AutoDOE Optimization
And
Direct Execution of
GT-Power Engine Simulations

GT-Suite Users Conference
Dearborn, Michigan
November 18, 2002

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James Smyth
A) Robust Design
   - Design for Variability (DFV)
   - Ingredients
   - Tools
   - Results

B) Application to Engine Modeling and Simulation

C) AutoDOE Integrated Execution and Optimization
Robust Design – Design for Variability

Nominal Design Approach
*nominal* design meets requirements with margin

Robust Design Approach
specific fraction of design *population* meets requirements  \(|\text{UCL-Mean}| = 3 \, \sigma\)

![Frequency Comparison](image1.png)

![Chart](image2.png)
Design for Variability – Ingredients

Raw Ingredients
a) Predictive physical plant model
   – e.g. engine model

a) List of controlling parameters and their variability: $X$, $\sigma_X$
Design for Variability– Tools

Tools

a) GTpower
   • Diesel Engine Model

b) AutoDOE
   • DOE Creation & setup
   • Controls Execution of GTpower
   • Sensitivity Analysis (Screening)
   • Goodness of Fit Evaluation
   • Optimization (RSM) wrt UCL

c) Crystal-Ball
   • Monte Carlo Simulation with RS

Input X’s → Engine Model → Output Y’s

Param. Settings → AutoDOE → Results

Response Surface

Optimize wrt UCL

Population Distribution

GTpower Diesel Engine Model

AutoDOE DOE Creation & setup

Crystal-Ball Monte Carlo Simulation with RS

Population Distribution
Design for Variability – Results

Results
Optimized Settings from DOE result in
i. NOx Mean = 3σ below UCL
ii. Minimize BSFC

Reduce NOx defects WITHOUT significant increase in Fuel Consumption defects
**Input Table**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Baseline Settings</th>
<th>sigma</th>
<th>Low Limit</th>
<th>High Limit</th>
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<tbody>
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<td>Tcyl</td>
<td>(K)</td>
<td>450</td>
<td>16.7</td>
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<tr>
<td>InVal</td>
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**Response Table**

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<th>Parameter</th>
<th>Units</th>
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<th>sigma</th>
<th>Control Limit</th>
<th>(CL-Mean) /sigma</th>
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<tbody>
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<td>BSFC</td>
<td>(g/kw-hr)</td>
<td>233</td>
<td>2.48</td>
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<th>(CL-Mean) /sigma</th>
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Tools: AutoDOE

AutoDOE
a) DOE Set-up
b) Direct Execution of GTpower
c) Extract Results
d) Regression – Ordinary Least Squares (OLS)
e) Main Effects
f) Optimize – RSM
g) Extract – Transfer Function

h) Variability Assessment*

DOE Set-up
Factors
Responses
Design & Runs

DOE Run Definition, Execution & Extraction
Tools: AutoDOE

AutoDOE
a) DOE Set-up
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h) Variability Assessment*
Tools: AutoDOE

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e) Main Effects
f) Optimize – RSM, Minimize Fn
g) Extract – Transfer Fn
h) Variability Assessment

Target: NOx mean = 3 \sigma below UCL
Tools: AutoDOE

AutoDOE
a) DOE Set-up
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h) Variability Assessment

Variability Analysis

RS-Transfer Function

X’s, σX

Y’s, σY

DOE Extracted Transfer Function: NOx = f( X₁, X₂, X₃, … Xₙ )

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<th>Equation Terms</th>
<th>Constant</th>
<th>Tcyl</th>
<th>InVal</th>
<th>SOI</th>
<th>ClrT</th>
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18 November 2002

GT-Suite Users Conference/ Dearborn, MI
Tools: Crystal-Ball

AutoDOE

h) Variability Assessment

Note: Currently performed using Crystal-Ball. Available in AutoDOE 1st QTR 2003.

Variability Analysis

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</tr>
<tr>
<td>BSNOx</td>
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BSFC Distribution

NOx Distribution
Conclusions

A) An approach has been demonstrated to reduce the NOx defect rate for an engine design population without proportional sacrifice of Fuel Consumption, breaking the trade-off.

B) The method is Robust Design or Design for Variability. The focus is on the optimal design population.

C) The direct execution of GT-Power engine models by AutoDOE provides an easy-to-use tool for identifying optimized designs.

D) A New Monte Carlo Simulation (MCS) based variability analysis feature in AutoDOE will make the variability assessment process easier in 2003.