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Subject **Sheldon's ANSYS Tips and Tricks: DesignXplorer and Response Surfaces**
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1. Introduction:

ANSYS DesignXplorer enables the user to perform optimization studies based on multiple objectives, to account for uncertainties in product design and use, and to determine how best to improve product reliability.[1] These tasks are accomplished through the use of *response surfaces*, and this memo hopes to cover some of the basics of DesignXplorer operation.[2]

2. Performing Studies in DesignXplorer:

In *Goal-Driven Optimization*, the optimal designs are sought which satisfies one or several criteria, such as minimizing weight and deflection. In *Six Sigma Analyses*, scatter in input variables are accounted for, such as variability in material properties or operating conditions, and results are expressed as probabilities. *Robust Design* combines both of these aspects by determining how to change certain input variables to control the uncertainty in the results to achieve more predictable, reliable designs.

In the above three types of studies that can be performed in DesignXplorer, hundreds or thousands of iterations may need to be executed in order to obtain desired results. Since the duration of some FEA runs may range from half-an-hour to a couple of hours, running the minimum required number of iterations may be impractical. Consequently, DesignXplorer uses *response surfaces* to establish a mathematical relationship between input and output parameters, and optimization or probabilistic studies can be performed on the response surfaces.

Several steps are performed in DesignXplorer to generate response surfaces, and these are outlined below:

1) The user specifies input and output parameters. For example, this may involve specifying the range or the probabilistic distribution of an input variable, such as a geometric dimension, and identifying what output variables DesignXplorer should track, such as the maximum stress of a given region.
2) Based on the number of input parameters, DesignXplorer then automatically determines how many solutions (a.k.a. "automatic design points") need to be solved for using a *Design-of-Experiment (DOE)* method.
   Specifically, *Central Composite Design (CCD)* is used to locate the design points based on the range of input variables in the most efficient manner.[3]
3) DesignXplorer then solves the automatic design points, which involves varying the input parameters and retrieving the calculated output parameter.
   If Workbench Simulation is used, DesignXplorer will utilize the Workbench Simulation solver settings, including asynchronous solutions (Remote Solution Manager).
4) Once the input and corresponding output parameter values are known, DesignXplorer performs a *regression analysis* to generate the response surfaces. A somewhat overly-simplified yet useful description of the regression analysis is that it is a sophisticated curve-fitting of the output parameters. CCD provides the location of the design points, and a quadratic polynomial is used for the regression model.
   One may note that a second-order polynomial may not always provide a good approximation of the relationship of input and output parameters. Hence, a *Yeo-Johnson transformation* is automatically performed on the output parameters y_i as follows:

[1] In *ANSYS DesignXplorer*, these are referred to as "Goal-Driven Optimization," "Six Sigma Analysis," and "Robust Design," respectively.
[2] Many of the points covered in this memo are also applicable to the use of the *ANSYS Probabilistic Design System (PDS)*
[3] "Most efficient" meaning solving for the fewest number of design points.

$$y_i^* = \begin{cases} \dfrac{(y+1)^{\lambda} - 1}{\lambda} & \text{if } \lambda \neq 0 \text{ and } y \geq 0 \\ \log(y+1) & \text{if } \lambda = 0 \text{ and } y \geq 0 \\ \dfrac{(-y+1)^{2-\lambda} - 1}{\lambda - 2} & \text{if } \lambda \neq 2 \text{ and } y < 0 \\ -\log(-y+1) & \text{if } \lambda = 2 \text{ and } y < 0 \end{cases}$$

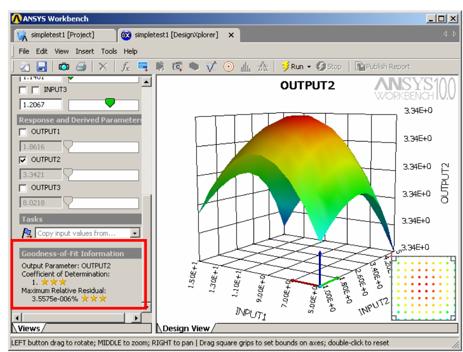
Through the use of the transformation parameter λ, special cases of exponential, logarithm, and power transformation can be handled. Hence, although a quadratic polynomial is used to generate the response surface, it is done so on the *transformed output parameter* y_i^*, which allows for a more accurate approximation of complex relationships.

5) The user then can review the response surfaces in DesignXplorer. The *Goodness-of-Fit* information provides the user with details on how well the response surface represents the input-output relationships.
Single Parameter Sensitivity Charts and Spider Charts can also be reviewed by the user to provide information on the impact input parameters have on output parameters
6) Once the user determines that the generated response surfaces provide a useful representation of the input-output relationship, Goal-Driven Optimization, Six Sigma Analysis, or Robust Design studies can then be performed. Instead of running hundreds or thousands of FEA solutions, thousands to hundreds-of-thousands of iterations can be performed very efficiently *on the response surfaces* since mathematical relationships of the input and output parameters have been established.

As one can see, DesignXplorer provides the user with a very powerful tool for determining the relationship between input and output parameters and for using this information in optimization or uncertainty analyses. Only steps 1, 5, and 6 are performed by the user, as DesignXplorer automates many of the involved tasks.

3. Points of Consideration:

There are several things to keep in mind when using DesignXplorer:



a) The user should always review the Goodness-of-Fit information, as shown in the red box on the right. The *Coefficient of Determination* is the ratio of the explained to total variation, where a value of 1.0 indicates that the response surface explains all of the variability of the given output parameter y_i. The *Maximum Relative Residual* describes the distance of the furthest automatic design point from the response surface, where a value of 0.0 means that all the design points lie on the response surface.
b) The response surface is an approximation of the relationship of input to output parameters, so any design based on the response surface can be verified by using a "reference design point," which is a separate solution that solves a given configuration. The user can then compare the predicted and actual output values under "Custom Design Points."
c) Although a Yeo-Johnson transformation is performed on the output parameters to capture complicated relationships between input and output variables, the user should note that discontinuous responses may not be represented well with response surfaces. A situation such as geometric instability (e.g., buckling) is but one example of this. Also, if input parameters are specified with a wide range of values, complicated behavior that may occur within that scope may not be captured, either.
d) Because Goal-Driven Optimization, Six Sigma Analysis, and Robust Design studies are all performed on the response surfaces, the user should be aware that these results are only as

accurate as the generated response surfaces. For example, trying to achieve tight probability constraints may not be meaningful if the Goodness-of-Fit measures indicate that the output parameters are not predicted well by the response surface.

e) The location of the sampling points (i.e., the quantity and values of the automatic design points' input parameter values) is automatically defined. However, the knowledgeable user may select the type of CCD used under the "Tools menu > Options: Automatic Design Points," including appending a mini CCD.

f) The response surface method used in DesignXplorer is much more efficient than solving multi-objective optimization or probabilistic problems with a brute-force approach. However, the number of simulations required in the DOE method is dependent on the number of input parameters (not output parameters), so using more than 5-11 input parameters requires a significant number of iterations.

4. Conclusion:

DesignXplorer generates a response surface to establish the relation between input and output parameters. Samples are then generated on the calculated response surfaces to allow the user to perform optimization or uncertainty analyses in the most efficient manner. However, the user should always remember that the basis of this is a mathematical approximation (i.e., response surface), so care should be taken first in verifying whether the response surfaces represent the behavior in a reasonable manner.

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