Robust Design Optimization with OptiY®

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OptiY e.K. Germany

Probabilistik – Workshop

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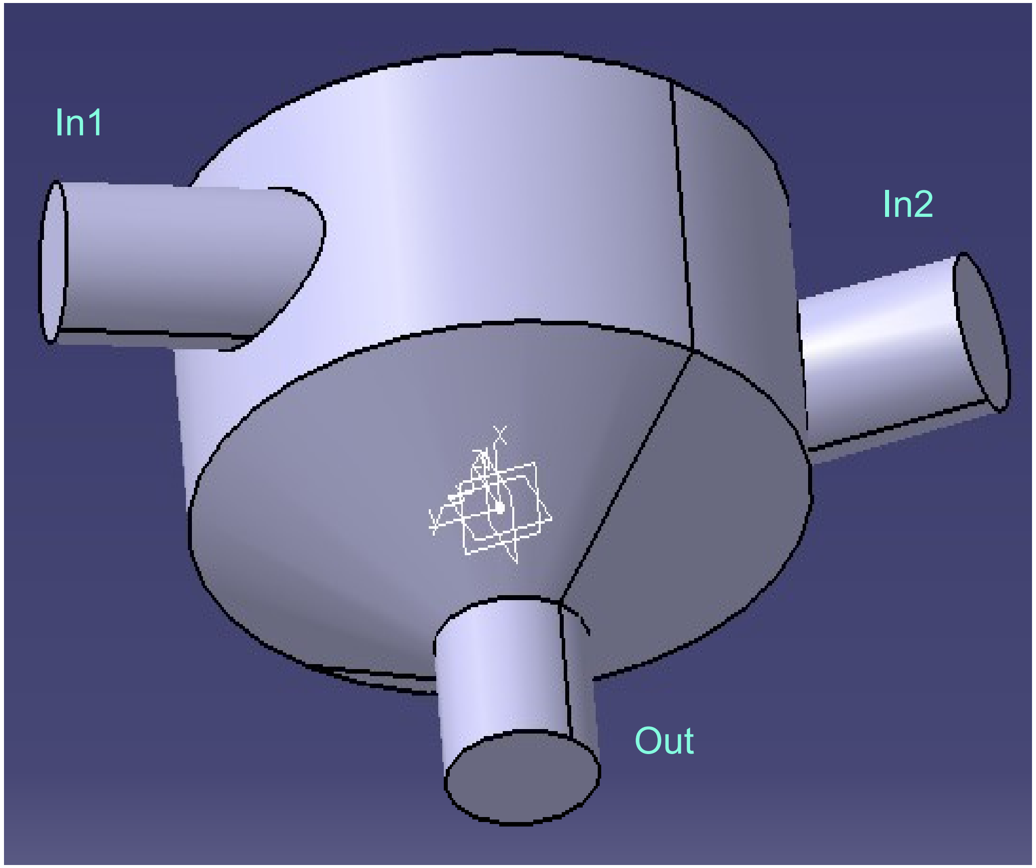
Design of Static Mixer with Uncertainties



- Inlet in1 and in2, Outlet out
- Inlet temperature in1Temp, in2Temp
- Inlet velocity: in2Vel, in2Vel
- Design goal: outlet temperature

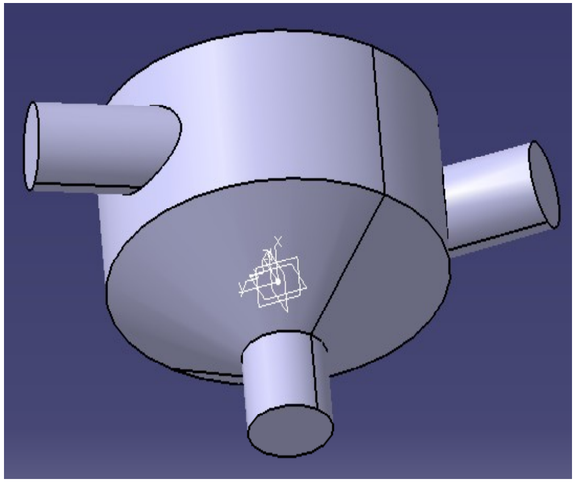
- 4 variable and uncertainty design parameters: in1radius, in2angle, in1Vel and in2Vel
- 4 fix and uncertainty process and environment parameters: Capacity, Conductivity, in1Temp and in2Temp

Design Parameters

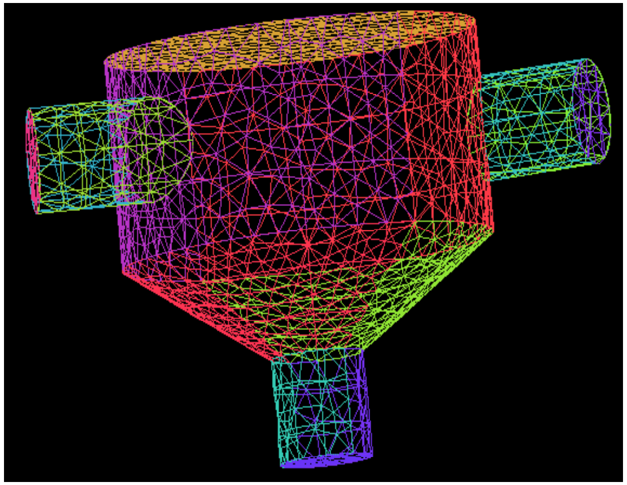
Name	Nominal	Tolerance	Unit	Comment
in1radius	0.6	0.6	mm	in1 radius
in2angle	40	60	deg	in2 angle
in1Vel	3	3	m s^-1	in1 velocity
in2Vel	3	3	m s^-1	in2 velocity
Capacity	4181.7	41.817	J kg^-1 K^-1	specific heat capacity
Conductivity	0.6069	0.006069	W m^-1 K^-1	thermal conductivity
in1Temp	315	3.15	K	in1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

CAD/CAE -Systems

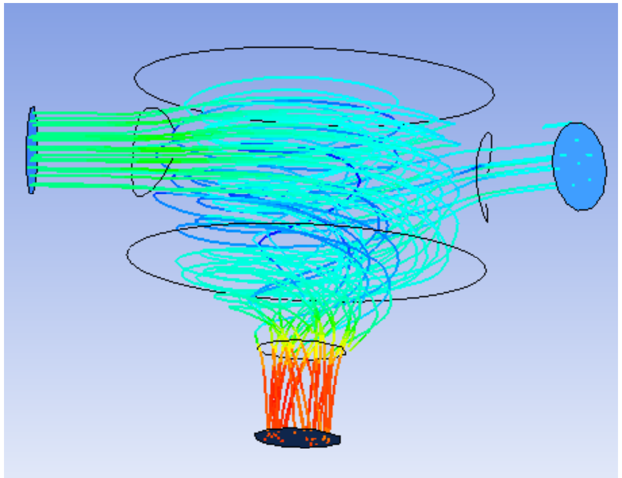
Geometry: CATIA



Meshing: ICEM



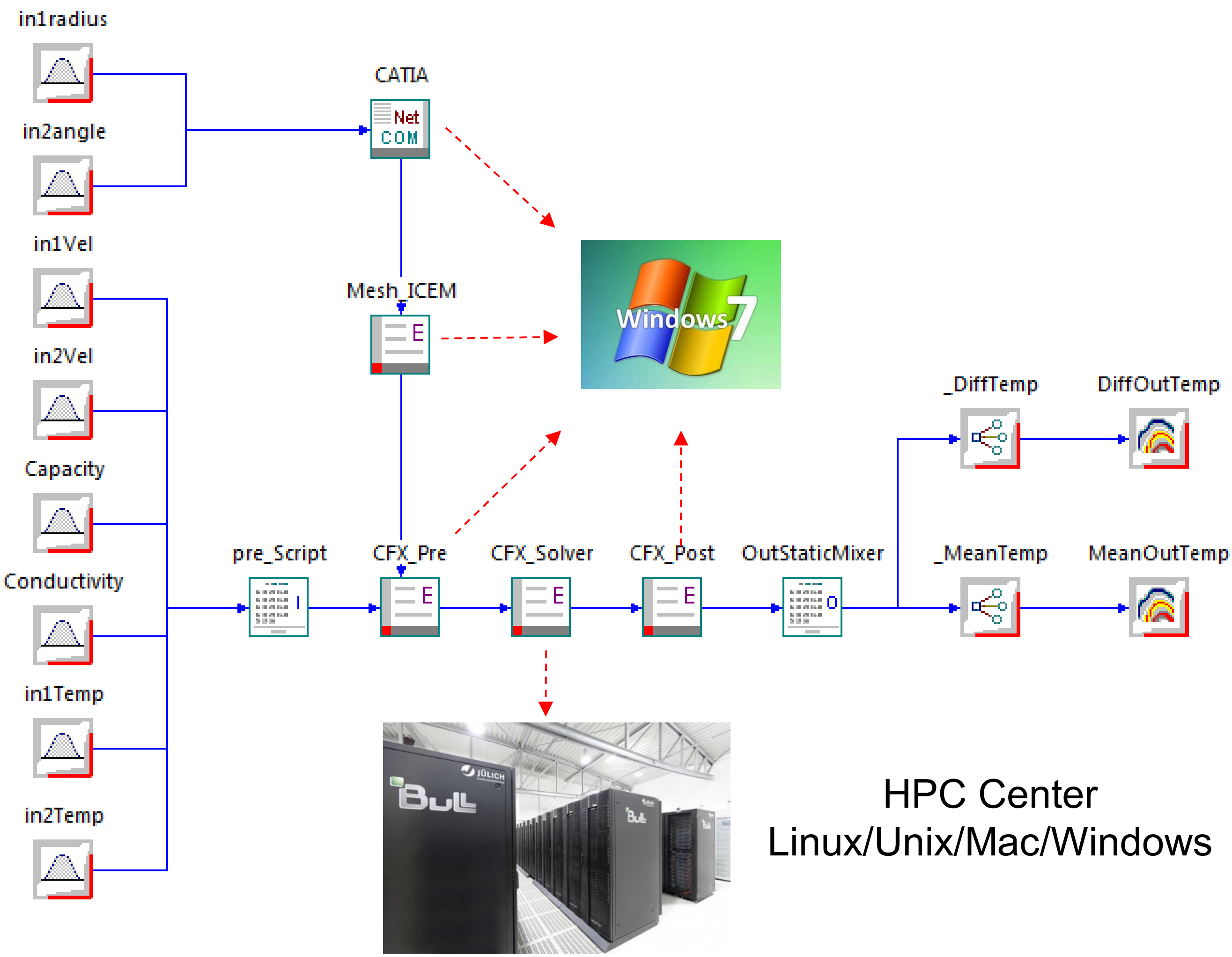
Fluid Dynamic: CFX



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
- Team working: designer and CAE-specialist

Process Workflow



Use-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:

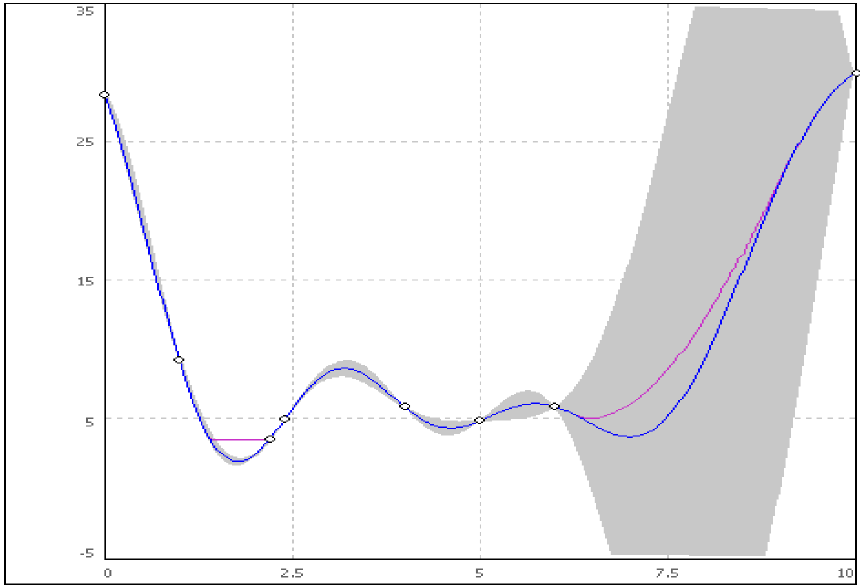
- Number of design parameters
- Degree of response nonlinearity
- Correlation between design parameters

Property

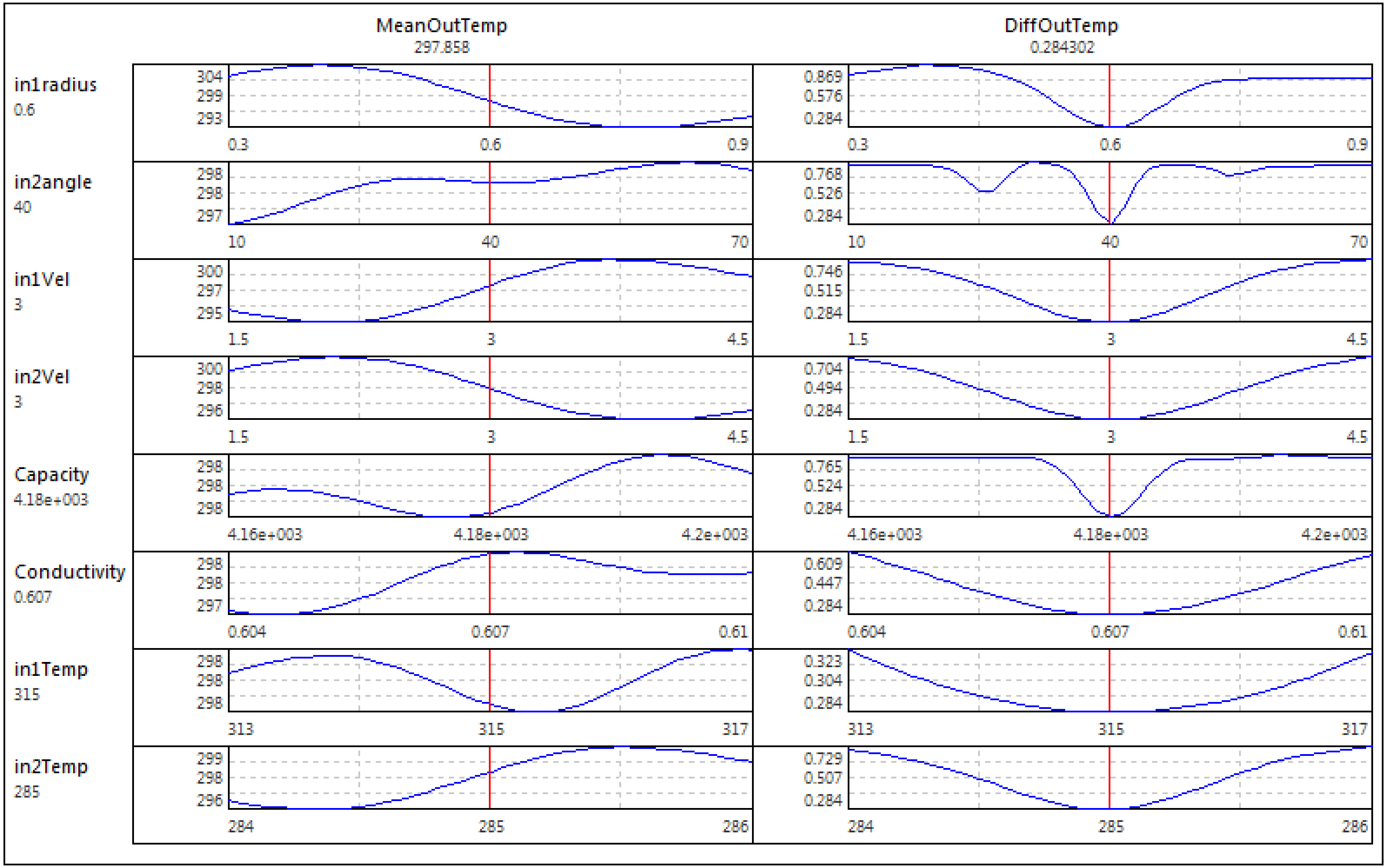
⊟ Design of Experiment	
Method	Sampling Methods
Parameter	Sobol
Sample Size	40
Adaptive Design	True
Accuracy [1..10]	5
Suggested Points	6
Maximal Points	100
Virtual Sample Size	100000
Distribution Points	50
Random Generator	Init

For Static Mixer:

- 8 design parameters
- 1 design goal: out 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

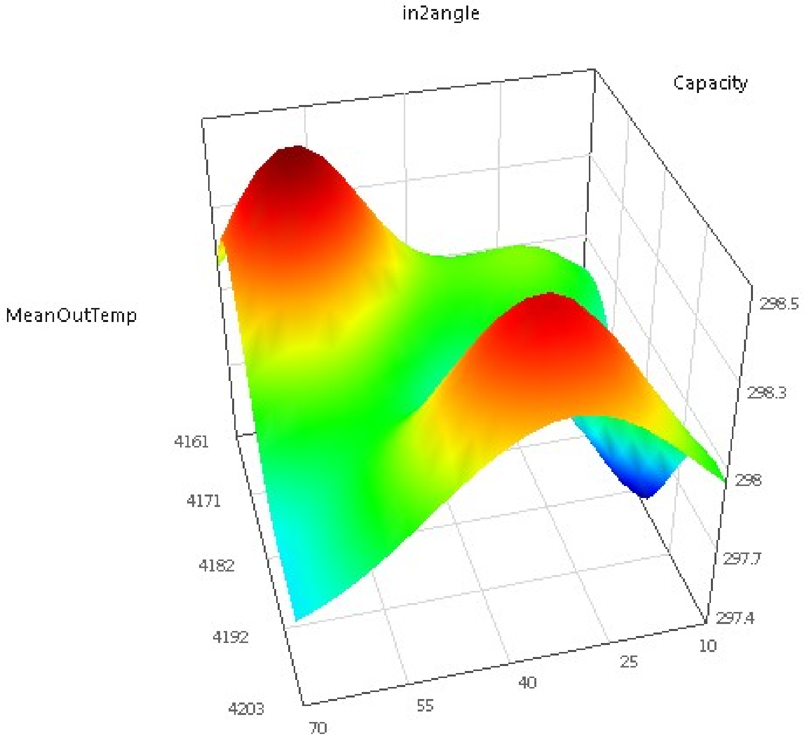


Design Space Visualization: 2D Section Diagrams

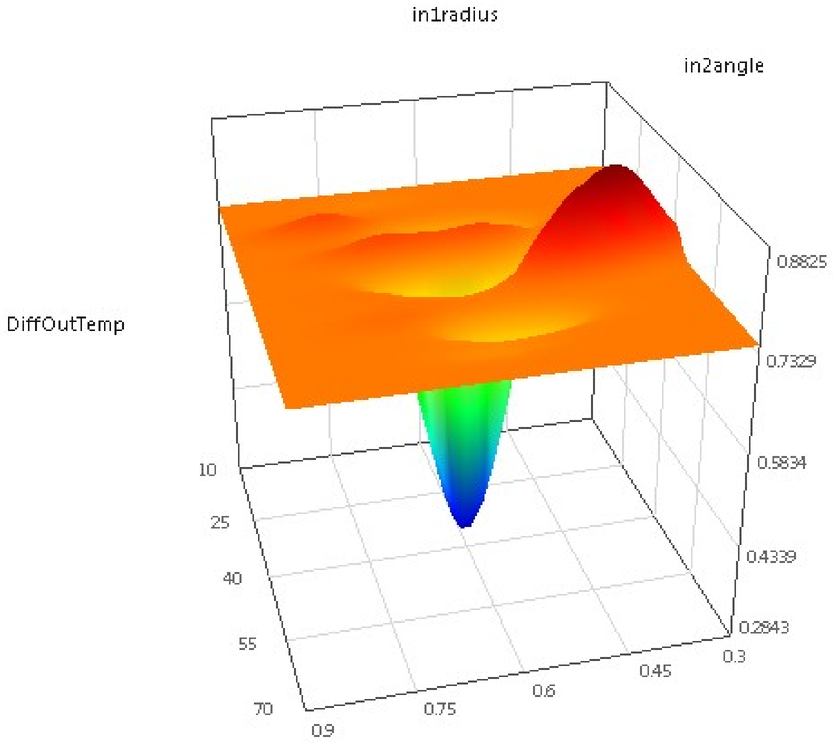


Design Space Visualization: 3D Graphics

Out Mean Temperature

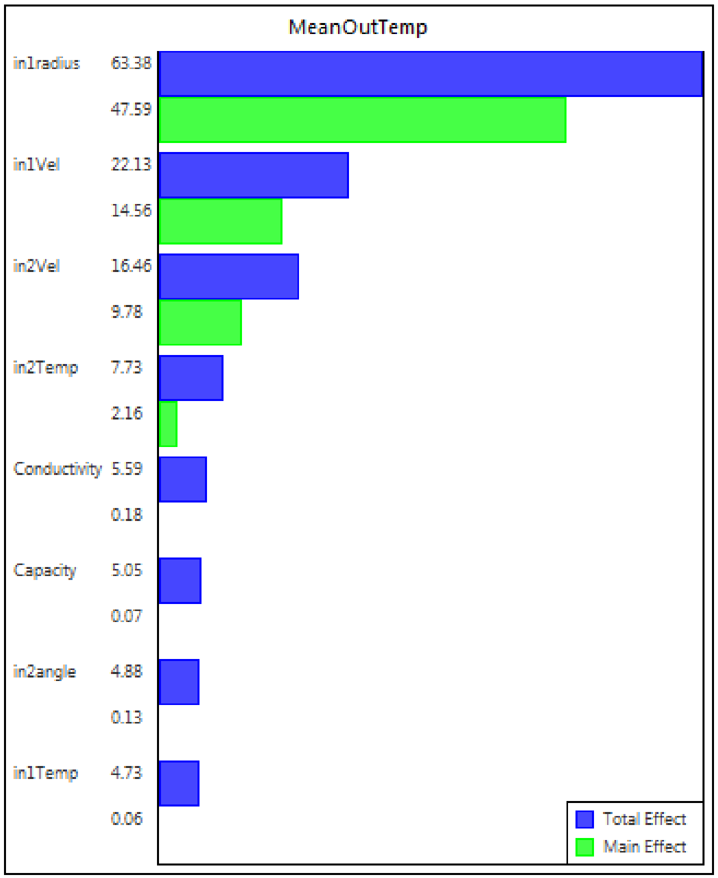


Out Temperature Difference

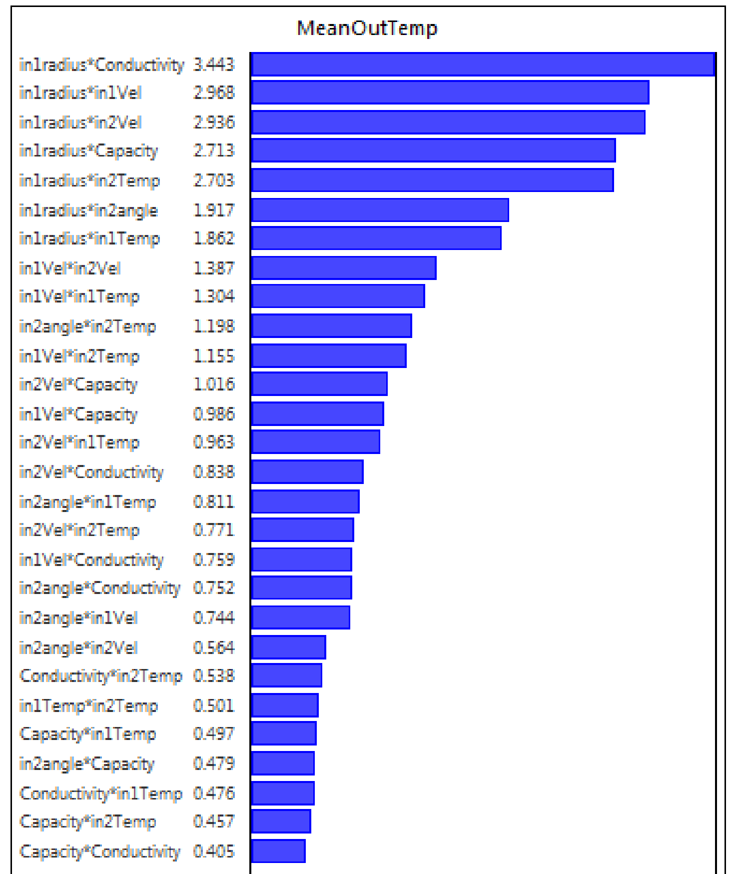


Global Nonlinear and Quantitative Sensitivity Analysis

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)

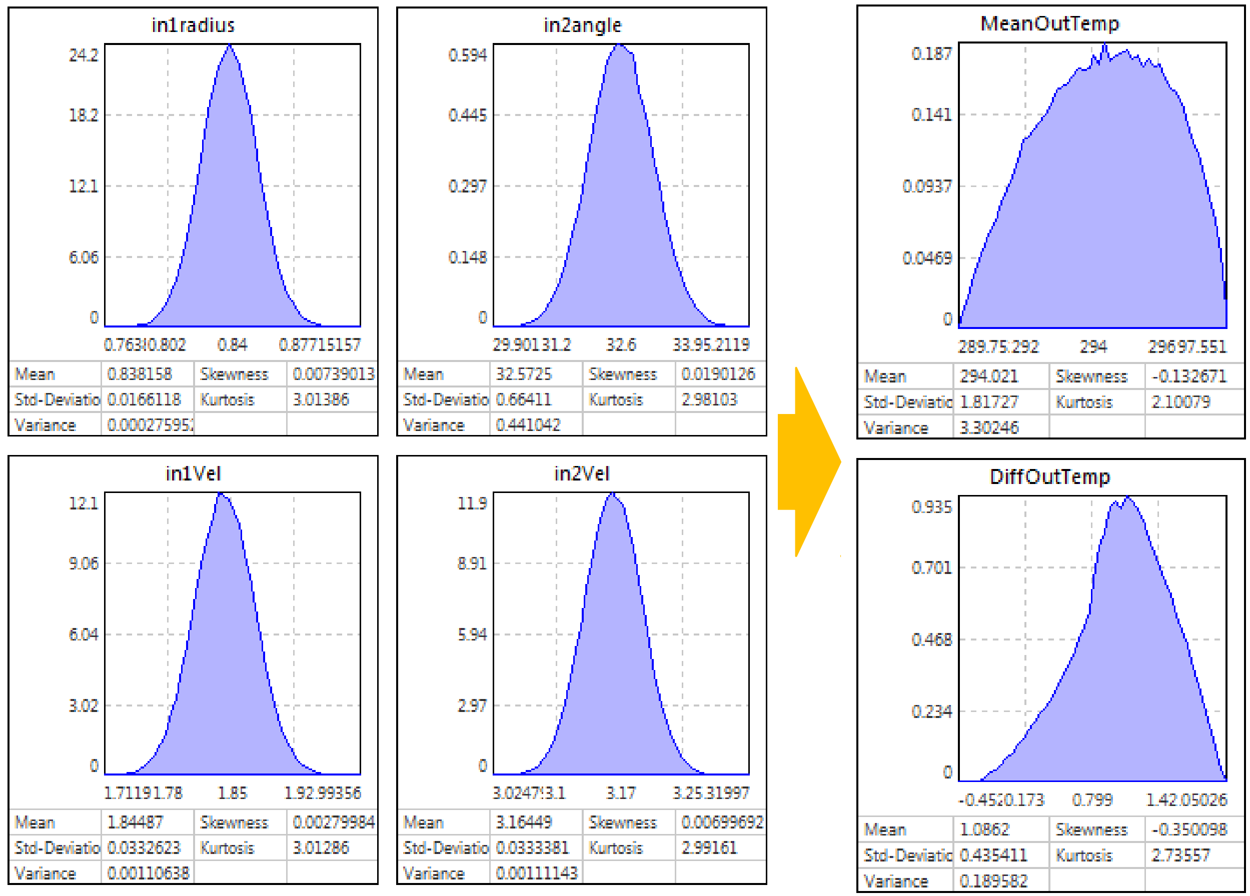
Design Parameters

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	K	in1 temperature
in2Temp	285	2.85	K	in2 temperature

Design Robustness

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

Input Distributions | Output Distributions



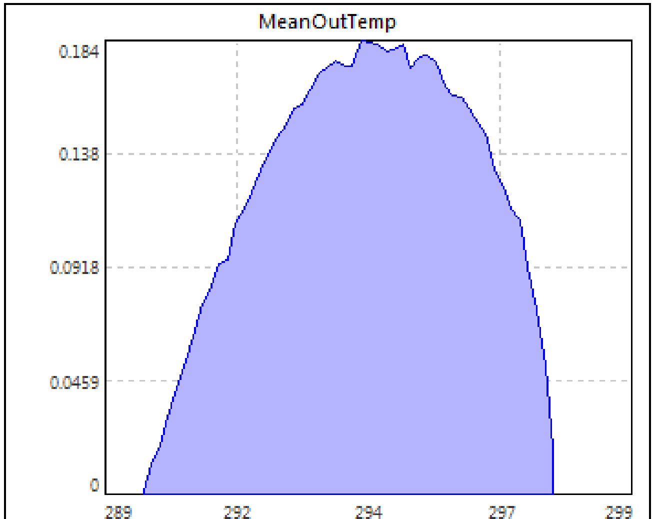
Virtual Sampling Size: 100.000 Points

Fast Robust Design Optimization

Taguchi Quality Loss Function:

$$L = Cost*(Variance + (Mean - Target)^2)$$

Nominal Design



Mean	294.009	Skewness	-0.118471
Std-Deviation	1.81874	Kurtosis	2.10653
Variance	3.30781		

Design Parameters

Name	Nominal	Toleran...	Unit	Comment
in1radius	0.8381008...	0.1	mm	in1 radius
in2angle	32.5715075	4	deg	in2 angle
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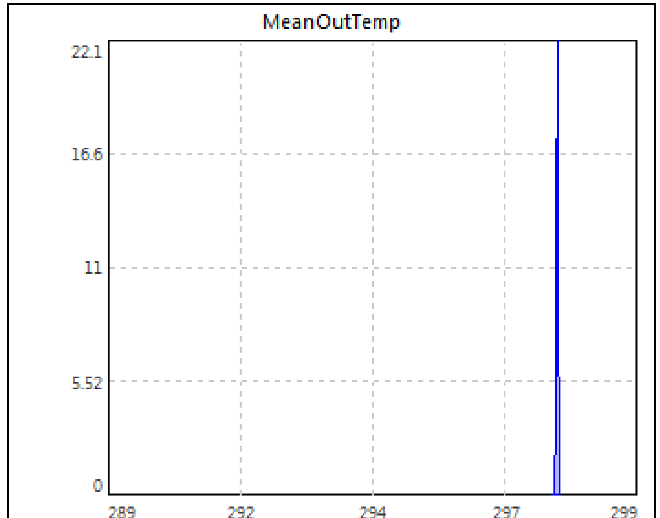
Robust Design



Mean	297.514	Skewness	-0.608174
Std-Deviation	0.0179474	Kurtosis	3.1272
Variance	0.000322111		

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	K	in1 temperature
in2Temp	285	2.85	K	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:

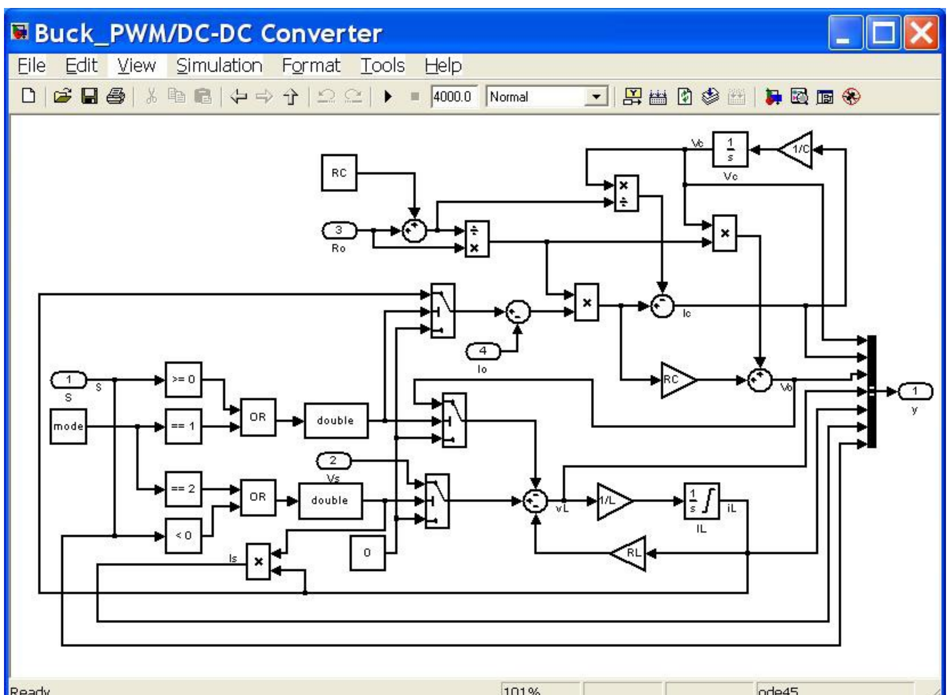
- Low mean temperature versus high variance
- High mean temperature versus low variance

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, MBS-Simulator)
- Development of controller 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 = -46.7372056;
    y = y+10.5264863*pow(i,1);
    y = y+4.62081477*pow(s,1);
    p[0] = 0.161298213;
    p[1] = 0.928373134;
    x1[0] = i;
    x1[1] = s;
    x2[0] = 5.01;
    x2[1] = 2.02;
    y = y-183.986679*Covariance(x1,x2,p);
    x2[0] = 0.01;
    x2[1] = 0.02;
    y = y-8624.5598*Covariance(x1,x2,p);
    x2[0] = 2.01;
    x2[1] = 0.02;
    y = y+27677.7263*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 turn out 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