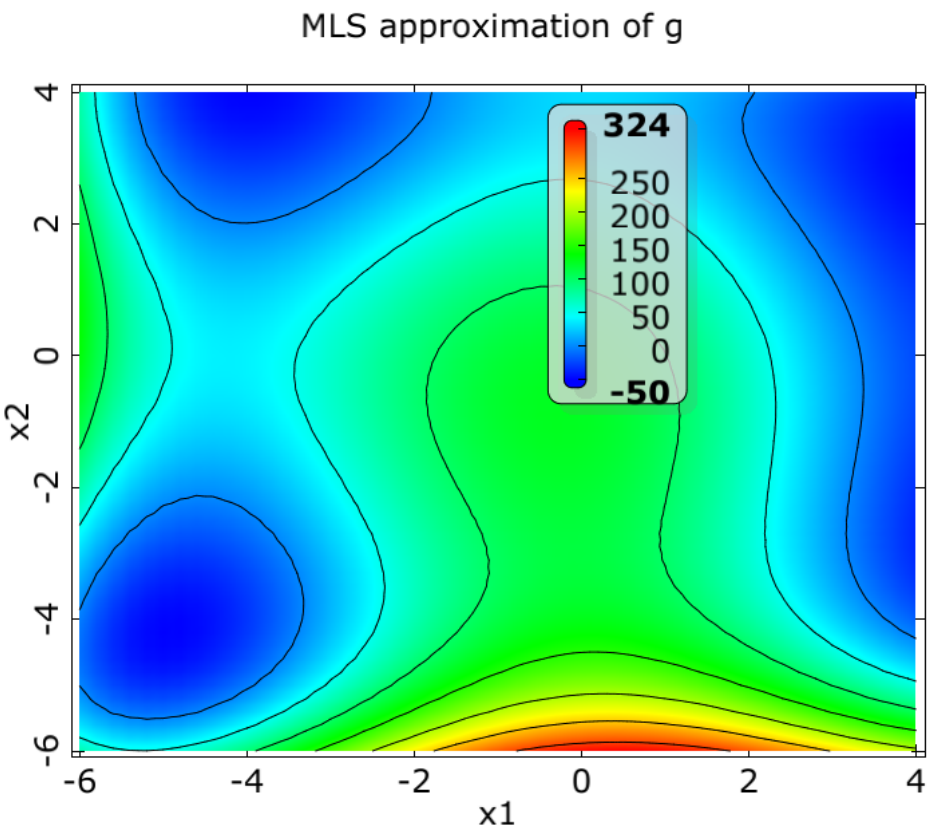
Reliability Analysis within optiSLang 3.1.0

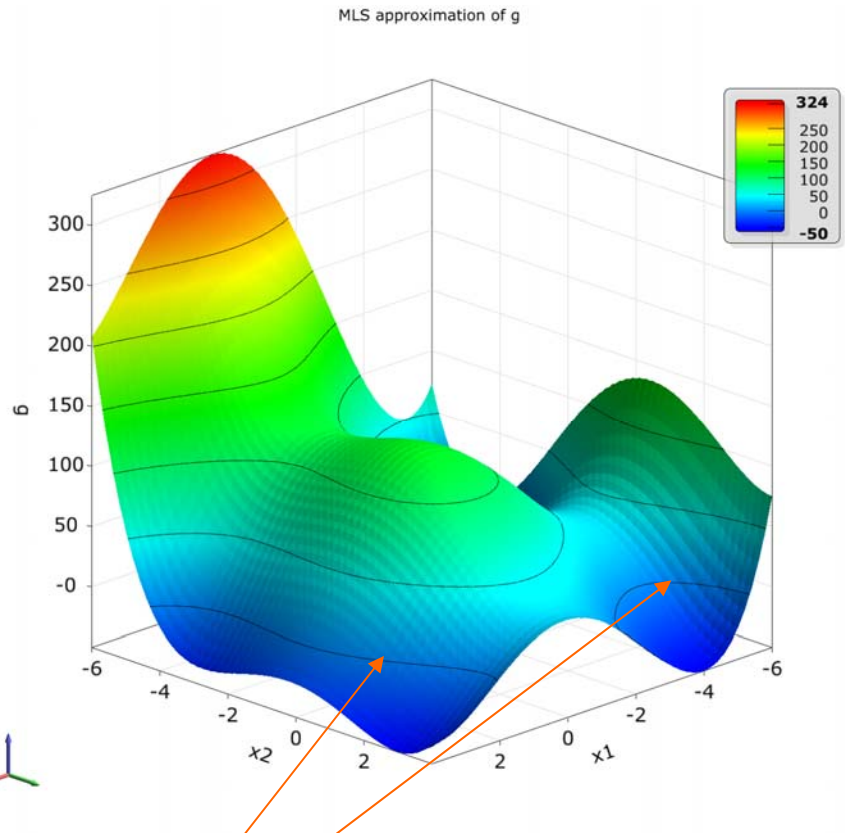
Dirk Roos

dynardo – dynamic software and engineering GmbH

dynardo

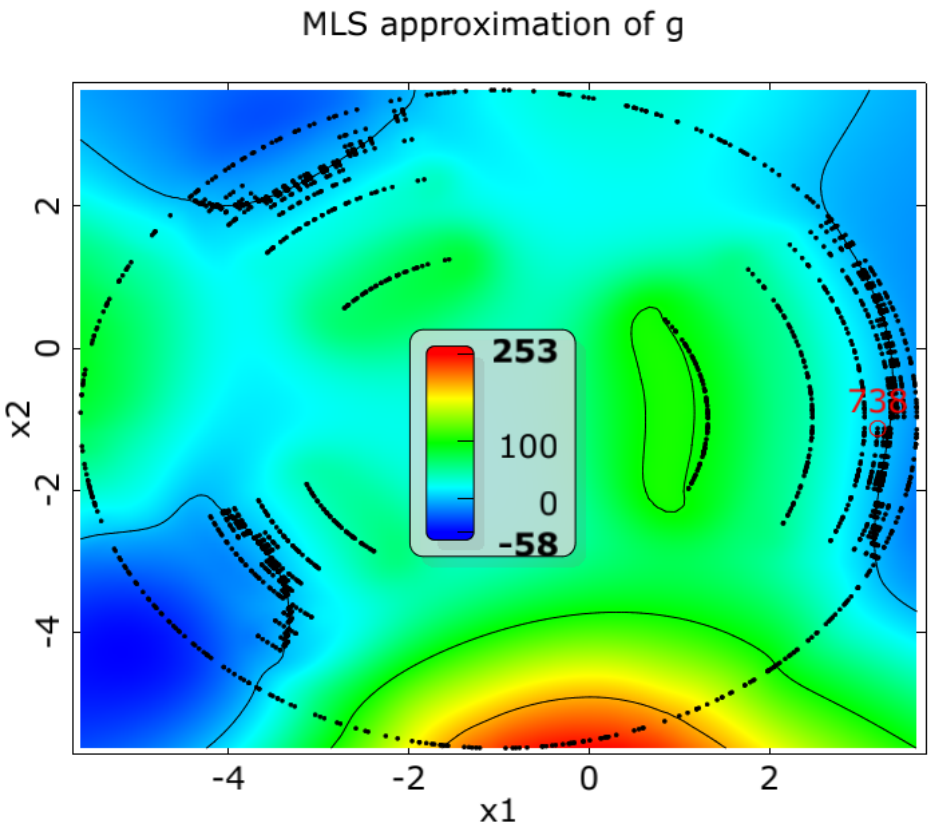
Reliability Analysis

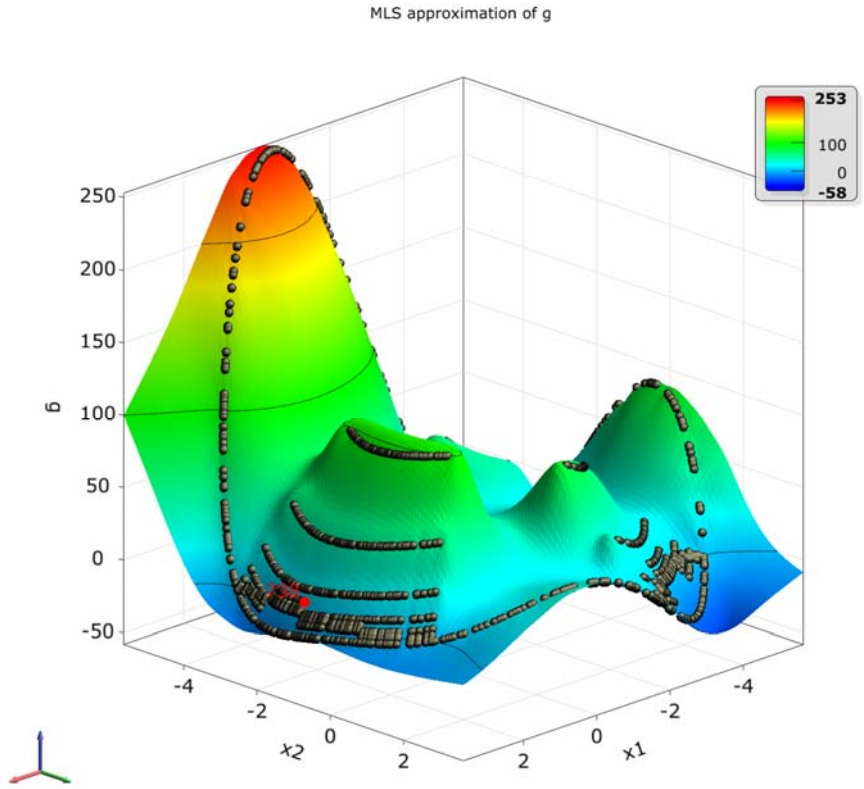




- Himmelblau function
- Nonlinear two dimensional state function g(x1,x2)
- Nonlinear limit state function g(x1,x2)=0
- Three separated domains with high failure probability density

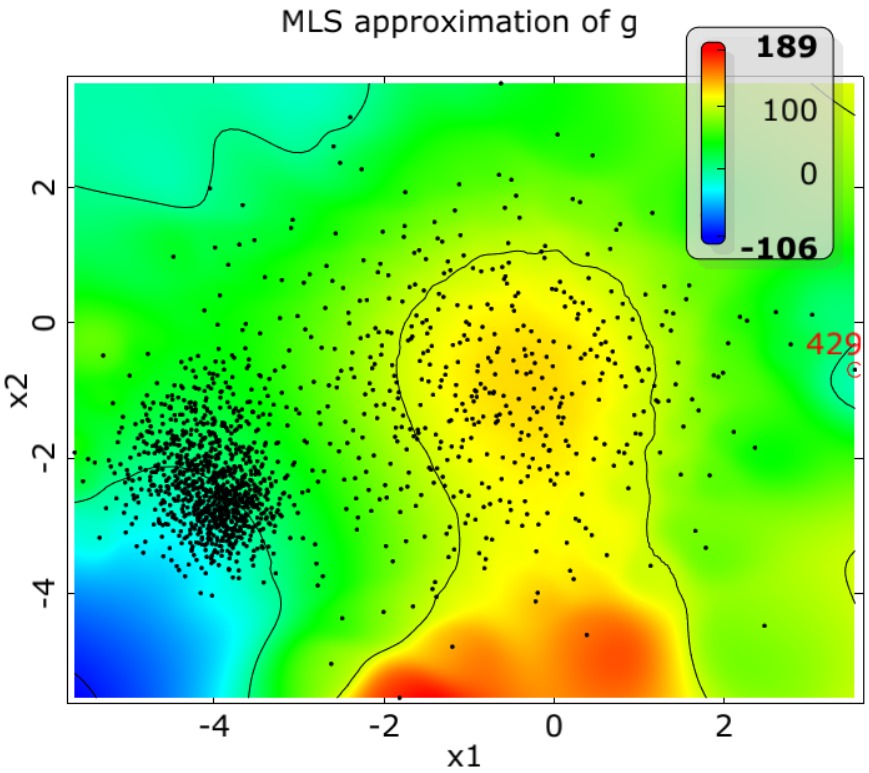
Reliability Analysis

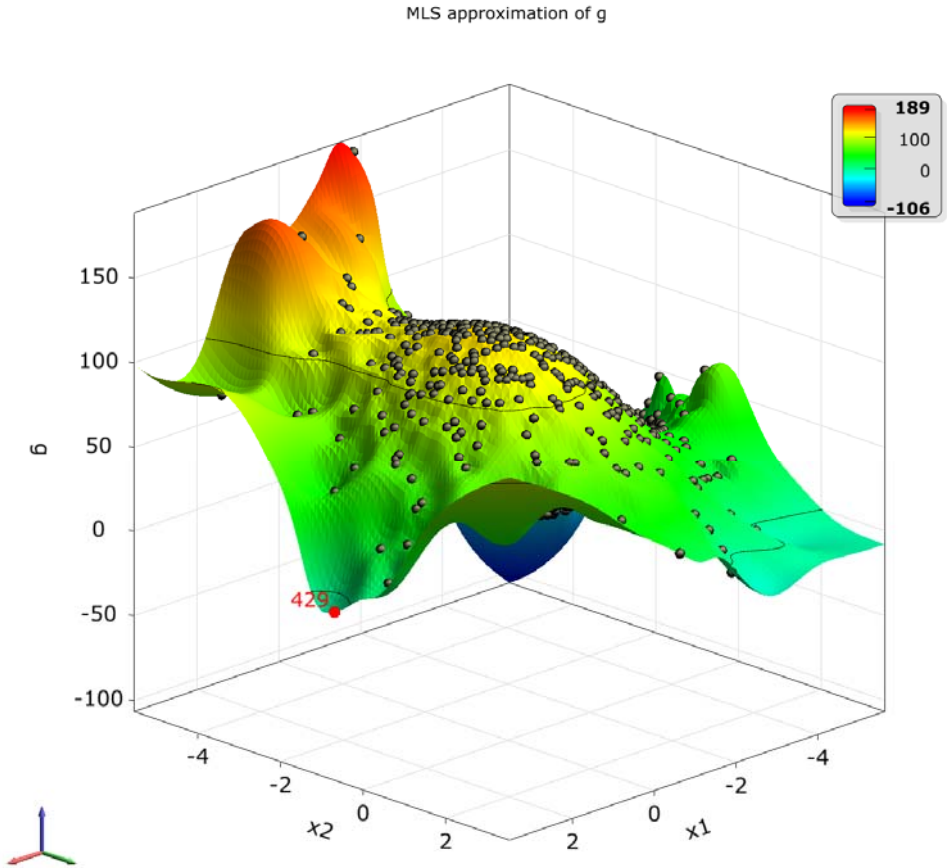




- Directional Sampling
- Design evaluations: 2612
- PF = 1.99E-06 (1.99E-06)
- Standard error: 3.46E-07

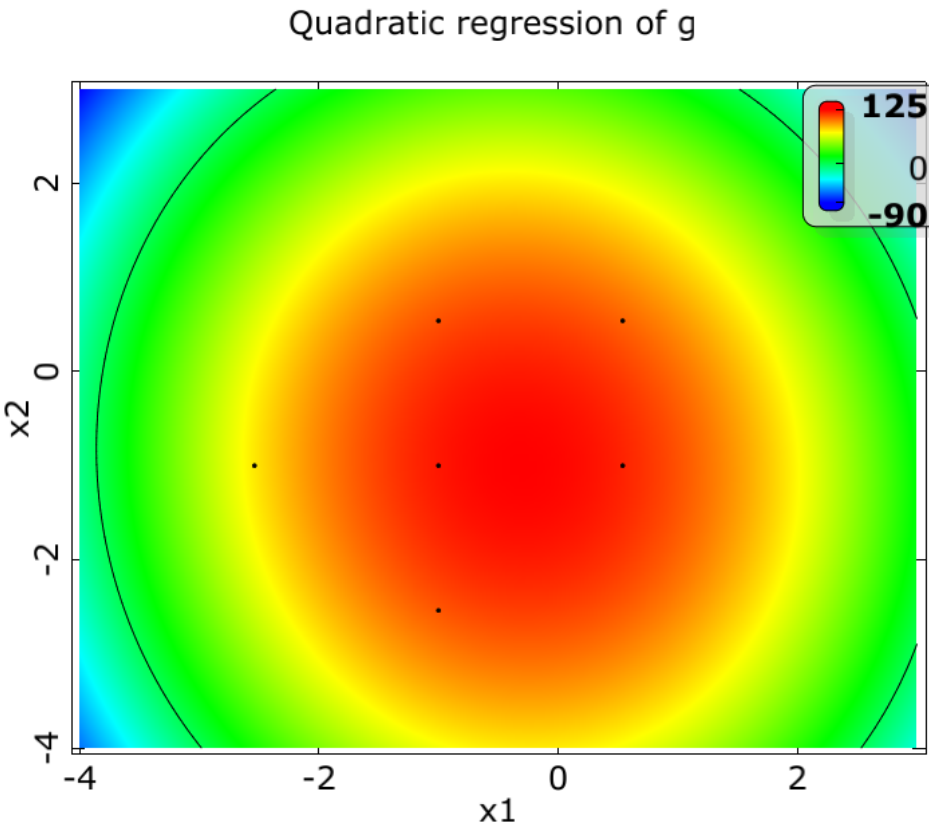
Reliability Analysis

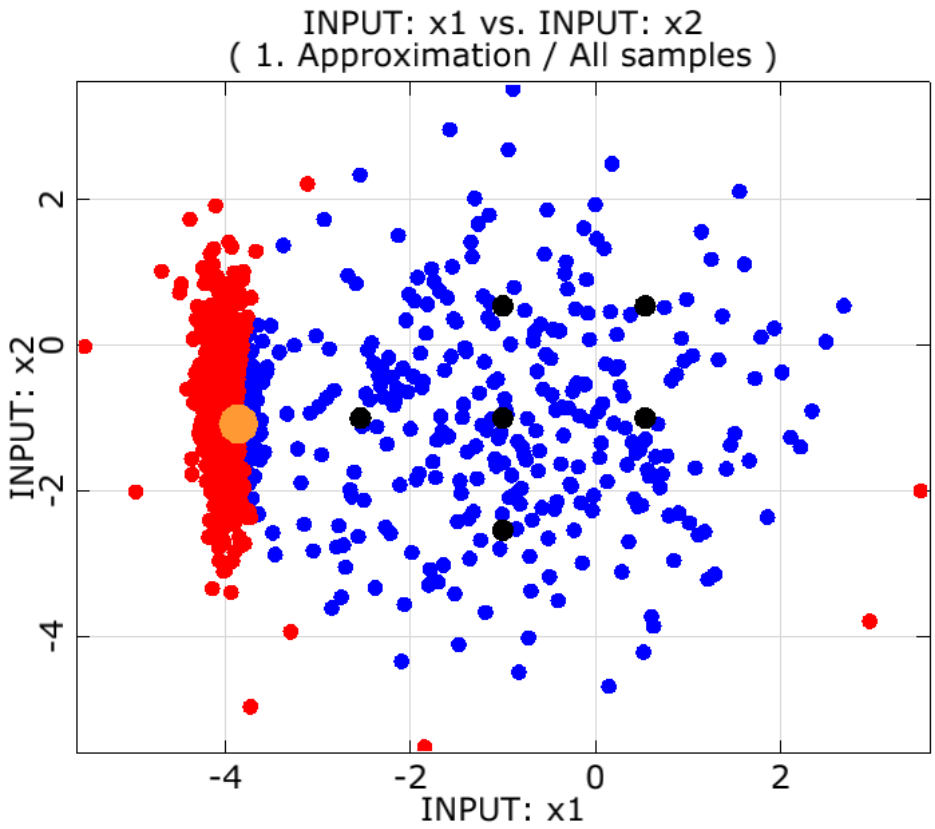




- Adaptive Sampling
- Design evaluations: 1500
- PF = 1.56E-06 (1.99E-06)
- Standard error: 1.25E-07

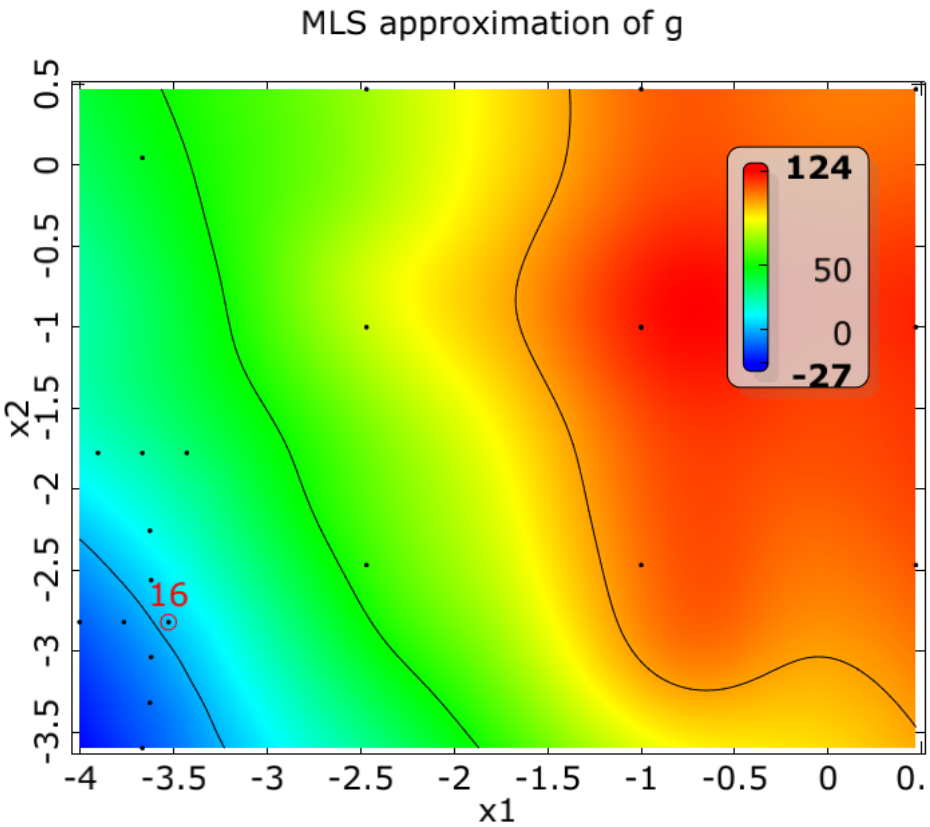
Reliability Analysis

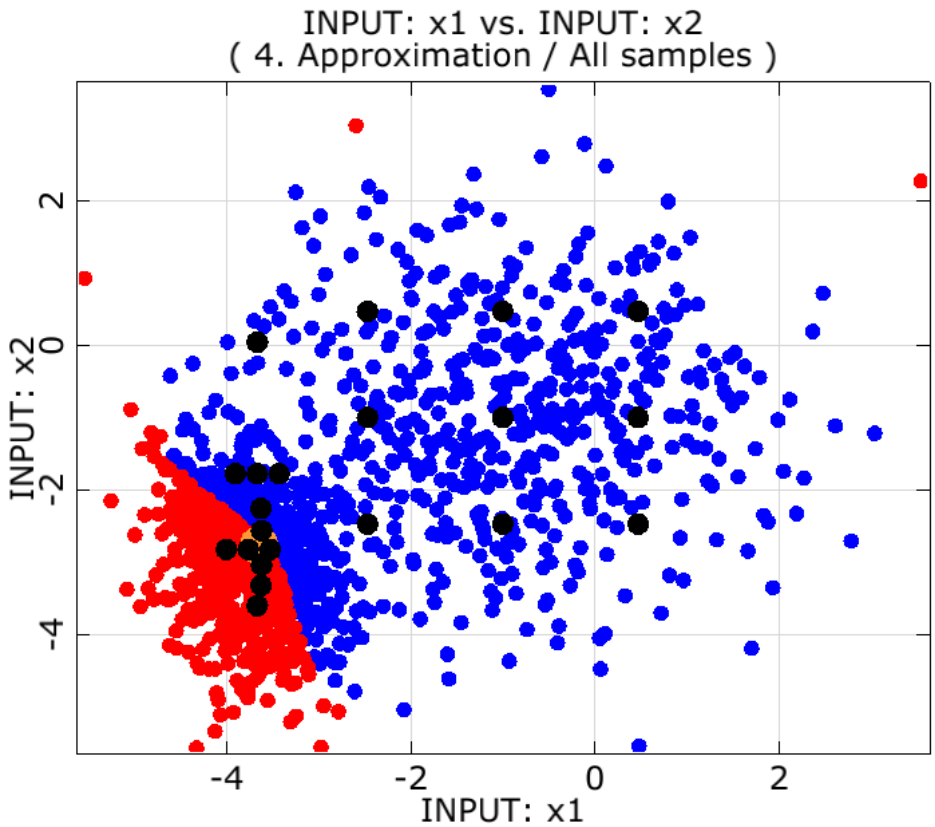




- Classic response surface method
- Design evaluations: 6
- PF = 2.89E-05 (1.99E-06)

Reliability Analysis

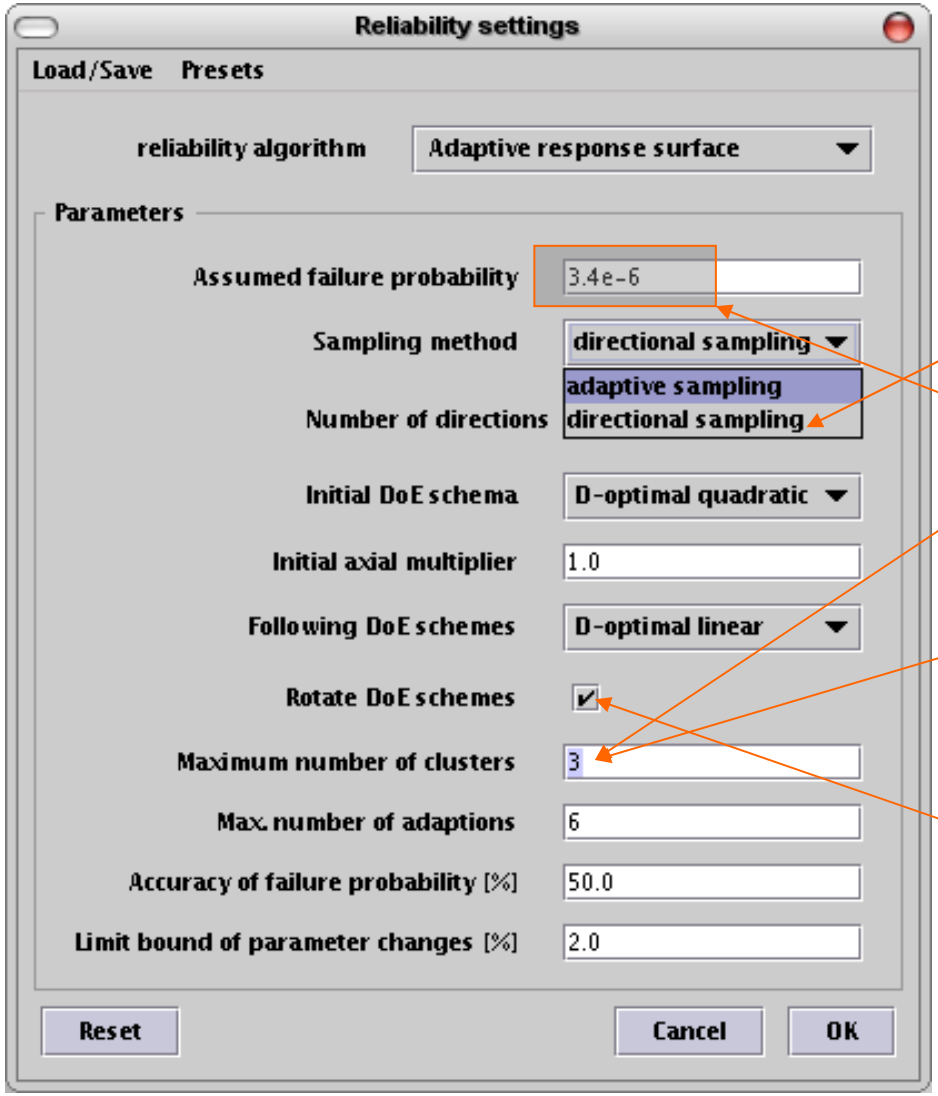




- Adaptive response surface method
- Adaptive sampling on MLS (optiSLang 3.0)
- Design evaluations: 22
- PF = 1.94E-06 (1.99E-06)

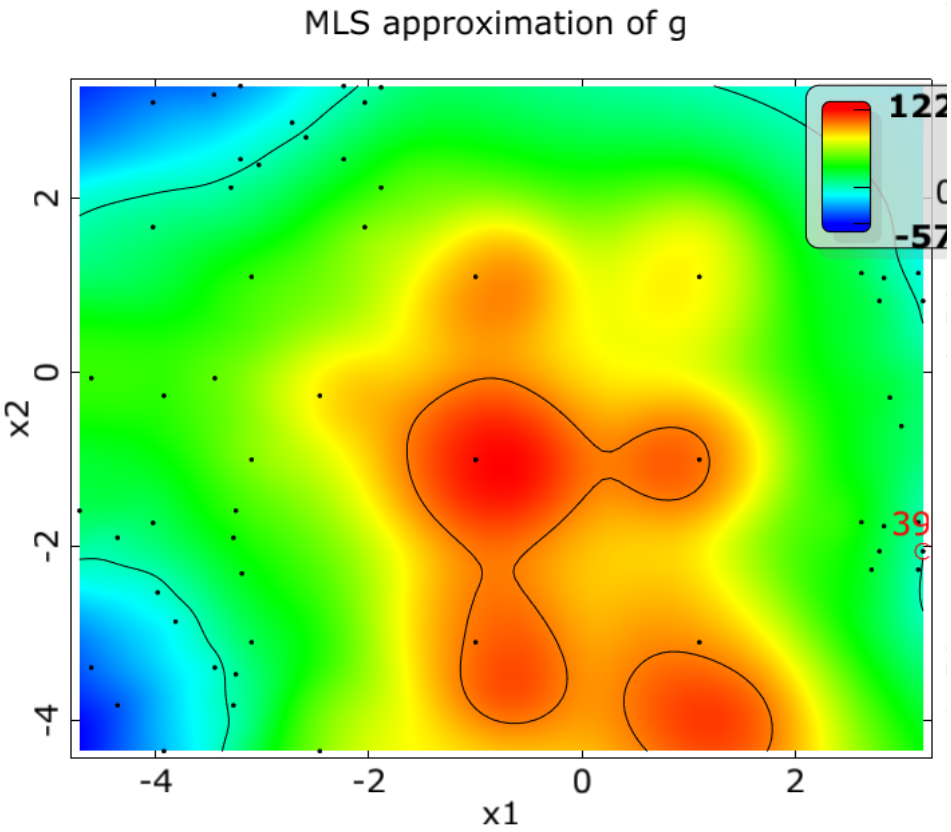
- Sigma level dependent
- $n \leq 15$
- Single adaptive DOE
- Supports two unsafe domains only

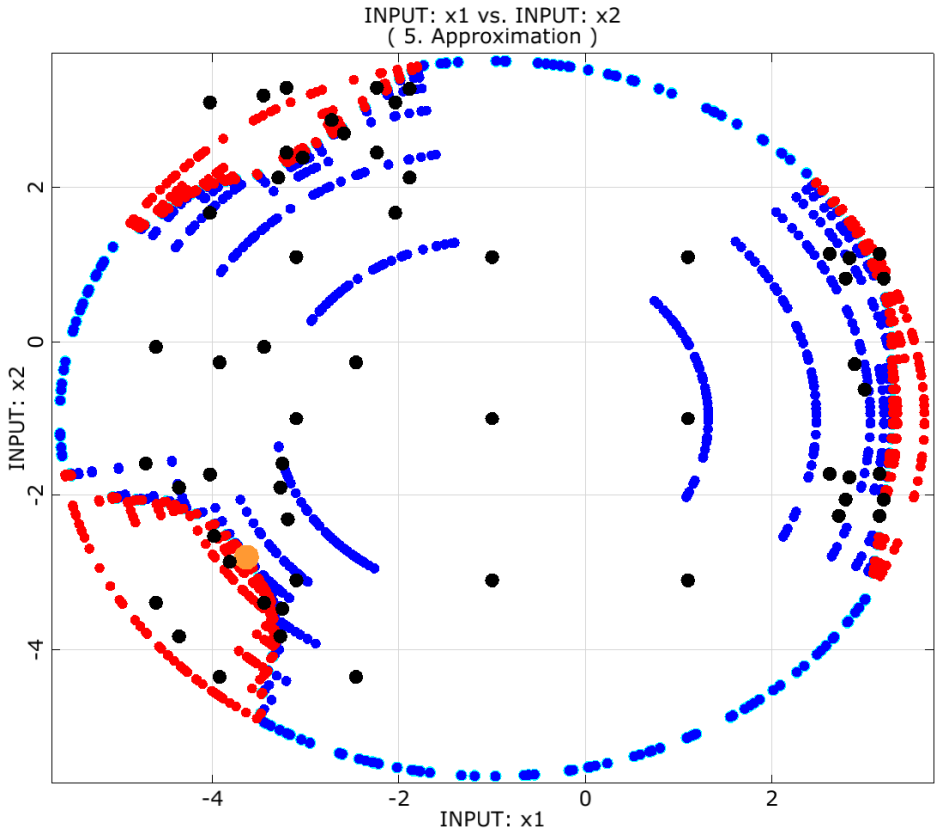
Adaptive response surface approximation



- Sampling methods on the MLS approximation:
  - Adaptive Sampling
  - Directional Sampling
    - supports more than two failure domains
    - and sigma level independent
- Cluster analysis to detect number of failure domains with high failure probability
- Rotatable adaptive designs of experiments to improve the approximation accuracy

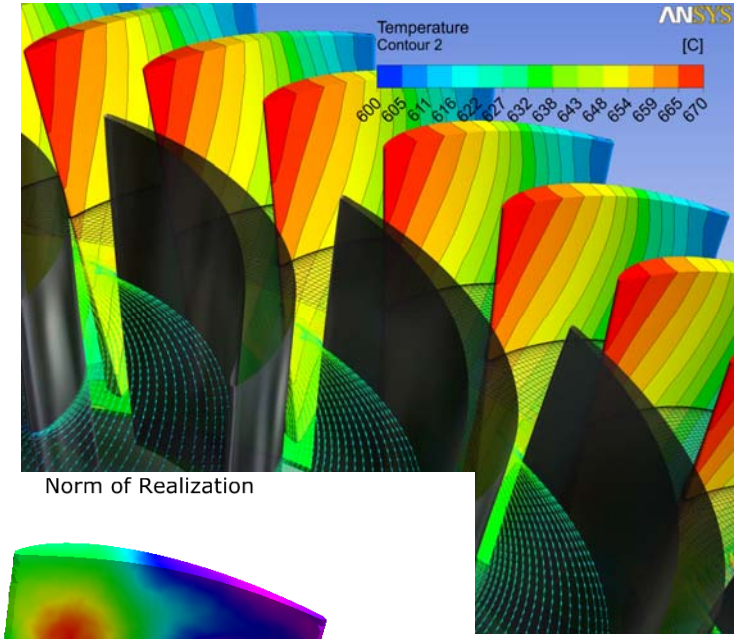
Reliability Analysis



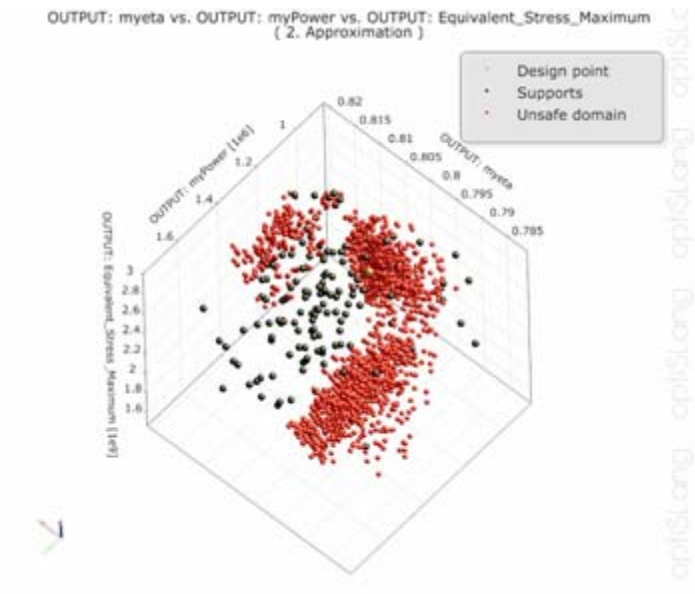


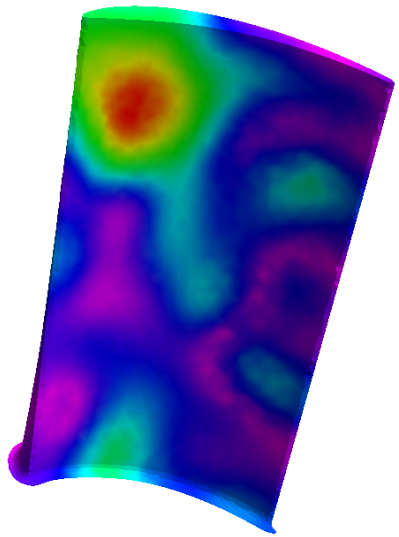
- Adaptive response surface method
- Directional sampling on MLS (optiSLang 3.1)
- Design evaluations: 58
- PF = 1.67E-06 (1.99E-06)

Reliability Analysis with Manufacturing Tolerances

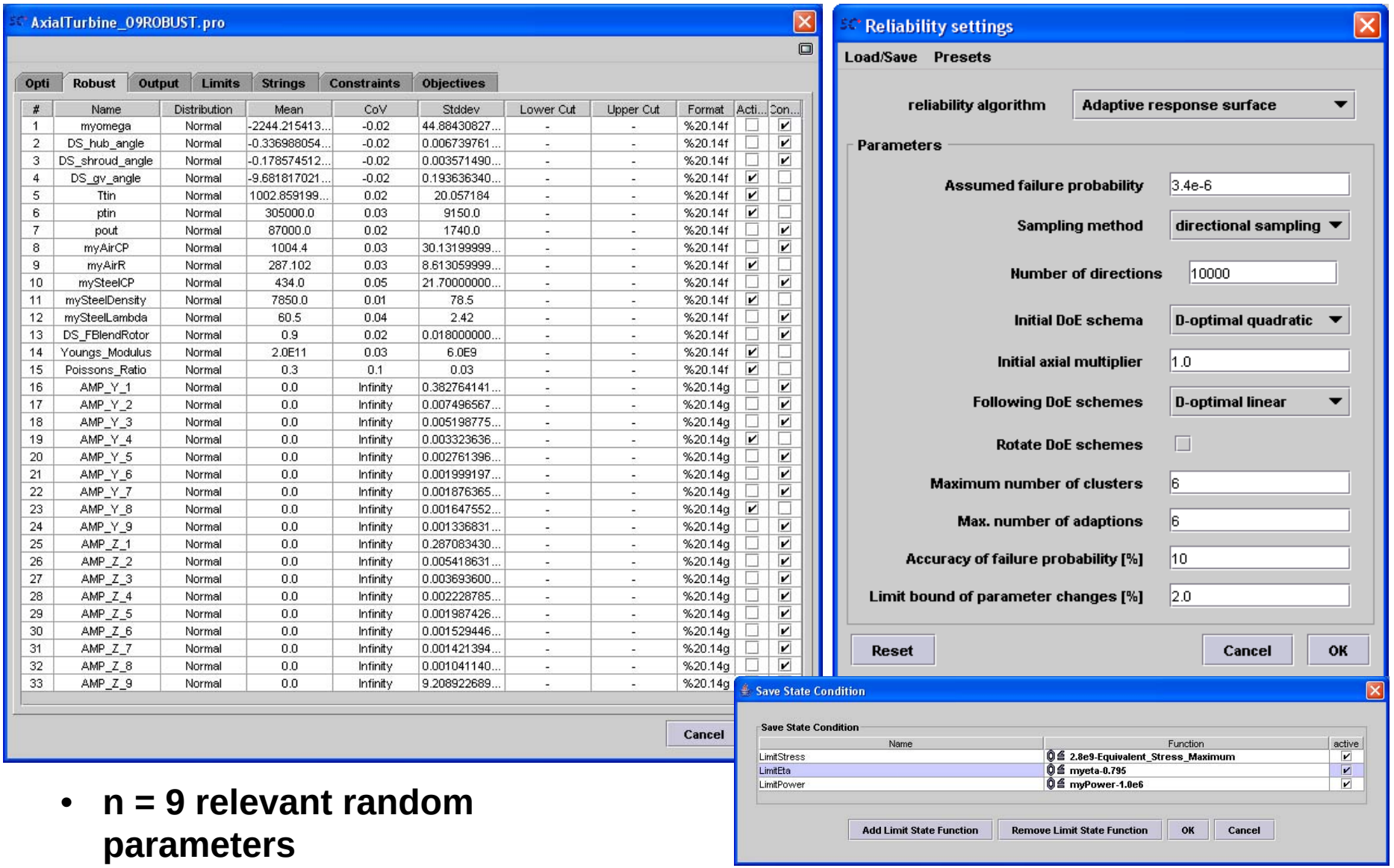


Norm of Realization





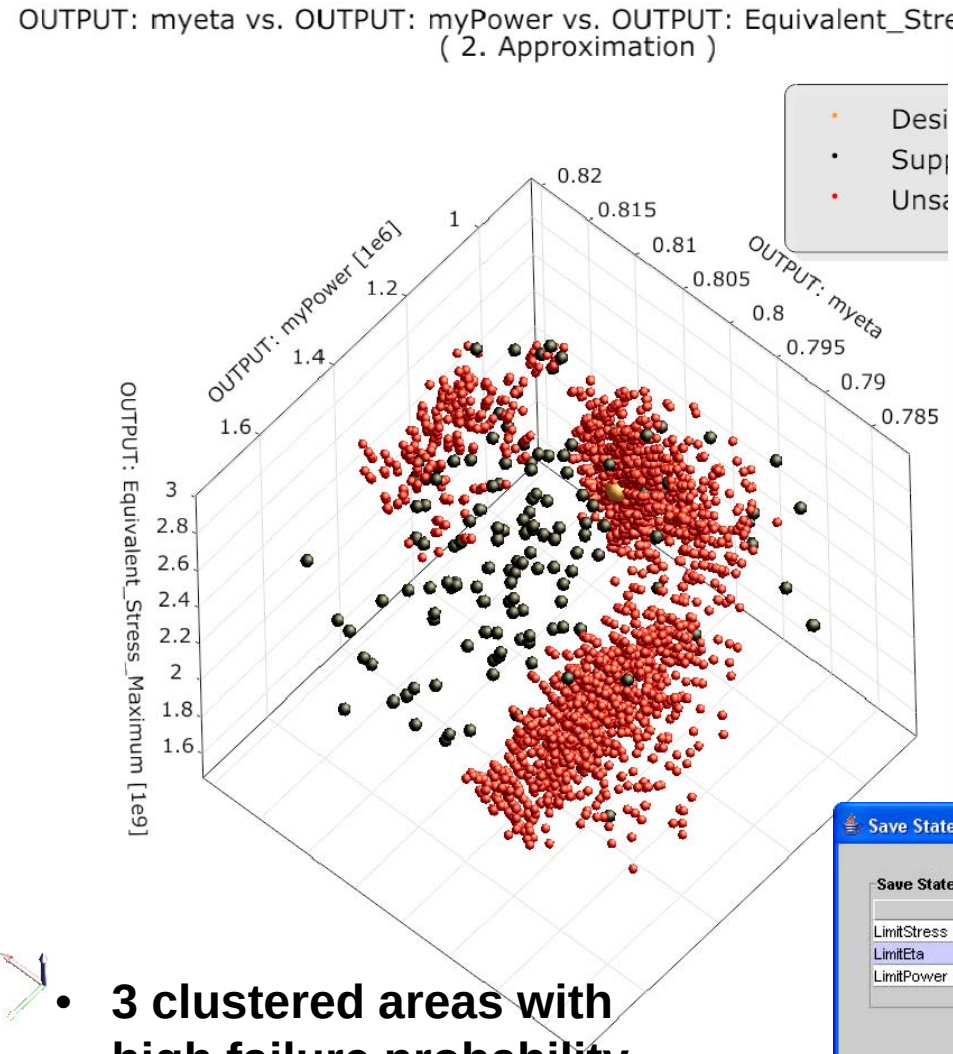
Example: Axial Turbine Blade

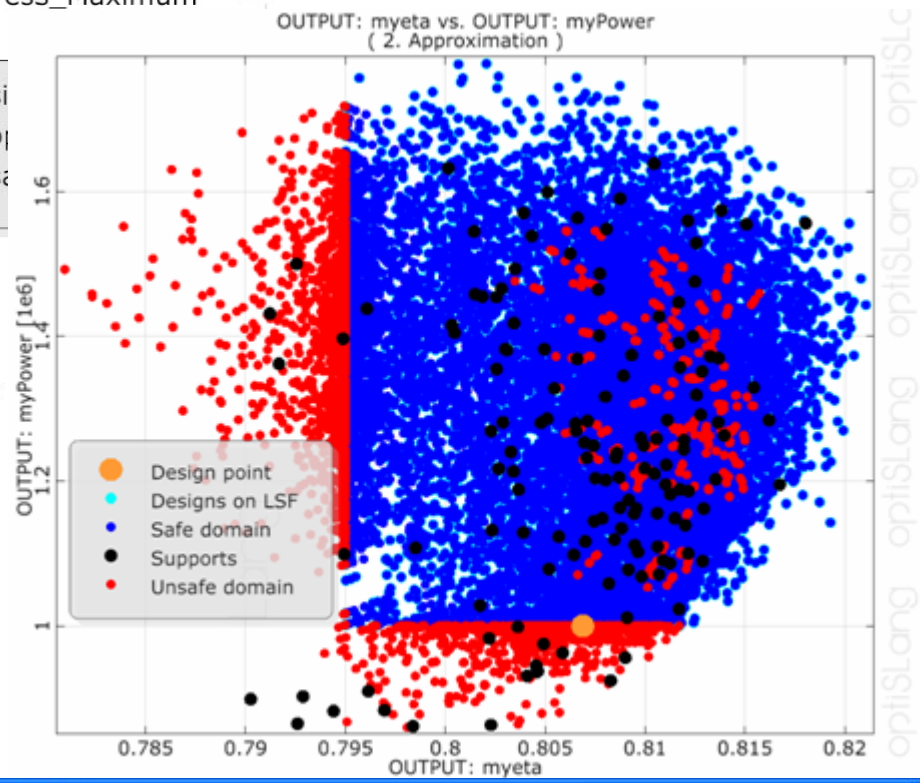


#	Name	Distribution	Mean	CoV	Stddev	Lower Cut	Upper Cut	Format	Acti...	Con...
1	myomega	Normal	-2244.215413...	-0.02	44.88430827...	-	-	%20.14f	☐	☑
2	DS_hub_angle	Normal	-0.336988054...	-0.02	0.006739761...	-	-	%20.14f	☐	☑
3	DS_shroud_angle	Normal	-0.178574512...	-0.02	0.003571490...	-	-	%20.14f	☐	☑
4	DS_gv_angle	Normal	-9.681817021...	-0.02	0.193636340...	-	-	%20.14f	☑	☐
5	Ttin	Normal	1002.859199...	0.02	20.057184	-	-	%20.14f	☑	☐
6	ptin	Normal	305000.0	0.03	9150.0	-	-	%20.14f	☑	☐
7	pout	Normal	87000.0	0.02	1740.0	-	-	%20.14f	☐	☑
8	myAirCP	Normal	1004.4	0.03	30.13199999...	-	-	%20.14f	☐	☑
9	myAirR	Normal	287.102	0.03	8.613059999...	-	-	%20.14f	☑	☐
10	mySteelCP	Normal	434.0	0.05	21.70000000...	-	-	%20.14f	☐	☑
11	mySteelDensity	Normal	7850.0	0.01	78.5	-	-	%20.14f	☑	☐
12	mySteelLambda	Normal	60.5	0.04	2.42	-	-	%20.14f	☐	☑
13	DS_FBlendRotor	Normal	0.9	0.02	0.018000000...	-	-	%20.14f	☐	☑
14	Youngs_Modulus	Normal	2.0E11	0.03	6.0E9	-	-	%20.14f	☑	☐
15	Poissons_Ratio	Normal	0.3	0.1	0.03	-	-	%20.14f	☑	☐
16	AMP_Y_1	Normal	0.0	Infinity	0.382764141...	-	-	%20.14g	☐	☑
17	AMP_Y_2	Normal	0.0	Infinity	0.007496567...	-	-	%20.14g	☐	☑
18	AMP_Y_3	Normal	0.0	Infinity	0.005198775...	-	-	%20.14g	☐	☑
19	AMP_Y_4	Normal	0.0	Infinity	0.003323636...	-	-	%20.14g	☑	☐
20	AMP_Y_5	Normal	0.0	Infinity	0.002761396...	-	-	%20.14g	☐	☑
21	AMP_Y_6	Normal	0.0	Infinity	0.001999197...	-	-	%20.14g	☐	☑
22	AMP_Y_7	Normal	0.0	Infinity	0.001876365...	-	-	%20.14g	☐	☑
23	AMP_Y_8	Normal	0.0	Infinity	0.001647552...	-	-	%20.14g	☑	☐
24	AMP_Y_9	Normal	0.0	Infinity	0.001336831...	-	-	%20.14g	☐	☑
25	AMP_Z_1	Normal	0.0	Infinity	0.287083430...	-	-	%20.14g	☐	☑
26	AMP_Z_2	Normal	0.0	Infinity	0.005418631...	-	-	%20.14g	☐	☑
27	AMP_Z_3	Normal	0.0	Infinity	0.003693600...	-	-	%20.14g	☐	☑
28	AMP_Z_4	Normal	0.0	Infinity	0.002228785...	-	-	%20.14g	☐	☑
29	AMP_Z_5	Normal	0.0	Infinity	0.001987426...	-	-	%20.14g	☐	☑
30	AMP_Z_6	Normal	0.0	Infinity	0.001529446...	-	-	%20.14g	☐	☑
31	AMP_Z_7	Normal	0.0	Infinity	0.001421394...	-	-	%20.14g	☐	☑
32	AMP_Z_8	Normal	0.0	Infinity	0.001041140...	-	-	%20.14g	☐	☑
33	AMP_Z_9	Normal	0.0	Infinity	9.208922689...	-	-	%20.14g	☐	☑

- **n = 9 relevant random parameters**

Example: Axial Turbine Blade





- **3 clustered areas with high failure probability**

Reliability Analysis

- n = 9 random parameters
- N = 141 design evaluations
- Pf = 2.4e-7 < 3.4e-6 (4.5 sigma)
- Six Sigma Design

Method : Directional Sampling on Adaptive Response Surfaces (ARSM-DS)

Selected data :	2. Approximation
Number of designs :	141 (7 failed)
Complete directions :	10000 / 10000
Number of samples :	
Total :	19590
Safe domain :	15143
Unsafe domain :	4447
Failure strings :	0
Unsuccessful :	0
Probability of failure :	2.45e-07 (2.45e-07)
Standard deviation error :	4.771e-08 (4.771e-08)

- Calculation of the MPP or design point
- Corresponding FORM result

Most probable failure point:

myomega :	-2217.04008841
DS_gv_angle :	-9.99561718295
Ttin :	960.730885684
ptin :	266629.901461
pout :	90929.4317189
myAirCP :	1023.31803947
myAirR :	279.505216069
Youngs_Modulus :	202109405683
Poissons_Ratio :	0.285449914136
Distance median - design point (beta) :	5.623
Probability of failure (FORM):	9.372e-09

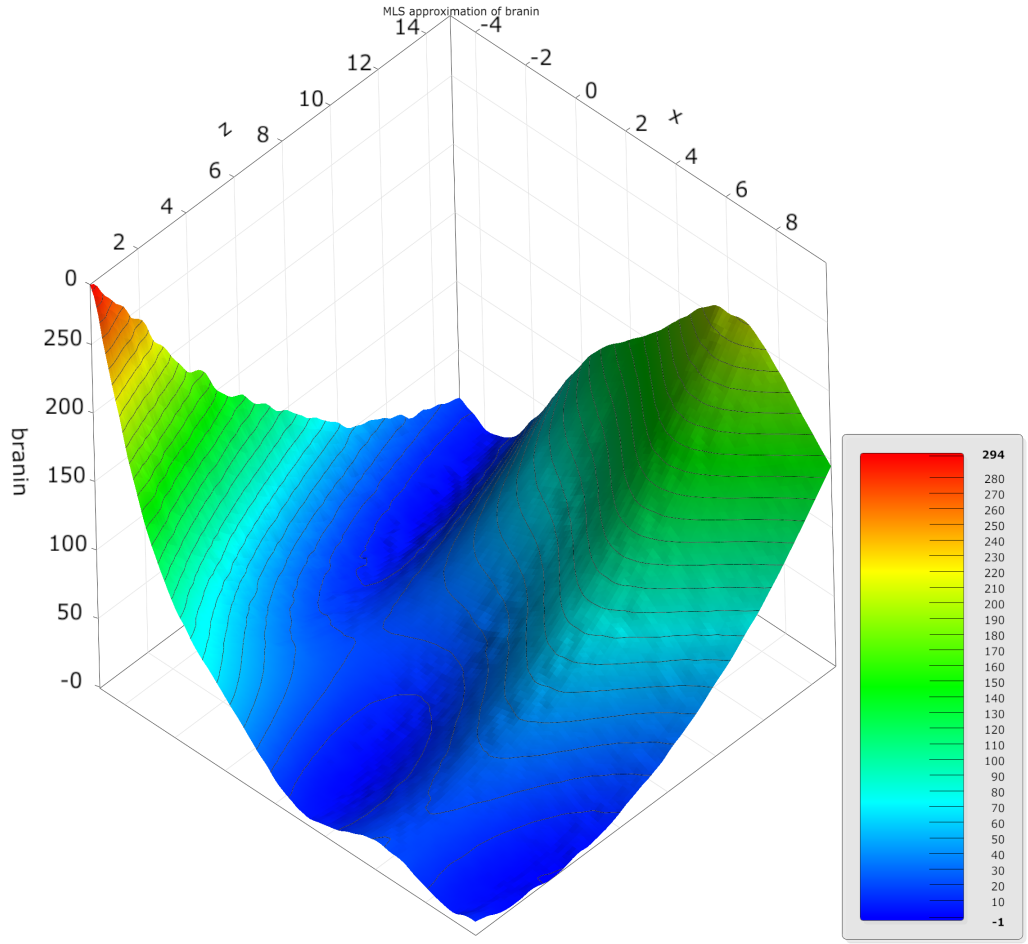
RDO - Examples

Overview

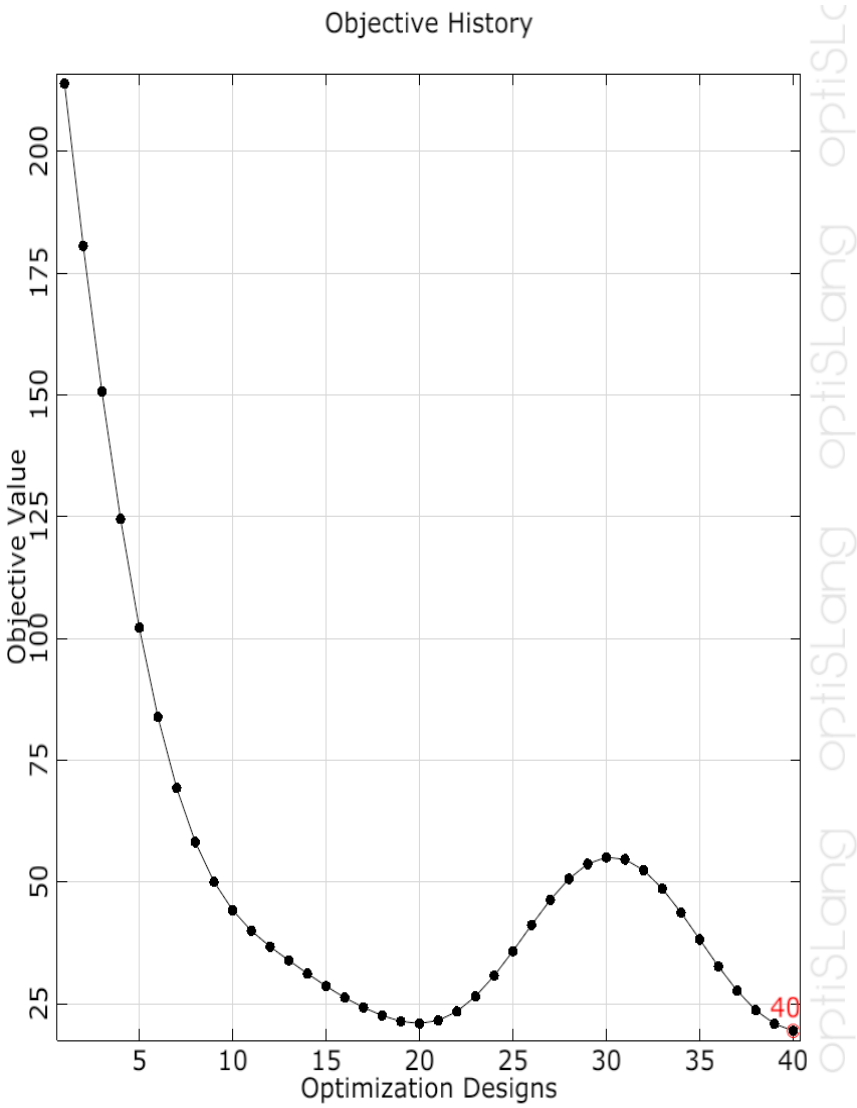
- Braninfunction
- Beam under dynamic load
- New highdimensional Example

Braninfunction

$$f(x,z) = \left(z - \frac{5.1}{4\,\pi^2}\,x^2 + \frac{5}{\pi}\,x - 6\right)^2 + 10\left(1 - \frac{1}{8\,\pi}\right)\cos(x) + 10$$



Braninfunction



deterministic parameter:

$-5 \leq x \leq 10$

stochastic parameter:

$\sigma_z = 2$

$\mu_z = 2$

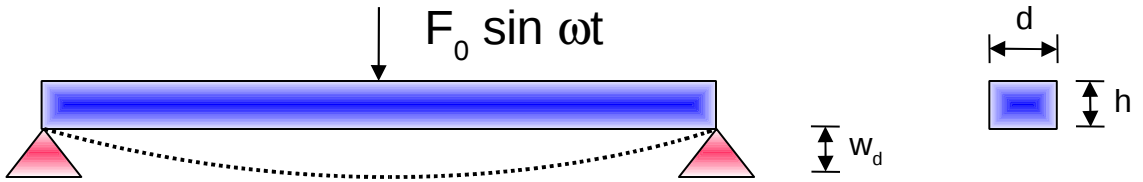
minimize:

$$\delta_{qbranin}(x) = \mu(f(x)) + \sigma(f(x))$$

- ARSM / 25LHS
- SR: 1.0σ / 5%
- Minimum found at x = 10

- 47 runs

Example – simple beam



Optimization parameter:

d[0..1]

h[0..1]

Stochastic parameter:

F_0[μ=2e5,σ=2e4]

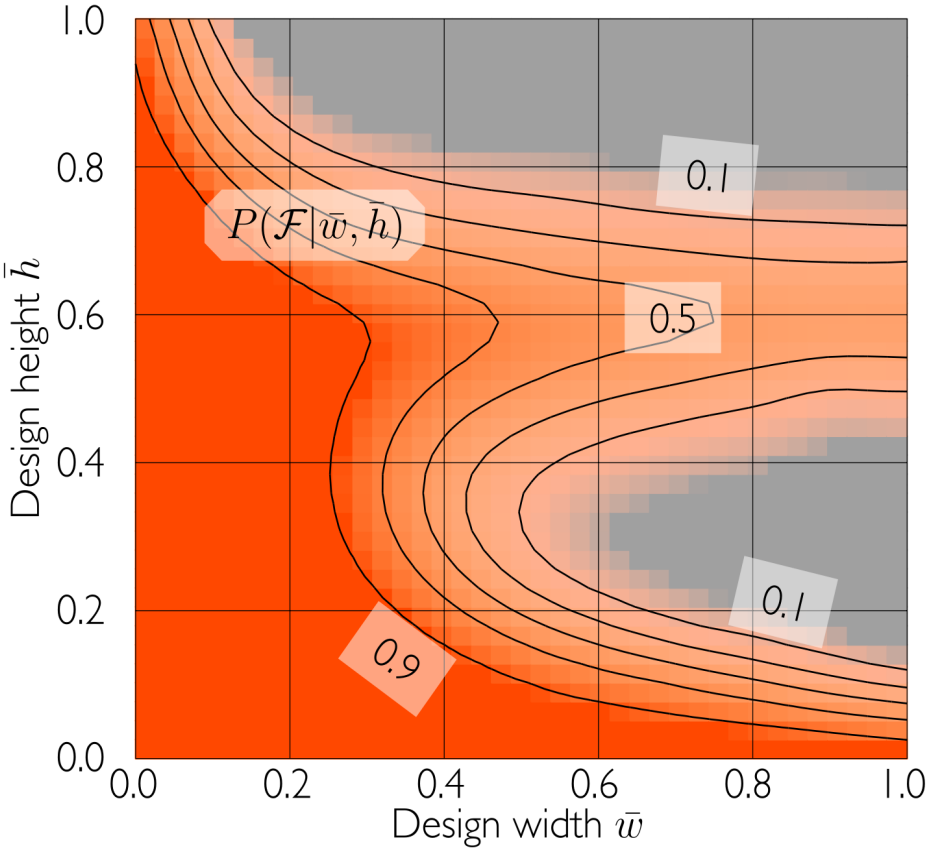
ω[μ=60,σ=6]

Objective:

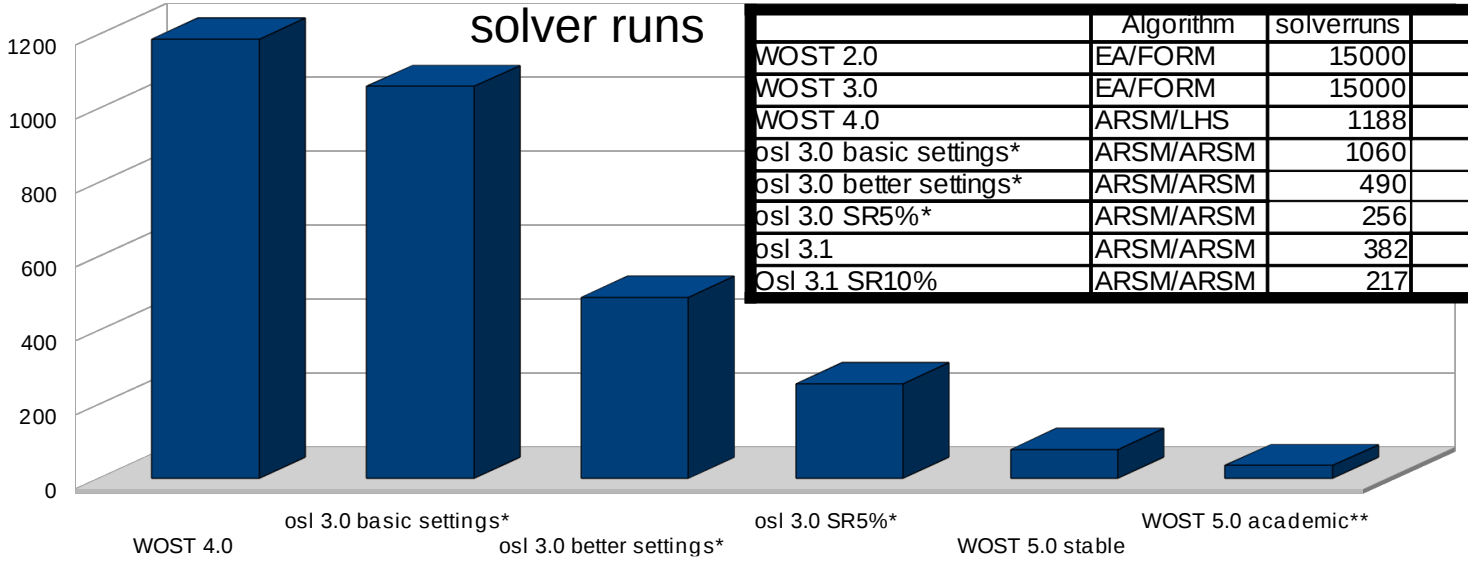
min(d*h)

Constraint:

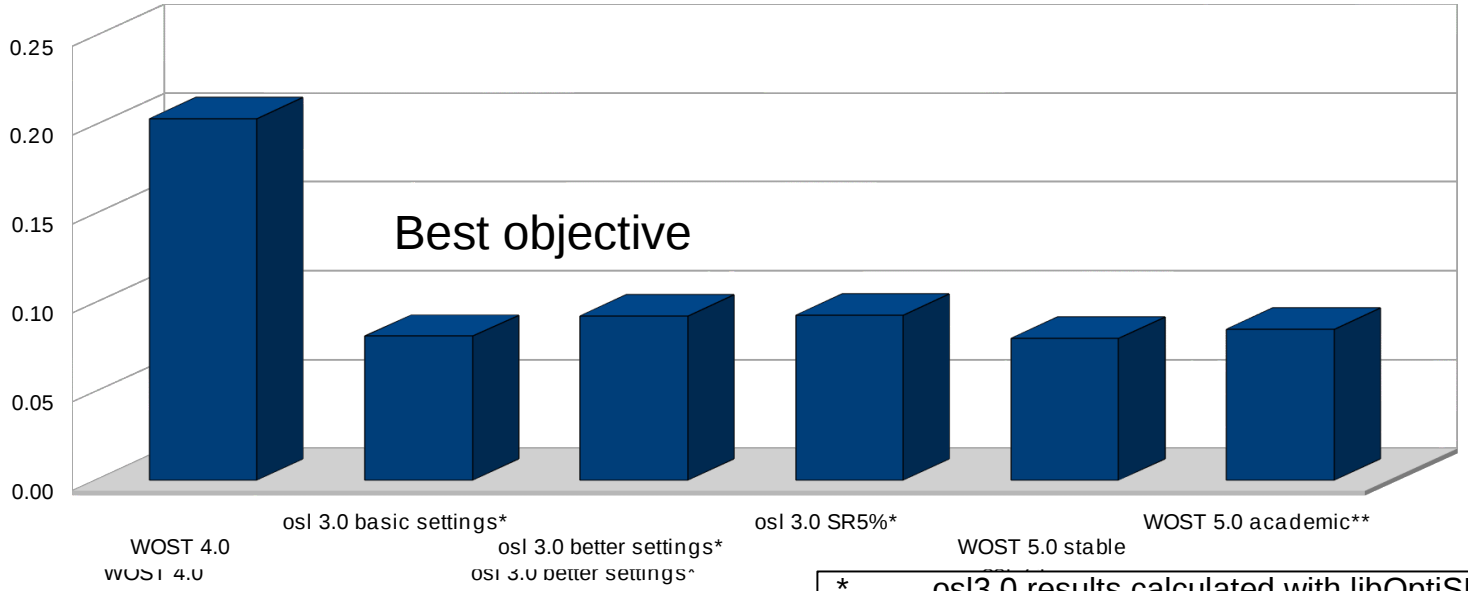
$P_f(w_d > 0.005) < 0.01$



Results – a comparison



	Algorithm	solverruns	d	h	d*h
WOST 2.0	EA/FORM	15000	0.888	0.29	0.26
WOST 3.0	EA/FORM	15000	0.888	0.29	0.26
WOST 4.0	ARSM/LHS	1188	0.925	0.22	0.20
osl 3.0 basic settings*	ARSM/ARSM	1060	0.081	1.00	0.08
osl 3.0 better settings*	ARSM/ARSM	490	0.093	1.00	0.09
osl 3.0 SR5%*	ARSM/ARSM	256	0.093	1.00	0.09
osl 3.1	ARSM/ARSM	382	0.080	1.00	0.08
Osl 3.1 SR10%	ARSM/ARSM	217	0.085	1.00	0.09



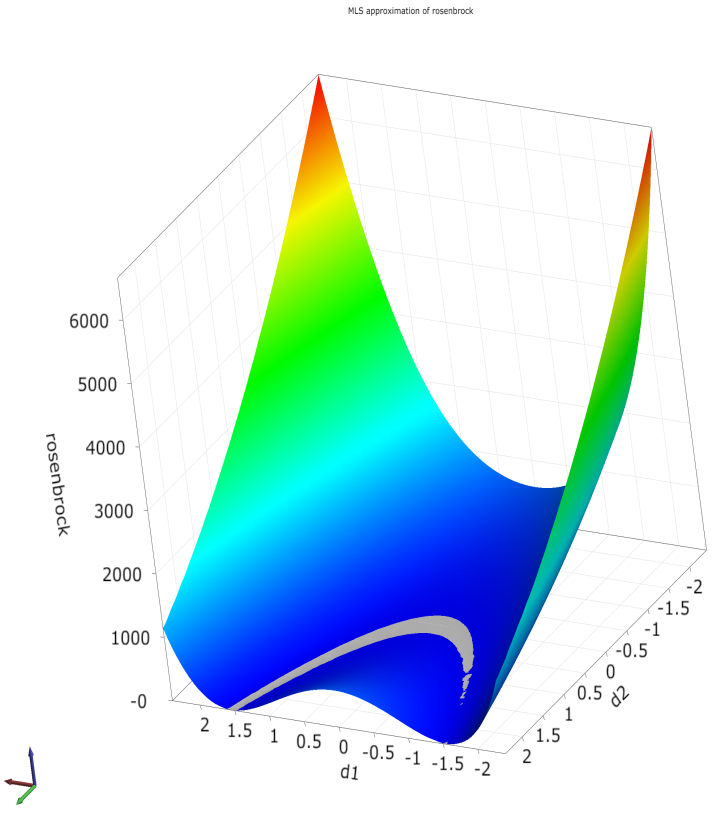
* osl3.0 results calculated with libOptiSLang++
** not stable yet
*** exact number of solverruns $20*50 * N_{FORM}$

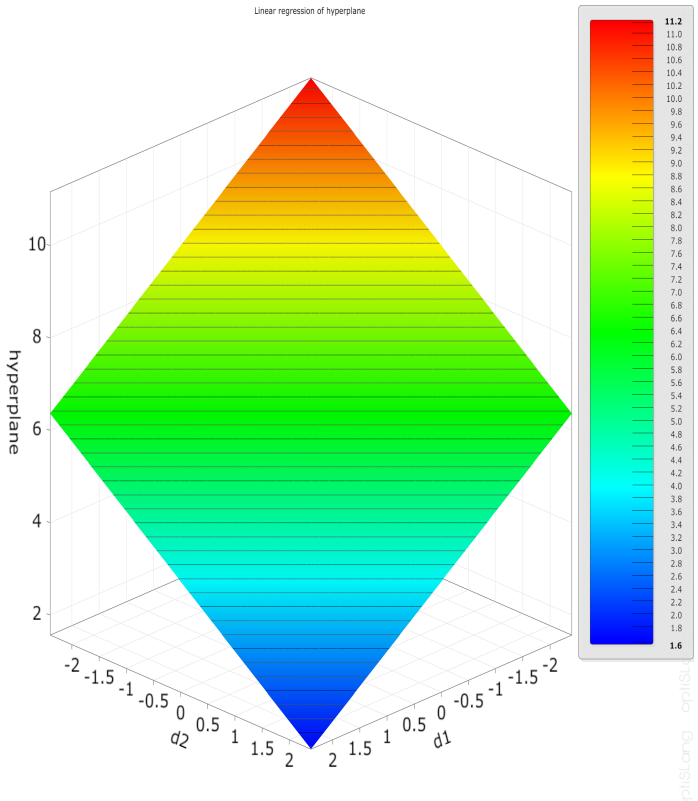
Highdimensional Example

Combination of Rosenbrock-function and Hyperplane

$$rosenB(d_0, \ldots, d_n) = \sum_{i=0}^{n-1} \left[(1 - x_i)^2 + 100(x_{i+1} - x_i^2)^2 \right]$$

$$hyperP(\beta, p_0, \ldots, p_m) = \beta\sqrt{m} - \sum_{i=0}^{m} p_i$$



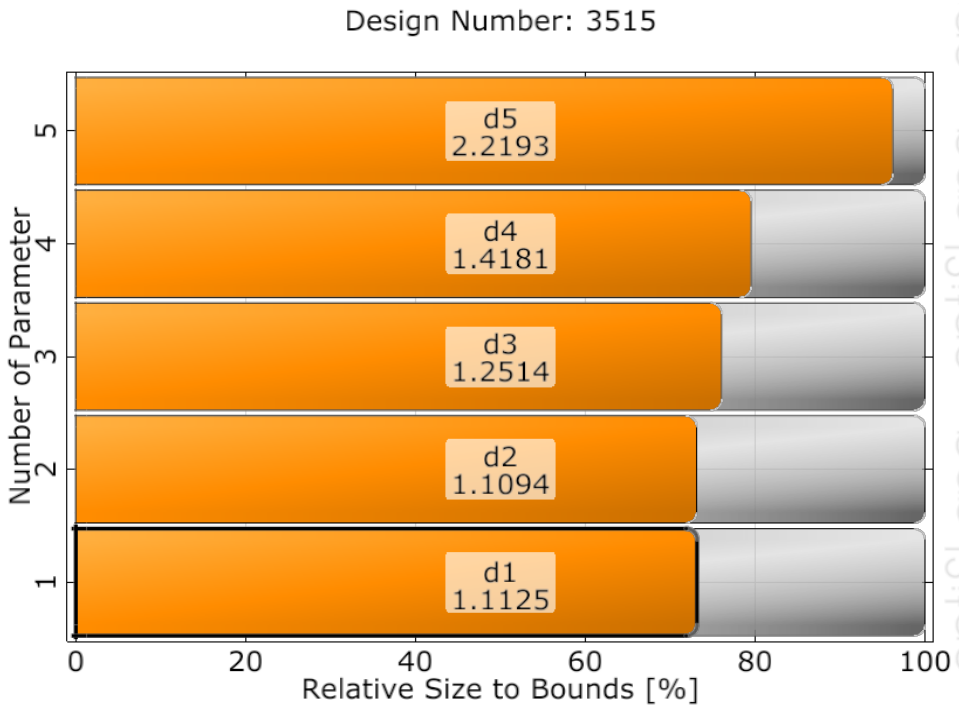


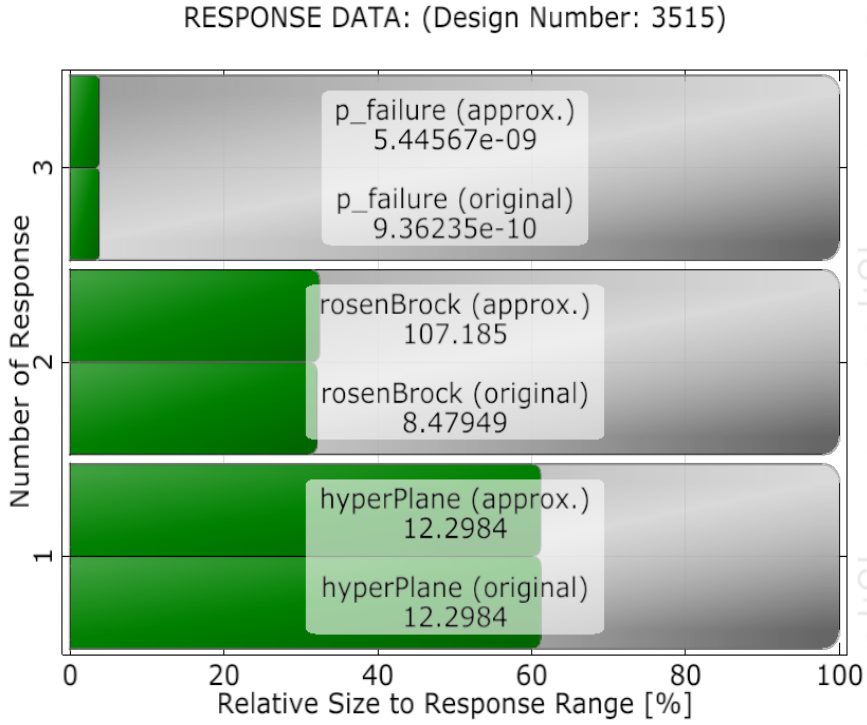
Highdimensional Example

$$min(rosenB(d_0, \ldots, d_n))$$

$$-2.4 \leq x_i \leq 2.4$$

$$P[hyperP(\beta, p_0, \ldots, p_m) + \sqrt{n} * (d_0) < 0] \leq 3.4E-6$$





Outlook

- Better decision criteria for SR
- Easy and understandable parameters
- Apply to total space
- Find and use best metamodel

- Braninfunction: 17 designs
- Simple beam: 81 designs
- Rosenbrock/hyperplane: less than 500 designs

RDO - Examples