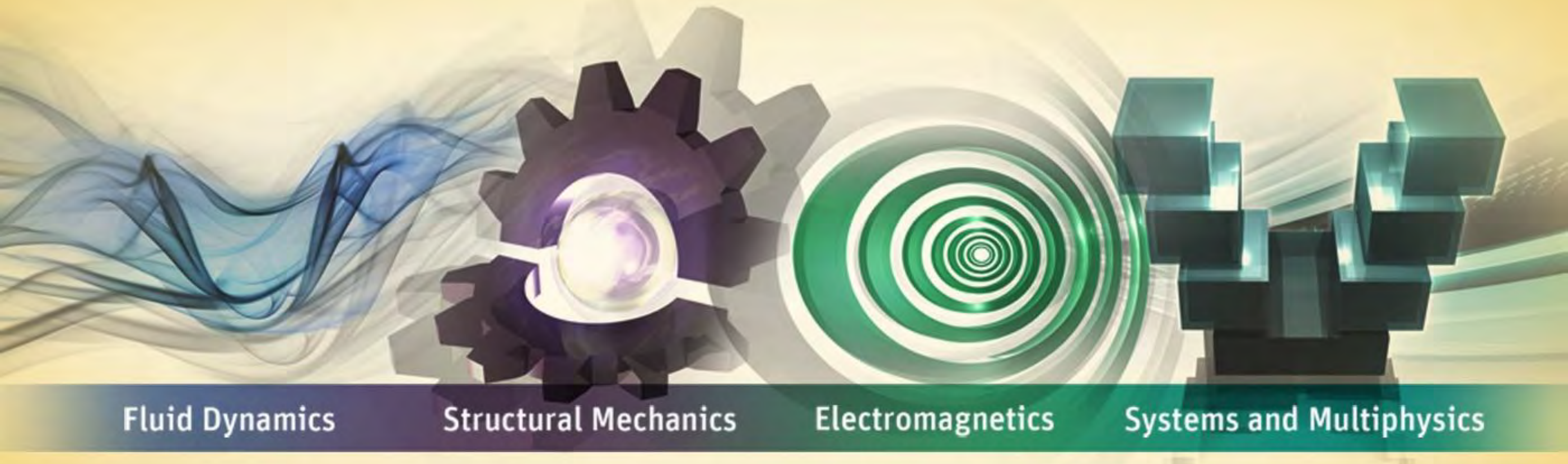
Realize Your Product Promise™

Optimization in ANSYS Workbench



YY. Perng
Lead Application Engineer
ANSYS, Inc.

Johannes Will
CEO
Dynardo, GmbH

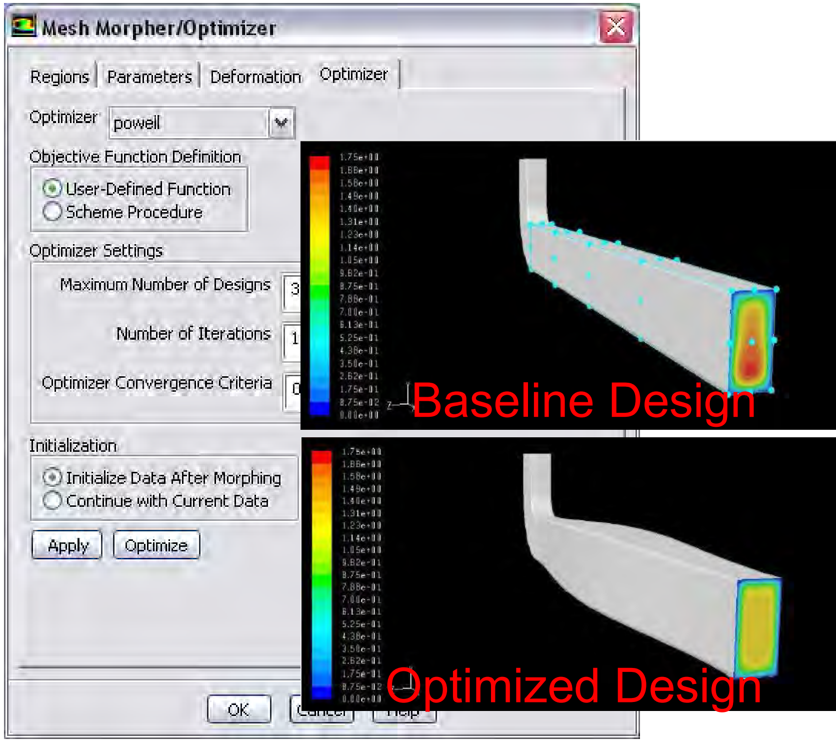
Agenda

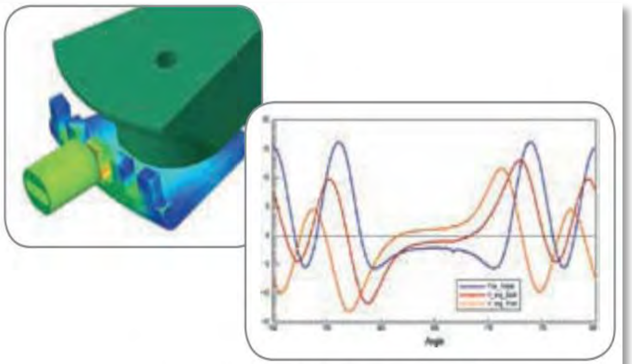
- Optimization using ANSYS DesignXplorer
  - Overview
  - DOE (Design of Experiments)
  - Response Surface
  - Goal Driven Optimization(GDO)

- Optimization using OptiSlang
  - Sensitivity Analysis for Large Number of Parameters
  - Optimization using Meta Model of Optimal Prognosis
  - Live Demo

Optimization tools at ANSYS

- ANSYS DesignXplorer
  - Unified Workbench solution
- ANSYS Fluent
  - Built-in morphing and optimization tools
  - Adjoint solver
- ANSOFT Optimetrics
- ANSYS MAPDL
  - DX VT
- Icepak Optimization



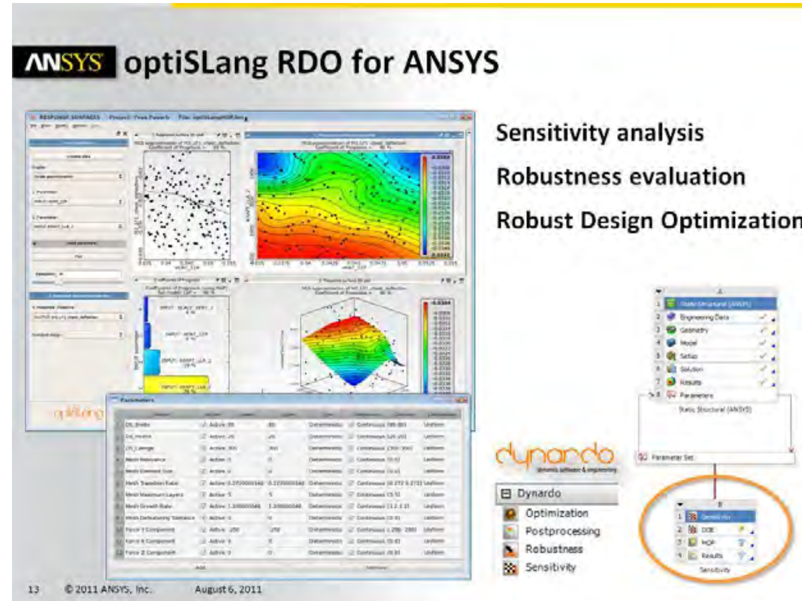


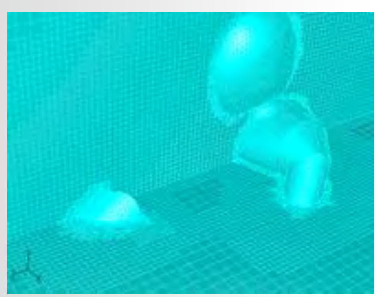
Current sensor optimization results using Maxwell 3D and Optimetrics

Optimization Partners

ANSYS simulation software has been effectively used to drive innovation in concert with optimization partners

- OptiSLang (Dynardo)
- RBF-Morph
- MATLAB (Mathworks)
- ModeFrontier (Esteco)
- Sculptor (Optimal)
- Sigma Technology (IOSO)
- TOSCA (FE-DESIGN)
- Qfin (Qfinsoft)
- and more…

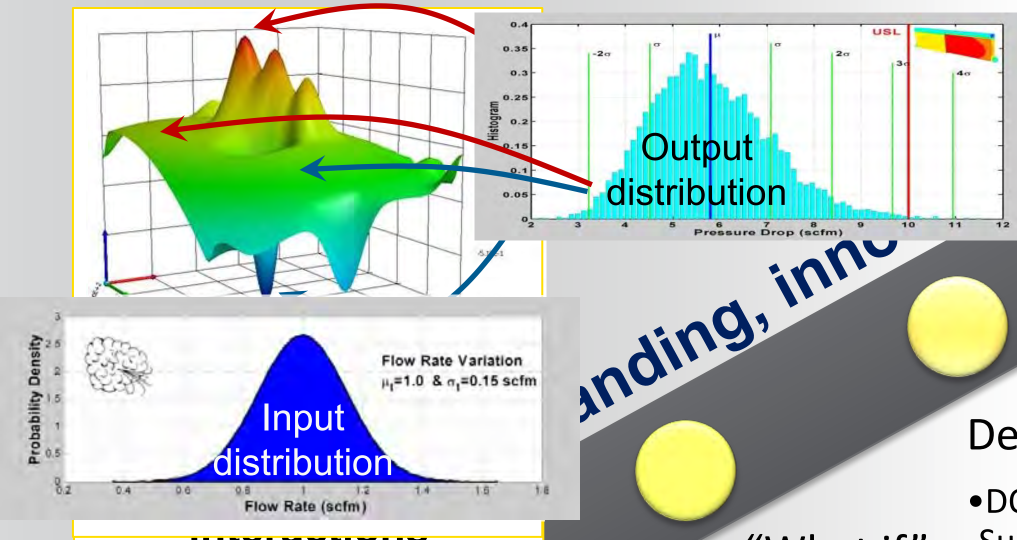




A Good Design in Three Steps

1. Identify key design parameters of your design
2. Identify the variation of the performance of your design with respect to the variations of the design parameters
3. Make the right decision based upon the right information with the appropriate tools

The Path to Robust Design



Single Physics Solution
- Accuracy, robustness, speed…

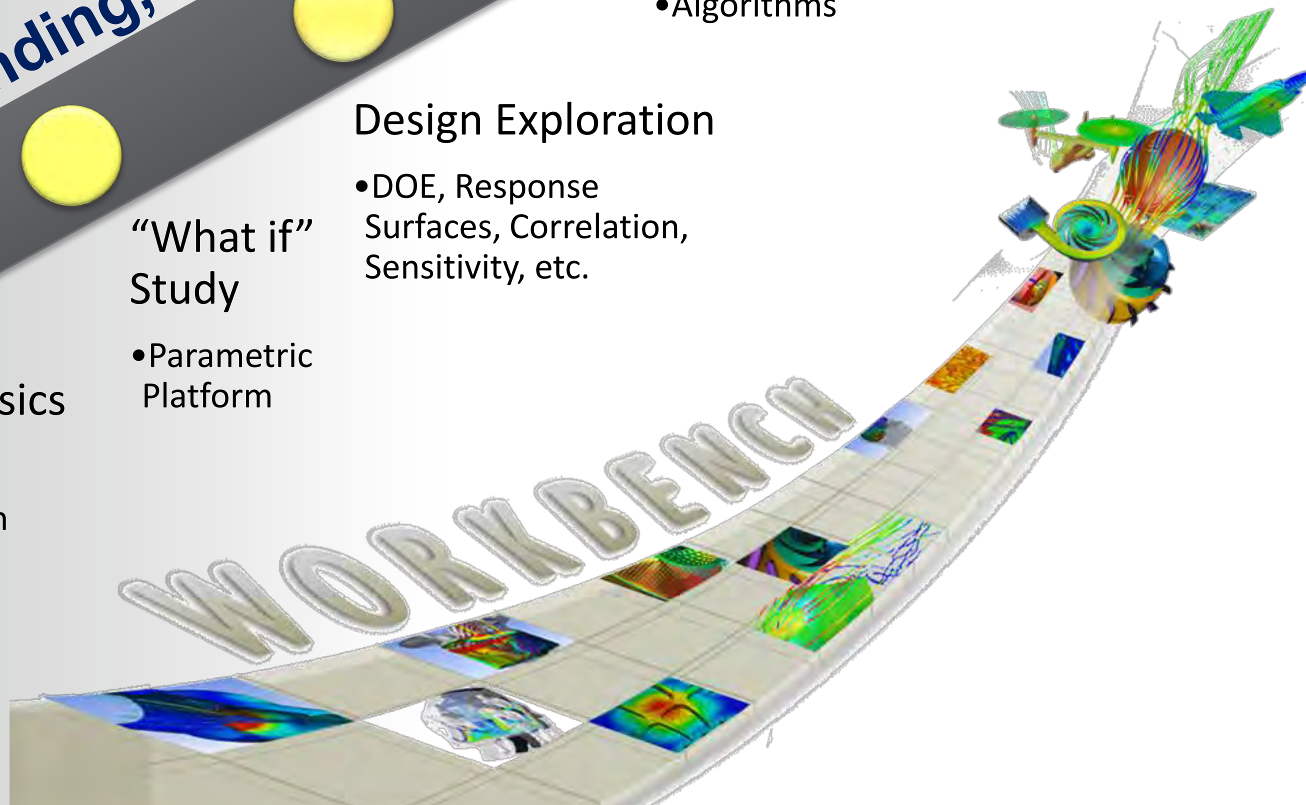
Multiphysics Solution
- Integration Platform

"What if" Study
- Parametric Platform

Design Exploration
- DOE, Response Surfaces, Correlation, Sensitivity, etc.

Optimization
- Algorithms

Robust Design
- Probabilistic Algorithms
- Adjoint solver methods



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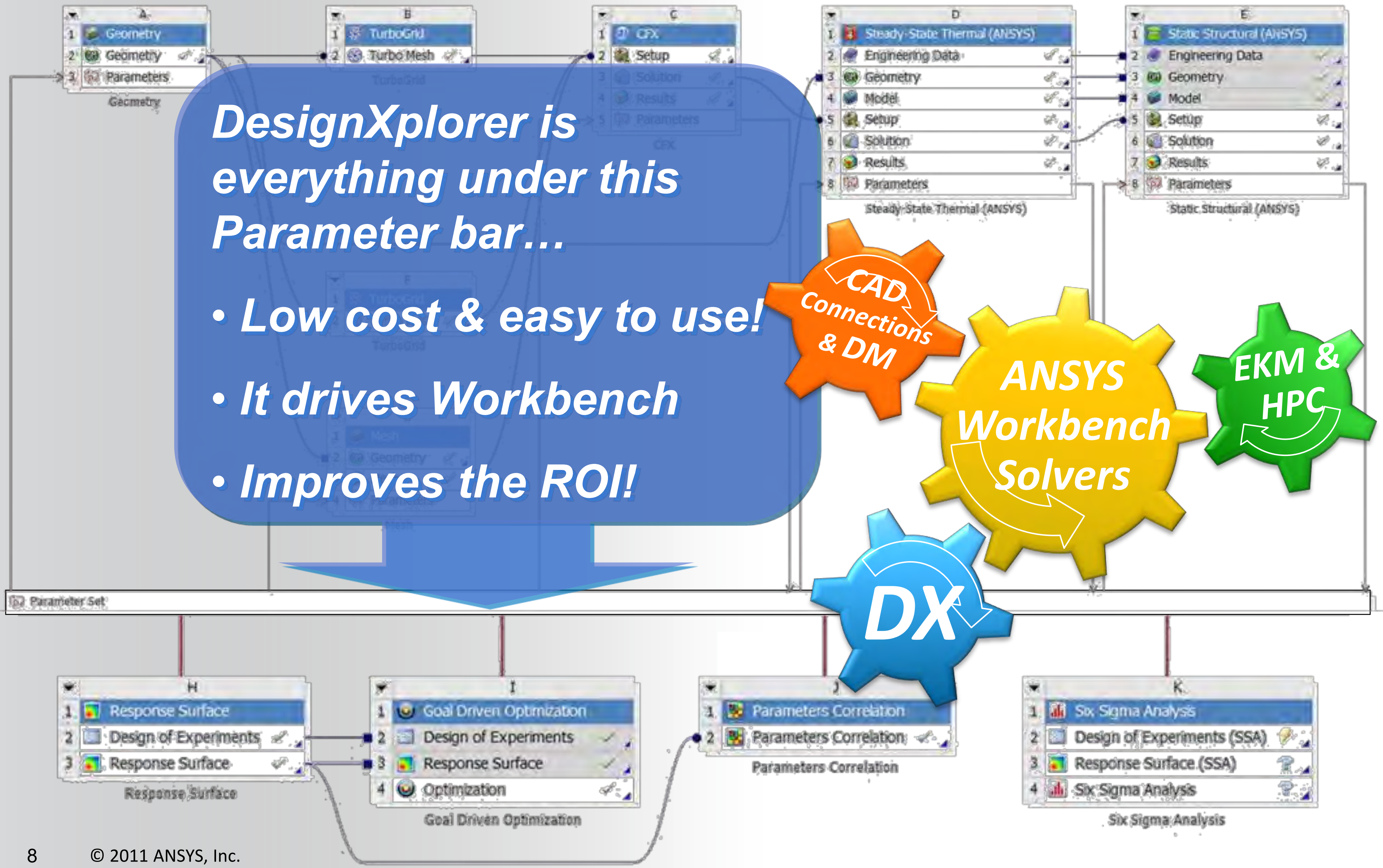
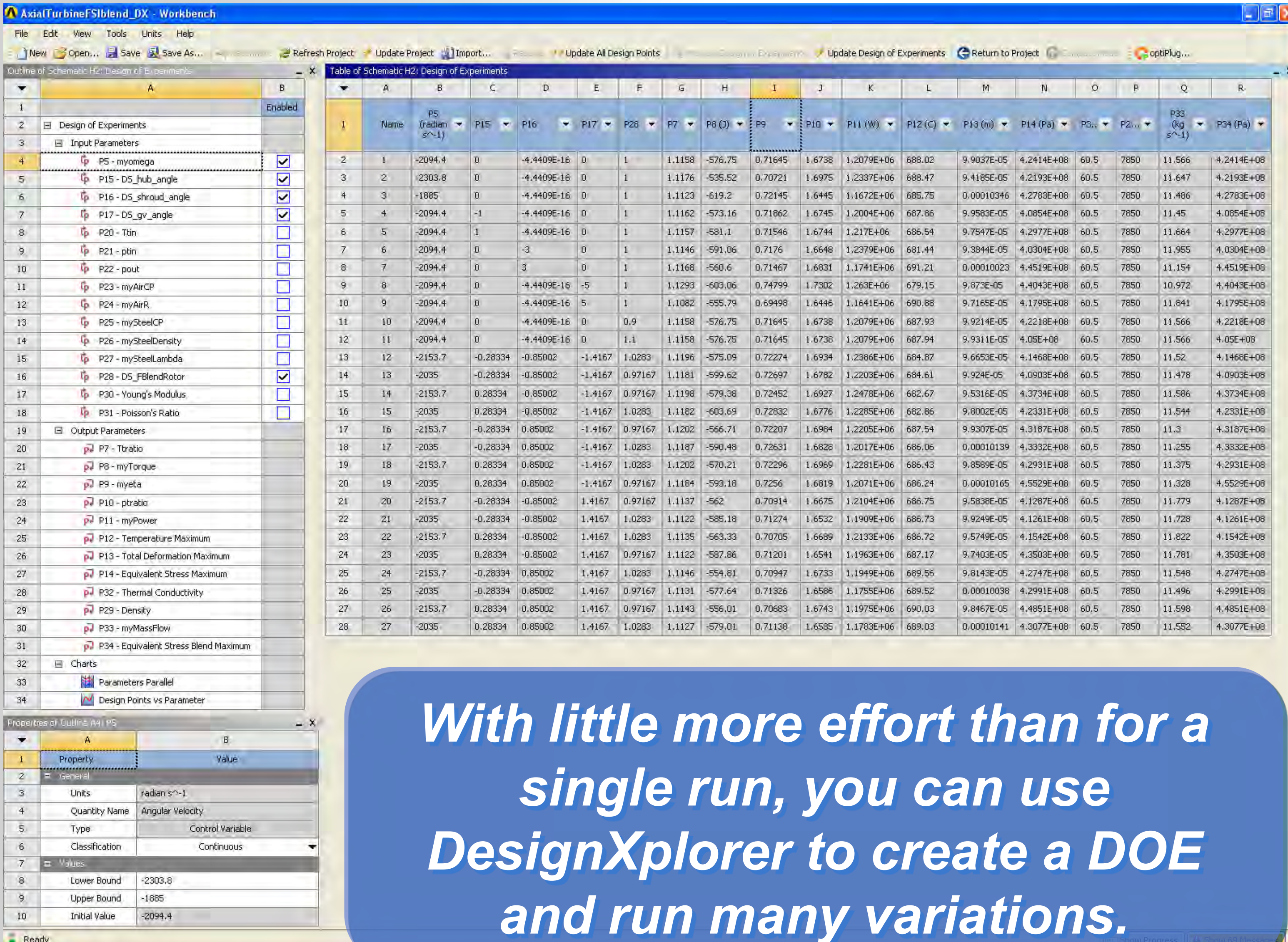
ANSYS DesignXplorer

DesignXplorer is everything under this Parameter bar…

- ***Low cost & easy to use!***
- ***It drives Workbench***
- ***Improves the ROI!***



ANSYS DesignXplorer Design of Experiments

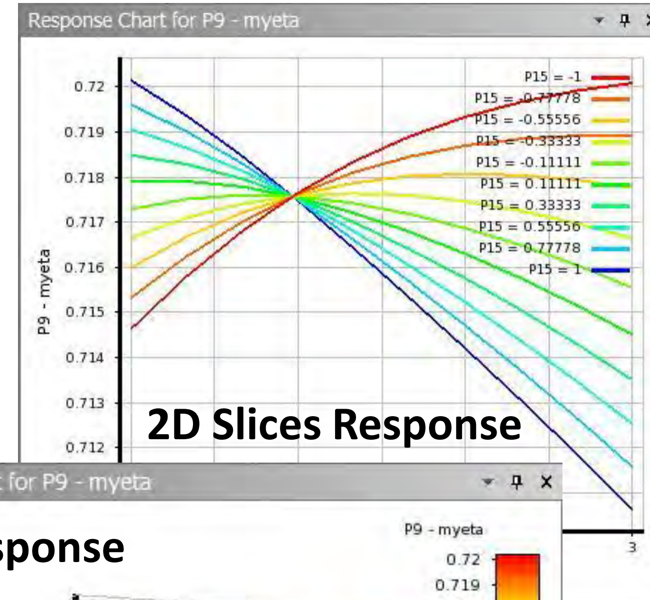


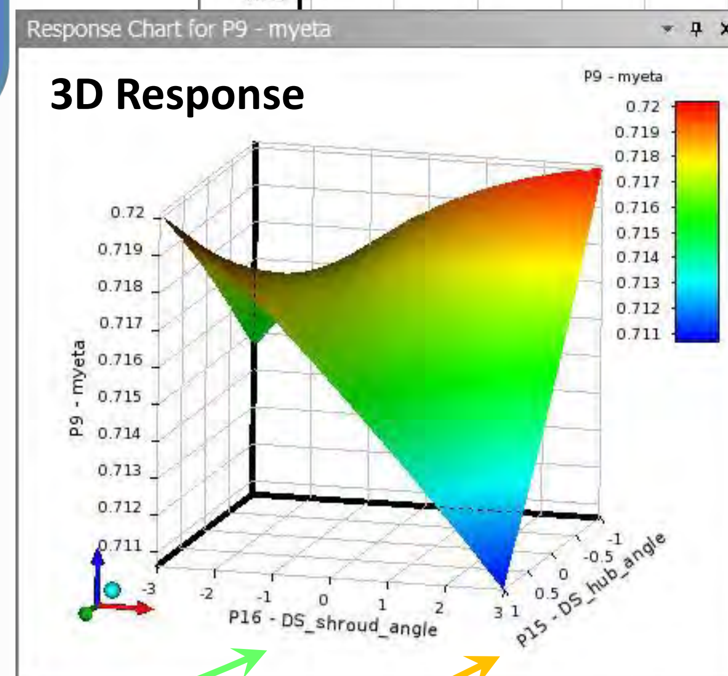
	Name	P5 (radian s^-1)	P15	P16	P17	P28	P7	P8 (J)	P9	P10	P11 (W)	P12 (C)	P13 (m)	P14 (Pa)	P3...	P2...	P33 (kg s^-1)	P34 (Pa)
2	1	-2094.4	0	-4.4409E-16	0	1	1.1158	-576.75	0.71645	1.6738	1.2079E+06	688.02	9.9037E-05	4.2414E+08	60.5	7850	11.566	4.2414E+08
3	2	-2303.8	0	-4.4409E-16	0	1	1.1176	-535.52	0.70721	1.6975	1.2337E+06	688.47	9.4185E-05	4.2193E+08	60.5	7850	11.647	4.2193E+08
4	3	-1885	0	-4.4409E-16	0	1	1.1123	-619.2	0.72145	1.6445	1.1672E+06	685.75	0.00010346	4.2783E+08	60.5	7850	11.486	4.2783E+08
5	4	-2094.4	-1	-4.4409E-16	0	1	1.1162	-573.16	0.71862	1.6745	1.2004E+06	687.86	9.9583E-05	4.0854E+08	60.5	7850	11.45	4.0854E+08
6	5	-2094.4	1	-4.4409E-16	0	1	1.1157	-581.1	0.71546	1.6744	1.217E+06	686.54	9.7547E-05	4.2977E+08	60.5	7850	11.664	4.2977E+08
7	6	-2094.4	0	-3	0	1	1.1146	-591.06	0.7176	1.6648	1.2379E+06	681.44	9.3844E-05	4.0304E+08	60.5	7850	11.955	4.0304E+08
8	7	-2094.4	0	3	0	1	1.1168	-560.6	0.71467	1.6831	1.1741E+06	691.21	0.00010023	4.4519E+08	60.5	7850	11.154	4.4519E+08
9	8	-2094.4	0	-4.4409E-16	-5	1	1.1293	-603.06	0.74799	1.7302	1.263E+06	679.15	9.873E-05	4.4043E+08	60.5	7850	10.972	4.4043E+08
10	9	-2094.4	0	-4.4409E-16	5	1	1.1082	-555.79	0.69498	1.6446	1.1641E+06	690.88	9.7165E-05	4.1795E+08	60.5	7850	11.841	4.1795E+08
11	10	-2094.4	0	-4.4409E-16	0	0.9	1.1158	-576.75	0.71645	1.6738	1.2079E+06	687.93	9.9214E-05	4.2218E+08	60.5	7850	11.566	4.2218E+08
12	11	-2094.4	0	-4.4409E-16	0	1.1	1.1158	-576.75	0.71645	1.6738	1.2079E+06	687.94	9.9311E-05	4.05E+08	60.5	7850	11.566	4.05E+08
13	12	-2153.7	-0.28334	-0.85002	-1.4167	1.0283	1.1196	-575.09	0.72274	1.6934	1.2386E+06	684.87	9.6653E-05	4.1468E+08	60.5	7850	11.52	4.1468E+08
14	13	-2035	-0.28334	-0.85002	-1.4167	0.97167	1.1181	-599.62	0.72697	1.6782	1.2203E+06	684.61	9.924E-05	4.0903E+08	60.5	7850	11.478	4.0903E+08
15	14	-2153.7	0.28334	-0.85002	-1.4167	0.97167	1.1198	-579.38	0.72452	1.6927	1.2478E+06	682.67	9.5316E-05	4.3734E+08	60.5	7850	11.586	4.3734E+08
16	15	-2035	0.28334	-0.85002	-1.4167	1.0283	1.1182	-603.69	0.72832	1.6776	1.2285E+06	682.86	9.8002E-05	4.2331E+08	60.5	7850	11.544	4.2331E+08
17	16	-2153.7	-0.28334	0.85002	-1.4167	0.97167	1.1202	-566.71	0.72207	1.6984	1.2205E+06	687.54	9.9307E-05	4.3187E+08	60.5	7850	11.3	4.3187E+08
18	17	-2035	-0.28334	0.85002	-1.4167	1.0283	1.1187	-590.48	0.72631	1.6826	1.2017E+06	686.06	0.00010139	4.3332E+08	60.5	7850	11.255	4.3332E+08
19	18	-2153.7	0.28334	0.85002	-1.4167	1.0283	1.1202	-570.21	0.72296	1.6969	1.2281E+06	686.43	9.8589E-05	4.2931E+08	60.5	7850	11.375	4.2931E+08
20	19	-2035	0.28334	0.85002	-1.4167	0.97167	1.1184	-593.18	0.7256	1.6819	1.2071E+06	686.24	0.00010165	4.5529E+08	60.5	7850	11.328	4.5529E+08
21	20	-2153.7	-0.28334	-0.85002	1.4167	0.97167	1.1137	-562	0.70914	1.6675	1.2104E+06	686.75	9.5838E-05	4.1287E+08	60.5	7850	11.779	4.1287E+08
22	21	-2035	-0.28334	-0.85002	1.4167	1.0283	1.1122	-585.18	0.71274	1.6532	1.1909E+06	686.73	9.9249E-05	4.1261E+08	60.5	7850	11.728	4.1261E+08
23	22	-2153.7	0.28334	-0.85002	1.4167	1.0283	1.1135	-563.33	0.70705	1.6689	1.2133E+06	686.72	9.5749E-05	4.1542E+08	60.5	7850	11.822	4.1542E+08
24	23	-2035	0.28334	-0.85002	1.4167	0.97167	1.1122	-587.86	0.71201	1.6541	1.1963E+06	687.17	9.7403E-05	4.3503E+08	60.5	7850	11.781	4.3503E+08
25	24	-2153.7	-0.28334	0.85002	1.4167	1.0283	1.1146	-554.81	0.70947	1.6733	1.1949E+06	689.56	9.8143E-05	4.2747E+08	60.5	7850	11.548	4.2747E+08
26	25	-2035	-0.28334	0.85002	1.4167	0.97167	1.1131	-577.64	0.71326	1.6586	1.1755E+06	689.52	0.00010038	4.2991E+08	60.5	7850	11.496	4.2991E+08
27	26	-2153.7	0.28334	0.85002	1.4167	0.97167	1.1143	-556.01	0.70683	1.6743	1.1975E+06	690.03	9.8467E-05	4.4851E+08	60.5	7850	11.598	4.4851E+08
28	27	-2035	0.28334	0.85002	1.4167	1.0283	1.1127	-579.01	0.71138	1.6585	1.1783E+06	689.03	0.00010141	4.3077E+08	60.5	7850	11.552	4.3077E+08

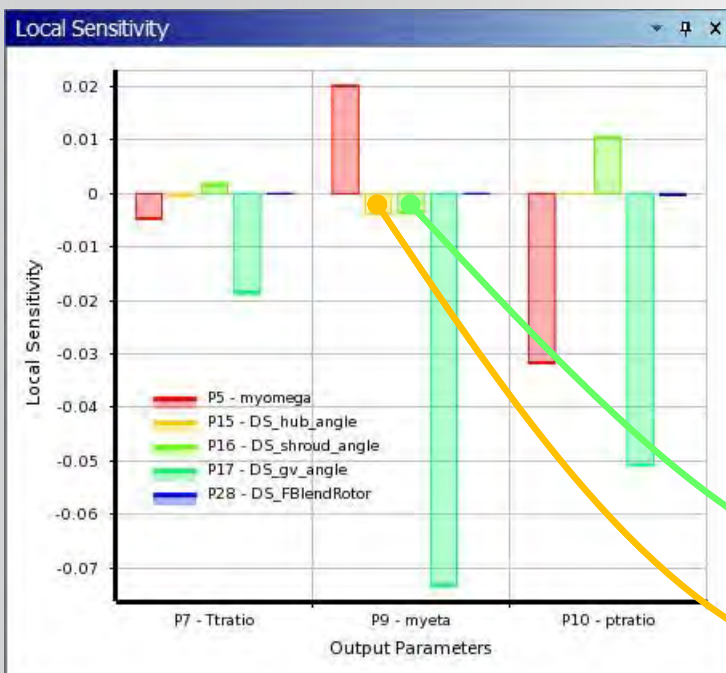
With little more effort than for a single run, you can use DesignXplorer to create a DOE and run many variations.

Response Surface

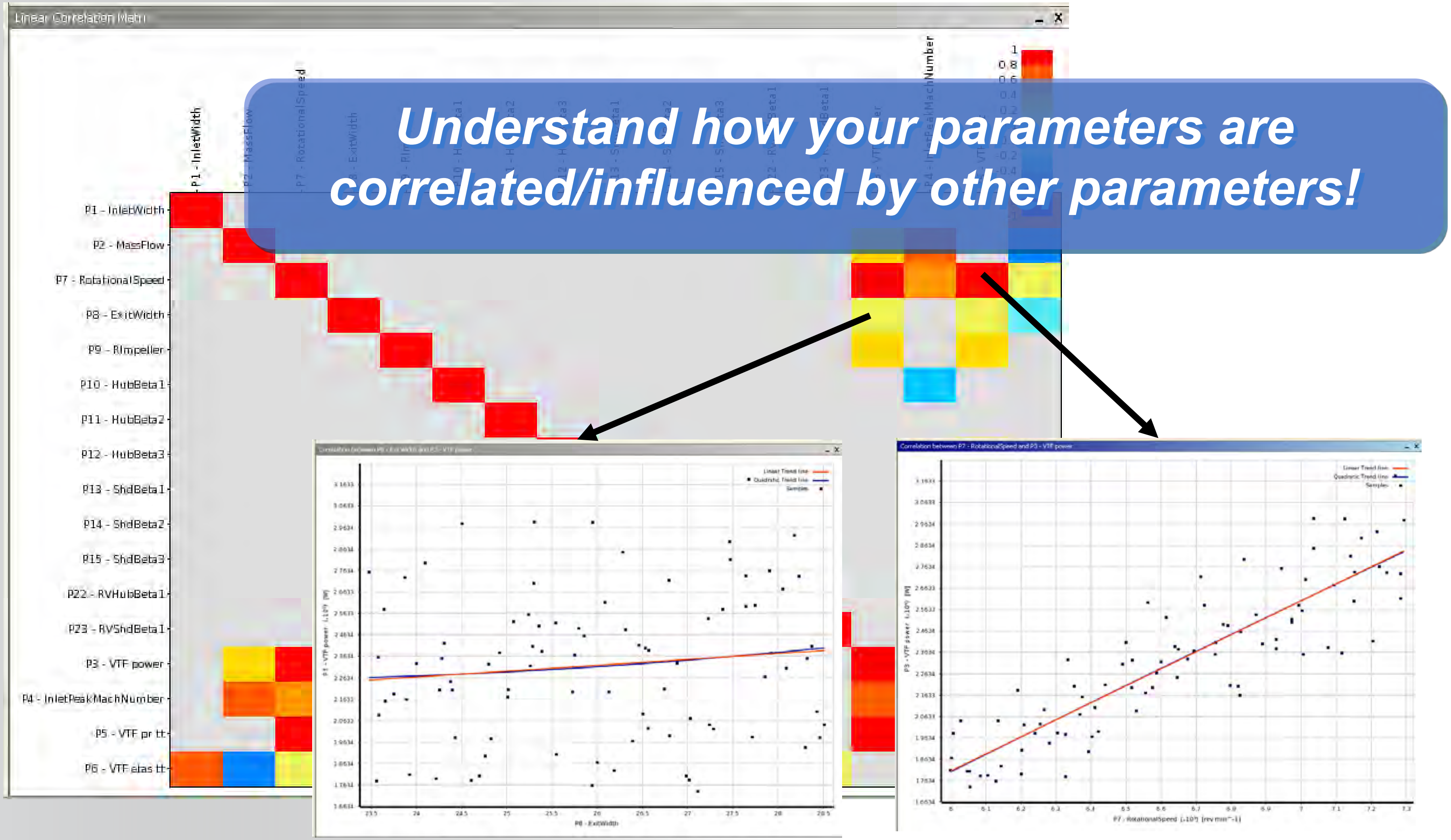
Understand the sensitivities of the output parameters (results) wrt the input parameters.



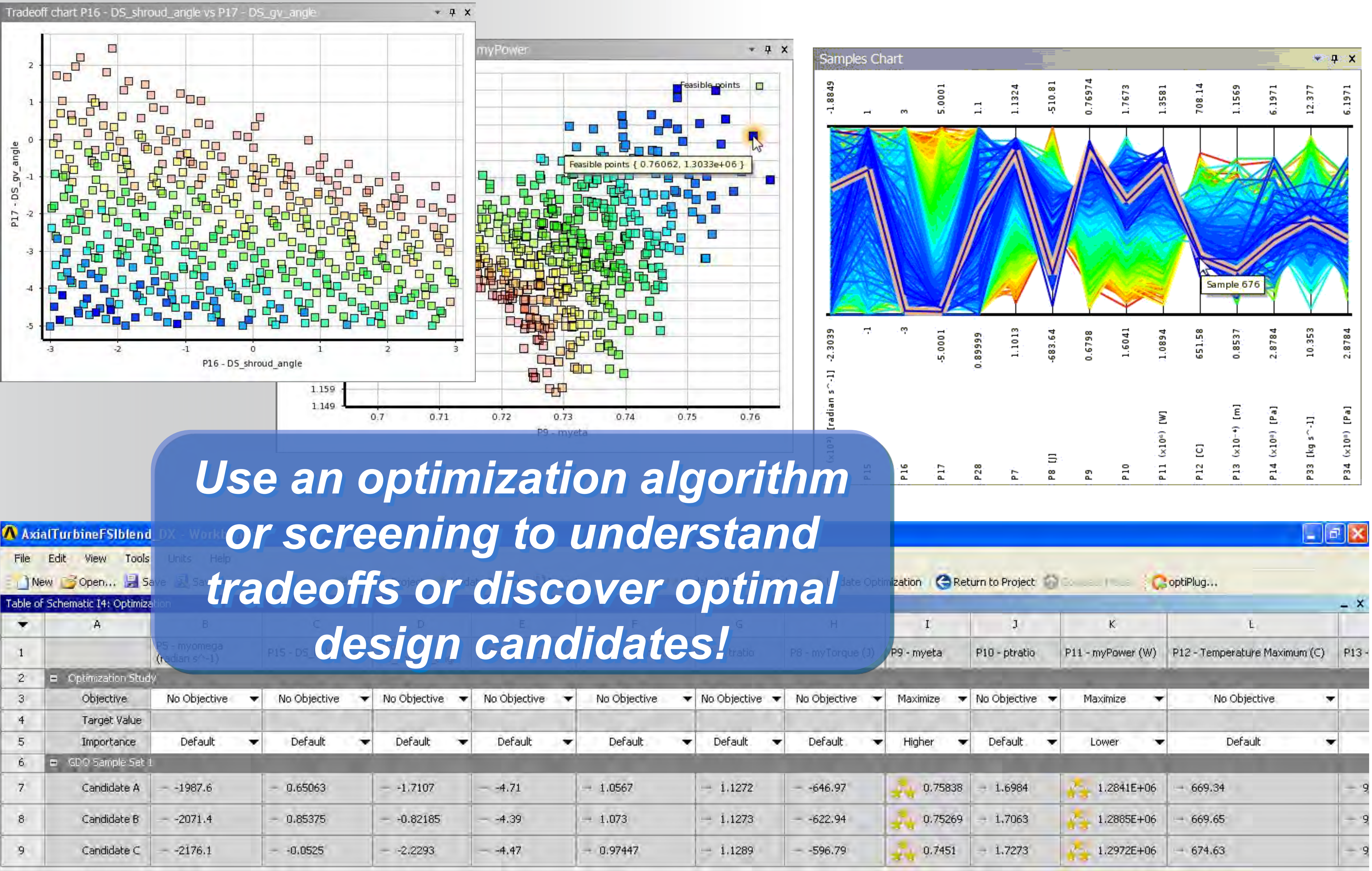




Correlation Matrix



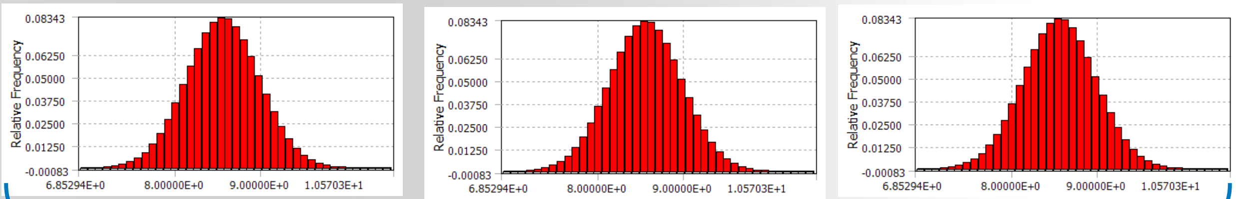
Goal-Driven Optimization



Use an optimization algorithm or screening to understand tradeoffs or discover optimal design candidates!

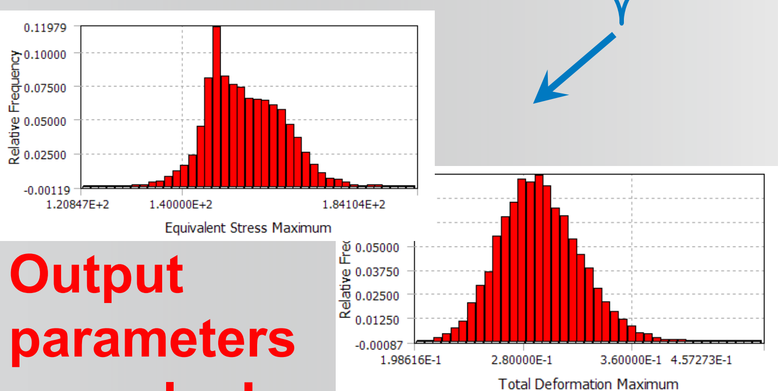
Robustness Evaluation

Input parameters have variation!



Make sure your design is robust!

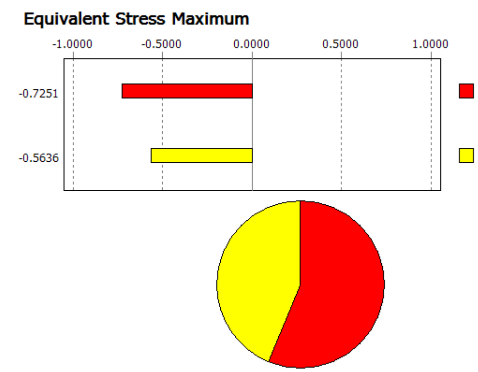
Six Sigma, TQM



Output parameters vary also!

Inverse Probability Table

	Probability	Sigma-Level	Total Deformation Maximum
Min	6.9312e-005	-3.8106	0.2067
	1.e-004	-3.719	0.20834
	5.e-004	-3.2905	0.21691
	1.e-003	-3.0902	0.21811
	1.3499e-003	-3.	0.21949
	5.e-003	-2.5758	0.22743
	1.e-002	-2.3263	0.23231
	2.275e-002	-2.	0.24076
	2.5e-002	-1.96	0.24176
	5.e-002	-1.6449	0.24888
	0.1	-1.2816	0.25813
	0.15866	-1	0.26536
	0.3	-0.5244	0.2782
	0.5	0.	0.29276
	0.7	0.5244	0.30882
	0.84134	1	0.32413
	0.9	1.2816	0.33301
	0.95	1.6449	0.34566
	0.975	1.96	0.35592
	0.97725	2.	0.3569
	0.99	2.3263	0.36859
	0.995	2.5758	0.37717
	0.99865	3.	0.39772
	0.999	3.0902	0.40085
	0.9995	3.2905	0.41375
	0.9999	3.719	0.44766
Max	0.99993	3.8106	0.44919



How will your performance vary with your design tolerances?

How many parts will likely fail?

Which inputs require the greatest control?

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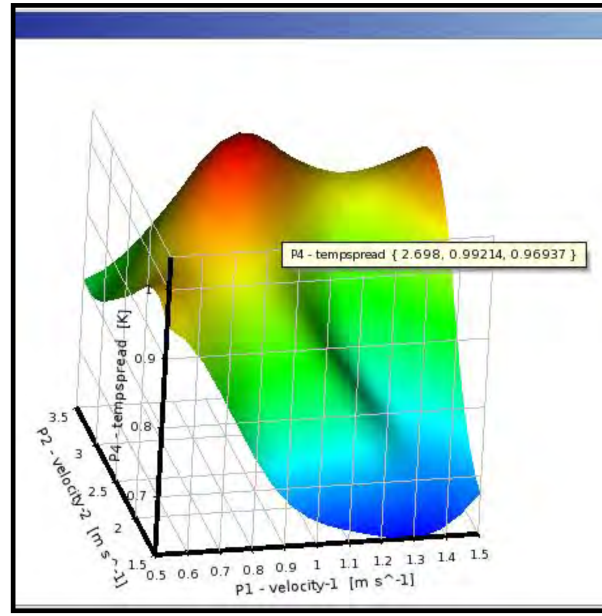
Limitations of the Parametric Analysis

- This approach is a trial & error approach and could require some time in order to get an appropriate parameter set for the goal to be achieved
- To get a reliable information, the number of configurations to examine can be quite important if the number of input parameters is high
- Even if a valid design can be found, there are little estimates about its quality: can I achieve a better solution?

- Response Surface Method addresses limitations of parametric analysis and to further explore design options and perform optimization, 6-sigma, and more

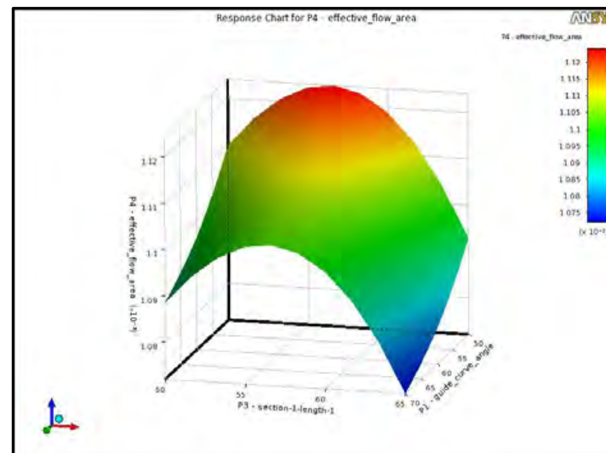
Response Surface Method

- Response surfaces are an efficient way to get the variation of a given performance with respect to input parameters
- Provide a continuous variation of the performance over a given variation of the input
- Accuracy can be controlled
- Usually work well for up to 10 input parameters
- A great basis for further analyses: optimization, 6-sigma robust design…



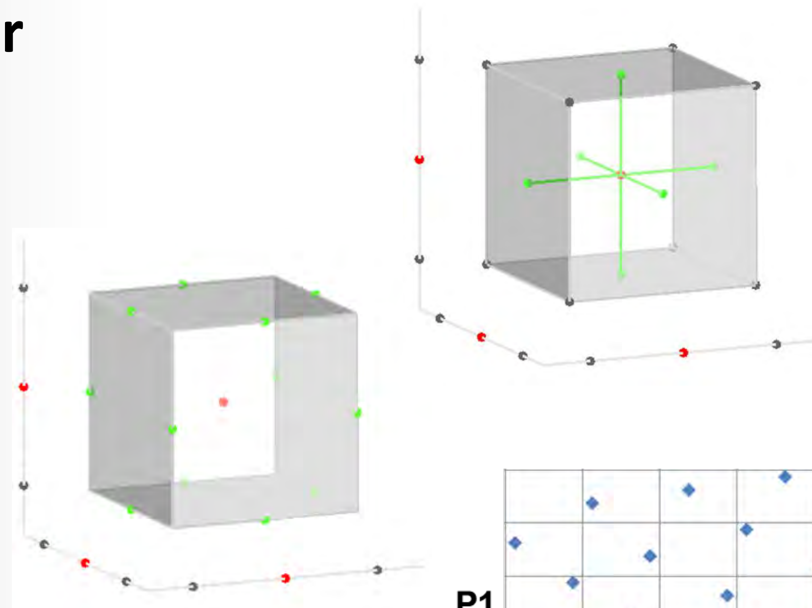
Principles of Response Surface Method:

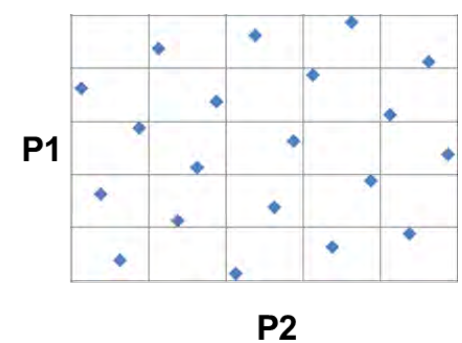
- The user gives an acceptable range of variation for each input parameter (thus defining the *design space*)
- A Design of Experiment (DOE) is computed: only a few points are computed in the design space
- A response surface (best fit surface) is computed from the DOE results for each output parameter
- The user can then investigate the results



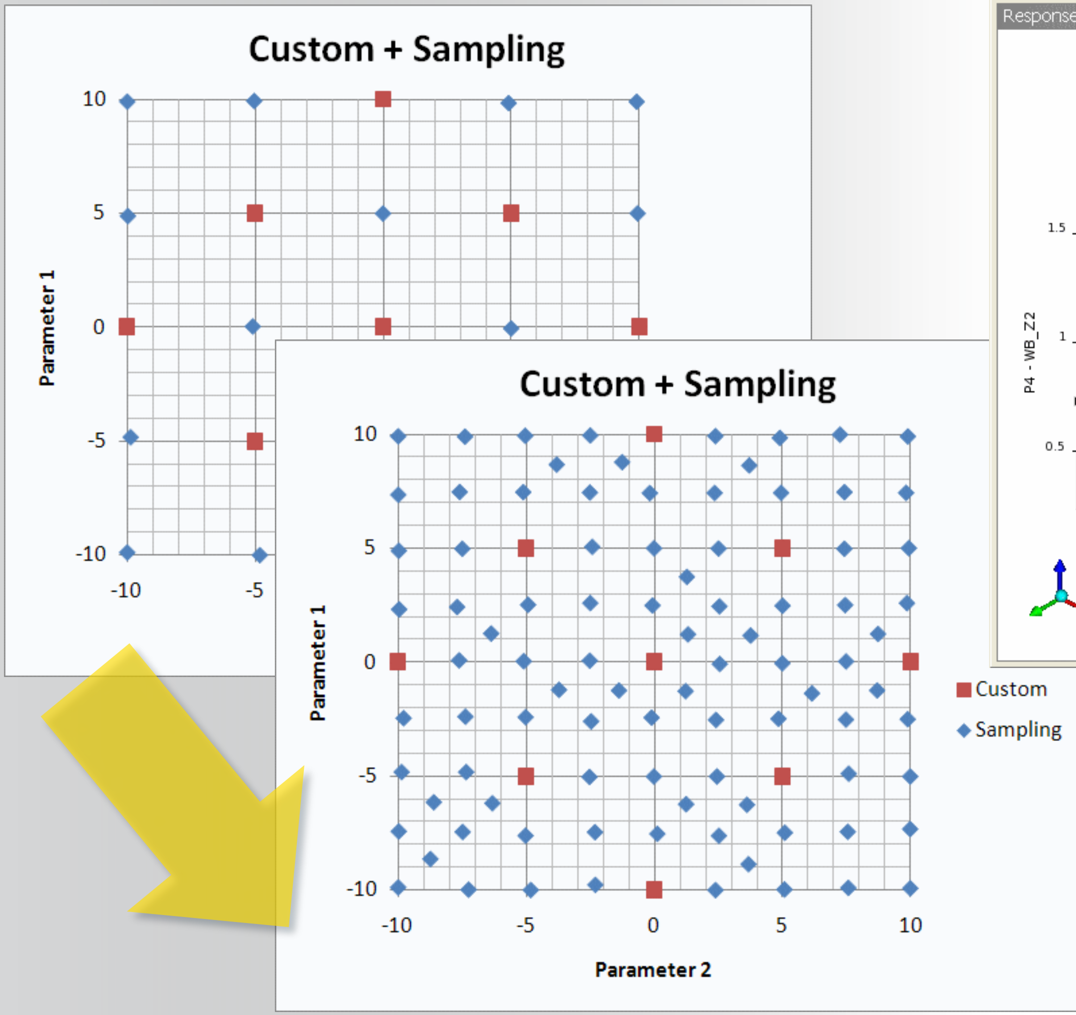
Design of Experiments (DOE)

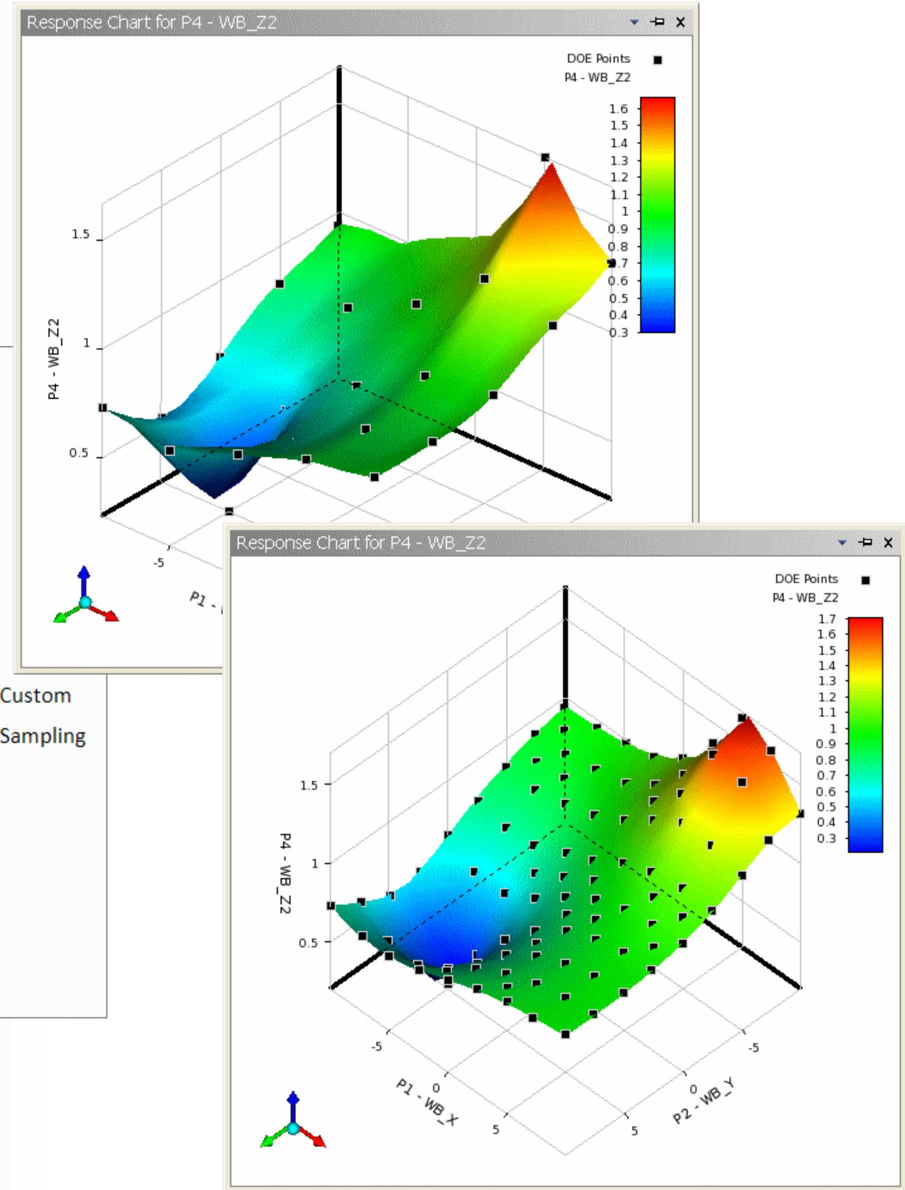
- Basically, a DOE (Design of Experiments) is a scientific way to conduct a series of experiments with a given set of parameters, each with a range, that MINIMIZES the number of runs needed to understand the influence of the parameters…
- DOE algorithms in DesignXplorer
  - Central Composite Design
  - Box-Behnken Design
  - Optimal Space Filling
  - Custom
  - Custom + Sampling
  - Sparse Grid Initialization





A DOE Example: Custom + Sampling





Increase to 100 Samples?

Manufacturable Values

Manufacturable Values

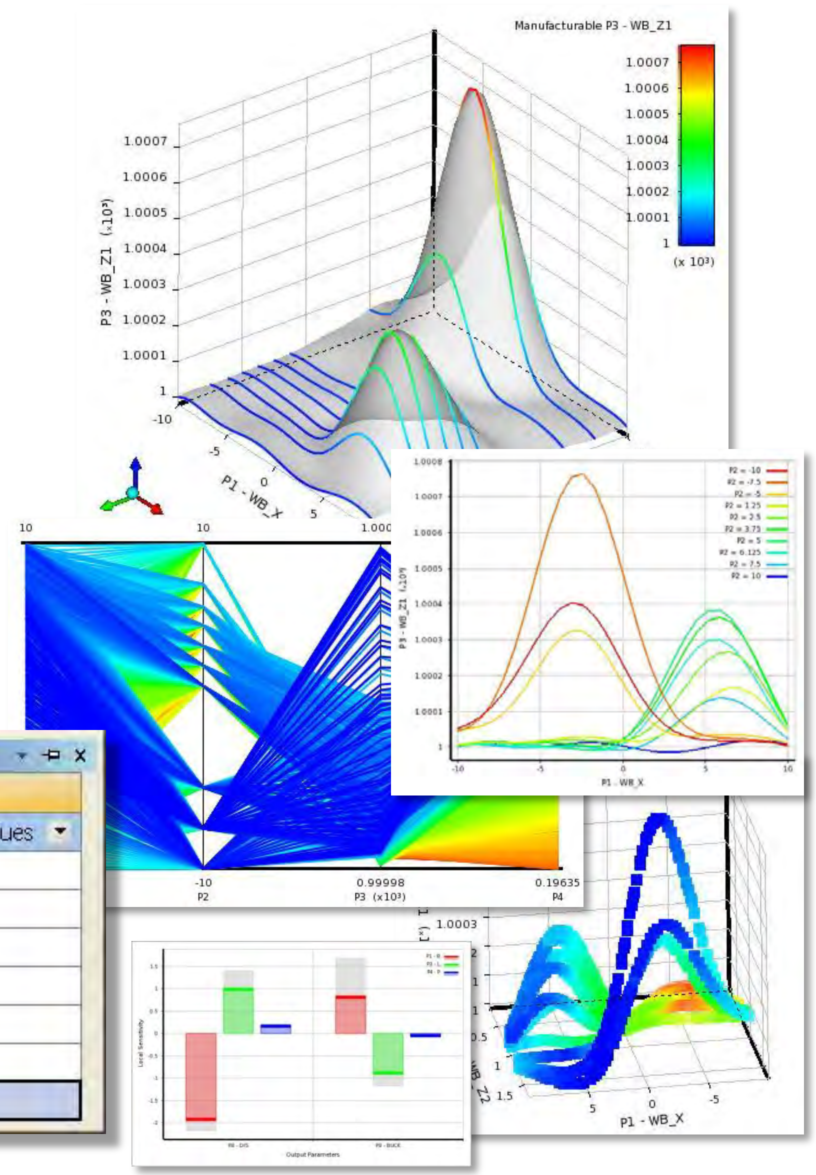
- **DOE is the same as for Continuous**
- **Use to represent real world manufacturing or production constraints.**
  - **Only values that realistically represent manufacturing capabilities are included in the post-processing analysis**
  - **Verification points and optimization candidates will all be “manufacturable”**

Properties of Outline A5: P1

	A	B
1	Property	Value
2	General	
3	Units	
4	Type	Design Variable
5	Classification	Continuous
6	Values	
7	Initial Value	1
8	Lower Bound	-10
9	Upper Bound	10
10	Use Manufacturable Values	☑
11	Number Of Levels	6

Table of Outline : P1 - WB_X

	A	B
1	Name	Manufacturable Values
2	Level 1	0.125
3	Level 2	0.25
4	Level 3	0.75
5	Level 4	1
6	Level 5	1.5
7	Level 6	2
*	New Level	



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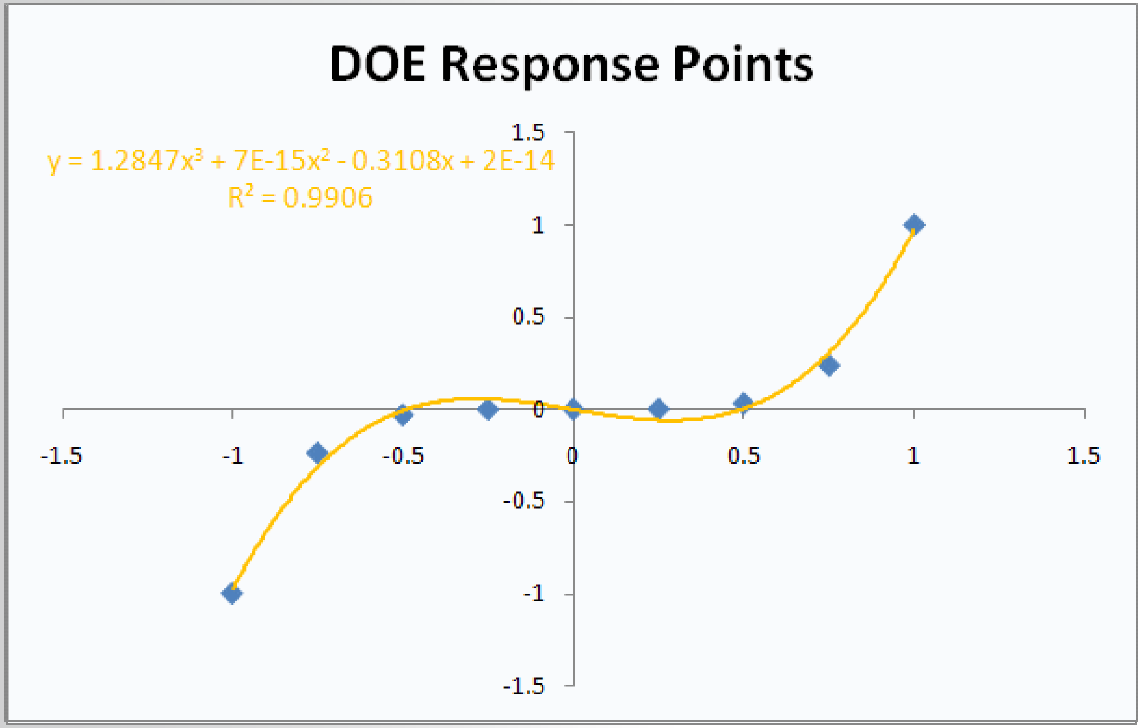
Response Surface Basics

Response surfaces fit thru the calculated points to interpolate the space

- **Like a best fit curve in MS Excel**
- **A response surface is created for each output parameter**



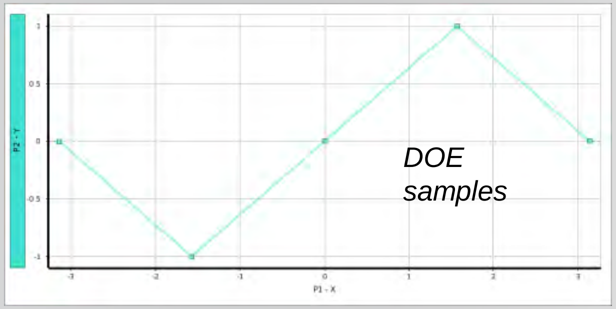
Response Surface Types

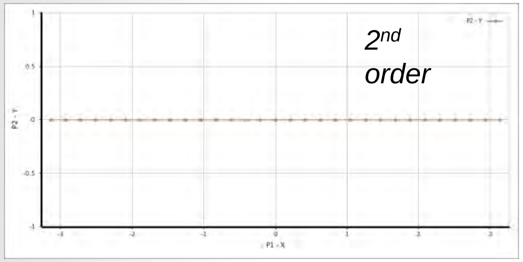
There are five response surface types in DX

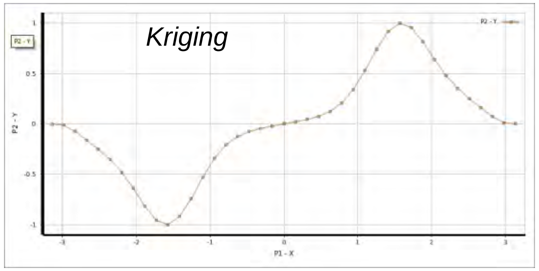
1. **Standard Response Surface (2nd order polynomial) [default]**
2. **Kriging**
3. **Non-parametric Regression**
4. **Neural Network**
5. **Sparse Grid**

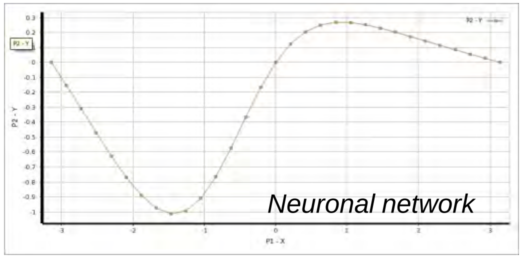
Each is trying to fit to the data…

Sinusoidal response



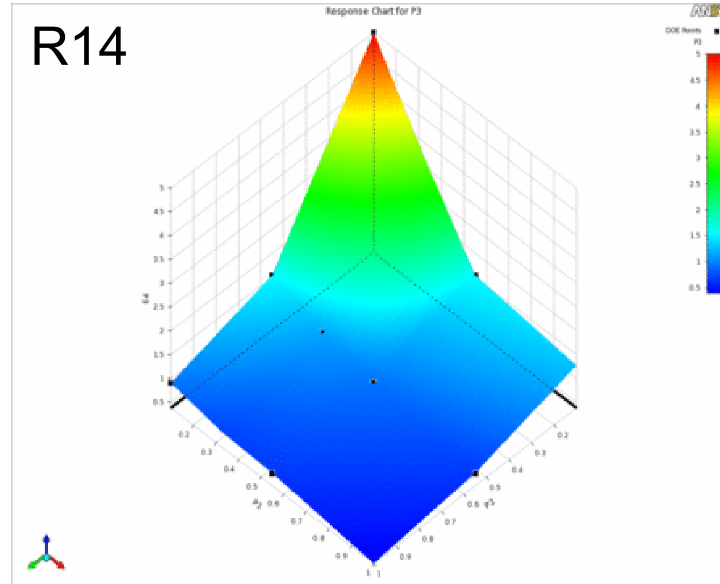


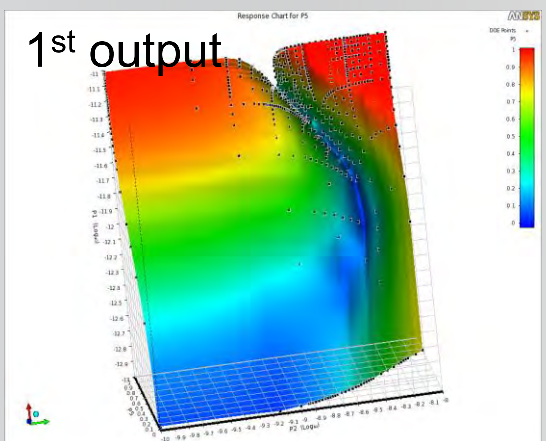


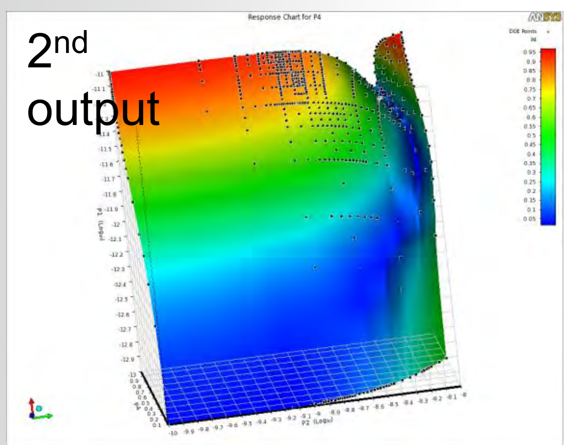


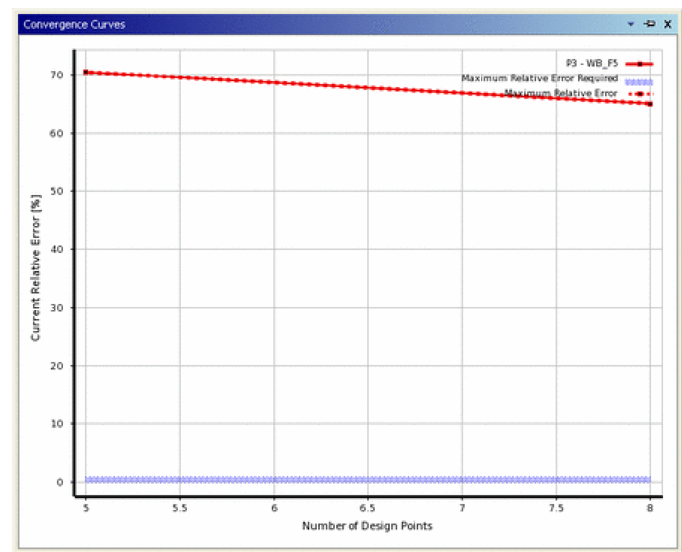
Sparse Grid Refinement in R14

- Sparse Grid adaptive refinement.
  - Enhanced local refinement process
    - Fewer design points for same resolution
    - Reaches required accuracy faster
    - Dynamic convergence feedback!
    - Option to limit refinement points
- Still requires a lot of solved design points, so works better with “quick solvers”









Response Surface

Procedure

Check goodness of fit by reviewing goodness of fit metrics

Coefficient of Determination (R^2 measure):

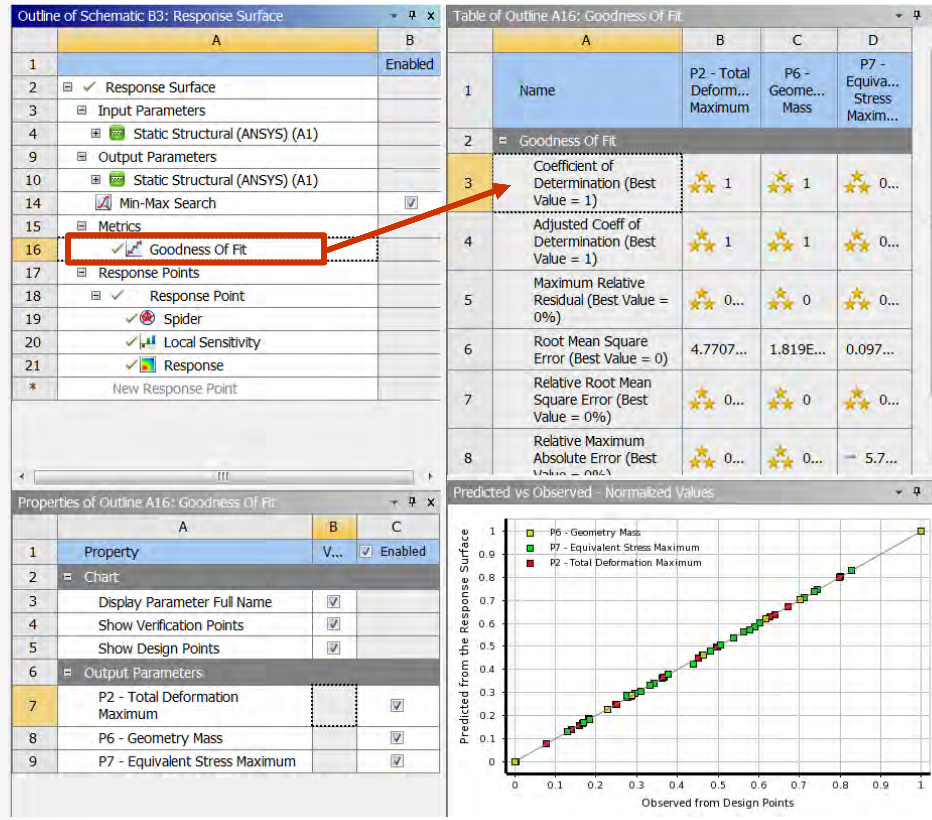
- Measures how well the response surface represents output parameter variability.
- Should be as close to 1.0 as possible.

Adjusted Coefficient of Determination:

- Takes the sample size into consideration when computing the Coefficient of Determination.
- Usually this is more reliable than the usual coefficient of determination when the number of samples is small (< 30).

Maximum Relative Residual:

- Similar measure for response surface using alternate mathematical representation.
- Should be as close to 0.0 as possible.

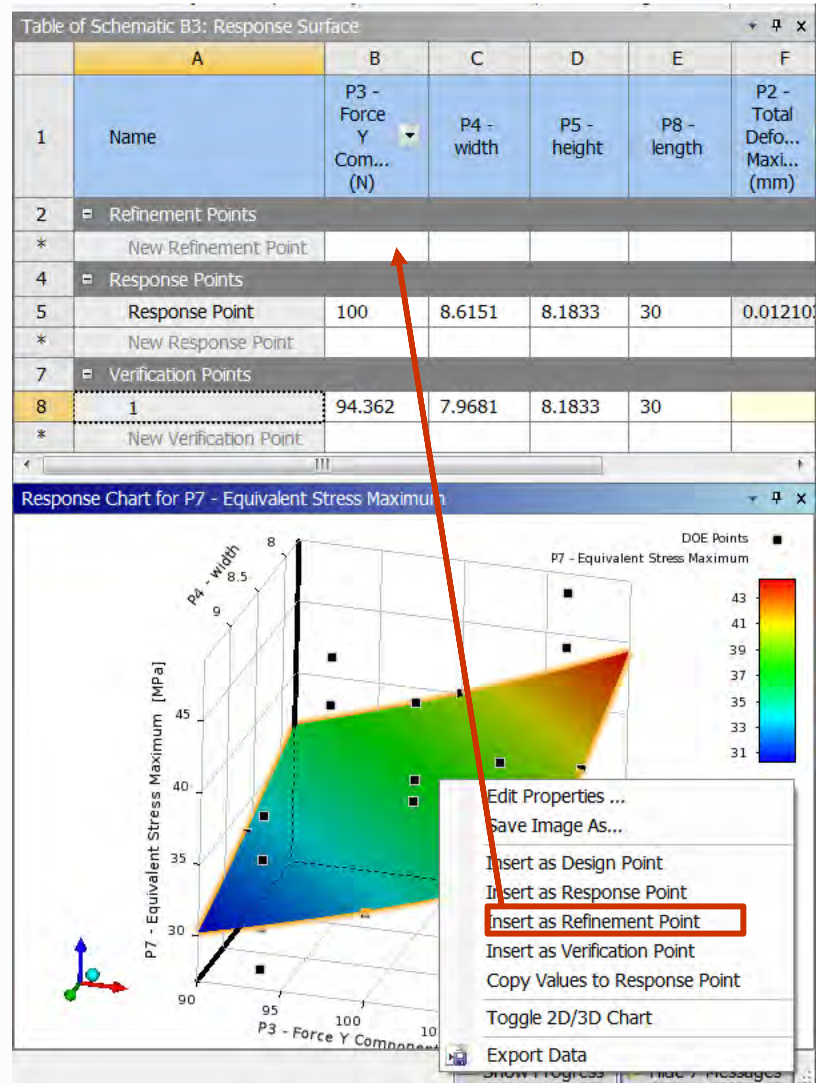


Improve Response Surface

Procedure

- Select a more appropriate response surface type

- Manually add Refinement Points: Points which are to be solved to improve the response surface quality in this area of the design space.



Agenda

- **Optimization using ANSYS DesignXplorer**
  - Overview
  - DOE (Design of Experiments)
  - Response Surface
  - **Goal Driven Optimization(GDO)**
- Optimization using OptiSlang
  - Sensitivity Analysis for Large Number of Parameters
  - Optimization using Meta Model of Optimal Prognosis
  - Live Demo

Goal Driven Optimization (GDO)

- Determines candidate designs based on your design goals
- Uses DOE/response surface results to quickly explore parameter space

- State a series of design goals to generate candidate designs
  1. Select optimization method
  2. Rank objectives based on importance
  3. DX returns candidate designs
  4. Drill down to further resolve promising design spaces

Table of Schematic B4: Optimization

	A	B	C	D	E
1		P1 - guide_curve_angle	P2 - guide-curve-radius	P3 - section-1-length-1	P4 - effective_flow_area
2	Optimization Study				
3	Objective	Minimize	Maximize	No Objective	Maximize
4	Target Value				
5	Importance	Default	Default	Default	Higher
6	GDO Sample Set 1				
7	Candidate A	50.127	49.689	50.927	0.001129
8	Candidate B	53.583	49.952	50.652	0.0011331
9	Candidate C	57.039	49.82	50.854	0.0011318

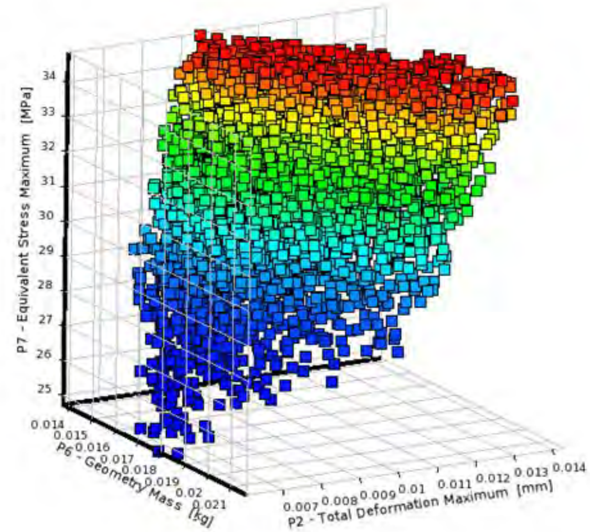
Goal Driven Optimization Methods

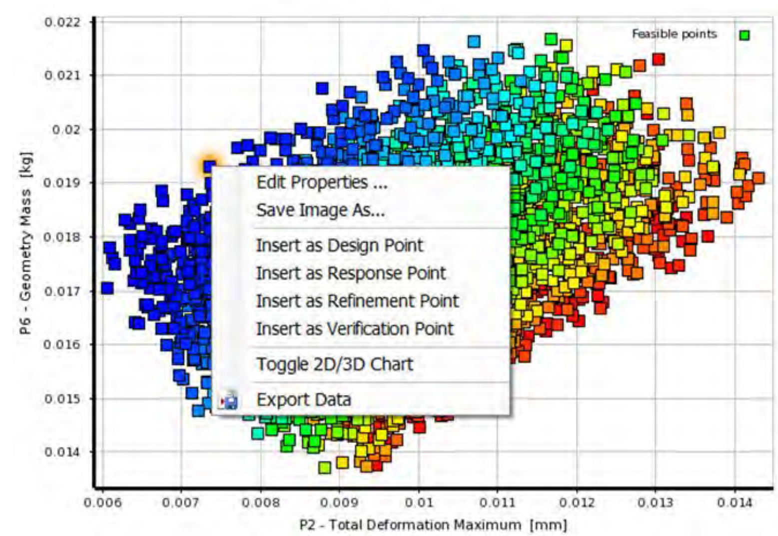
There are three optimization methods in DX

1. Screening (Shifted Hammersley) [default]
   - Direct sampling method by a quasi-random number generator
   - Good for preliminary designs
2. MOGA (Multi-objective Genetic Algorithm)
   - Multi-goal optimization
   - Provides several candidates
3. NLPQL (Non-linear Programming by Quadratic Lagrangian)
   - Fast gradient based local optimization algorithm for single objective

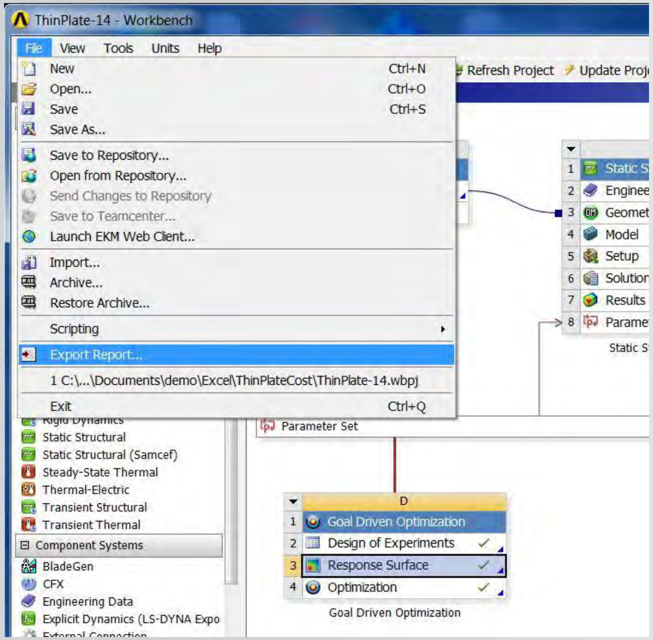
Goal Driven Optimization: Tradeoff Chart

- **Parameters are displayed on each axis so you can see the tradeoff**
- **A Pareto front is a group of solutions such that selecting any one of them in place of another will always sacrifice quality for at least one objective, while improving at least one other.**
- **The best set of samples (first Pareto front) is indicated in blue**
- **The worst set of samples (worst Pareto front) is indicated in red**
- **Verify Candidates**
  - **Creating and updating Design Points with a "real solve" using the input parameter values of the Candidate Points.**



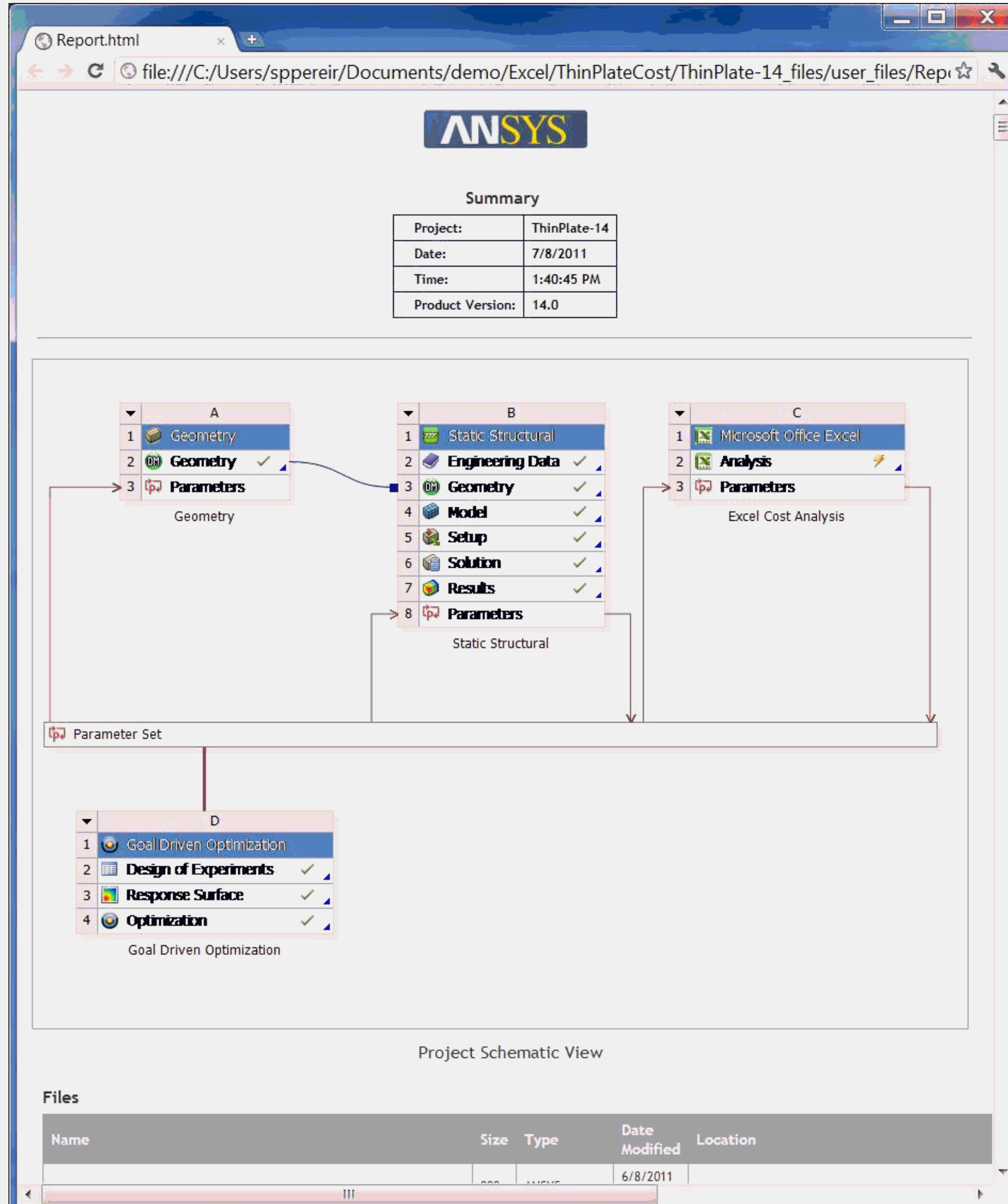


ANSYS Unified Reporting



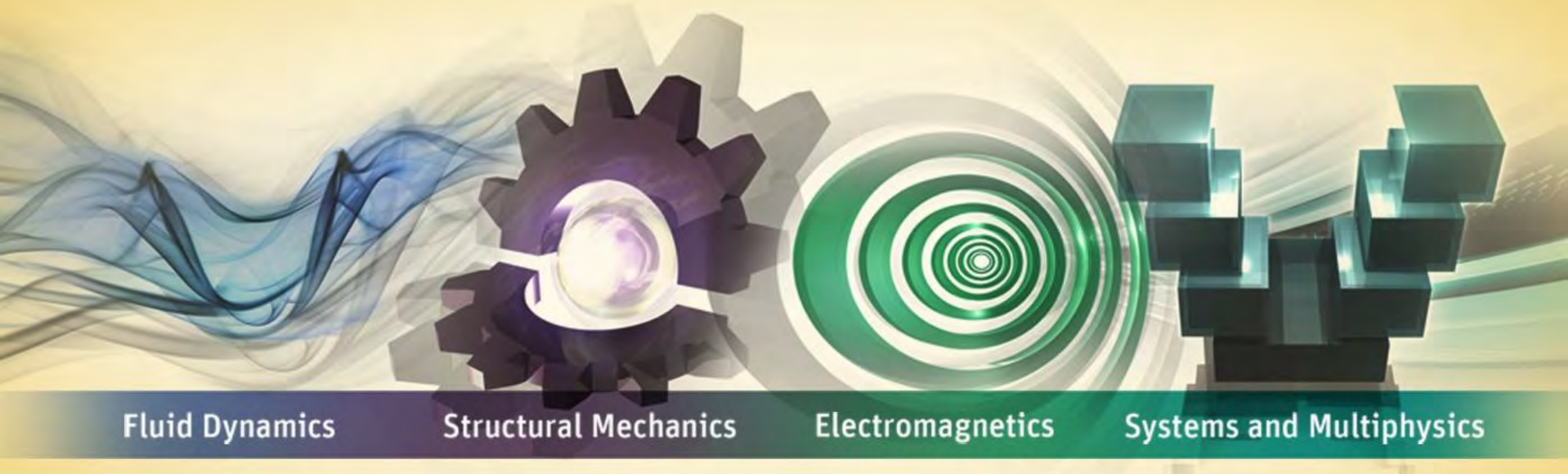
DX Systems contribute to the unified report

Includes all DX tables and Charts



Realize Your Product Promise™

Intake Manifold



Design optimization Intake Manifold

Boundary Conditions

- Fresh air mass flow = 0.04 kg/s
- EGR mass flow 0.004 kg/s

Objective

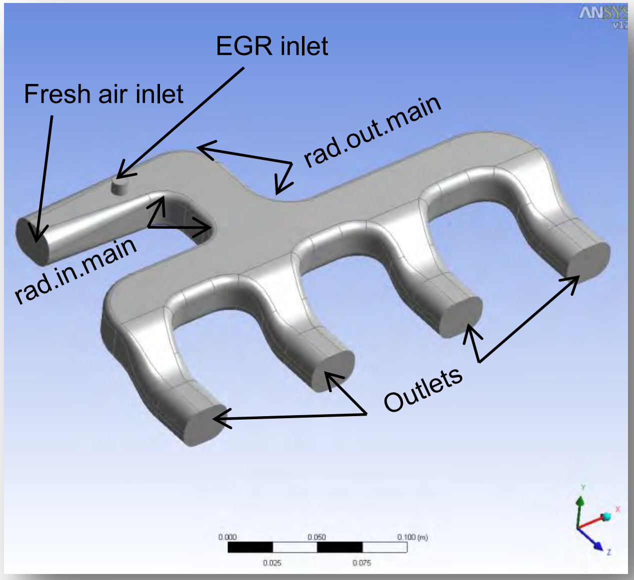
- Outlet pressure = atmospheric
- Equal fresh and EGR mass flow distribution to each cylinder
- To minimize the overall pressure drop

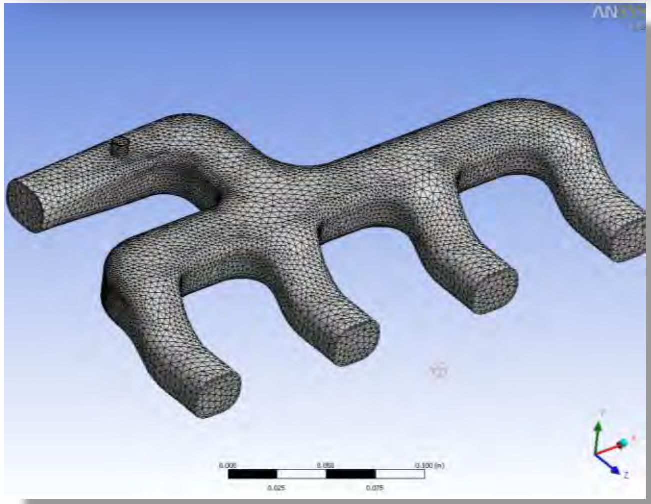
Output parameter

- totmassimb = $\sum_{i=1}^{alloutlets} abs(0.25 + \left(\frac{mass\ flow\ out_i}{Total\ mas\ in}\right))$
- egrimb = $\sum_{i=1}^{alloutlets} abs(0.25 + \left(\frac{EGR\ mass\ flow\ out_i}{Total\ EGR\ mas\ in}\right))$
- delp = Inlet pressure – outlet Pressure

Design Variables

- Inner radius of rounds on the inlet elbow
- Outer radius of rounds on the inlet elbow





Design optimization Intake Manifold

Design of experiment

- Design space defined by providing the lower and upper bounds of the input parameters
- Default Auto defined CCD algorithm
- 9 DOE points generated

Parameter	Lower Bound (mm)	Upper Bound (mm)
rad.in.main	4 mm	14 mm
Rad.out.main	6 mm	40mm

Response Surfaces

- Non parametric regression method used

Properties of Outline A9: P6

	A	B
1	Property	Value
2	General	
3	Units	
4	Quantity Name	
5	Values	
6	Calculated Minimum	0.44697
7	Calculated Maximum	1.2728
8	Goodness-of-Fit Information	
9	Coefficient of Determination (Best Value = 1)	1
10	Adjusted Coeff of Determination (Best Value = 1)	1
11	Maximum Relative Residual (Best Value = 0%)	1.9884E-07
12	Root Mean Square Error (Best Value = 0)	9.5874E-10
13	Relative Root Mean Square Error (Best Value = 0%)	1.0274E-07
14	Relative Maximum Absolute Error (Best Value = 0%)	7.4145E-07
15	Relative Average Absolute Error (Best Value = 0%)	3.4377E-07

Design optimization Intake Manifold

Goal Driven Optimization

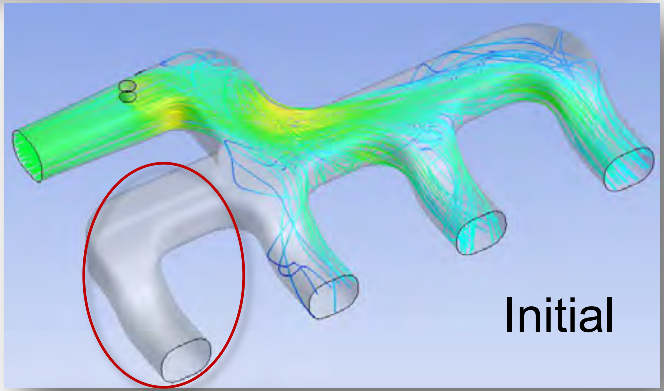
- **Multi-Objective Genetic Algorithm (MOGA)**
- **Goals**
  - totmassimb: minimize, high importance
  - egrimb: minimize, high importance
  - delp: minimize, low importance

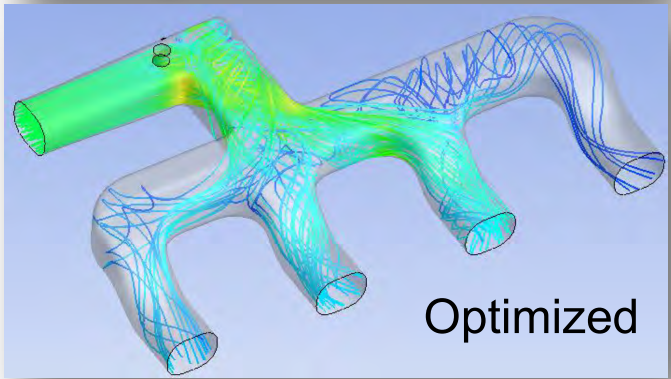
Properties of Outline A2: Optimization

	A	B
1	Property	Value
2	Optimization	
3	Optimization Method	MOGA
4	Number of Initial Samples	6000
5	Number of Samples Per Iteration	100
6	Maximum Allowable Pareto Percentage	70
7	Maximum Number of Iterations	20
8	Initial Samples	Generate Initial Samples
9	Constraint Handling (GDO)	As Goals
10	Size of Generated Sample Set	100

Table of Schematic B4: Optimization

	A	B	C	D	E	F
1		P1 - rad.in.main	P3 - rad.out.main	P4 - delp (Pa)	P5 - egrimb	P6 - totlamassimb
2	Optimization Study					
3	Objective	No Objective	No Objective	Minimize	Minimize	Minimize
4	Target Value					
5	Importance	Default	Default	Lower	Higher	Higher





Summary

- ANSYS DesignXplorer
  - Enables extensive design exploration and optimization in Workbench environment
  - Quickly optimize designs based on your criteria
  - Is very easy to use: minimal extra effort than a single run
  - Adds tremendous engineering understanding for innovation and ROI

Agenda

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