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

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

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



Goal: Decide UQ Method

- Optimization under uncertainty (OUU) is significantly more costly than a traditional optimization involving deterministic inputs and outputs. Part of the cost is due to the number of black box function runs that are necessary to perform the uncertainty quantification (UQ) and determine the tail probabilities.
- Sampling alone is the simplest but one of the costliest methods for UQ. The mean value first-order second-moment (MVFOSM) method is one of the least expensive UQ methods, but is limited to responses that are linear or nearly linear, response distributions that are normal (Gaussian) or nearly normal, and requires gradients. Efficient OUU depends on carefully selecting the least costly and accurate UQ method.

Classification	Characteristics	
Sampling	nonsmooth, multimodal response functions;	sampling (Monte Carlo or LHS)
	response evaluations are relatively inexpensive	
Local	smooth, unimodal response functions;	local_reliability (MV, AMV/AMV ² ,
reliability	larger sets of random variables;	AMV+/AMV ² +, TANA, FORM/SORM)
	estimation of tail probabilities	
Global	smooth or limited nonsmooth response;	global_reliability
reliability	multimodal response; low dimensional;	
	estimation of tail probabilities	
Adaptive	smooth or limited nonsmooth response;	importance_sampling,
Sampling	multimodal response; low dimensional;	gpais, adaptive_sampling,

Desired Problem

Table 5.3: Guidelines for UQ method selection.

estimation of tail probabilitiespof_dartssmooth or limited nonsmooth response;
multimodal response; low dimensional;
estimation of moments or moment-based metricspolynomial_chaos,
stoch_collocationuncertainties are poorly characterizedinterval: local_interval_est,
global_interval_est, sampling;
BPA: local_evidence, global_evidencesome uncertainties are poorly characterizednested UQ (IVP, SOP, DSTE) with epistemic
outer loop and aleatory inner loop, sampling

Source: Dakota User's Manual

Applicable Methods



Method

Stochastic

expansions

Epistemic

Mixed UQ

Uncertainty Quantification Problem Statement





Goal

The goal of this exercise is to determine the distribution of mass, stress and displacement responses. If the distribution is normal or nearly normal, the MVFOSM method may be used for UQ and OUU.

An initial sampling of 50 MSC Nastran runs is performed. The responses of each run is collected and the following is done.

- 1. Create histograms (Histogram and Frequency Diagram)
- 2. Compare histograms with a normal distribution

If the histograms have a normal or nearly normal distribution, the MVFOSM method may be used.

The MVFOSM method also requires gradients to be available, which is also discussed in this exercise.

Histograms



Sample moment statistics for each response function

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

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Examples of Nonnormal Distributions

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

- 1. For example 1, the response's skewness value is 1.0035985638e+00. This is a significantly large skewness value and indicates the distribution is highly asymmetric. A look at the histogram confirms the distribution is asymmetric. The orange plot which is the PDF for a normal distribution does not align to the histogram. Also, Microsoft PowerPoint was used to superimpose a possible PDF that better aligns to the histogram, refer to the red dashed line/plot. The actual distribution is likely a bi-modal distribution, not a normal distribution.
- P. For example 2, the response's skewness value is -7.0504626153e+00. This is a significantly large skewness value and indicates the distribution is highly asymmetric. A look at the histogram confirms the distribution is asymmetric. The orange plot which is the PDF for a normal distribution does not align to the histogram. Also, Microsoft PowerPoint was used to superimpose a possible PDF that better aligns to the histogram, refer to the red dashed line/plot.

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





Example 2 2





Goal: Decide UQ Method

- The goal of this exercise is to detail a procedure to do the following:
 - Determine if the response distributions are normal
 - Decide to use the MVFOSM method for a future UQ and OUU
 - Configure an MSC Nastran SOL 200 optimization assuming the inputs and outputs are deterministic
 - Determine an ideal starting point for a future OUU
 - Identify critical constraints to consider in a future OUU
 - Prepare MSC Nastran bulk data files (BDF) for future OUU configuration



Contact me

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

christian@ the-engineering-lab.com



Tutorial

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Tutorial Overview

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

Special Topics Covered

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



SOL 200 Web App Capabilities

Compatibility

- Google Chrome, Mozilla Firefox or Microsoft Edge Installable on a company laptop, workstation or
- Windows and Red Hat Linux

server. All data remains within your company.

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

Benefits

entries.

- REAL TIME error detection. 200+
- error validations.
- REALT TIME creation of bulk data •
- 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.



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



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



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



PBMSECT Web App Generate PBMSECT and PBRSECT entries graphically



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



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



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



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The Engineering Lab

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.

Select a web app to begin Before After Optimization for SOL 200 Multi Model Optimization Machine Learning | Parameter HDF5 Explorer Viewer Study Tutorials and User's Guide (1)Full list of web apps

SOL 200 Web App

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Obtain Starting Files

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

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

There are many methods available for uncertainty quantification to approximate statistics such as mean, standard deviation and tail probabilities of stochastic responses. Each method has its own computational cost. During an optimization under uncertainty (OUU), an uncertainty quantification (UQ) is performed frequently. If the cost of each UQ is high, the OUU's computational costs will also be prohibitively high.

The mean value first-order second-moment (MVFOSM) method is the one of the least expensive UQ methods and





Diskn Sensitvities



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



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Create the Starting H5 File

(1

MSC Nastran

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
- Navigate to the directory named 1_starting_files_part_a
- 3. Select the indicated file
- 4. Click Open
- 5. Click Run
- 6. The starting H5 file is created

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MSC/NASTRAN Command Information
MSC/NASTRAN Input File
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File...
Optional keywords
Run
Cancel
Clear





Use the same MSC Nastran version throughout this exercise

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

To ensure compatibility, <u>use the same MSC Nastran version throughout this exercise</u>. 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.



Overview

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

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

Part B – Performing a Preliminary Optimization with Deterministic Inputs, and Screening Constraints

- An MSC Nastran SOL 200 optimization is performed to determine a starting point for a future OUU.
- The number of constraints is reduced by only considering the most critical, active or violated constrains found during a SOL 200 optimization.

Part C – Preparing MSC Nastran Bulk Data Files to Output Gradients for Optimization Under Uncertainty

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



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



Uncertainty Quantification Problem Statement





Open the Correct Page

1. Click on the indicated link

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20

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. < >

Select BDF Files





Parameters

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

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

Select Parameters



Configure Parameters





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

- Description of the set of the
- 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.

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Select Responses

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



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Select Responses

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

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Results

SOL 200 Web App - Machine Learning Parameters Samples Responses Download



: >

5 10 20 30 50 100

Select Responses

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

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

View Responses to Monitor

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Settings

1. Click Settings

2. Set Procedure to Dakota

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

- 1. Click Dakota
- 2. Set UQ Method to Sampling

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Dakota -Uncertainty Quantification (UQ)

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

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

Uncertainty Quantification 1

Configure UQ Variables





Uncertainty Quantification

- Click Method
- 2. Set the keyword samples to 50
 - The uncertainty quantification will use 50 MSC Nastran runs
 - Why 50 runs? The gold rule with sampling is "more runs are better as long as budget allows for it." A convergence study was performed for 10, 20, 40, and 80 runs and revealed after 40 runs, the mean, standard deviation and other statistics converge. 40 runs could be selected, but if resources allow for more runs, use more runs. 50 runs were selected for this exercise since resources allowed for additional runs.
- Refer to the Dakota Reference Manual for a description of each keyword, e.g. model_pointer, distribution, fixed_seed, seed,

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Technology Partner



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.

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Start Desktop App

- 1. Inside of the new folder, double click on Start Desktop App
- 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



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Open

x

Cancel

Status

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

SOL 200 Web App - Status

Status

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



MSC Nastran

n Python

UQ Completion

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

Machine Learning × Status	× Dakota Results	× HDF5 Explorer	× +
\leftrightarrow \rightarrow C (i) localhost:8080/optimization/hdf5/?room=79445			
SOL 200 Web App - HDF5 Explorer Acquire Dataset	Plots Browser Combine Plots	Last Plot Added	



3

Statistics based on 50 samples

2

Sample	e moment statistics for each response f	unction	(5)	🛃 Download CSV		
4	Mean	Standard Deviation	Skewness	Kurtosis		
r1	4.8279590943e+00	1.1754839330e-01	5.3215577792e-02	-4.1072200142e-01		
r2	1.3550873230e+04	4.7109459188e+02	1.5126416459e-01	-2.7255138682e-01		
r3	4.4340359141e+03	7.8657599827e+01	-9.4060255845e-02	-7.1675181810e-01		
r4	-9.1168373160e+03	4.2713590041e+02	-1.5808602311e-01	-2.5354362937e-01		
r5	-9.1168373160e+03	4.2713590041e+02	-1.5808602311e-01	-2.5354362937e-01		
r6	4.4340359141e+03	7.8657599827e+01	-9.4060255845e-02	-7.1675181810e-01		
r7	1.3550873230e+04	4.7109459188e+02	1.5126416459e-01	-2.7255138682e-01		
r8	2.2667710546e-02	8.9585901001e-04	1.5733778402e-01	-2.5950843535e-01		
r9	-4.4340359141e-03	7.8657599827e-05	9.4060255845e-02	-7.1675181810e-01		
r10	-2.2667710546e-02	8.9585901001e-04	-1.5733778402e-01	-2.5950843535e-01		
r11	-4.4340359141e-03	7.8657599827e-05	9.4060255845e-02	-7.1675181810e-01		

(1) File: dakota.out

<<<< Function evaluation summary (UQ_I): 50 total (50 new, 0 duplicate)

Statistics based on 50 samples:

Sample moment statistics for each response function:

	Mean	Std Dev	Skewness	Kurtosis
r1	4.8279590943e+00	1.1754839330e-01	5.3215577792e-02	-4.1072200142e-01
r2	1.3550873230e+04	4.7109459188e+02	1.5126416459e-01	-2.7255138682e-01
r3	4.4340359141e+03	7.8657599827e+01	-9.4060255845e-02	-7.1675181810e-01

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UQ Results

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

UQ Results

1. Click Histograms

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

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



Sample moment statistics for each response function

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



UQ Results

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



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Examples of Nonnormal Distributions

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

- 1. For example 1, the response's skewness value is 1.0035985638e+00. This is a significantly large skewness value and indicates the distribution is highly asymmetric. A look at the histogram confirms the distribution is asymmetric. The orange plot which is the PDF for a normal distribution does not align to the histogram. Also, Microsoft PowerPoint was used to superimpose a possible PDF that better aligns to the histogram, refer to the red dashed line/plot. The actual distribution is likely a bi-modal distribution, not a normal distribution.
- 2. For example 2, the response's skewness value is -7.0504626153e+00. This is a significantly large skewness value and indicates the distribution is highly asymmetric. A look at the histogram confirms the distribution is asymmetric. The orange plot which is the PDF for a normal distribution does not align to the histogram. Also, Microsoft PowerPoint was used to superimpose a possible PDF that better aligns to the histogram, refer to the red dashed line/plot.

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





Example 2 2





Can MVFOSM be used for uncertainty quantification?

- For the MVFOSM method to yield good approximations of tail probabilities, the response's distributions must be normal or nearly normal. Also, gradients must be available.
 - As confirmed in the previous steps, the response distributions are nearly normal.
 - Also, the weight, displacement and stress responses are response types supported by MSC Nastran SOL 200. Since MSC Nastran SOL 200 outputs sensitivities/gradients, gradients are available for the responses of interest.
- The answer to the original question is as follows: <u>Yes,</u> the MVFOSM method may be used for UQ and OUU.
- If the answer is no, then one of the other UQ methods available in Sandia Dakota should be considered, e.g. polynomial chaos, stochastic collocation, etc. Also, the

other UQ methods are greatly limited by the curse of dimensionality, so problems within 1-10 parameters are practical. Problems with more than 10 parameters may require up to thousands of FEA runs and are impractical. The true cost will vary depending on the UQ method and number of parameters and responses.

The MVFOSM method is significantly less computationally expensive and can address higher dimension problems, so take advantage of the MVFOSM method when possible. In a separate tutorial, a UQ and OUU involving +50 parameters is optimized with approximately 300 FEA runs. While some might call this costly, it is actually not considering other UQ methods during OUU might require +5,000 FEA runs.



Another Comment

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

Consider 2 examples.

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

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

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

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





+3σ

True Response Function

Approximate Response Function (Taylor Series)

Part B – Performing a Preliminary Optimization with Deterministic Inputs, and Screening Constraints



Optimization Problem Statement





Note

Since the MVFOSM method may be used, gradients must be available. MSC Nastran SOL 200 has a sensitivity analysis capability that outputs gradients. The bulk data files must be configured for MSC Nastran SOL 200. Variables, objective and constraints must be defined via entries DESVAR, DVPREL1, DRESP1, DCONSTR, etc. This has already been done. 6

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

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

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Optimization Results

After the analysis model is configured for SOL 200, the optimization is performed for two reasons.

- 1. Determine a starting point for the OUU.
- 2. Screen constraints, i.e. reduce the number of constraints for the OUU.

When the input variables are certain, or deterministic, a traditional optimization with MSC Nastran SOL 200 may be performed. The solution from this optimization is termed the *SOL 200 solution*.

From experience, it is found the OUU solution is often near the SOL 200 solution. If the OUU starts at the initial design, the optimizer has to travel further and takes longer to converge. If the OUU starts at or near the SOL 200 solution, the optimizer travels less and converges faster to the OUU solution. Starting the OUU from the SOL 200 solution helps reduce the computational cost associated with OUU.



200 solution



Determine a starting point for the OUU

- 1. The SOL 200 optimization has already been performed and results are contained in file model.f06. Open this file in a text editor and navigate to the end of the file where the results of the optimization are visible.
- 2. The SOL 200 solution for variables x1 and x2 are recorded and will be used as the starting point for a future OUU.
 - x1 = 8.3724E-1
 - x2 = 3.2830E-1

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Open the Responses App

1. Click on the indicated link

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### Open the Responses App

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



#### Select a Results App



Global Optimization (multiopt.log)



Global Optimization Type 2 (.f06)



Local Optimization (.f06)



Parameter Study (.f06)









Topology Viewer (.des)

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



### Responses During Optimization

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

A new page is open to the Responses web app.

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

Upload .f06 File	Open	Search 1_starting_files_p P
1     1. Select files     model.f06       5     2. Upload files	Organize ▼ New folder	BEE ▼ □ Date modified Type 11/16/2024 7:30 PM Notepad+
	File name: model.f06	▼ Notepad++ Document (*.f06) ▼ 4 Open Cancel

#### Responses 7 Reset view Violated constraints Active constraints Maximum constraint for each design cycle 6 Design Response Show More Subcase Normalized Lower Upper Normalized ELEMENT COMPONENT Label \$ Туре Bound Bound Constraint designCycleNumber Cycle Constraint Value ¢ Information ID NO. Search Searc Search Search Searc Search Search Search Search

(8)



SOL 200 Web App - Responses



#### Responses

						Reset view	Violated c	onstraints 💿	Active constrain	ts 👁 Maximum con	straint for ea	ch design cycle
Design Çycle	${\displaystyle \overset{{\rm Subcase}}{\hat{\varphi}}}$	Label ≑	Response Type [≑]	Normalized Constraint	Lower Bound	Value ¢	Upper Bound ≑	Normalized Constraint [≑]	Show More Information	designCycleNumber	ELEMENT ID	COMPONENT NO.
Search	Search	Sea	Search	Search	Sear	Search	Search	Search				
1	1	r2	STRESS		N/A	1.9883E+04	2.0000E+04 A	-5.8502E-03**	<b>—</b> (4)	1	1	2
1	2	r2	STRESS		N/A	1.9883E+04	2.0000E+04 A	-5.8502E-03**		1	3	2
2	1	r2	STRESS		N/A	1.9640E+04	2.0000E+04 A	-1.7978E-02**		2	1	2
2	2	r2	STRESS		N/A	1.9640E+04	2.0000E+04 A	-1.7978E-02**		2	3	2
3	1	r2	STRESS		N/A	1.9934E+04	2.0000E+04 A	-3.2965E-03**		3	1	2
3	2	r2	STRESS		N/A	1.9934E+04	2.0000E+04 A	-3.2965E-03**		3	3	2
4	1	r2	STRESS		N/A	2.0001E+04	2.0000E+04 A	5.1584E-05**		4	1	2
4	2	r2	STRESS		N/A	2.0001E+04	2.0000E+04 A	5.1584E-05**		4	3	2
5	1	r2	STRESS		N/A	2.0009E+04	2.0000E+04 A	4.2618E-04**		5	1	2
5	2	r2	STRESS		N/A	2.0009E+04	2.0000E+04 A	4.2618E-04**		5	3	2
6	1	r2	STRESS		N/A	2.0022E+04	2.0000E+04 A	1.1166E-03**		6	1	2
6	2	r2	STRESS		N/A	2.0022E+04	2.0000E+04 A	1.1166E-03**		6	3	2
FINAL - 7	1	r2	STRESS		N/A	2.0033E+04	2.0000E+04 A	1.6263E-03**		7	1	2
FINAL - 7	2	r2	STRESS		N/A	2.0033E+04	2.0000E+04 A	1.6263E-03**		7	3	2

 $\bigcirc$ 

Screening Responses and Constraints for OUU

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

(3)





#### Screening Responses and Constraints for OUU

The OUU may be computationally expensive when hundreds or thousands of constraints are involved. It is important to the reduce the number of constraints involved in an OUU.

- During the SOL 200 optimization, only the stress constraints are active. These constraints will also be active during the OUU. Notice the displacement constraints are absent, indicating the optimizer is nowhere near violating the displacement constraints. The displacement constraints are screened out or ignored during the future OUU.
- The analysis model has truss members 1, 2 and 3, but during the SOL 200 optimization, only the axials stresses for elements 1 and 3 are active. The constraints for axial stress on element 2 are screen out, and only the axial stresses for elements for elements 1 and 3 are considered.
- 3. Lastly, there is another trend worth considering.
  - The stress constraint for element 1 is only active for subcase 1.
  - The stress constraint for element 3 is only active for subcase 2.
- 4. The only constraints considered during the OUU are:
  - The stress constraint for element 1, subcase 1.
  - The stress constraint for element 3. subcase 2.

#### Responses

	<ul> <li>Reset view</li> <li>Violated constraints</li> <li>Active constraints</li> <li>Maximum</li> </ul>					nts   Maximum cons	ximum constraint for each design cycle					
Design Çycle	Subcase	Label ≑	Response Type [⊕]	Normalized Constraint	Lower Bound	Value ¢	Upper Bound ≑	Normalized Constraint [⊕]	Show More Information	designCycleNumber	ELEMENT ID	COMPONENT NO.
Search	Search	Sea	Search	Search	Sear	Search	Search	Search			2	
1	1	r2	STRESS		N/A	1.9883E+04	2.0000E+04 A	-5.8502E-03**		1	1	2
1	2	r2	STRESS		N/A	1.9883E+04	2.0000E+04 A	-5.8502E-03**		1	3	2
2	1	r2	STRESS		N/A	1.9640E+04	2.0000E+04 A	-1.7978E-02**		2	1	2
2	2	r2	STRESS		N/A	1.9640E+04	2.0000E+04 A	-1.7978E-02**		2	3	2
3	1	r2	STRESS		N/A	1.9934E+04	2.0000E+04 A	-3.2965E-03**		3	1	2
3	2	r2	STRESS		N/A	1.9934E+04	2.0000E+04 A	-3.2965E-03**		3	3	2
4	1	r2	STRESS		N/A	2.0001E+04	2.0000E+04 A	5.1584E-05**		4	1	2
4	2	r2	STRESS		N/A	2.0001E+04	2.0000E+04 A	5.1584E-05**		4	3	2
5	1	r2	STRESS		N/A	2.0009E+04	2.0000E+04 A	4.2618E-04**		5	1	2
5	2	r2	STRESS		N/A	2.0009E+04	2.0000E+04 A	4.2618E-04**		5	3	2
6	1	r2	STRESS		N/A	2.0022E+04	2.0000E+04 A	1.1166E-03**		6	1	2
6	2	r2	STRESS		N/A	2.0022E+04	2.0000E+04 A	1.1166E-03**		6	3	2
FINAL - 7	1	r2	STRESS		N/A	2.0033E+04	2.0000E+04 A	1.6263E-03**		7	1	2
FINAL - 7	2	r2	STRESS		N/A	2.0033E+04	2.0000E+04 A	1.6263E-03**		7	3	2





# Part C – Preparing MSC Nastran Bulk Data Files to Output Gradients for Optimization Under Uncertainty



Open the Correct Page

1. Click on the indicated link

#### The Engineering Lab



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### Upload BDF Files

Step 1 - Upload .BDF Files

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

#### 1. Select files 2 files selected 1 Inspecting: 100% 📀 Open X (5) « 1_starting_files + 1_starting_files_part_b (2) + ++ Search 1_starting_... 🔎 Organize 🔻 New folder -2 List of Selected Files . Name Date modified Type ☆ Favorites Nesktop design_model.bdf (3) 11/16/2024 7:11 PM Notepad+ 📔 model.bdf Downloads 11/16/2024 7:11 PM Notepad+ Recent Places 📄 Libraries Documents A Music Pictures Videos π ₹ III Computer Custom Files (*.bdf;*.dat;*.inc;* 🔻 File name: "design_model.bdf" "model.bdf" • Open 4 Cancel **HEXAGON** Questions? Email: christian@ the-engineering-lab.com 55

Technology Partner

### Modify Variables

- Navigate to section Step 2 Adjust design variables
- 2. The design variables configured in a separate tutorial are now available for modification
- Remove all the bounds from each variable
- The DESVAR bounds may conflict with the bounds configured for OUU. For example, if the OUU variable x1 mean is configured between -10 and +10, but the DESVAR entry is configured to have bounds between -5 and +5, when the OUU optimizer submits a variable value x1 mean=+8, the MSC Nastran run will fail because +8 exceeds the bounds on the DESVAR entry. It is for this reason, that the bounds on DESVAR entries should be removed prior to configuring an OUU. Quick reminder that part B is meant to configure bulk data files to output gradients, a formal OUU configuration comes in a future tutorial.

#### SOL 200 Web App - Optimization Upload Variables Objective Constraints Subcases Exporter Results



X Delete Visible Rows

#### + Options

Size

	Label ≑	Status 🌲	Property ≑	Property Description ≑	Entry ≑	Entry ID 💠	Initial Value	Lower Bound	Upper Bound	Allowed Discrete Values
	Search	Search	Search	Search	Search	Search	Search	Search	Search	Search
×	x1	0	A	Area of the rod	PROD	11	1.0	Lower	Upper	Examples: -2.0, 1.0, THRU, 10.0,
×	x2	0	A	Area of the rod	PROD	12	2.0	Lower	Upper	Examples: -2.0, 1.0, THRU, 10.0,
×	x3	0	A	Area of the rod	PROD	13	1.0	Lower	Upper	Examples: -2.0, 1.0, THRU, 10.0,



3

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

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

1

#### Optimization Settings

Parameter \$	Description 🗢		Configure ≑
Search	Search	Search	
APRCOD	Approximation method to be used		2 - Mixed Method
CONV1	Relative criterion to detect convergence		Enter a positive real number
CONV2	Absolute criterion to detect convergence		Enter a positive real number
DELX	Fractional change allowed in each design variable during any optimization cycle		Enter a positive real number
DESMAX	Maximum number of design cycles to be performed		20
DISBEG	Design cycle number for discrete variable processing initiation		Enter a positive integer
GMAX	Maximum constraint violation allowed at the converged optimum		Enter a positive real number
P1	Print items, e.g. objective, design variables, at every n-th design cycle to the .f06 file		1
P2	Items to be printed to the .f06 file		15 - Print objective, design variab 🗸 🗸

#### Optimization Type

Perform Local Optimization
 Perform Sensitivity Analysis
 Perform Global Optimization
 Perform Global Optimization Type 2
 Perform Parameter Study

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



#### SOL 200 Web App - Optimization Upload Variables Objective Constraints Subcases Exporter Results

< >

#### BDF Output - Model

### Export New BDF Files

1. Click Exporter

2. Click Download BDF Files

 When the download button is clicked a new file named "nastran_working_directory" is downloaded. If the file already exists in your local folder, the folder name is appended with a number, e.g. "nastran_working_directory (1).zip"

assign use	rfile = 'optimization_results.csv', status = unknown, mattad unit = 52
\$ 1	
TD MSC DS	
TIME 10	s
SOL 200	
CEND	
TITLE = SY	MMETRIC THREE BAR TRUSS DESIGN OPTIMIZATION - DSOUG1
SUBTITLE =	BASELINE - 2 CROSS SECTIONAL AREAS AS DESIGN VARIABLES
\$ Result 0	lutput
ECHO	= NONE
SPC	= 100
DISPLACEME	NT(SORT1,REAL)=ALL
SPCFORCES(	SORT1,REAL)=ALL
STRESS(SOF	T1,REAL,VONMISES,BILIN)=ALL
\$ Subcases	
DESOB3(	MIN) = 5000000
DSAPRT(	FORMATTED, EXPORT, END=SENS) = ALL
\$ DESGL	8 Slot
SUBCASE 1	
ANALYS1	S = STATICS
DESSUB	= 40000001
\$ DRSP/	N Slot
LABEL =	LOAD CONDITION 1
LOAD =	300
SUBCASE 2	
ANALYS1	S = STATICS
DESSUB	= 40000001

#### Download BDF Files



BDF Output - Design Model

\$*								8
\$*				Dest	ign Model			*
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\$			0	Design Va	ariables - Type	2.1		
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DVPREI 1	1000001	PROD	12	A				
	100002	1.0						
DVPREL1	1000003	PROD	13	A				
	100003	1.0						
\$								
\$								
DESVAR	100001	X1	1.0	.01	100.			
DESVAR	100002	х2	2.0	.01	100.			
DESVAR	100003	хЗ	1.0	.01	100.			
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5					abi abi			
2 4				Design	objective			
\$								

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### Perform the Optimization with Nastran SOL 200

A new .zip file has been downloaded

- 1. Right click on the file
- 2. Click Extract All
- 3. Click Extract on the following window
- Always extract the contents of the ZIP file to a new, empty folder.

					×	
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Organize 🔻 🛛 🛜 Open	✓ Share with ▼ New folder				?	
🔆 Favorites	Name	Date modi	fied	Туре		
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〕 Downloads	鷆 nastran_working_directory	11/9/2024	4:51 PM	File fol	der	
📳 Recent Places	鷆 nastran_working_directory (1)	11/9/2024	5:07 PM	File fol	der	
	solution_ws_dsoug1	11/9/2024	5:11 PM	File fol	der	
📜 Libraries	hastran_working_directory (1).zip	0nen	C 3C 014	0	ssed	
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nastran workin	directory (1) zip. Date modified: 11/0				c comp	pressed (Lipped) i olders
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			5	select a	Dest	ination and Extract Files
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# Update the DSCREEN entries

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

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

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

#### Before

\$ 1

Ś.

\$ Design Constraint Screening

\$				
DSCREEN	WEIGHT	-10000.	10	(2)
DSCREEN	VOLUME	-10000.	10	
DSCREEN	EIGN	-10000.	10	
DSCREEN	CEIG	-10000.	10	
DSCREEN	FREQ	-10000.	10	
DSCREEN	LAMA	-10000.	10	
DSCREEN	DISP	-10000.	10	
DSCREEN	STRAIN	-10000.	10	
DSCREEN	ESE	-10000.	10	
DSCREEN	STRESS	-10000.	10	
DSCREEN	FORCE	-10000.	10	
DSCREEN	FATIGUE	-10000.	10	
DSCREEN	FRFTG	-10000.	10	
DSCREEN	SPCFORCE	E-10000.	10	
DSCREEN	CSTRAIN	-10000.	10	
DSCREEN	CSTRESS	-10000.	10	
DSCREEN	CFAILURE	E-10000.	10	
DSCREEN	CSTRAT	-10000.	10	
DSCREEN	TOTSE	-10000.	10	
[]				
DSCREEN	STMOND1	-10000.	10	
DSCREEN	MONPNT3	-10000.	10	
DSCREEN	AEMONP1	-10000.	10	
DSCREEN	AEMOND1	-10000.	10	
DSCREEN	TRIM	-10000.	10	
DSCREEN	STABDER	-10000.	10	
DSCREEN	FLUTTER	-10000.	10	
DSCREEN	DIVERG	-10000.	10	
DSCREEN	WMPID	-10000.	10	
DSCREEN	EQUA	-10000.	10	

Dev				
De:				
7 4 2				
DSCREEN	WEIGHT	-10000.	100	(3)
DSCREEN	VOLUME	-10000.	100	
DSCREEN	EIGN	-10000.	100	
DSCREEN	CEIG	-10000.	100	
DSCREEN	FREQ	-10000.	100	
DSCREEN	LAMA	-10000.	100	
DSCREEN	DISP	-10000.	100	
DSCREEN	STRAIN	-10000.	100	
DSCREEN	ESE	-10000.	100	
DSCREEN	STRESS	-10000.	100	
DSCREEN	FORCE	-10000.	100	
DSCREEN	FATIGUE	-10000.	100	
DSCREEN	FRFTG	-10000.	100	
DSCREEN	SPCFORCE	E-10000.	100	
DSCREEN	CSTRAIN	-10000.	100	
DSCREEN	CSTRESS	-10000.	100	
DSCREEN	CFAILURE	E-10000.	100	
DSCREEN	CSTRAT	-10000.	100	
DSCREEN	TOTSE	-10000.	100	
[]				
DSCREEN	STMOND1	-10000.	100	
DSCREEN	MONPNT3	-10000.	100	
DSCREEN	AEMONP1	-10000.	100	
DSCREEN	AEMOND1	-10000.	100	
DSCREEN	TRIM	-10000.	100	
DSCREEN	STABDER	-10000.	100	
DSCREEN	FLUTTER	-10000.	100	
DSCREEN	DIVERG	-10000.	100	
DSCREEN	WMPID	-10000.	100	
DSCREEN	EQUA	-10000.	100	



After

### Sensitivity Analysis Only

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

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



### Ensure H5 Output is Enabled

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

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

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

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

MDLPRM,HDF5,2

HDF50UT



^B Option 1

MDLPRM HDF5 2

Option 2

HDF50UT



# Next Step

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



#### Perform the Optimization with Nastran SOL 200

- 1. Inside of the new folder, double click on Start MSC Nastran
- Click Open, Run or Allow Access on any subsequent windows
- MSC Nastran will now start
- After a successful run, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- One can run the Nastran job on a remote machine as follows: 1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the remote machine. 3) After completion, copy the BDF, F06, LOG, H5 files to the local machine. 4) Click "Start MSC Nastran" to display the results.

#### **Using Linux?**

Follow these instructions: 1) Open Terminal 2) Navigate to the nastran working directory cd ./nastran working directory 3) Use this command to start the process ./Start MSC Nastran.sh

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

sudo chmod -R u+x ./nastran working directory





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Open

X

Cancel

#### SOL 200 Web App - Status

Status

#### Republic Python MSC Nastran

### Status

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

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

 The status of the MSC Nastran job is reported on the Status page. Note that Windows 7 users will experience a delay in the status updates. All other users of Windows 10 and Red Hat Linux will see immediate status updates.



### Review Optimization Results

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

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

#### SOL 200 Web App - Sensitivities



*d*r2_{sc1,2,1}/*d*x1 *d*r2_{sc2,2,3}/*d*x1 *d*r2_{sc2,2,1}/*d*x1 *d*r2_{sc1,2,3}/*d*x1 *d*r2_{sc1,2,2}/*d*x2 *d*r2_{sc2,2,2}/*d*x2 *d*r2_{sc1,2,2}/*d*x1 *d*r2_{sc2,2,2}/*d*x1 *d*r2_{sc2,2,2}/*d*x1 *d*r2_{sc2,2,2}/*d*x1 *d*r2_{sc2,2,1}/*d*x2



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Home

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### Confirm the H5 is Present

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





# Summary

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

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

Part B – Performing a Preliminary Optimization with Deterministic Inputs, and Screening Constraints

- An MSC Nastran SOL 200 optimization is performed to determine a starting point for a future OUU.
- The number of constraints is reduced by only considering the most critical, active or violated constrains found during a SOL 200 optimization.

Part C – Preparing MSC Nastran Bulk Data Files to Output Gradients for Optimization Under Uncertainty

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



End of Tutorial

