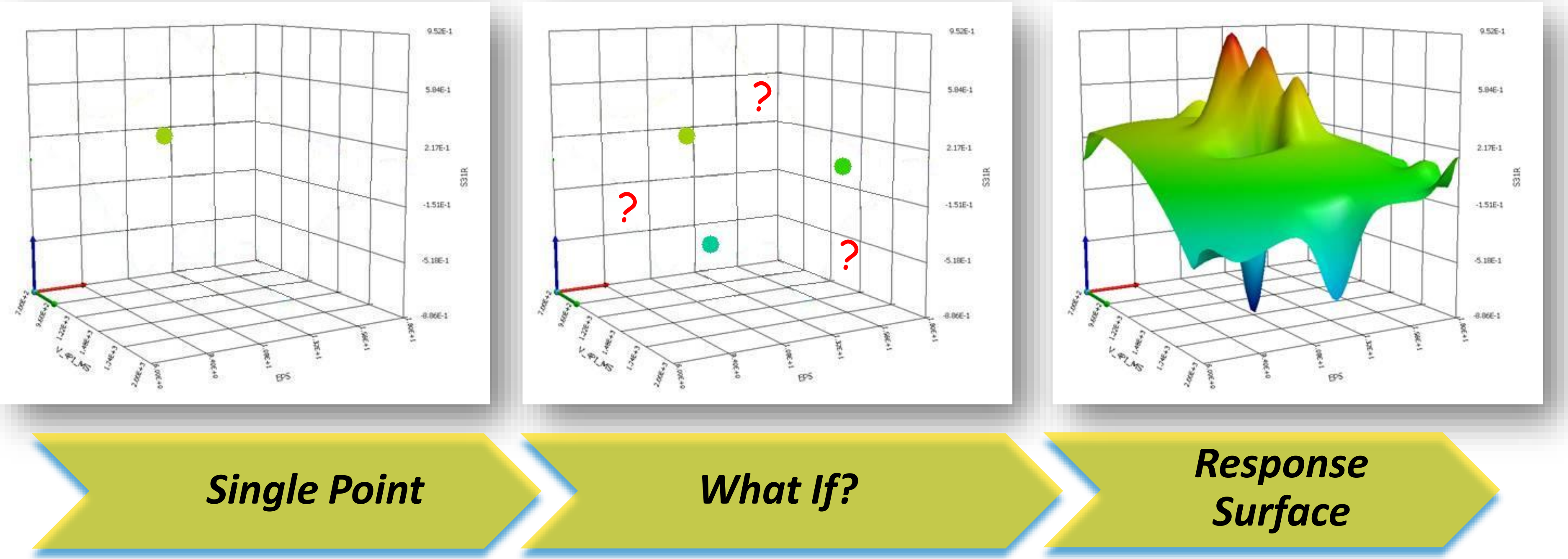
DesignXplorer
Tip & Tricks Session

What is DesignXplorer?

- DesignXplorer, also called DX, is a powerful approach to explore, understand and optimize your engineering challenges
  - Determine the key parameters influencing the design
  - Explore and understand the performance at other design or operating conditions
  - Find the conditions which give the best performance
  - Explore the robustness of the design



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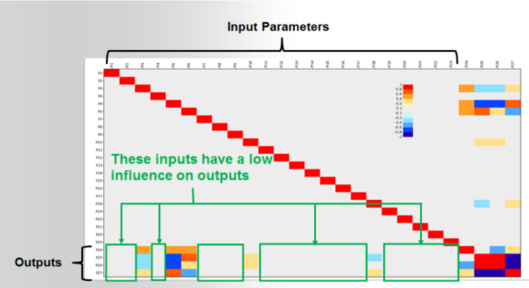
DesignXplorer Features



What if Study

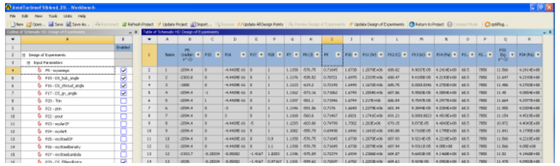
Manual Search

Sensitivity / Correlation Analysis

Find the relevant parameters

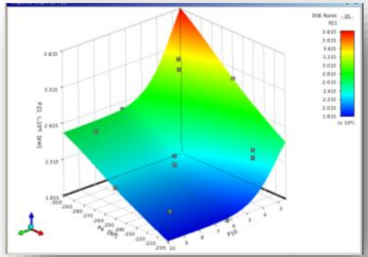
Design of Experiments

Run a smart set of Design Points



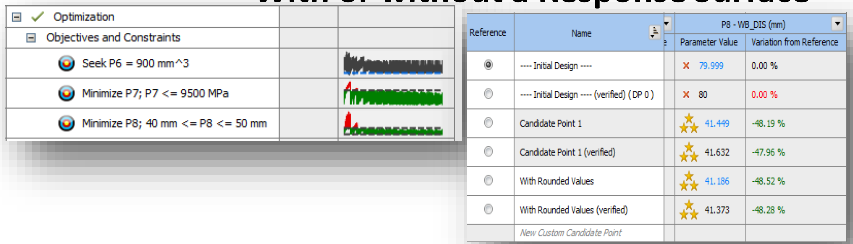
Response Surface

Build a Mathematical model



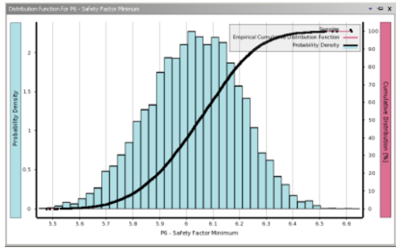
Optimization

With or without a Response Surface



Robust Design

Six Sigma Analysis



Optimized and Robust Design

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Free ACT Extensions on the Customer Portal (For DesignXplorer)

DOE from Correlation v1

Response surface reader

MATLAB Optimizers for DX 17.0

Version: 170.3

Direct Optimization from RSO v1

Full Factorial DOE v1

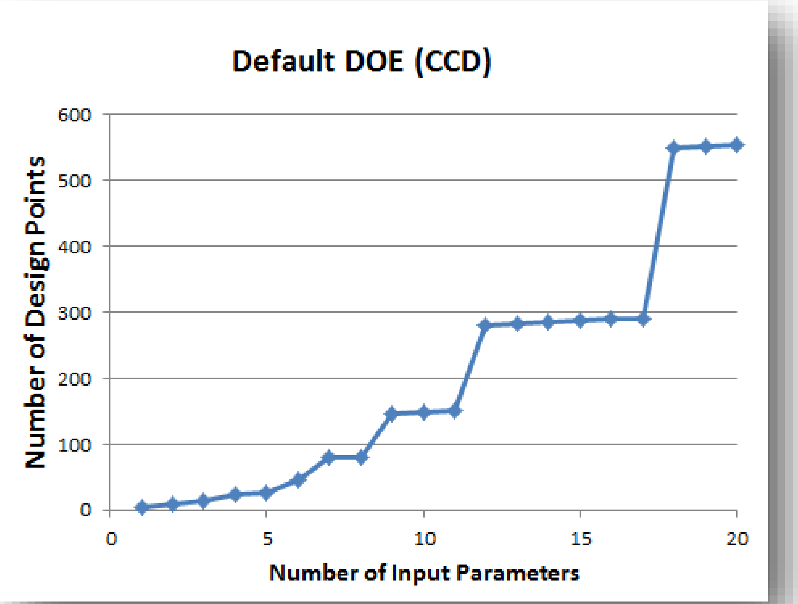
Many more …

https://support.ansys.com/AnsysCustomerPortal/en_us/Downloads/ANSYS+ACT+Application+Store

Parameters Correlation

Parameters Correlation

- In a DOE study, the amount of design points increases quickly as the number of input parameters increases, which can reduce the efficiency of the analysis process.
- It is recommended to exclude unimportant input parameters from the DOE sampling in order to reduce unnecessary sampling points.



Parameters Correlation

- The parameter correlation tool allows us to identify important parameters
- Sampling in based on Latin Hypercube Sampling
- Correlation Type :Spearman or Pearson
- Filtering method

Outline of Schematic B2: Parameters Correlation

	A	B
1		Enabled
2	Parameters Correlation	
3	Input Parameters	
4	Mechanical APDL (A1)	
5	P1 - WIDTH	☑
6	P2 - HEIGHT	☑
7	P3 - LENGTH	☑
8	P4 - FORCE	☑
9	P5 - YOUNG	☑
10	Output Parameters	

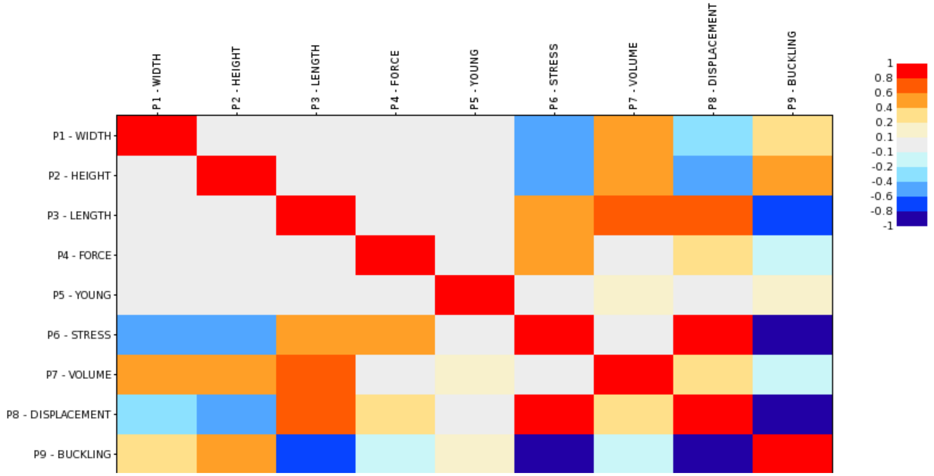
Properties of Outline A2: Parameters Correlation

	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	☐
4	Failed Design Points Management	
5	Number of Retries	0
6	Parameters Correlation	
7	Reuse the samples already generated	☑
8	Correlation Type	Spearman
9	Number Of Samples	30
10	Auto Stop Type	Enable Auto Stop
11	Mean Value Accuracy	0.01
12	Standard Deviation Accuracy	0.02
13	Convergence Check Frequency	10
14	Correlation Status	
15	Size of Generated Sample Set	30
16	Converged	No
17	Filtering Method	
18	Relevance Threshold	0.5
19	Correlation Filtering	☑
20	R2 Contribution Filtering	☑
21	Maximum Number of Major Inputs	5

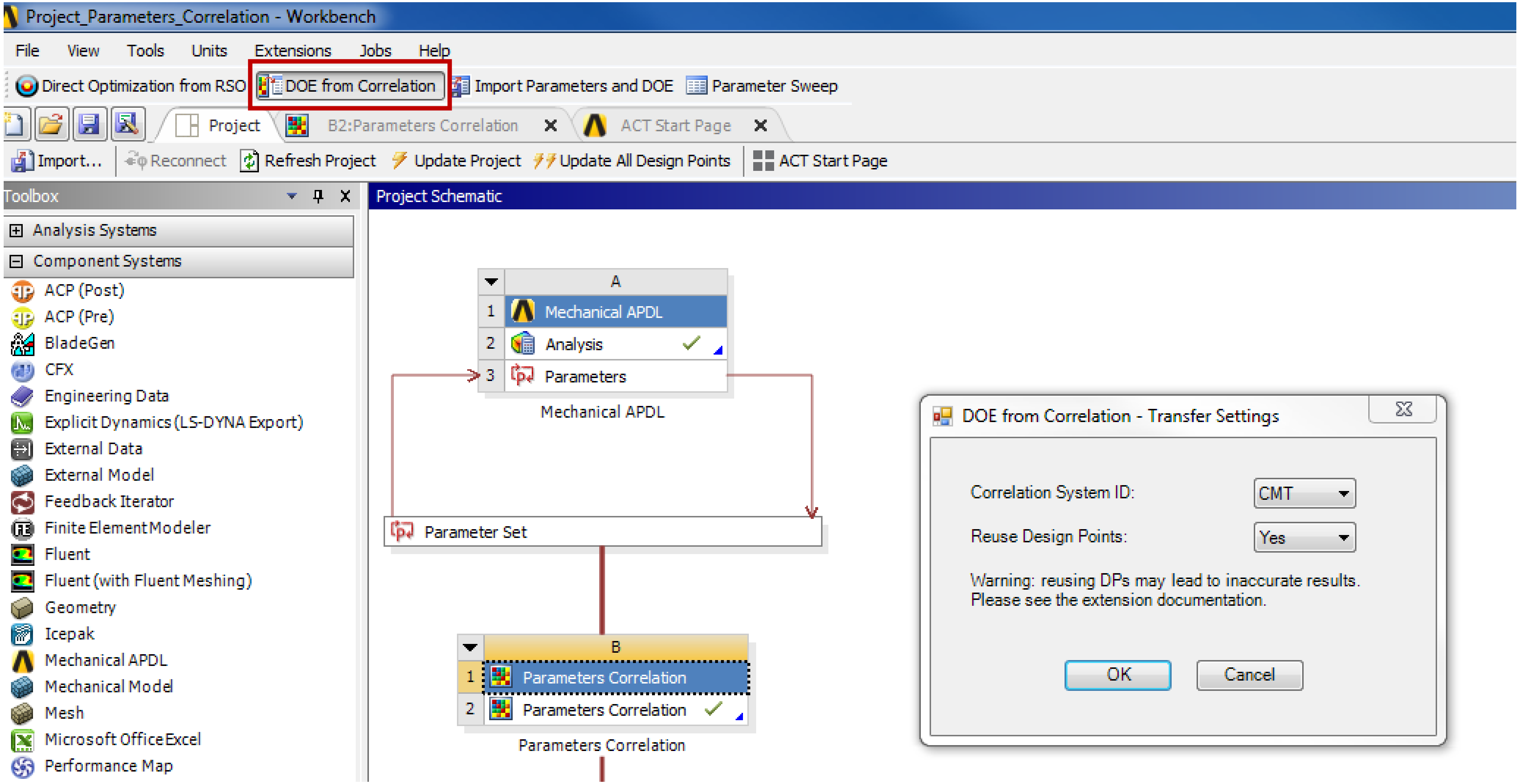
Table of Schematic B2: Parameters Correlation

	A	B	C	D	E
1	Filtering Method				
2	Relevance Threshold	0.5			
3	Configuration	Filtering on Correlation Value and R2 Contribution, with a maximum of 5 major input parameters			
4	Filtering Output Parameters	P6 - STRESS, P7 - VOLUME, P8 - DISPLACEMENT, P9 - BUCKLING			
5	Major Input Parameters				
6	Input Parameter	Best Relationship With Filtering Output Parameter			
7		Relevance	Output Parameter	R2 Contribution	Correlation Value
8	P2 - HEIGHT	1	P6 - STRESS	0.1864	-0.61042
9	P3 - LENGTH	1	P7 - VOLUME	0.6055	0.76841
10	P4 - FORCE	0.97229	P6 - STRESS	0.17133	0.59066
11	P1 - WIDTH	0.80185	P6 - STRESS	0.096101	0.52696
12	Minor Input Parameters				
13	Input Parameter	Best Relationship With Filtering Output Parameter			
14		Relevance	Output Parameter	R2 Contribution	Correlation Value
15	P5 - YOUNG	0.45028	P9 - BUCKLING	0.023264	0.16786

Chart: No data



DOE from Correlation ACT



Design of Experiments

DOE Purpose and Schemes

The purpose of a Design Of Experiments is to gather a representative set of data to compute a Response Surface, and then run an Optimization (for a Response Surface Optimization)

Basically, a set of Design Points will be calculated

The Response Surface accuracy will greatly depend on the DOE scheme, and especially the number of Design Points that were calculated

DesignXplorer proposes several DOE schemes. Design Points are automatically chosen to explore the parametric space efficiently:

- **Central Composite Design (CCD) [default]**
- **Box Behnken Design**
- **Optimal Space Filling Design**
- **Custom + Sampling**
- **Sparse Grid Initialization**
- **Latin Hypercube Sampling Design**

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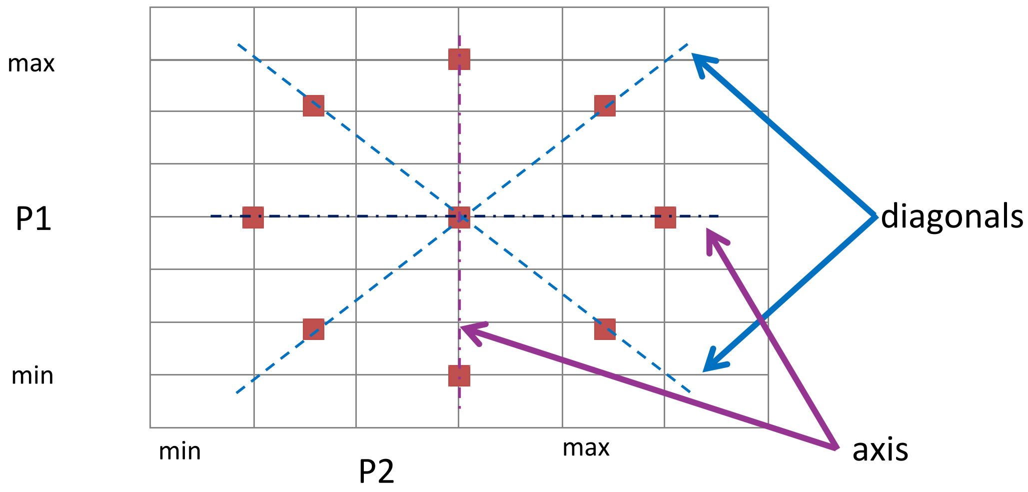
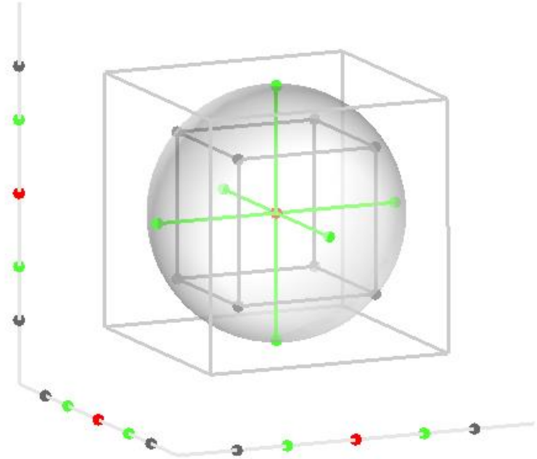
Central Composite Design (CCD)

- **Central Composite designs are five-level fractional factorial designs that are suitable for calibrating the quadratic response model**
- **A CCD consists of:**
  - **1 center point**
  - **2*N axis points located at the –a and +a positions on each axis of the selected input parameter**
  - **2^(N-f) factorial points located at the -1 and +1 positions along the diagonals of the input parameter space**
    [factorial number f discussed on next slide]

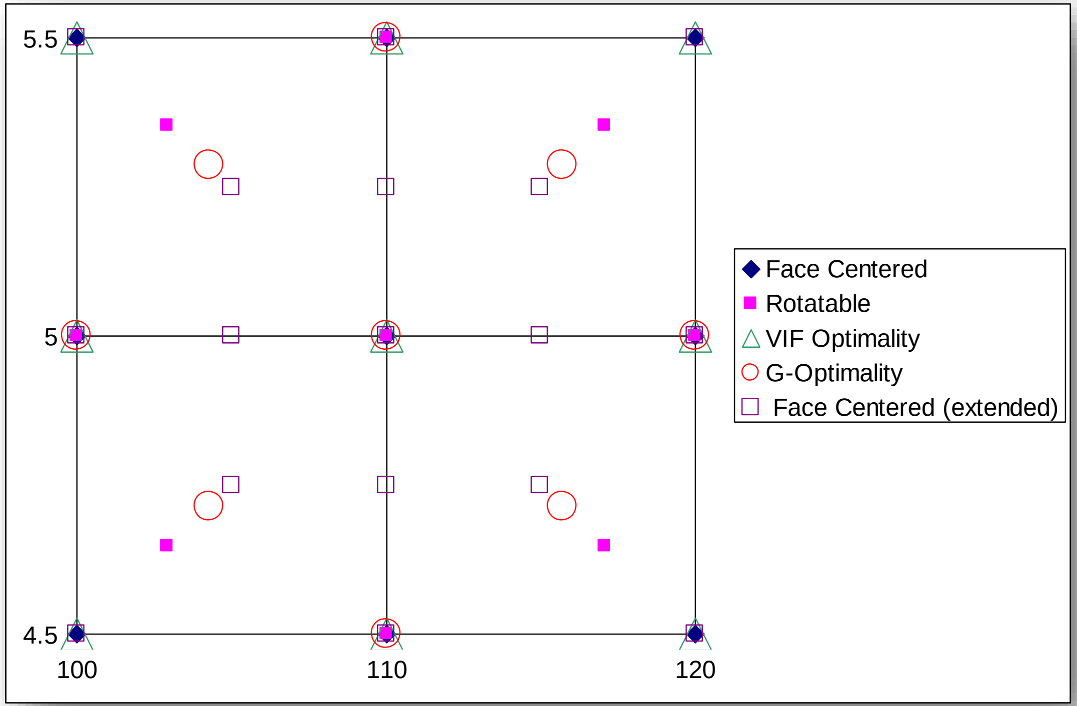




Central Composite Design (CCD)

- **There are 5 types of CCDs available each with their own benefits and drawbacks**

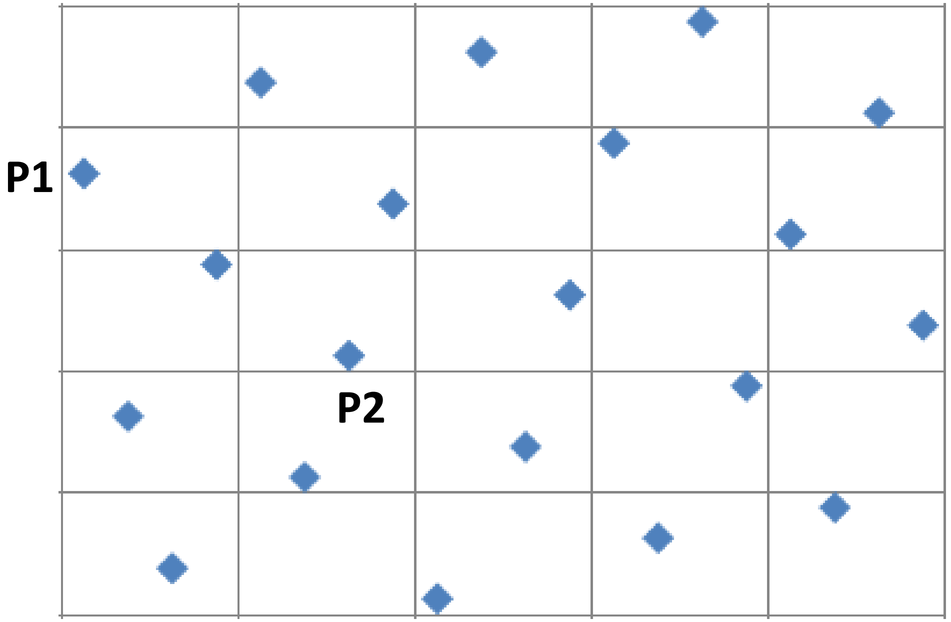
1. **Auto Defined (default):** Automatically switches between the G-Optimal (if the number of input variables is 5) or VIF-optimal otherwise
2. **Face Centered:** 3 levels, not rotatable. Benefit is that it gets sampling points at all extremes.
3. **Rotatable:** 5 levels and rotatable. Drawback: does not get sampling points at all extremes. Advantage: variance prediction is the same for any two locations that are the same distance from the design center
4. **VIF (Variance Inflation Factor) Optimality:** Maximizes orthogonality
5. **G-Optimality:** Minimizes leverage



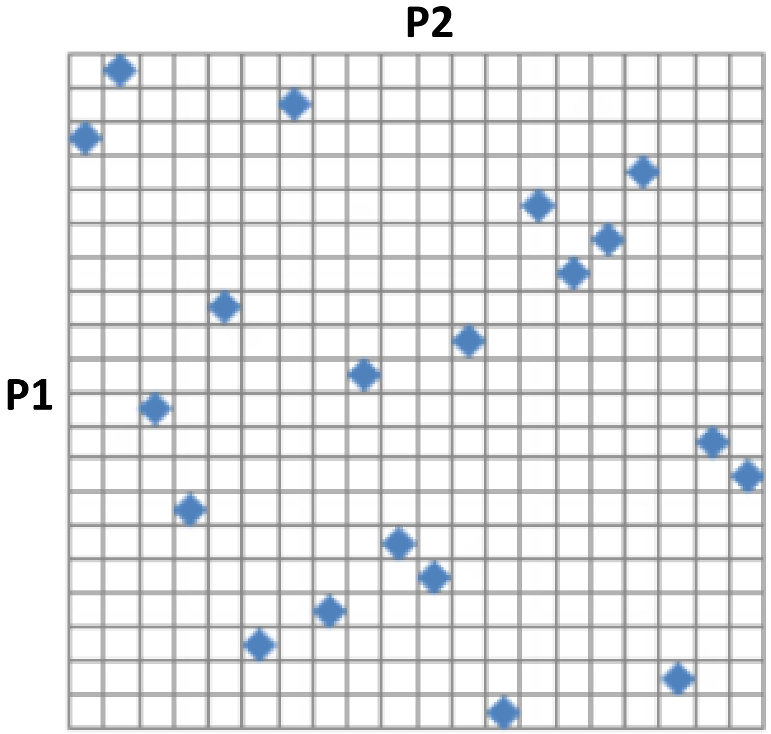
- **For 2 parameters, the standard CCD schemes are based on 9 points**
- **The "extended" face centered is made of 17 points (note: there is also a 17 points Rotatable scheme)**

Other DOE's

Optimal Space Filling Design

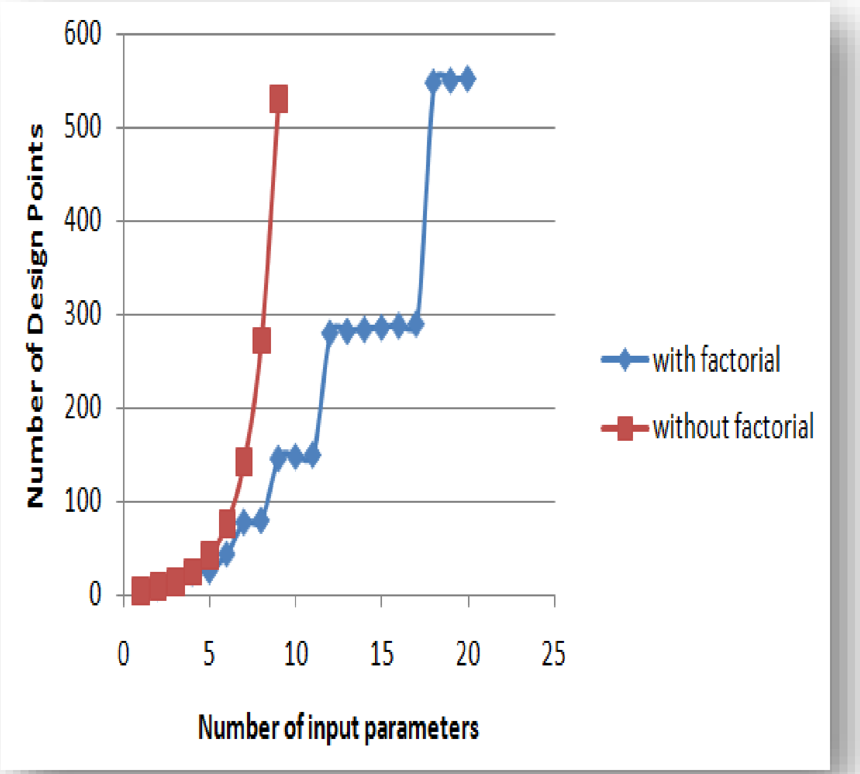


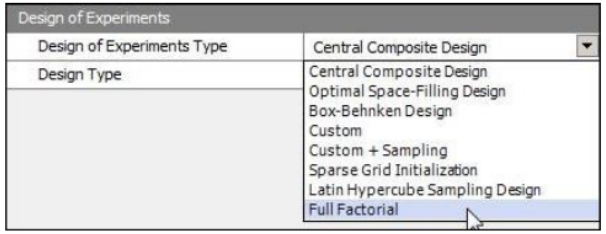
Latin Hypercube Sampling



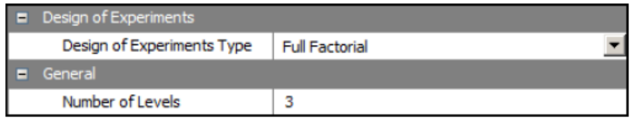
Full Factorial DOE ACT

Number of Parameters	f	with factorial	without factorial
1	0	5	5
2	0	9	9
3	0	15	15
4	0	25	25
5	1	27	43
6	1	45	77
7	1	79	143
8	2	81	273
9	2	147	531
10	3	149	1,045
11	4	151	2,071
12	4	281	4,121
13	5	283	8,219
14	6	285	16,413
15	7	287	32,799
16	8	289	65,569
17	9	291	131,107
18	9	549	262,181
19	10	551	524,327
20	11	553	1,048,617



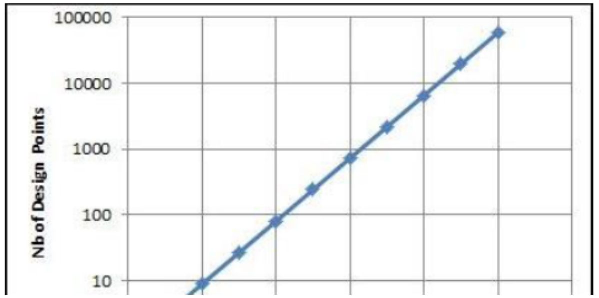


Under **General**, the **Number of Levels** property is shown. The default is 3 to create lower, mid, and upper parameter bounds.



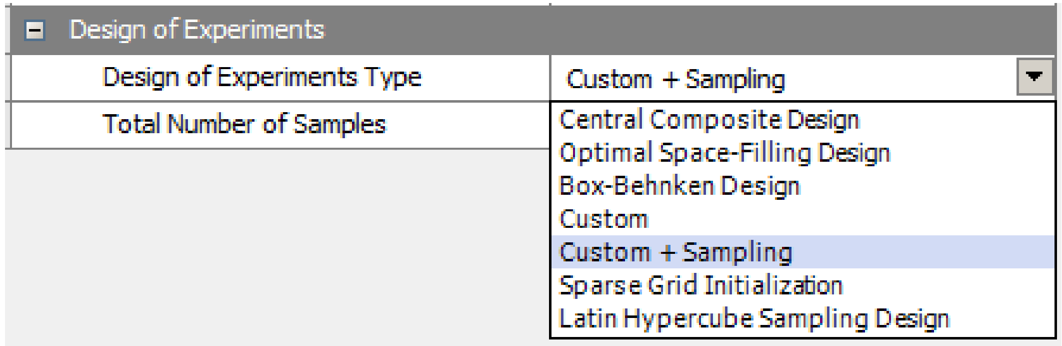
4. Specify the number of levels that you want to use.

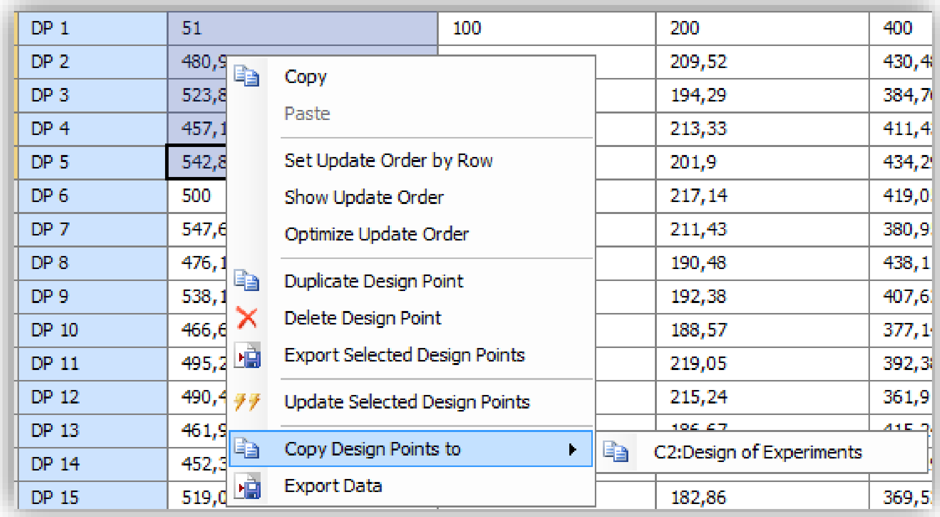
CAUTION: The number of required design points increases very quickly when the **Full Factorial** DOE type is used. For a three-level full factorial design, the following graph shows the log scale on the Y axis.



Custom Design of Experiments

- To import a DOE generated with 3rd party tool
- To import external DOE or experimental data with output parameters values
- To reuse design points (CSV import, or copy from the Parameter Set)





CSV Input File Requirements

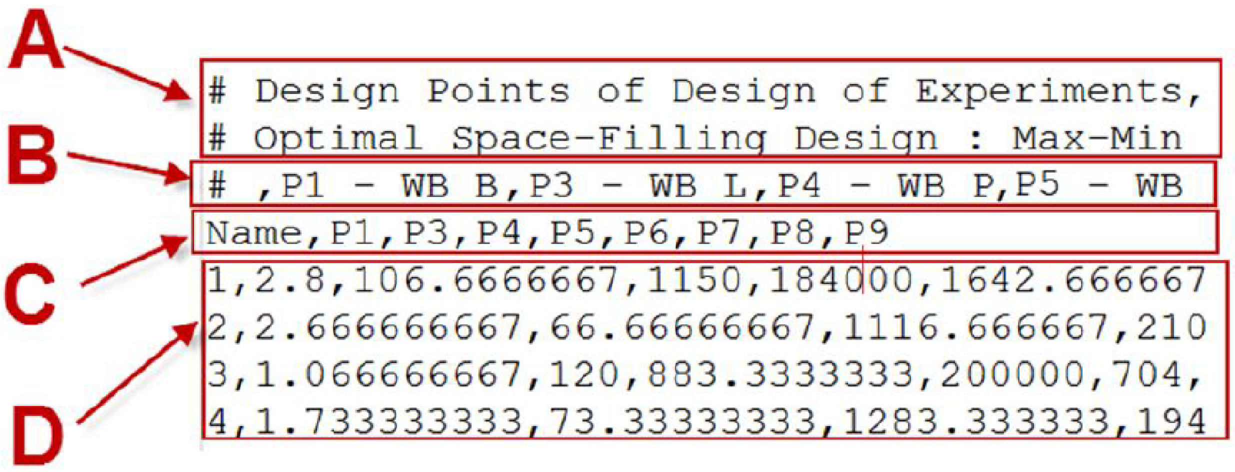
The CSV input file must be in the extended format supported by Workbench. The sample CSV file below is truncated for the purposes of illustration.

A: The lines beginning with "#" are comment lines. Except for the line defining the parameter names (see B), these comment lines are ignored.

B: The parameter names must be listed one line above the line defining the IDs. Parameter full names are extracted from this line. Based on the comma separator, the parameter names should be aligned with the corresponding parameter IDs in the line below. Parameter names cannot include commas.

C: The parameter IDs are extracted from this line. The line must be below the line defining the parameter full names.

D: The DOE values must be listed below the line defining the parameter IDs.



DOE with failed DPs: how to proceed?

DOE table with a failed DP:

	A	B	C
1	Name	P1	P2
2	1	3	0.33333
3	2 DP 1	0	
4	3	6	0.16667
5	4	1.5	0.66667
6	5	4.5	0.22222

1. Set the DOE type to Custom:

Design of Experiments	
Design of Experiments Type	Custom

2. Right click on the failed DP > Delete

Name	P1	P2
1	3	0.33333
2 DP 1	0	
3	6	0.1666
4	1.5	0.6666
5	4.5	0.2222
New Design Point		

- Show Update Order
- Set Update Order by Row
- Optimize Update Order
- Import Design Points...
- Insert as Design Point
- Delete
- Set Output Values as Editable

3. Update DOE (no solve is required)

Failed DPs can also be deleted using python script

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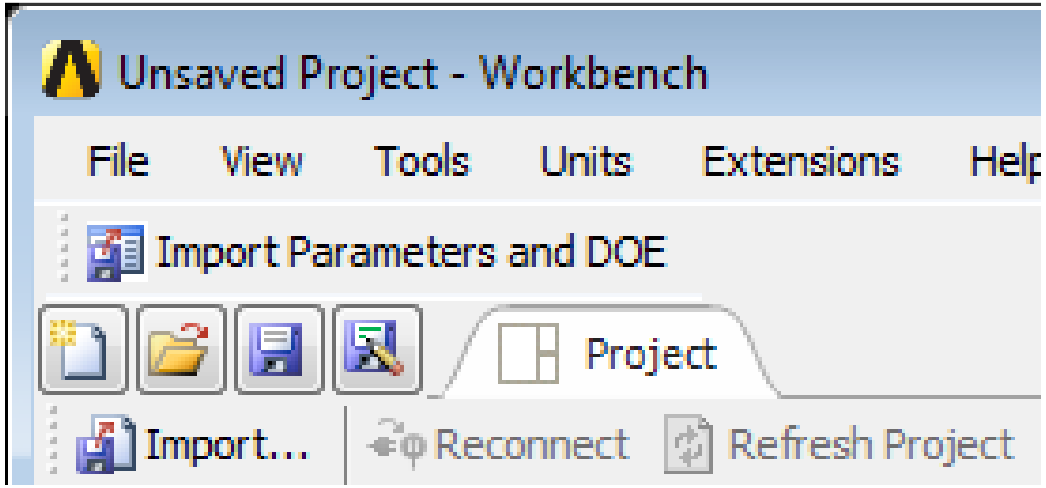
Import Parameters and DOE ACT

The Import Parameters and DOE extension enables you to automatically create parameters and import their DOE values into an empty Workbench project. For example, if a DOE was solved in Workbench (or any other tool) and saved as a CSV file, you can load it into Workbench to generate a response surface and eventually run an optimization using a standalone DesignXplorer system.



Easily Switch Between Solved Design Points

- Take advantage of "Retained Data"
  - Quickly switch between retained design points
    - "Set as Current" option
  - Export retained design points

Table of Design Points

	A	B	C	D	E	F	G
1	Name	P1 - Pressure Magnitude	P2 - Equivalent Stress Minimum	P3 - Equivalent Stress Maximum	☐ Retain	Retained Data	Note
2	Units	Pa	Pa	Pa			
3	DP 0 (Current)	2000	19.512	1.0622E+05	☑	✓	Harmonic testing
4	DP 1	5000	48.779	2.6556E+05	☑	✓	
5	DP 2	3000	29.267	1.5934E+05	☑	⚡	Harmonic testing
6	DP 3	4000	⚡ 58.535	⚡ 3.1867E+05	☑	⚡✓	Harmonic testing
7	DP 4	6000	39.023	2.1245E+05	☐		
*					☐		

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Response Surface

Response Surface

Definition

- Response Surface = Surrogate Model = Meta Model = Approximation Model
- Response Surfaces are functions of different nature where the output parameters are described in terms of the input parameters
- Response Surfaces provide the approximated values of the output parameters, everywhere in the analyzed design space, without the need to perform a complete solution
- The response surface methods described here are suitable for problems using up to ~10-15 input parameters

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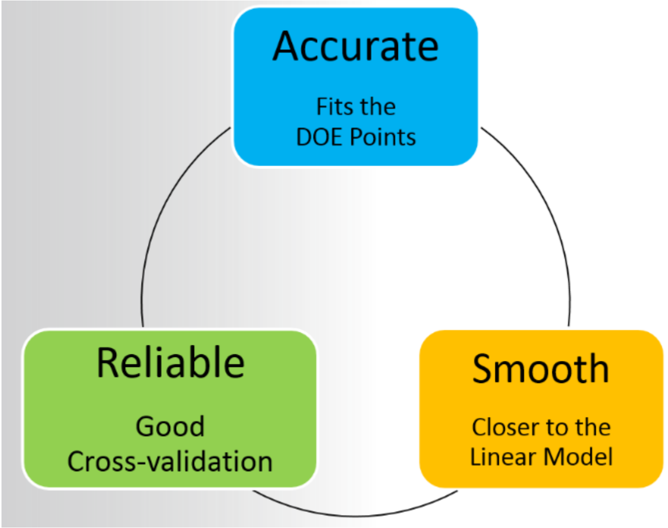
Genetic Aggregation

- It runs an iterative genetic algorithm to find the best Response Surface type and settings for each output parameter. It selects the best ones and combines them to build an "aggregation" of several Response Surfaces. It results to the best RS quality and different settings for each output parameter
- Even if the algorithm runs on several CPUs, this method can still be long when dealing with high number of design points and/or parameters
- The goal is to meet the 3 main criteria to obtain the best Response Surface:



Genetic Aggregation

Automatic Refinement new from R17.1

Auto refinement adds design points until response surface accuracy meets user requirements

Outline of Schematic B3: Response Surface

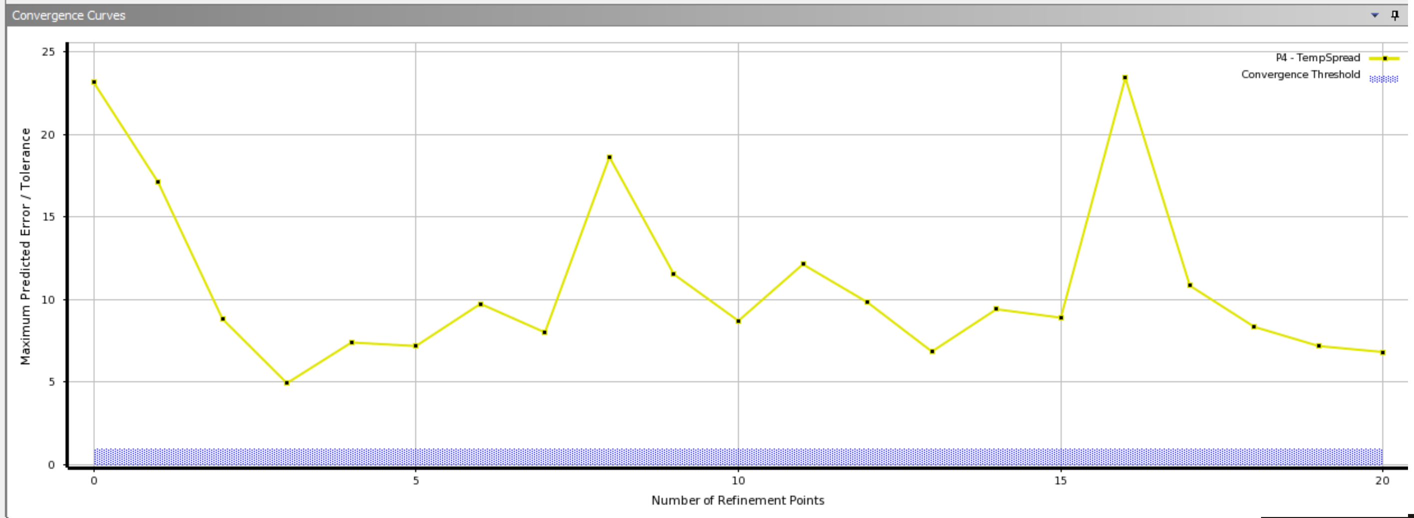
	A	B
1		Enabled
2	Response Surface	
3	Input Parameters	
4	Fluid Flow (FLUENT) (A1)	
5	P1 - inletcold_velocity	☑
6	P2 - inlethot_velocity	☑
7	Output Parameters	
8	Fluid Flow (FLUENT) (A1)	
9	P3 - PressureDrop	
10	P4 - TempSpread	
11	Min-Max Search	☑
12	Refinement	
13	Tolerances	
14	Refinement Points	
15	Quality	
16	Goodness Of Fit	

Table of Schematic B3: Response Surface: Tolerances

	A	B	C	D	E	F
1	Name	Calculated Minimum	Calculated Maximum	Maximum Predicted Error	Refinement	Tolerance
2	P3 - PressureDrop (Pa)	12.235	144.26	0.90251	☐	
3	P4 - TempSpread (K)	0.33964	0.98977	0.06829	☑	0.01

Properties of Outline A2: Response Surface

	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	☐
4	Failed Design Points Management	
5	Number of Retries	0
6	Meta Model	
7	Response Surface Type	Genetic Aggregation
8	Refinement	
9	Maximum Number of Refinement Points	20
10	Number of Refinement Points	20
11	Convergence State	Not Converged: Maximum Number of Points reached
12	Verification Points	
13	Generate Verification Points	☐

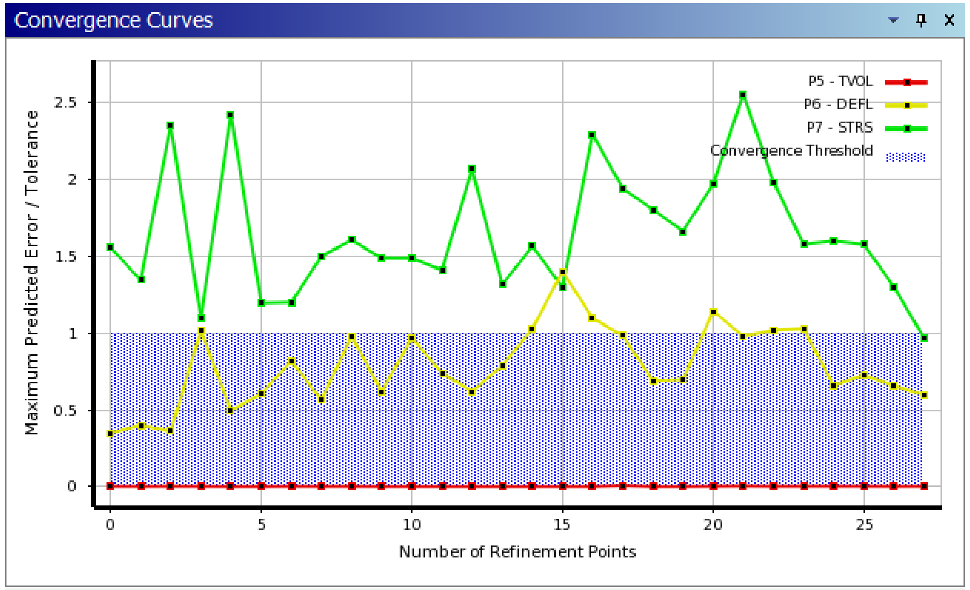


Genetic Aggregation

Automatic Refinement Convergence new from R17.1

Table of Schematic B3: Response Surface

	A	B	C	D	E	F	G	H
1	Name	P1 - TK16	P2 - TK27	P3 - TK38	P4 - TK49	P5 - TVOL	P6 - DEFL	P7 - STRS
22	20	0.19896	0.15	0.27	0.22162	4.0297	0.63451	34352
23	21	0.19329	0.17568	0.25328	0.21978	4.0915	0.47772	27603
24	22	0.20472	0.19524	0.27	0.15	3.881	0.47407	43324
25	23	0.2693	0.21473	0.27	0.20692	4.4619	0.28046	28690
26	24	0.2586	0.19297	0.26845	0.15	3.9604	0.42261	43447
27	25	0.15	0.15	0.20441	0.218	3.6404	0.79337	33818
28	26	0.20816	0.27	0.27	0.15	4.3389	0.3179	40722
29	27	0.26664	0.15	0.27	0.22273	4.1617	0.50478	29969
*	New Refiner Point							



- **Refinement points are added automatically**
  - Algorithm to place new refinement points efficiently uses NLPQL optimization to find the location where predicted error is greatest

- **X-axis shows number of refinement points**
- **Y-axis shows ratio between the max predicted error and the tolerance for each output**
- **Convergence occurs when all the outputs are within the convergence threshold**

Goodness of Fit Table

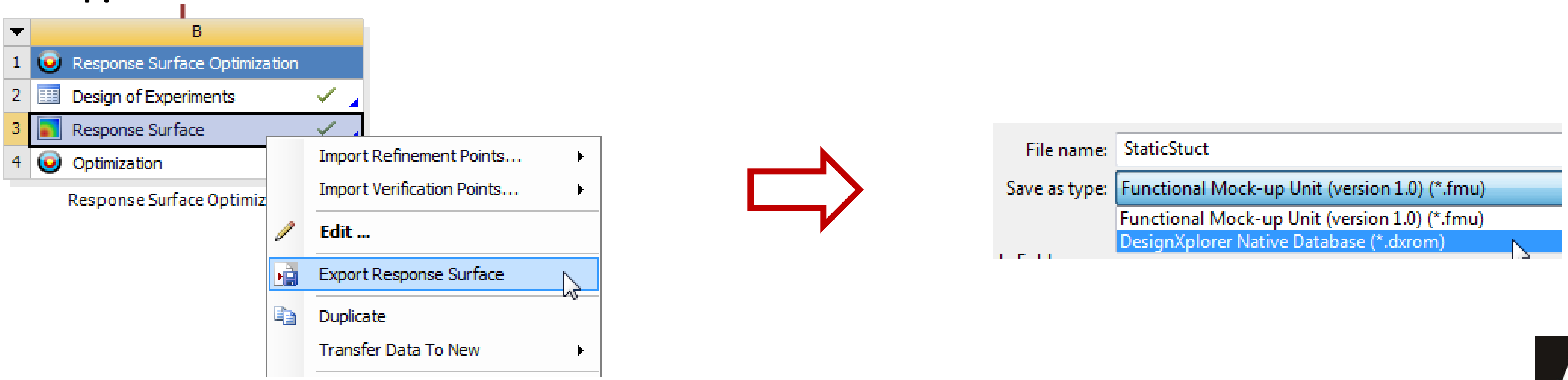
	A	B	C	D
	Table of Schematic C3: Response Surface			
1		P6 - Geometry Mass	P14 - Safety Factor HOOP Minimum	P15 - Safety Factor PIPE Minimum
2	Coefficient of Determination (Best Value = 1)			
3	Learning Points	★★★ 1	★★★ 0.99997	★★★ 0.99998
4	Cross-Validation on Learning Points	★★★ 1	★★★ 0.9994	★★★ 0.99949
5	Root Mean Square Error (Best Value = 0)			
6	Learning Points	1.8876E-06	0.0044675	0.00051469
7	Verification Points	4.4587E-06	0.01796	0.00025673
8	Cross-Validation on Learning Points	5.0531E-06	0.020459	0.0023788
9	Relative Maximum Absolute Error (Best Value = 0%)			
10	Learning Points	★★★ 0	★★ 1.3133	★★ 1.2211
11	Verification Points	★★★ 0	★ 2.1574	★★★ 0.24427
12	Cross-Validation on Learning Points	★★★ 0.011966	− 5.3961	− 6.4131
13	Relative Average Absolute Error (Best Value = 0%)			
14	Learning Points	★★★ 0	★★★ 0.41866	★★★ 0.36291
15	Verification Points	★★★ 0	★ 2.1574	★★★ 0.24427
16	Cross-Validation on Learning Points	★★★ 0.0027904	★ 2.0526	★★ 1.7183

Type of Point:	GOF Measures:
Learning Points	Quality of the interpolation
Verification Points	Quality of the prediction
Cross-Validation Learning Points	Stability/reliability of the response surface

Response Surface

Export

- All Response Surfaces can be exported, except Neural Network and Sparse Grid
- DesignXplorer can export a DX-ROM response surface in the following file formats:
  - Functional Mock-up Unit: *.fmu
    - Broadest applicability; can be used by Simplorer, MATLAB, or any software with Functional Mock-up Interface (FMI) support. Recommended format for export to external software
  - DesignXplorer Native Database: *.dxrom
    - Can be imported into Excel or Workbench using custom DX-ROM tools provided by ANSYS on the ACT Application Store



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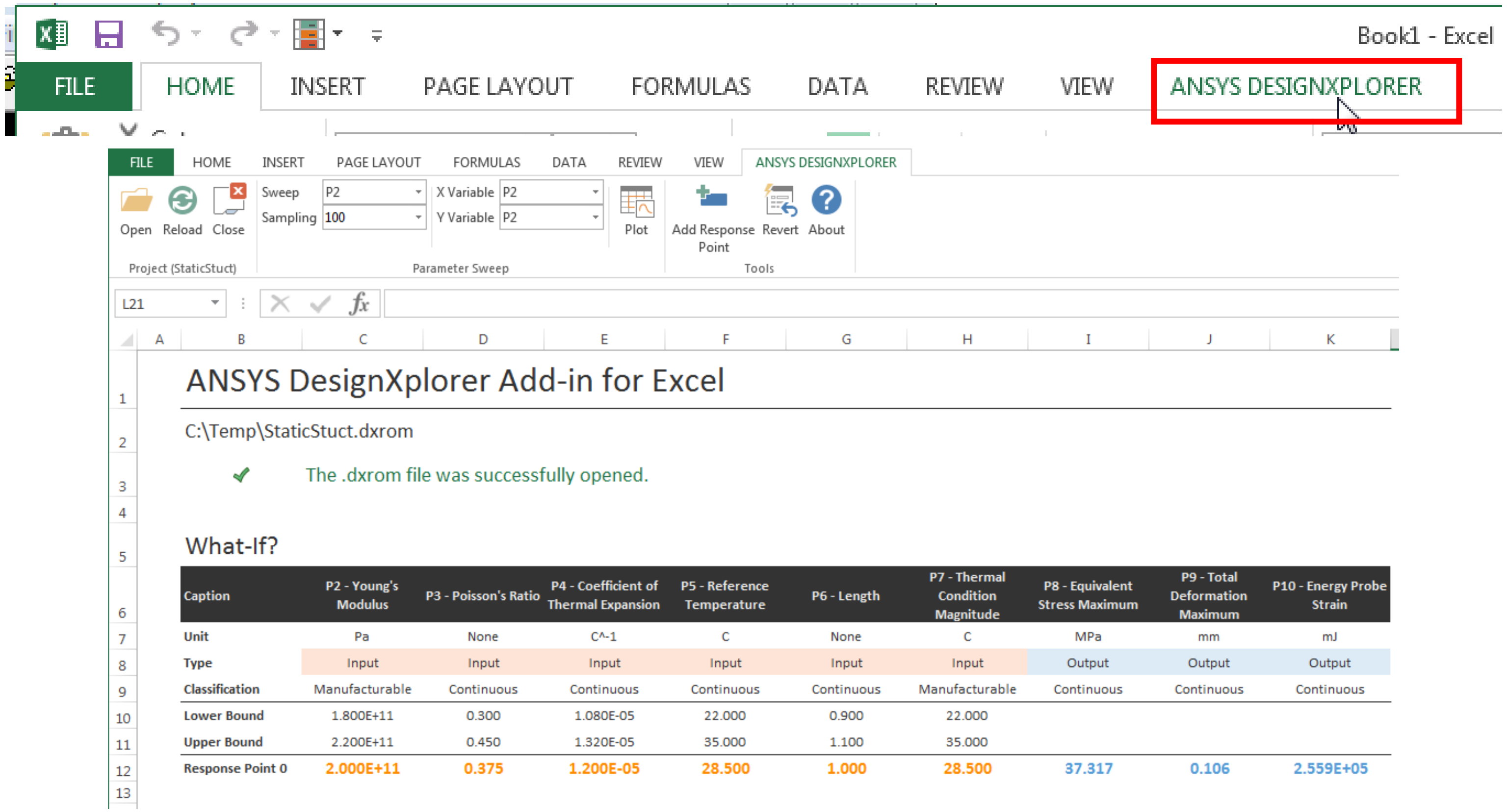
Response Surface

Import in Excel using the ‘Response Surface Reader’ ACT extension

- Response Surfaces that were exported as *.dxrom files can be imported in Excel
- *.fmu file, we can rename it to *.zip, unpack it and grab the dxrom file under the folder



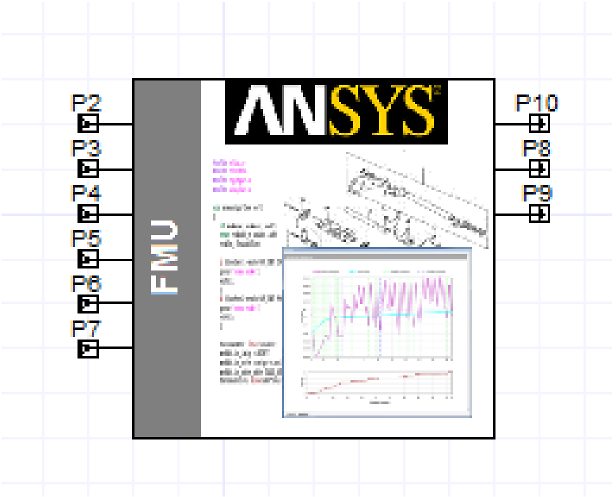
Caption	P2 - Young's Modulus	P3 - Poisson's Ratio	P4 - Coefficient of Thermal Expansion	P5 - Reference Temperature	P6 - Length	P7 - Thermal Condition Magnitude	P8 - Equivalent Stress Maximum	P9 - Total Deformation Maximum	P10 - Energy Probe Strain
Unit	Pa	None	C^-1	C	None	C	MPa	mm	mJ
Type	Input	Input	Input	Input	Input	Input	Output	Output	Output
Classification	Manufacturable	Continuous	Continuous	Continuous	Continuous	Manufacturable	Continuous	Continuous	Continuous
Lower Bound	1.800E+11	0.300	1.080E-05	22.000	0.900	22.000			
Upper Bound	2.200E+11	0.450	1.320E-05	35.000	1.100	35.000			
Response Point 0	2.000E+11	0.375	1.200E-05	28.500	1.000	28.500	37.317	0.106	2.559E+05

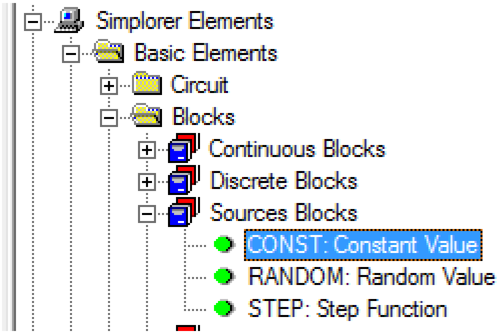
Importing the Response Surface in Excel does not necessarily need an ANSYS license

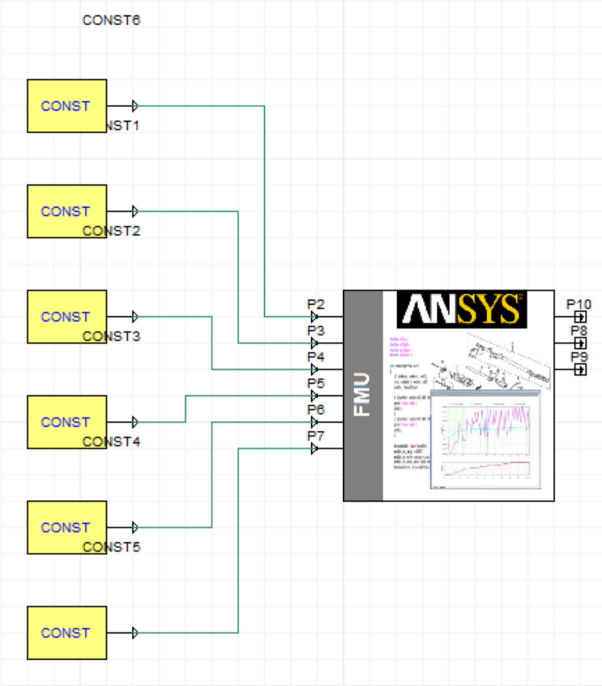
Response Surface

Import in Simplorer

- **Response Surfaces that were exported as *.fmu files can be imported in Simplorer**
  - In Simplorer, go to Simplorer Circuit > Sub-circuit > Add FMU Component
  - Select the *.fmu file > Open > OK
  - Click to place the MU system into the circuit. Then press Esc
  - Then link the input/output pins to the other component
  - To test this component, you can add some constant inputs and check the output values





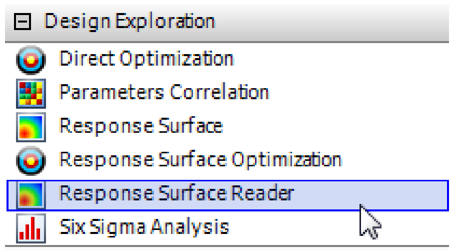


RS Reader ACT

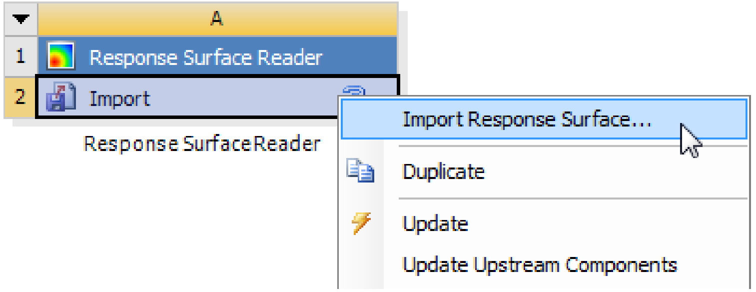
Import a Response Surface in Workbench

Once the extension is loaded, you can create a Response Surface Reader system.

- Double click on the RS Reader system from the Toolbox, under Design Exploration



- Right click on Import > Import Response Surface...



- Select the *.dxrom file > Open

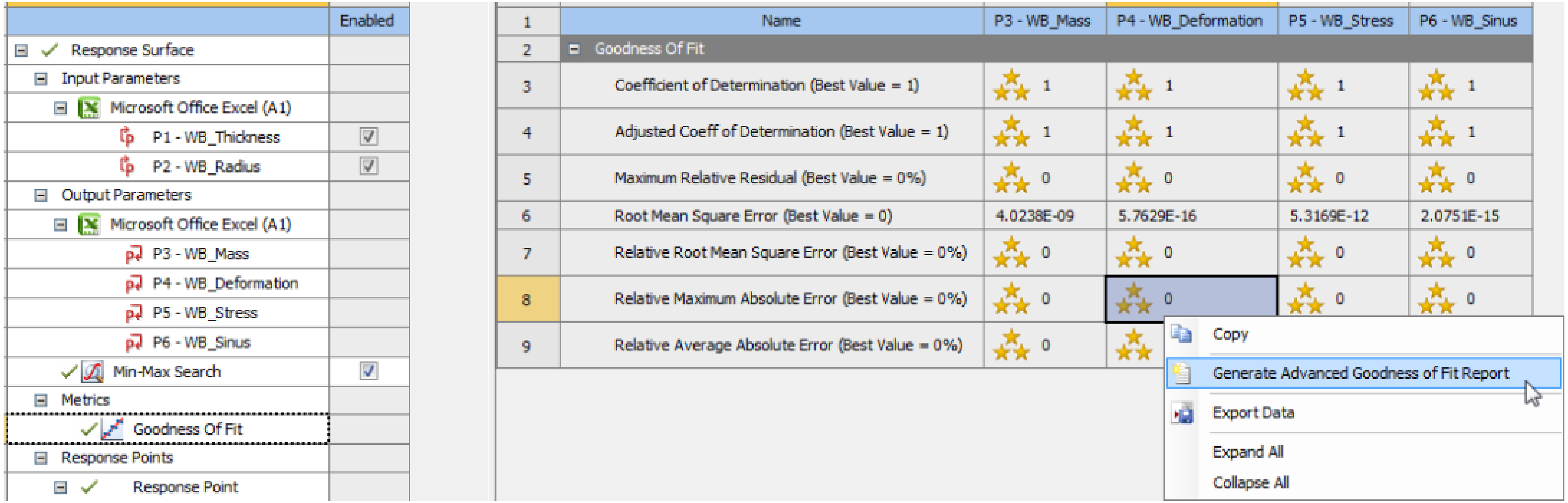
  The file is loaded. Input and output parameters are automatically created.

Quadratic RS: how to extract the equations?

Generate the Advanced Goodness of Fit Report

1. Edit the Response Surface component, select Goodness of Fit

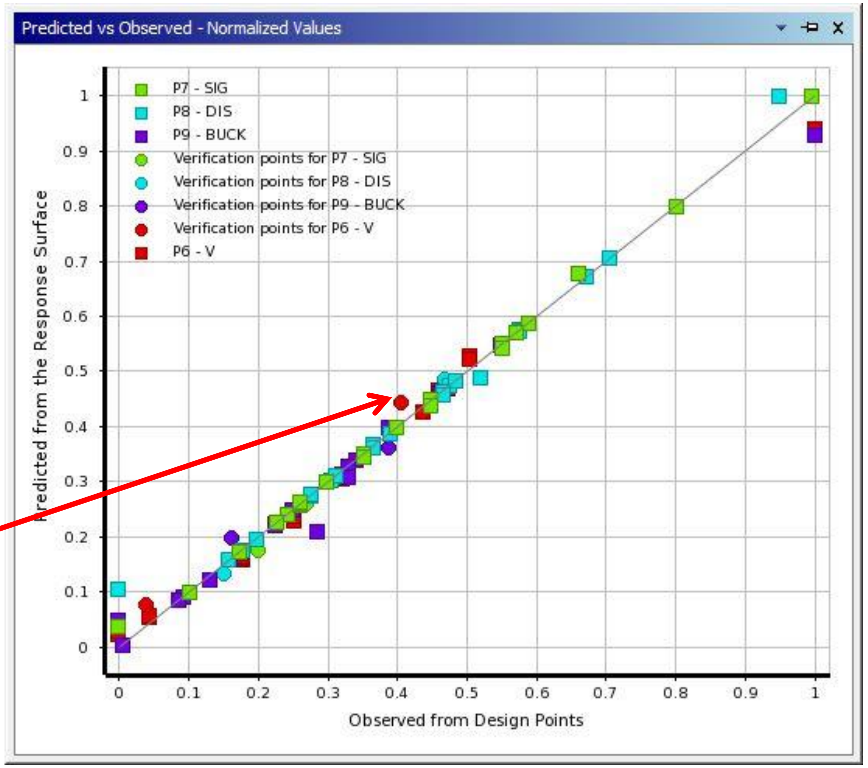
2. Right click on the output parameter you want to assess > Generate Advanced Goodness of Fit Report



Always check the response surface quality

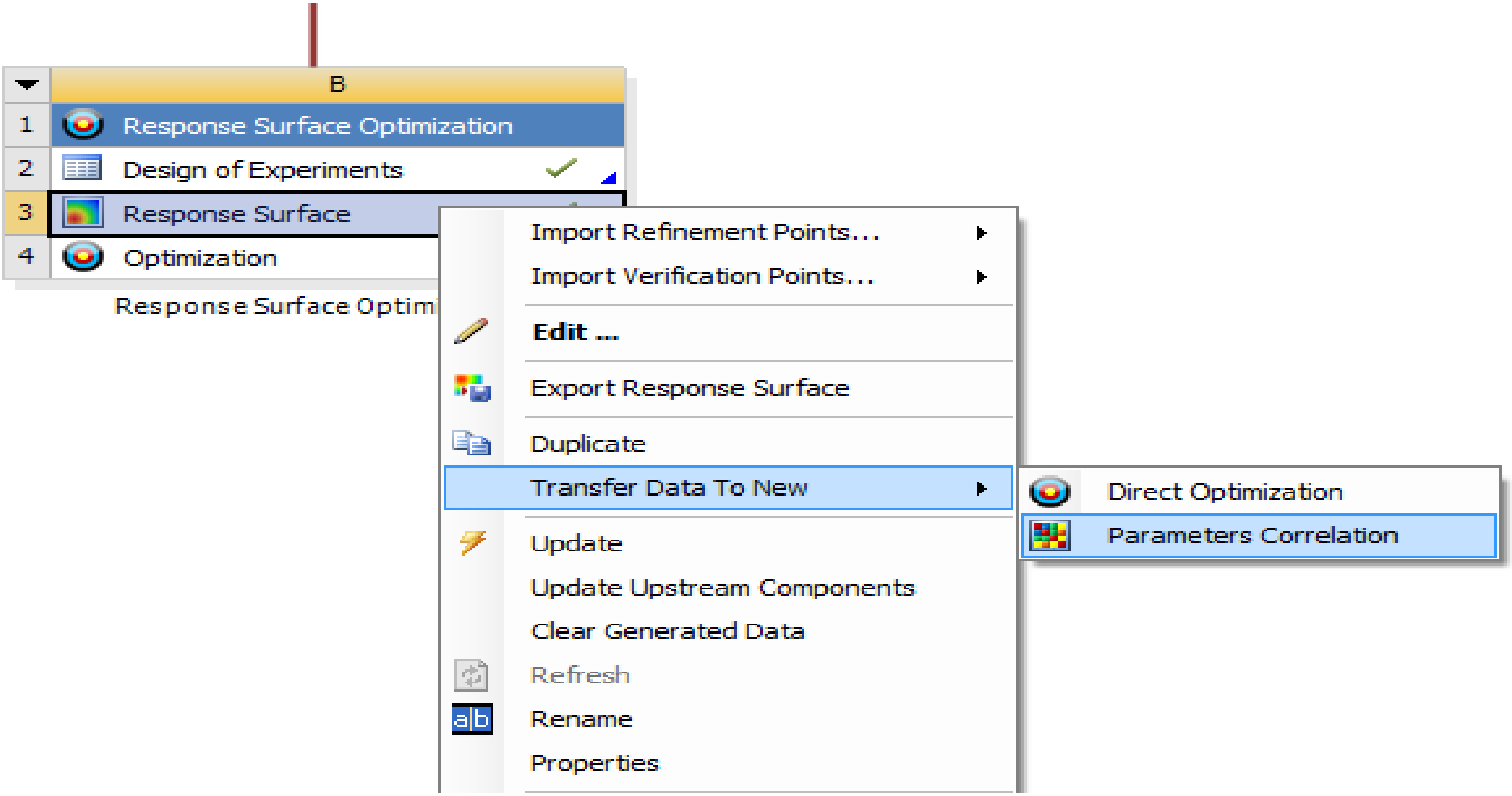
- To estimate the approximation accuracy on DOE points
- To check if output variations are explained by the variation of inputs (with verification points)
- Using Goodness of Fit metrics and associated chart
- Using verification points:
  - Automatically generated
  - Random and/or candidates
  - Manually defined
  - Not needed when GARS (cross validation) is used

Manual refinement: select a point to be appended to the DOE as a refinement point



Response Surface data to Parameters Correlation

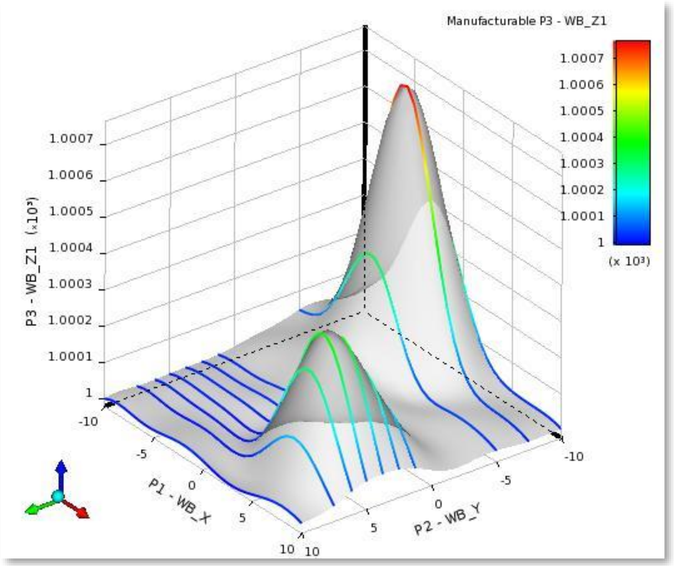
The Parameter Correlation runs are done based on the Response Surface data and no real solve. Right click Response surface and export that data to Parameters Correlation

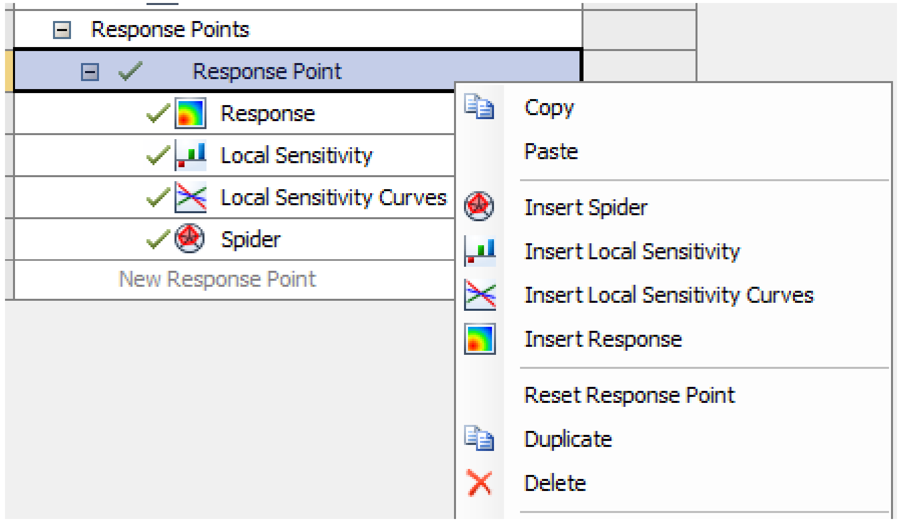


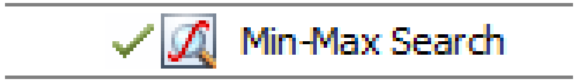
  September 7, 2020

Min-Max Search

- Prefer Manufacturable values to Discrete when possible => more efficient and accurate, less limitations in DX features
- Check results of the Min-Max Search to estimate feasibility of the design specification
- Create multiple Response Points and charts to store interesting results and compare them



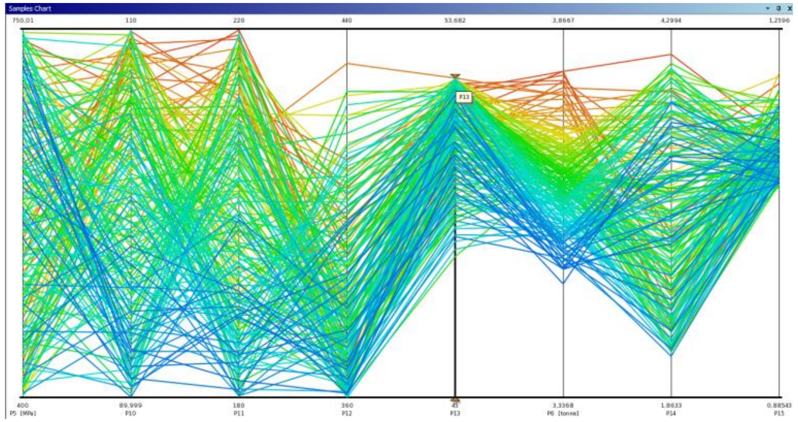


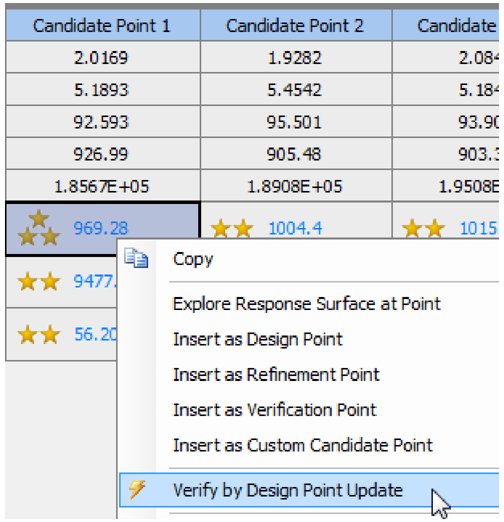


Optimization

Optimization

- Screening and manual exploration with parallel chart can provide you good insights
- For a single objective, pick a screening candidate as the starting point for gradient based optimization (NLPQL, MISQP).
- Verify candidates automatically, or manually, to measure approximation error. If possible, also launch a direct optimization using the best candidate as a starting point.





Candidate Point 1	Candidate Point 1 (verified)
2.0169	
5.1893	
92.593	
926.99	
1.8567E+05	
★★★ 969.28	★★★ 969.1
★★ 9477.4	★★ 9482
★★ 56.204	★★ 56.25

Parameter Relationships in Optimization

- Parameter relationships give you greater flexibility in defining optimization limits on input parameters than the standard single-parameter constraints such as Greater Than, Less Than, and Inside Bounds. When you define parameter relationships, you can specify expression-based relationships between multiple input parameters, with the values remaining physically bounded and reflecting the constraints on the optimization problem.

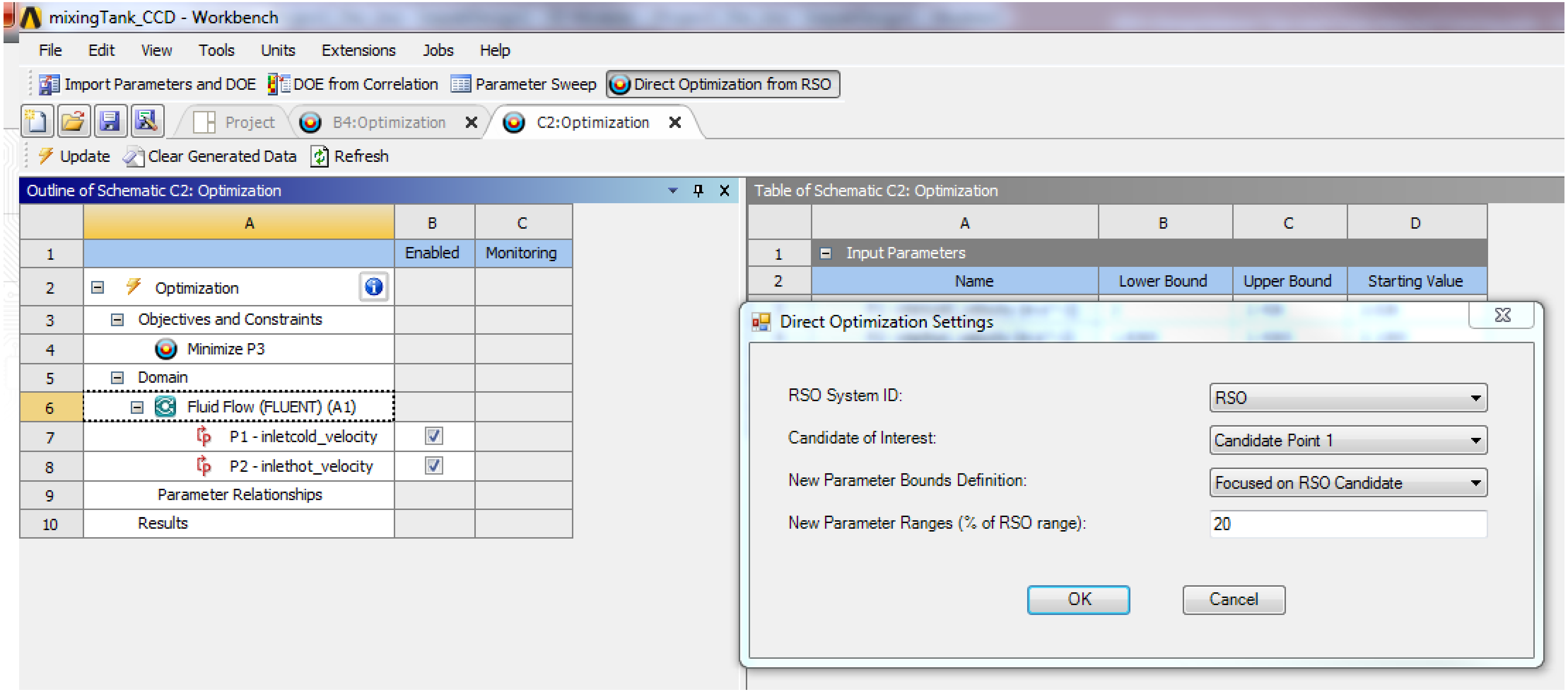
Outline of Schematic C4: Optimization

	A	B	C
1		Enabled	Monitoring
2	Optimization		
3	Objectives and Constraints		
4	Minimize P8		
5	Domain		
6	Microsoft Office Excel (A1)		
7	P1 - WB_B	☑	
8	P2 - WB_D	☑	
9	P3 - WB_L	☑	
10	P4 - WB_P	☑	
11	P5 - WB_E	☑	
12	Parameter Relationships		
13	2*P1 >= P2	☑	
14	P1+P2 <= 0.3[in]	☑	

Table of Schematic C4: Optimization

	A	B	C	D
1	Input Parameters			
2	Name	Lower Bound	Upper Bound	Starting Value
3	P1 - WB_B (mm)	1.8	2.2	2
4	P2 - WB_D (mm)	4.5	5.5	5
5	P3 - WB_L (mm)	90	110	100
6	P4 - WB_P (N)	900	1100	1000
7	P5 - WB_E (MPa)	1.8E+05	2.2E+05	2E+05
8	Parameter Relationships			
9	Name	Left Expression	Operator	Right Expression
10	2*P1 >= P2	2*P1	>=	P2
11		4 [mm]		5 [mm]
12	P1+P2 <= 0.3[in]	P1+P2	<=	0.3[in]
13		7 [mm]		7.62 [mm]
*	New Parameter Relationship	New Expression	<=	New Expression

Direct Optimization from RSO ACT



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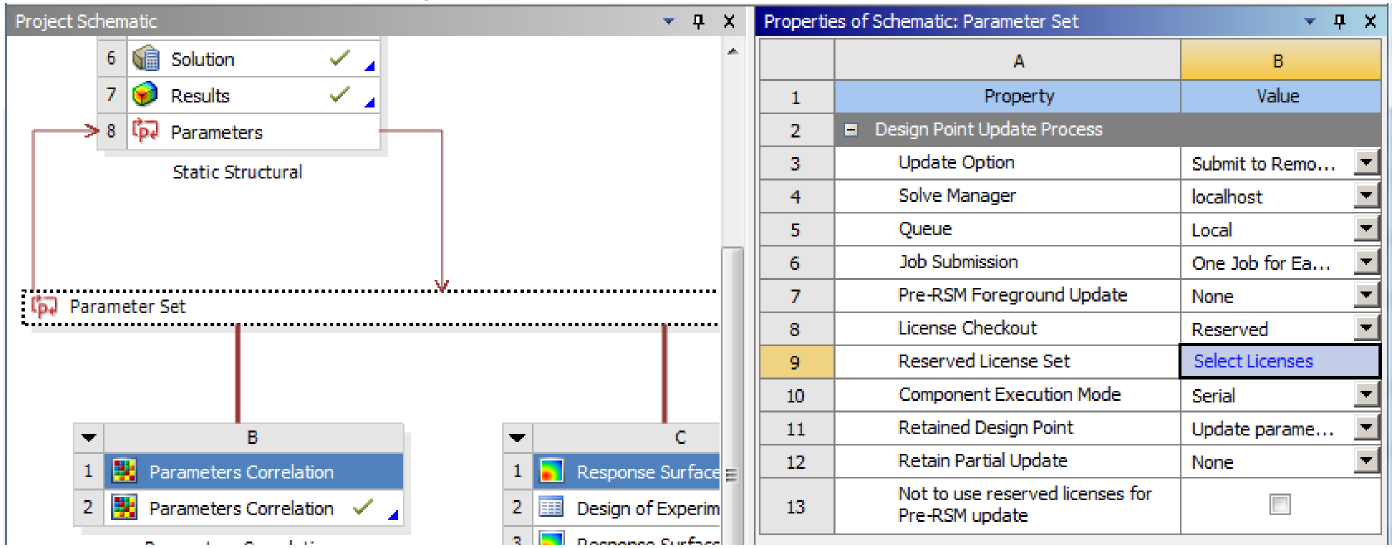
Miscellanous

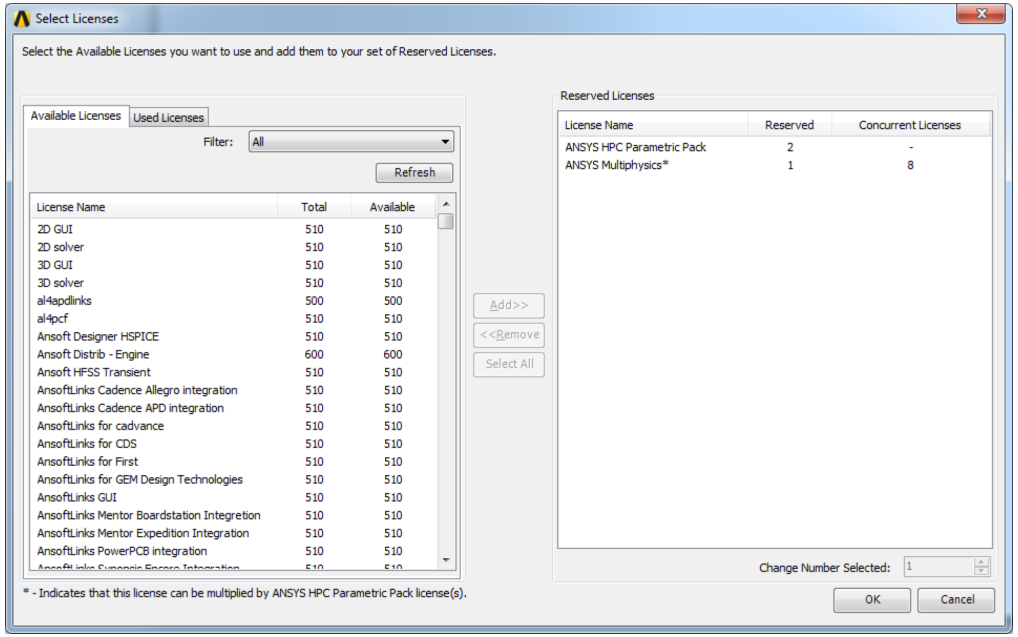
Working with Design Points

- R16.0: if geometry is complicated, check the geometry by updating several design points (just some extremes or the entire DOE) using “Partial Update = Geometry”
- Update failure? Before opening the editor to investigate, copy the project (save as or export DP) to avoid invalidating parametric results.
- RSM: use the mode “One Job for Each Design Point”, so that several design points can be updated simultaneously
  - Look into HPC Parametric packs for licensing
- The file user_files/DesignPoint.log contains parameter values of all calculated DPs. It is a CSV file that you can import in a Custom DOE.

Licences

- Reserve licenses to avoid losing them between Design Points updates (common cause of failure)
- Use the HPC Parametric Pack to cost effectively update multiple design points simultaneously

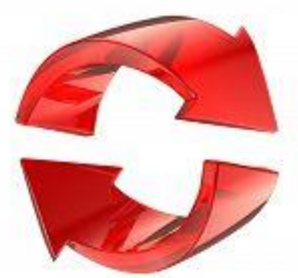




Failing design Points?

- Update of Design Points from DX
- Use the "Retry" option, to reduce DP failures.

⊟ Failed Design Points Management		
Number of Retries	3	
Retry Delay	120	s



- Available in each DX component
- Some minor failures are just due to license server hiccups and a short pause is all that is needed before you can try again…

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DX Scripting

DX Scripting

- Workbench platform actions are journaled
  - By default, available under %TEMP%\WorkbenchJournals
- All DX operations and data are journaled and accessible via commands and queries.
- Power of IronPython (.Net)

Design of Experiments	
Design of Experiments Type	Latin Hypercube Sampling Design
Samples Type	User-Defined Samples
Random Generator Seed	0
Number of Samples	30

```
dOEModel1 = designofExperiment1.GetModel()
dOEModel1.MethodName = "Latin Hypercube Sampling Design"
dOEModel1.SampType = "SFD_USER"
dOEModel1.NumSamp = 30
```

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Questions & Answers