

## Robust Design Optimization with OptiY®

The-Quan Pham

OptiY e.K. Germany

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## Design of Static Mixer with Uncertainties



- Inlet in1 and in2, Outlet out
- Inlet temperature in1Temp, in2Temp
- Inlet velocity: in1Vel, in2Vel
- Design goal: outlet temperature
- 4 variable uncertainty design parameters: in1radius, in2angle, in1Vel and in2Vel
- 4 fix uncertainty process and environment parameters: Capacity, Conductivity, in1Temp and in2Temp

Name	Nominal	Tolerance	Unit	Comment
in1radius	0.6	0.6	mm	in1 radius
in2angle	40	60	deg	in2 angle
in1Vel	3	3	m s^-1	in1 velocity
in2Vel	3	3	m s^-1	in2 velocity
Capacity	4181.7	41.817	J kg^-1 K^-1	specific heat capacity
Conductivity	0.6069	0.006069	W m^-1 K^-1	thermal conductivity
in1Temp	315	3.15	К	in1 temperature
in2Temp	285	2.85	К	in2 temperature

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## CAD/CAE -Systems

#### Geometry: CATIA

### Meshing: ICEM

#### Fluid Dynamic: CFX



#### Advantages of specialized systems:

- · Fast and user-friendly handling of the software
- Competence and know-how through long time research and development
- · Detailed system component behaviour
- Import and export in standard format for data exchange
- Teamwork: designer and CAE-specialist



## **Process Workflow**



# User-friendly graphical process workflow with distributed computing:

• Fast process (CAD, Meshing, Pre- and Post-Processing) in comfortable OS Windows with MS Office

• Computationally intensive process (Solver) in HPC-Center via SSH Networking and FTP File Transfer



## **DoE: Adaptive Gaussian Process**

Providing information about expected improvement and uncertainty of the total design space. Extremely efficient design of experiment. The required number of model calculations (points) depends on:

- Number of design parameters
- Degree of response nonlinearity
- Correlation between design parameters

#### For Static Mixer:

- 8 design parameters
- 1 design goal: outlet mean temperature
- Initial sampling: 40 points (Sobol Sampling)
- Covariance function = Square Exponential
- Polynomial order = 0
- High accuracy of the response surface
- Total sampling: 88 points after 8 loops

Property 🛛						
⊡	Design of Experiment					
	Method	Sampling Methods				
	Parameter	Sobol				
	Sample Size	40				
	Adaptive Design	True				
	Accuracy [110]	5				
	Suggested Points	6				
	Maximal Points	100				
	Virtual Sample Size	100000				
	<b>Distribution Points</b>	50				
	Random Generator	Init				
	Virtual Sample Size Distribution Points Random Generator	100000 50 Init				



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## Design Space Visualization: 2D Section Diagrams



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## Design Space Visualization: 3D Graphics

#### Outlet Mean Temperature

#### **Outlet Temperature Difference**







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## Global Nonlinear and Quantitative Sensitivity Analysis



#### **Design Parameter Importance**



#### **Design Parameter Interactions**



## Design Optimization and Probabilistic Simulation

#### **Design Optimization**

Design goal: minimize the out temperature to get the optimal design point in the design space (Table: optimal design parameters with manufacturing tolerances)

🗠 Design Parameters 📃 🖻 🔀				
Name	Nominal	Toleran	Unit	Comment
in1radius	0.8381008	0.1	mm	in1 radius
in2angle	32.5715075	4	deg	in2 angle
in1Vel	1.84504689	0.2	m s^-1	in1 velocity
in2Vel	3.16437001	0.2	m s^-1	in2 velocity
Capacity	4181.7	41.817	J kg^-1 K^-1	specific heat capacity
Conductivity	0.6069	0.006069	W m^-1 K^-1	thermal conductivity
in1Temp	315	3.15	К	in1 temperature
in2Temp	285	2.85	К	in2 temperature

#### **Design Robustness**

Tolerances of design parameters cause variability of the out temperature: quality and reliability in batch production



#### Output Distributions





#### Virtual Sample Size: 100.000 Points



## Fast Robust Design Optimization

Taguchi Quality Loss Function: L = Cost\*(Variance + (Mean – Target)<sup>2</sup>)

#### Nominal Design



🗠 Design Parameters 📃 🖂 🖂				
Name	Nominal	Toleran	Unit	Comment
in1radius	0.8381008	0.1	mm	in1 radius
in2angle	32.5715075	4	deg	in2 angle
in1Vel	1.84504689	0.2	m s^-1	in1 velocity
in2Vel	3.16437001	0.2	m s^-1	in2 velocity
Capacity	4181.7	41.817	J kg^-1 K^-1	specific heat capacity
Conductivity	0.6069	0.006069	W m^-1 K^-1	thermal conductivity
in1Temp	315	3.15	К	in1 temperature
in2Temp	285	2.85	К	in2 temperature

#### Robust Design



Design Parameters				
Name	Nominal	Toleran	Unit	Comment
in1radius	0.304053239	0.1	mm	in1 radius
in2angle	50.165564	4	deg	in2 angle
in1Vel	1.51153931	0.2	m s^-1	in1 velocity
in2Vel	4.41115449	0.2	m s^-1	in2 velocity
Capacity	4181.7	41.817	J kg^-1 K^-1	specific heat capacity
Conductivity	0.6069	0.006069	W m^-1 K^-1	thermal conductivity
in1Temp	315	3.15	К	in1 temperature
in2Temp	285	2.85	К	in2 temperature

Minimizing the variance of the out temperature:

The mean temperature and its variance conflict each other. The extreme cases are nominal design and robust design:

- Low mean temperature versus high variance
- High mean temperature versus low variance

#### Multi-Objective Design Optimization



## Code-Export of Surrogate Model for System Simulation

- Automatic Code-Export in C, Modelica or Matlab
- Fast surrogate model for total system simulation (e.g. Matlab/Simulink, Circuit- or MBS-Simulator)
- Development of controller, circuit or mechanical system in case of co-simulation with fluid dynamics



```
double F(double i, double s)
 double p[2];
 double x1[2];
 double x2[2];
 double y = -45.7372055;
 y = y+10.5254853 \pm pow(i,1);
 y = y+4.52081477 \pm pow(s,1);
p[0] = 0.151298213;
p[1] = 0.928373134;
x1[0] = i;
x1[1] = s;
x2[0] = 5.01;
x2[1] = 2.02;
 y = y-183.985579*Covariance(x1,x2,p);
x2[0] = 0.01;
x2[1] = 0.02;
y = y - 8524.5598 * Covariance(x1,x2,p);
x2[0] = 2.01;
x2[1] = 0.02;
 y = y+27577.7253*Covariance(x1,x2,p);
x2[0] = 10.01;
x2[1] = 4.02;
y = y-1042.30105*Covariance(x1,x2,p);
 return y;
```



## Conclusion

- Design of technical system with uncertainties requires efficient computing of product model. Adaptive Gaussian process is the best approach for robust design optimization.
- The meta-model of the static mixer with 8 design parameters needs totally only 88 model calculations and yields the response surface of the outlet temperature accurately.
- Based on the meta-model, the robust design process of the static mixer has been demonstrated. It leads into a multi-objective design optimization task.
- **OptiY**® is a user-friendly multidisciplinary software platform also for robust design of large technical systems with uncertainties.