

# Workshop – Prediction Analysis, Frequency Response Analysis (SOL 111)

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AN MSC NASTRAN MACHINE LEARNING WEB APP TUTORIAL

# Goal: Prediction Analysis

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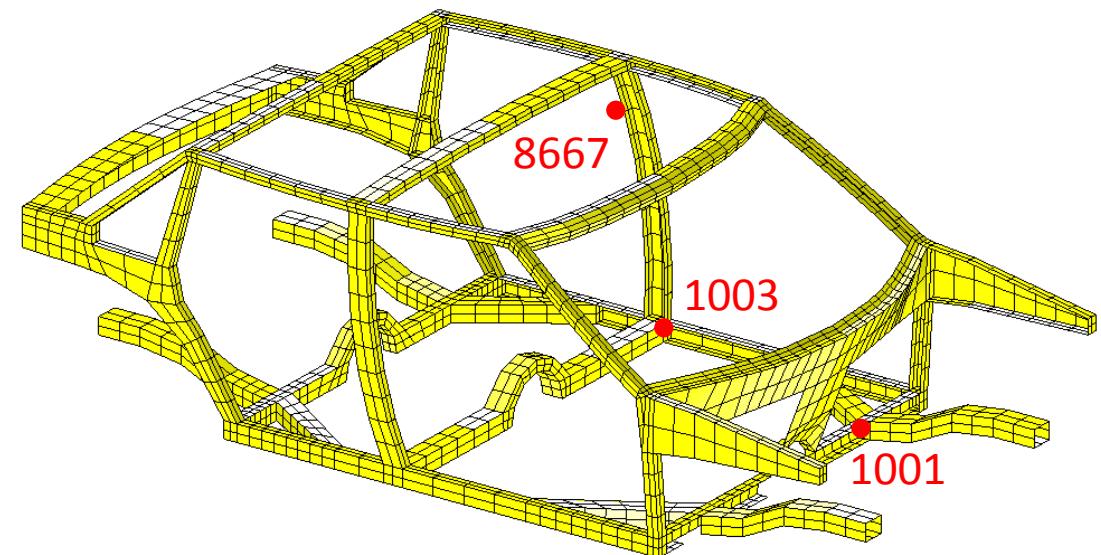
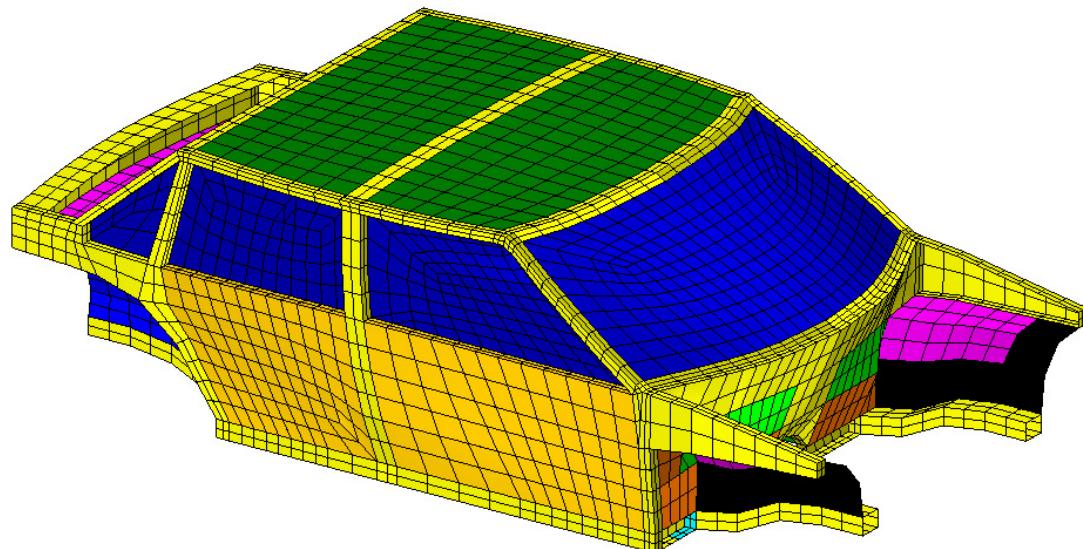
This tutorial consists of multiple parts

1. Configuring The Problem Statement
  - In this tutorial, we configure the parameters and the responses to monitor.
2. Configuring Multiple Batch Runs
  - This section discusses how to configure and execute multiple MSC Nastran runs.
3. Determining Parameter Relevance (Parameter/Variable Screening)
  - This example starts with 11 parameters. Automatic relevance determination (ARD) is used to identify important parameters and reduce the problem to 4 parameters.
4. Performing Predictions
  - Gaussian process (GP) regression is used to train a surrogate model and perform predictions.
5. Creating Response vs. Frequency Plots with the HDF5 Explorer
  - The HDF5 Explorer web app is used to create Response vs. Frequency Plots.

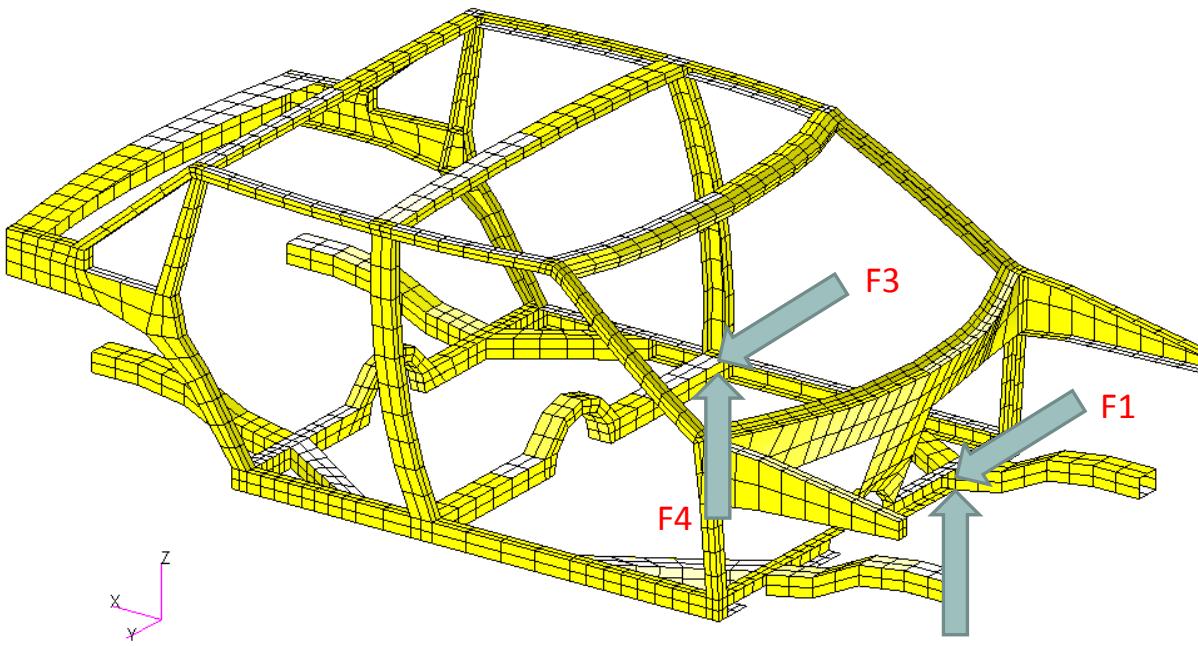
# Details of the Structural Model

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1. Perform a frequency response analysis for different thickness values
2. Create XYPLOTs for nodes 1001, 1003, and 8667

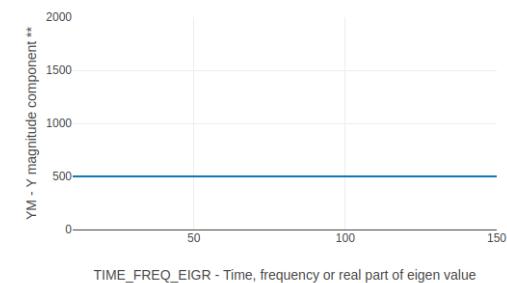


# Details of the Structural Model



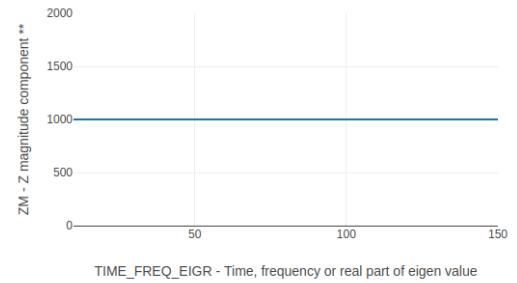
F1 – Load at node 1001, y direction,  
Subcase 12

NODAL/APPLIED\_LOAD\_CPLX



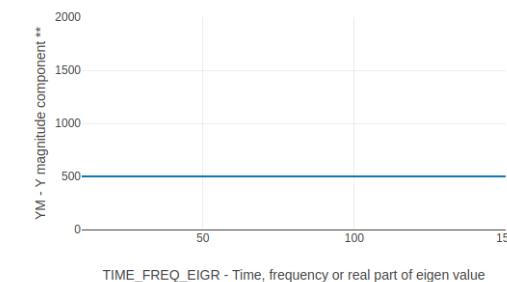
F2 – Load at node 1001, z direction,  
Subcase 13

NODAL/APPLIED\_LOAD\_CPLX



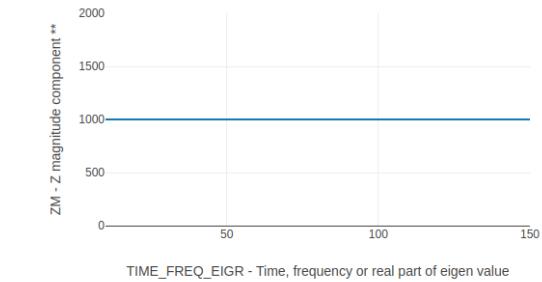
F3 – Load at node 1003, y direction,  
Subcase 32

NODAL/APPLIED\_LOAD\_CPLX



F4 – Load at node 1003, z direction,  
Subcase 33

NODAL/APPLIED\_LOAD\_CPLX



# Problem Statement

## Design Variables

x1: The thickness of PSHELL 1

x2: The thickness of PSHELL 2

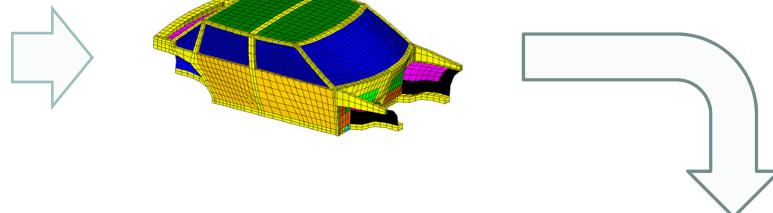
...

x11: The thickness of PSHELL 11

$1.0 < x_1, x_2, \dots, x_{11}, < 6.0$

## Samples

- Batch set 1 – 55 run LHS Design
- Batch set 2 – 40 run LHS Design
- Batch set 3 – 8 run LHS Design



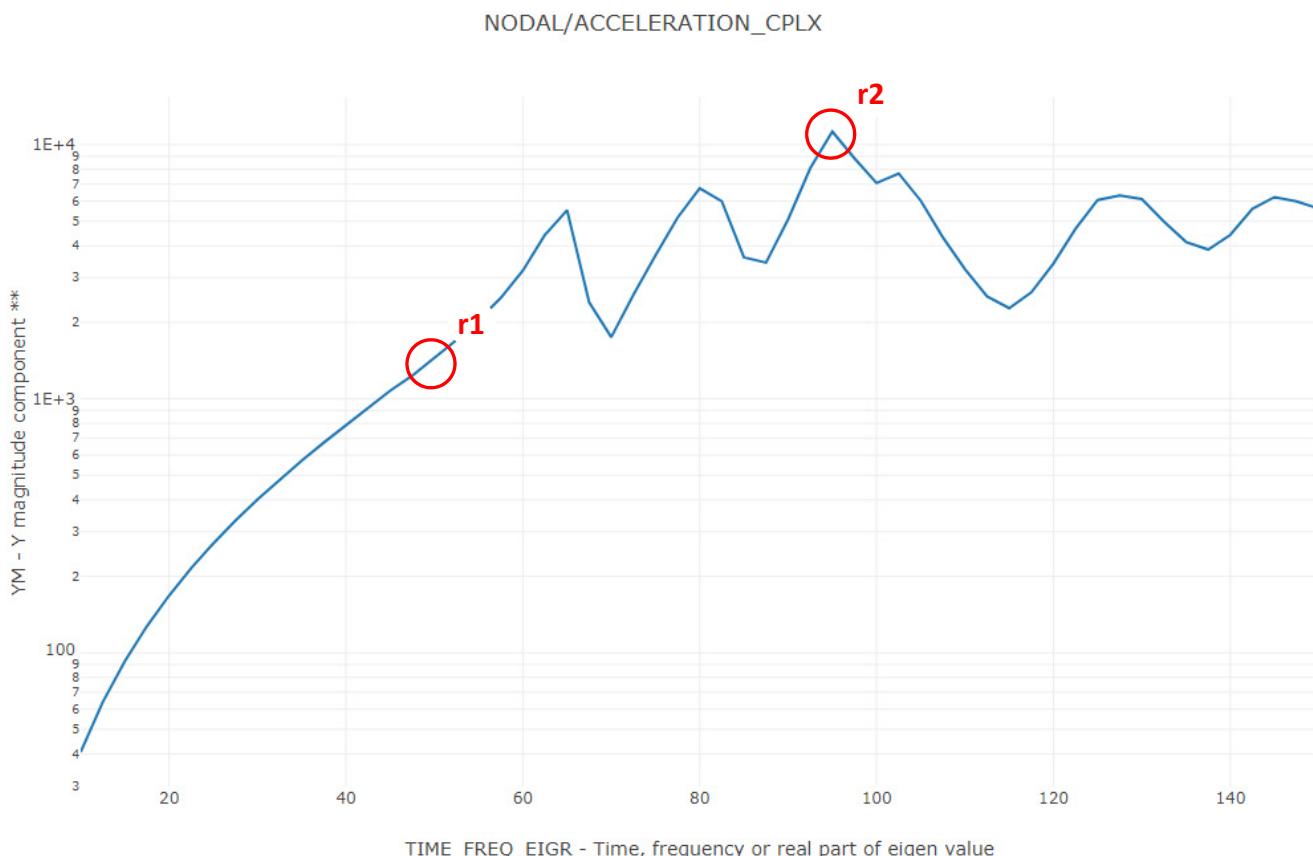
## Monitored Responses

Label	Dataset Name	Field	Field Description	Node ID	SUBCASE	Frequency
r1	Acceleration	YM	Y magnitude component	1001	12	50 Hz
r2	Acceleration	YM	Y magnitude component	1001	12	Max Value
r3	Acceleration	ZM	Z magnitude component	1001	13	Max Value
r4	Acceleration	YM	Y magnitude component	1003	32	Max Value
r5	Acceleration	ZM	Z magnitude component	1003	33	Max Value
r6	Pressure	PM	Sound pressure level - magnitude	8667	12	Max Value
r7	Pressure	PM	Sound pressure level - magnitude	8667	13	Max Value
r8	Pressure	PM	Sound pressure level - magnitude	8667	32	Max Value
r9	Pressure	PM	Sound pressure level - magnitude	8667	33	Max Value

# Problem Statement, Continued

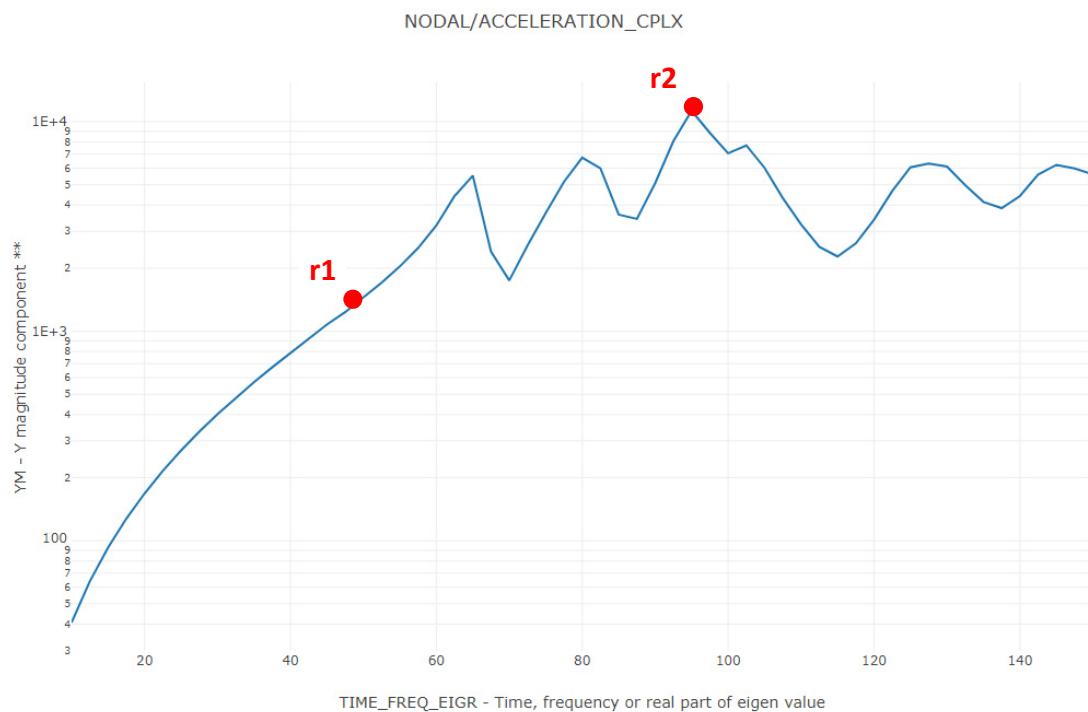
The responses defined in this tutorial correspond to points on frequency response plots

- Response r1 is the acceleration at 50 Hz
- Response r2 is the max acceleration for the forcing frequency range
- Other responses correspond to different node ID, component, subcase number and frequency

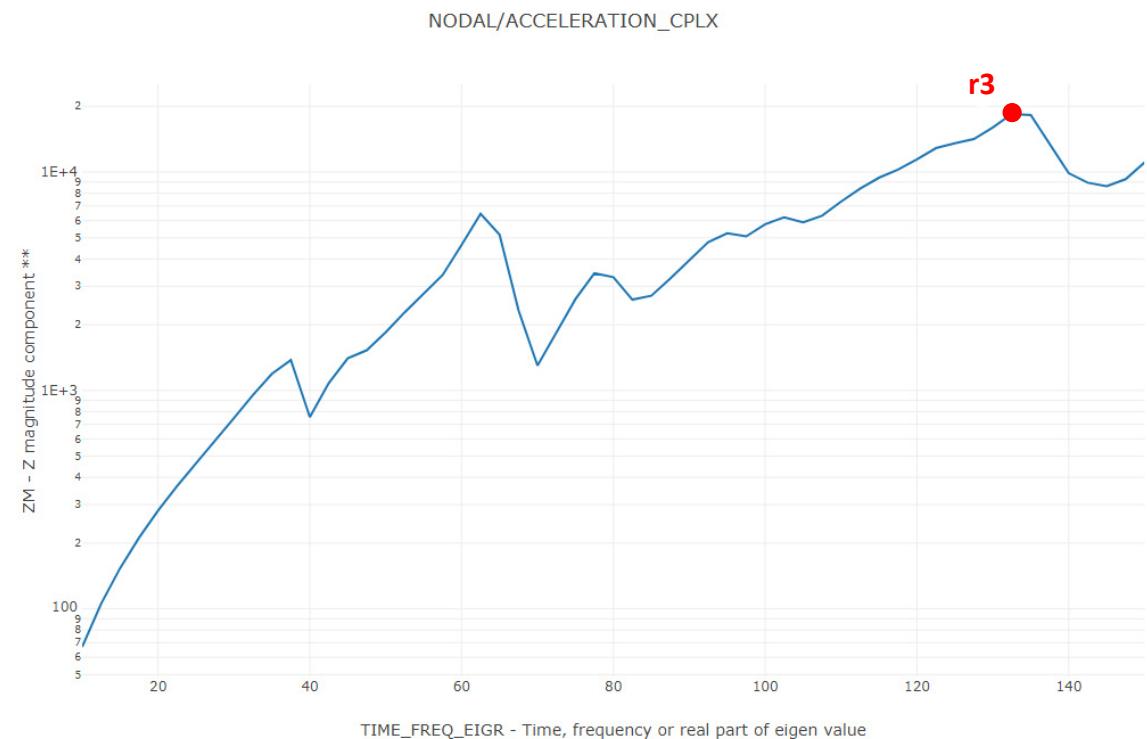


# Monitored Responses

## r1, r2, r3



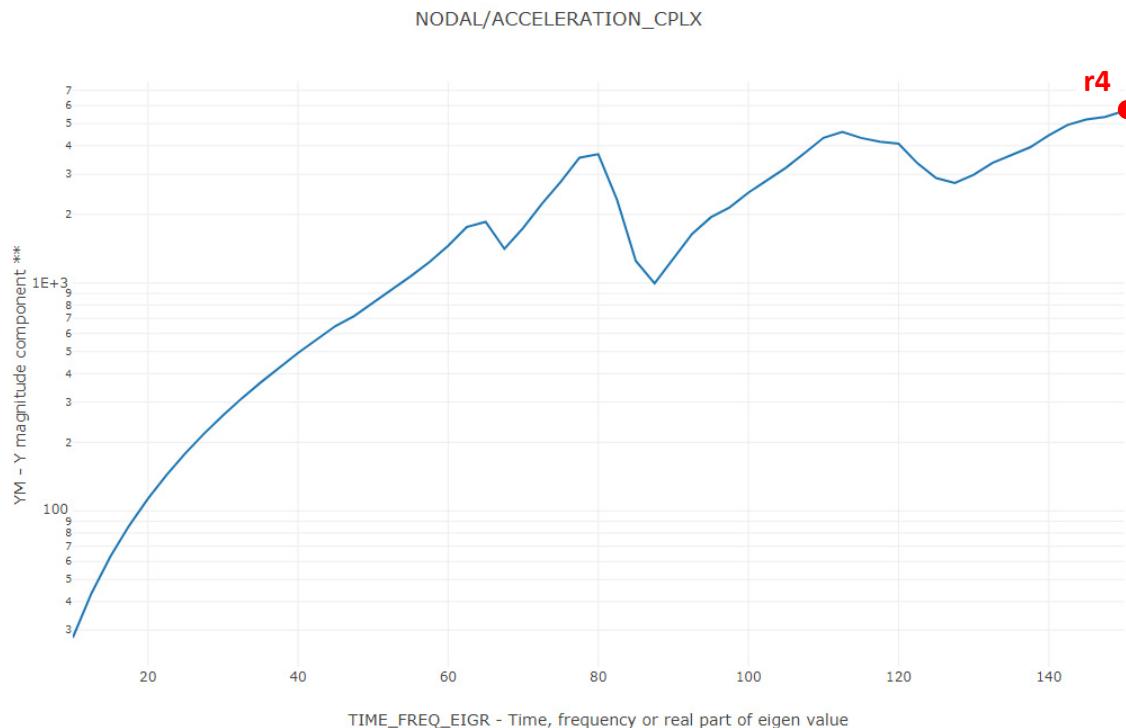
ID: 1001 | SUBCASE: 12 | YM vs. TIME\_FREQ\_EIGR



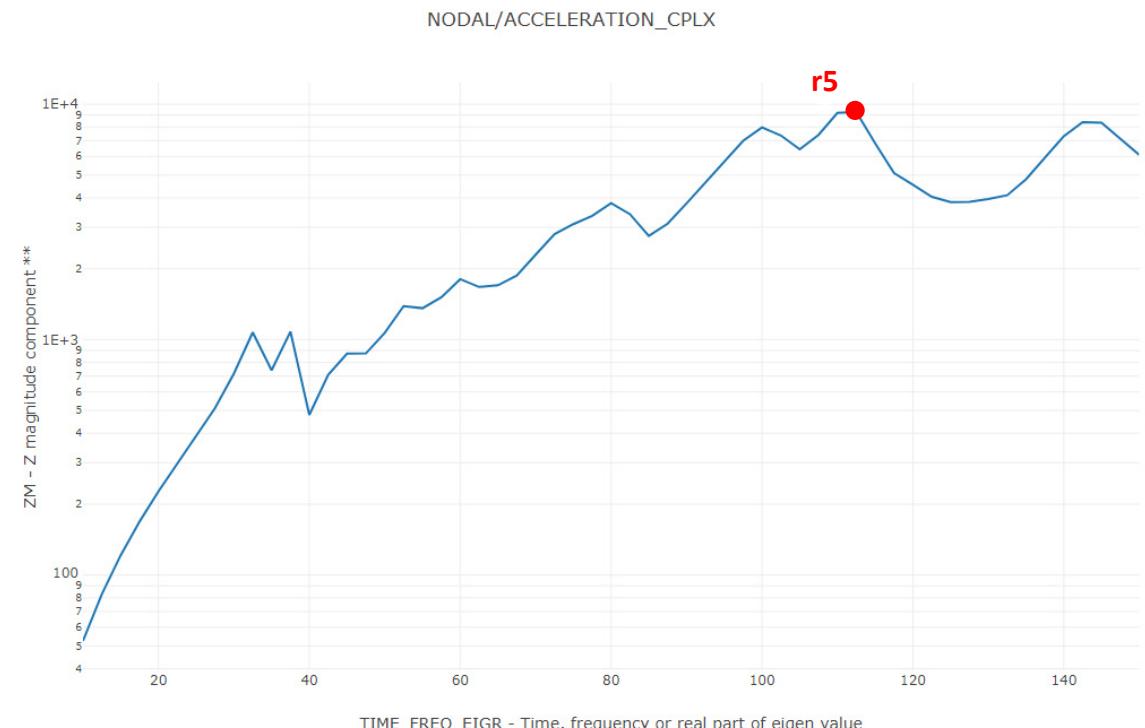
ID: 1001 | SUBCASE: 13 | ZM vs. TIME\_FREQ\_EIGR

# Monitored Responses

## r4, r5



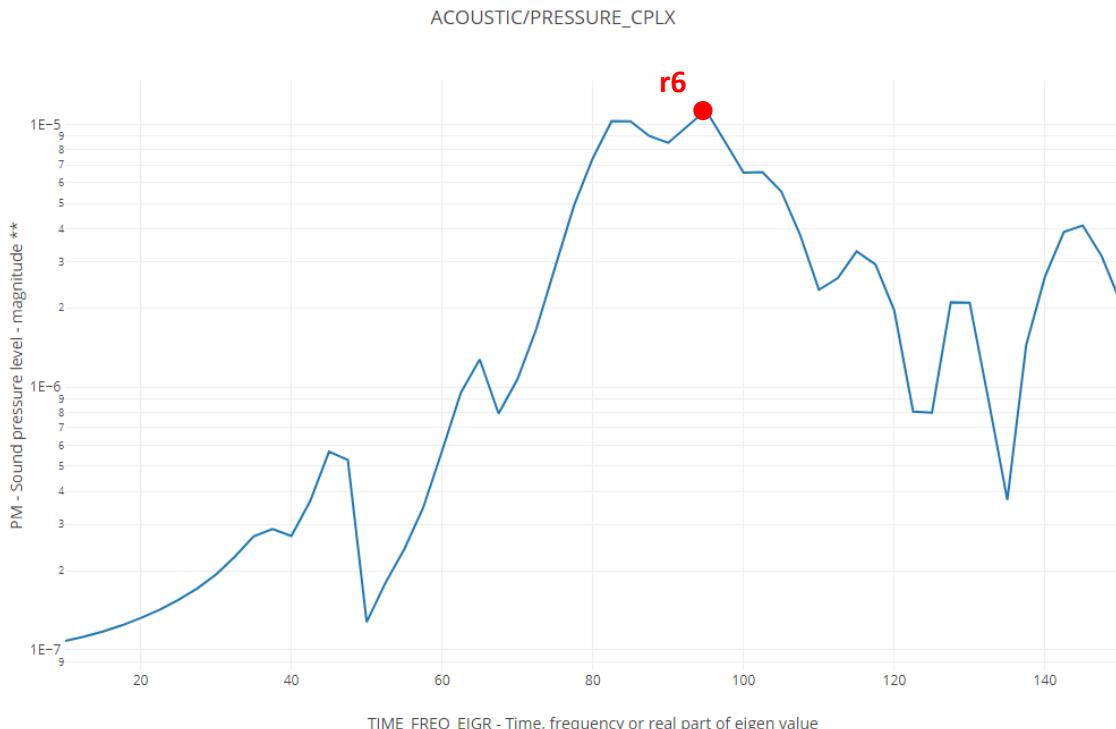
ID: 1003 | SUBCASE: 32 | YM vs. TIME\_FREQ\_EIGR



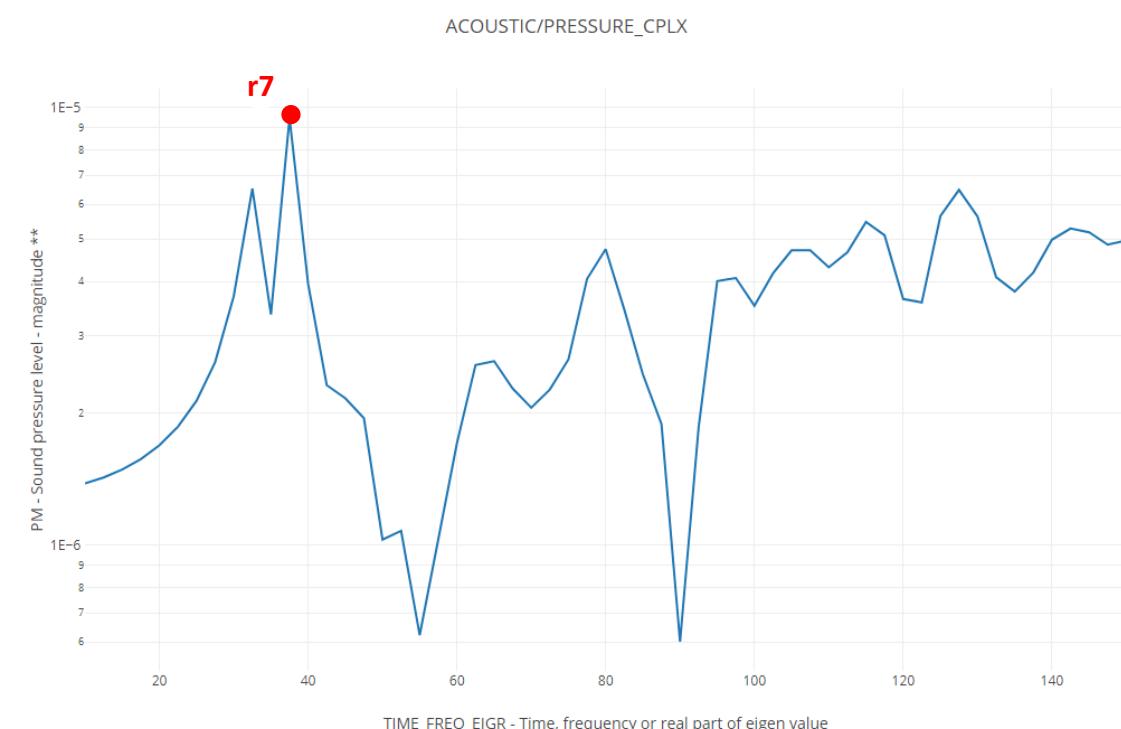
ID: 1003 | SUBCASE: 33 | ZM vs. TIME\_FREQ\_EIGR

# Monitored Responses

## r6, r7



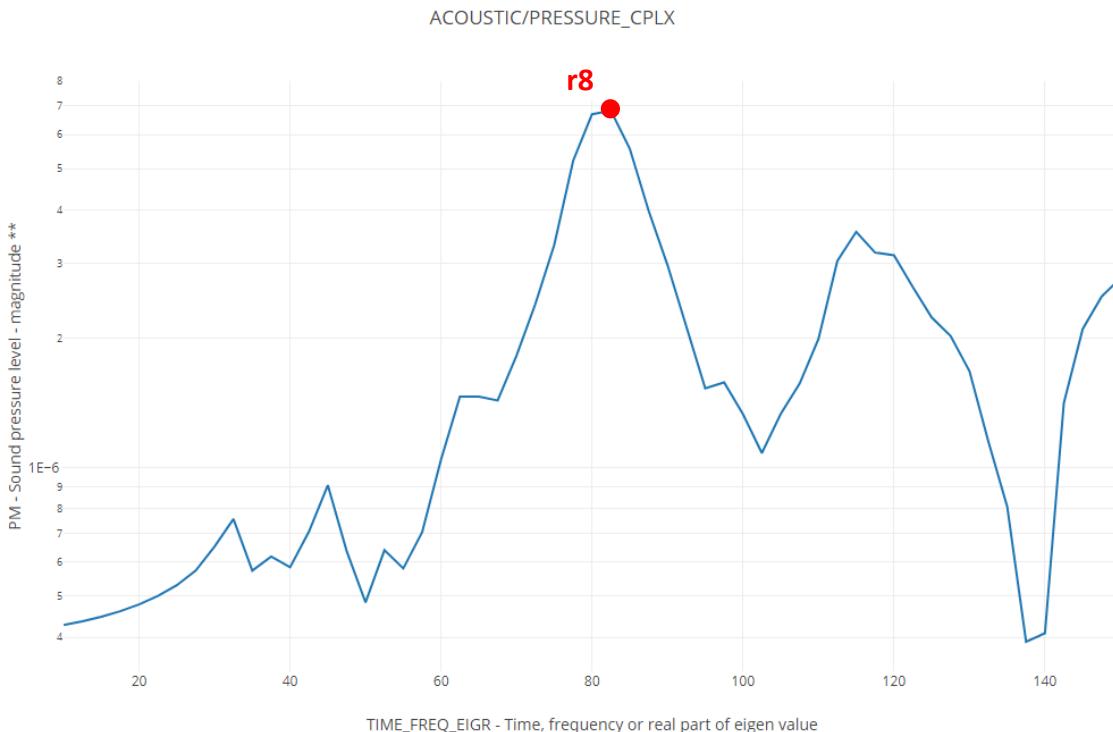
ID: 8667 | SUBCASE: 12 | PM vs. TIME\_FREQ\_EIGR



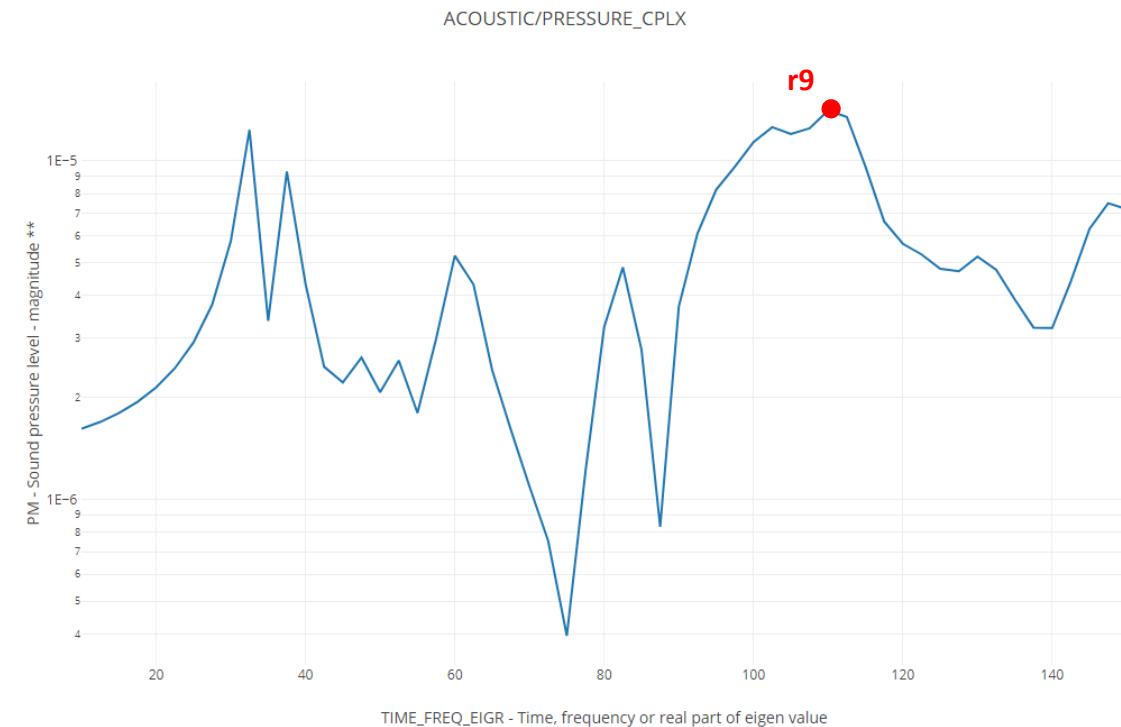
ID: 8667 | SUBCASE: 13 | PM vs. TIME\_FREQ\_EIGR

# Monitored Responses

## r8, r9



ID: 8667 | SUBCASE: 32 | PM vs. TIME\_FREQ\_EIGR

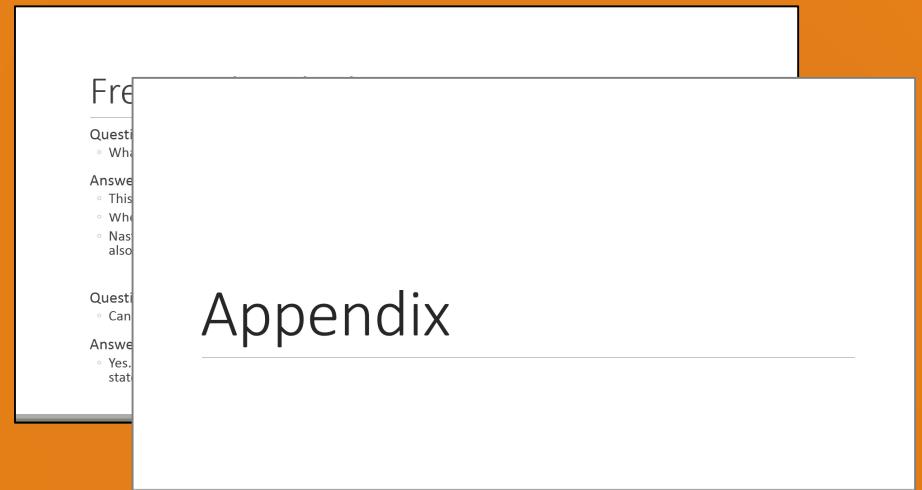


ID: 8667 | SUBCASE: 33 | PM vs. TIME\_FREQ\_EIGR

# More Information Available in the Appendix

The Appendix includes information regarding the following:

- Response Configuration
  - Monitor the maximum or minimum response, whichever has the greatest absolute value: Yes, No or blank
- How to import and edit files
- What is Gaussian Process Regression?



# 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](mailto:christian@the-engineering-lab.com)

# Tutorial

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# Tutorial Overview

1. Start with a .bdf or .dat file
2. Use the Machine Learning web app to:
  1. Configure the problem statement
  2. Configure multiple batch runs
3. Use the Prediction Analysis web app to:
  1. Determine parameter relevance (parameter/variable screening)
  2. Perform predictions
4. Use the HDF5 Explorer to:
  1. Create response vs. frequency plots

## Special Topics Covered

**Training Data** – The training data consists of the parameter inputs and respective output responses for multiple MSC Nastran runs. This tutorial describes how to configure multiple MSC Nastran runs, each with different parameter inputs, and how to monitor each response.

**Gaussian process regression** – This tutorial describes the procedure to use Gaussian process regression to train a surrogate model and make predictions.

**Automatic Response Extraction** – Often responses are manually or automatically extracted from the F06 file. This becomes challenging when extracting responses from multiple F06 files. This tutorial highlights the web app's ability to automatically extract responses from multiple H5 files with minimal user effort.

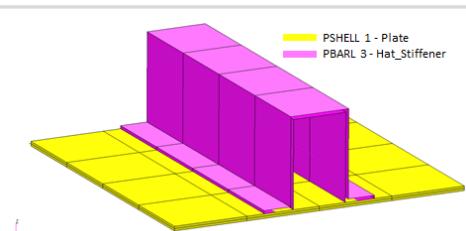
**Automatic Plots** - Multiple plots must be created. This traditionally involves extracting data from result files, for example the F06 file, and using Excel to create the plots. This tutorial highlights the automatic generation of these plots that require minimal user effort.

# SOL 200 Web App Capabilities

## Benefits

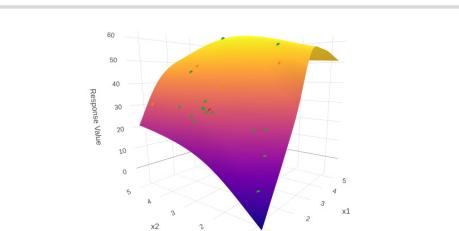
- 200+ error validations (real time)
- Web browser accessible
- Automated creation of entries (real time)
- Automatic post-processing
- 76 tutorials

## Capabilities



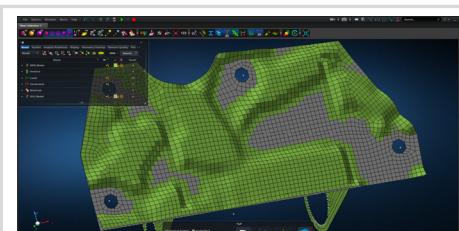
### Web Apps for SOL 200

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



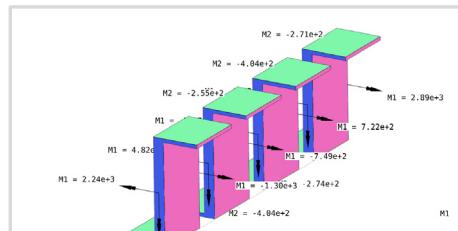
### Machine Learning Web App

Bayesian Optimization for nonlinear  
response optimization (SOL 400)



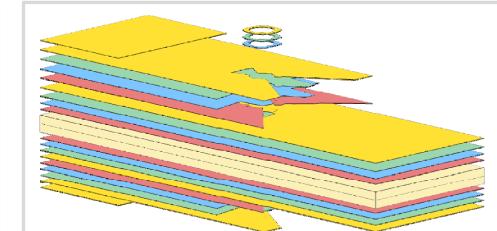
### MSC Apex Post Processing Support

View the newly optimized model  
after an optimization



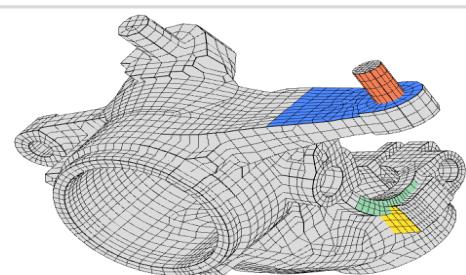
### Beams Viewer Web App

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



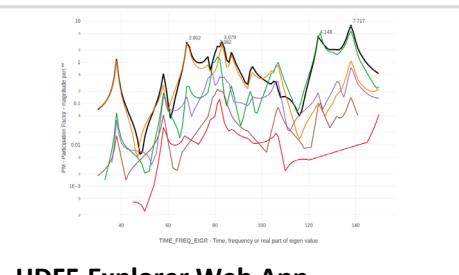
### Ply Shape Optimization Web App

Spread plies optimally and generate  
new PCOMPG entries



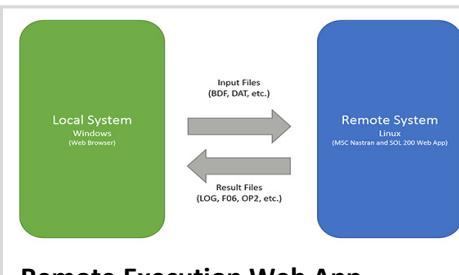
### Shape Optimization Web App

Use a web application to configure  
and perform shape optimization.



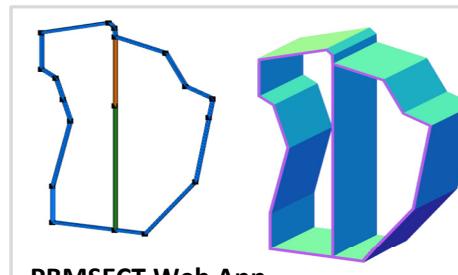
### HDF5 Explorer Web App

Create XY plots using data from the  
H5 file



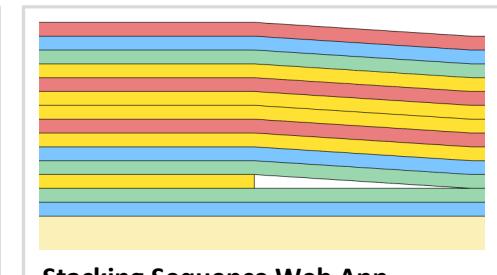
### Remote Execution Web App

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



### PBSECT Web App

Generate PBSECT and PBRSECT  
entries graphically



### Stacking Sequence Web App

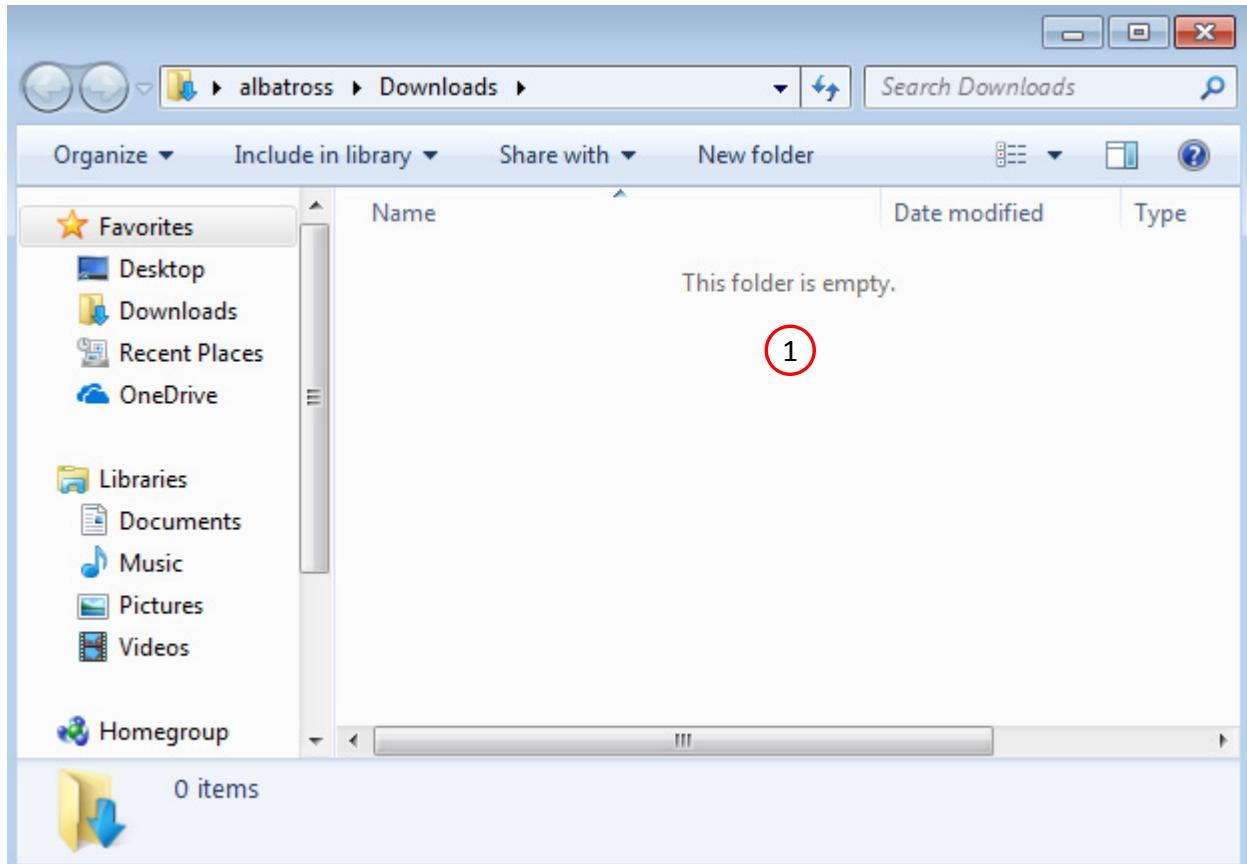
Optimize the stacking sequence of  
composite laminate plies

# Configuring The Problem Statement

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# Before Starting

1. Ensure the Downloads directory is empty in order to prevent confusion with other files
  
- Throughout this workshop, you will be working with multiple file types and directories such as:
  - .bdf/.dat
  - nastran\_working\_directory
  - .f06, .log, .pch, .h5, etc.
- To minimize confusion with files and folders, it is encouraged to start with a clean directory.



# Go to the User's Guide

1. Click on the indicated link

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

# SOL 200 Web App

Select a web app to begin

The interface features a central title "SOL 200 Web App" and a subtitle "Select a web app to begin". Below the subtitle are five main menu items, each with an icon and a brief description:

- Optimization for SOL 200**: Shows a "Before" and "After" comparison of a mechanical part.
- Multi Model Optimization**: Shows a flow diagram with arrows indicating data exchange between a "Remote System" and a "Local System".
- Machine Learning | Parameter Study**: Shows four small plots illustrating data analysis.
- HDF5 Explorer**: Shows a plot of data over time.
- Remote Execution**: Shows a diagram of a network connection between "Input Files" and "Results Files".

At the bottom left, there is a red circle with the number "1" and a red box around the "Tutorials and User's Guide" link. Below the links are two additional buttons: "Full list of web apps" and "Logout".

# Obtain Starting Files

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

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

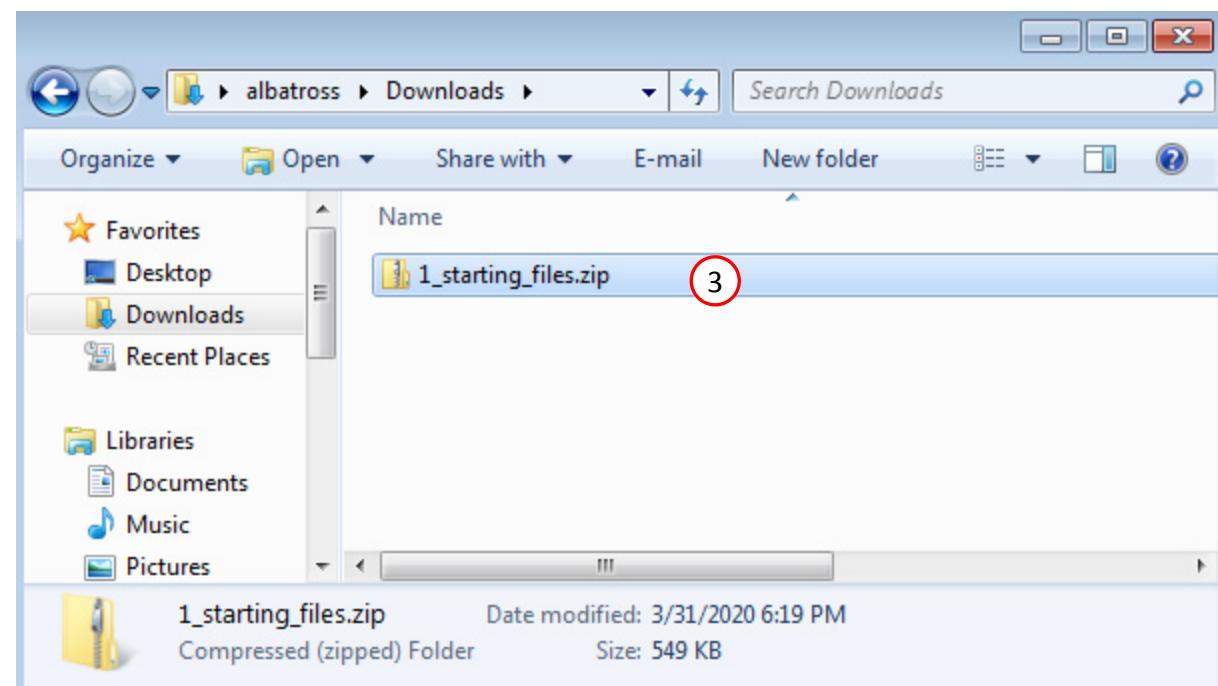


## Prediction Analysis, Frequency Response Analysis (SOL 111) 1

Consider a frequency response analysis of a ground vehicle. For different configurations of the ground vehicle, there is a desire to rapidly determine the frequency responses, including accelerations and pressures, while keeping the number of Finite Element (FE) solver runs to a minimum.

This tutorial describes the procedure to use Gaussian process regression as a surrogate model for computationally expensive Finite Element (FE) based simulations. This tutorial walks users through the process of acquiring training data, fitting the surrogate model, making predictions and quantifying uncertainty. In addition, the process to screen variables/parameters via Automatic relevance determination (ARD) is discussed.

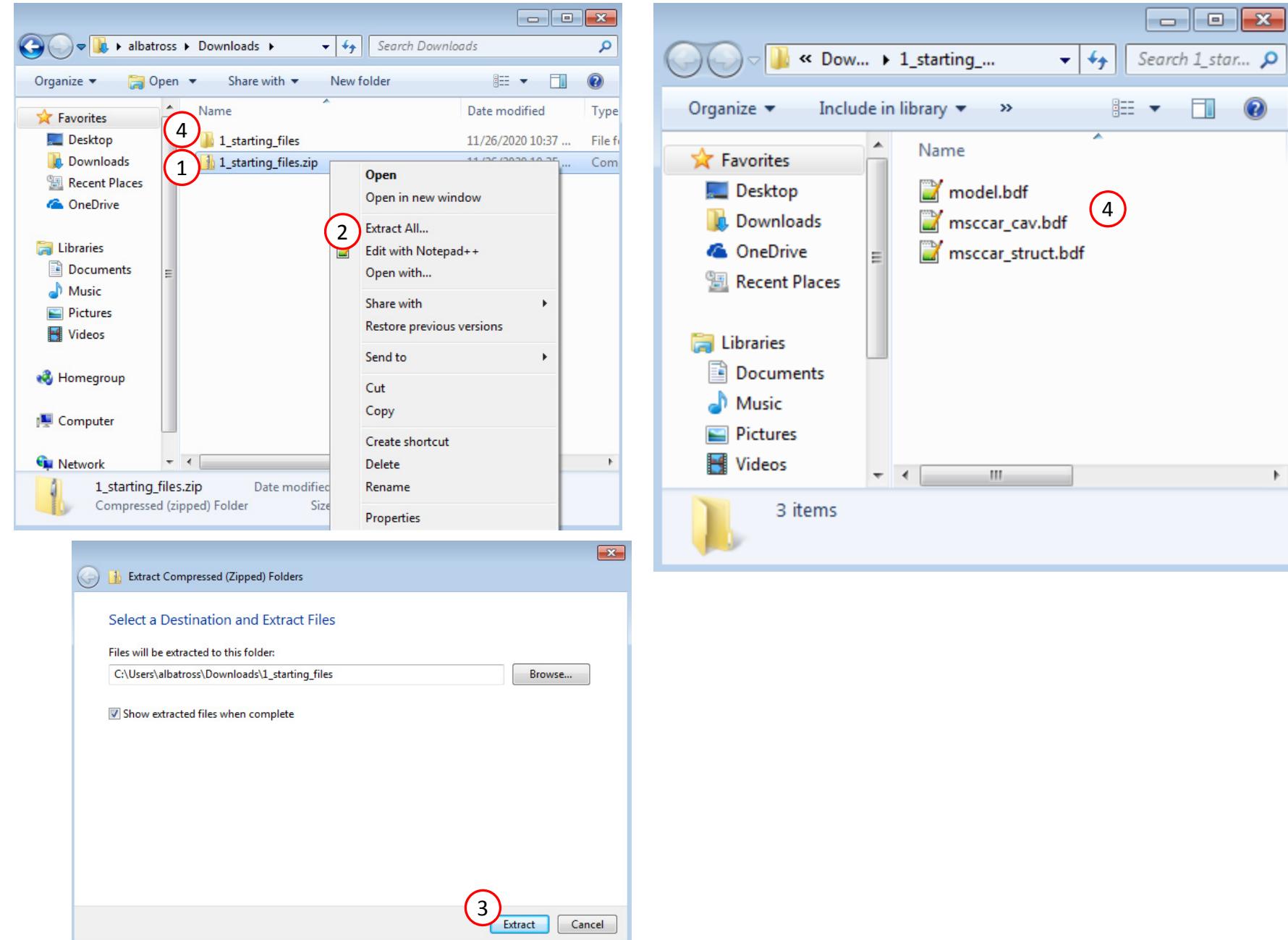
Starting Files: [Link](#) 2  
Solution BDF Files: [Link](#)



# 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

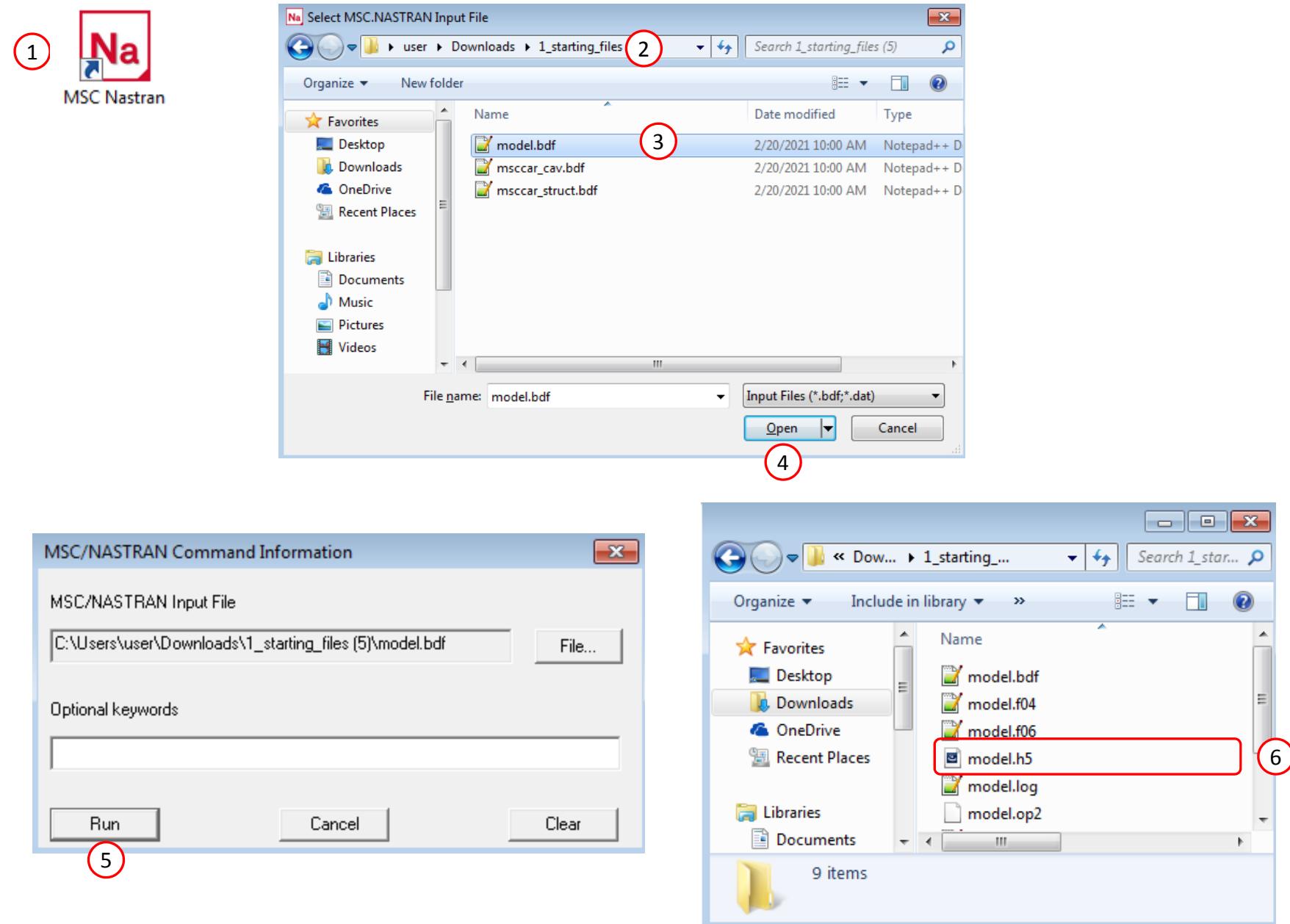
- The starting files for this tutorial are contained in a ZIP file and must be extracted as shown.



# 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

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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 Engineering Lab

# SOL 200 Web App

Select a web app to begin

1

Optimization for SOL 200

Multi Model Optimization

Machine Learning | Parameter Study

HDF5 Explorer

Remote Execution

Tutorials and User's Guide

Full list of web apps

Remote System

Input Files      Results Files

Local System



## Select BDF Files

1

1. Select files 3 files selected

Inspecting: 100%

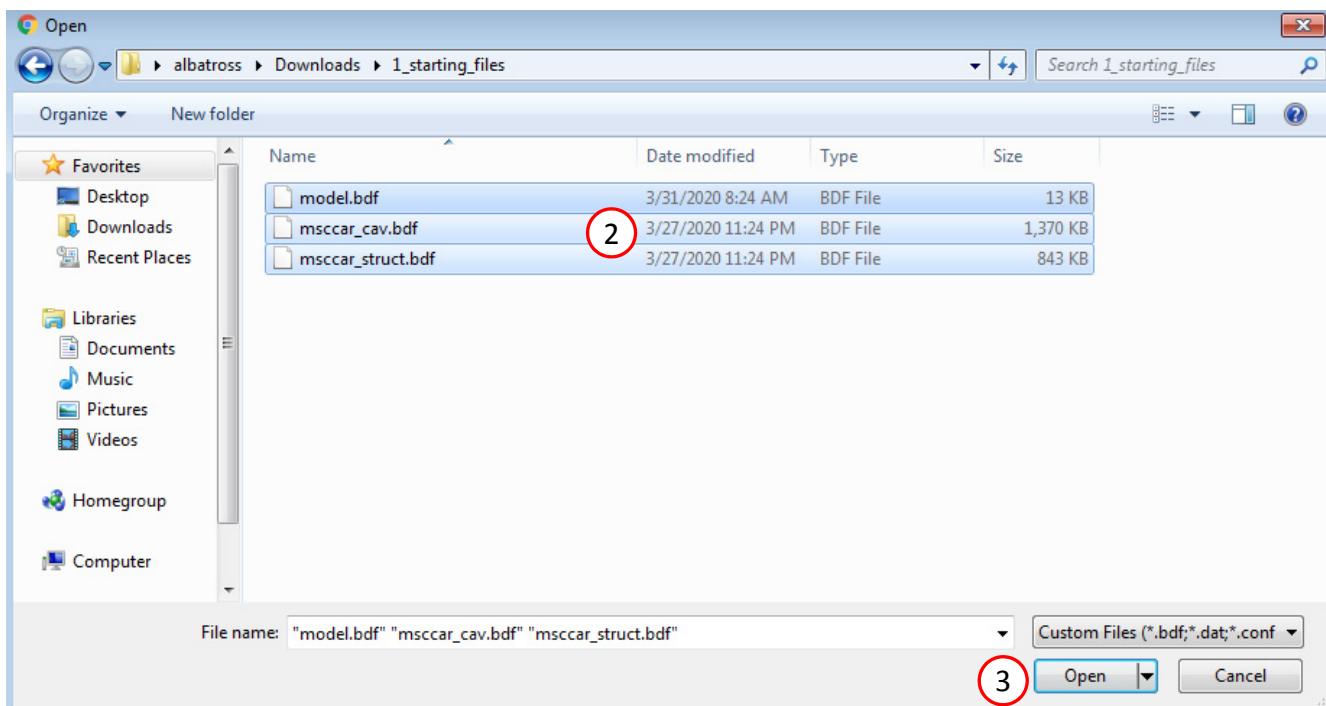
4

2. Upload files

Uploading: 100 %

## Select BDF Files

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



# Parameters

- Set the following fields as parameters
    - x1: The thickness of PSHELL 1
    - x2: The thickness of PSHELL 2
    - ...
    - x11: The thickness of PSHELL 11
  - Parameters have been created for the selected fields
  - For each parameter, use the following settings:
    - Low: 1.
    - High: 6.
- Bulk data entries will always be displayed in the small field format.  
• Only fields that have real or integer data entries may be selected as parameters. If the field is blank or contains only characters, the field may not be selected.

## Select Parameters

\$ _1_    _2_    _3_    _4_    _5_    _6_					
EIGRL	1	225.			
EIGRL	2	300.			
FORCE	212	1001	500.	0.0	
FORCE	213	1001	1000.	0.0	
FORCE	232	1003	500.	0.0	
FORCE	233	1003	1000.	0.0	
FREQ1	5	10.	2.5	56	
MAT1	7	210000.0	0.3	7.90E-06	
MAT1	8	620000.0	0.24	2.30E-06	
MAT10	6	1.23E-12340000.0			
PARAM	G	0.06			
PARAM	GFL	0.12			
PARAM	LFREQ	0.1			
PARAM	PREFDB	2.E-11			
PARAM	WTMASS	.001			
PSHELL	1	7	%x1%	1.0	1
PSHELL	2	7	%x2%	1.0	
PSHELL	3	7	%x3%	1.0	
PSHELL	4	7	%x4%	1.0	
PSHELL	5	7	%x5%	1.0	
PSHELL	6	7	%x6%	1.0	
PSHELL	7	7	%x7%	1.0	
PSHELL	8	7	%x8%	7	
PSHELL	9	7	%x9%	7	
PSHELL	10	7	%x10%	7	
PSHELL	11	8	%x11%	8	
RBE3	1501		1001	123456	1.0
	3646	2685	5709	2697	3819

## Configure Parameters

Delete	Parameter	Status	Low	High	Comments
	x1	<input checked="" type="checkbox"/>	1.	6.	Field 4 of PSHELL 1
	x2	<input checked="" type="checkbox"/>	1.	6.	Field 4 of PSHELL 2
	x3	<input checked="" type="checkbox"/>	1.	6.	Field 4 of PSHELL 3
	x4	<input checked="" type="checkbox"/>	1.	6.	Field 4 of PSHELL 4
	x5	<input checked="" type="checkbox"/>	1.	6.	Field 4 of PSHELL 5
	x6	<input checked="" type="checkbox"/>	1.	6.	Field 4 of PSHELL 6
	x7	<input checked="" type="checkbox"/>	1.	6.	Field 4 of PSHELL 7
	x8	<input checked="" type="checkbox"/>	1.	6.	Field 4 of PSHELL 8
	x9	<input checked="" type="checkbox"/>	1.	6.	Field 4 of PSHELL 9
	x10	<input checked="" type="checkbox"/>	1.	6.	Field 4 of PSHELL 10
	x11	<input checked="" type="checkbox"/>	1.	6.	Field 4 of PSHELL 11

1

## Upload .h5 File

2

1. Select files

model.h5

5

2. Upload files

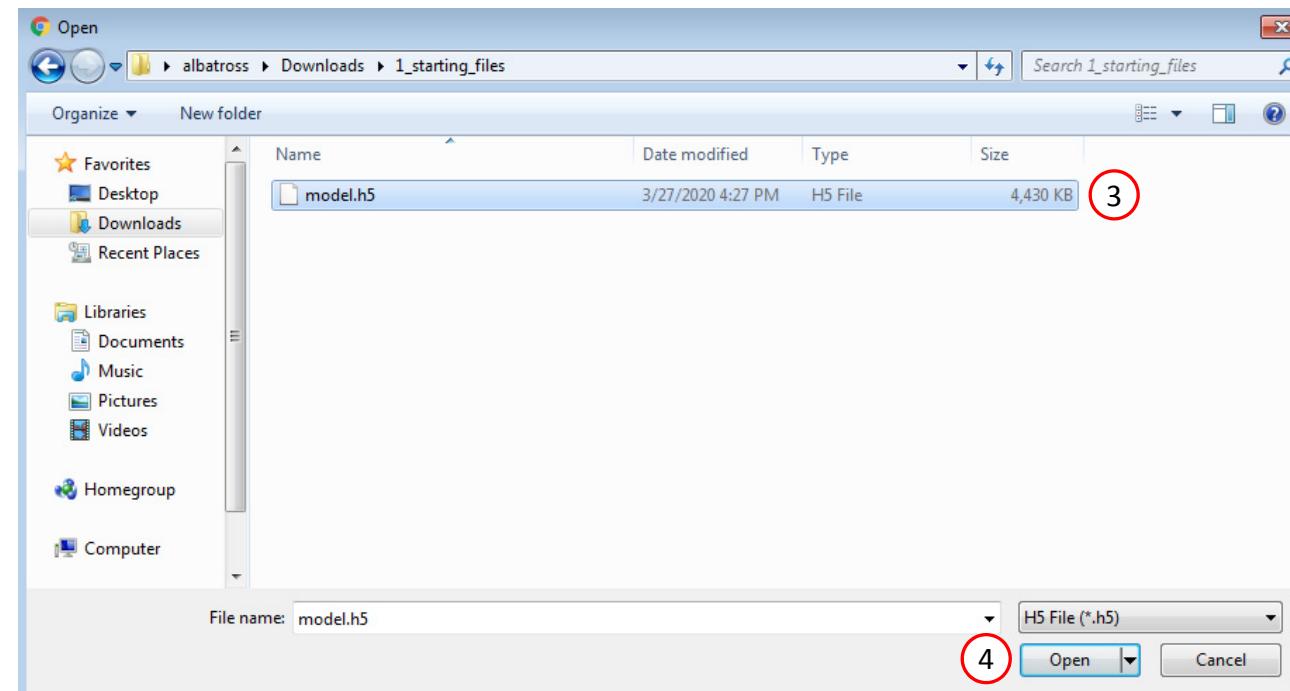
Uploading

Loading

## 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

SOL 200 Web App - Machine Learning   Parameters   Samples   Responses   Download   Results   Connection   Settings   Home

Select Responses to Monitor   Session ID: 3710   HDF5

Acquired Dataset   Reset Filters

Monitored Responses   Hide/Show Columns   Reset Filters   Download CSV

Delete	Label	Status	Objective	Lower Bound	Upper Bound	Monitor the cycle (SC)
X	r1	✓		Lower	Upper	

SOL 200 Web App - Machine Learning   Parameters   Samples   Responses   Download   Results   Connection   Settings   Home

Select Responses to Monitor   Session ID: 3710   HDF5

Acquired Dataset   Reset Filters

Monitored Responses   Hide/Show Columns   Reset Filters   Download CSV

Sample	Domain_ID	Subcase	Step	Analysis	Time_Freq_Eig	Im Eig API

Specify Entities  
Name of H5 File\*\*  
Subcase number  
Step number  
Analysis type  
Time, frequency or real part of eigen value

Examples: 0, etc.

Model   0   0   0   0

5 10 20 30 50 100

# Select Responses

1. Select the following dataset:  
NODAL/ACCELERATION\_CPLX
2. Use the horizontal scroll bar until the column TIME\_FREQ\_EIGR is visible
3. Use the vertical scroll bar until the value 50 is visible
4. Select the value 50 to only display rows that correspond to 50 Hz
5. Search for the column YM and click the indicated cell
6. A new response r1 is created
7. Set the following option:
  - Monitor the maximum or minimum response, whichever has the greatest absolute value [...]

response : No

- The responses defined in this tutorial correspond to points on frequency response plots
- Refer to the Appendix for an explanation on the use of the following:
  - Use MAX absolute value of response: Yes, No or blank

**Select Responses to Monitor**

Session ID: 1918

Select Dataset		Acquired Dataset	
		NODAL/ACCELERATION_CPLX - 1001, 1003	
ACOUSTIC/PRESSURE		YM	ZM
<b>NODAL/ACCELERATION_</b>			
NODAL/DISPLACEMENT			
NODAL/GRID_WEIGHT			
NODAL/VELOCITY_CPLX			

Specify Entities  
1001, 1003  
Grid identifier (ID)  
Examples: 1001, 1003, etc.

Auto Execute

**Acquire Dataset**

**Acquisition complete and successful**

**View Responses to Monitor**

Monitored Responses

Delete	Label	Status	Objective	Lower Bound	Upper Bound	Monitor the response of the FINAL design cycle (SOL 200 only)	Monitor the maximum or minimum response, whichever has the greatest absolute value
	r1					<input type="checkbox"/>	<input type="checkbox"/>

Time, frequency or real part of eigen value

47.5	50	52	55	57.5
47.5	50	52	55	57.5
50	50	50	50	50

# Select Responses

1. Use the horizontal scroll bar until the column TIME\_FREQ\_EIGR is visible
2. Select the value 10 to only display rows that correspond to 10 Hz
3. Search for the column YM and click the 4 indicated cells
4. Four (4) new response r2, r3, r4 and r5 have been created
5. Set the following option for these 4 new responses:
  - Monitor the maximum or minimum response, whichever has the greatest absolute value [...] response : Yes
  - The responses defined in this tutorial correspond to points on frequency response plots
  - Refer to the Appendix for an explanation on the use of the following:
    - Use MAX absolute value of response: Yes, No or blank

**Select Responses to Monitor**

Session ID: 1918      

**Select Dataset**

- ACOUSTIC/PRESSURE\_CPLX
- NODAL/ACCELERATION\_CPLX - 1001, 1003
- NODAL/DISPLACEMENT\_CPLX
- NODAL/GRID\_WEIGHT\_CPLX
- NODAL/VELOCITY\_CPLX

**Acquired Dataset**

NODAL/ACCELERATION\_CPLX - 1001, 1003

YM	ZM
Y magnitude component **	Z magnitude component **
<input style="font-size: 1em; padding: 2px 10px; border: 1px solid #ccc; border-radius: 4px;" type="button" value="TIME_FREQ_EIGR"/>	
<input style="font-size: 0.8em; padding: 2px 10px; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Reset Filters"/>	

**Specify Entities**

1001, 1003  
Grid identifier (ID)  
Examples: 1001, 1003, etc.

Auto Execute

**Acquire Dataset**

Acquisition complete and successful

**View Responses to Monitor**

Monitored Responses

Delete	Label	Status	Objective	Lower Bound	Upper Bound	Monitor the response of the FINAL design cycle (SOL 200 only)	Monitor the maximum or minimum response, whichever has the greatest absolute value
<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="r1"/>	r1	<input checked="" type="checkbox"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Lower"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Upper"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="No - Monitor response of correspon"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="NO"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="YES"/>
<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="r2"/>	r2	<input checked="" type="checkbox"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Lower"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Upper"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>
<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="r3"/>	r3	<input checked="" type="checkbox"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Lower"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Upper"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>
<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="r4"/>	r4	<input checked="" type="checkbox"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Lower"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Upper"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>
<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="r5"/>	r5	<input checked="" type="checkbox"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Lower"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Upper"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>	<input style="font-size: 0.8em; border: 1px solid #ccc; border-radius: 4px;" type="button" value="Yes - Monitor the maximum respon"/>

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

# Select Responses

1. Select the following dataset:  
ACOUSTIC/PRESSURE\_CPLX
2. Use the horizontal scroll bar until the column TIME\_FREQ\_EIGR is visible
3. Select the value 10 to only display rows that correspond to 10 Hz
4. Search for the column PM and click the 4 indicated cells
5. Four (4) new response r6, r7, r8 and r9 have been created
6. Set the following option for these 4 new responses:
  - Monitor the maximum or minimum response, whichever has the greatest absolute value [...] response: Yes

- The responses defined in this tutorial correspond to points on frequency response plots
- Refer to the Appendix for an explanation on the use of the following:
  - Monitor the maximum or minimum response, whichever has the greatest absolute value : Yes, No or blank

**Select Responses to Monitor**

Session ID: 8345 

Select Dataset		Acquired Dataset		Monitored Responses	
Select Dataset		Acquired Dataset		Monitored Responses	
<input type="checkbox"/> ACOUSTIC/PRESSURE_CPLX <input type="checkbox"/> NODAL/ACCELERATION_CPLX <input type="checkbox"/> NODAL/DISPLACEMENT_CPLX <input type="checkbox"/> NODAL/GRID_WEIGHT <input type="checkbox"/> NODAL/VELOCITY_CPLX <input type="checkbox"/> OTHER_NODAL_CPLX		Session ID: 8345  ACOUSTIC/PRESSURE_CPLX - 8667 PM PRMSM Sound pressure level - magnitude ** RMS Sound pressure level - magnitude ** p Time, frequency or real part of eigen value		Monitored Responses	
		Sound pressure level - magnitude ** RMS Sound pressure level - magnitude ** p Time, frequency or real part of eigen value		Monitored Responses	
<input type="checkbox"/> Auto Execute  Acquire Dataset  Acquisition complete and successful		10 12.5 15 17.5 20		Monitored Responses	
1		4		3	
2		5		6	

**View Responses to Monitor**

Monitored Responses

Delete	Label	Status	Objective	Lower Bound	Upper Bound	Monitor the response of the FINAL design cycle (SOL 200 only)	Monitor the maximum or minimum response, whichever has the greatest absolute value
	r1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Lower	Upper		No - Monitor response of correspon
	r2	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Lower	Upper		Yes - Monitor the maximum respon
	r3	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Lower	Upper		Yes - Monitor the maximum respon
	r4	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Lower	Upper		Yes - Monitor the maximum respon
	r5	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Lower	Upper		Yes - Monitor the maximum respon
	r6	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Lower	Upper		Yes - Monitor the maximum respon
	r7	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Lower	Upper		Yes - Monitor the maximum respon
	r8	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Lower	Upper		Yes - Monitor the maximum respon
	r9	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Lower	Upper		Yes - Monitor the maximum respon

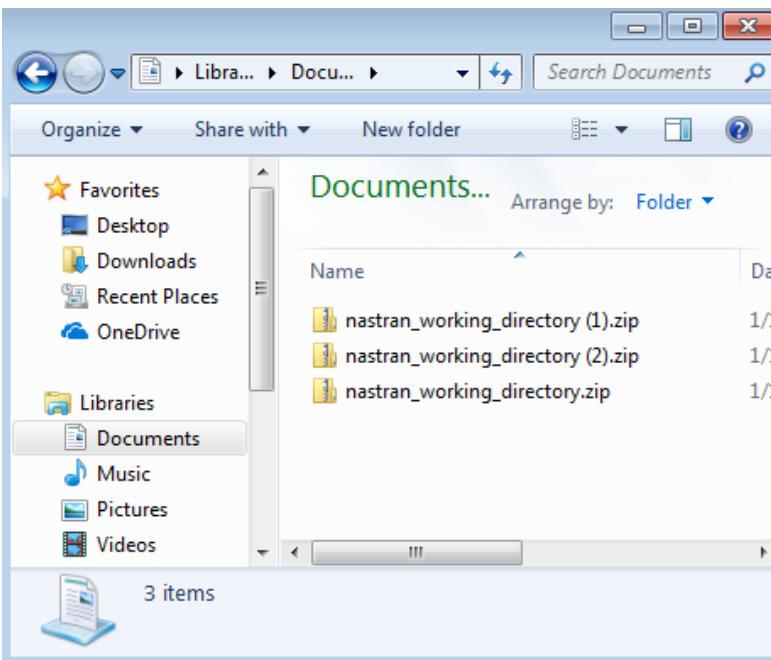
Hide/Show Columns  

# Configuring Multiple Batch Runs

---

# Samples

In the following slides, we will configure 3 batches to run.



Batch	File Name	Number of Runs	Number of Parameters	Purpose
1	nastran_working_directory.zip	55	11	This configuration includes 11 parameters. The goal is to use the data from the 55 run set to screen parameters and reduce the problem to 4 parameters. Automatic relevance determination (ARD) is used to identify the 4 most relevant parameters.
2	nastran_working_directory (1).zip	40	4	This configuration includes 4 parameters. The goal of this 40 run set is to produce training data to fit the surrogate model and make predictions.
3	nastran_working_directory (2).zip	8	4	This is an 8 run configuration. This set is used to compare the predicted responses with MSC Nastran responses.

# Samples

1. Click Samples
  2. Ensure the following design is selected:  
Latin Hypercube, Reproducible
  3. Set Number of Samples to 55
  4. The samples have been updated, note that  
samples 1, 2, 3, ..., 55 are visible
  5. The indicated controls can be used to  
display the other samples

- An initial 55 MSC Nastran runs will be executed to generate training data. The training data will be used for parameter/variable screening, via ARD, to reduce the dimensionality of the problem from 11 to 4 parameters.
  - For parameter screening purposes, 5 runs per parameter are used. Since there are 11 parameters configured, a total of 55 MSC Nastran runs have been configured for later execution.
  - Later on, when the goal is to fit the surrogate model for prediction purposes, 10 runs per parameter is used.

SOL 200 Web App - Machine Learning    Parameters    Samples **1**    Responses    Download    Results    Connection    Settings    Home

Configure Samples

Design    Latin Hypercube, Reproducible **2**

+ Info

Number of Samples    55 **3**

Samples to Run

+ Options

**4**

	Parameters			
Sample Number	x1	x2	x3	x4
1	3.308001	3.912181	2.622108	3.752609
2	2.788307	3.581974	4.839418	2.475032
3	3.783668	4.265475	3.415489	3.857485
4	3.130653	4.519993	2.208596	2.868824
5	2.843559	4.133313	2.918711	5.1189

**5**

« 1 2 3 4 5 6 7 ... 11 »

4 | 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

# Download

1. Click Download
2. Click Download BDF Files
3. A new ZIP file has been downloaded

SOL 200 Web App - Machine Learning    Parameters    Samples    Responses    **Download**    Results

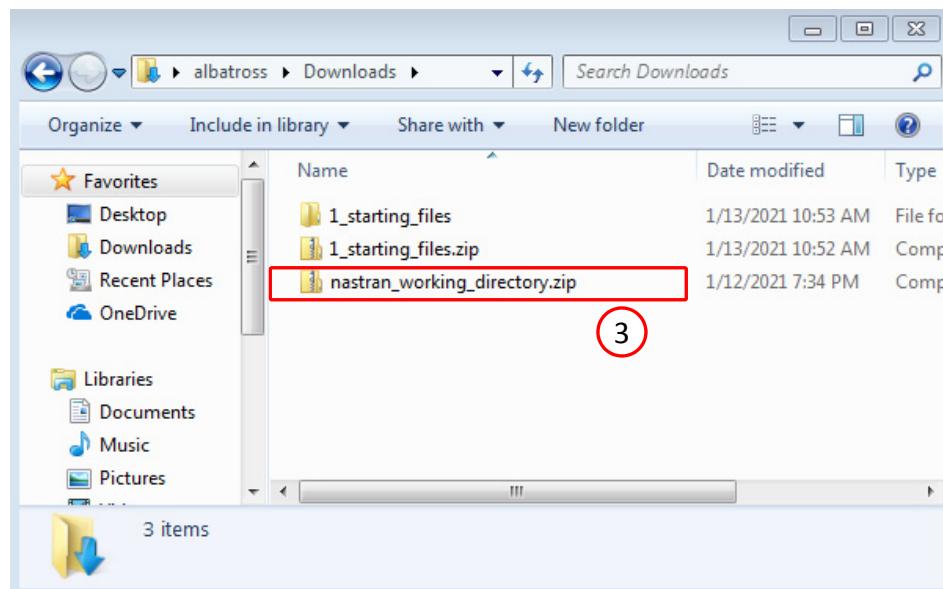
Connection    Settings    Home

1

## Download

 Download BDF Files

2



# Parameters

1. Click Parameters
2. Deselect the following fields to delete parameters: x3, x4, x5, x6, x7, x9, x10
3. The following 4 parameters should remain:  
x1, x2, x8, x11

SOL 200 Web App - Machine Learning    Parameters    **Samples**    Responses    Download    Results    Connection    Settings    Home

1

Select Parameters

\$\_1||\_2||\_3||\_4||\_5||\_6||\_7||\_8||\_9||\_10|

EIGRL	1	225.				
EIGRL	2	300.				
FORCE	212	1001	500.	0.0	1.0	0.0
FORCE	213	1001	1000.	0.0	0.0	1.0
FORCE	232	1003	500.	0.0	1.0	0.0
FORCE	233	1003	1000.	0.0	0.0	1.0
FREQ1	5	10.	2.5	56		
MAT1	7	210000.0	0.3	7.90E-06		
MAT1	8	62000.0	0.24	2.30E-06		
MAT10	6		1.23E-12340000.0			
PARAM	G	0.06				
PARAM	GFL	0.12				
PARAM	LFREQ	0.1				
PARAM	PREFDB	2.E-11				
PARAM	WTMASS	.001				
PSHELL	1	7	%x1%	7	1.0	0.833333
PSHELL	2	7	%x2%	7	1.0	0.833333
PSHELL	3	7	1.905	7	1.0	0.833333
PSHELL	4	7	1.27	7	1.0	0.833333
PSHELL	5	7	6.35	7	1.0	0.833333
PSHELL	6	7	3.81	7	1.0	0.833333
PSHELL	7	7	2.54	7	1.0	0.833333
PSHELL	8	7	%x8%	7	7	
PSHELL	9	7	3.0	7	7	
PSHELL	10	7	5.0	7	7	
PSHELL	11	8	%x11%	8	8	
RBE3	1501		1001	123456	1.0	123
					7047	263

2

Configure Parameters

Delete	Parameter	Status	Low	High	Comments
x	x1	✓	1.	6.	Field 4 of PSHEL
x	x2	✓	1.	6.	Field 4 of PSHEL
x	x8	✓	1.	6.	Field 4 of PSHEL
x	x11	✓	1.	6.	Field 4 of PSHEL

3

# Samples

1. Click Samples
2. Set the Design as Latin Hypercube, Reproducible
3. Set the Number of Samples as 40
4. The table now has 40 samples

SOL 200 Web App - Machine Learning    Parameters    **Samples**    Responses    Download    Results    Connection    Settings    Home

1

Configure Samples

Design    2

+ Info

Number of Samples    3

Samples to Run

+ Options

4

Sample Number	x1	x2	x8	x11
1	1.	4.333333	3.051282	4.717949
2	1.128205	2.538462	3.435897	3.051282
3	1.25641	4.076923	5.102564	1.897436
4	1.384615	5.102564	2.794872	2.282051
5	1.512821	2.025641	3.692308	5.487179

5 10 20 30 40 50

« 1 2 3 4 5 6 7 8 »

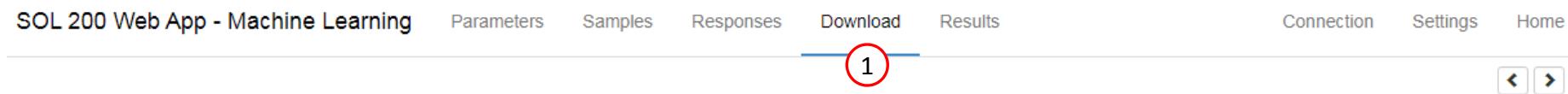
# Download

1. Click Download
2. Click Download BDF Files
3. A new ZIP file has been downloaded

SOL 200 Web App - Machine Learning    Parameters    Samples    Responses    **Download**    Results

Connection    Settings    Home

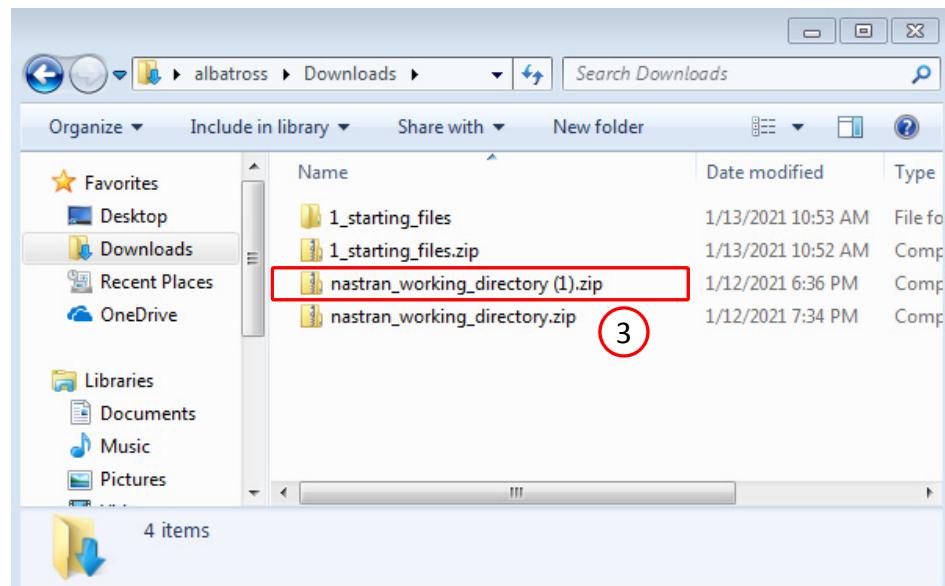
1



## Download

 Download BDF Files

2



# Samples

1. Click Samples
2. Set the Design as Latin Hypercube, Reproducible
3. Set the Number of Samples as 8
4. The table now has 8 samples
5. Click +Options
6. Click Export
7. A CSV file has been downloaded and contains the values from the table with 8 samples

SOL 200 Web App - Machine Learning

Parameters Samples Responses Download Results Connection Settings Home

Configure Samples

Design: Latin Hypercube, Reproducible (1)

Number of Samples: 8 (3)

Samples to Run

+ Options (5)

CSV Export

Export (6)

Parameters (4)

Sample Number	x1	x2	x8	x11
1	1.	4.571429	3.142857	1.714286
2	1.714286	3.857143	4.571429	6.
3	2.428571	1.	1.714286	3.857143
4	3.142857	1.714286	6.	2.428571
5	3.857143	5.285714	1.	4.571429

samples.csv (7)

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

HEXAGON Technology Partner

# Download

1. Click Download
2. Click Download BDF Files
3. A new ZIP file has been downloaded

SOL 200 Web App - Machine Learning    Parameters    Samples    Responses    **Download**    Results

Connection    Settings    Home

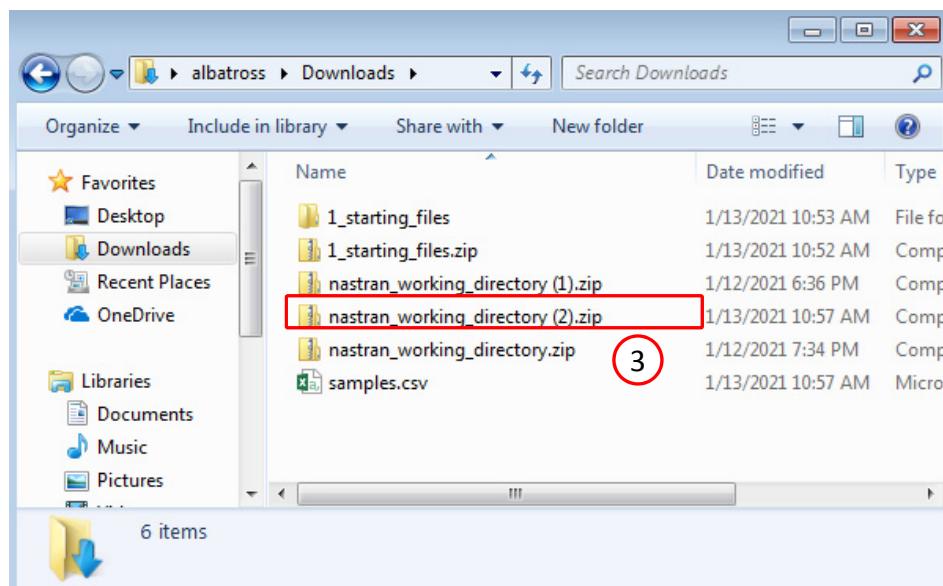
1



## Download

 Download BDF Files

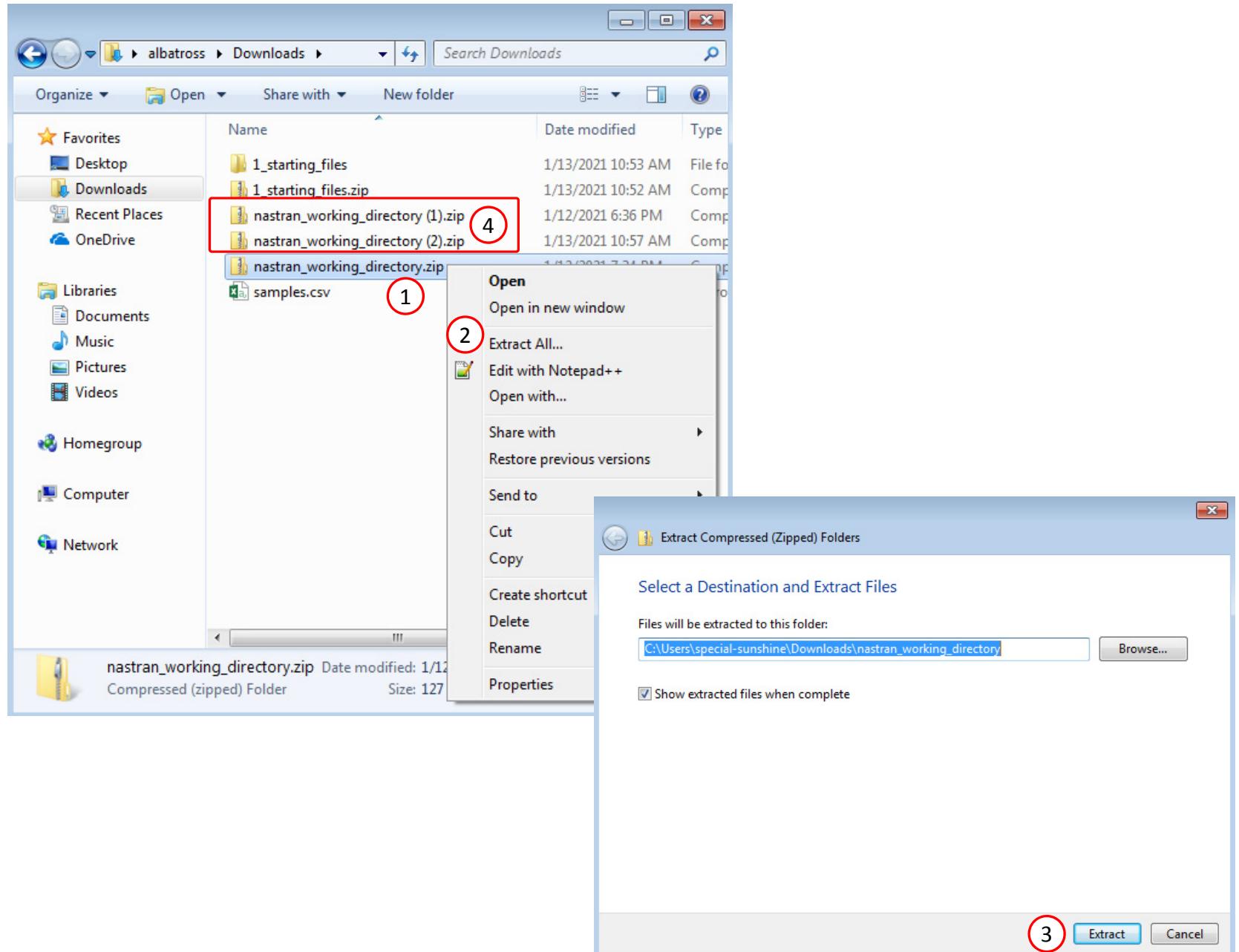
2



# Start Desktop App

1. Right click on the indicated file
2. Click Extract All
3. Click Extract on the following window
4. Repeat steps 1-3 for the indicated files

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



# Start Desktop App

1. Open this folder:  
nastran\_working\_directory
2. Inside of the new folder, double click on  
Start Desktop App
3. Click Open, Run or Allow Access on any  
subsequent windows
4. MSC Nastran 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.

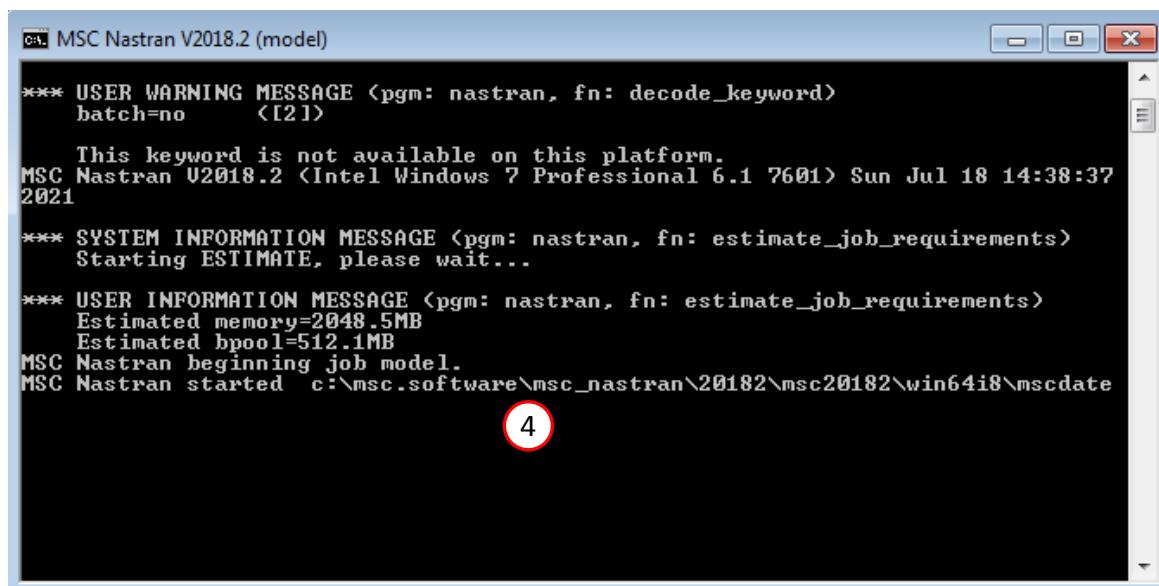
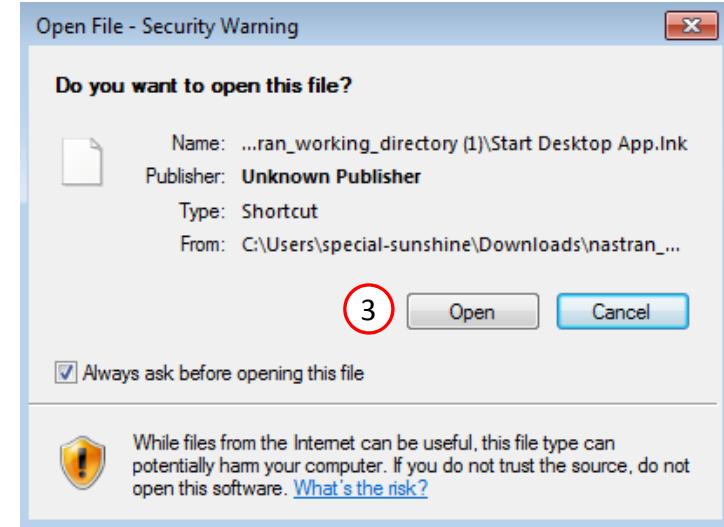
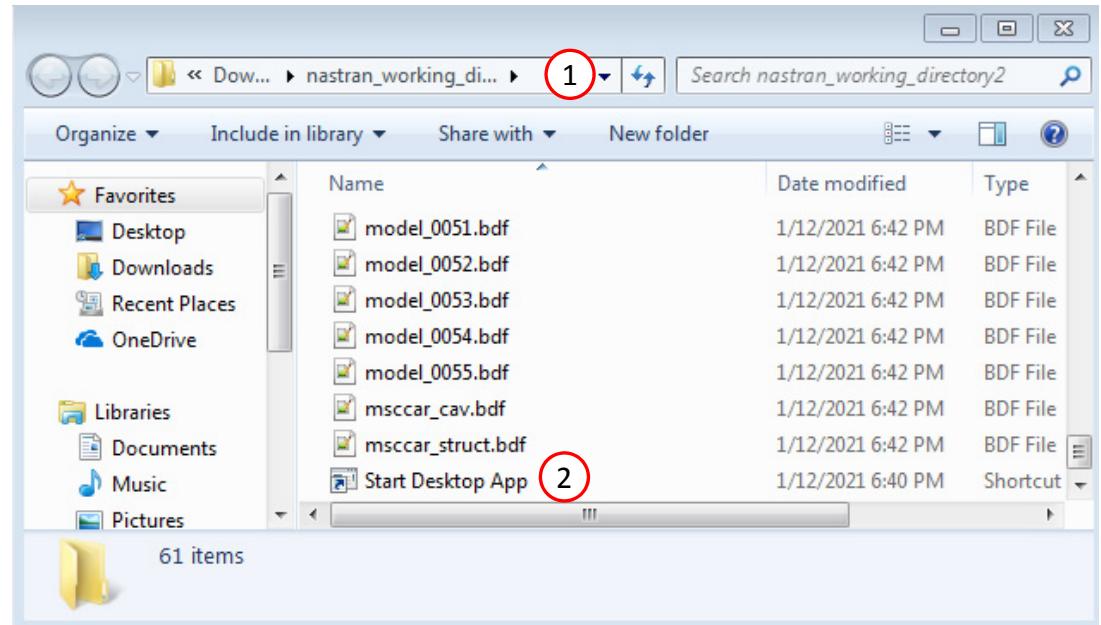
## Using Linux?

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

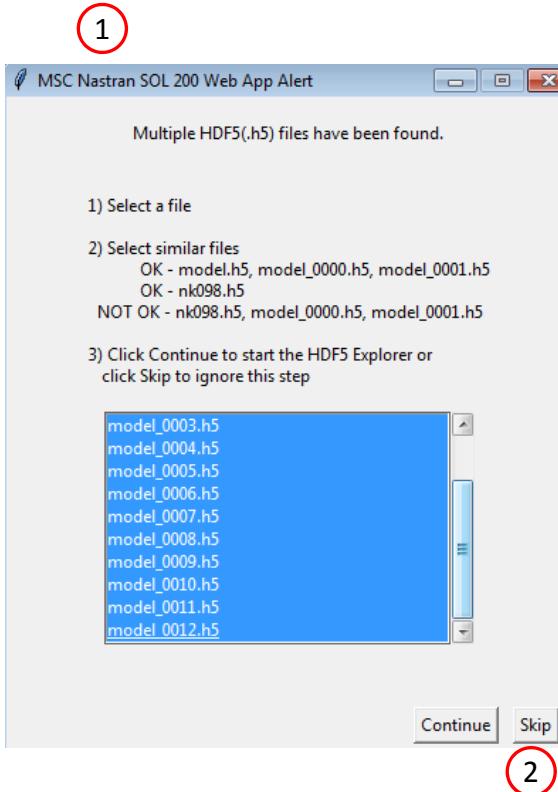
MSC Nastran

### Status

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

# Review Results

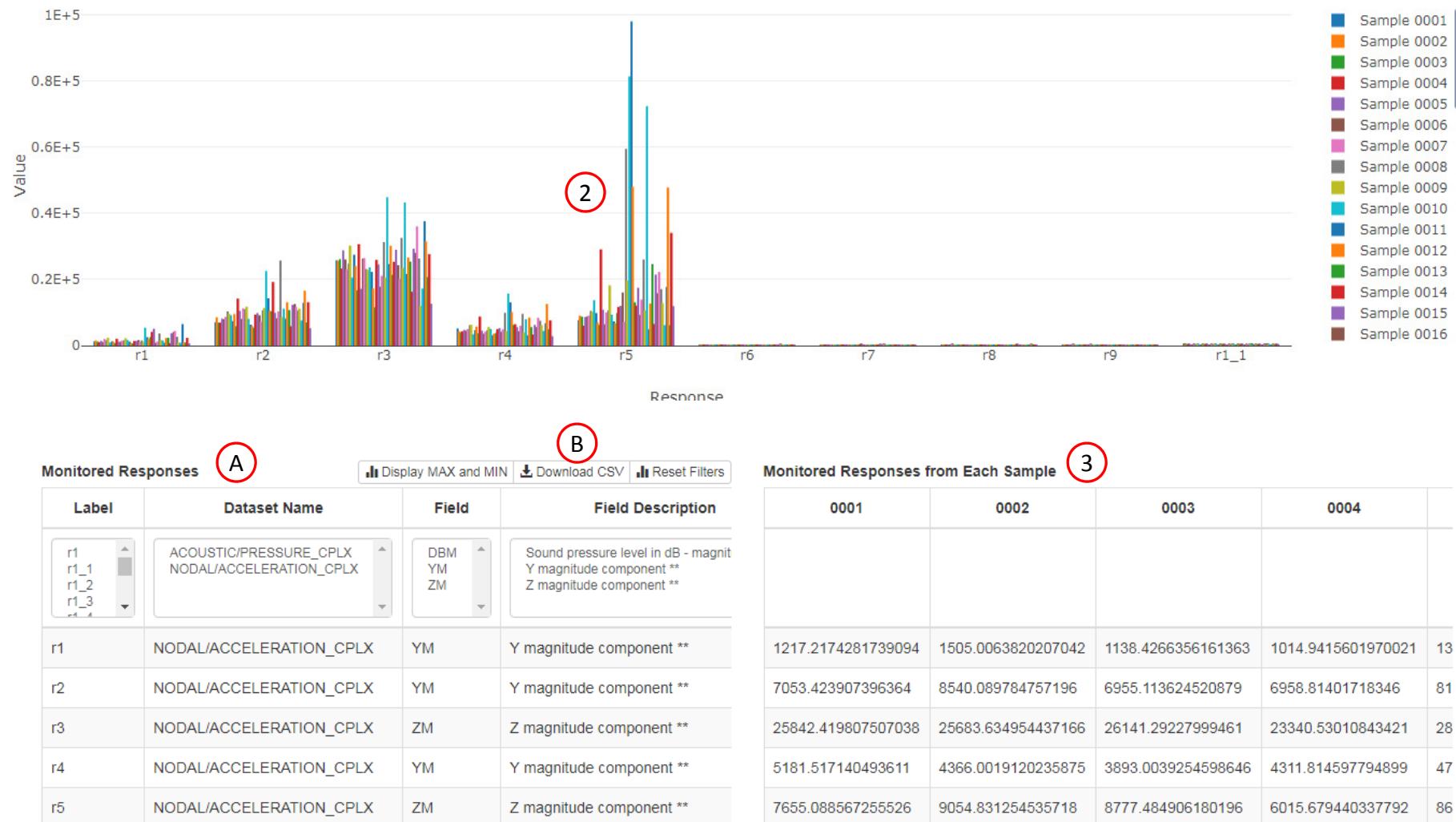
1. A window appears asking to start the HDF5 Explorer
2. Click Skip to not open the HDF5 Explorer



# Review Results

1. The Monitored Responses web app is opened
2. The value of each response and for each sample is displayed in a bar chart
3. A table lists the values for each response and sample.

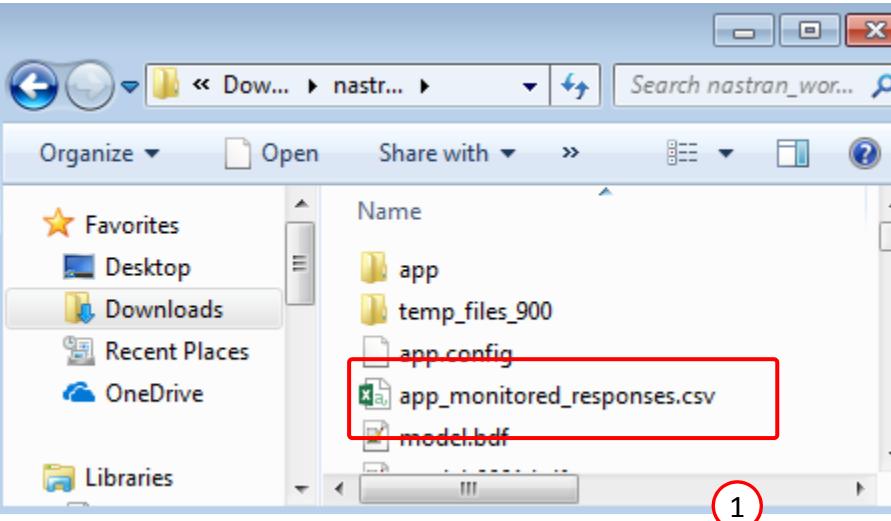
- A. The table titled Monitored Response can be interacted with. Each column in the table contains filters. Once a filter is modified, the Bar Chart will instantly update.
- B. Additional functions include the ability to highlight the MAX and MIN bars, download a CSV file and reset the filters.



# Review Results

1. The monitored responses are contained in the CSV file named app\_monitored\_responses.csv

The responses in this CSV file will be used to train the surrogate model.

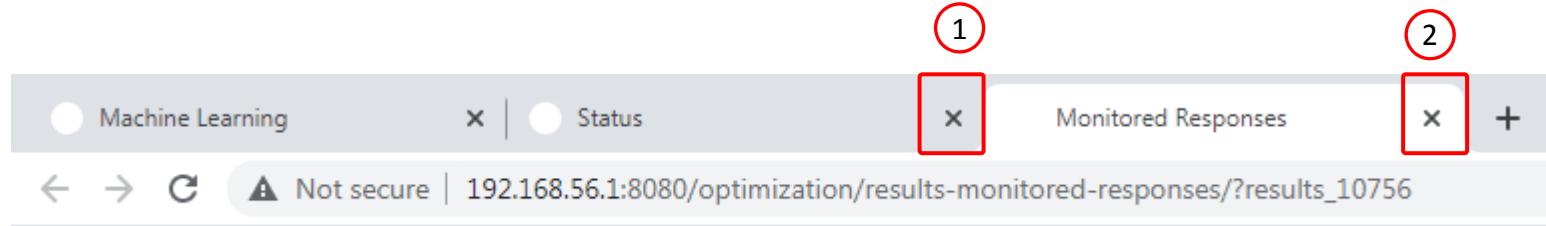


A screenshot of an Excel spreadsheet titled 'app\_monitored\_responses.csv - Excel'. The data is organized into columns labeled A through J. Column A is labeled 'Sample'. The data rows are as follows:

Sample	r1	r2	r3	r4	r5	r6	r7	r8	r9
1	1217.217	7053.424	25842.42	5181.517	7655.089	7.54E-06	2.38E-05	3.73E-06	1.53E-05
2	1505.006	8540.09	25683.63	4366.002	9054.831	1.05E-05	2.47E-05	7.78E-06	1.97E-05
3	1138.427	6955.114	26141.29	3893.004	8777.485	9.88E-06	2.60E-05	4.92E-06	2.19E-05
4	1014.942	6958.814	23340.53	4311.815	6015.679	5.89E-06	1.29E-05	5.46E-06	1.10E-05
5	1379.038	8133.175	28819.79	4774.837	8635.851	9.60E-06	2.08E-05	5.52E-06	1.57E-05

# Close Pages

1. The Status page can be closed
2. The Monitored Responses page can be closed



# Start Desktop App

1. Open this folder:  
nastran\_working\_directory (1)
2. Inside of the new folder, double click on  
Start Desktop App
3. Click Open, Run or Allow Access on any  
subsequent windows
4. MSC Nastran 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.

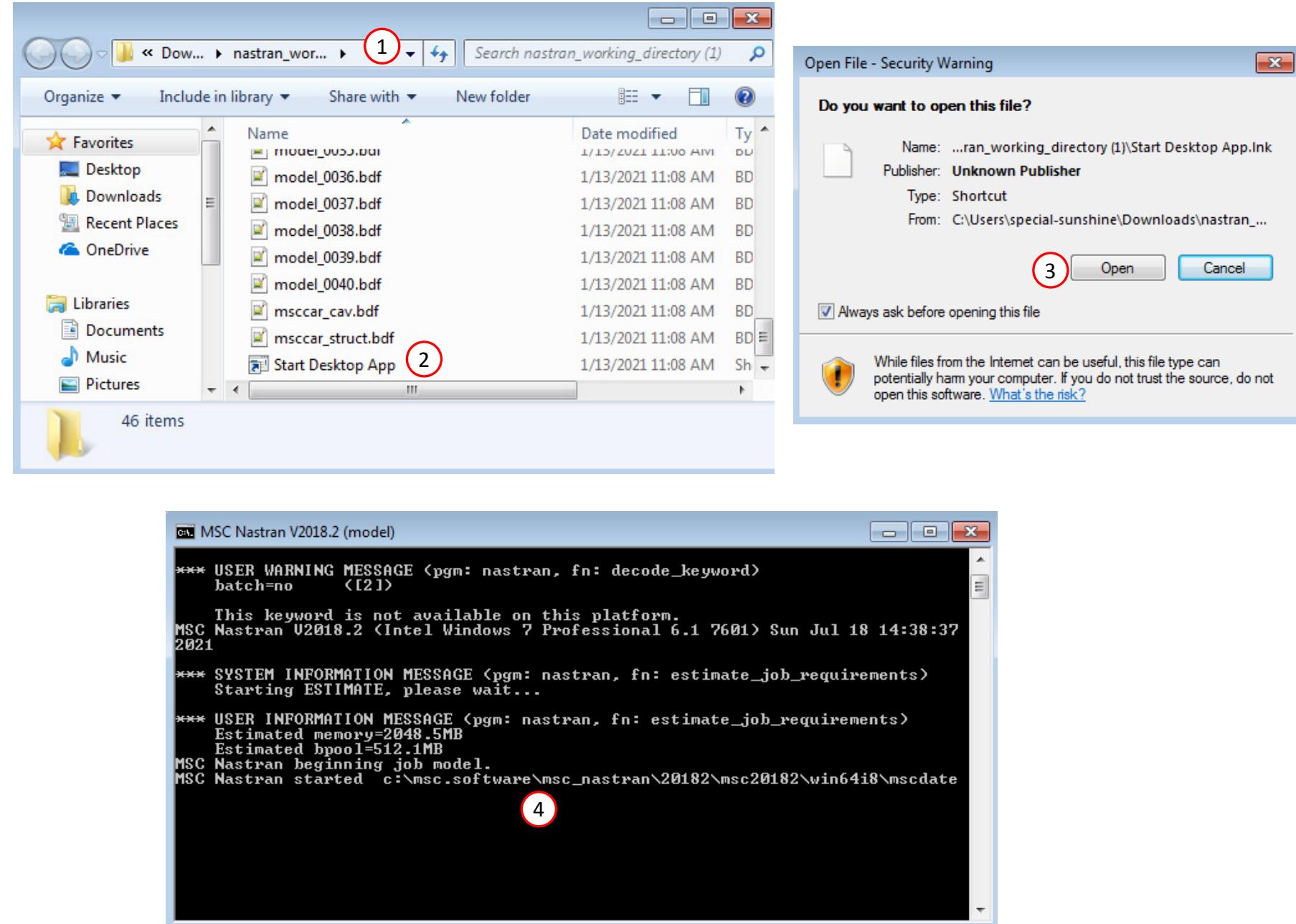
## Using Linux?

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

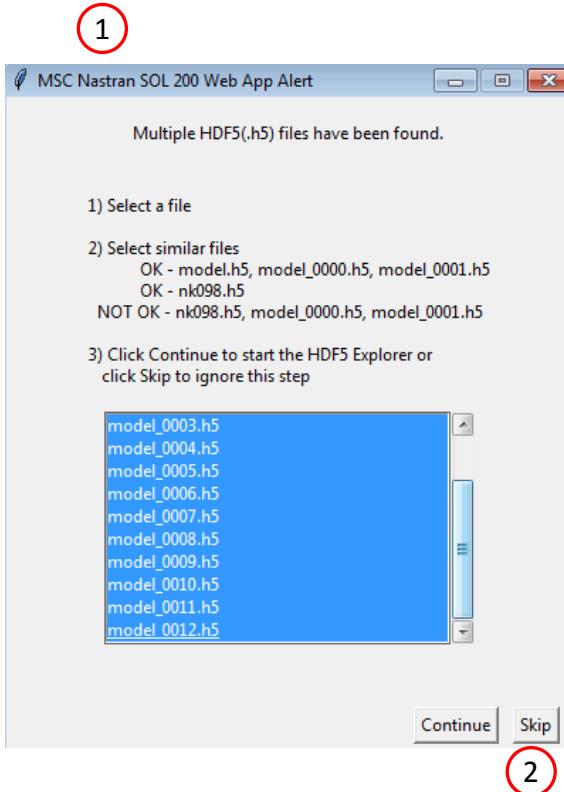
MSC Nastran

### Status

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

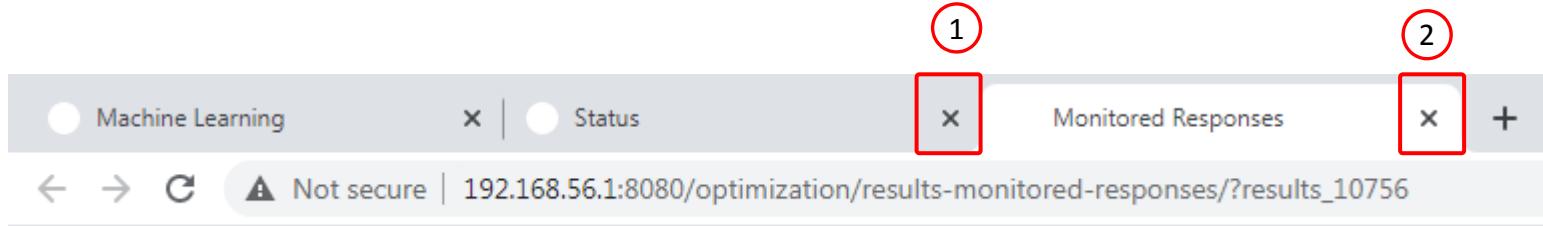
# Review Results

1. A window appears asking to start the HDF5 Explorer
2. Click Skip to not open the HDF5 Explorer



# Close Pages

1. The Status page can be closed
2. The Monitored Responses page can be closed



# Start Desktop App

1. Open this folder:  
nastran\_working\_directory (2)
2. Inside of the new folder, double click on  
Start Desktop App
3. Click Open, Run or Allow Access on any  
subsequent windows
4. MSC Nastran 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.

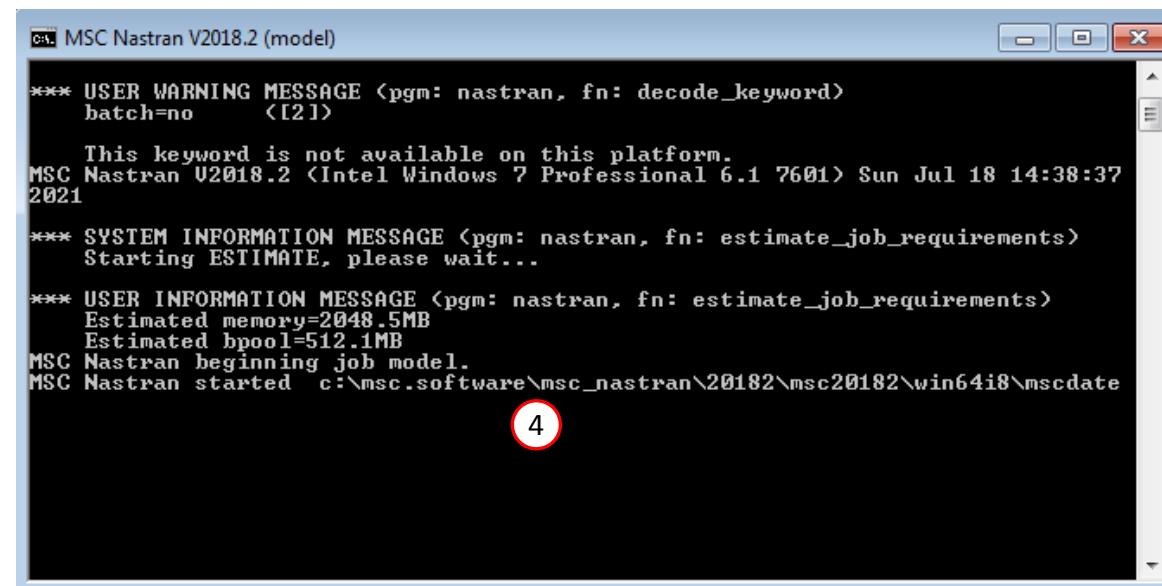
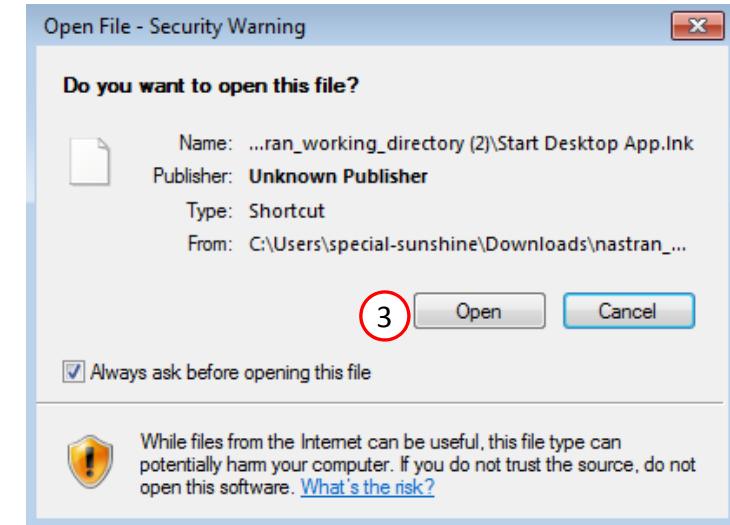
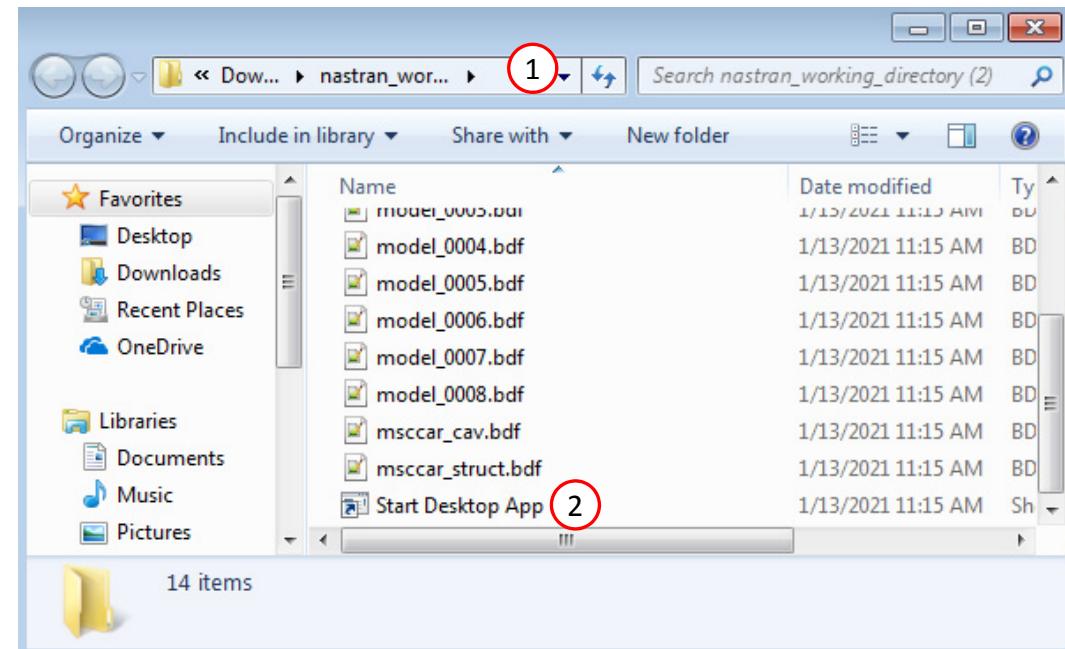
## Using Linux?

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

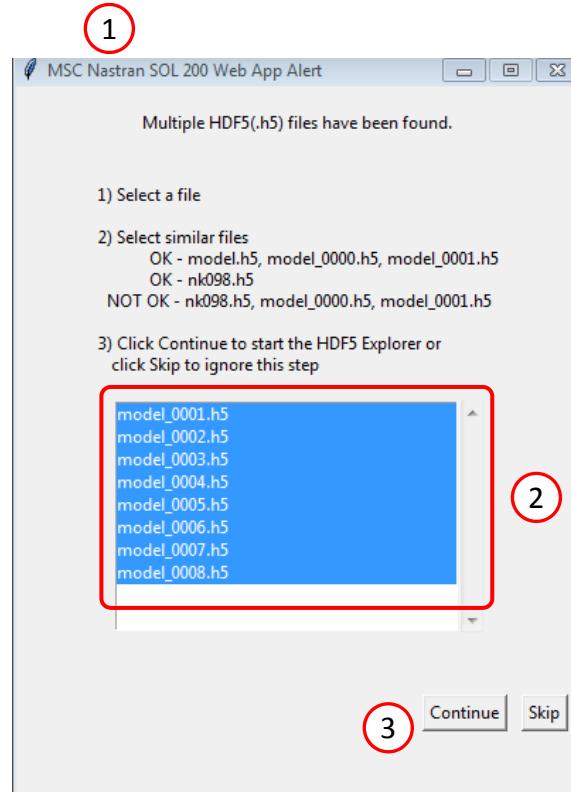
MSC Nastran

### Status

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

# Review Results

1. A window appears asking to start the HDF5 Explorer
2. Select all 8 H5 files
3. Click Continue



# HDF5 Explorer

1. Navigate to the Plots Browser section
2. Click the indicated icon

SOL 200 Web App - HDF5 Explorer      Acquire Dataset      Plots Browser **1**      Combine Plots      Last Plot Added      Connection      Home

## Plots Browser

### ACOUSTIC/PRESSURE\_CPLX

**Download CSV**

Plot #: 1 - ID: 8667 | SAMPLE: model\_0001, model\_0002, model\_0003, ... | SUBCASE: 12 | PM vs. TIME\_FREQ\_EIGR

Plot #: 2 - ID: 8667 | SAMPLE: model\_0001, model\_0002, model\_0003, ... | SUBCASE: 13 | PM vs. TIME\_FREQ\_EIGR

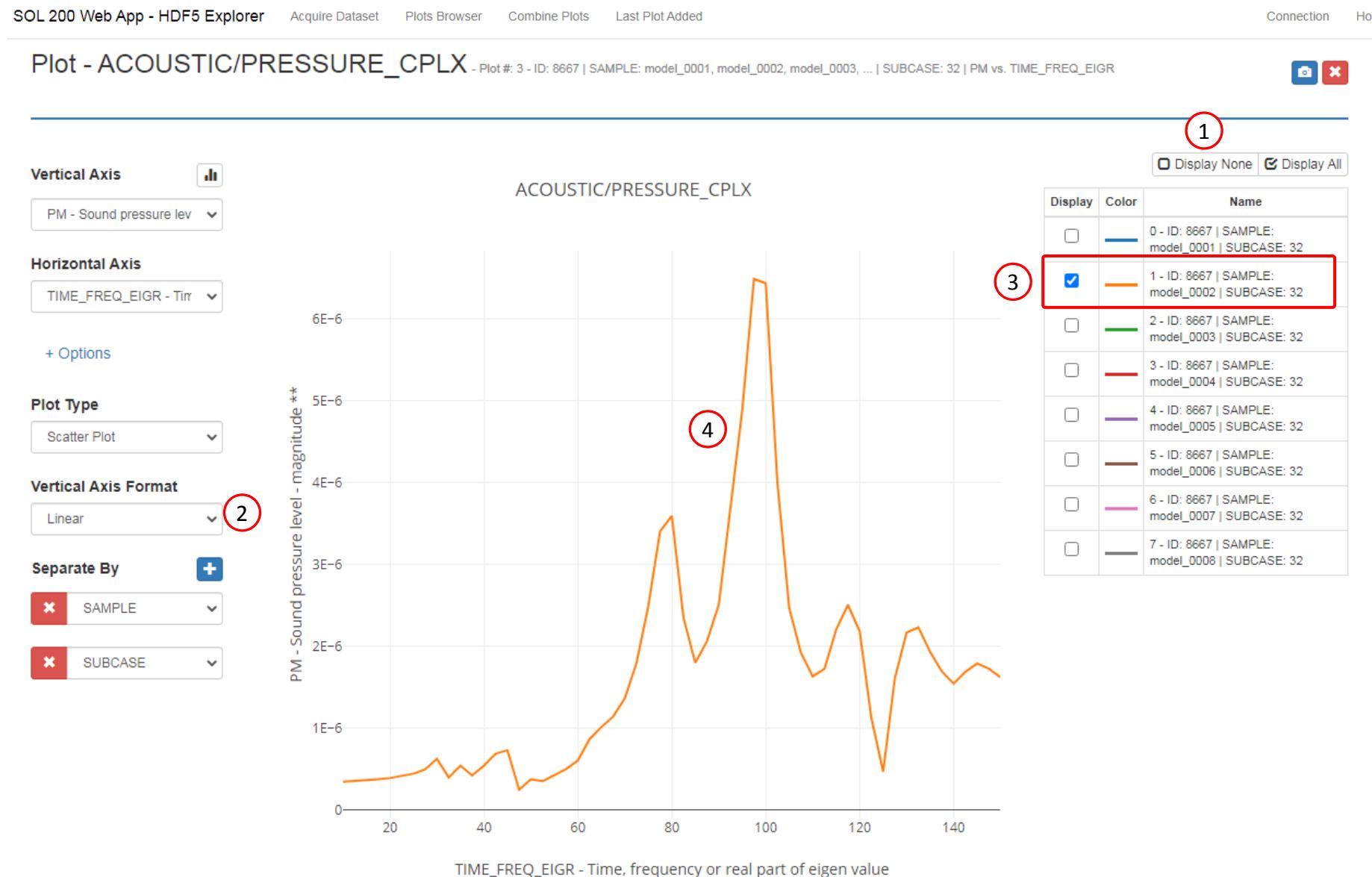
Plot #: 3 - ID: 8667 | SAMPLE: model\_0001, model\_0002, model\_0003, ... | SUBCASE: 32 | PM vs. TIME\_FREQ\_EIGR

Plot #: 4 - ID: 8667 | SAMPLE: model\_0001, model\_0002, model\_0003, ... | SUBCASE: 33 | PM vs. TIME\_FREQ\_EIGR

# HDF5 Explorer

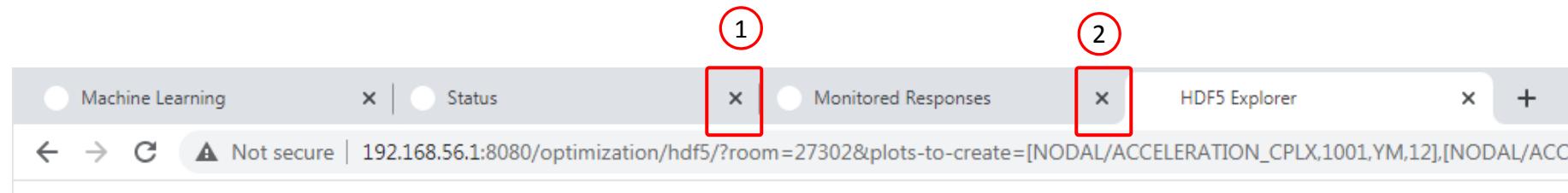
1. Click Display None to hide all the plotted traces
2. Set the Vertical Axis Format to Linear
3. Select only the 2<sup>nd</sup> trace which corresponds to the pressure at grid 8867, subcase 32, sample 2
4. The corresponding trace is now plotted

This trace will be used to compare the MSC Nastran response and predicted responses



# Close Pages

1. The Status page can be closed
2. The Monitored Responses page can be closed



# Determining Parameter Relevance (Parameter/Variable Screening)

---

# Prediction Analysis Web App

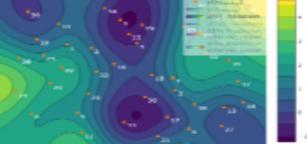
1. Return to the Machine Learning web app
2. Click Results
3. Click Prediction Analysis
4. The Prediction Analysis web app is now open
5. Ensure it says Connected

SOL 200 Web App - Machine Learning

Parameters Samples Responses Download **Results** Connection Settings Home

1 2 < >

### Select a Results App



Prediction Analysis 3

### SOL 200 Web App - Prediction Analysis 4 Home

#### Gaussian Process (GP) App Connection Status

Connected 5 Session ID: 8207

**Output**

```
GP App Update - Starting the Gaussian Process (GP) app on the server
- Session ID: 8207
- Address: http://localhost:8080/optimization
Desktop App Update - Connecting to the SOL 200 Web App...
GP App Update - Connection successful between the Node JS server and GP app
```

**Warnings and Errors**

Warnings can be ignored

# Training Data

1. Navigate to the Training and Testing Data section
2. Delete any previous table data by clicking the four (4) buttons named Delete all rows

- **x\_training, y\_training** - This specifies the x inputs and y outputs used to train the surrogate model.
- **x\_testing, y\_testing** - This specifies the x inputs and y outputs used to calculate the Normalized Root Mean Square Error (NRMSE) between the predicted values and actual MSC Nastran responses. This testing data is optional.
- **x\_prediction** – The x inputs at which to make predictions.

## Training and Testing Data 1

### x\_training

CSV Export      CSV Import

Export      Select files Select a CSV File Import

CSV  
imported

sample	
--------	--

### y\_training

CSV Export      CSV Import

Export      Select files Select a CSV File Import

sample	
--------	--

### x\_testing

CSV Export      CSV Import

Export      Select files Select a CSV File Import

sample	
--------	--

### y\_testing

CSV Export      CSV Import

Export      Select files Select a CSV File Import

sample	
--------	--

2

Delete all rows

sample	
--------	--

Delete all rows

y1	
----	--

Delete all rows

x1	
----	--

Delete all rows

x2	
----	--

Delete all rows

y1	
----	--

# Training Data

1. Navigate to the section titled x\_training
2. Click Select files
3. Navigate to the folder named nastran\_working\_directory which contains data for 55 runs
4. Select the file app.config
5. Click Open
6. Click Import
7. The table is now loaded with the x inputs for all 55 runs

## Training and Testing Data

x\_training (1)

CSV Export CSV Import (6)  
Export Select files app.config Import (2)

CSV imported (7)

sample x1 x2 x8 x11

1	1.	4.333333	3.051282	4.717949
2	1.128205	2.538462	3.435897	3.051282
3	1.25641	4.076923	5.102564	1.897436
4	1.384615	5.102564	2.794872	2.282051
5	1.512821	2.025641	3.692308	5.487179
6	1.641026	2.923077	5.615385	4.205128
7	1.769231	2.153846	1.384615	4.333333
8	1.897436	1.512821	5.230769	1.769231
9	2.025641	3.435897	1.128205	2.025641
10	2.153846	5.358974	4.974359	3.692308

Delete all rows

Open (3)  
File name: app.config (5)  
Custom Files (\*.csv;\*.config)

1 2 3 4 5 6 >  
10 25 50 100

# Training Data

1. Navigate to the section titled `y_training`
2. Click `Select files`
3. Navigate to the folder named `nastran_working_directory` which contains data for 55 runs
4. Select the file `app_monitored_responses.csv`
5. Click `Open`
6. Click `Import`
7. The table is now loaded with the `y` outputs (monitored responses) for all 55 runs

The screenshot shows a software interface for managing CSV files. At the top, there are tabs for "CSV Export" and "CSV Import". The "CSV Import" tab is active, indicated by a green background and the word "imported" next to it. Below the tabs are three buttons: "Export" (orange), "Select files" (blue), and "Import" (green). The "Select files" button is highlighted with a red circle labeled "2". To its right, the file "app\_monitored\_responses.csv" is listed. Above the file list is a red circle labeled "6" around the "Import" button. To the right of the file list, there is a red circle labeled "7" around the table area.

sample	y1	y2	y3	y4	y5
0001	1217.2174281...	7053.4239073...	25842.419807...	5181.5171404...	7655.0885672...
0002	1505.0063820...	8540.0897847...	25683.634954...	4366.0019120...	9054.8312545...
0003	1138.42663561...	6955.11362452...	26141.292279...	3893.0039254...	8777.4849061...
0004	1014.9415601...	6958.8140171...	23340.530108...	4311.8145977...	6015.6794403...
0005	1379.03821311...	8133.1753262...	28819.790379...	4774.8375075...	8635.8513076...
0006	1047.6175683...	7973.2957981...	26054.675419...	4523.9543601...	8849.2091520...
0007	1981.5433834...	8692.3242639...	23054.2571136...	4995.6044695...	9071.9554061...
0008	1598.2086637...	10324.491827...	24808.673325...	6146.4902246...	10474.352170...
0009	2351.7355373...	9636.5472108...	30268.013988...	6305.1596798...	10217.706642...
0010	923.115645225...	9180.8271441...	20546.846849...	3444.3692147...	13782.262157...

Below the table is a file selection dialog titled "Open". The path "Downloads > nastran\_working\_directory" is shown in the title bar. The file "app\_monitored\_responses.csv" is selected, indicated by a blue border and a red circle labeled "4" over it. The "Open" button at the bottom is highlighted with a red circle labeled "5".

# Perform Regression

1. Click Perform Regression and the surrogate model will be fitted
2. The regression is complete when the following status message is visible:
  - Process complete
3. The output will be used on the next page

### Regression

Data	Link to Table	Status	Status Description
x_training	<a href="#">Link</a>		Ready
y_training	<a href="#">Link</a>		Ready
x_testing (Optional)	<a href="#">Link</a>		Ready
y_testing (Optional)	<a href="#">Link</a>		Ready

[Perform Regression](#)

1

[Process complete](#)

2

[Click here](#) to view the Regression Results section

3

#### Output

GP App Update - Saving initial data  
GP App Update - Summary of Automatic Relevance Determination (ARD)  
ARD measures predictive relevance of parameters and is used for parameter selection:  
- High Value: The parameter xi is relevant  
- Low Value: The parameter xi is irrelevant and could potentially be selected for removal

Kernel: Matern52

Response	x1	x2	x3	x4	x5
y1	4.41523	11.181	0.659106	2.17256e-09	3.3067e-09
y2	2.6569	3.0316	3.96957	1.37152e-07	1.21214
y3	1.43826	5.22752	9.84035e-07	1.20974e-06	0.433083
y4	0.0857389	22.2011	2.80218	0.0084688	1.54202e-09
y5	0.00394936	73.9887	0.0320619	0.119963	0.248584
y6	0.532546	8.6371	0.777735	5.41834e-05	2.99273
y7	0.383766	31.5844	3.9199e-09	0.616215	5.33463e-09
y8	0.0615319	49.5679	2.03028e-08	1.21104	2.07824e-08
y9	0.31014	7.12581	1.19458	4.37308e-08	0.289277

Parameters listed in decreasing order of relevance: x2, x8, x1, x11, x3, x5, x9, x4.

Kernel: Exponential

Response	x1	x2	x3	x4	x5
y1	0.633904	3.97626	8.68101e-10	5.9275e-10	9.24688e-10
y2	0.119435	0.338008	0.102887	4.80711e-10	4.06709e-10
y3	0.0342023	0.391405	2.72361e-09	6.14333e-09	0.0271812
y4	0.00116244	0.155004	0.0221579	5.60043e-11	4.89368e-11
y5	3.82391e-11	0.41135	2.14606e-11	2.50395e-11	1.47319e-11
y6	9.32315e-06	1.35509	0.0606396	1.84373e-06	0.230813
y7	0.0097128	1.41159	4.10616e-10	3.07655e-10	1.83933e-10
y8	0.0515579	7.13954	5.35455e-08	3.83144e-07	6.88943e-08
y9	0.00201582	0.273497	2.67888e-10	2.10806e-10	0.0241915

Parameters listed in decreasing order of relevance: x2, x1, x8, x11, x10, x3, x6, x5.

Kernel: RBF

# Automatic Relevance Determination (ARD)

1. Click and hold the bottom right corner of the output window (gray color) and vertically drag to adjust the height of the window. This will make more text visible.
2. For the Output window, move the scroll bar to the very bottom
3. Ensure the following section is visible:  
Summary of Automatic Relevance  
Determination (ARD)
4. ARD values for each response with respect to  
each parameter have been computed

Output

```
GP App Update - Saving initial data
GP App Update - Summary of Automatic Relevance Determination (ARD) 3
ARD measures predictive relevance of parameters and is used for parameter selection.
- High Value: The parameter xi is relevant
- Low Value: The parameter xi is irrelevant and could potentially be selected for removal.

Kernel: Matern52
| Response | x1 | x2 | x3 | x4 | x5 | |
|---|---|---|---|---|---|---|
| y1 | 4.41523 | 11.181 | 0.659106 | 2.17256e-09 | 3.3067e-09 | 1.8521 |
| y2 | 2.6569 | 3.0316 | 3.96957 | 1.37152e-07 | 1.21214 | 0.0482 |
| y3 | 1.43826 | 5.22752 | 9.84035e-07 | 1.20974e-06 | 0.433083 | 1.4890 |
| y4 | 0.0857389 | 22.2011 | 2.80218 | 0.0084688 | 1.54202e-09 | 0.0129 |
| y5 | 0.00394936 | 73.9887 | 0.0320619 | 0.119963 | 0.248584 | 4.7087 |
| y6 | 0.532546 | 8.6371 | 0.777735 | 5.41834e-05 | 2.99273 | 0.0472 |
| y7 | 0.383766 | 31.5844 | 3.9199e-09 | 0.616215 | 5.33463e-09 | 0.0254 |
| y8 | 0.0615319 | 49.5679 | 2.03028e-08 | 1.21104 | 2.07824e-08 | 2.2841 |
| y9 | 0.31014 | 7.12581 | 1.19458 | 4.37308e-08 | 0.289277 | 0.0793 |

Parameters listed in decreasing order of relevance: x2, x8, x1, x11, x3, x5, x9, x4.

Kernel: Exponential
| Response | x1 | x2 | x3 | x4 | x5 | |
|---|---|---|---|---|---|---|
| y1 | 0.633904 | 3.97626 | 8.68101e-10 | 5.9275e-10 | 9.24688e-10 | 6.455 |
| y2 | 0.119435 | 0.338008 | 0.102887 | 4.80711e-10 | 4.06709e-10 | 0.049 |
| y3 | 0.0342023 | 0.391405 | 2.72361e-09 | 6.14333e-09 | 0.0271812 | 8.122 |
| y4 | 0.00116244 | 0.155004 | 0.0221579 | 5.60043e-11 | 4.89368e-11 | 1.120 |
| y5 | 3.82391e-11 | 0.41135 | 2.14606e-11 | 2.50395e-11 | 1.47319e-11 | 3.482 |
| y6 | 9.32315e-06 | 1.35509 | 0.0606396 | 1.84373e-06 | 0.230813 | 3.064 |
| y7 | 0.0097128 | 1.41159 | 4.10616e-10 | 3.07655e-10 | 1.83933e-10 | 3.214 |
| y8 | 0.0515579 | 7.13954 | 5.35455e-08 | 3.83144e-07 | 6.88943e-08 | 4.176 |
| y9 | 0.00201582 | 0.273497 | 2.67888e-10 | 2.10806e-10 | 0.0241915 | 2.542 |

Parameters listed in decreasing order of relevance: x2, x1, x8, x11, x10, x3, x6, x5, x4, x1.

Kernel: RBF
```

1. Vertical scroll bar at the bottom of the output window.  
2. Bottom right corner of the output window, which is being held down for dragging.

# Automatic Relevance Determination (ARD)

1. A single line lists the most relevant parameters, in decreasing order, across all responses. Parameters x1, x2, x8 and x11 are the most relevant, and the other parameters can be optionally removed.
  2. During the regression, 3 different kernel functions are used. As a result, there will be 3 sets of ARD values. As shown, the Exponential kernel function has produced a similar list of relevant parameters x1, x2, x8 and x11.
  3. If desired, more relevant parameters can be determined, but it is expected some disagreement may occur as indicated. The parameter selection process is left to your judgement. For example, when you repeat this example, you may find these parameters as the most relevant: x1, x2 x3 and x8.
- For large dimension problems, i.e. problems with 10 or more parameters, the training data to fit the surrogate model may require 10-20 runs per parameter, possibly more. There is a need to reduce the dimensionality of the problem.
  - As an example, suppose computation constraints limit us to 40 runs and the goal is to use 10 runs per parameter, the problem needs to be reduced to 4 parameters. This page demonstrates the parameter selection process.

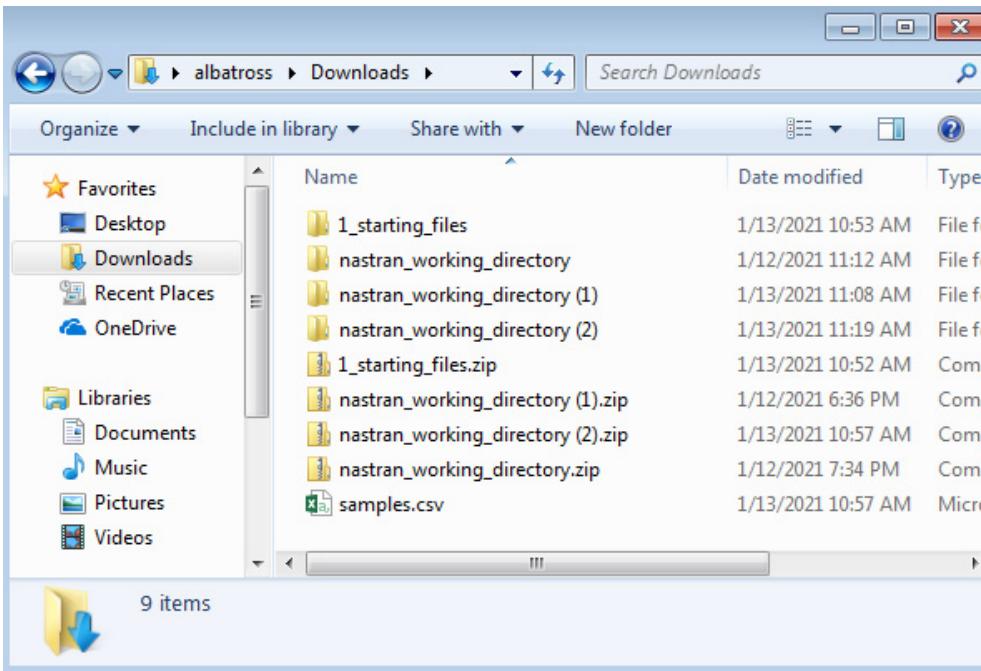
Output						
GP App Update - Saving initial data						
GP App Update - Summary of Automatic Relevance Determination (ARD)						
ARD measures predictive relevance of parameters and is used for parameter selection.						
- High Value: The parameter $x_i$ is relevant						
- Low Value: The parameter $x_i$ is irrelevant and could potentially be selected.						
Kernel: Matern52						
Response	x1	x2	x3	x4	x5	
y1	4.41523	11.181	0.659106	2.17256e-09	3.3067e-09	1.8521
y2	2.6569	3.0316	3.96957	1.37152e-07	1.21214	0.0482
y3	1.43826	5.22752	9.84035e-07	1.20974e-06	0.433083	1.4890
y4	0.0857389	22.2011	2.80218	0.0084688	1.54202e-09	0.0129
y5	0.00394936	73.9887	0.0320619	0.119963	0.248584	4.7087
y6	0.532546	8.6371	0.777735	5.41834e-05	2.99273	0.0472
y7	0.383766	31.5844	3.9199e-09	0.616215	5.33463e-09	0.0254
y8	0.0615319	49.5679	2.03028e-08	1.21104	2.07824e-08	2.2841
y9	0.31014	7.12581	1.19458	4.37308e-08	0.289277	0.0793
Parameters listed in decreasing order of relevance: x2, x8, x1, x11, x3, x5, x9, x4						
Kernel: Exponential						
Response	x1	x2	x3	1	x5	
y1	0.633904	3.97626	8.68101e-10	5.9275e-10	9.24688e-10	6.4551
y2	0.119435	0.338008	0.102887	4.80711e-10	4.06709e-10	0.0493
y3	0.0342023	0.391405	2.72361e-09	6.14333e-09	0.0271812	8.1221
y4	0.00116244	0.155004	0.0221579	5.60043e-11	4.89368e-11	1.1200
y5	3.82391e-11	0.41135	2.14606e-11	2.50395e-11	1.47319e-11	3.4040
y6	9.32315e-06	1.35509	0.0606396	1.84373e-06	0.230813	3.0644
y7	0.0097128	1.41159	4.10616e-10	3.07655e-10	1.83933e-10	3.2140
y8	0.0515579	7.13954	5.35455e-08	3.83144e-07	6.88943e-08	4.1768
y9	0.00201582	0.273497	2.67888e-10	2.10806e-10	0.0241915	2.5221
Parameters listed in decreasing order of relevance: x2, x1, x8, x11, x10, x3, x6, x5						
Kernel: RBF						
Response	x1	x2	x3	2	x5	
y1	0.633904	3.97626	8.68101e-10	5.9275e-10	9.24688e-10	6.4551
y2	0.119435	0.338008	0.102887	4.80711e-10	4.06709e-10	0.0493
y3	0.0342023	0.391405	2.72361e-09	6.14333e-09	0.0271812	8.1221
y4	0.00116244	0.155004	0.0221579	5.60043e-11	4.89368e-11	1.1200
y5	3.82391e-11	0.41135	2.14606e-11	2.50395e-11	1.47319e-11	3.4040
y6	9.32315e-06	1.35509	0.0606396	1.84373e-06	0.230813	3.0644
y7	0.0097128	1.41159	4.10616e-10	3.07655e-10	1.83933e-10	3.2140
y8	0.0515579	7.13954	5.35455e-08	3.83144e-07	6.88943e-08	4.1768
y9	0.00201582	0.273497	2.67888e-10	2.10806e-10	0.0241915	2.5221

# Samples

It has been determined that 4 parameters  $x_1$ ,  $x_2$ ,  $x_8$  and  $x_{11}$  should be kept, and the other 7 parameters should be removed.

The next batch, Batch 2, has been configured previously for 4 parameters and 40 runs.

The following pages go over the regression process, making predictions and comparing the predictions to MSC Nastran outputs.



Batch	File Name	Number of Runs	Number of Parameters	Purpose
1	nastran_working_directory.zip	55	11	This configuration includes 11 parameters. The goal is to use the data from the 55 run set to screen parameters and reduce the problem to 4 parameters. Automatic relevance determination (ARD) is used to identify the 4 most relevant parameters.
2	nastran_working_directory (1).zip	40	4	This configuration includes 4 parameters. The goal of this 40 run set is to produce training data to fit the surrogate model and make predictions.
3	nastran_working_directory (2).zip	8	4	This is an 8 run configuration. This set is used to compare the predicted responses with MSC Nastran responses.

# Performing Predictions

---

# Prediction Analysis Web App

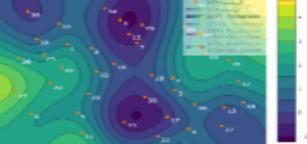
1. Return to the Machine Learning web app
2. Click Results
3. Click Prediction Analysis
4. The Prediction Analysis web app is now open
5. Ensure it says Connected

SOL 200 Web App - Machine Learning

Parameters Samples Responses Download **Results** Connection Settings Home

1 2 < >

### Select a Results App



Prediction Analysis 3

### SOL 200 Web App - Prediction Analysis 4 Home

#### Gaussian Process (GP) App Connection Status

Connected 5

Session ID: 8207

**Output**

```
GP App Update - Starting the Gaussian Process (GP) app on the server
- Session ID: 8207
- Address: http://localhost:8080/optimization
Desktop App Update - Connecting to the SOL 200 Web App...
GP App Update - Connection successful between the Node JS server and GP app
```

**Warnings and Errors**

Warnings can be ignored

# Training Data

1. Navigate to the Training and Testing Data section
2. Delete any previous table data by clicking the four (4) buttons named Delete all rows

## Training and Testing Data 1

### x\_training

CSV Export      CSV Import

Export    Select files Select a CSV File Import

CSV

imported

### y\_training

CSV Export      CSV Import

Export    Select files Select a CSV File Import

2

sample
y1

sample	x1	x2
x1	x2	

sample
y1

Delete all rows

Delete all rows

Delete all rows

Delete all rows

### x\_testing

CSV Export      CSV Import

Export    Select files Select a CSV File Import

### y\_testing

CSV Export      CSV Import

Export    Select files Select a CSV File Import

# Training Data

1. Navigate to the section titled x\_training
2. Click Select files
3. Navigate to the folder named nastran\_working\_directory (1) which contains data for 40 runs
4. Select the file app.config
5. Click Open
6. Click Import
7. The table is now loaded with the x inputs for all 40 runs

## Training and Testing Data

x\_training 1

CSV Export CSV Import 6

2 7 7 Delete all rows

CSV imported

sample	x1	x2	x8	x11
1	1.	4.333333	3.051282	4.717949
2	1.128205	2.538462	3.435897	3.051282
3	1.25641	4.076923	5.102564	1.897436
4	1.384615	5.102564	2.794872	2.282051
5	1.512821	2.025641	3.692308	5.487179
6	1.641026	2.923077	5.615385	4.205128
7	1.769231	2.153846	1.384615	4.333333
8	1.897436	1.512821	5.230769	1.769231
9	2.025641	3.435897	1.128205	2.025641
10	2.153846	5.358974	4.974359	3.692308

Open 3 Search nastran\_working\_direct...

Organize New folder 4

Name	Date modified	Type	Size
app	1/12/2021 6:40 PM	File folder	
temp_files_900	1/12/2021 7:08 PM	File folder	
app.config	1/12/2021 6:40 PM	CONFIG File	
app_monitored_responses.csv	1/12/2021 7:05 PM	Microsoft Excel C...	

File name: app.config 5 Open Cancel

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

# Training Data

1. Navigate to the section titled y\_training
2. Click Select files
3. Navigate to the folder named nastran\_working\_directory (1) which contains data for 40 runs
4. Select the file app\_monitored\_responses.csv
5. Click Open
6. Click Import
7. The table is now loaded with the y outputs (monitored responses) for all 40 runs

The screenshot shows a software interface for importing CSV data. At the top, there are tabs for 'CSV Export' and 'CSV Import'. The 'CSV Import' tab is selected, indicated by a blue background and white text. A red circle labeled '1' is around the word 'y\_training'. Below the tabs, there are buttons for 'Export' (orange), 'Select files' (blue), and 'Import' (green). The 'Select files' button has a red circle labeled '2' over it. To its right is a file path 'app\_monitored\_responses.csv'. A green 'Import' button is highlighted with a red circle labeled '6'. To the right of the import area, a status message 'imported' is shown next to a green circular icon. A red circle labeled '7' is around the first column of a data table.

sample	y1	y2	y3	y4	y5
0001	1623.91901167...	8805.8452178...	22821.193146...	5541.2567430...	10385.666479...
0002	3359.8379505...	16480.136627...	27563.192091...	8512.8851463...	13898.654026...
0003	1651.6868959...	10161.883720...	23104.282217...	5376.7000454...	6222.3223568...
0004	1232.0005870...	8255.9317966...	24803.977455...	5250.8626775...	8347.9430198...
0005	4946.2021206...	19512.637712...	35145.876227...	9580.9854331...	19529.638862...
0006	2380.4355554...	14895.288913...	26506.159979...	5969.11718835...	8810.7736512...
0007	5150.3717122...	12922.949712...	34311.3147552...	9088.31169865...	23296.951237...
0008	2873.0197230...	20380.366829...	33906.789193...	11502.2642270...	38950.712096...
0009	2555.8025261...	9876.4214755...	26702.360968...	5760.68110761...	21661.738549...
0010	1032.2065319...	9012.4160087...	22089.927747...	4261.0030036...	5458.8500027...

Below the table, a file selection dialog is open. It shows a list of files in the 'nastran\_working\_directory (1)' folder. The file 'app\_monitored\_responses.csv' is selected and highlighted with a red circle labeled '4'. The 'Open' button at the bottom of the dialog is highlighted with a red circle labeled '5'. The 'File name:' dropdown also has a red circle labeled '3' over it.

# Perform Regression

1. Click Perform Regression and the surrogate model will be fitted
  2. The regression is complete when the following status message is visible:
    - Process complete

SOL 200 Web App - Prediction Analysis

Home

## Regression

Data	Link to Table	Status	Status Description
x_training	<a href="#">Link</a>		Ready
y_training	<a href="#">Link</a>		Ready
x_testing (Optional)	<a href="#">Link</a>		Ready
y_testing (Optional)	<a href="#">Link</a>		Ready

## Perform Regression

1

 Process complete

1

[Click here to view the Regression Results section](#)

Output

y3	6.34332	22.8637	0.285728	12.5891
y4	0.329643	7.79946	7.49135	3.58932
y5	0.00412772	298.861	0.9722	0.00234721
y6	0.65093	20.7999	22.9172	3.70404
y7	0.274844	35.1077	1.39711	3.72269
y8	0.00739204	105.864	6.33735	2.76692
y9	0.22452	47.8042	0.824128	4.19834

Parameters listed in decreasing order of relevance: x2, x8, x11, x1

GP App Update - Sending initial data to the web browser

GP App Update - Sending complete

## Warnings and Errors

Warnings can be ignored

# Perform Prediction

1. Navigate to the section titled x\_prediction
2. Click Select files
3. Navigate to the location of the file named samples.csv
4. Select the file samples.csv
5. Click Open
6. Click Import
7. The table is now loaded with the x inputs for 8 runs

## Prediction

x\_prediction 1

CSV Export CSV Import

Export

Select files

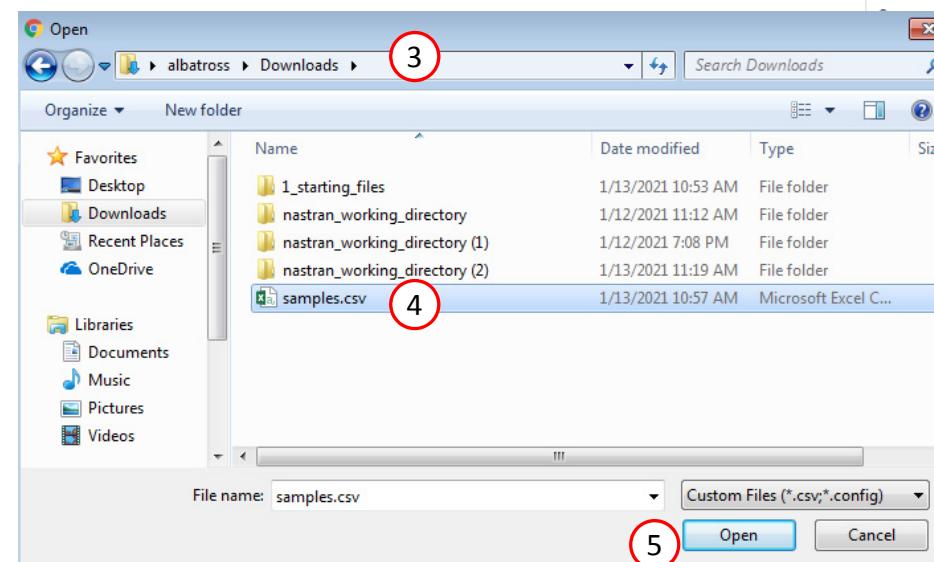
samples.csv

Import

CSV imported

X Delete all rows

sample	x1	x2	x8	x11
1	1.	4.571429	3.142857	1.714286
2	1.714286	3.857143	4.571429	6.
3	2.428571	1.	1.714286	3.857143
4	3.142857	1.714286	6.	2.428571
5	3.857143	5.285714	1.	4.571429
6	4.571429	6.	5.285714	3.142857
7	5.285714	3.142857	2.428571	1.
8	6.	2.428571	3.857143	5.285714



# Perform Prediction

1. Navigate to the section titled Perform Prediction
  2. Click Perform Prediction
  3. The prediction is complete when the following status message is visible:
    - Process complete
- Note that the predictions are performed seemingly instantly

Perform Prediction 1

Perform Prediction 2

Process complete 3

[Click here](#) to view the Prediction Results section

**Output**

```
GP App Update - The web browser has requested a prediction
GP App Update - Determining prediction
GP App Update - Normalizing Design - Scaling and shifting the input space to [0,1]
GP App Update - Sending prediction data to the web browser
GP App Update - Sending complete
```

**Warnings and Errors**

Warnings can be ignored

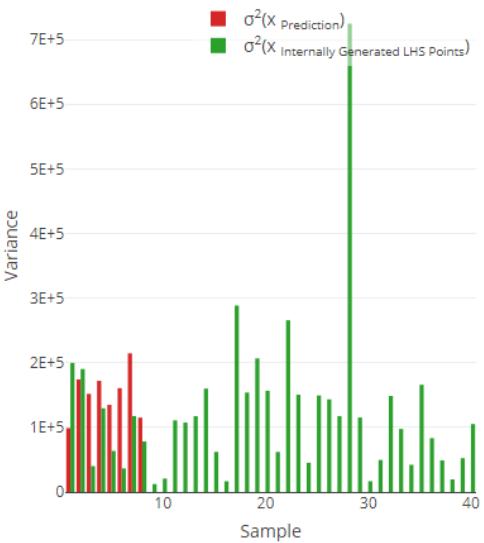
# Variance

1. Navigate to the section titled Variance

Variance 1

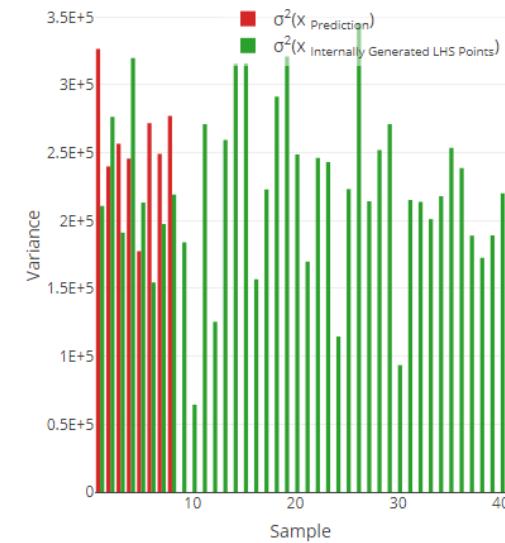
Matern52

NRMSE:



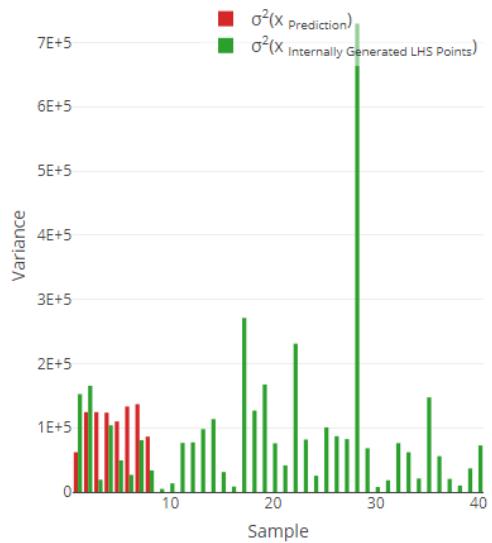
Exponential

NRMSE:



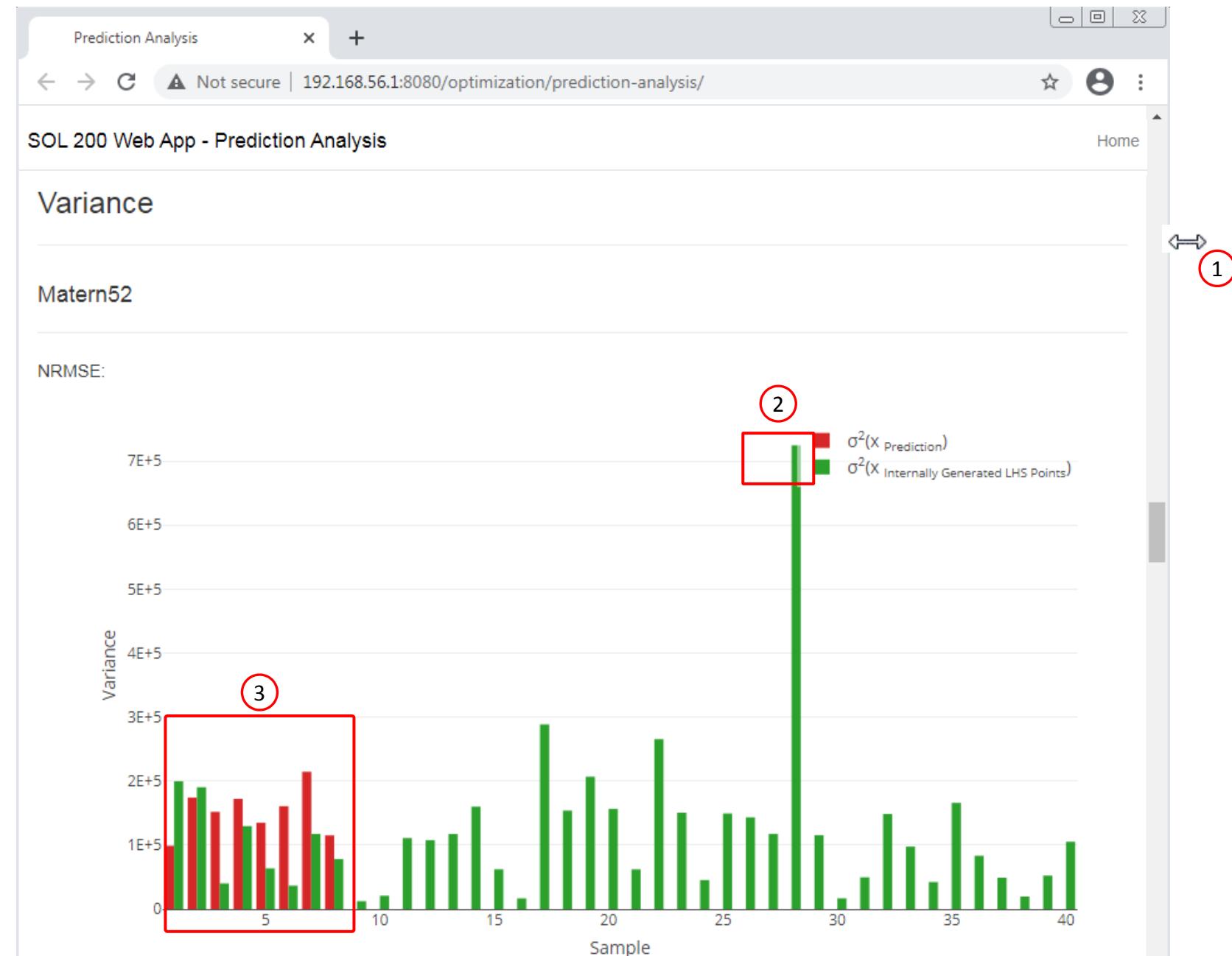
RBF

NRMSE:



# Variance

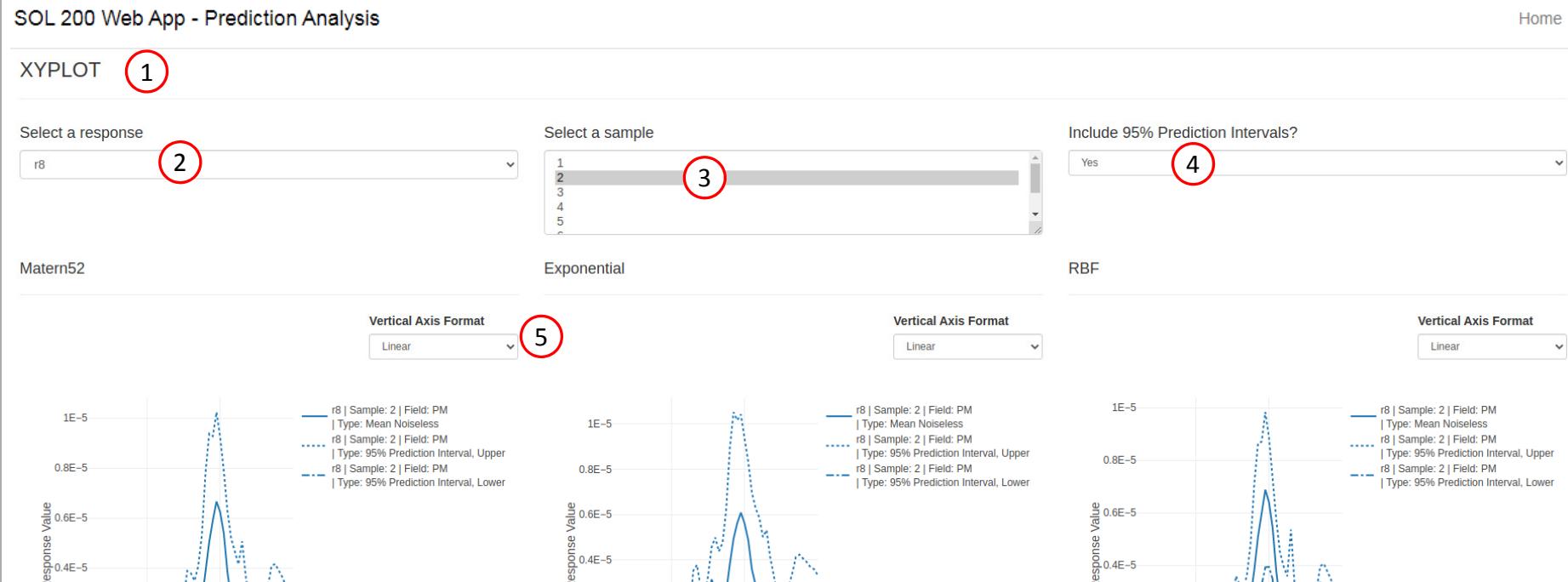
1. Resize the window to fit half the screen, this causes the plot to be increased in size
  2. A high bar indicates a high prediction uncertainty, or a high variance, and is indication that we do not have enough information to conclude the prediction is credible at that prediction point.
  3. Predictions have been made at 8 samples and are indicated by 8 red bars
    - When making predictions, the prediction uncertainty should ideally be low, like in this example
- In this tutorial, variance ( $\sigma^2$ ) is used to gauge the prediction uncertainty. Sometimes, you will see this prediction uncertainty expressed as the standard deviation ( $\sigma$ ).



# Pressure vs. Frequency

For frequency responses and after a prediction is performed, Response vs. Frequency plots are automatically generated.

1. Navigate to the section titled XY PLOT
2. Set Select a response to r8
3. Set Select a sample to 2
4. Set Include 95% Prediction Intervals to Yes
5. Set the Vertical Axis Format to Linear
6. The predicted plots are now displayed.  
Since 3 kernel functions were used during regression, there are 3 predicted plots.



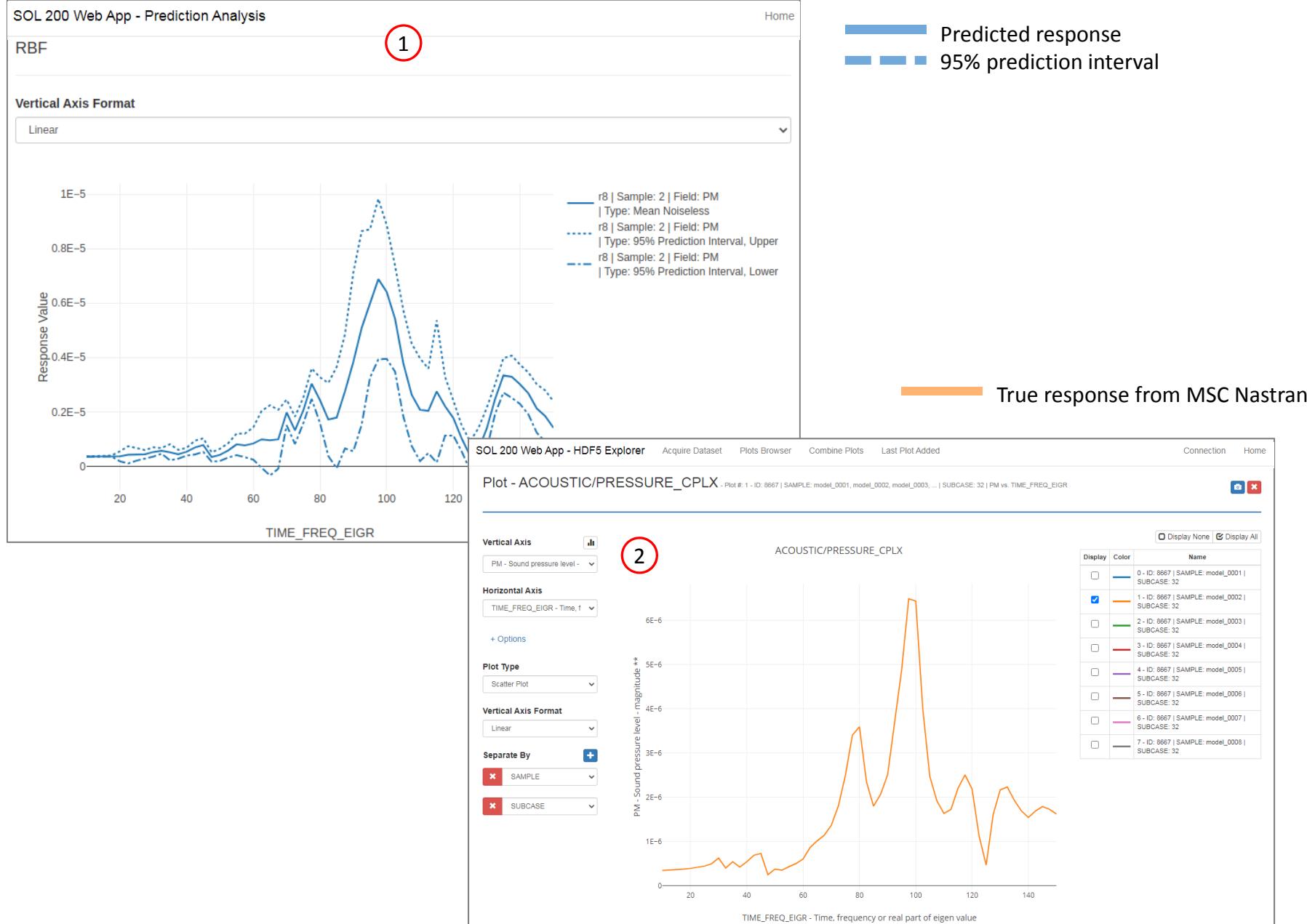
# Comparison of Prediction with MSC Nastran

Recall that batch 2 was used to produce the training data and fit the surrogate model. Batch 3 contained 8 sample points.

1. The surrogate model was used to predict the output responses at the 8 sample points. The predicted response vs. frequency plot is displayed.
2. MSC Nastran was used to evaluate all 8 sample points and the HDF5 Explorer was used to display the true response vs. frequency plots.

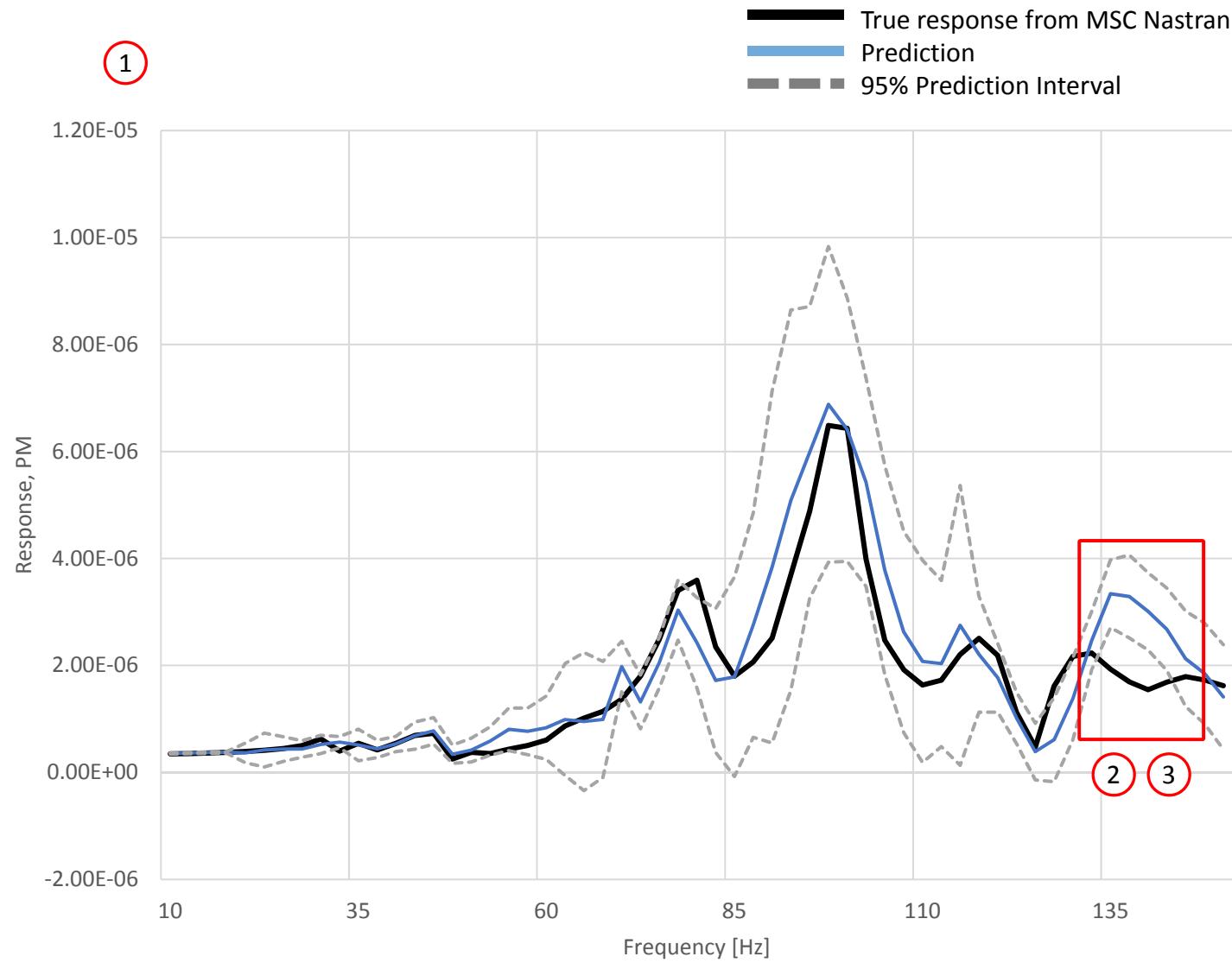
A comparison can be made between the prediction and MSC Nastran output.

- In this tutorial, variance ( $\sigma^2$ ) is used to gauge the prediction uncertainty. Sometimes, you will see this prediction uncertainty expressed as the standard deviation ( $\sigma$ ).



# Comparison of Prediction with MSC Nastran

1. Optional - Excel was used to overlap the MSC Nastran output over the predicted response
  2. Note that the 95% prediction interval does not guarantee the true value is within this interval.
  3. With a limited number of samples, the surrogate model poorly predicts the true response between 80-100Hz
- In some cases, using more samples improves the surrogate model. You are encouraged to repeat this exercise but with additional samples. For example, this prediction used 40 samples. Perhaps repeat this prediction with 50, 60 or 70 samples.



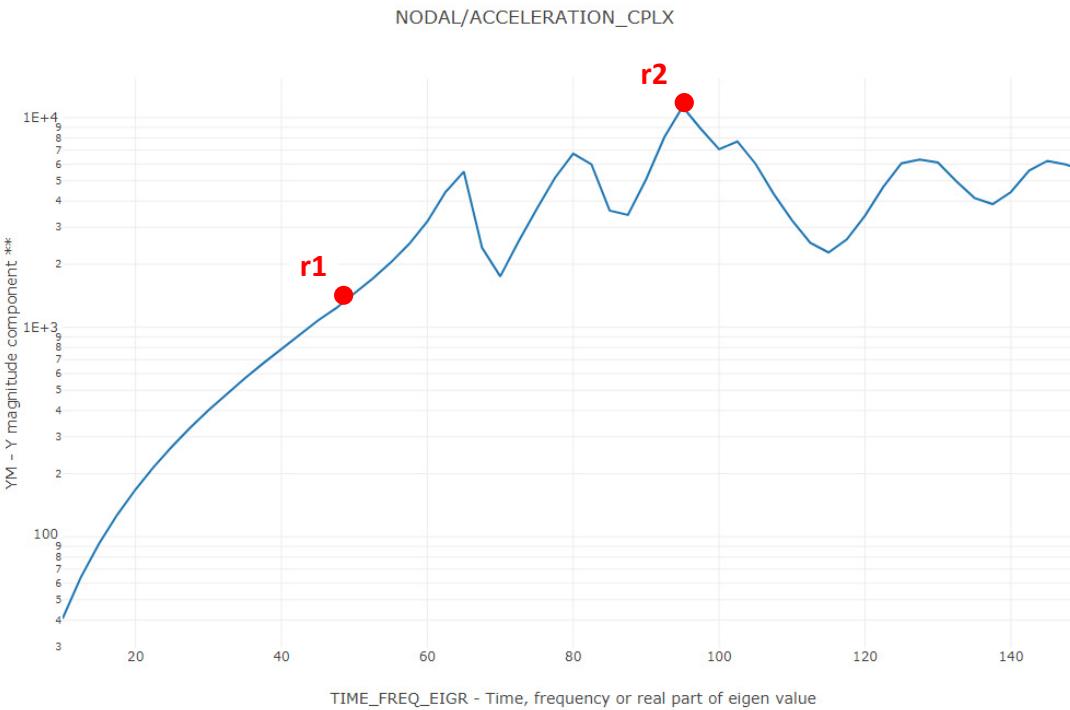
# Creating Response vs. Frequency Plots with the HDF5 Explorer

---

# Responses

Recall the following

- r1 is the response at 50Hz
- r2 is the maximum responses across all frequencies



ID: 1001 | SUBCASE: 12 | YM vs. TIME\_FREQ\_EIGR

# Start Desktop App

1. Open this folder:  
nastran\_working\_directory (2)
2. Inside of the new folder, double click on  
Start Desktop App
3. Click Open, Run or Allow Access on any  
subsequent windows

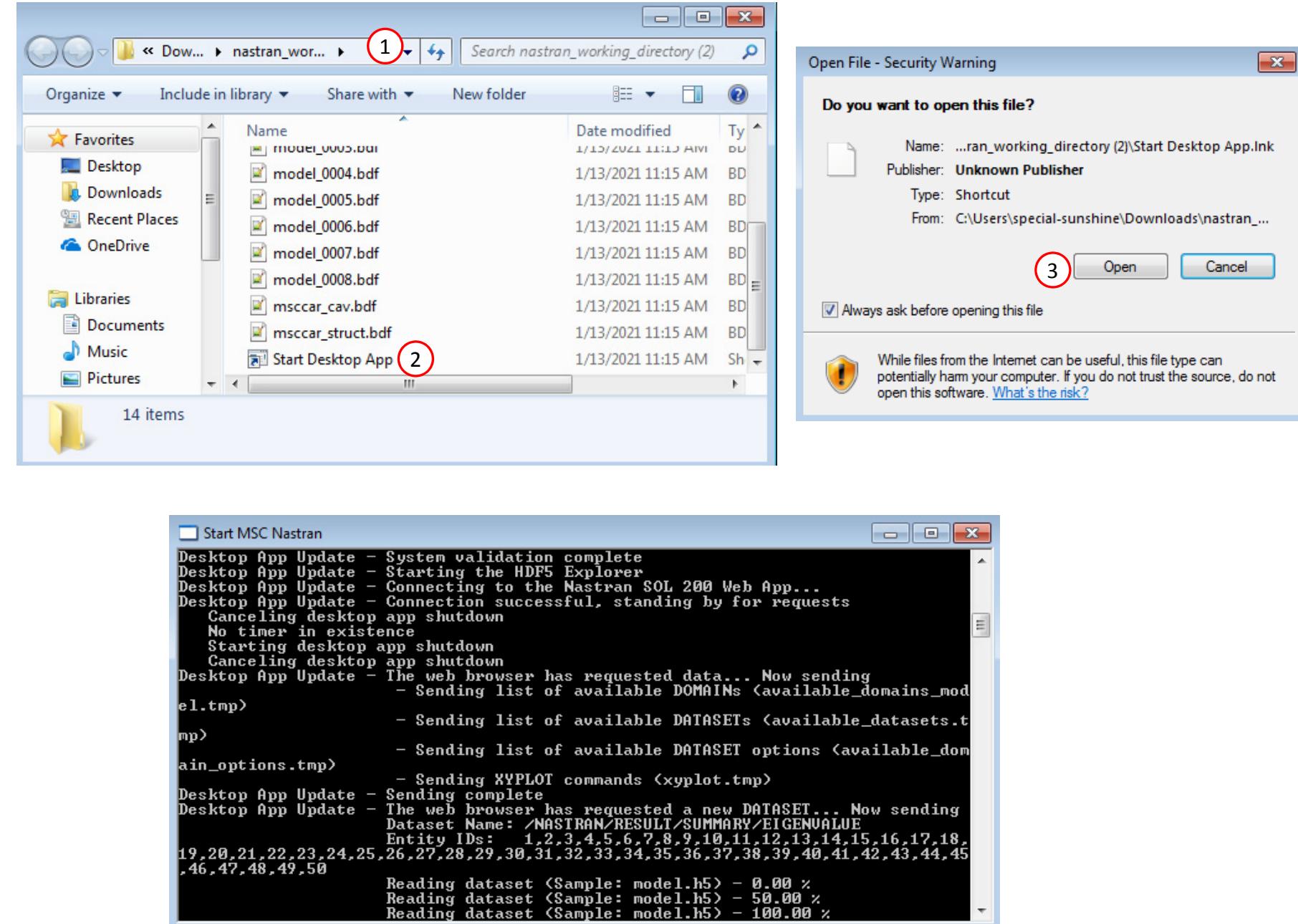
## Using Linux?

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.

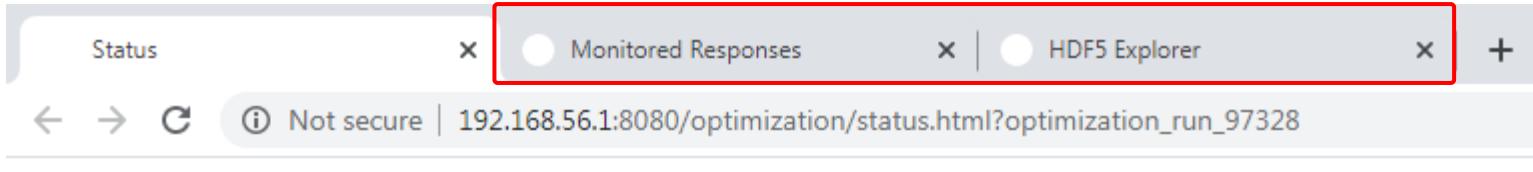
```
sudo chmod -R u+x ./nastran_working_directory
```



# Results

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.



1

SOL 200 Web App - Status

2

Name of Web App	Purpose	Description
Monitored Responses	<ul style="list-style-type: none"><li>The response value from each sample can be compared.</li></ul>	<ul style="list-style-type: none"><li>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.</li></ul>
HDF5 Explorer	<ul style="list-style-type: none"><li>This web app is used to probe each H5 file and generate XY plots.</li></ul>	

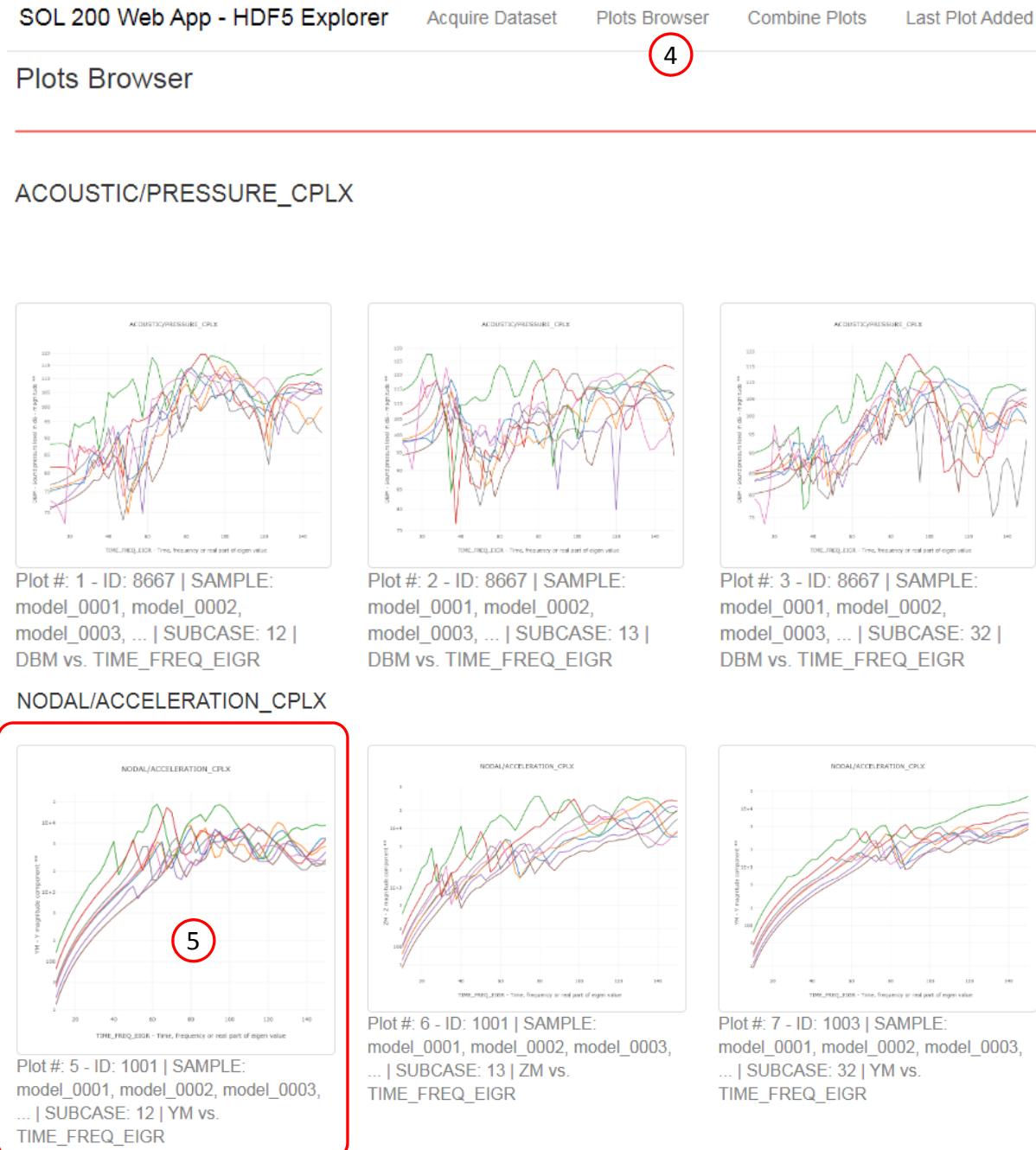
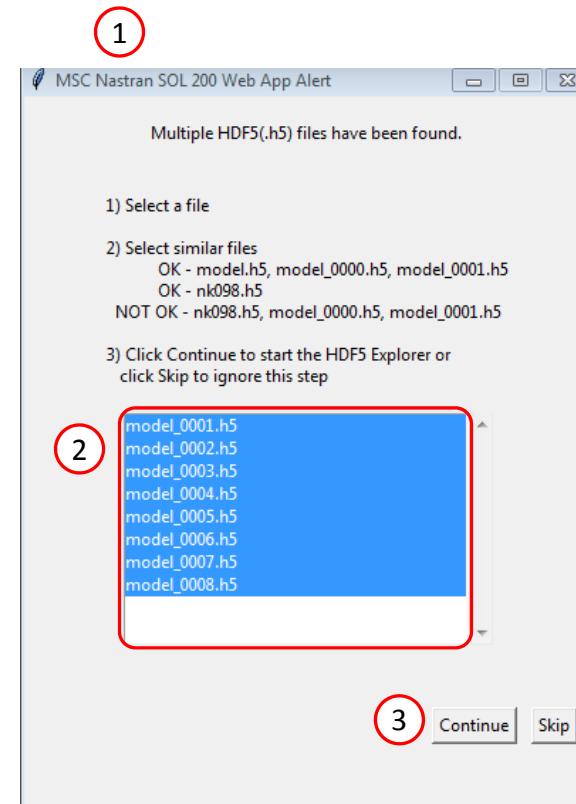
# Review Results

The following steps describe how to start the HDF5 Explorer and display the plots for responses r1 and r2.

1. A new window is opened
  2. Select all H5 files in the list
  3. Click Continue
  4. Click Plots Browser
  5. Click the indicated plot:
- Plot #: 5 - ID: 1001 | SAMPLE: model\_0001, model\_0002, model\_0003, ... | SUBCASE: 12 | YM vs. TIME\_FREQ\_EIGR

The HDF5 Explorer is broken into sections.

- Acquire Dataset – Specific datasets from the H5 file can be extracted in this section.
- Plots Browser – Use this section to navigate every plot created.
- Combine Plots – This section allows you to combine multiple plots. For example, you can create Load vs. Displacement plots in this section.
- Last Plot Added – This display the last plot that was created.



# Review Results

This plot will be referenced later

The plots in the HDF5 explorer have additional functionalities that are hidden by default. Click on any of the following to show the extra functions.

- A. + Options
- B. + View Filters and Plotted Values

Users are encouraged to experiment with the additional functions.

## Plot - NODAL/ACCELERATION\_CPLX - Plot #: 5 - ID: 1001 | SAMPLE: model\_0001, model\_0002, model\_0003, ... | SUBCASE: 12 | YM vs. TIME\_FREQ\_EIGR



### Vertical Axis



YM - Y magnitude compon

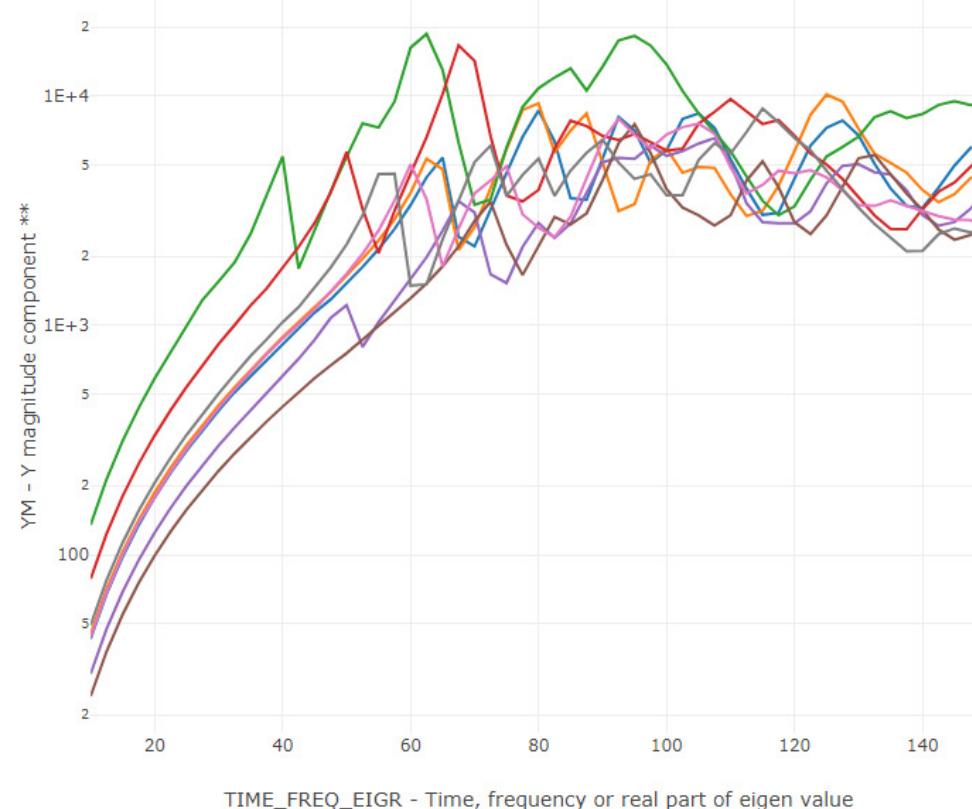
### Horizontal Axis

TIME\_FREQ\_EIGR - Time

+ Options

A

## NODAL/ACCELERATION\_CPLX



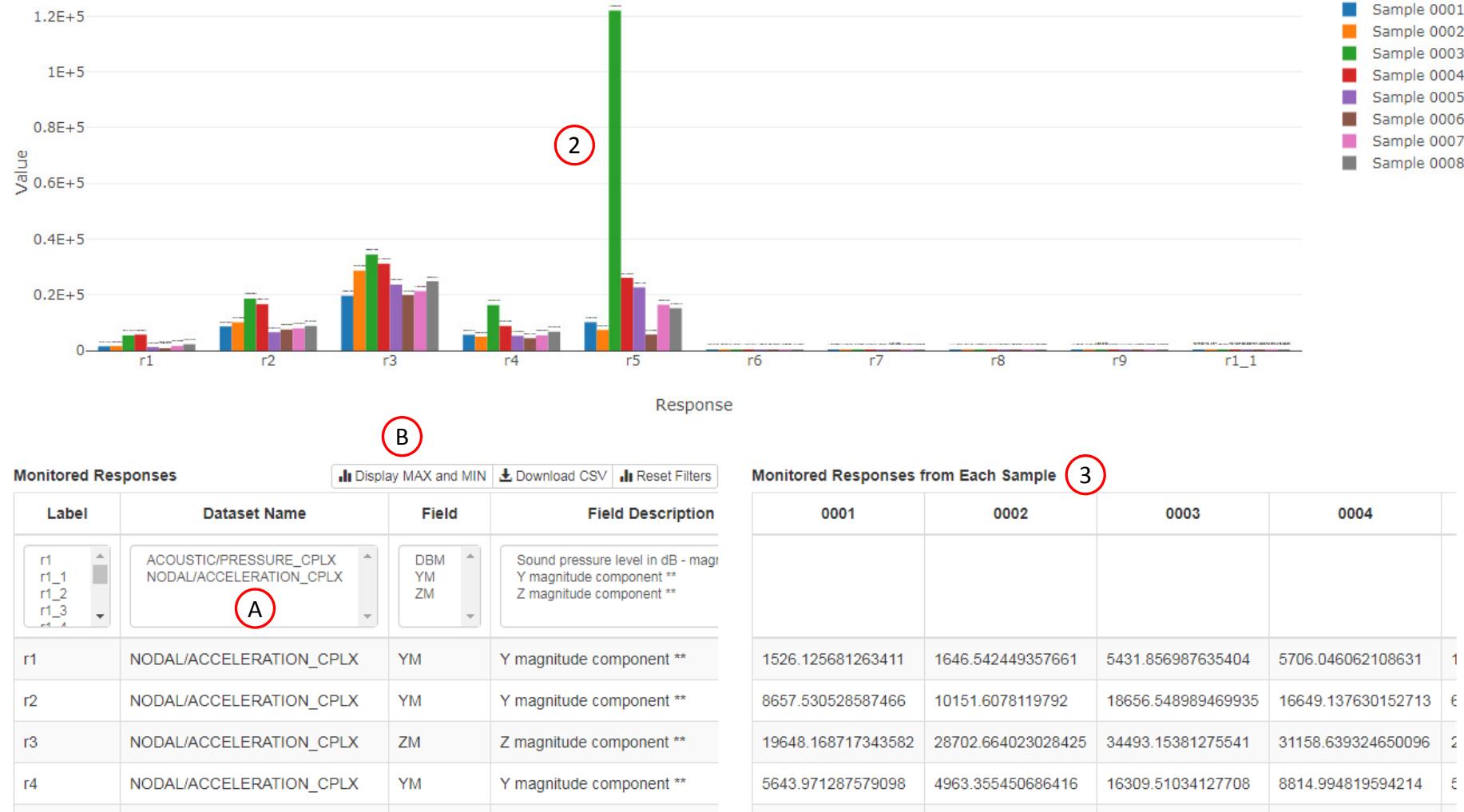
Display None  Display All

Display	Color	Name
<input checked="" type="checkbox"/>	Blue	0 - ID: 1001   SAMPLE: model_0001   SUBCASE: 12
<input checked="" type="checkbox"/>	Orange	1 - ID: 1001   SAMPLE: model_0002   SUBCASE: 12
<input checked="" type="checkbox"/>	Green	2 - ID: 1001   SAMPLE: model_0003   SUBCASE: 12
<input checked="" type="checkbox"/>	Red	3 - ID: 1001   SAMPLE: model_0004   SUBCASE: 12
<input checked="" type="checkbox"/>	Purple	4 - ID: 1001   SAMPLE: model_0005   SUBCASE: 12
<input checked="" type="checkbox"/>	Brown	5 - ID: 1001   SAMPLE: model_0006   SUBCASE: 12
<input checked="" type="checkbox"/>	Magenta	6 - ID: 1001   SAMPLE: model_0007   SUBCASE: 12
<input checked="" type="checkbox"/>	Grey	7 - ID: 1001   SAMPLE: model_0008   SUBCASE: 12

# Review Results

1. The Monitored Responses web app is opened
2. The value of each response and for each sample is displayed in a bar chart
3. A table lists the values for each response and sample.

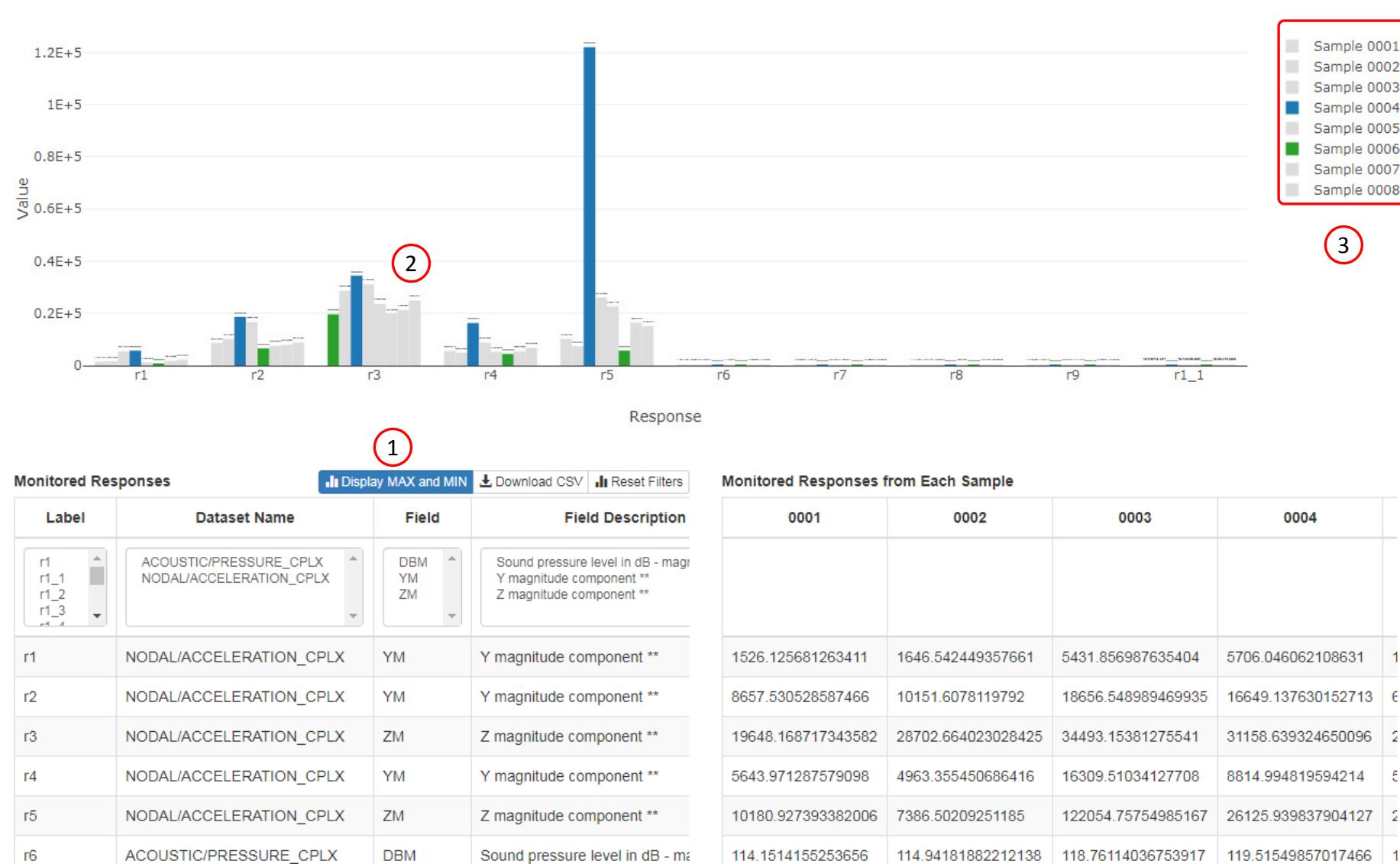
- A. The table titled Monitored Response can be interacted with. Each column in the table contains filters. Once a filter is modified, the Bar Chart will instantly update.
- B. Additional functions include the ability to highlight the MAX and MIN bars, download a CSV file and reset the filters.



# Review Results

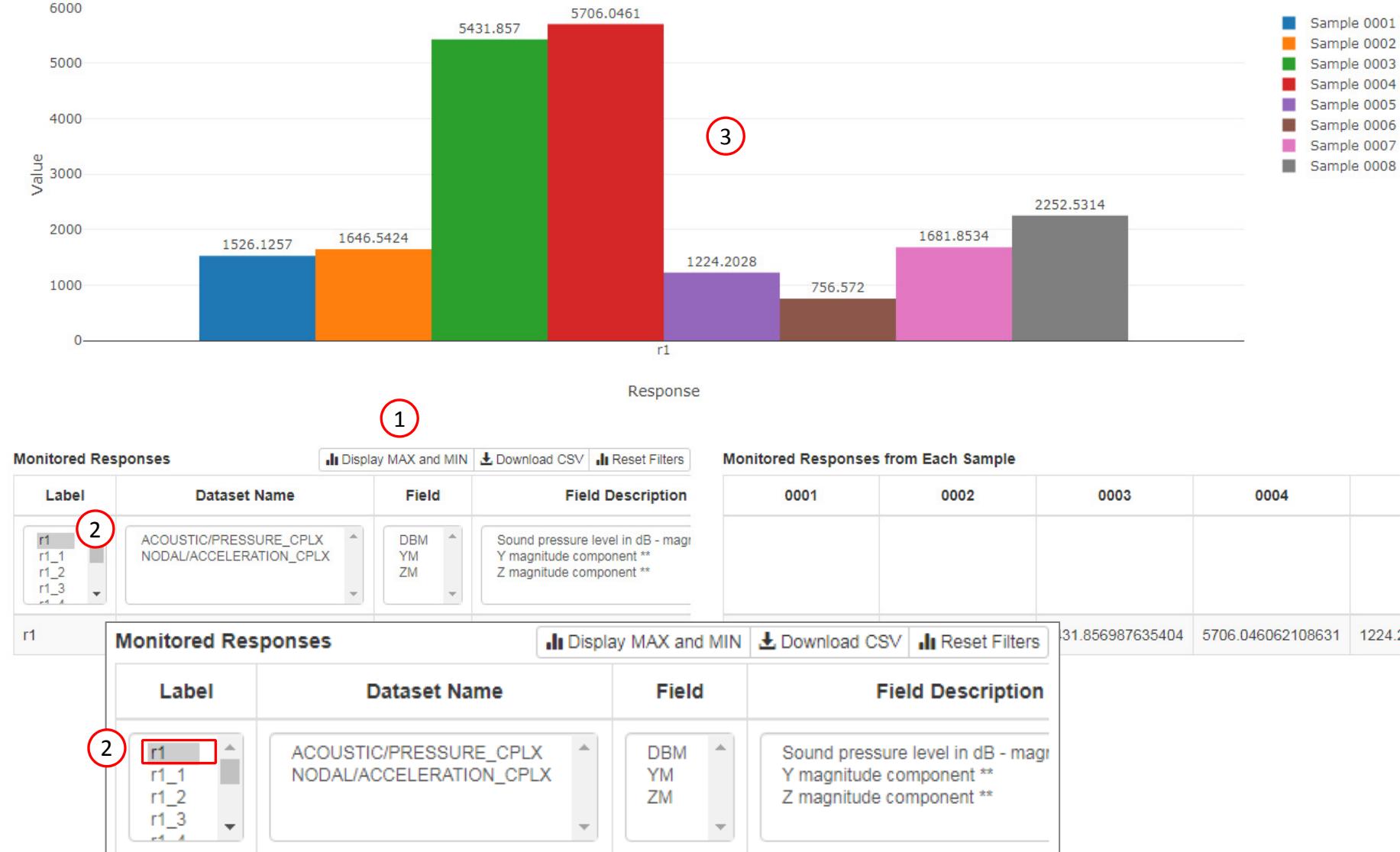
1. Click Display MAX and MIN
2. The bars are now colored blue, green and gray
3. The legend is displayed on the top right corner

- When Display MAX and MIN is clicked, for each response the maximum bar is colored blue and the minimum is colored green.
- The coloring in the legend on the top right corner is only accurate for the first response displayed. In the figure shown, for response r1, sample 4 produces the maximum response and sample 6 produces the minimum response.



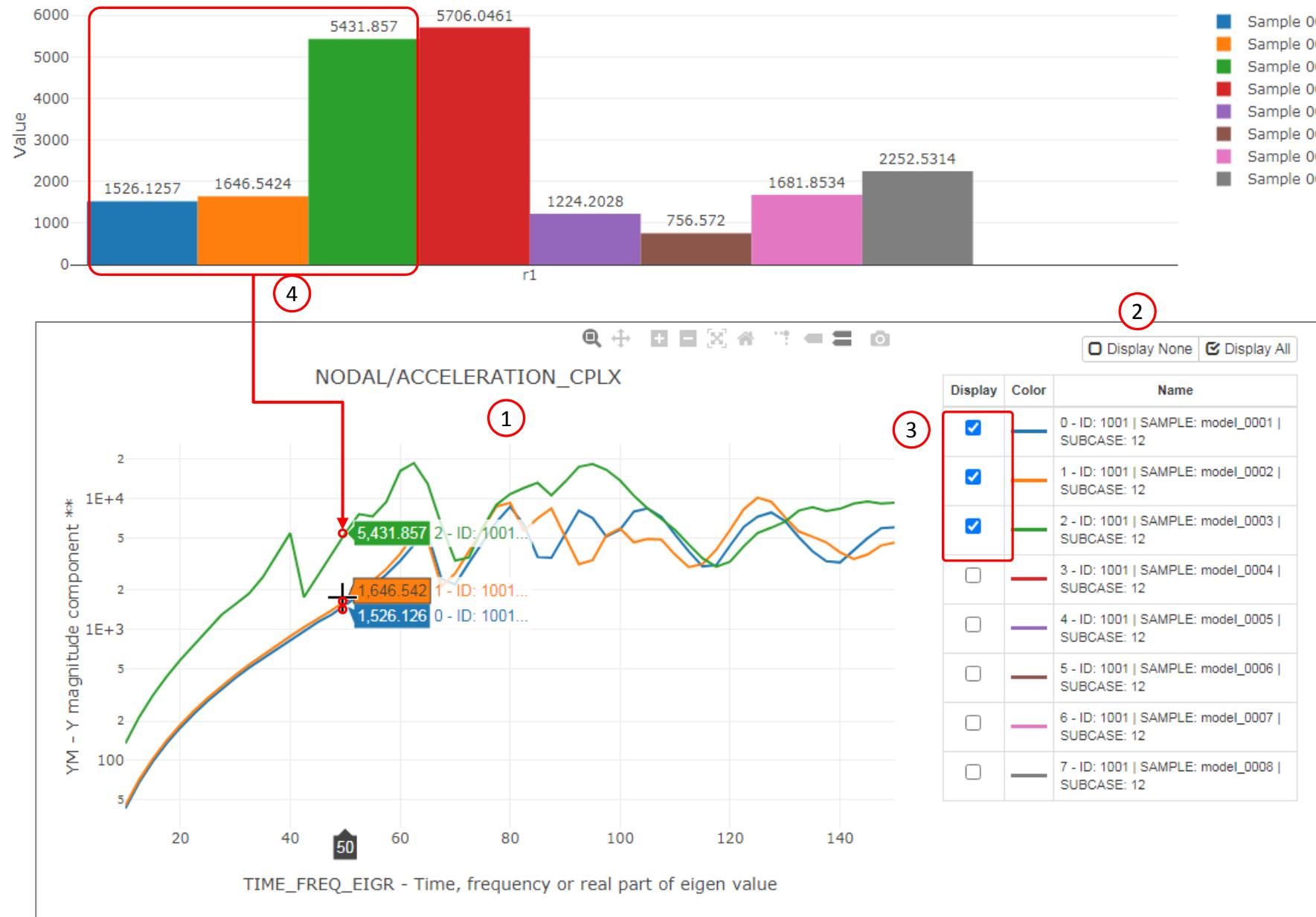
# Review Results

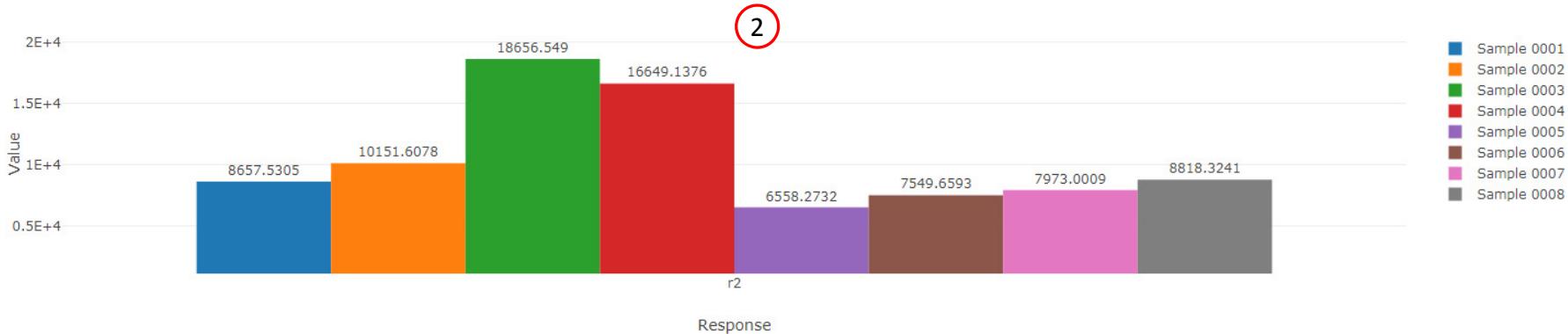
1. Click Display MAX and MIN
2. In the filters, select the following:
  - Label: r1
3. Only the responses for response r7 are now shown



# Review Results

1. Refer to the plot that was previously shown
  2. Click Display None
  3. Mark the checkboxes for the first 3 rows (Samples 0, 1 and 2)
  4. The response values that were extracted and displayed in the bar chart match the values at 50Hz in the Acceleration vs. Frequency plot
- Refer to the Appendix for an explanation on the use of the following:
- Monitor the maximum or minimum response, whichever has the greatest absolute value: Yes, No or blank





# Review Results

1. In the filters, select only response r2
2. Only the responses for response r2 are now shown

**Monitored Responses**

Label	Dataset Name	Field	Field Description
r1_56 r1_57 <b>r2</b> <span style="border: 1px solid red; padding: 2px;">1</span> r3 r2_1	ACOUSTIC/PRESSURE_CPLX NODAL/ACCELERATION_CPLX	DBM YM ZM	Sound pressure level in dB - magnitude ** Y magnitude component ** Z magnitude component **
r2	NODAL/ACCELERATION_CPLX	YM	Y magnitude component **

**Monitored Responses from Each Sample**

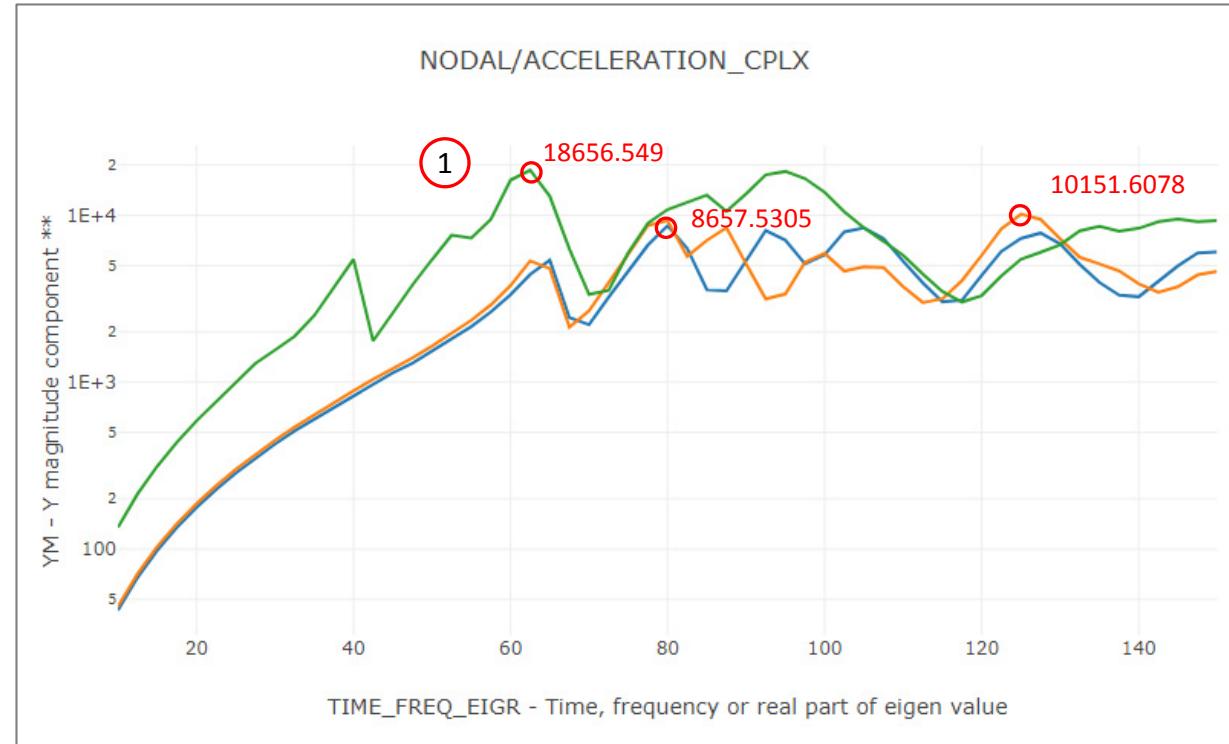
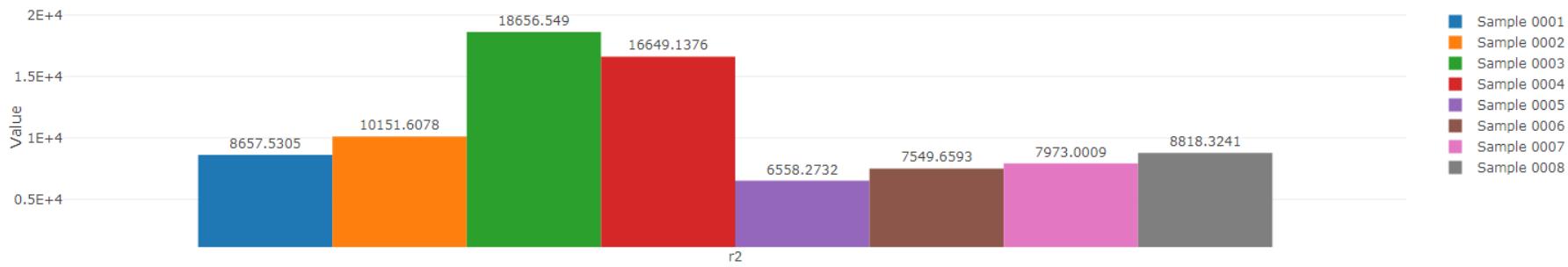
0001	0002	0003	0004	0005
8657.530528587466	10151.6078119792	18656.548989469935	16649.137630152713	6558.273211742

<b>Monitored Responses</b>	
<b>Label</b>	<b>Dataset Name</b>
r1_56 r1_57 <b>r2</b> <span style="border: 1px solid red; padding: 2px;">1</span> r3 r2_1	ACOUSTIC/PRESSURE_CPLX NODAL/ACCELERATION_CPLX
r2	NODAL/ACCELERATION_CPLX

# Review Results

1. The response values that were extracted and displayed in the bar chart match the peak values in the Acceleration vs. Frequency plot

- Refer to the Appendix for an explanation on the use of the following:
  - Monitor the maximum or minimum response, whichever has the greatest absolute value: Yes, No or blank



End of Tutorial

# Appendix

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# Appendix Contents

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- Response Configuration
  - Monitor the maximum or minimum response, whichever has the greatest absolute value: Yes, No or blank
- How to import and edit previous files
- What is Gaussian Process Regression?

# Response Configuration

During this tutorial, this option was used:

- Monitor the maximum or minimum response, whichever has the greatest absolute value : Yes

Suppose response r99 is configured for 10 seconds and corresponds to point A on the plot. When Yes is used for the option, the response furthest from the horizontal axis is monitored. In this example, points B and C are furthest from the horizontal axis. Since point B is furthest from the horizontal axis, a value of -15000.0 is monitored.

View Responses to Monitor

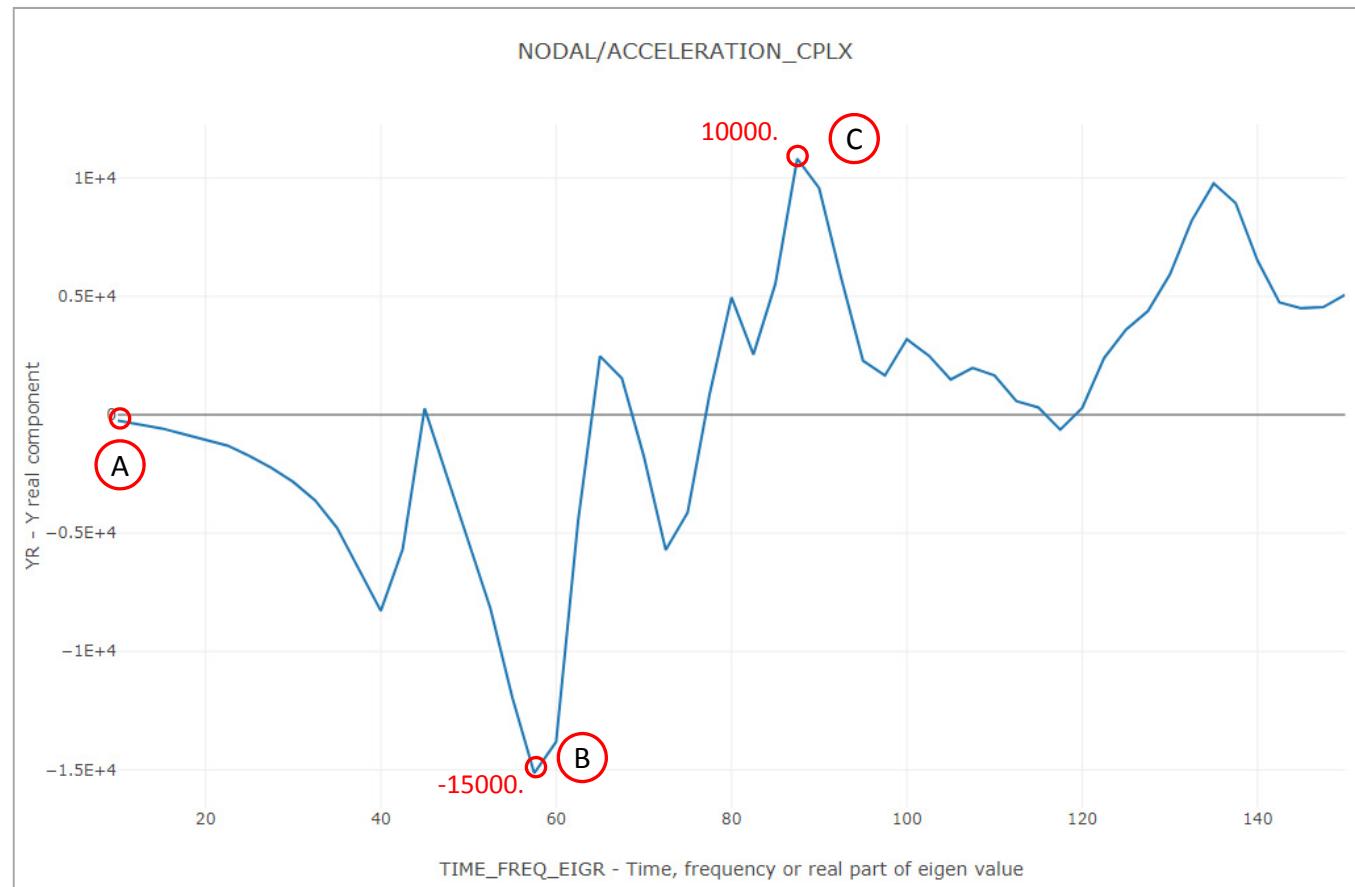
Monitored Responses

Delete	Label	Status	Objective	Lower Bound	Upper Bound	Monitor the response of the FINAL design cycle (SOL 200 only)	Monitor the maximum or minimum response, whichever has the greatest absolute value
<input type="button" value="x"/>	r99	<input checked="" type="radio"/>	<input type="button" value="▼"/>	<input type="button" value="Lower"/>	<input type="button" value="Upper"/>	<input type="button" value="▼"/>	Yes - Monitor the maximum response

Monitor the maximum or minimum response, whichever has the greatest absolute value

Yes - Monitor the maximum response

Current Value	ID	SUBCASE	STEP	ANALYSIS
1443.476297324485	1001	12	0	5



# How to import and edit previous files

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# How to import and edit previous files

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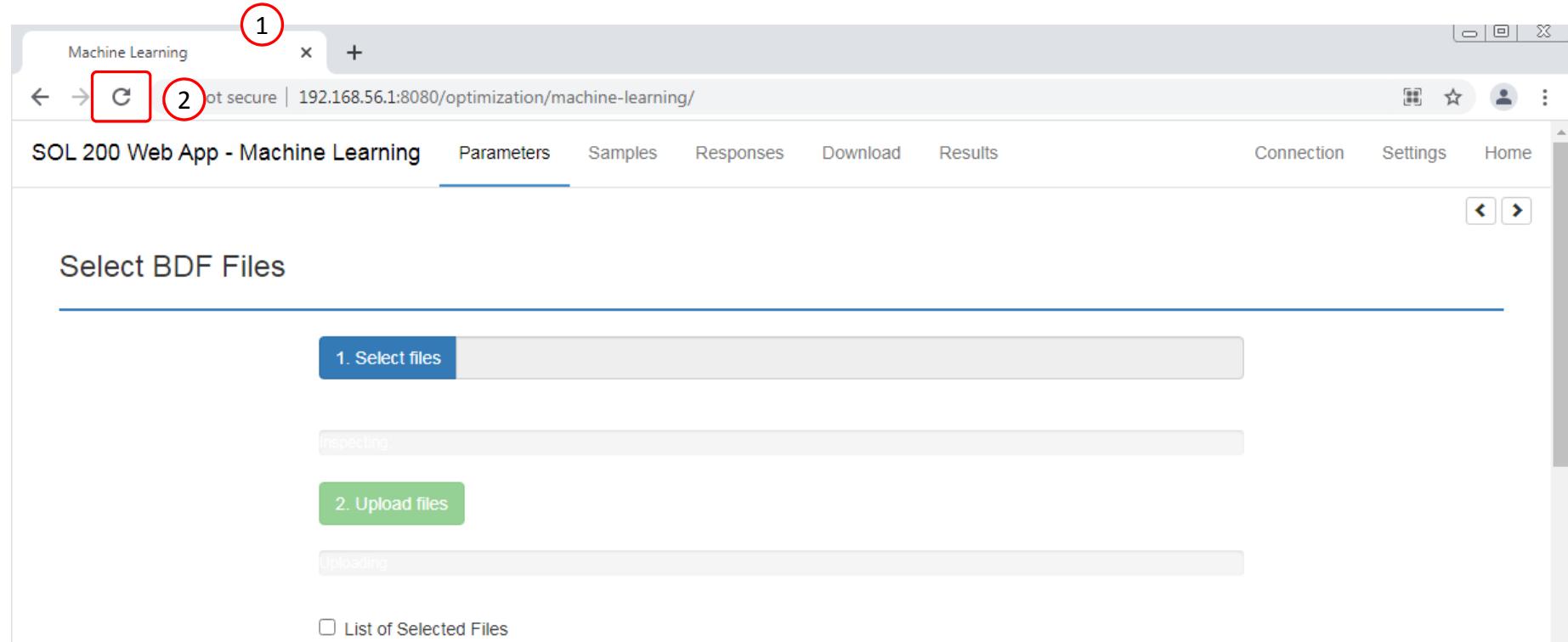
The parameters, samples and responses are contained in the following files

- app.config
- BDF files

These files may be imported back to the Machine Learning web app, and any parameters, samples and responses can be reconfigured

# Import

1. Return to the window or tab that has the Machine Learning web app opened
  2. Refresh the web page to start a new session
- Refreshing the page is only required when the *Select files* button is disabled.

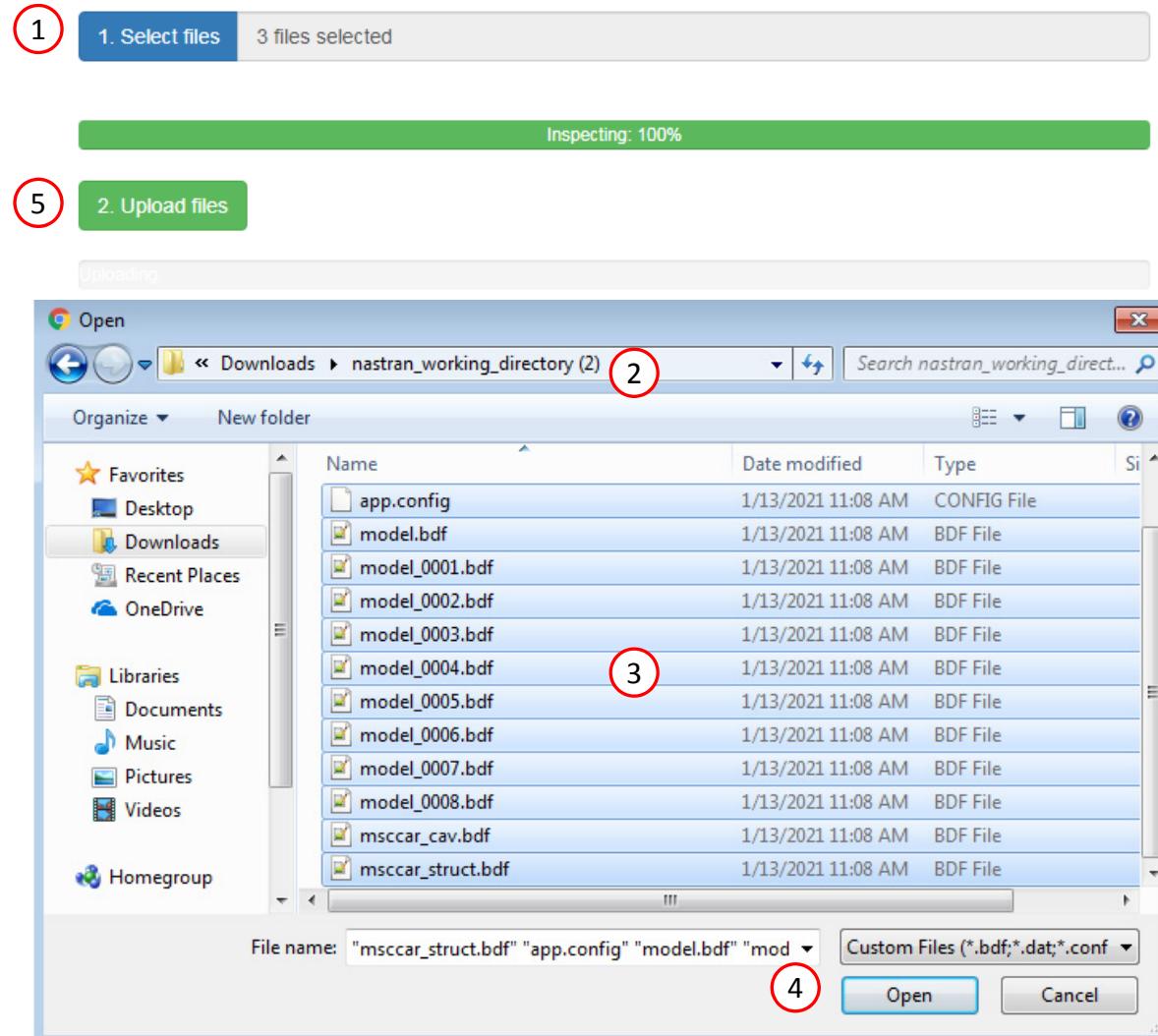




# Import

1. Click Select Files
  2. Navigate to the folder named nastran\_working\_directory (2)
  3. Select all the BDF files AND the app.config file.
  4. Click Open
  5. Click Upload files
- All imports require the app.config file to be selected.

## Select BDF Files



# Import

For the Response section, the H5 file will need to be re-uploaded.

1. Click Responses
2. Select the H5 file
3. Click Upload
4. Data from the H5 is loaded and ready to use

**SOL 200 Web App - Machine Learning** Parameters Samples Responses Download Results

Upload .h5 File

1. Select files model.h5

2. Upload files

Select Responses to Monitor Session ID: 7429

Monitored Responses

Delete	Label	Status	Objective	Lower Bound	Upper Bound	Monitor the response of the FINAL design cycle (SOL 200 only)	Monitor the response greater
	r1 r2 r3 r4 r5	<input checked="" type="checkbox"/>				No - Monitor	NO YES
X	r1	<input checked="" type="checkbox"/>		Lower	Upper		
X	r2	<input checked="" type="checkbox"/>		Lower	Upper		
X	r3	<input checked="" type="checkbox"/>		Lower	Upper		
X	r4	<input checked="" type="checkbox"/>		Lower	Upper		
X	r5	<input checked="" type="checkbox"/>		Lower	Upper		

**SOL 200 Web App - Machine Learning** Parameters Samples Responses Download Results

Select Responses to Monitor Session ID: 7429

Monitored Responses

Delete	Label	Status	Objective	Lower Bound	Upper Bound	Monitor the response of the FINAL design cycle (SOL 200 only)	Monitor the response greater
	r1 r2 r3 r4 r5	<input checked="" type="checkbox"/>				No - Monitor	NO YES
X	r1	<input checked="" type="checkbox"/>		Lower	Upper		
X	r2	<input checked="" type="checkbox"/>		Lower	Upper		
X	r3	<input checked="" type="checkbox"/>		Lower	Upper		
X	r4	<input checked="" type="checkbox"/>		Lower	Upper		
X	r5	<input checked="" type="checkbox"/>		Lower	Upper		
X	r6	<input checked="" type="checkbox"/>		Lower	Upper		



# Import

After import, any Parameter, Samples or Responses can be modified.

## Select Parameters

\$ _1_    _2_    _3_    _4_    _5_    _6_    _7_    _8_    _9_    _10_						
EIGRL	1		225.			
EIGRL	2		300.			
FORCE	212	1001	500.	0.0	1.0	0.0
FORCE	213	1001	1000.	0.0	0.0	1.0
FORCE	232	1003	500.	0.0	1.0	0.0
FORCE	233	1003	1000.	0.0	0.0	1.0
FREQ1	5	10.	2.5	56		
MAT1	7	210000.0	0.3	7.90E-06		
MAT1	8	62000.0	0.24	2.30E-06		
MAT10	6		1.23E-12340000.0			
PARAM	G	0.06				
PARAM	GFL	0.12				
PARAM	LFREQ	0.1				
PARAM	PREFDB	2.E-11				
PARAM	WTMASS	.001				
PSHELL	1	7	%x1%	7	1.0	0.833333

## Configure Parameters

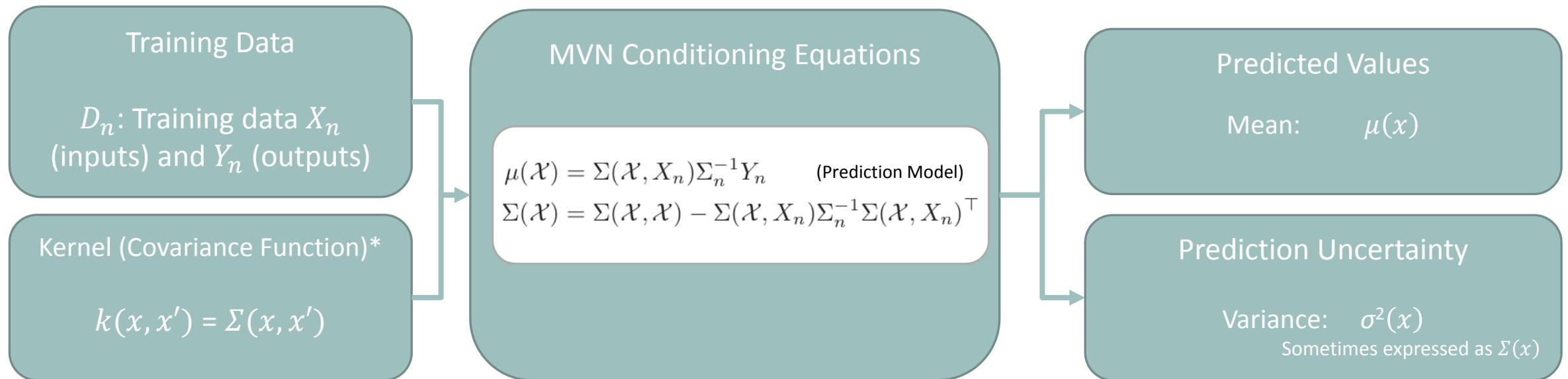


Delete	Parameter	Status	Low	High	Comments
	x1		1.	6.	Field 4 of PSHE
	x2		1.	6.	Field 4 of PSHE
	x8		1.	6.	Field 4 of PSHE
	x11		1.	6.	Field 4 of PSHE

# What is Gaussian Process Regression?

---

# Gaussian Process Regression Overview



\* Hyperparameter optimization is part of the procedure but not covered in this presentation

\*\*  $\mu(x)$ : This function corresponds to the mean function or kriging model. This function is the prediction model, also known as the surrogate model, meta model or emulator.

# Multivariate Normal (MVN) Conditioning Equations

---

The following must be calculated: Covariance Matrix, Mean and Variance

Covariance Matrix

$$\Sigma = \begin{pmatrix} \Sigma(\chi, \chi) & \Sigma(\chi, X_n) \\ \Sigma(X_n, \chi) & \Sigma_n = \Sigma(X_n, X_n) \end{pmatrix}$$

$X_n$ : Training locations  
 $\chi$ : Testing (predictive) locations

Apply the covariance function  $\Sigma(x, x')$  (kernel  $k(x, x')$ )

- $\Sigma(\chi, \chi)$ : Covariance between testing (predictive) locations and themselves
- $\Sigma(\chi, X_n)$ : Covariance between testing (predictive) and training locations
- $\Sigma(\chi, X_n)$ : Covariance between training and testing (predictive) locations, which is the transpose of  $\Sigma(\chi, X_n)$
- $\Sigma_n = \Sigma(X_n, X_n)$ : Covariance between training locations and themselves

MVN Conditioning Equations (Mean and Variance)

Also referred to as “Gaussian process regression,” “kriging” or “kriging equations”

$$\text{mean } \mu(\mathcal{X}) = \Sigma(\mathcal{X}, X_n) \Sigma_n^{-1} Y_n$$

Prediction Model (Vary  $\chi$  to make predictions)

$$\text{and variance } \Sigma(\mathcal{X}) = \Sigma(\mathcal{X}, \mathcal{X}) - \Sigma(\mathcal{X}, X_n) \Sigma_n^{-1} \Sigma(\mathcal{X}, X_n)^\top$$

Prediction Uncertainty

# Example 1

---

# Example 1

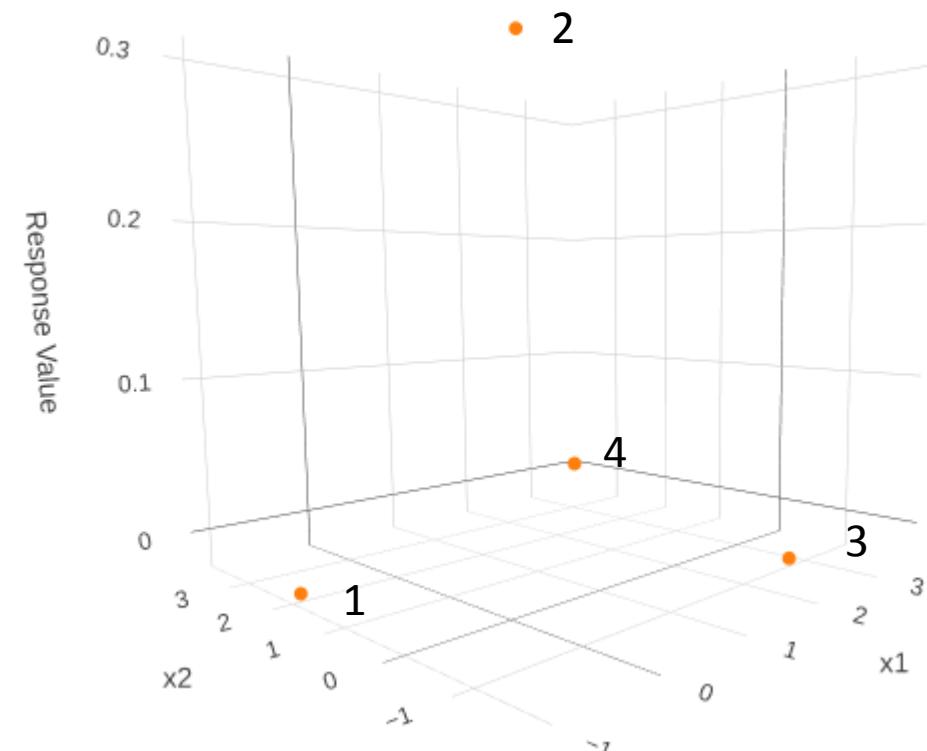
---

Suppose a black box function was executed at 4 different samples ( $x_1, x_2$  combinations)

With limited data ( $x$  and  $y$ ), what does the response surface look like?

**Training Data**

Sample	x1	x2	y
1	-1.03	1.76	-1.56E-02
2	.49	.49	3.04E-01
3	1.77	-1.77	3.38E-03
4	3.62	3.76	5.43E-12



# Training Data and Testing (Predictive) Locations

Suppose you have the following training data ( $X_n$  and  $Y_n$ ) and testing locations ( $\chi$ )

- $X_n$  : The training design consists of 4 points
- $\chi$  : The test design (locations to make predictions) consists of 2 points

$$X = \begin{bmatrix} \chi \\ X_n \end{bmatrix} = \begin{bmatrix} .35 & .69 \\ .65 & .46 \\ -1.03 & 1.76 \\ .49 & .49 \\ 1.77 & -1.77 \\ 3.62 & 3.76 \end{bmatrix}$$

$$\begin{bmatrix} y^* \\ Y_n \end{bmatrix} = \begin{bmatrix} ? \\ ? \\ -1.56e - 02 \\ 3.04e - 01 \\ 3.38e - 03 \\ 5.43e - 12 \end{bmatrix}$$

The goal is make predictions ( $y^*$ ) for points in  $\chi$

Note

- $X_n$ : inputs of the training data
- $Y_n$ : outputs of the training data
- $\chi$  or  $x$ : inputs of the testing data (predictive locations, i.e. points to make predictions)
- $y^*$ : predicted outputs
- $D_n$ : Training data  $X_n$  and  $Y_n$

$X$ : upper case of Greek letter chi (pronounced kai in English)  
 $\chi$ : lower case of Greek letter chi

# Calculation of the Covariance Matrix

---

## 1. Select a covariance (kernel) function

- Many covariance functions (kernels) exist: Radial Basis Function (RBF), Matern 5/2, 3/2, Exponential, ...
- For this example, a form of the RBF covariance function is used. This covariance function is described as the “inverse exponentiated squared Euclidean distance”

$$k(x, x') = \Sigma(x, x') = \exp\{-\|x - x'\|^2\} = e^{-\|x-x'\|^2}$$

## 2. Calculate $D$ (Distance Matrix)

$$D = \|X - X\|^2 \quad \text{“Norm between } X \text{ and } X, \text{ squared”}$$

## 3. Calculate $\Sigma$ (Covariance Matrix)

$$\Sigma = e^{-D}$$

# Calculation of $D$

---

$$\sqrt{(.35 - .35)^2 + (.69 - .69)^2}^2 = 0$$

$$\sqrt{(.35 - .65)^2 + (.69 - .46)^2}^2 = .1429$$

$$\sqrt{(.35 - -1.03)^2 + (.69 - 1.76)^2}^2 = 3.0493$$

$$\sqrt{(.35 - .49)^2 + (.69 - .49)^2}^2 = .0596$$

$$\sqrt{(.35 - 1.77)^2 + (.69 - -1.77)^2}^2 = 8.068$$

$$\sqrt{(.35 - 3.62)^2 + (.69 - 3.76)^2}^2 = 20.1178$$

.1429

$$\sqrt{(.65 - .65)^2 + (.46 - .46)^2}^2 = 0$$

$$\sqrt{(.65 - -1.03)^2 + (.46 - 1.76)^2}^2 = 4.5124$$

$$\sqrt{(.65 - .49)^2 + (.46 - .49)^2}^2 = .0265$$

$$\sqrt{(.65 - 1.77)^2 + (.46 - -1.77)^2}^2 = 6.2273$$

$$\sqrt{(.65 - 3.62)^2 + (.46 - 3.76)^2}^2 = 19.7109$$

3.0493

4.5124

$$\sqrt{(-1.03 - -1.03)^2 + (1.76 - 1.76)^2}^2 = 0 \quad \sqrt{(-1.03 - .49)^2 + (1.76 - .49)^2}^2 = 3.9233$$

$$\sqrt{(-1.03 - 1.77)^2 + (1.76 - -1.77)^2}^2 = 20.3009 \quad \sqrt{(-1.03 - 3.62)^2 + (1.76 - 3.76)^2}^2 = 25.6225$$

$D =$

.0596

.0265

3.9233

$$\sqrt{(.49 - .49)^2 + (.49 - .49)^2}^2 = 0$$

$$\sqrt{(.49 - 1.77)^2 + (.49 - -1.77)^2}^2 = 6.746$$

$$\sqrt{(.49 - 3.62)^2 + (.49 - 3.76)^2}^2 = 20.4898$$

8.068

6.2273

20.3009

6.746

$$\sqrt{(1.77 - 1.77)^2 + (-1.77 - -1.77)^2}^2 = 0 \quad \sqrt{(1.77 - 3.62)^2 + (-1.77 - 3.76)^2}^2 = 34.0034$$

20.1178

19.7109

25.6225

20.4898

34.0034

$$\sqrt{(3.62 - 3.62)^2 + (3.76 - 3.76)^2}^2 = 0$$

# Calculation of $\Sigma$

---

$\Sigma =$

$$e^0 = 1$$

$$e^{-1429} = .8668$$

$$e^{-3.0493} = .0474$$

$$e^{-0.0596} = .9421$$

$$e^{-8.068} = .0003$$

$$e^{-20.1178} = 1.832e-9$$

$$.8668$$

$$e^0 = 1$$

$$e^{-4.5124} = .0110$$

$$e^{-0.0265} = .9738$$

$$e^{-6.2273} = .0020$$

$$e^{-19.7109} = 2.8e-9$$

$$.0474$$

$$.0110$$

$$e^0 = 1$$

$$e^{-3.9233} = .0198$$

$$e^{-20.3009} = 1.5e-9$$

$$e^{-25.6225} = 7.5e-12$$

$$.9421$$

$$.9738$$

$$.0198$$

$$e^0 = 1$$

$$e^{-6.746} = .0012$$

$$e^{-20.4898} = 1.263e-9$$

$$.0003$$

$$.0020$$

$$1.5e-9$$

$$.0012$$

$$e^0 = 1$$

$$e^{-34.0034} = 1.7e-15$$

$$1.832e-9$$

$$2.8e-9$$

$$7.5e-12$$

$$1.263e-9$$

$$1.7e-15$$

$$e^0 = 1$$

# Calculation of $\Sigma$

$$\Sigma = \begin{bmatrix} & & & \\ & e^0 = 1 & & e^{-1.1429} = .8668 \\ & \Sigma(\chi, \chi)_{e^0 = 1} & & \\ & .8668 & & \\ & & & \\ & .0474 & & .0110 \\ & & & \\ & .9421 & & .9738 \\ & & & \\ & \Sigma(X_n, \chi)_{.0003} & & .0020 \\ & & & \\ & & & \\ & 1.832\text{e-}9 & & 2.8\text{e-}9 \end{bmatrix}$$

$e^{-3.0493} = .0474$	$e^{-0.0596} = .9421$	$e^{-8.068} = .0003$	$e^{-20.1178} = 1.832e-9$
$e^{-4.5324} = .0110$	$e^{-0.0265} = .9738$	$e^{-6.2273} = .0020$	$e^{-19.7109} = 2.8e-9$
$e^0 = 1$	$e^{-3.9233} = .0198$	$e^{-20.3009} = 1.5e-9$	$e^{-25.6225} = 7.5e-12$
.0198	$e^0 = 1$	$e^{-6.746} = .0012$	$e^{-20.4893} = 1.263e-9$
$1.5e-9$	$\Sigma_n = \Sigma(X_n, X_n)$	$e^0 = 1$	$e^{-34.0034} = 1.7e-15$
$7.5e-12$	$1.263e-9$	$1.7e-15$	$e^0 = 1$

Since  $\Sigma$  is symmetric, note that  $\Sigma(X_n, \chi) = \Sigma(\chi, X_n)^T$

# Calculation of Predictive Quantities

---

The MVN conditioning equations are used to determine the predictive quantities mean and variance

$$\text{mean } \mu(\mathcal{X}) = \Sigma(\mathcal{X}, X_n) \Sigma_n^{-1} Y_n$$

$$\mu(\chi) = y * = \begin{pmatrix} 0.2849657 \\ 0.2954011 \end{pmatrix} \quad \text{Predicted values for locations in } \chi$$

$$\text{and variance } \Sigma(\mathcal{X}) = \Sigma(\mathcal{X}, \mathcal{X}) - \Sigma(\mathcal{X}, X_n) \Sigma_n^{-1} \Sigma(\mathcal{X}, X_n)^\top$$

$$\Sigma(\chi) = \begin{pmatrix} 0.11154162 & -0.05042265 \\ -0.05042265 & 0.05155061 \end{pmatrix} \quad \text{Prediction Uncertainty}$$

The diagonal terms are the variances at prediction points 1 and 2

$$\sigma^2(\chi) = \begin{pmatrix} 0.11154162 \\ 0.05155061 \end{pmatrix}$$

# R

# Code to replicate this example in R

```
library(plgp)

eps = sqrt(.Machine$double.eps)

# Training points
X = rbind(c(-1.03, 1.76), c(.49, .49), c(1.77, -1.77), c(3.62, 3.76))

# The goal is to fit this function: y(x) = x1 * exp(-x1^2 - x2^2)
y = X[,1] * exp(-X[,1]^2 - X[,2]^2)

# Test points
XX = rbind(c(.35, .69), c(.65, .46))
XX

# Sigma 22 (Sigma) and its inverse (Si)
# #####
# Distance among the Training Data
D = distance(X)
Sigma = exp(-D)
Si = solve(Sigma)

# Sigma 11
# #####
# Distance among the Testing Data
DXX = distance(XX)
SXX = exp(-DXX)

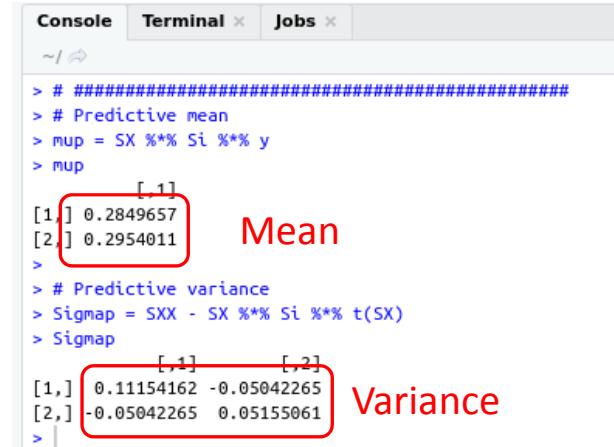
# Sigma 12 and Sigma 21 (Transpose of Sigma 12)
# #####
# Distance between training and testing data
```

```
DX = distance(XX, X)
SX = exp(-DX)

# Calculate the predictive mean and predictive variance
# #####
# Predictive mean
mup = SX %*% Si %*% y
mup

# Predictive variance
Sigmap = SXX - SX %*% Si %*% t(SX)
Sigmap
```

## Output



```
Console Terminal × Jobs ×
~/
> # #####
> # Predictive mean
> mup = SX %*% Si %*% y
> mup
[1] 0.2849657 [1]
[2] 0.2954011 [2]

Mean
```

```
> # Predictive variance
> Sigmap = SXX - SX %*% Si %*% t(SX)
> Sigmap
[1,] 0.11154162 -0.05042265 [1,]
[2,] -0.05042265 0.05155061 [2]

Variance
```

# R

# Code to replicate this example in R with Plots

```
library(plgp)
library(lhs)

eps = sqrt(.Machine$double.eps)

# Training Data
# #####
# Training points
number_of_sample_points = 4
X = rbind(c(-1.03,1.76), c(.49,.49), c(1.77,-1.77), c(3.62,3.76))

# Observed values
# The goal is to fit this function: y(x) = x1 * exp(-x1^2 - x2^2)
y = X[,1] * exp(-X[,1]^2 - X[,2]^2)

# Testing Data
# #####
# Test points
number_of_test_points_per_axis = 40
xx = seq(-2, 4, length=number_of_test_points_per_axis)
XX = expand.grid(xx, xx)

# Sigma 22 (Sigma) and its inverse (Si)
# #####
# Distance among the Training Data
D = distance(X)
Sigma = exp(-D) + diag(eps, nrow(X))
Si = solve(Sigma)

# Sigma 11
# #####
# Distance among the Testing Data

DXX = distance(XX)
SXX = exp(-DXX)

# Sigma 12 and Sigma 21 (Transpose of Sigma 12)
# #####
# Distance between training and testing data
DX = distance(XX, X)
SX = exp(-DX)

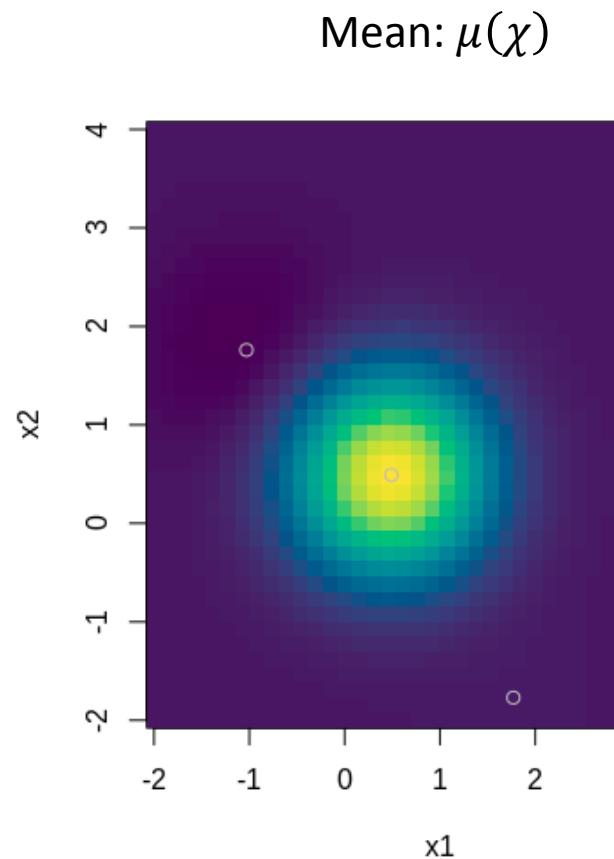
# Calculate the predictive mean and predictive variance
# #####
mup = SX %*% Si %*% y
Sigmap = SXX - SX %*% Si %*% t(SX)

# Predictive standard deviation
diag(Sigmap)
sdp = sqrt(diag(Sigmap))

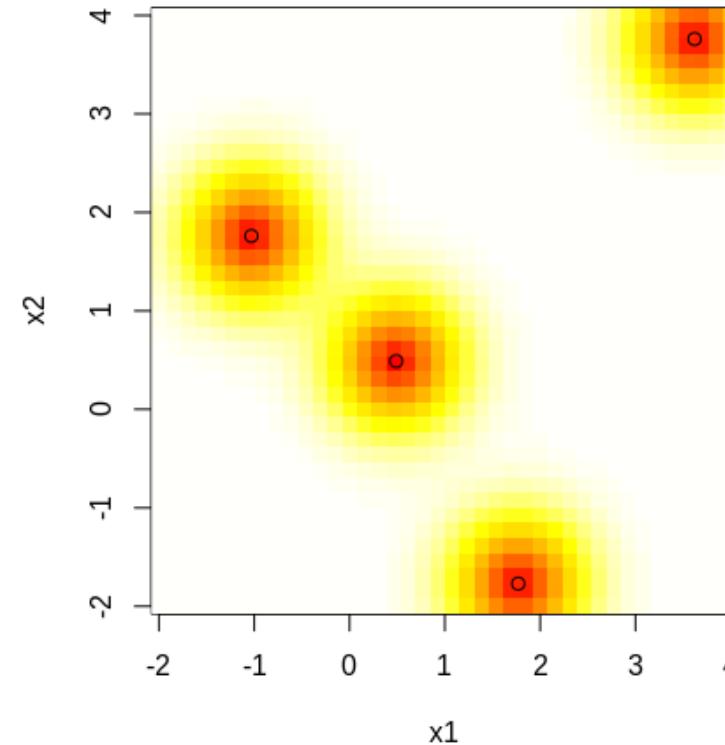
# Figure 5.5
par(mfrow=c(1, 2))
cols_a = hcl.colors(128, palette = "viridis")
cols_b = heat.colors(128)
image(xx, xx, matrix(mup, ncol=length(xx)), xlab='x1', ylab='x2', col=cols_a)
points(X[,1], X[,2])
image(xx, xx, matrix(sdp, ncol=length(xx)), xlab='x1', ylab='x2', col=cols_b)
points(X[,1], X[,2])

# Figure 5.6
persp(xx, xx, matrix(mup, ncol=number_of_test_points_per_axis), theta=-30, phi=30,
xlab='x1', ylab='x2', zlab='y', zlim = c(-.5,.5))
```

# Predictive Quantities Mean and Standard Deviation

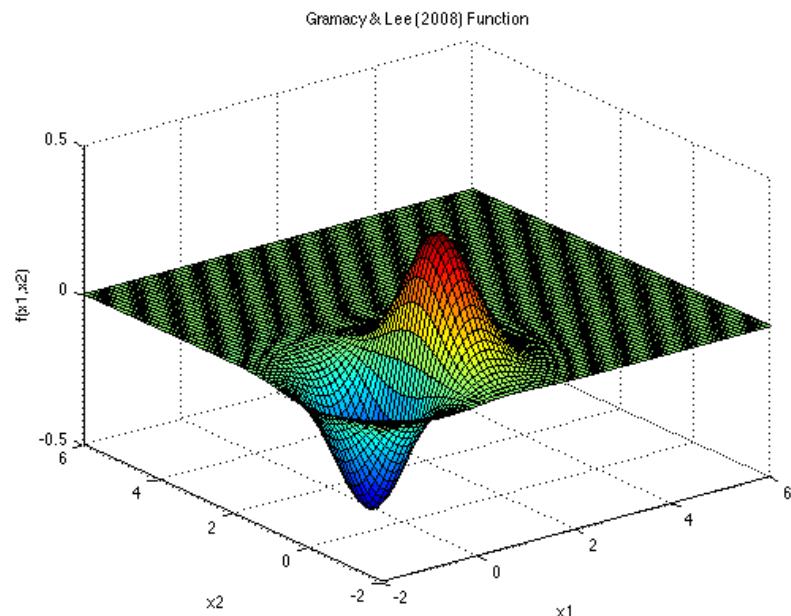


Standard Deviation:  $\sigma(\chi)$   
(Square root of variance)



# Comparison of True Function and Prediction Model

True Function



$$f(\mathbf{x}) = x_1 \exp(-x_1^2 - x_2^2)$$

Source: <https://www.sfu.ca/~ssurjano/grlee08.html>

Prediction Model ( $\mu(\chi)$ )

