Workshop - Machine Learning - Structural Optimization of a 3 Bar Truss

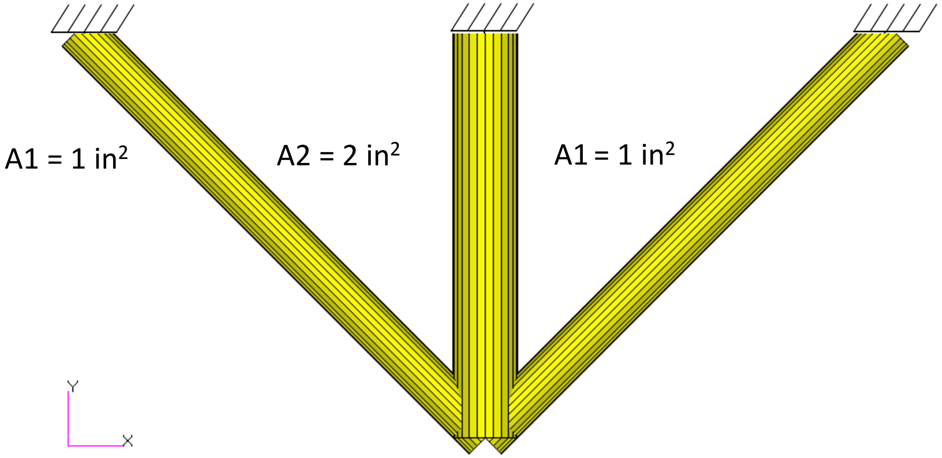
AN MSC NASTRAN MACHINE LEARNING WEB APP TUTORIAL

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

Goal: Use Machine Learning for Optimization

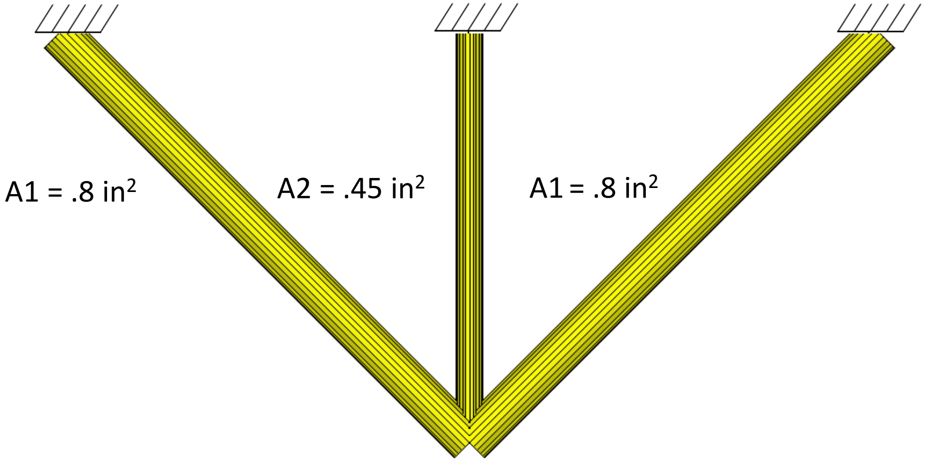
Before Optimization

- Weight: 4.82 lbs.



After Optimization

- Weight: ~2.7 lbs.



Details of the Structural Model

Three-Bar Truss

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

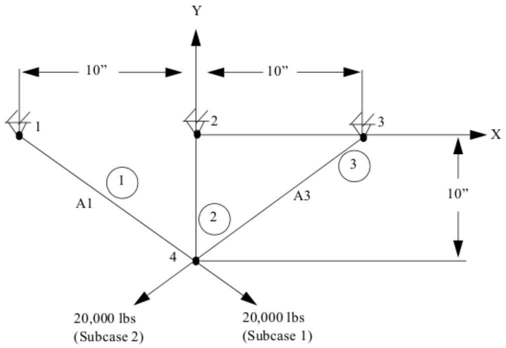
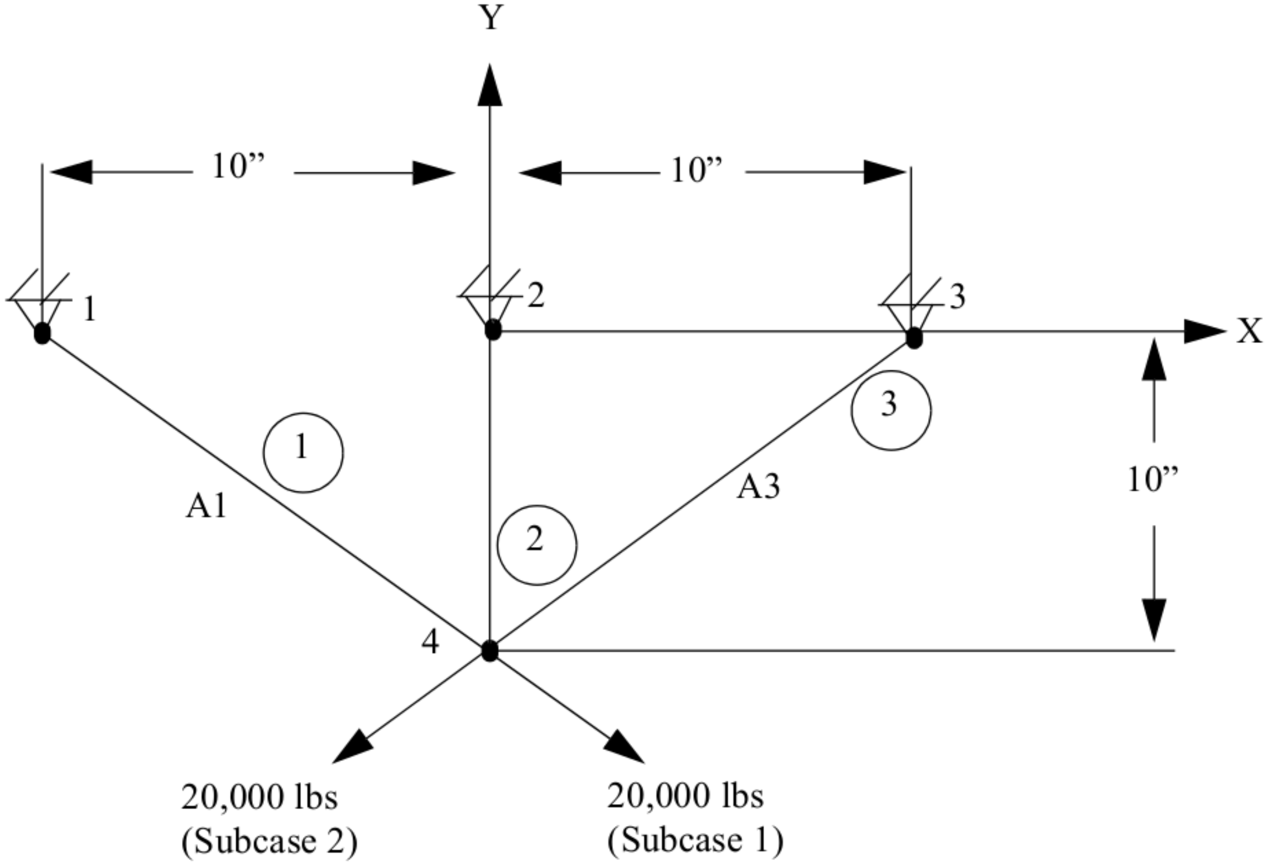


Figure 8-1 Three-Bar Truss

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

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

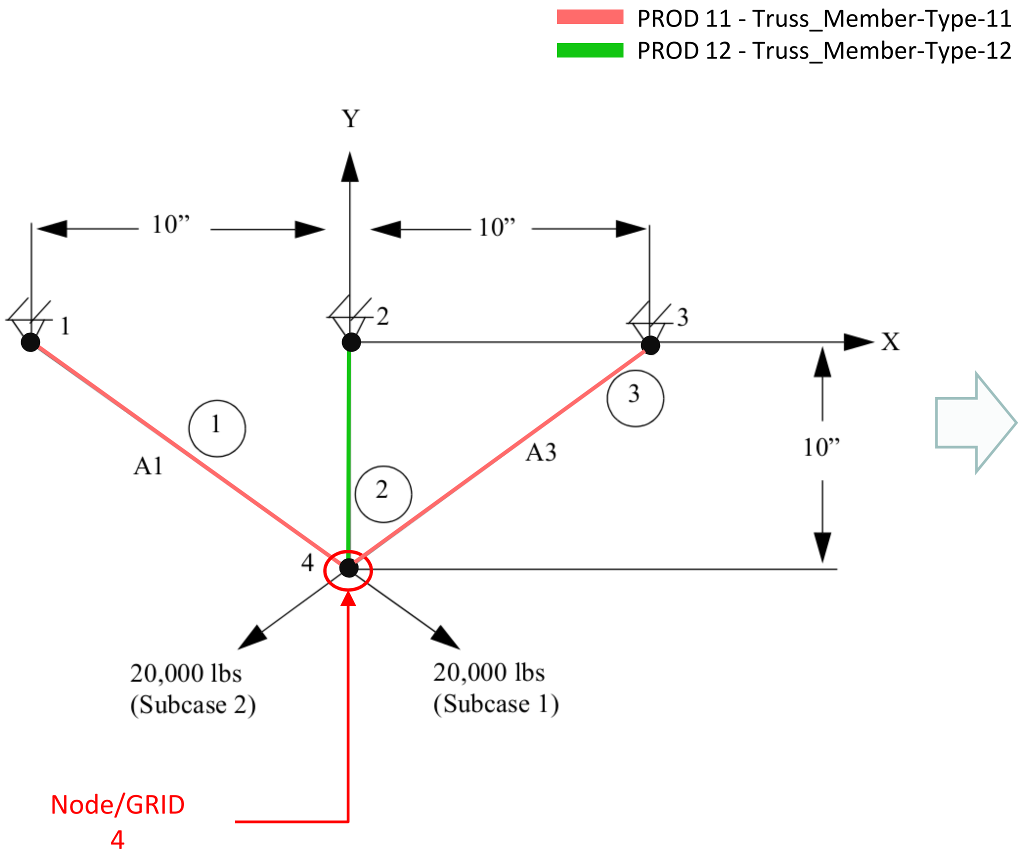


Optimization Problem Statement

Design Variables

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

.01 < x1, x2 < 5.



Design Objective

r1: Minimize weight

Design Constraints

r2-r7: Axial stress of elements related to PROD 11, 12, 13 for subcases 1 and 2

-15000 < r2-r7 < 20000

Contact me

- Nastran SOL 200 training
- Nastran SOL 200 questions
- Structural or mechanical optimization questions
- Access to the SOL 200 Web App

christian@ the-engineering-lab.com

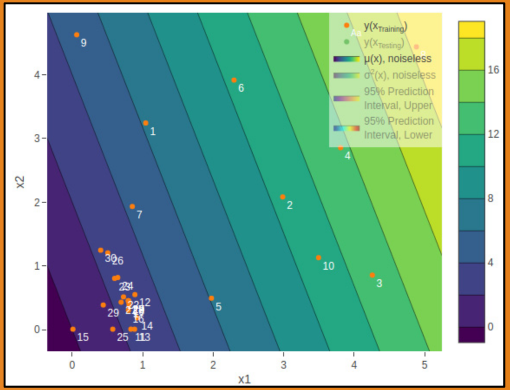
Tutorial

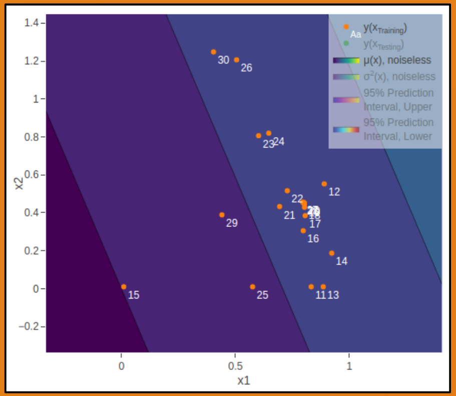
Tutorial Overview

1. Start with a .bdf and .h5 file
2. Use the SOL 200 Web App to:
   - Configure a Machine Learning task
     - Design Variables
     - Design Objective
     - Design Constraints
   - Perform optimization
3. Plot the Optimization Results

Special Topics Covered

Training Data - The machine learning process utilizes regression models of the objective and constraints to determine likely optimal locations. Before the machine learning process begins, the regression models are first constructed by using training data. The training data consists of the objective and constrained responses at various points, or samples, throughout the design space. This example uses a Latin Hypercube design of 10 samples to generate the necessary initial training data.





SOL 200 Web App Capabilities

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

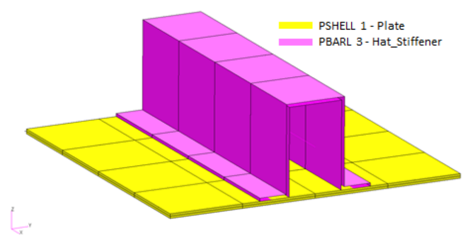
Compatibility

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

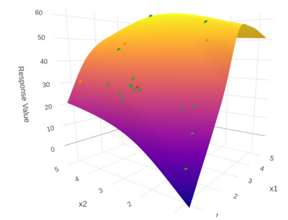
Benefits

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

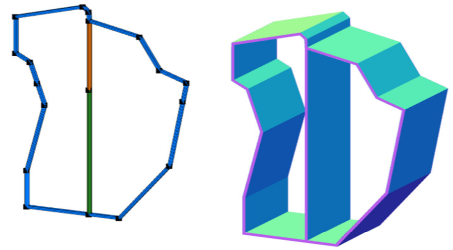
Web Apps



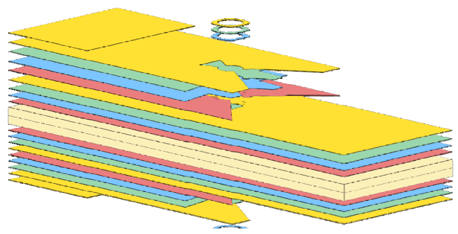
Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography, multi-model optimization.



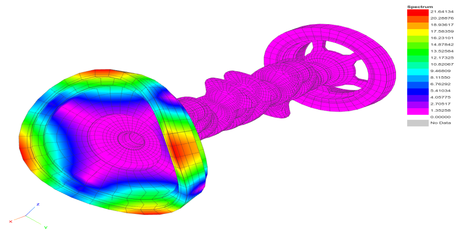
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



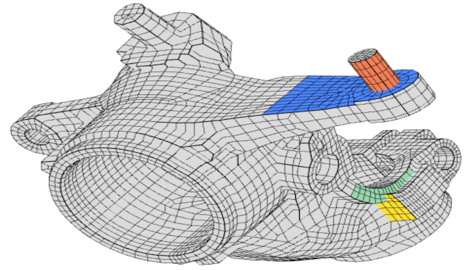
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



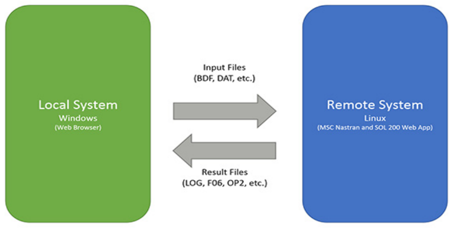
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries



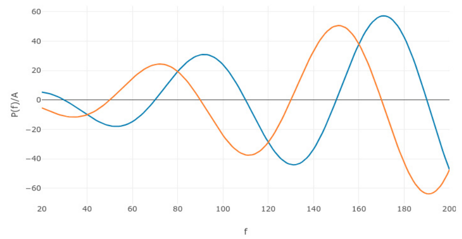
Post-processor Web App
View MSC Nastran results in a web browser on Windows and Linux



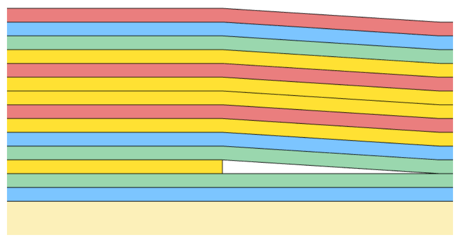
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



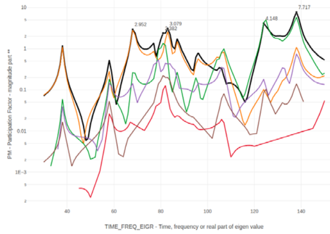
Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



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



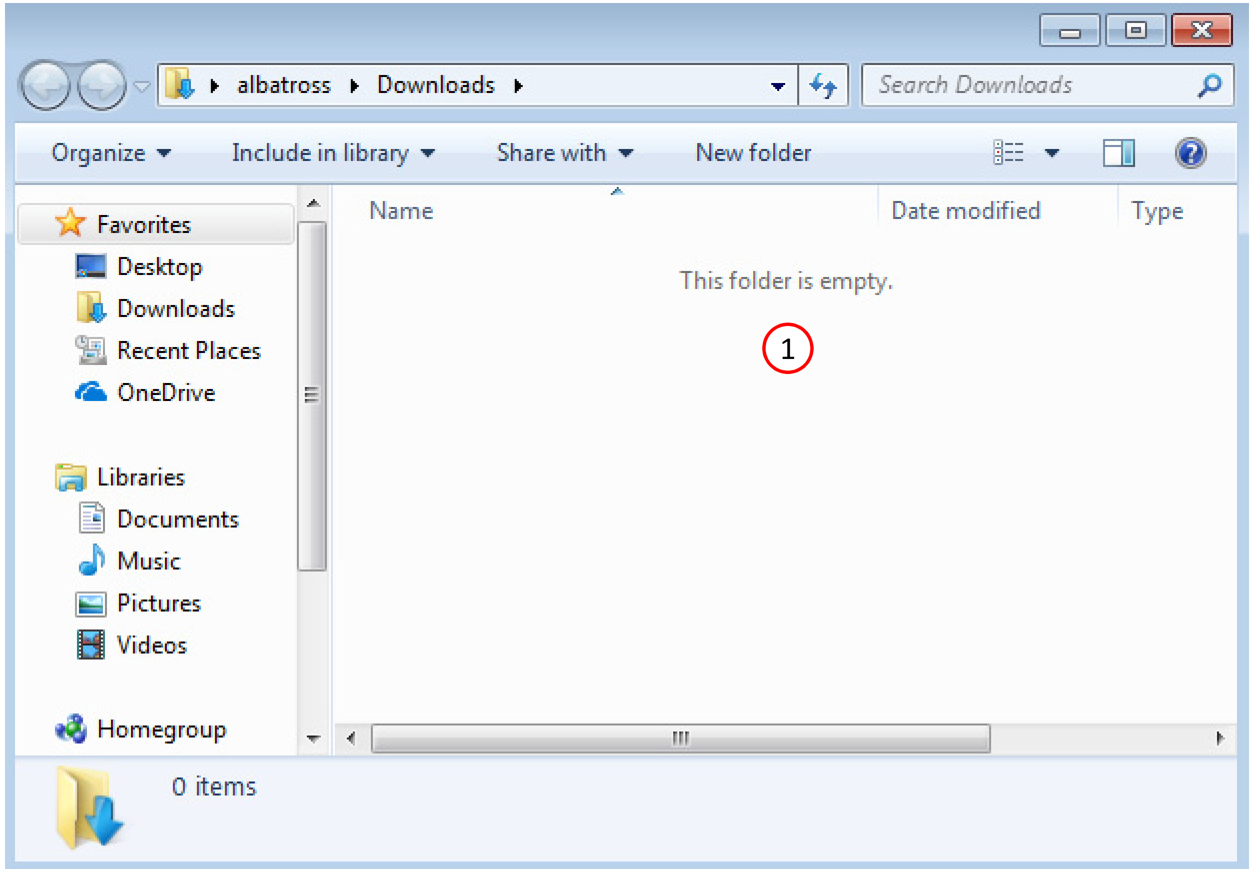
Stacking Sequence Web App
Optimize the stacking sequence of composite laminate plies



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

Before Starting

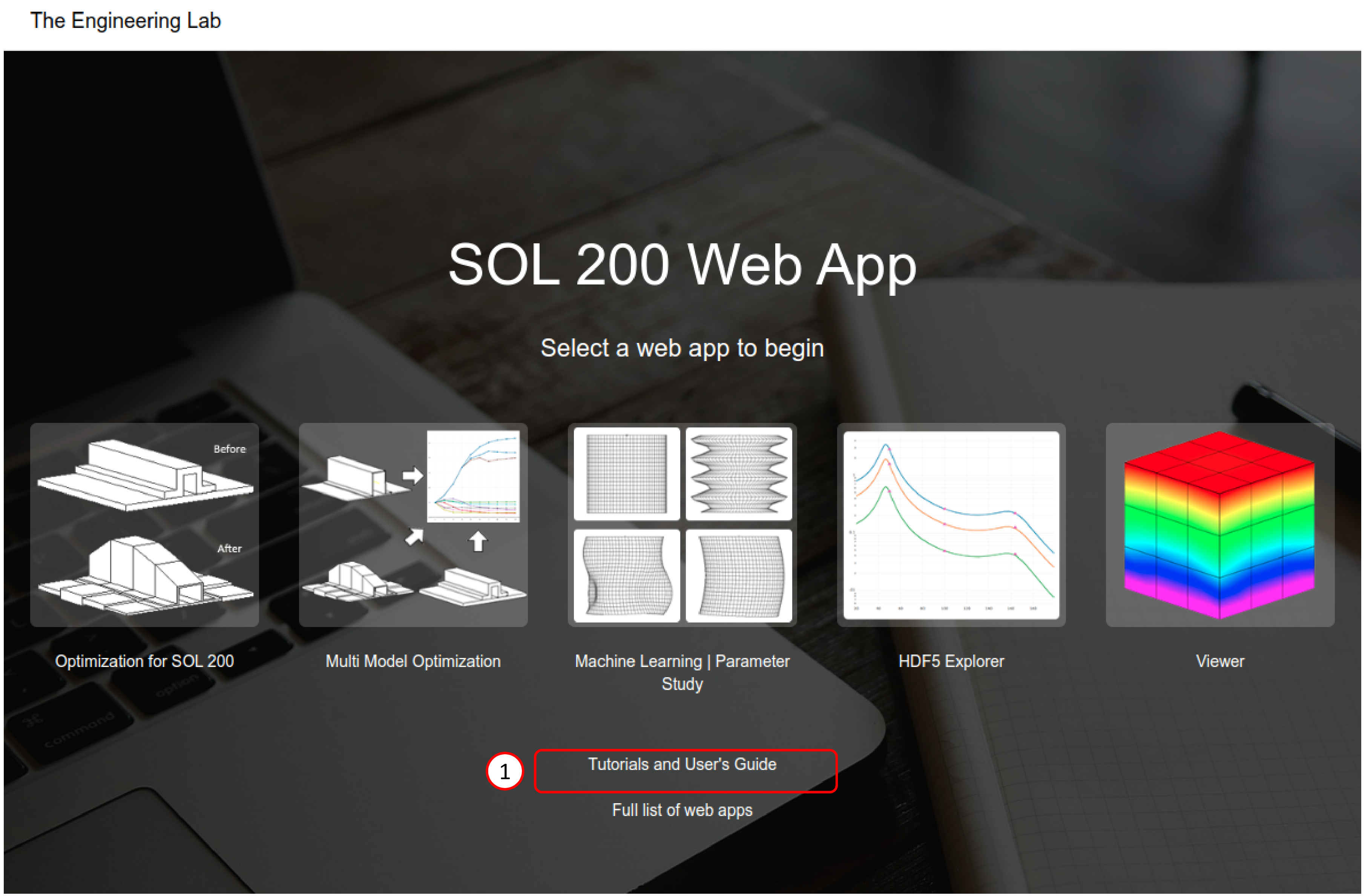
1. Ensure the Downloads directory is empty in order to prevent confusion with other files



Go to the User's Guide

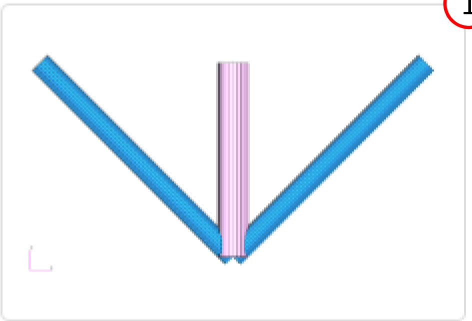
1. Click on the indicated link

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



Obtain Starting Files

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



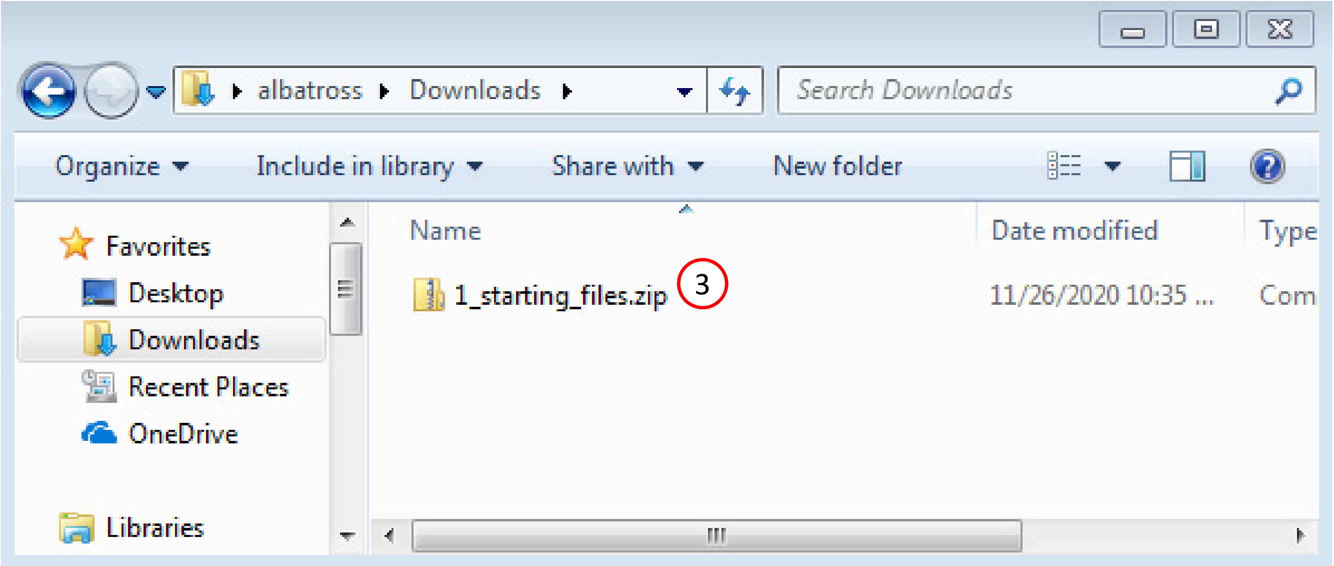
1

Machine Learning, Structural Optimization of a 3 Bar Truss

Machine learning methods are used to optimize a truss structure. MSC Nastran is used to evaluate the FE model. The design variables are the cross-sectional areas of the rod elements. The objective is to minimize the weight of the structure while constraining the axial stresses.

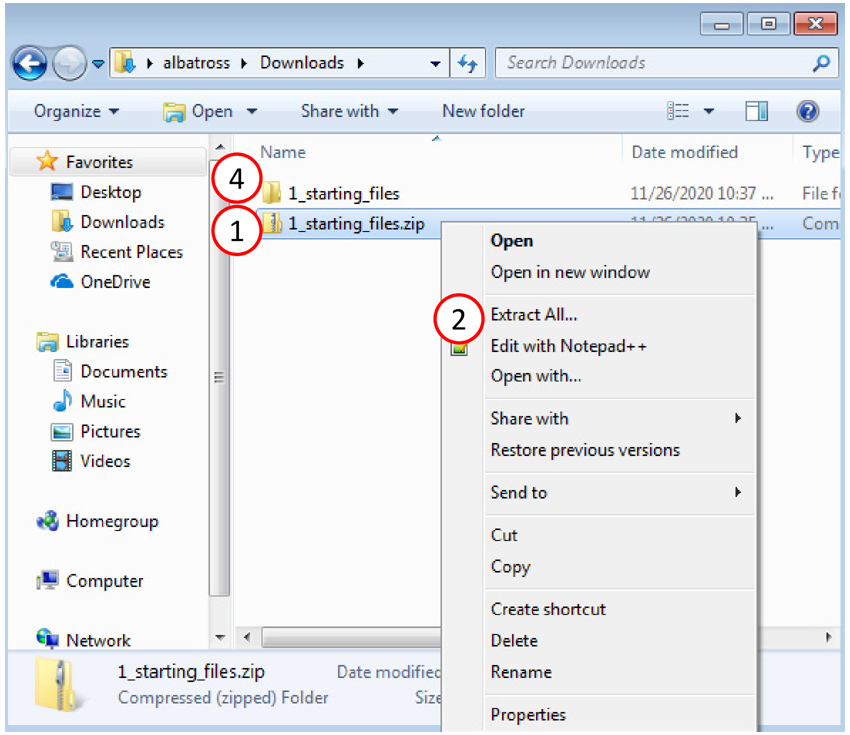
Starting Files: Link 2

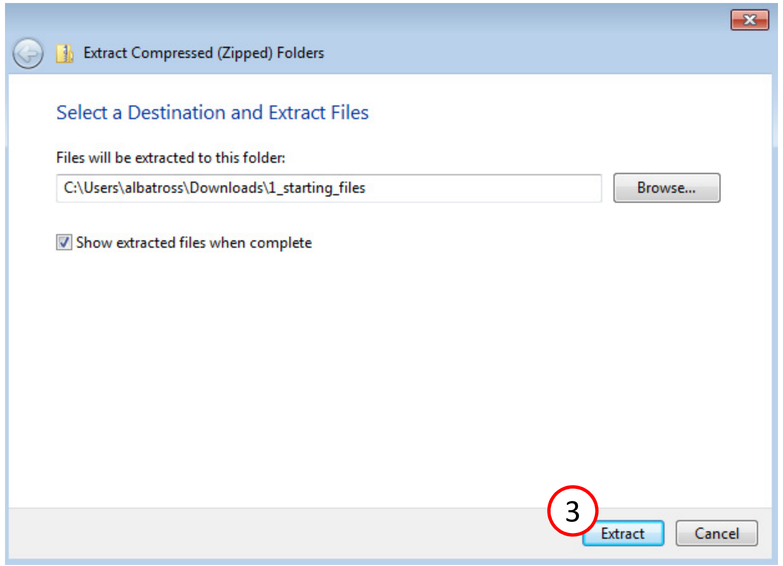
Solution BDF Files: Link

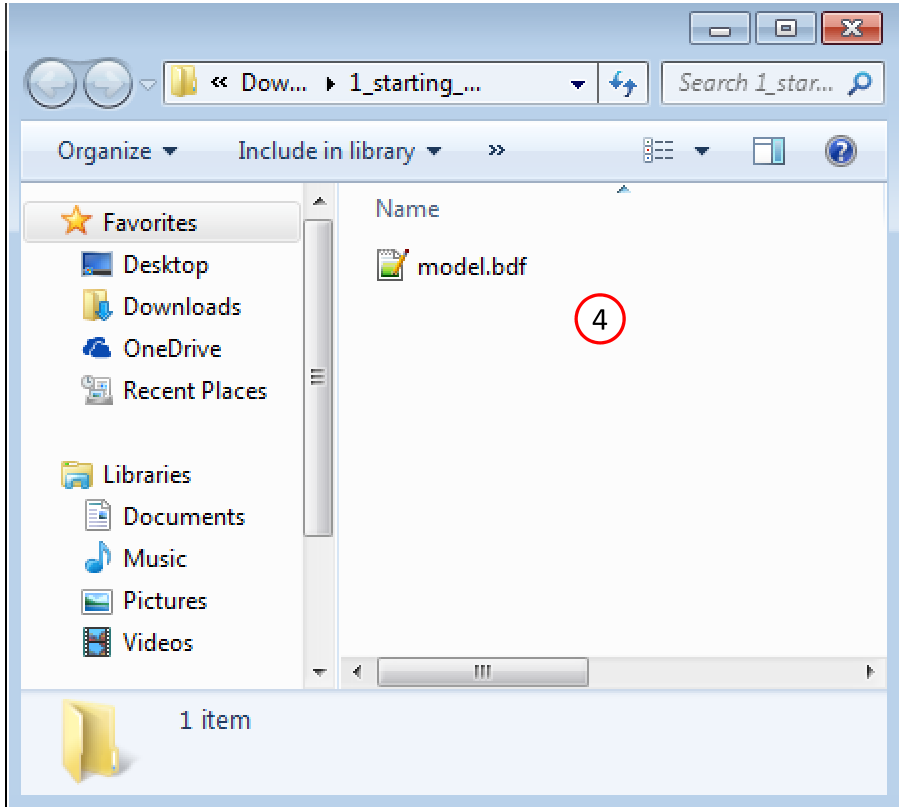


Obtain Starting Files

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



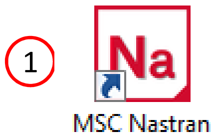


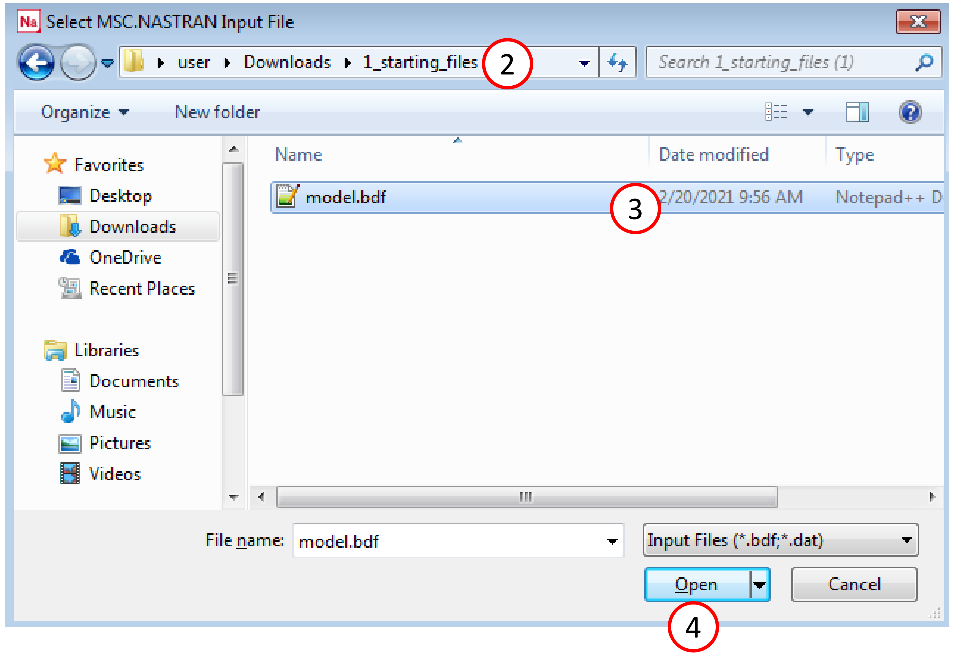


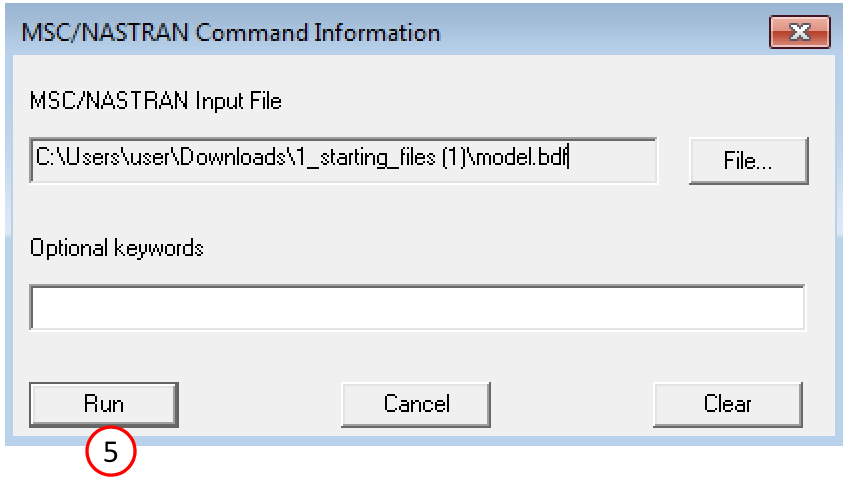
Create the Starting H5 File

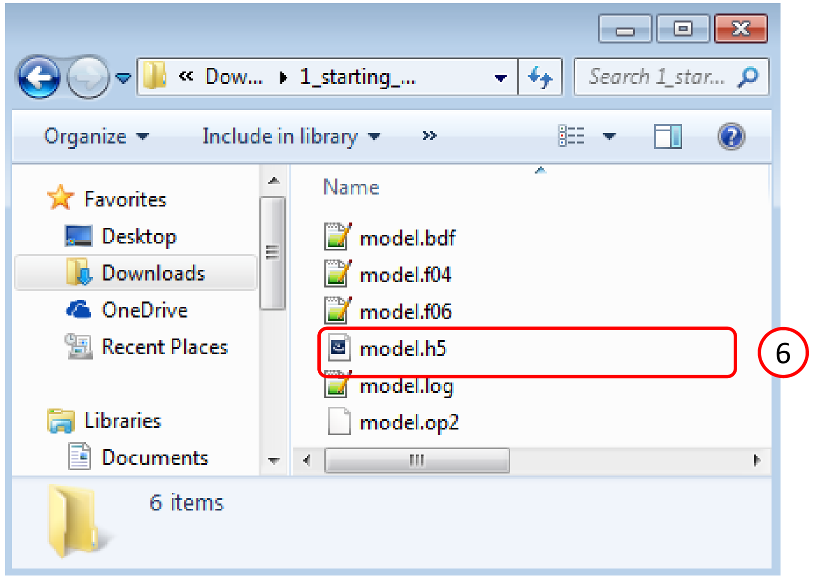
A starting H5 file must be created. This H5 file will be used to configure the responses later on.

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









Use the same MSC Nastran version throughout this exercise

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

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

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

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

Open the Correct Page

1. Click on the indicated link

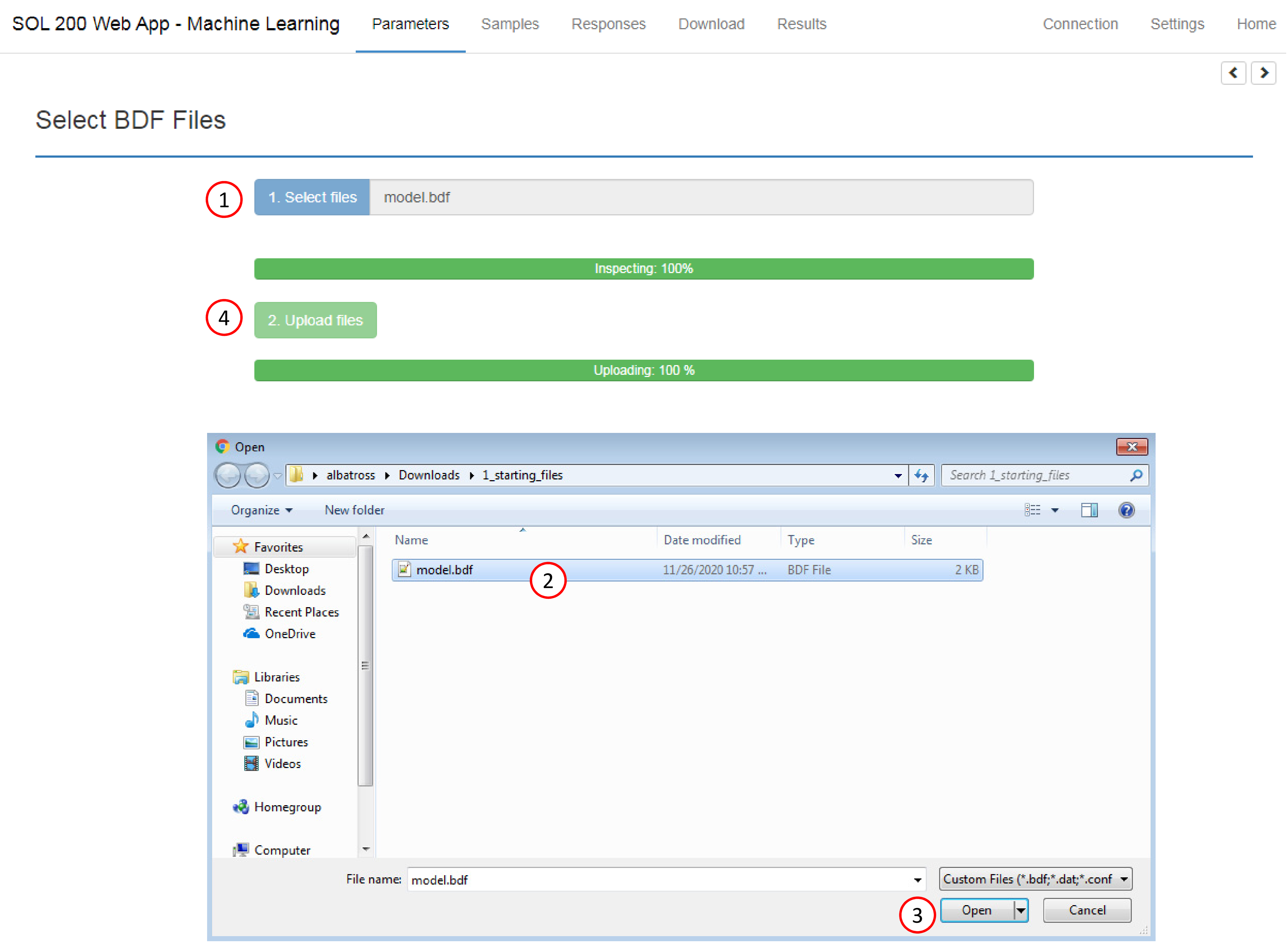
- MSC Nastran can perform many optimization types. The SOL 200 Web App includes dedicated web apps for the following:
  - Optimization for SOL 200 (Size, Topology, Topometry, Topography, Local Optimization, Sensitivity Analysis and Global Optimization)
  - Multi Model Optimization
  - Machine Learning
- The web app also features the HDF5 Explorer, a web application to extract results from the H5 file type.

The Engineering Lab

Select BDF Files

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

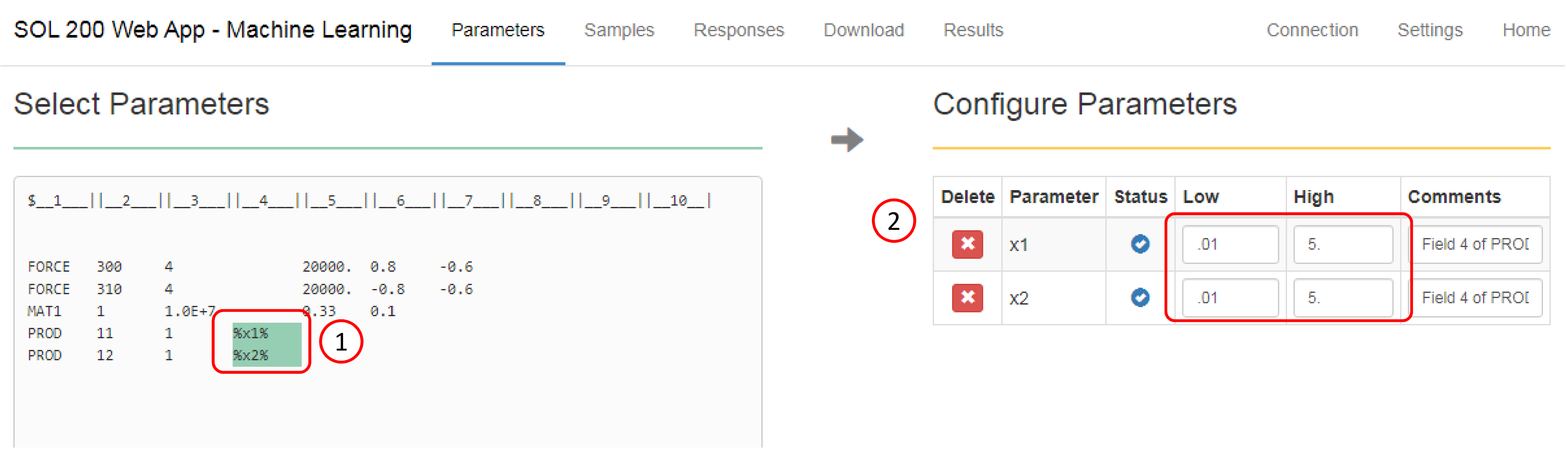
- When starting the procedure, all the necessary BDF, or DAT, files must be collected and uploaded together. Relevant INCLUDE files must also be collected and uploaded.



Parameters

1. Set the following fields as parameters
   - x1: Thickness, field 4, of PROD 11
   - x2: Thickness, field 4, of PROD 12
2. Use the following bounds for both parameters
   - Low: .01
   - High: 5.0

- 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.

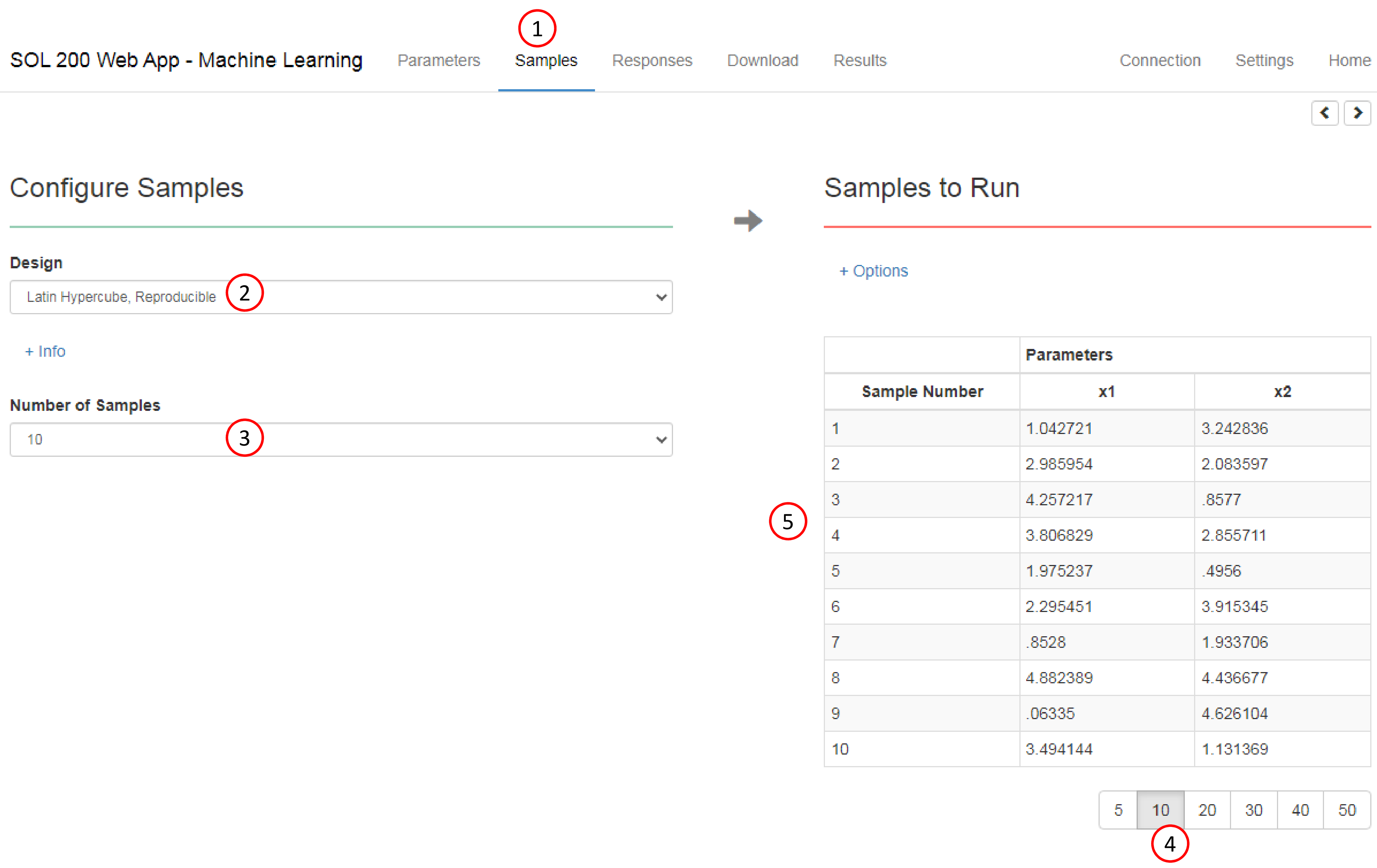


Samples

Configure 10 MSC Nastran runs at different values for the parameters

1. Click Samples
2. Set Design as Latin Hypercube, Reproducible
3. Set Number of Samples as 10
4. Click 10 to display 10 rows of the table
5. 10 samples have been configured

- Before machine learning can be performed, a regression model must be constructed. This section configures the points that will be used to generate the training data (monitored responses) that is used to train the regression model.
- For example, the objective response from each sample is used to create a regression model for the objective.

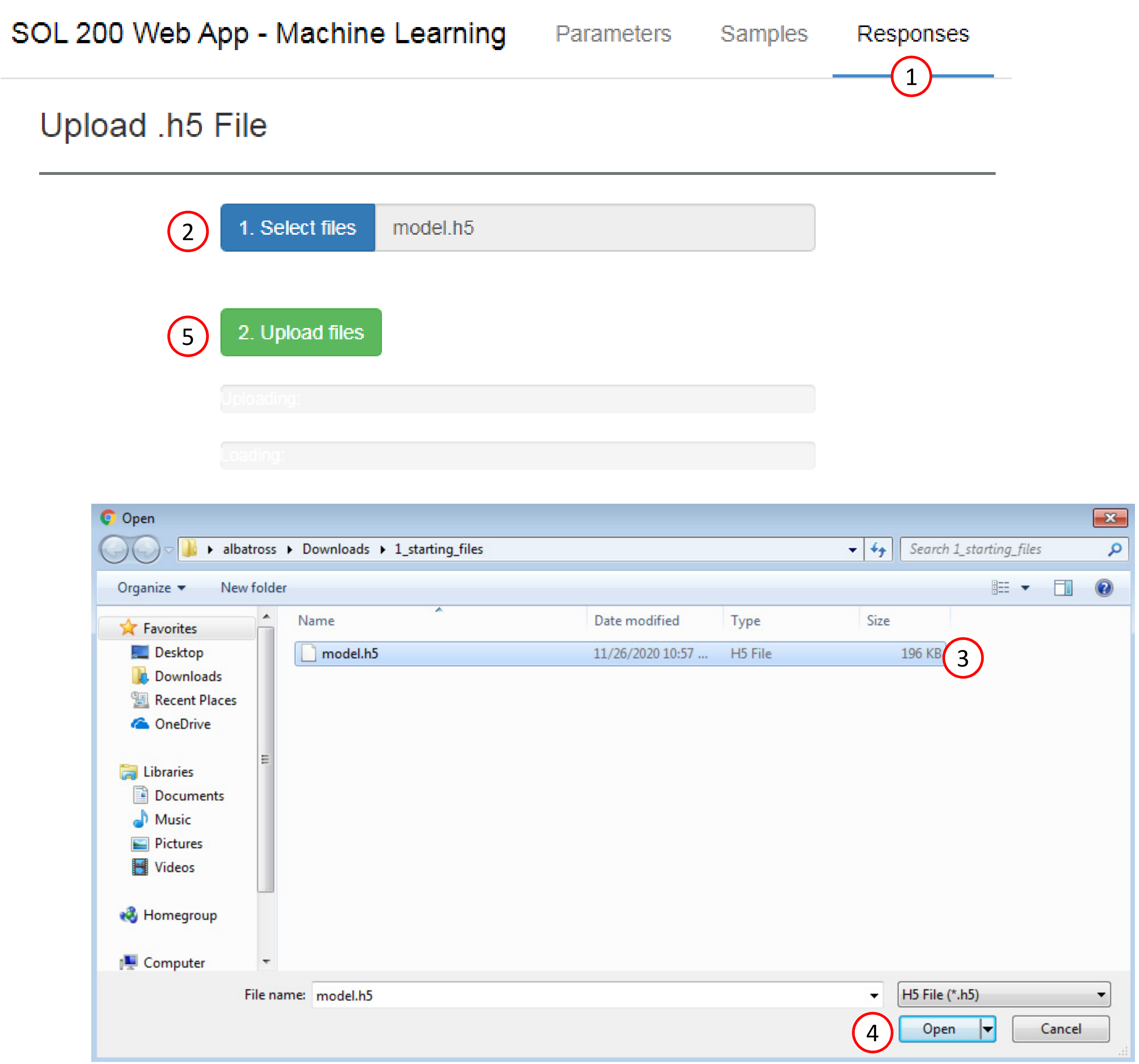


	Parameters	
Sample Number	x1	x2
1	1.042721	3.242836
2	2.985954	2.083597
3	4.257217	.8577
4	3.806829	2.855711
5	1.975237	.4956
6	2.295451	3.915345
7	.8528	1.933706
8	4.882389	4.436677
9	.06335	4.626104
10	3.494144	1.131369

Responses

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

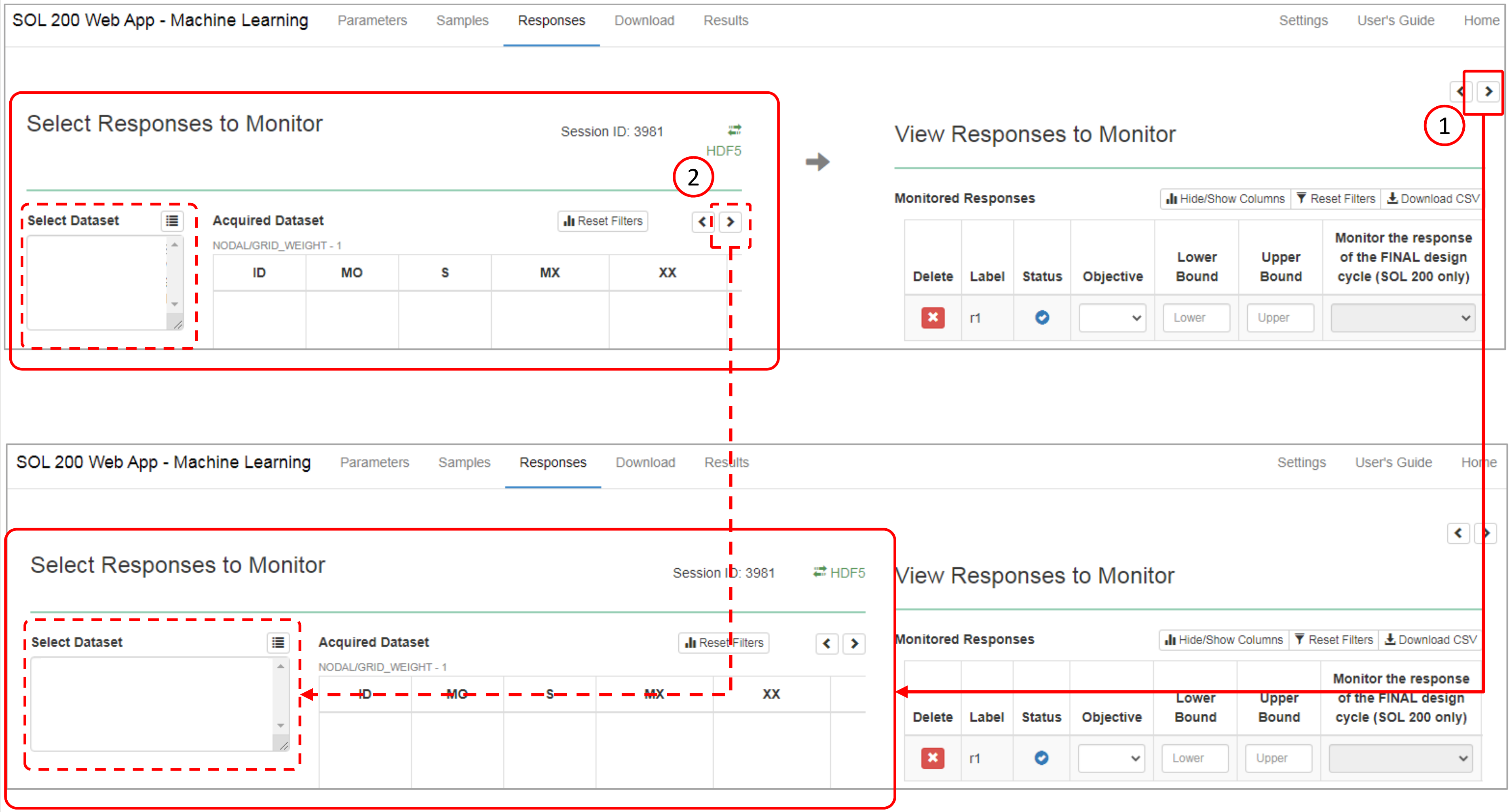
- On this page, the H5 file is uploaded to the web app.



Adjust the Column Width

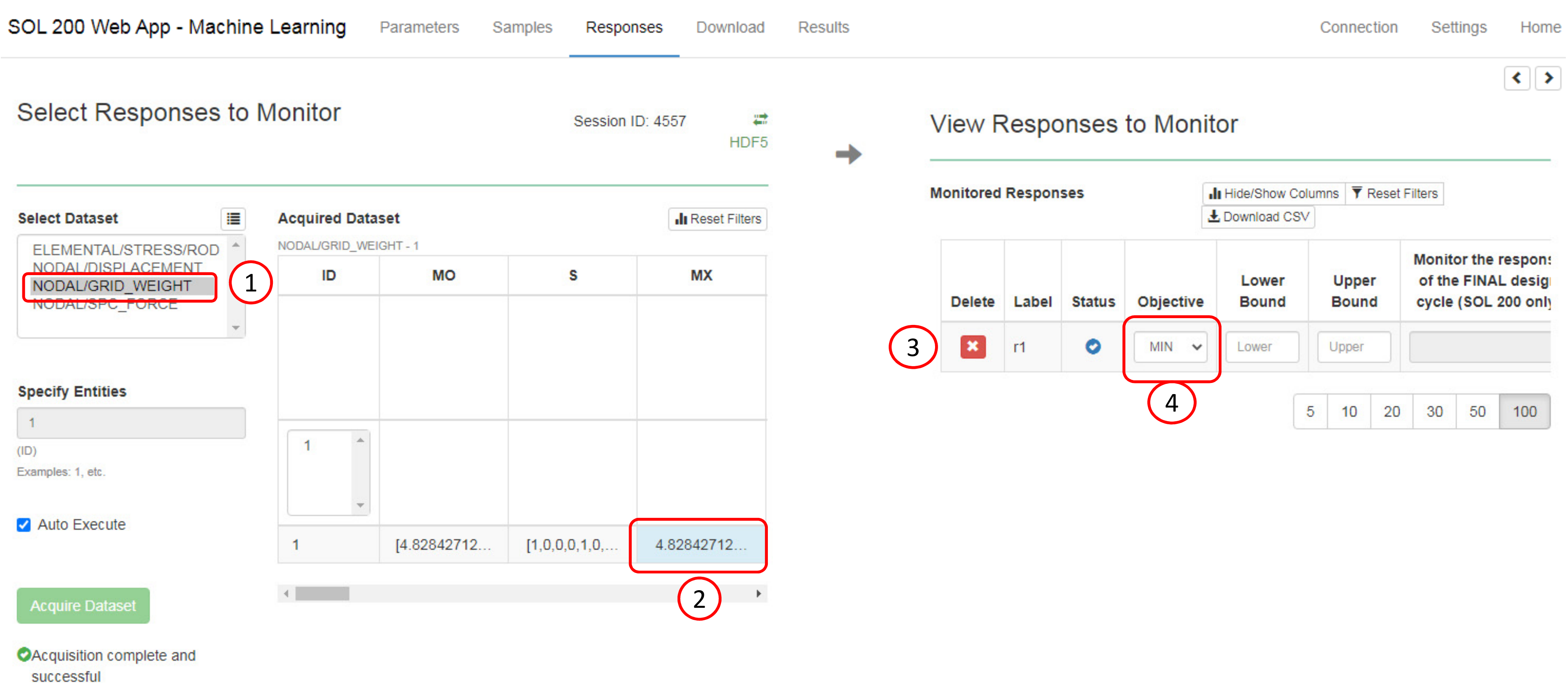
1. Optional - Use at your liking the buttons at the top right hand corner to adjust the width of the left and right columns
2. Optional – Use the indicated buttons to adjust the width of the column Select Dataset

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



Select Responses

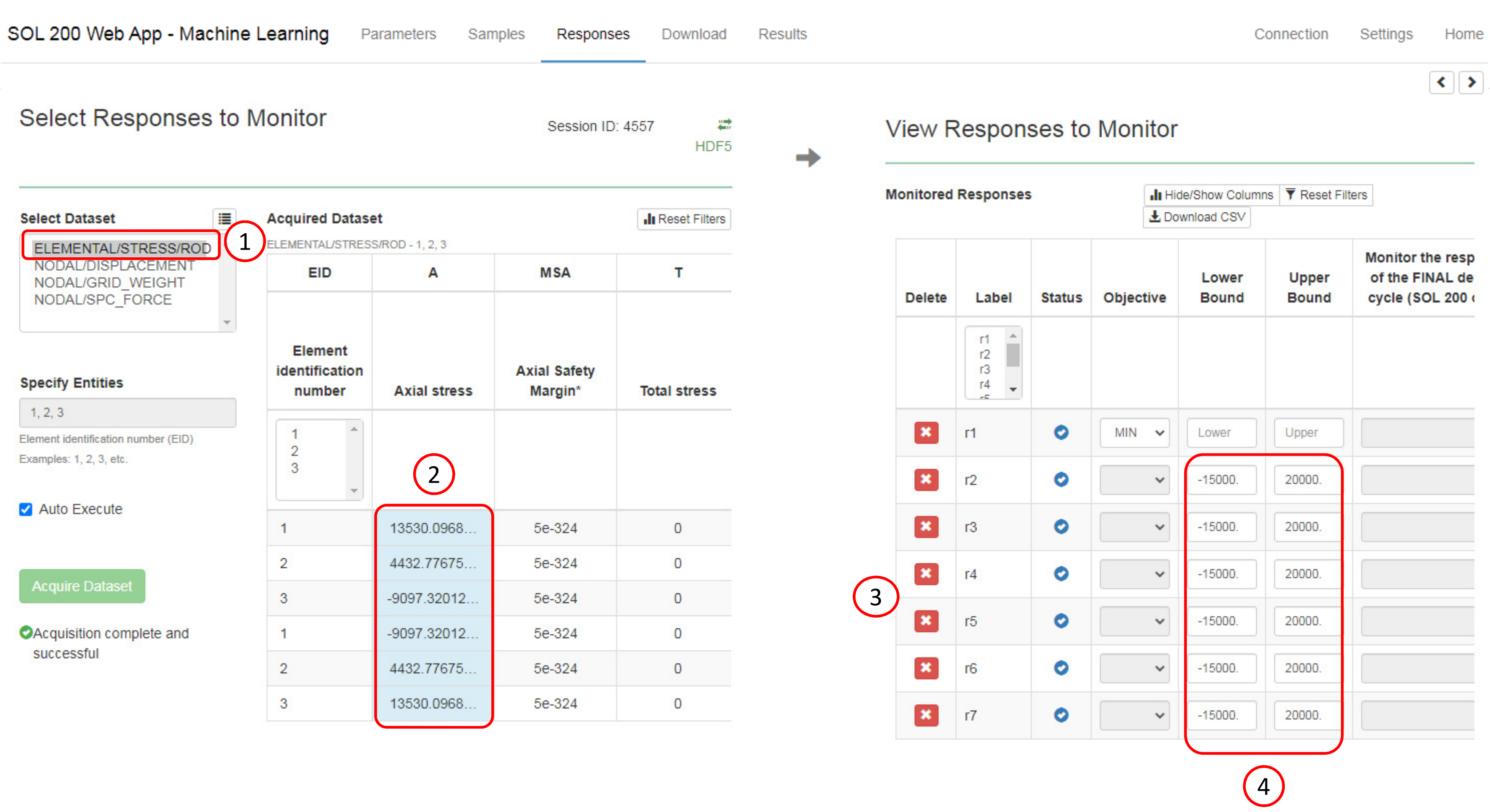
1. Select the following dataset: NODAL/GRID_WEIGHT
2. Select the indicated cell
3. The newly created Response to Monitor is listed as r1
4. Set this response to Objective: MIN



- Any cell that includes a single decimal point can be set as a response to monitor.
- For this example, cells in the MX column can be selected. Cells in the MO and S column cannot be selected because the cells contain bracket characters ([and]).

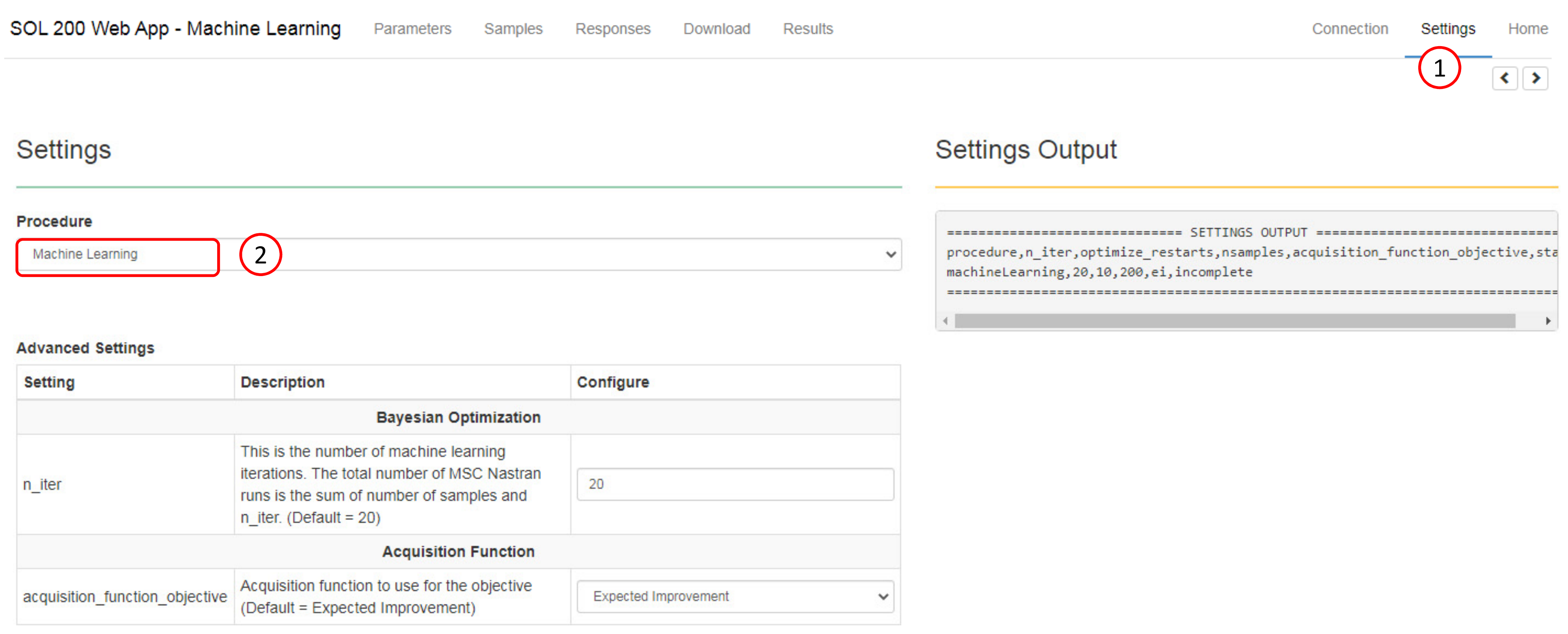
Select Responses

1. Select the following dataset: ELEMENTAL/STRESS/ROD
2. Select the indicated cells
3. The newly created Response to Monitor is listed as r2-r7
4. Use the following values to specify the constraints
    - Lower Bound: -15000.
    - Upper Bound: 20000.



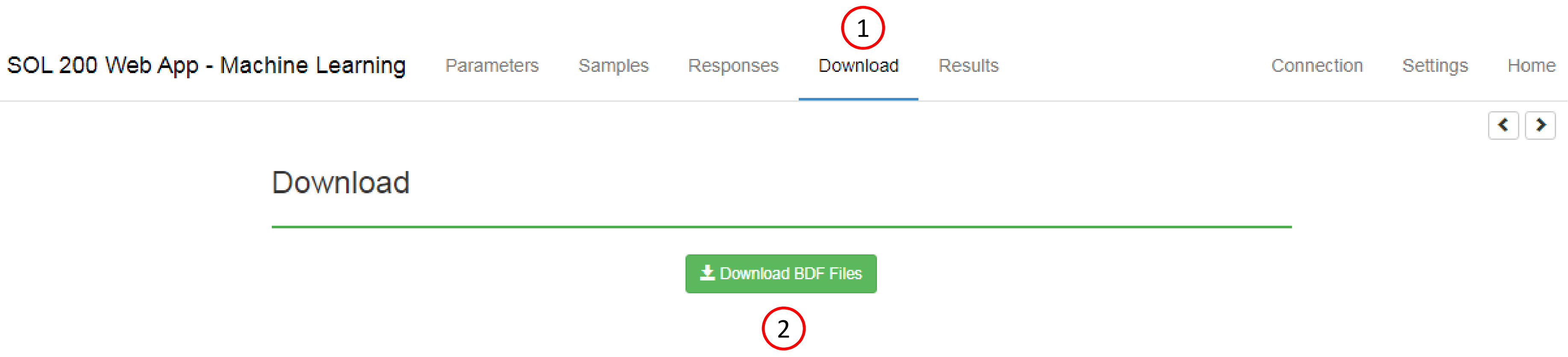
Settings

1. Click Settings
2. Set Procedure as Machine Learning



Download

1. Click Download
2. Click Download BDF Files

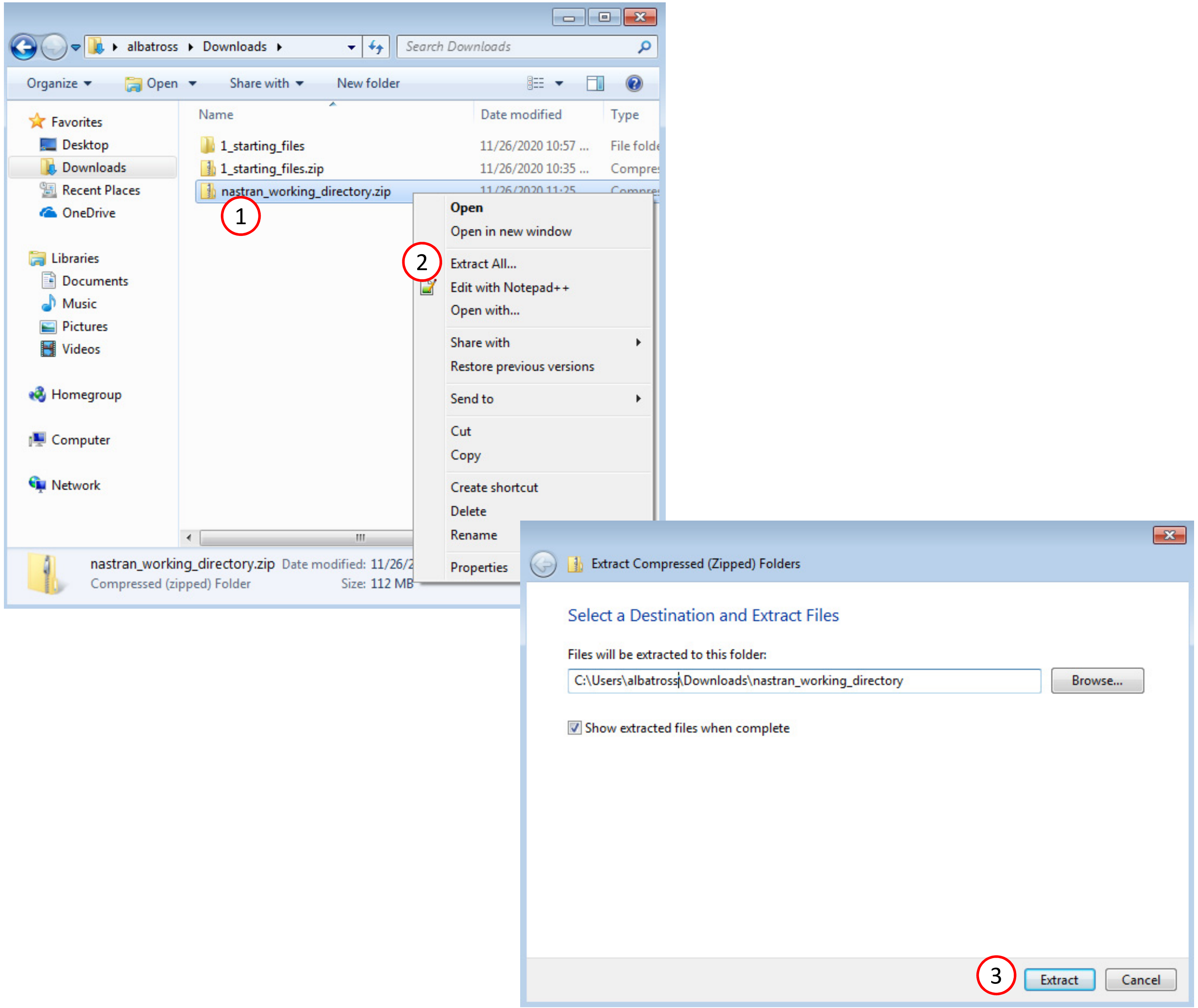


Start MSC Nastran

A new .zip file has been downloaded

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

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



Start Desktop App

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

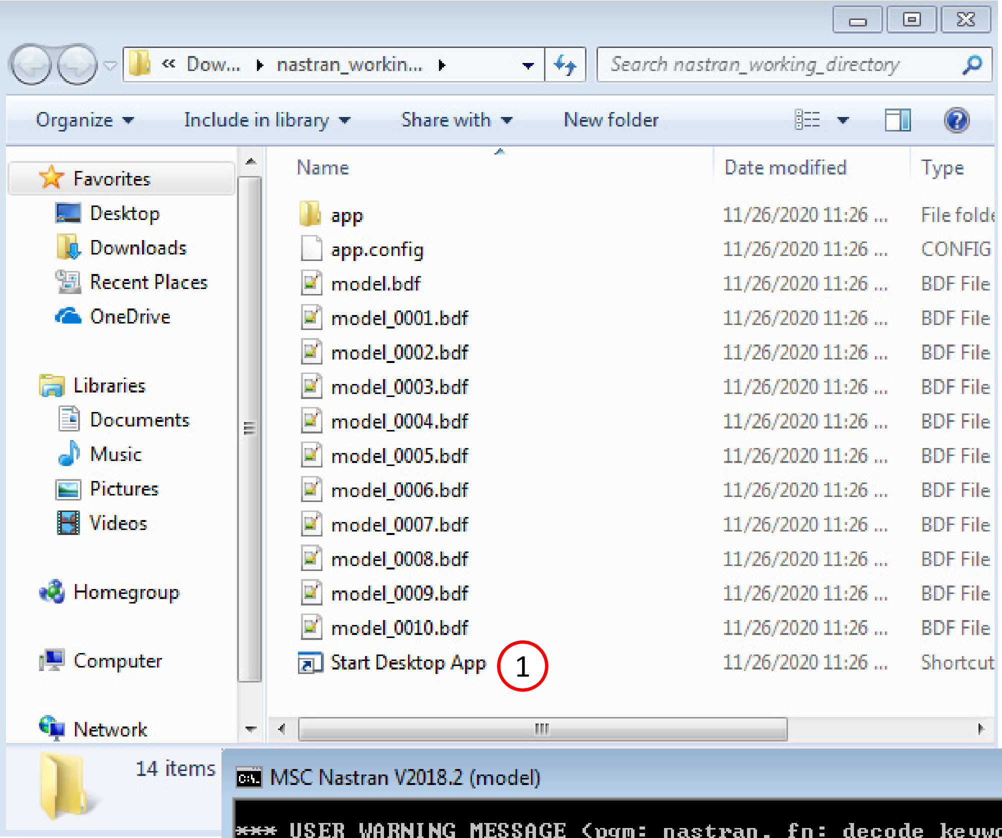
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the remote machine. 3) After completion, copy the BDF, F06, LOG, H5 files to the local machine. 4) Click "Start Desktop App" to display the results.

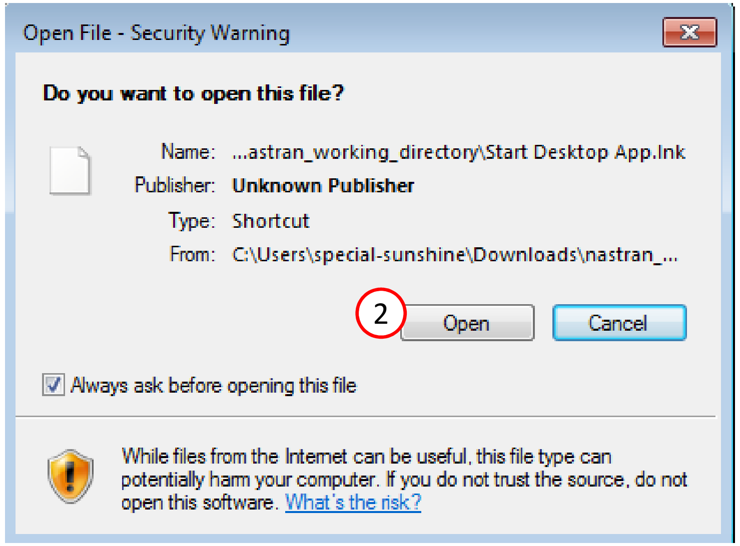
Using Linux?

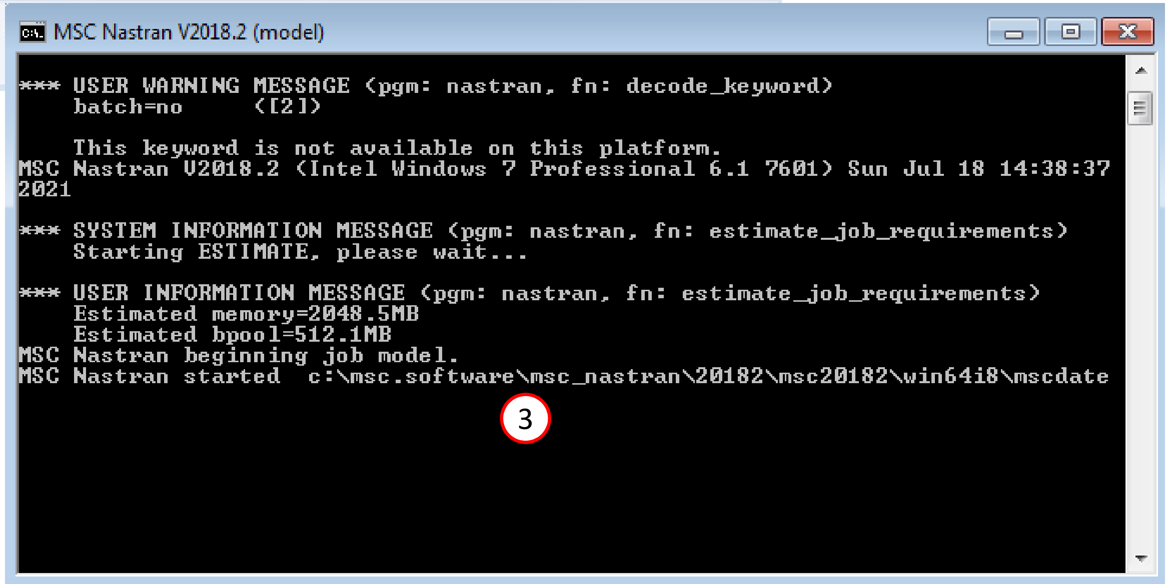
Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
   cd ./nastran_working_directory
3) Use this command to start the process
   ./Start_MSC_Nastran.sh

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

sudo chmod -R u+x ./nastran_working_directory







Status

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

SOL 200 Web App - Status

Python   MSC Nastran

Status

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

Machine Learning Results

- During execution of the Desktop App, you will get a progress update regarding the best feasible design

SOL 200 Web App - Machine Learning Results

Home

Session ID: 77272

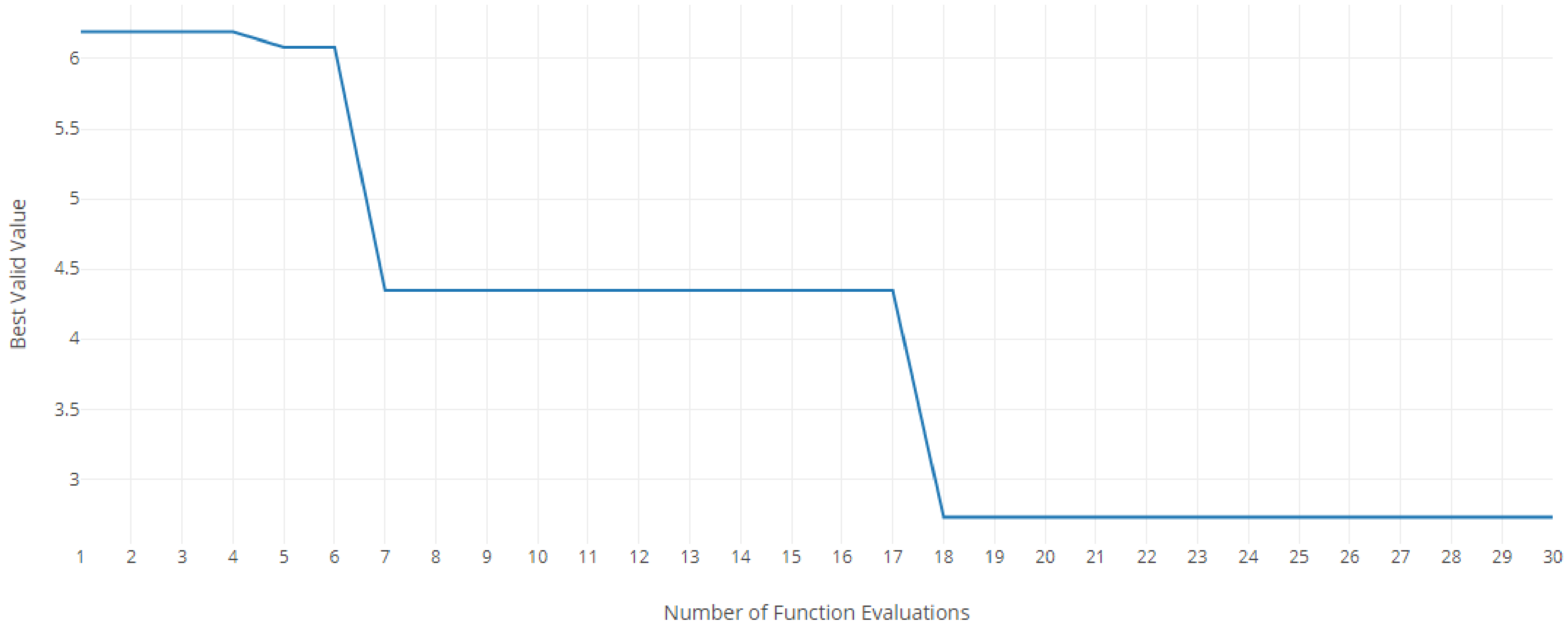
Completed successfully

Upload .csv File

CSV Import

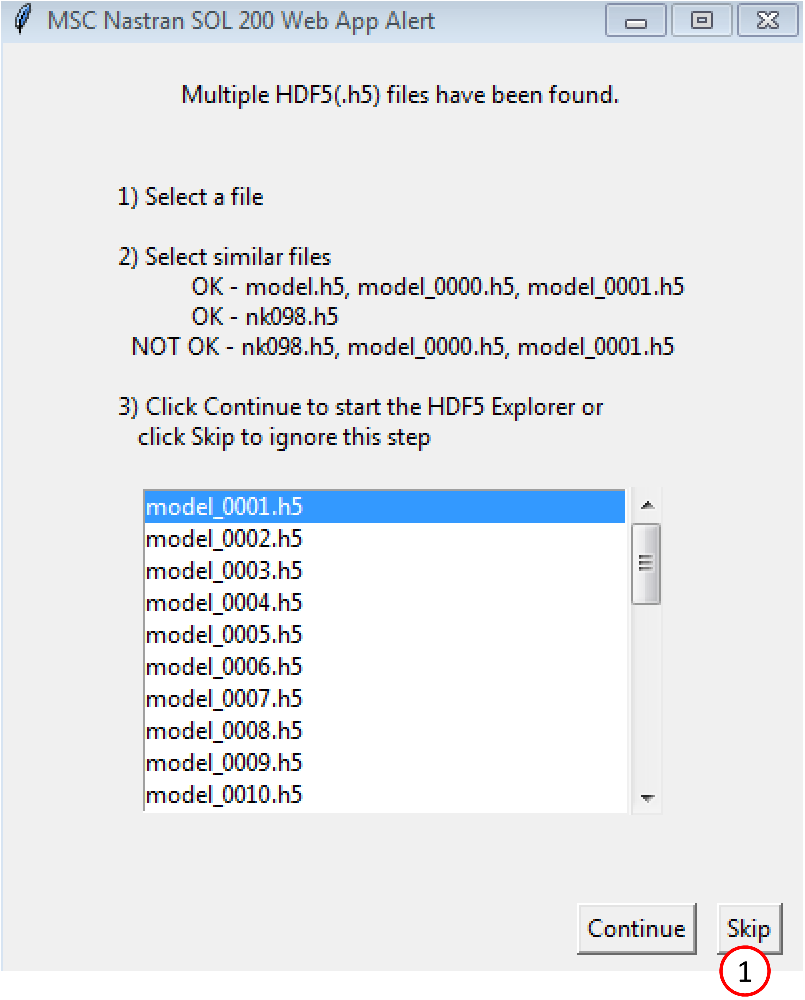
Select files | a_tmp_best_valid_value.csv | Import

Best Valid Value



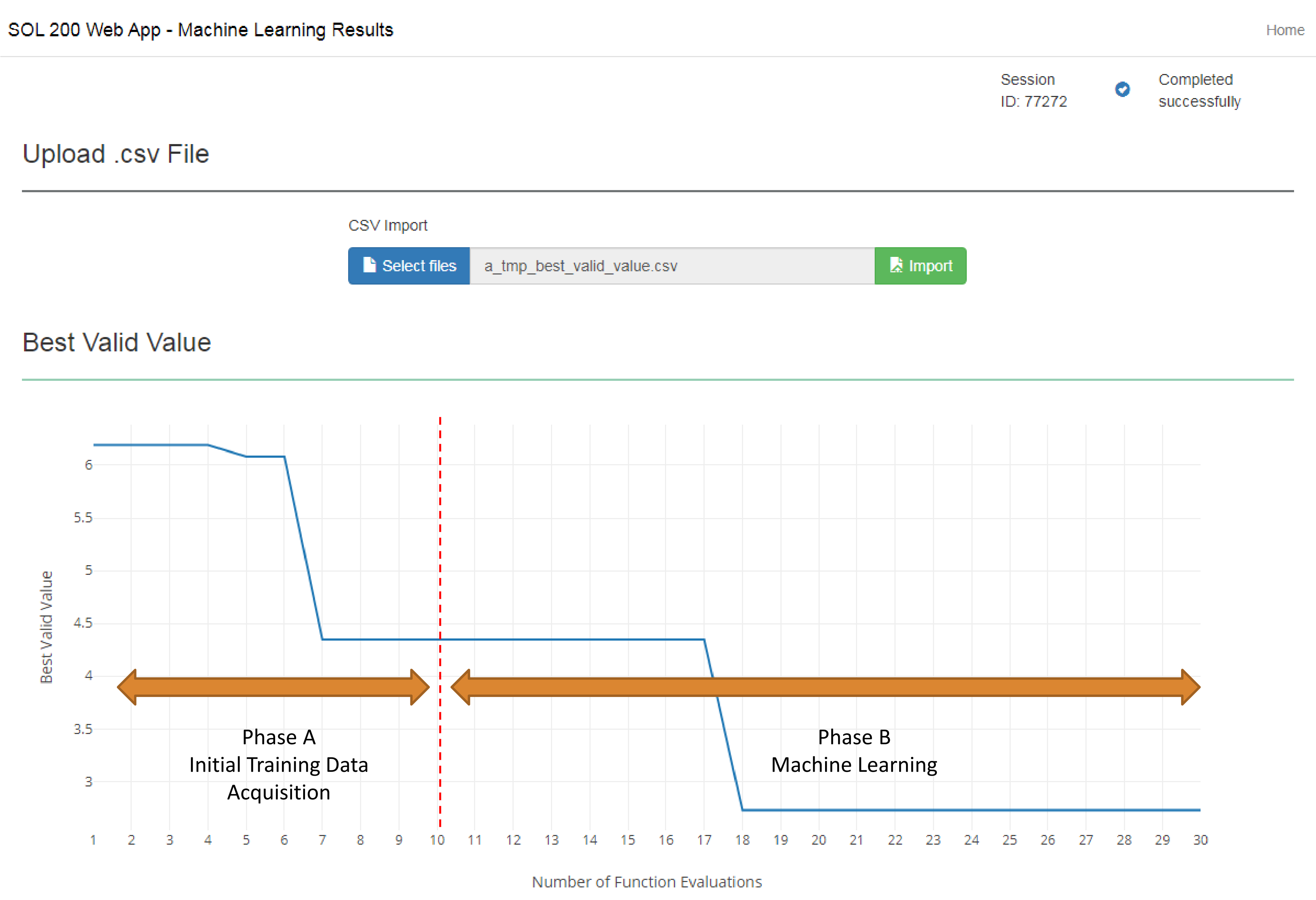
Machine Learning Results

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



Machine Learning Results

- The entire process consists of 2 phases.
  - Phase A – Initial Training Data Acquisition
    - This phase involves evaluating the FE model at different sampling points and recovering the monitored responses for the objective and constraints. The recovered monitored responses are referred to as training data.
    - This training data is used to train the regression model at the start of phase B, the machine learning phase.
  - Phase B – Machine Learning
    - This phase involves the machine learning process. The regression models for the objective and constraints are used to determine the next sample point to evaluate.
    - After each sample evaluated, the regression models are updated with the latest training data.
- This example was initially configured for a 10 sample Latin Hypercube design. After the initial training data was required, machine learning was executed for 20 runs. A total of 30 runs were performed.



Machine Learning Results

1. Each drop in the Best Valid Value (BVV) indicates a better feasible design has been obtained. For example, the machine learning process evaluates samples 15, 16 and 17 but the BVV is flat, indicating a better design has NOT been found. After sample 18 is evaluated, a better feasible design has been found, indicated by a drop in the BVV.

- Refer to the appendix for more explanation of the BVV.

SOL 200 Web App - Machine Learning Results

Home

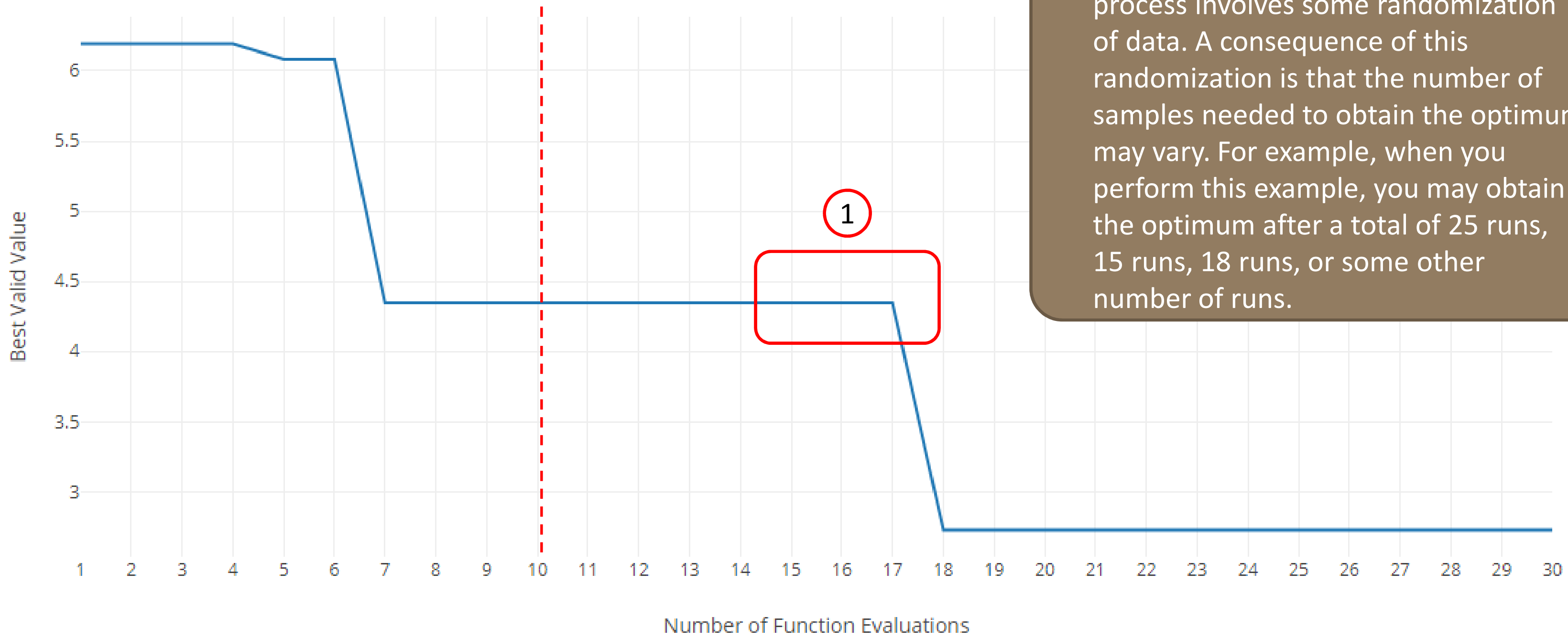
Session ID: 77272 Completed successfully

Upload .csv File

CSV Import

Select files a_tmp_best_valid_value.csv Import

Best Valid Value



- Important! The machine learning process involves some randomization of data. A consequence of this randomization is that the number of samples needed to obtain the optimum may vary. For example, when you perform this example, you may obtain the optimum after a total of 25 runs, 15 runs, 18 runs, or some other number of runs.

Machine Learning Results

1. A bar chart displays the objective value after each sample. A green colored bar indicates the constraints are satisfied for that sample. A gray colored bar indicates the constraints are NOT satisfied for that sample.
2. The Status message indicates sample 18 is the best design. Your solution might be different.
3. Use the horizontal bar to locate sample 18 in the table.

The best feasible design yields an objective between 2.7 and 2.9. Your solution will be different.

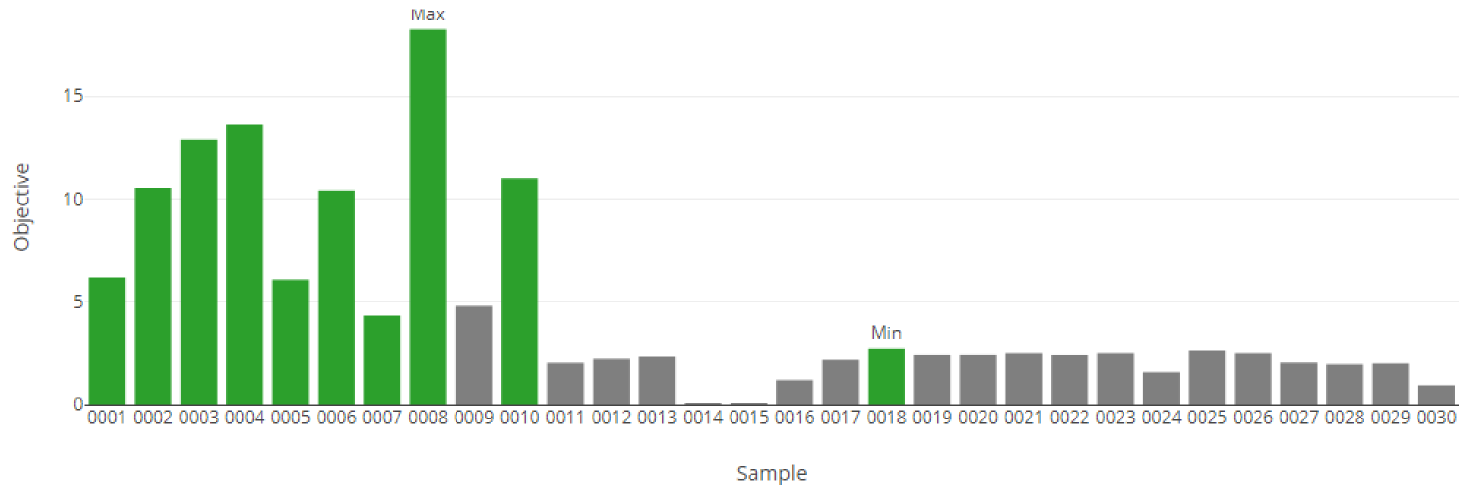
- Important! The machine learning process involves some randomization of data. A consequence of this randomization is that the number of samples needed to obtain the optimum may vary. For example, when you perform this example, you may obtain the optimum after a total of 25 runs, 15 runs, 18 runs, or some other number of runs.

Status

1

```
THE LATEST OPTIMAL SOLUTION IS: SAMPLE # 18 (MIN), SAMPLE # 8 (MAX)
OBJECTIVE                = 2.7291E+0 (MIN), 1.8246E+1 (MAX)
MAXIMUM CONSTRAINT VALUE = -5.0356E-3, -8.4611E-1 (FEASIBLE DESIGNS)
```

Objective for Each Sample



Data for Each Sample

3

Item	ample 0014	Sample 0015	Sample 0016	Sample 0017	Sample 0018	Sample 0019	Sample 0020	Sample 0021	Sample 0022	Sample
Extrema (Max/Min)					Min					
Objective	4144E-2	6.5943E-2	1.1807E+0	2.1914E+0	2.7291E+0	2.4248E+0	2.4272E+0	2.5084E+0	2.4212E+0	2.5090E+
Normalized Constraint	4679E+1	6.5482E+1	7.4080E+1	2.5760E-1	-5.0356E-3	1.2151E-1	1.5028E-1	8.5008E-2	1.5616E-1	1.1779E-
X1	0000E-2	1.0000E-2	1.0000E-2	7.5460E-1	8.1078E-1	7.1514E-1	8.5461E-1	7.3703E-1	6.5261E-1	6.7327E-
X2	5860E-2	3.7658E-2	1.1524E+0	5.7025E-2	4.3591E-1	4.0204E-1	1.0000E-2	4.2375E-1	5.7537E-1	6.0468E-

2

End of Tutorial

Appendix

Appendix Contents

What is the Best Valid Value?

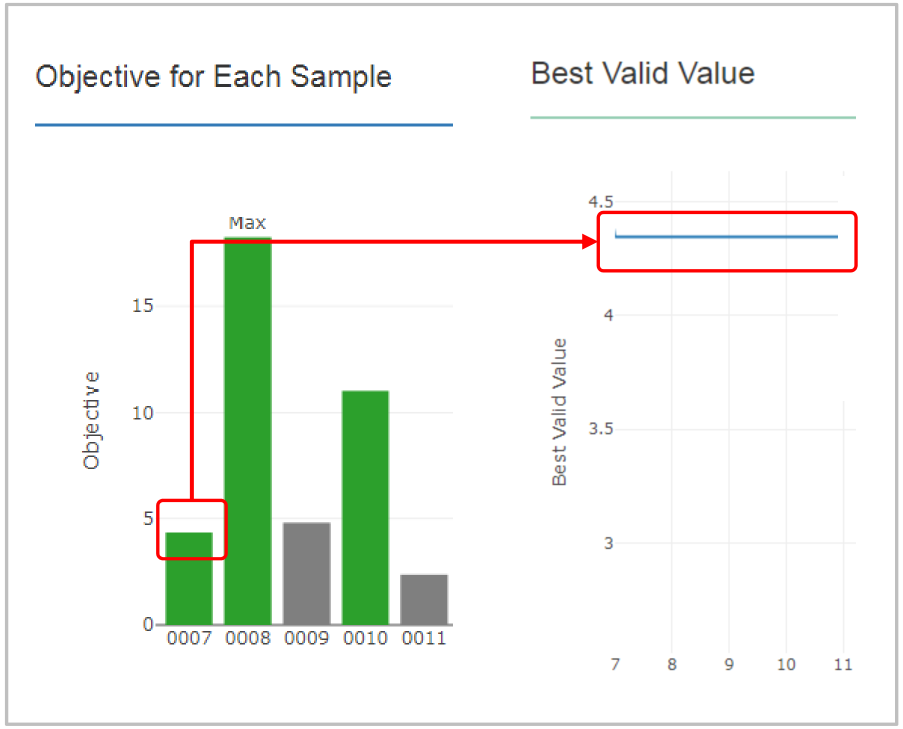
How to import and edit previous files

What is the Best Valid Value (BVV)?

The Best Valid Value (BVV) is the best objective value of all previously evaluated feasible samples.

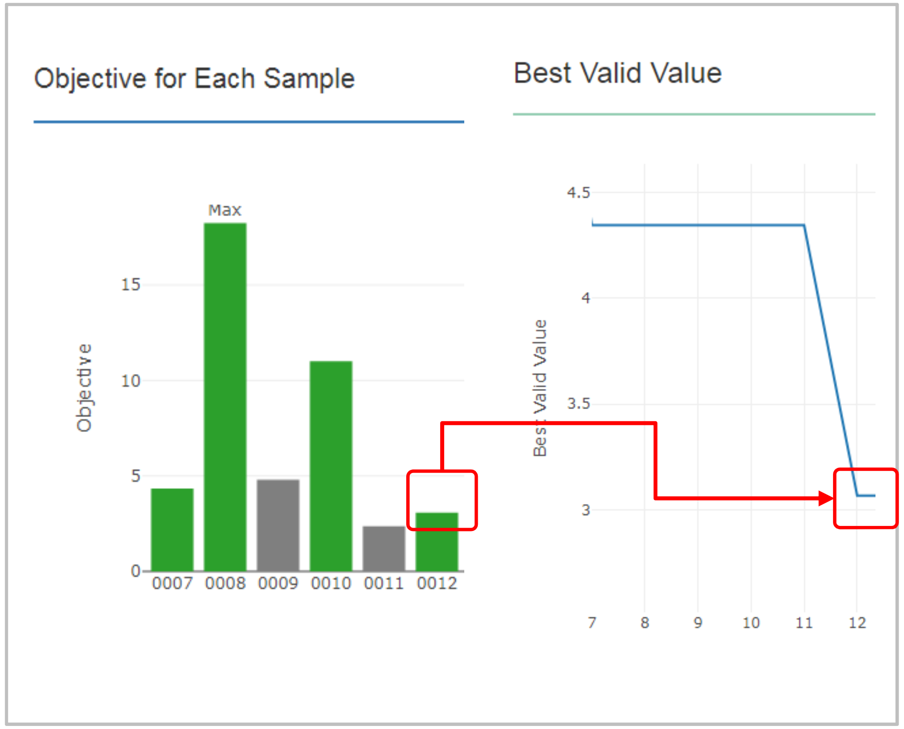
1. Consider samples 7-11. Out of samples 7-11, sample 7 is the best feasible design because its objective value is the lowest and the sample is a feasible design.
   - The BVV plot shows a flat line for samples 8, 9, 10 and 11 because a better feasible design has NOT been found.

2. Now consider samples 7-12. Samples 12 is now the best feasible design, the objective value of sample 12 is now less than sample 7.
   - The BVV plot is updated to reflect the new best design.



Samples 7-11

1



Samples 7-12

2

How to import and edit previous files

How to import and edit previous files

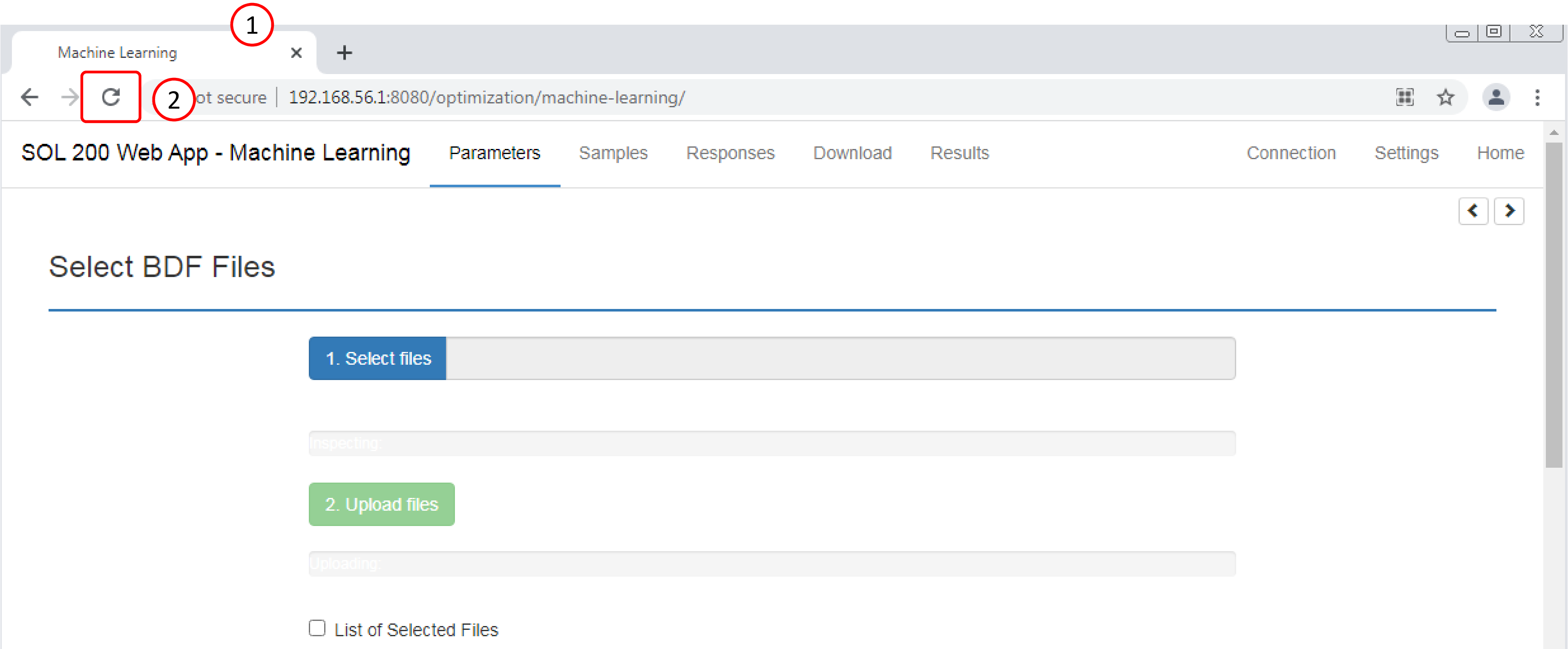
The parameters, samples and responses are contained in the following files

- 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

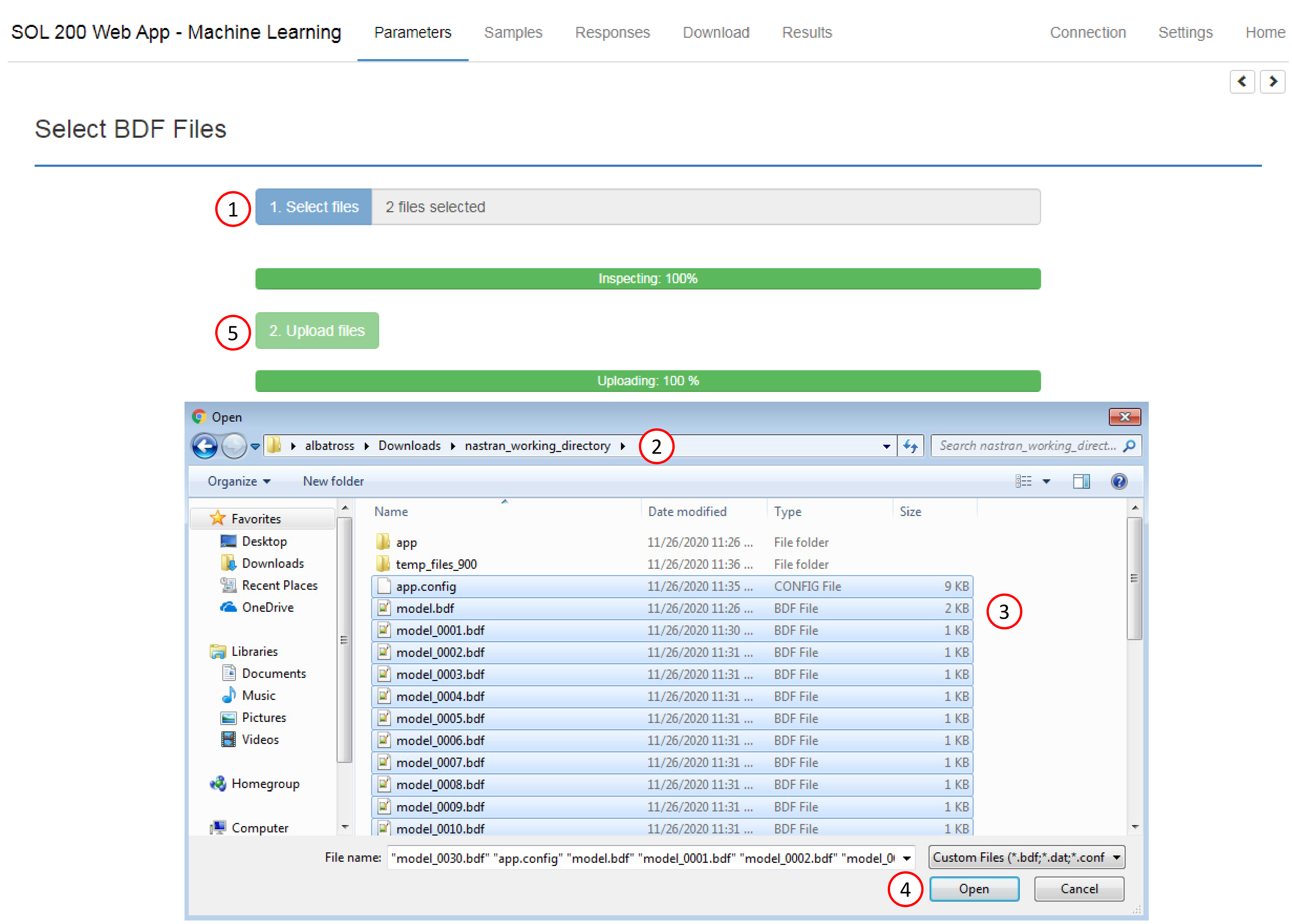


- Refreshing the page is only required when the *Select files* button is disabled.

Import

1. Click Select Files
2. Navigate to the folder named nastran_working_directory
3. Select all the BDF files AND the app.config file.
4. Click Open
5. Click Upload files

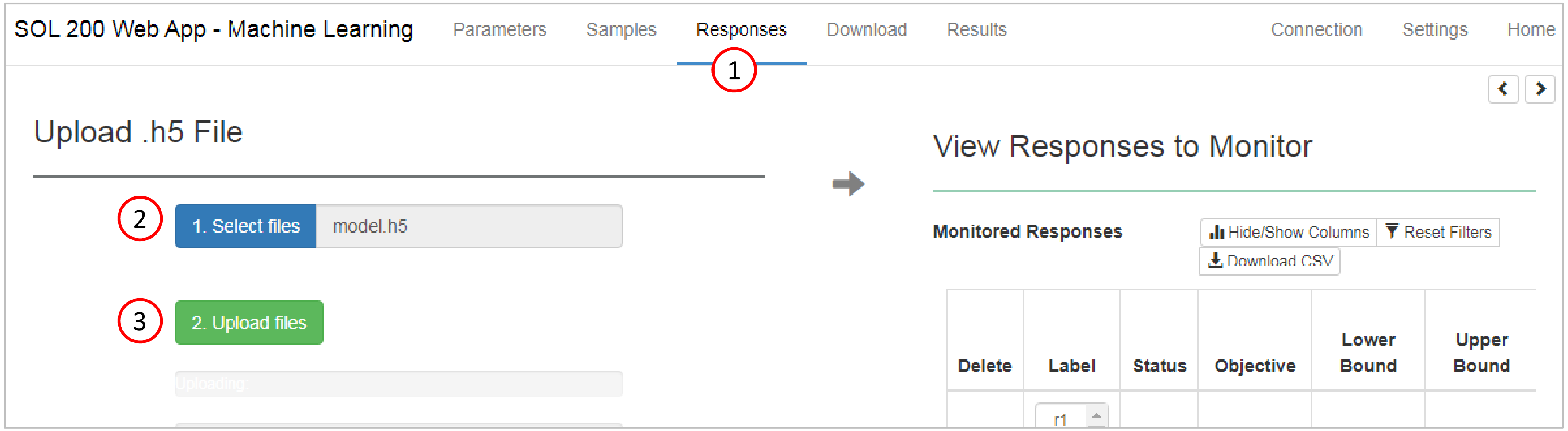
- All imports require the app.config file to be selected.

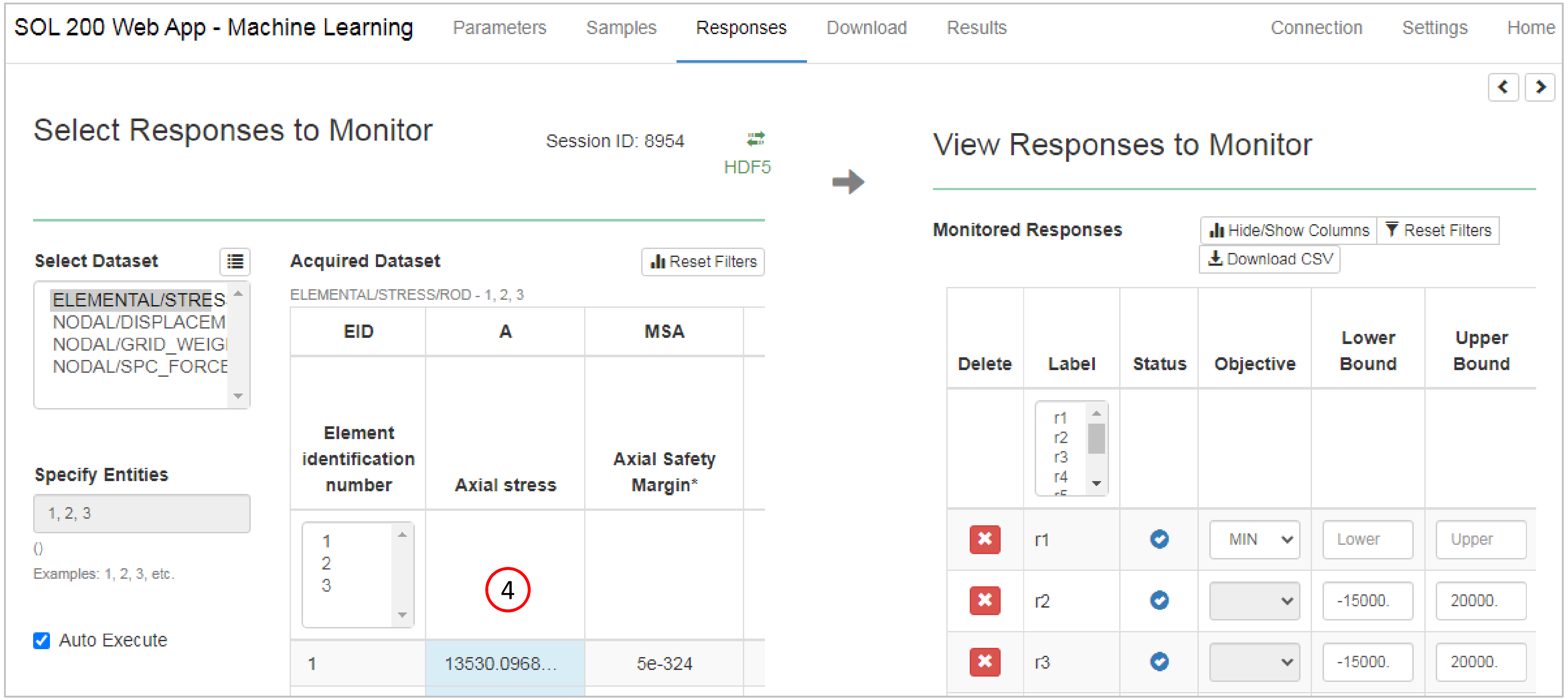


Import

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





Import

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

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

Select BDF Files

1. Select files | 2 files selected

Inspecting: 100%

2. Upload files

Uploading: 100 %

☐ List of Selected Files

Select Parameters

```
$__1___||__2___||__3___||__4___||__5___||__6___||__7___||__8___||__9___||__10__|

FORCE   300     4               20000.  0.8     -0.6
FORCE   310     4               20000.  -0.8    -0.6
MAT1    1       1.0E+7          0.33    0.1
PROD    11      1       %x1%
PROD    12      1       %x2%
```

Configure Parameters

Delete	Parameter	Status	Low	High	Comments
✖	x1	✔	.01	5.	Field 4 of PROI
✖	x2	✔	.01	5.	Field 4 of PROI