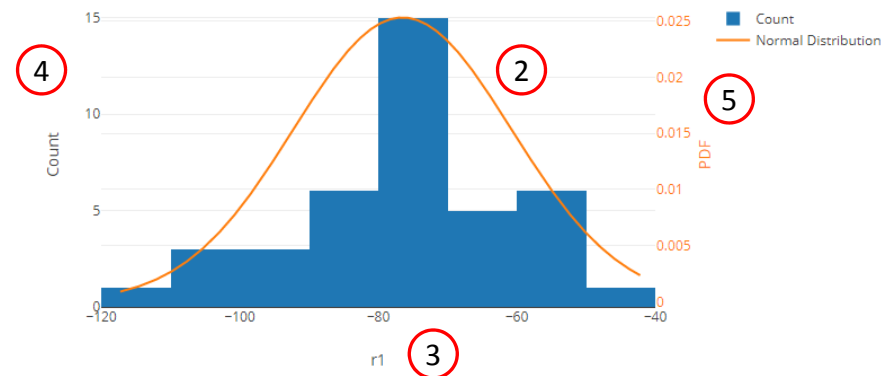
If the blue bars align to the PDF plot, the response's distribution is normal. If the bars do not align, the distribution is not normal.

1

Histograms

r1

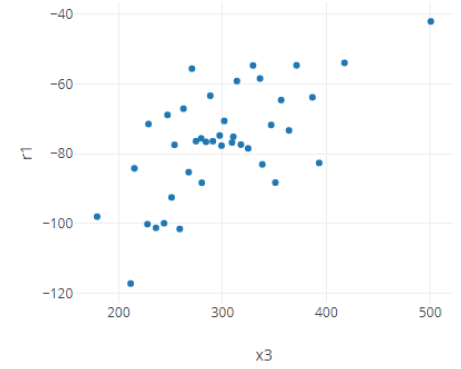
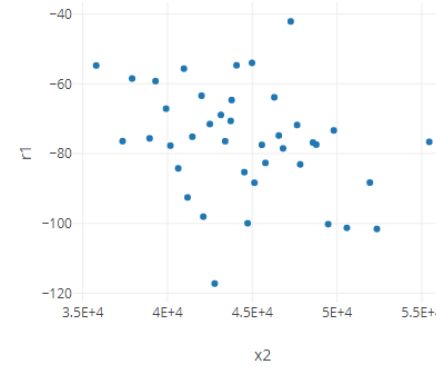
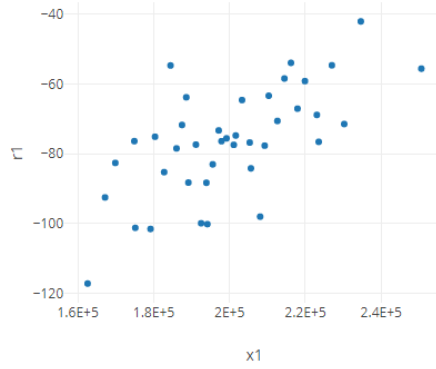
r2



1

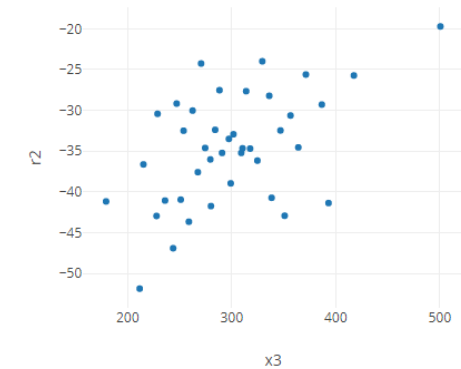
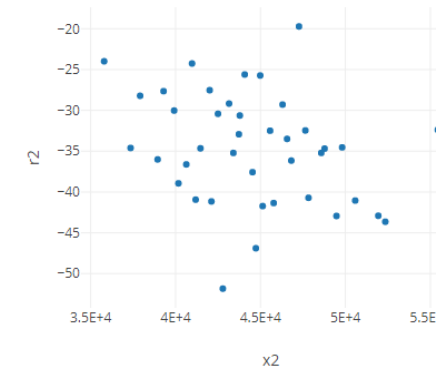
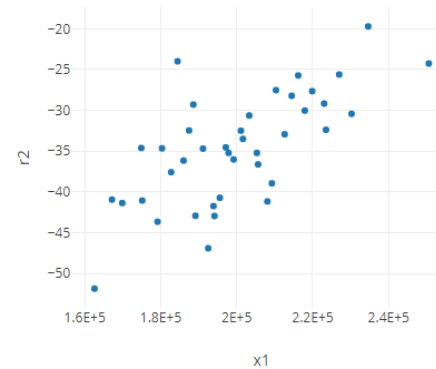
Scatter Plots 2

r1



r2

3



Review Results

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

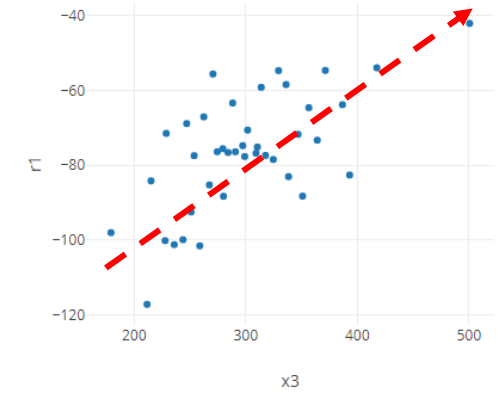
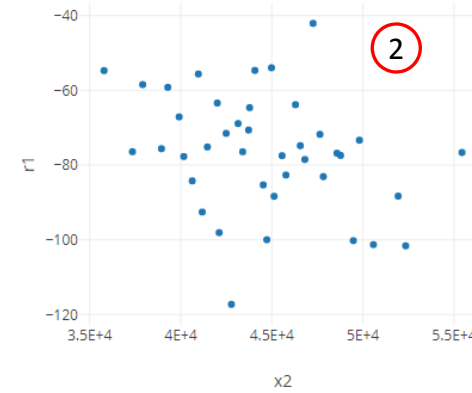
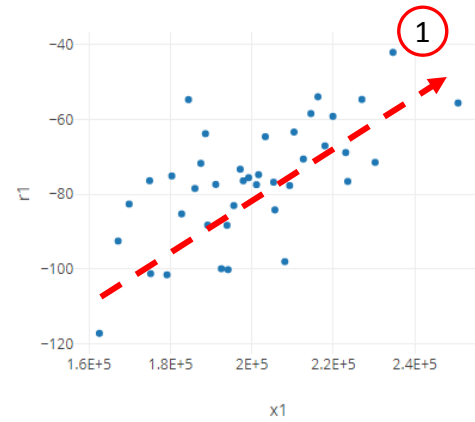
- To keep this exercise brief, not all the plots are discussed or displayed. Plots for variables x4 and x5 are not displayed in this exercise, but will be visible in the web app.
- Refer to the Appendix for an explanation of what is a projection.

Review Results

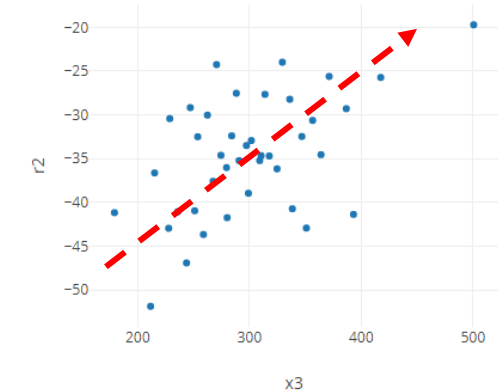
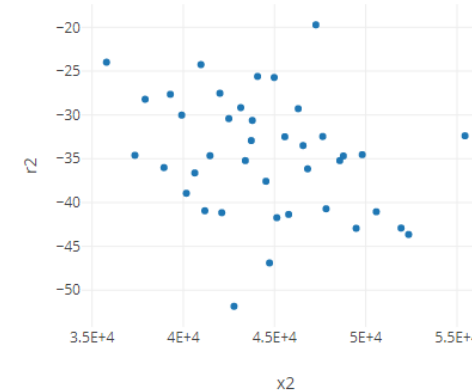
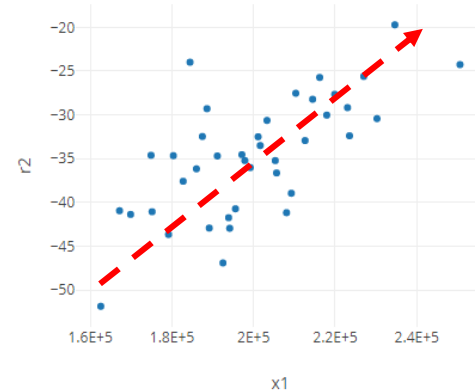
Notice some of the following trends.

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



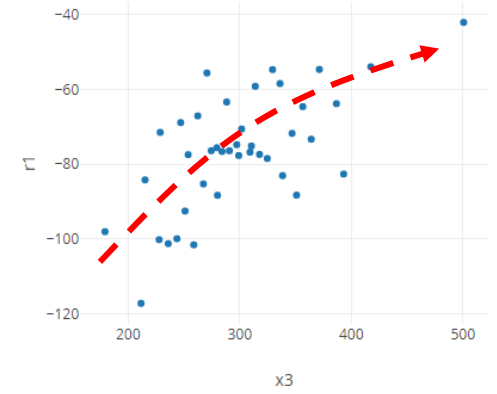
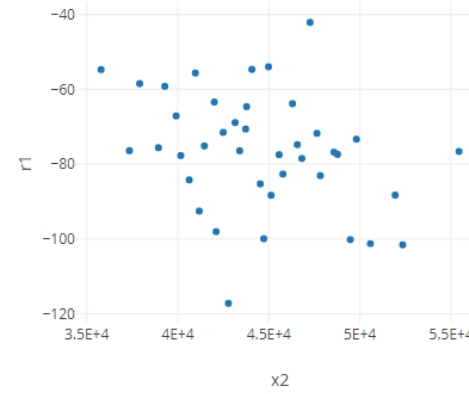
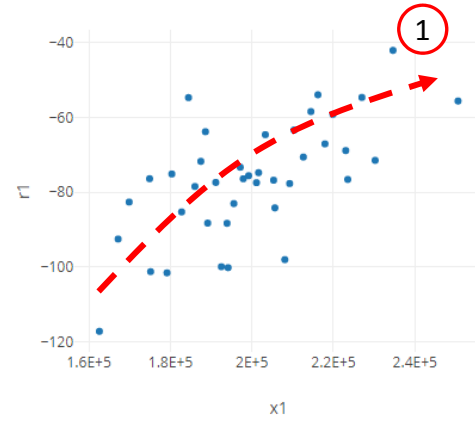
r2



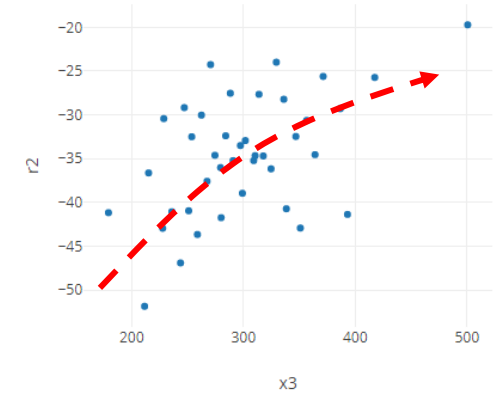
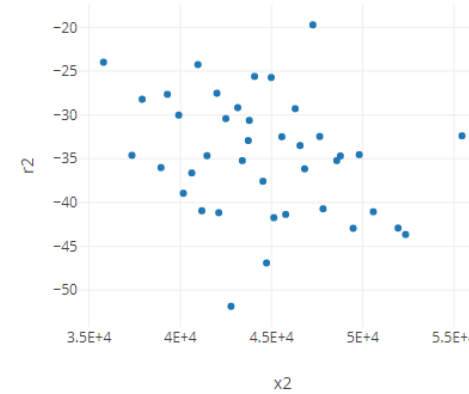
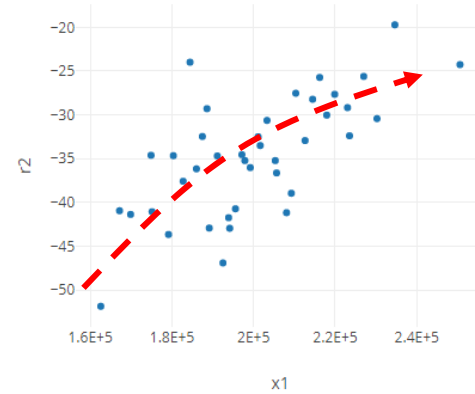
Review Results

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

Pearson
Correlation
Coefficients

```
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	8.604		
r3	-nan(ind)	-nan(ind)	-nan(ind)	-nan(ind)	-nan(ind)	-na		nd)

Spearman's
Correlation
Coefficients

```
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)

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		
NOT OK		

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

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

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

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

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.

SOL 200 Web App - Machine Learning **Parameters** Samples Responses Download Results Settings User's Guide Home

Select Parameters

	1	2	3	4	5	6	7	8	9	10
FORCE	300	2		1.0	0.0	-1.0	0.0			
FORCE	300	4		1.0	0.0	-1.0	0.0			
FORCE	400	7		1.0	0.0	-1.0	0.0			
LOAD	2	1.	%x2%	300	1.0	400				
MAT1	1	%x1%	0.0	0.3	7.86E-09					
mdlprm	hdf5	2								
PELAS	201	100.0								
PROD	1	1	%x3%							
PROD	2	1	%x4%							
PROD	3	1	%x5%							
SPC	1	5	123	0.0						
SPC	1	6	123	0.0						

Configure Parameters

Delete	Parameter	Status	Distribution	Mean	Standard Deviation	Comments
	x1		Lognorm: <input type="text" value="Lognorm:"/>	<input type="text" value="2.E5"/>	<input type="text" value="20000."/>	Field 3 of MAT1 1
	x2		Lognorm: <input type="text" value="Lognorm:"/>	<input type="text" value="4.45E4"/>	<input type="text" value="4450."/>	Field 4 of LOAD 2
	x3		Lognorm: <input type="text" value="Lognorm:"/>	<input type="text" value="300.0"/>	<input type="text" value="30.0"/>	Field 4 of PROD 1
	x4		Lognorm: <input type="text" value="Lognorm:"/>	<input type="text" value="300.0"/>	<input type="text" value="30.0"/>	Field 4 of PROD 2
	x5		Lognorm: <input type="text" value="Lognorm:"/>	<input type="text" value="300.0"/>	<input type="text" value="60.0"/>	Field 4 of PROD 3

Download

1. Click Download
2. Click Download BDF Files



Download

 Download BDF Files

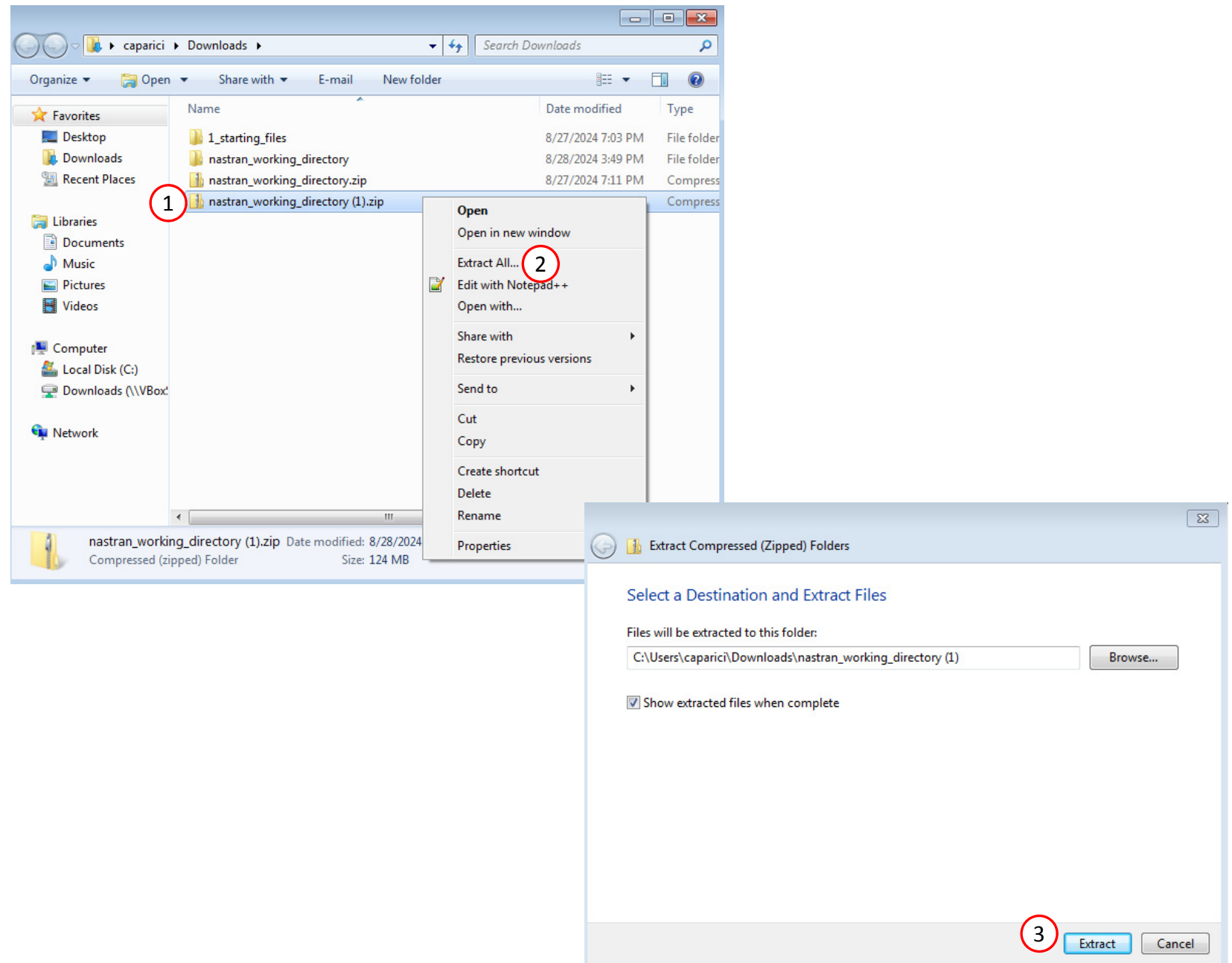
2

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.

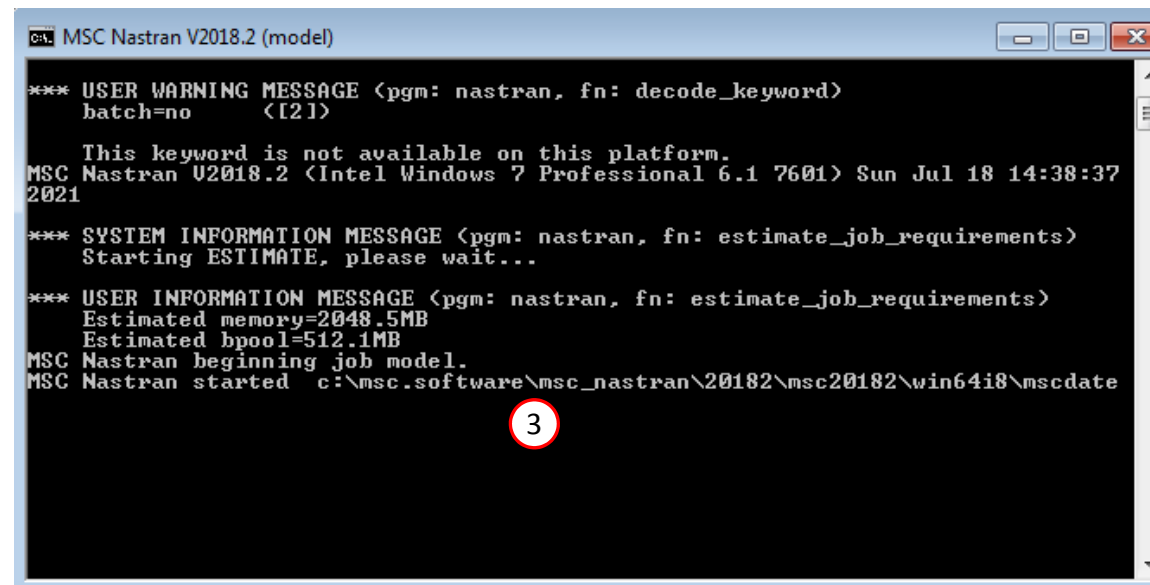
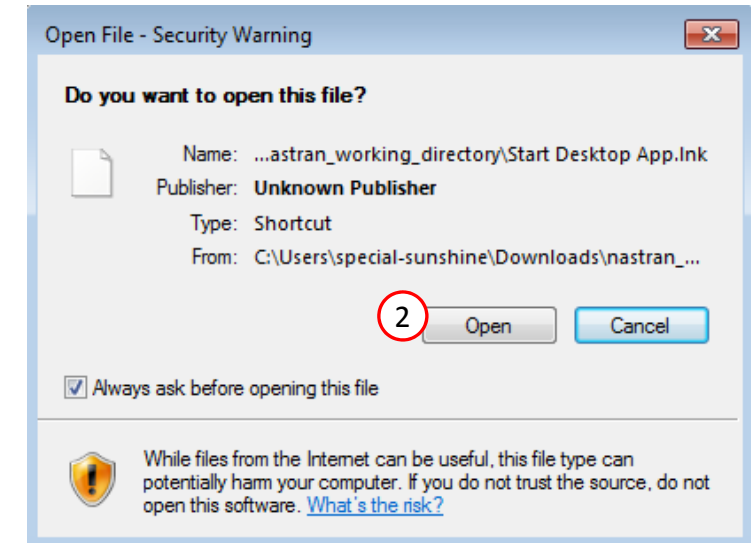
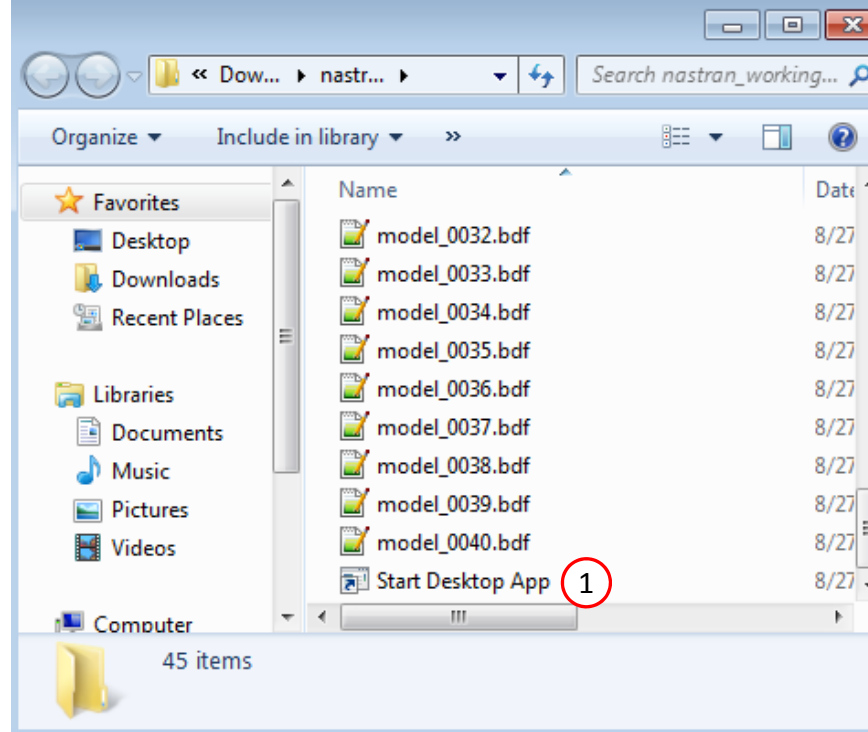
Using Linux?

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

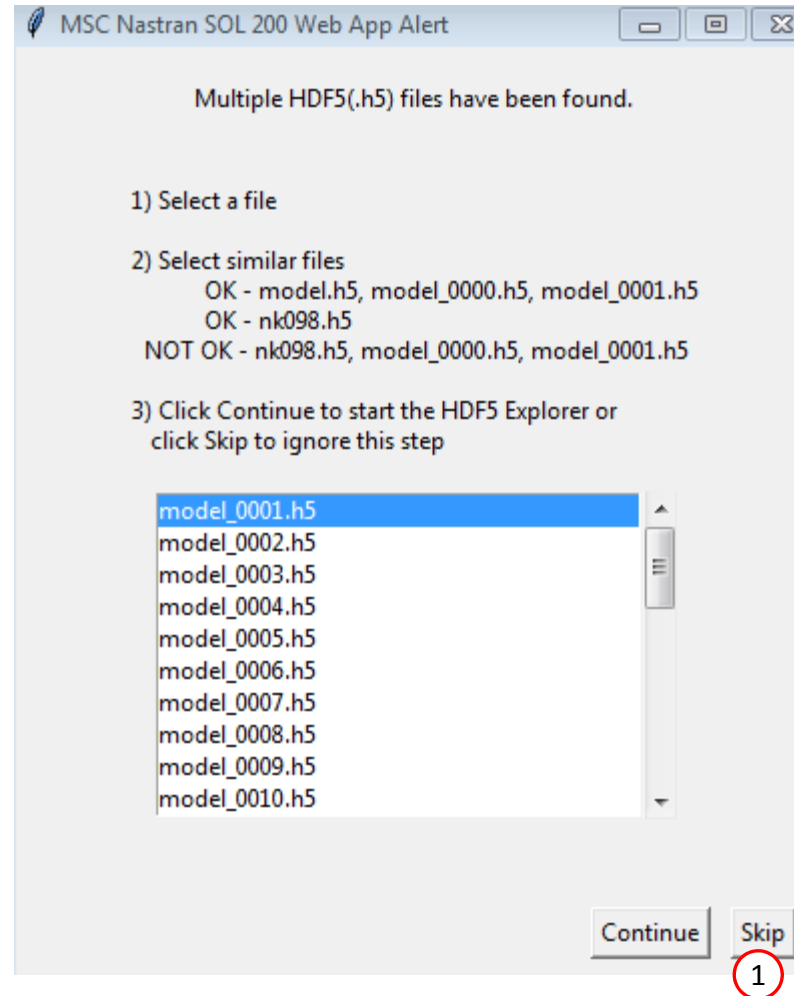
 MSC Nastran

Status

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

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](#)

	Mean	Standard Deviation 3	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

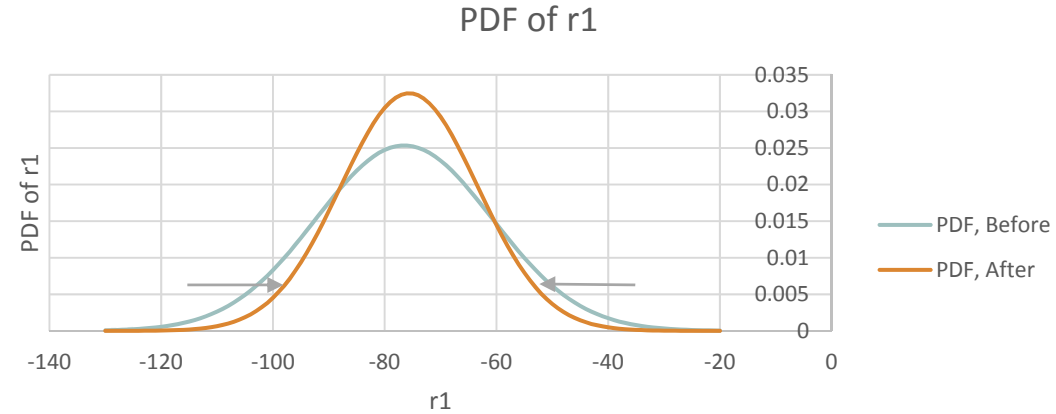
- Assuming a normal distribution for both responses, a probability density function is plotted for both responses by using the means and standard deviations from parts A and B.
- The standard deviations have been reduced for both responses r1 and r2, indicating the variances of the responses has been 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

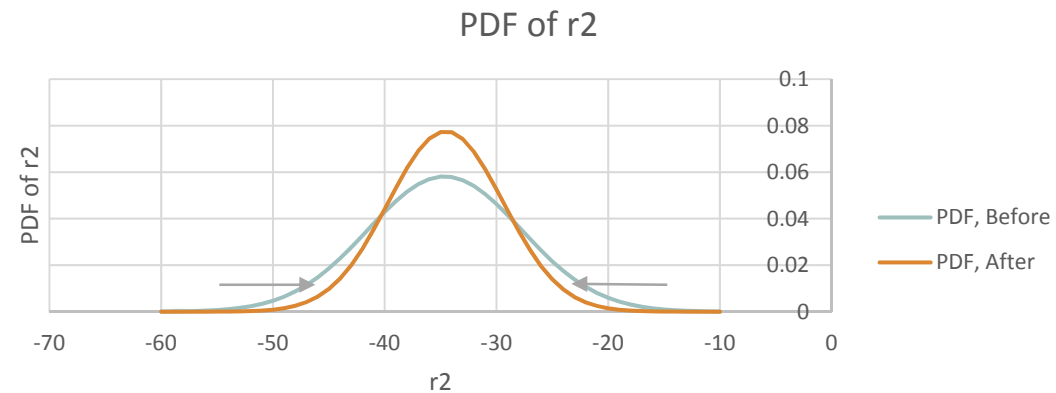


Before

◦ r2 Standard Deviation: 6.8557433340e+00

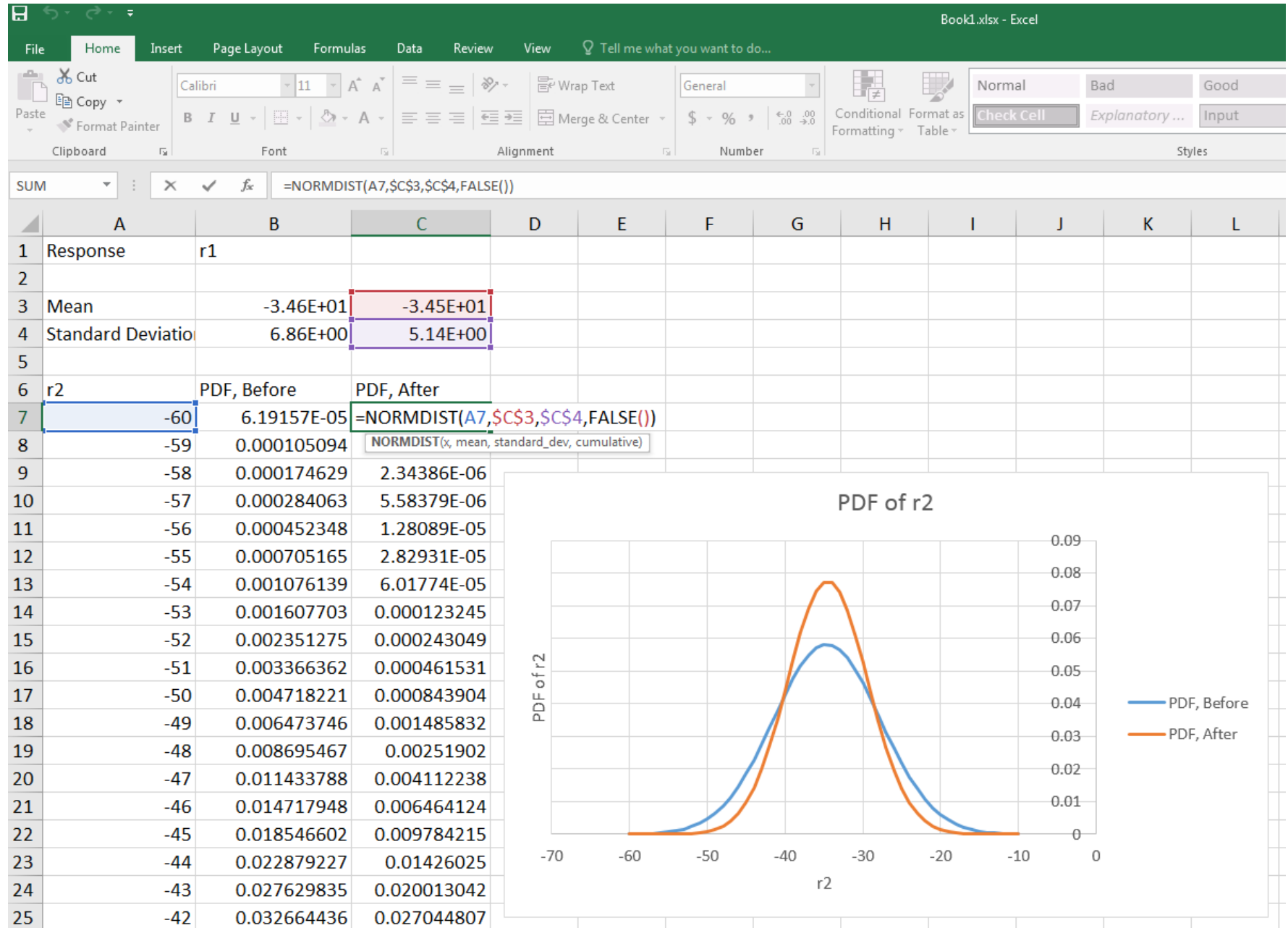
After

◦ 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.



End of Tutorial

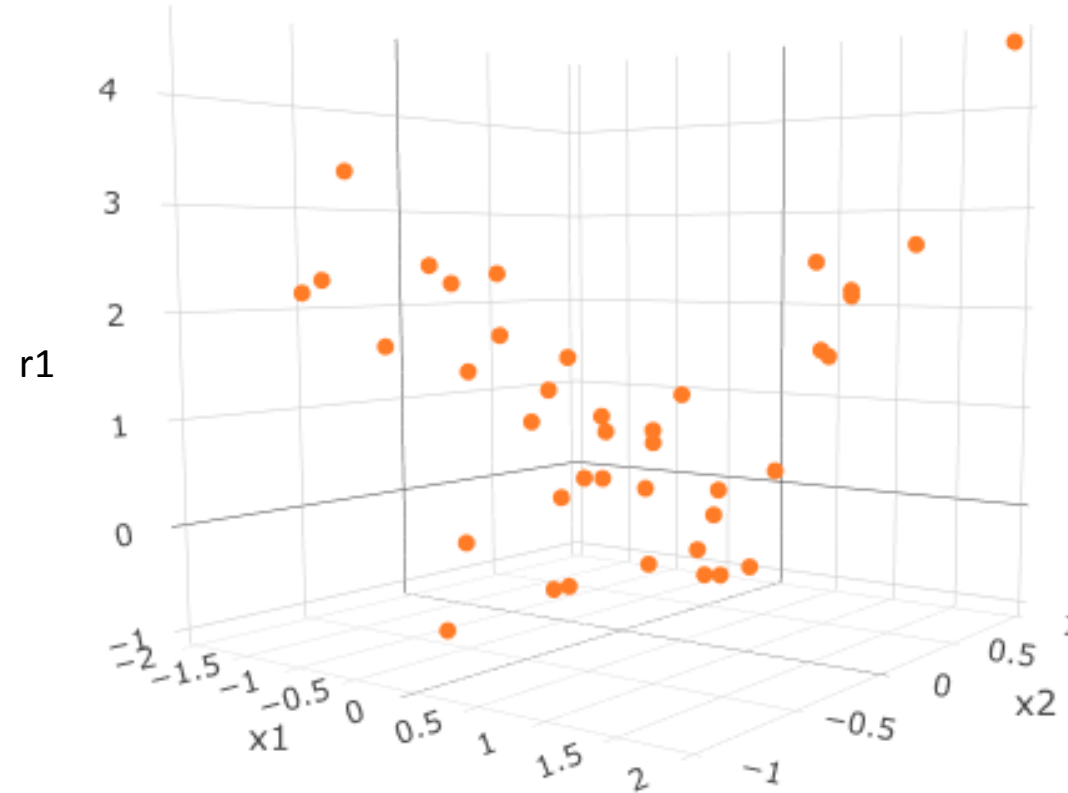
Appendix

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 x_1 and x_2 .



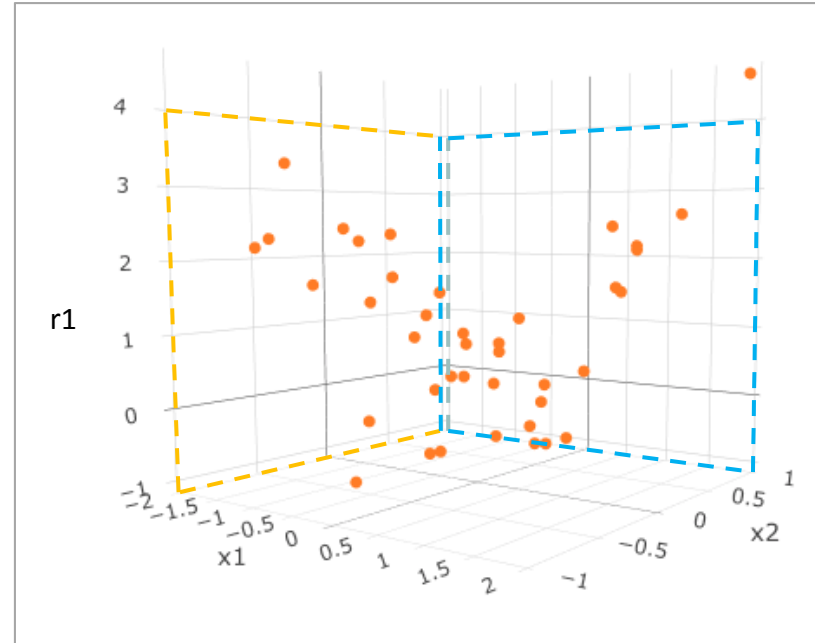
What is a projection?

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 x_1, r_1 plane.
2. For the indicated plot, the 3D data is visualized on the x_2, r_1 plane.

sample	x_1	x_2	r_1
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

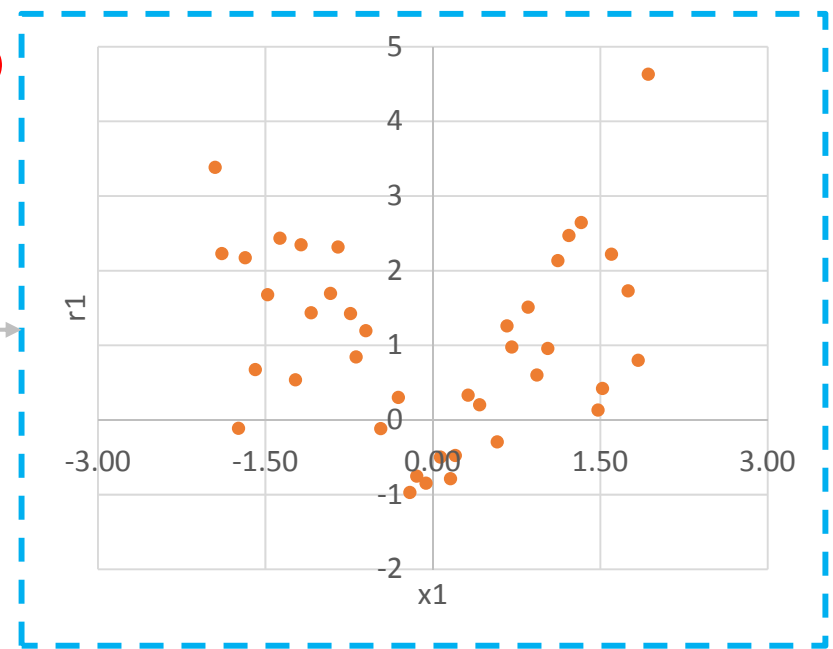
$$(x_1, x_2, r_1) \Rightarrow (x_1, r_1)$$



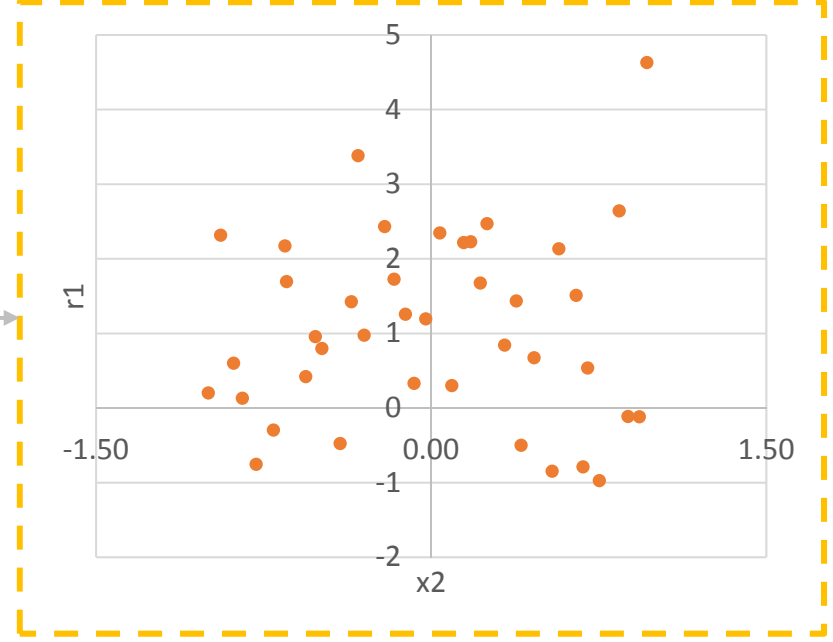
$$(x_1, x_2, r_1) \Rightarrow (x_2, r_1)$$

sample	x_1	x_2	r_1
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/#spearman-s-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