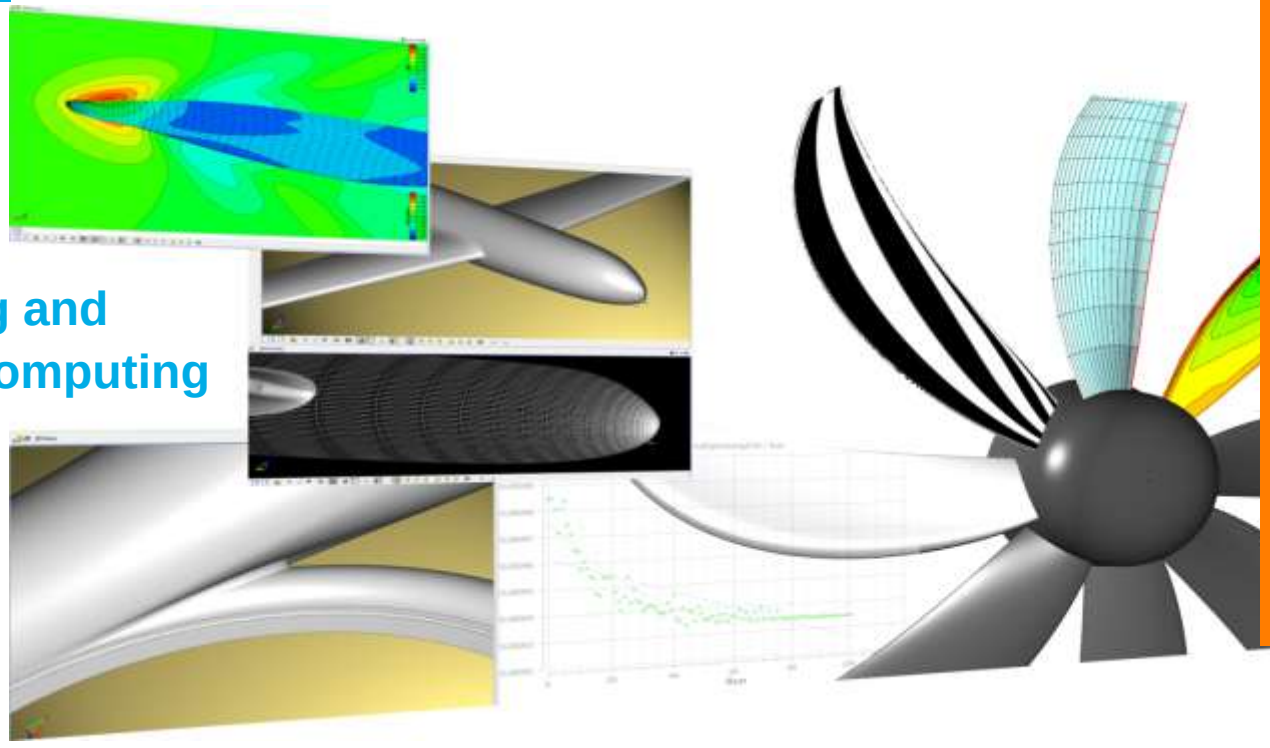
Robust Ship Design Optimization using Multidisciplinary Optimization and Stochastic Analysis.



Dirk Roos
Institute of Modelling and High-Performance Computing

Stefan Harries &
Jörg Palluch
Friendship Systems

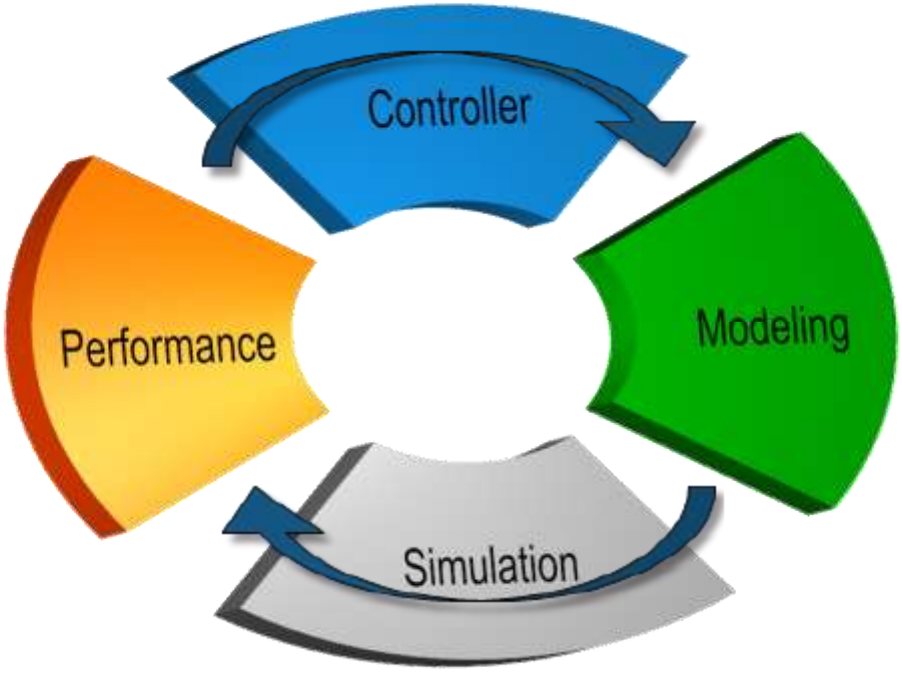
12/5/2012

presented at the 9th Weimar Optimization and Stochastic Days 2012
Source: www.dynardo.de/en/library

Simulation-driven design

Approach

Utilize simulation, in particular Computational Fluid Dynamics (CFD), to get optimal shapes



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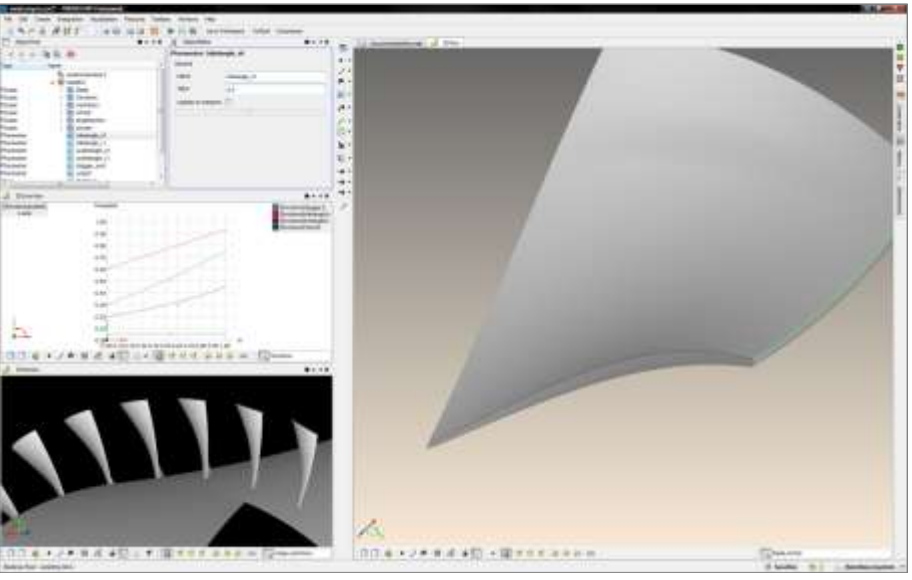
Simulation-driven design of functional surfaces

Typical bottlenecks

CFD is resource intensive and shapes need to be of high quality



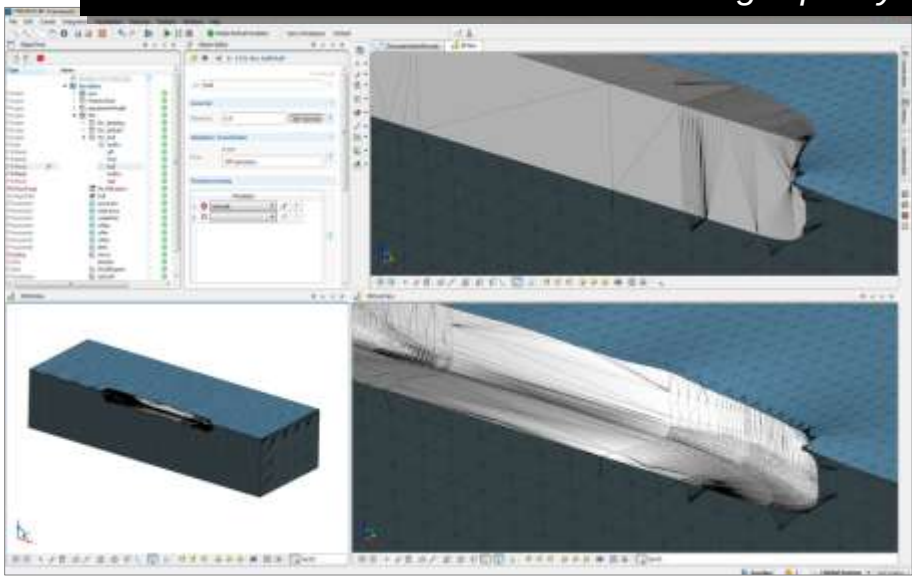


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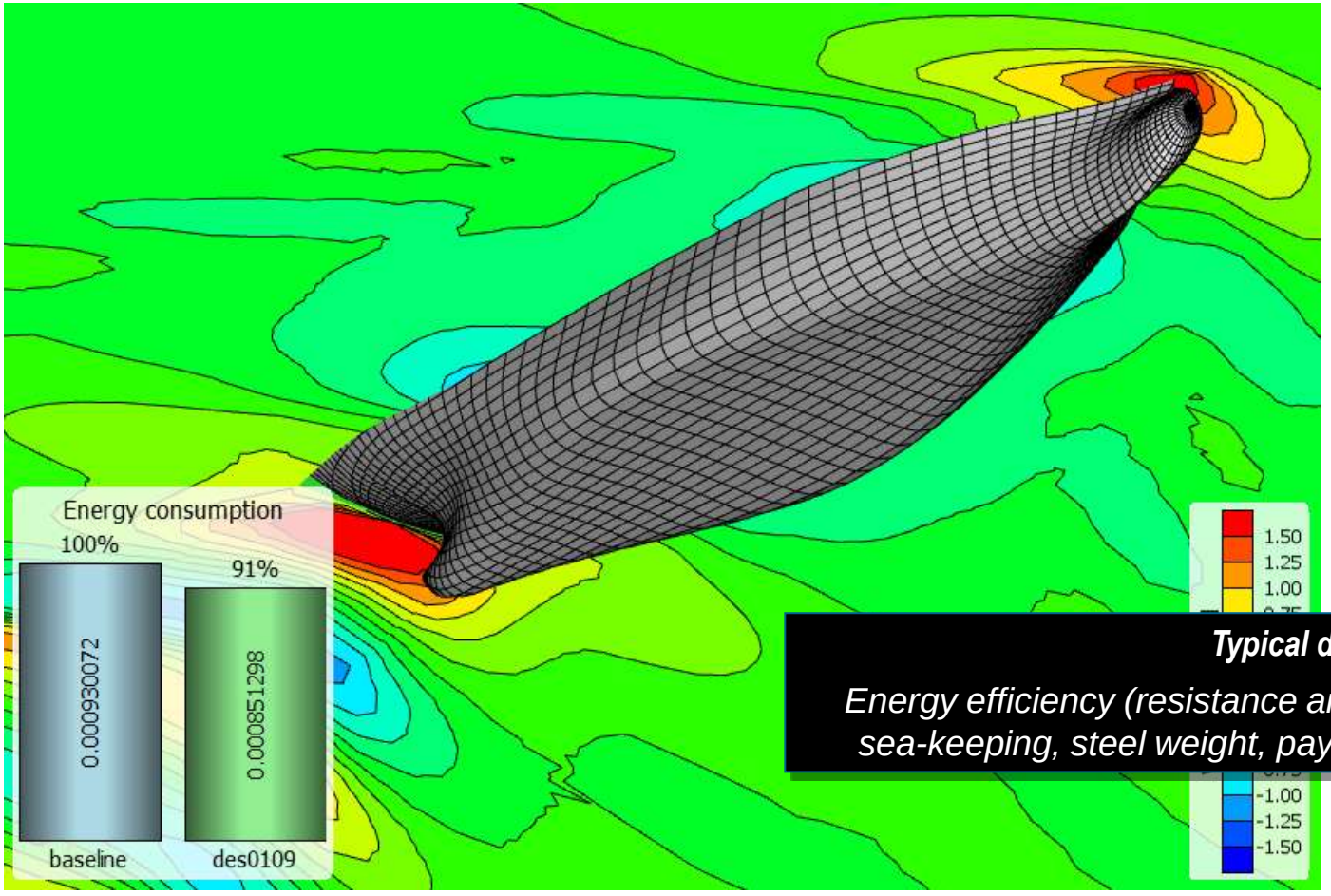
Illustration from ship design



Typical design objectives

Energy efficiency (resistance and propulsion), sea-keeping, steel weight, payload, RFR etc.

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Hull form development

Typical performance improvements even for good initial designs: 5%

Representative savings for a megaboxer of 13 000 TEU: 3 000 t of heavy fuel oil per year = 22 222 bathtubs, i.e., about 1 500 000 US $ every year

Photo by courtesy of DSME

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Typical users of the *FRIENDSHIP-Framework* (selected references)

- Blohm+Voss Naval
- China Ship Development and Design Center
- Daewoo Shipbuilding & Marine Eng. (DSME)
- FutureShip GmbH
- Hamburgische Schiffbau-Versuchsanstalt (HSVA)
- Hudong Zhonghua
- KSB AG
- Meyer Werft
- MTU Friedrichshafen
- Pusan National University (PNU)
- Rolls-Royce Aeroengines
- Shanghai Jiao Tong University
- Shanghai Merchant Ship Design and Research Institute (SDARI)
- STX Offshore & Shipbuilding
- Sumitomo Heavy Industries
- Sungdong Shipbuilding Marine Engineering
- SVA Potsdam
- Technische Universität Hamburg-Harburg
- Universidade de Sao Paulo (USP)
- Voith Turbo Schneider Propulsion

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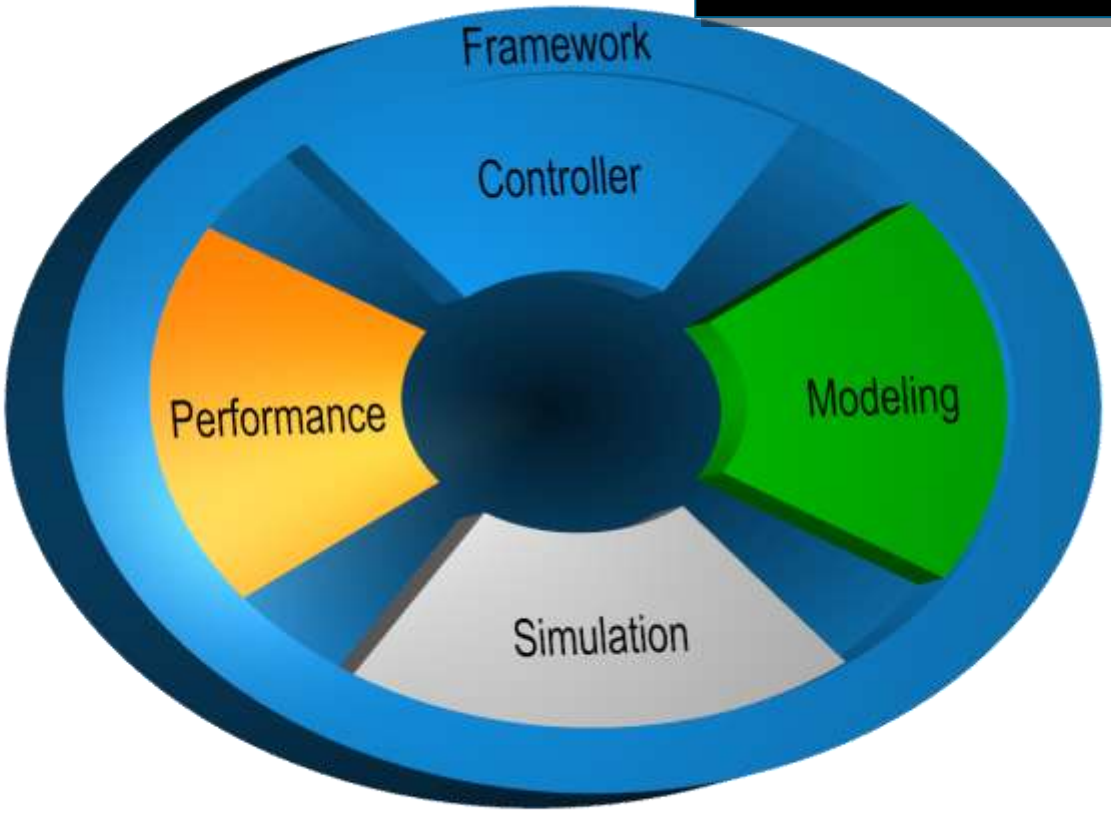
The *FRIENDSHIP-Framework*

Modes of operation

Use in batch mode as geometric engine or as complete CAE environment with full process control



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The *FRIENDSHIP-Framework*

Computer Aided Engineering and integration platform for

- **Design studies**
- **Formal optimization**

Focus on geometric modeling of functional surfaces

- **Complex geometries with internal and external flows**
- **In particular, free-form surfaces that are challenging to parameterize**

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User defined parametrics

Fully parametric modeling

- Complete geometry and all changes are defined parametrically

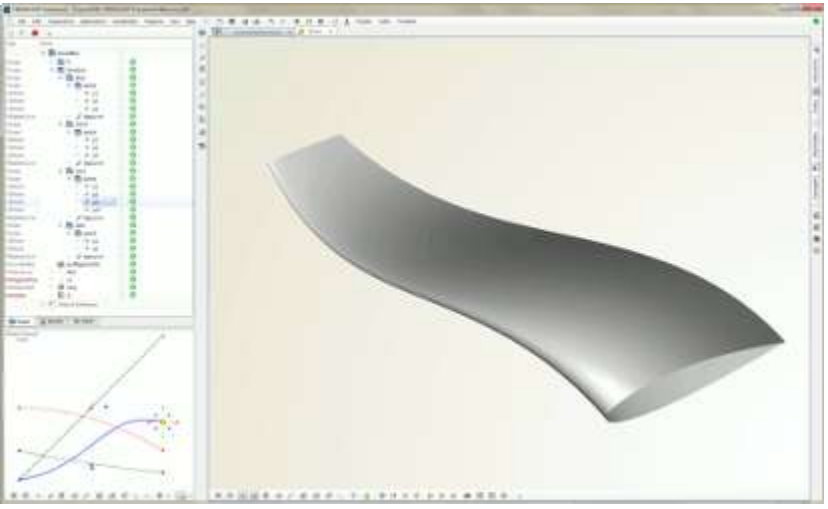
Partially parametric modeling

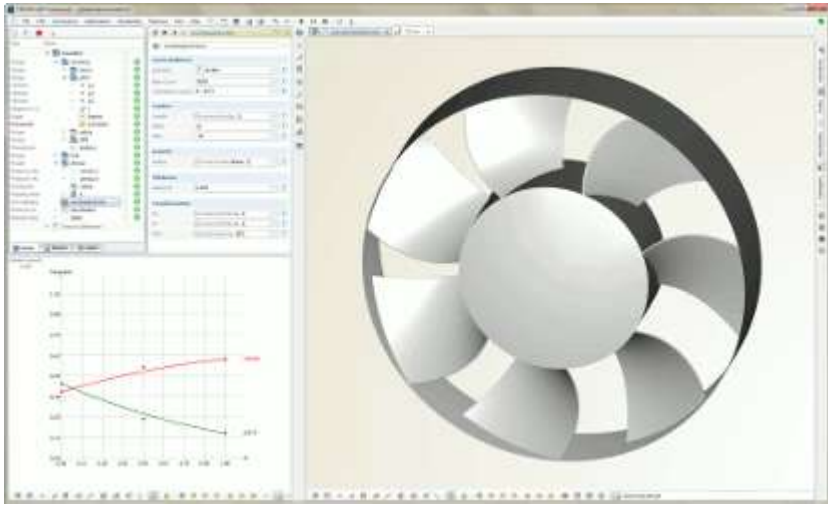
- Given geometry
- Changes are realized parametrically
- Applicable to all shapes

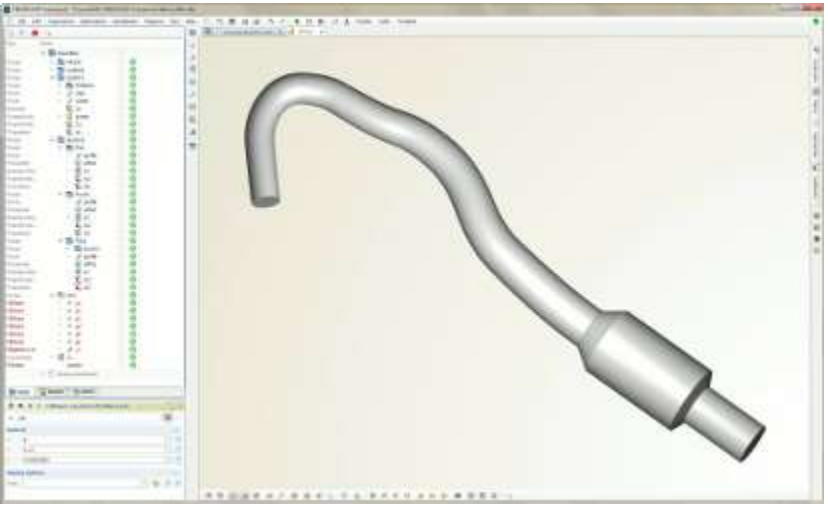
Modeling within the FRIENDSHIP-Framework

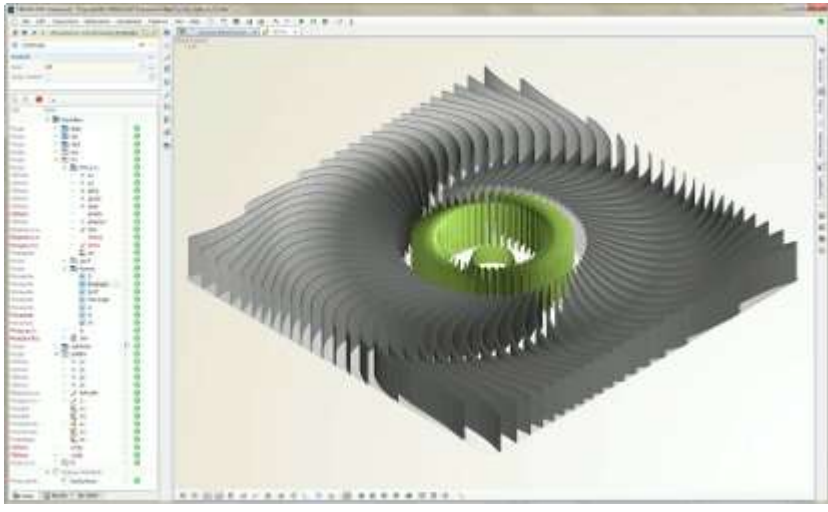
Users define their own high level objects, exported shapes are always named the same

Parameterize and model functional surfaces









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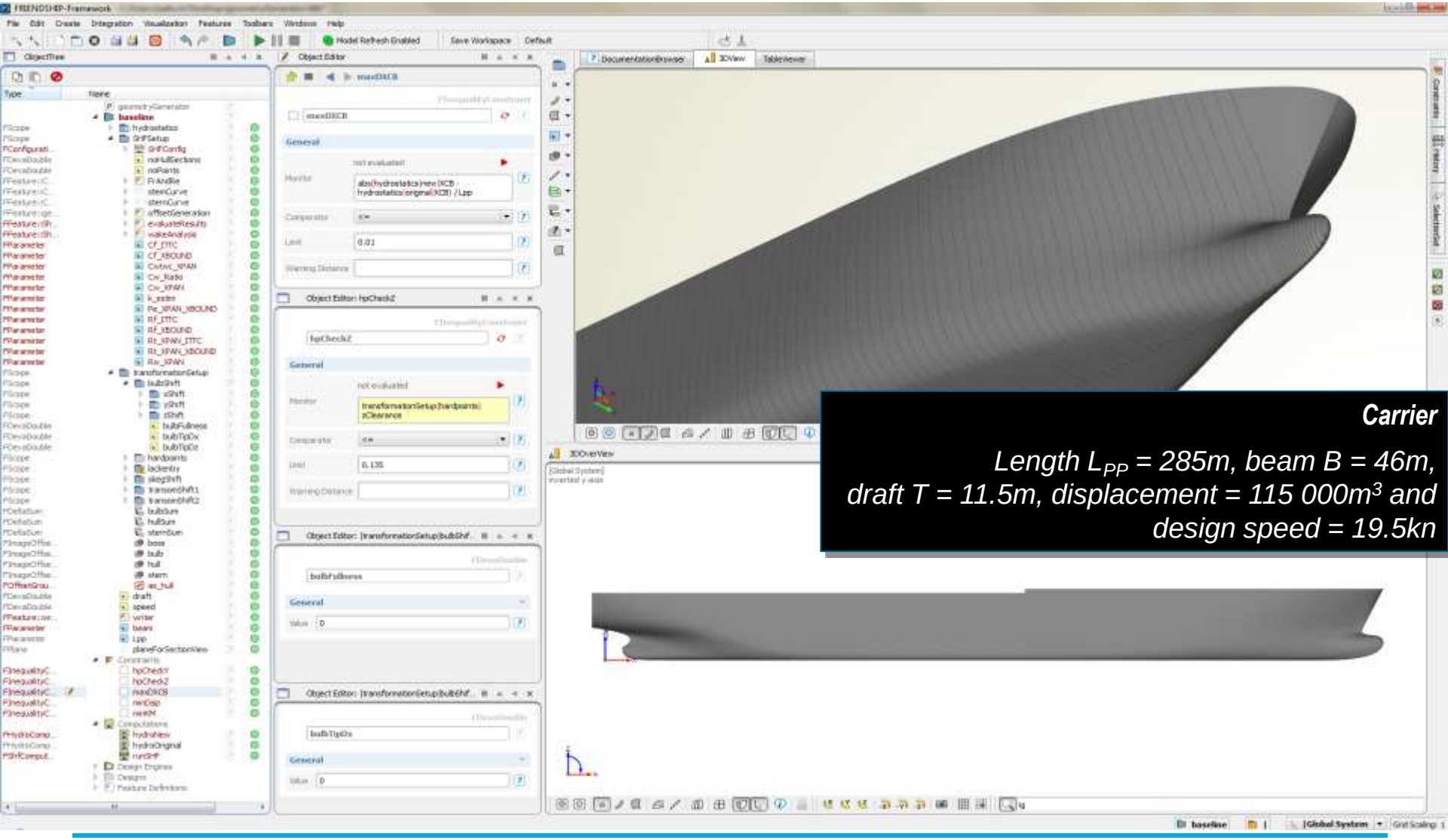
Example for robust design optimization



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Input Parameters | Bulb

bulbFullness

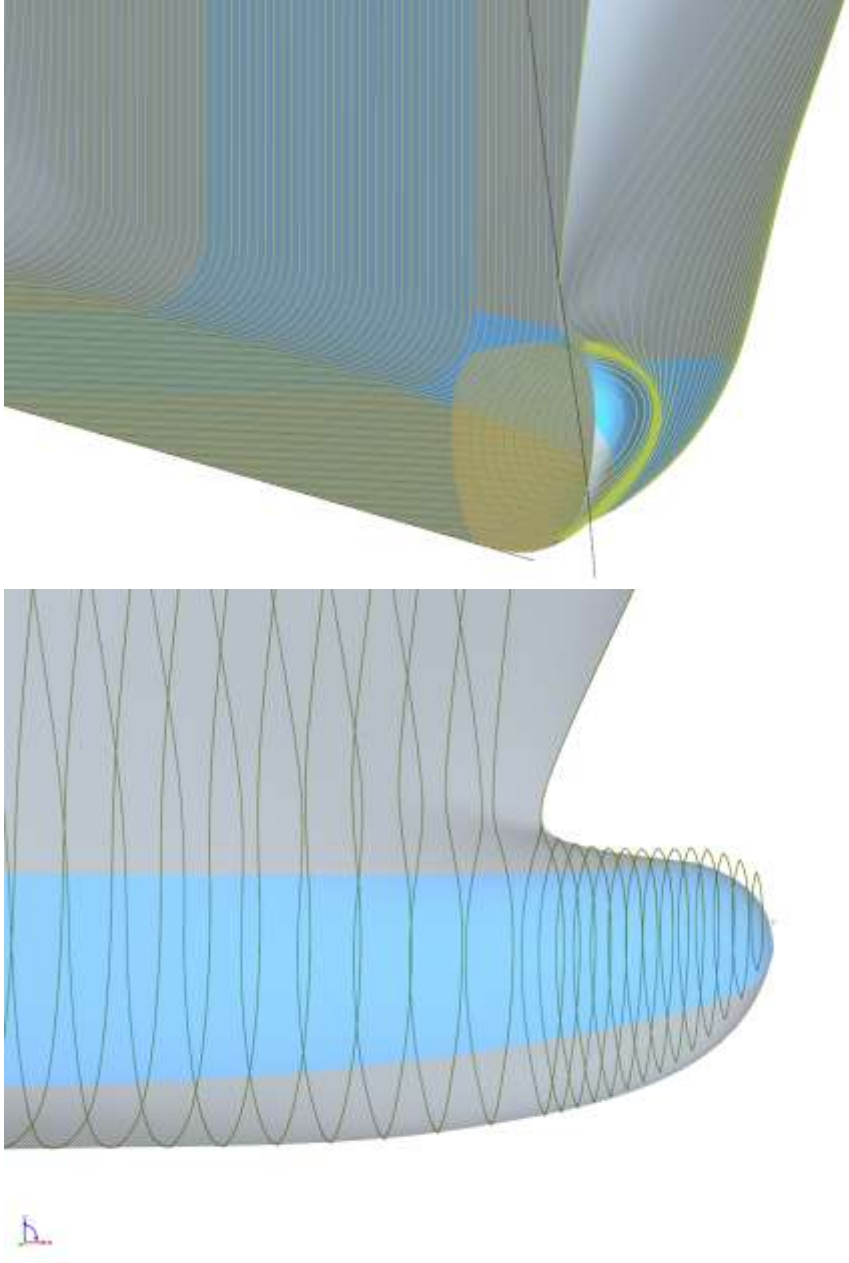
Controls the volume in the bulb

bulbTipDx

Longitudinal position of the bulb tip

bulbTipDz

Vertical position of the bulb tip



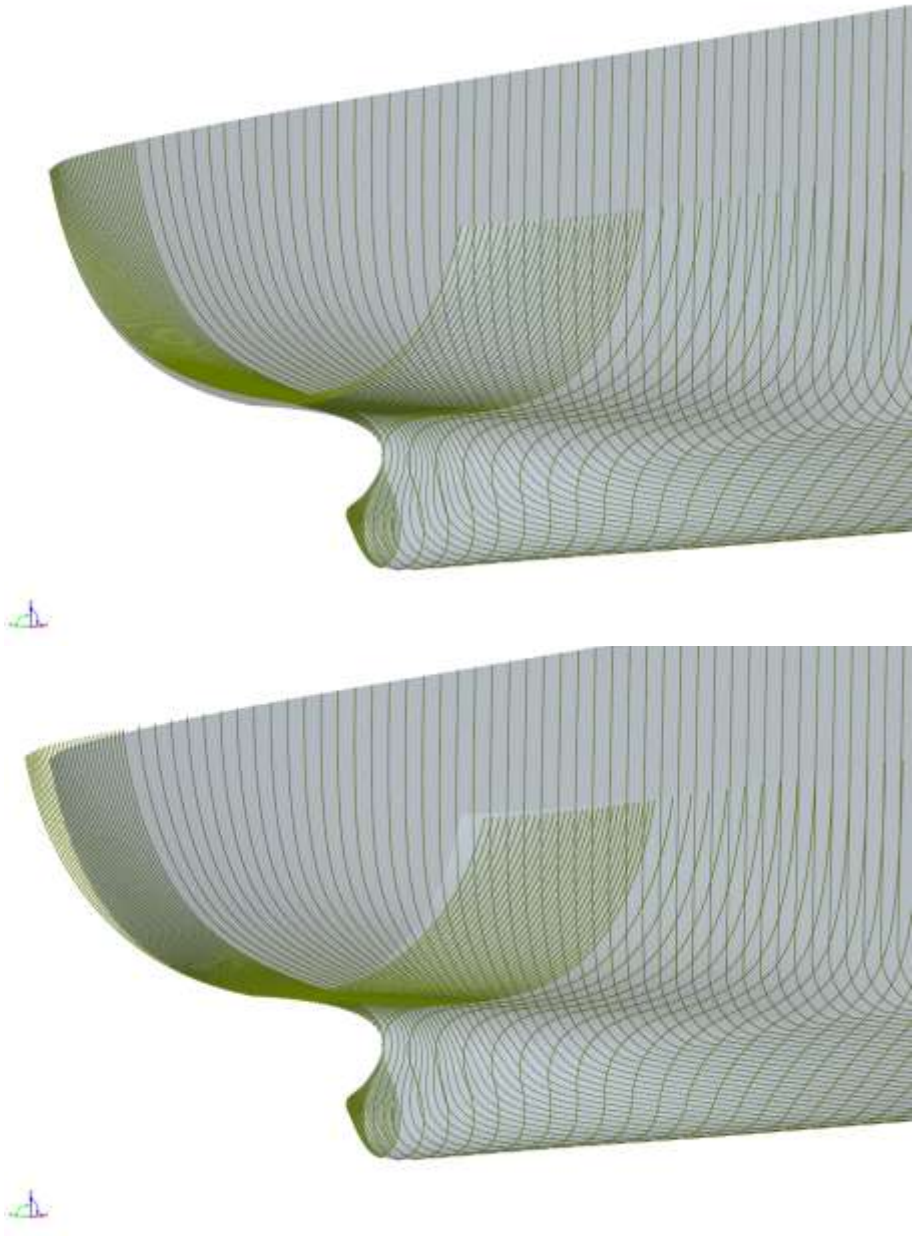
Input Parameters | Transom

transomDz

Vertical shift of the lower edge

transomDy

Width of the transom



Input Parameters | Global Displacement Shift

deltaCP

- Change of the prismatic coefficient, allows smoothly increasing or decreasing the hull's displacement

deltaXCB

- Controls the change of the longitudinal position of the hull's center of buoyancy

midTan

- Controls the middle tangent of the displacement shift function

lackenbyXMid

- Controls the longitudinal mid position of the displacement shift function (related to midTan)

Input Parameters | Skeg

dyLowMax

Maximum extension of the lower skeg transformation

dyUppMax

Maximum extension of the upper skeg transformation

xDyLowMax

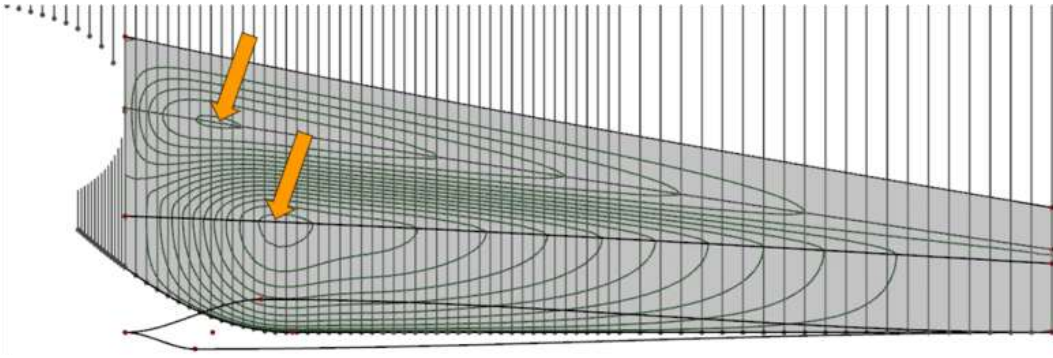
Longitudinal position of the lower maximum extension

xDyUppMax

Longitudinal position of the upper maximum extension

dvXFwd

End position of the skeg shift



Output Parameters | Objectives

CWTWC

Wave resistance coefficient from transverse wave cut, initial design: 0.227 E-03

CW

Wave resistance coefficient from pressure integration, initial design: 0.862 E-03

CF

Frictional resistance coefficient, initial design: 1.439 E-03

CFD system used here: SHIPFLOW

Integrations exist to STAR-CCM+, FINE/Turbo, OpenFOAM, ICON FOAM Pro, CFX etc.

Output Parameters | Constraints

hpCheckY

Hard point's check in y-direction

hpCheckZ

Hard point's check in z-direction

maxDXCB

Maximum percental change allowed for longitudinal position of the hull's center of buoyancy

minDISP

Minimum displacement for modified hull shape

minKM

Minimum stability value for modified hull shape

Parametric model

Takes care of further constraints implicitly, e.g. operational and production aspects

Output Parameters | Objective function

$$p(f_i(x_1, x_2, \ldots x_{14})) = \sum_{i=1}^{2} W_i \frac{f_i(\mathbf{x})}{\Gamma_i}$$

$$Rt = (1.0 \cdot CWTWC + 1.2 \cdot CF) \left(0.5 \cdot dens \left(Re \frac{visc}{Lpp} \right)^2 Sref \cdot Lpp^2 \right)$$

Sref

Wetted surface at zero speed

Dens

Water density

Visc

Water kinematic viscosity

Lpp

Length between perpendiculars

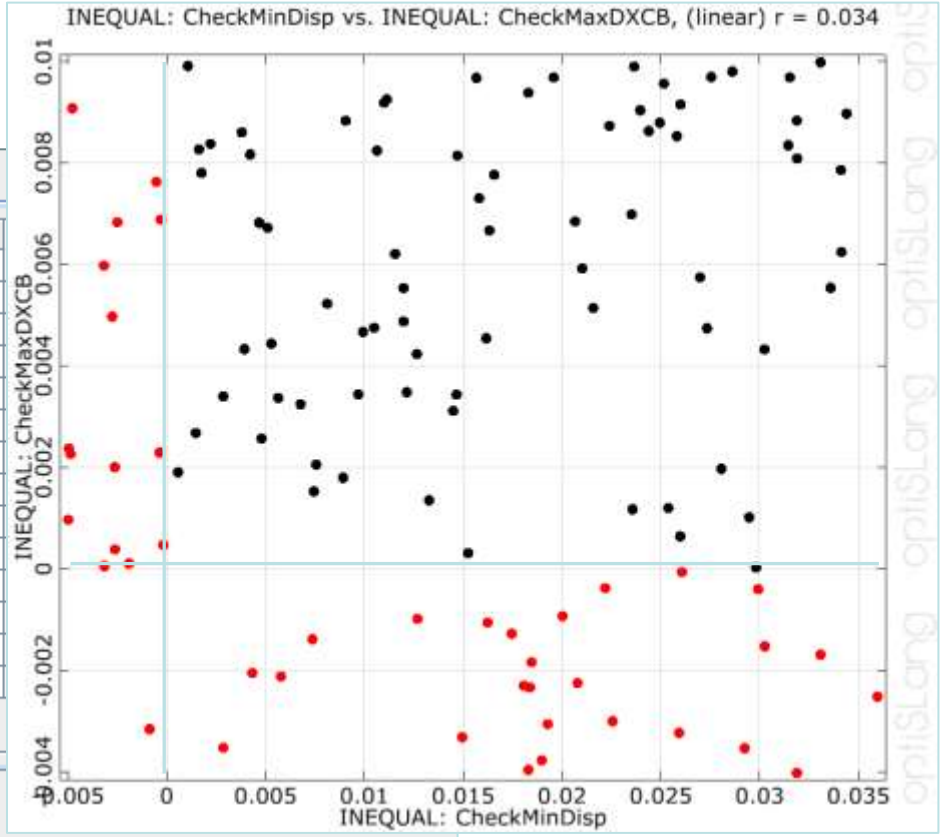
Re

Reynolds number

Sensitivity analysis I

Opti | Robust | Output | Strings | Constraints | Objectives

#	Name	Value	Ref.Value	Lower Bound	Upper Bound
1	bulbFullness	0.0000	0.0000	-0.5	2.5
2	bulbTipDx	0.0000	0.0000	-1.0	1.0
3	bulbTipDz	0.0000	0.0000	-1.0	1.0
4	deltaCP	0.00000000	0.00000000	-0.01	0.02
5	deltaXCB	0.00000000	0.00000000	-0.0020	0.0080
6	midTan	0.0000	0.0000	-30.0	40.0
7	lackenbyXMid	128.970	128.970	120.0	140.0
8	transomDz	0.0000	0.0000	-1.0	0.5
9	transomDy	0.0000	0.0000	-2.0	2.0
10	dyLowMax	0.0000	0.0000	-0.5	0.5
11	dyUppMax	0.0000	0.0000	-0.5	0.5
12	xDyLowMax	13.000	13.000	11.0	20.0
13	xDyUppMax	12.000	12.000	11.0	20.0
14	dvXFwd	40.000	40.000	35.0	50.0



- **Defined design (optimization) parameters $n_D = 14$ and responses (output)**
- **Given reference values**
- **Lower and upper bounds to define the box constrains used within optimization**

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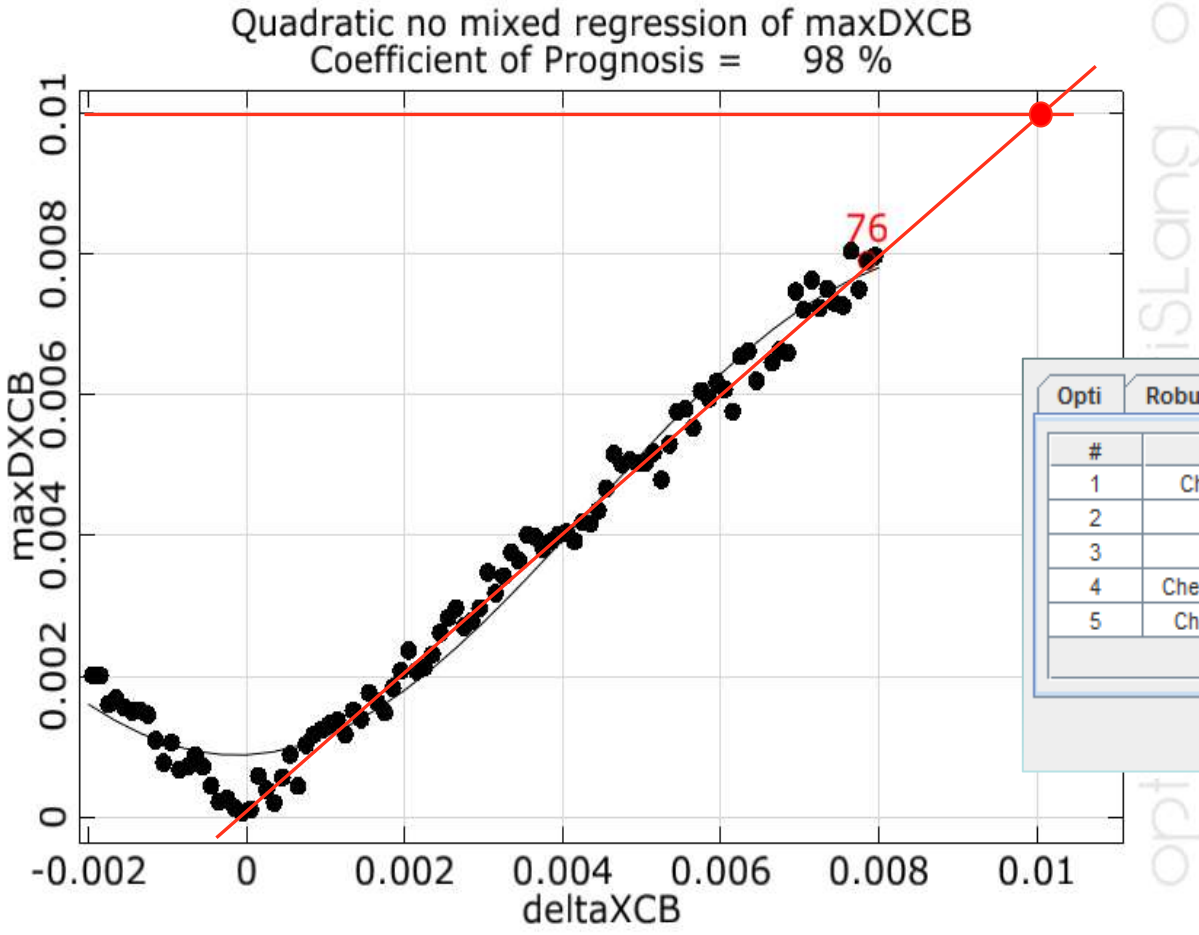
Sensitivity Analysis II

- **Extrapolation of the design parameters to make accessible optimization potential**



Opti | Robust | Output | Strings | **Constraints** | Objectives

#	Name	Type	Formula	Active
1	CheckMinKM	inequality	minKM-0.98	✔
2	CheckZ	inequality	0.135-hpCheckZ	✔
3	CheckY	inequality	hpCheckY+0.405	✔
4	CheckMaxDXCB	inequality	0.01-maxDXCB	✔
5	CheckMinDisp	inequality	minDISP-0.985	✔

Cancel OK

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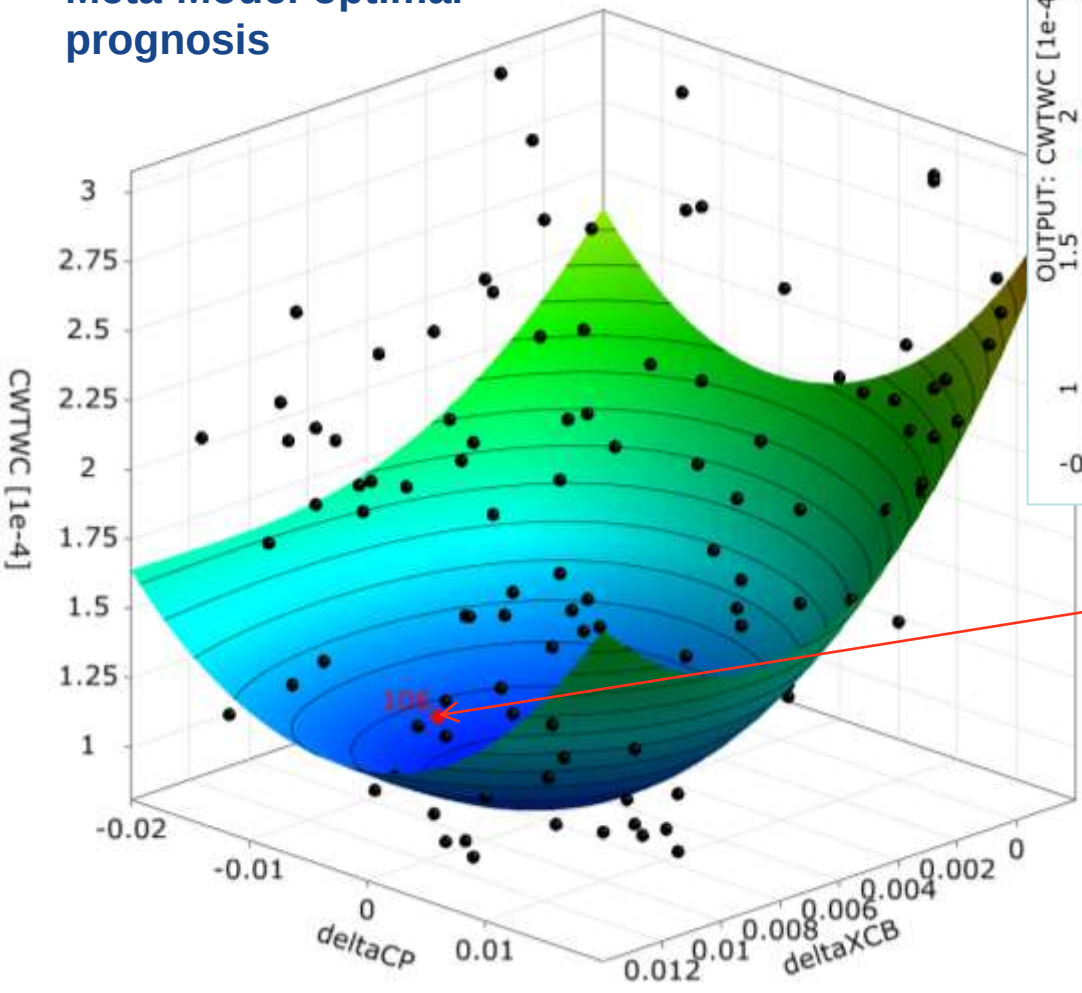
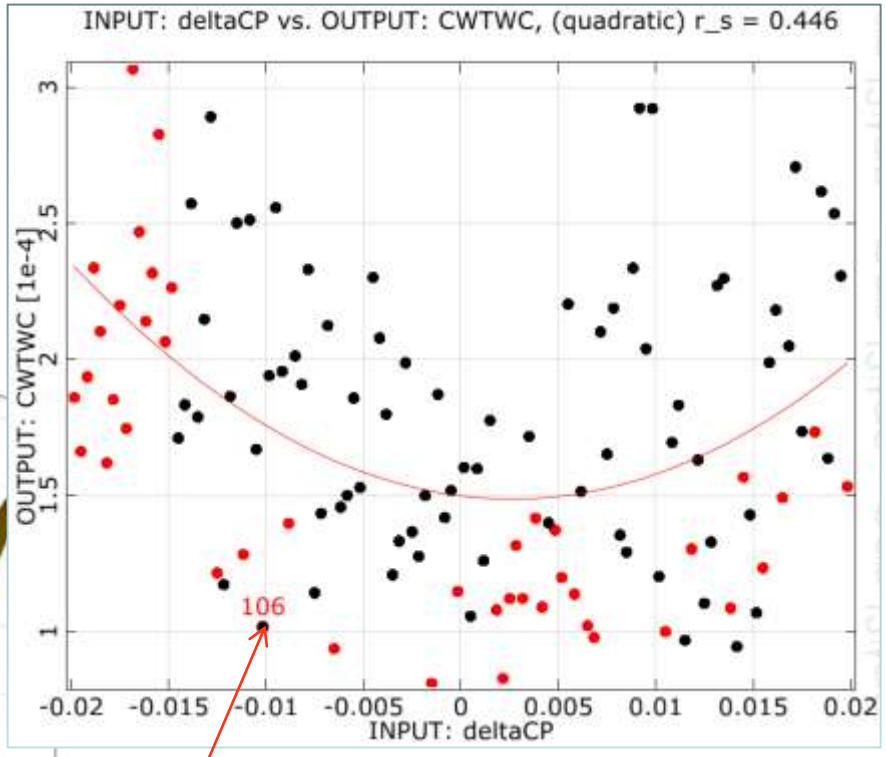
Response: CWTWC

Meta-Model optimal prognosis





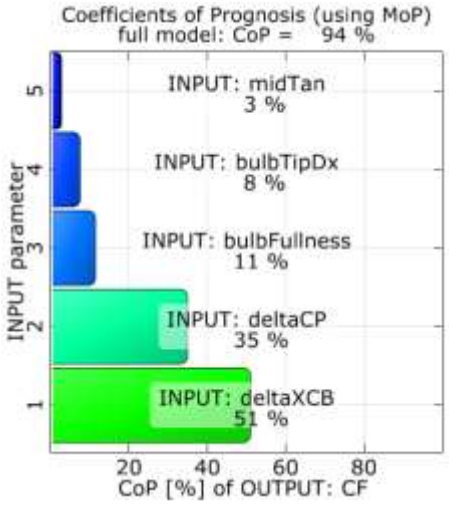
Best design within the latin hypercube sampling

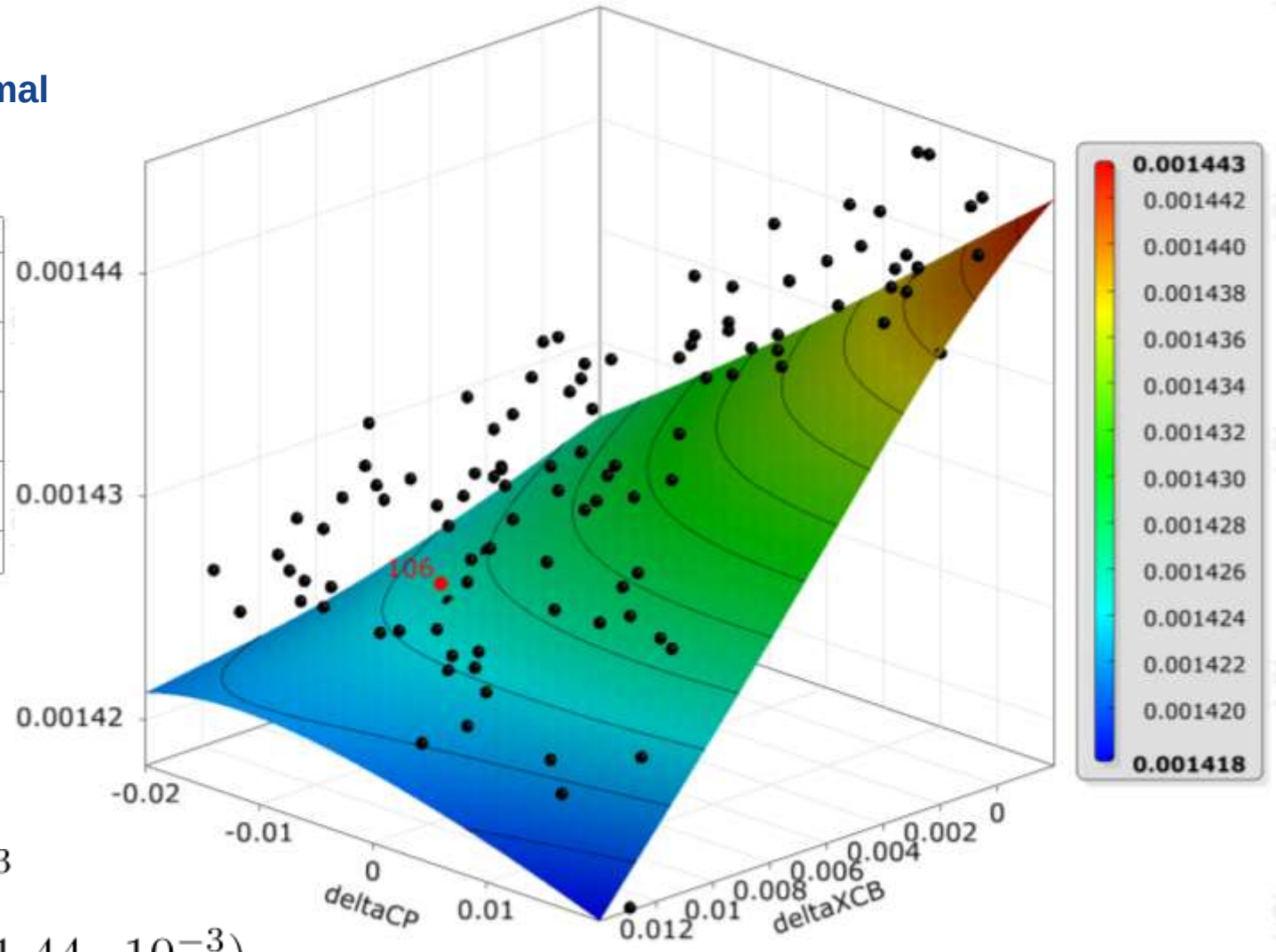
$$CWTWC = 1.02 \cdot 10^{-4}$$

$$\rightarrow (45\% \text{ of } 2.27 \cdot 10^{-4})$$

Response: CF

Meta-Model optimal prognosis





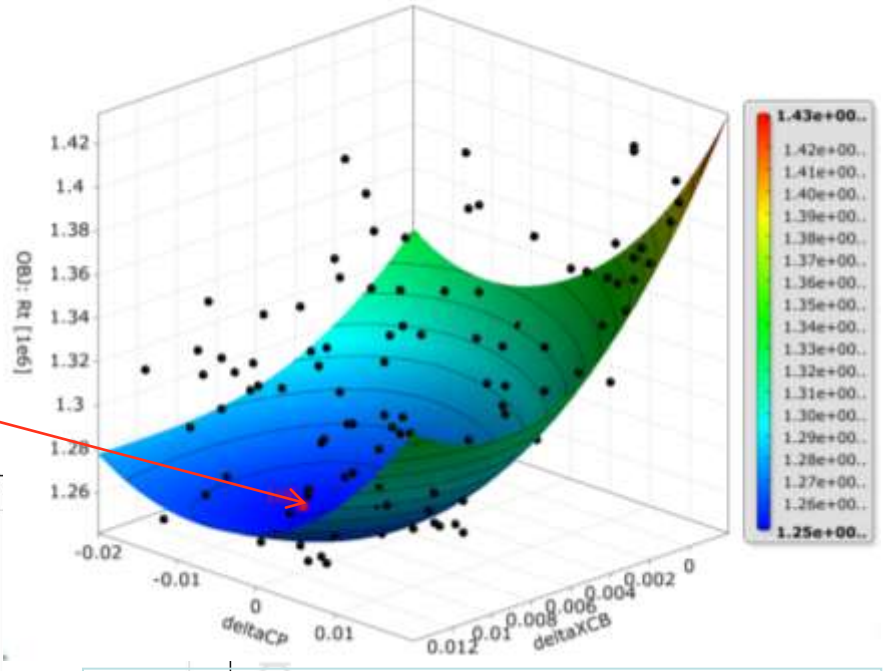
$$CF = 1.43 \cdot 10^{-3}$$

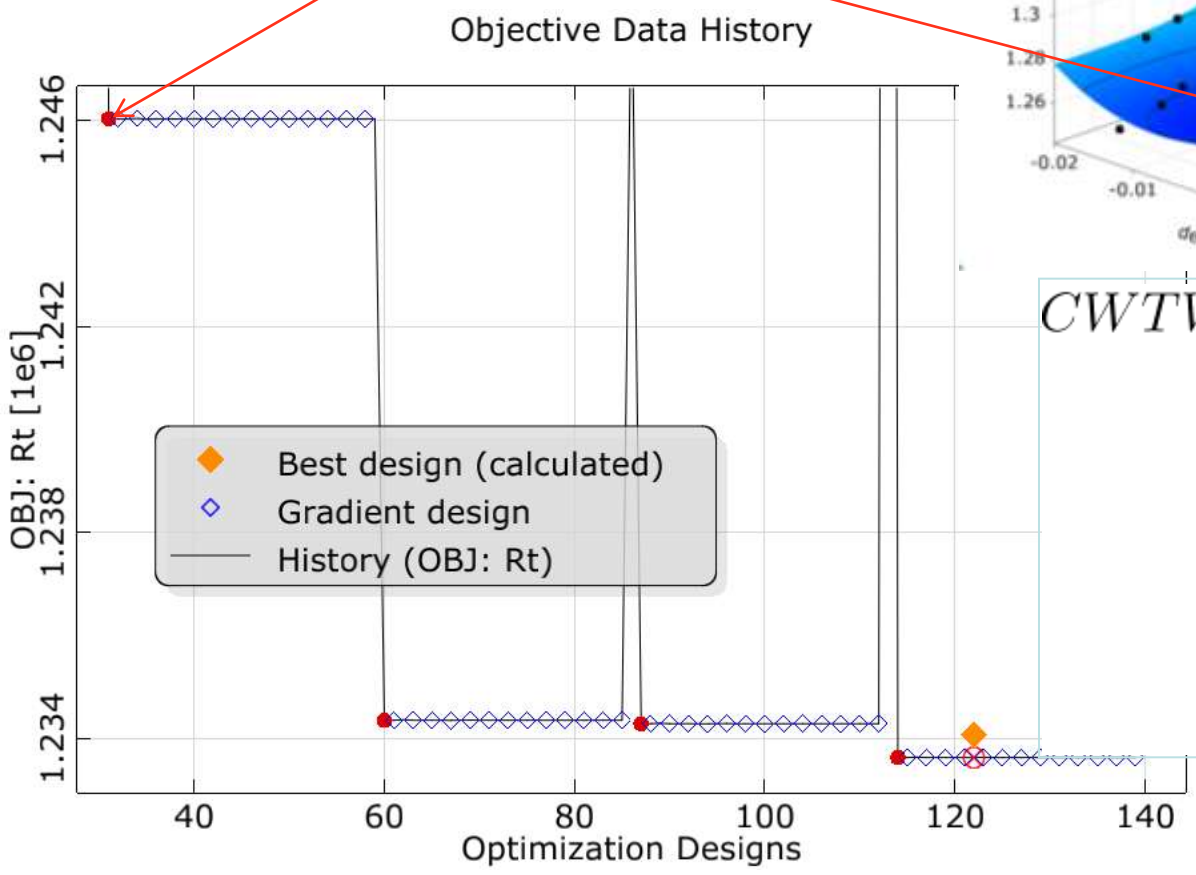
$$\rightarrow (99\% \text{ of } 1.44 \cdot 10^{-3})$$

Nonlinear Optimization

Gradient-based on surrogate model

objective $Rt = 1.246 \cdot 10^6$





$$CWTWC = 7.64 \cdot 10^{-5} \quad \text{(MoP)}$$
$$= 7.66 \cdot 10^{-5} \quad \text{(calc)}$$
$$\rightarrow (34\% \text{ of } 2.27 \cdot 10^{-4})$$
$$CF = 1.42 \cdot 10^{-3} \quad \text{(MoP)}$$
$$= 1.42 \cdot 10^{-3} \quad \text{(calc)}$$
$$\rightarrow (98\% \text{ of } 1.44 \cdot 10^{-3})$$

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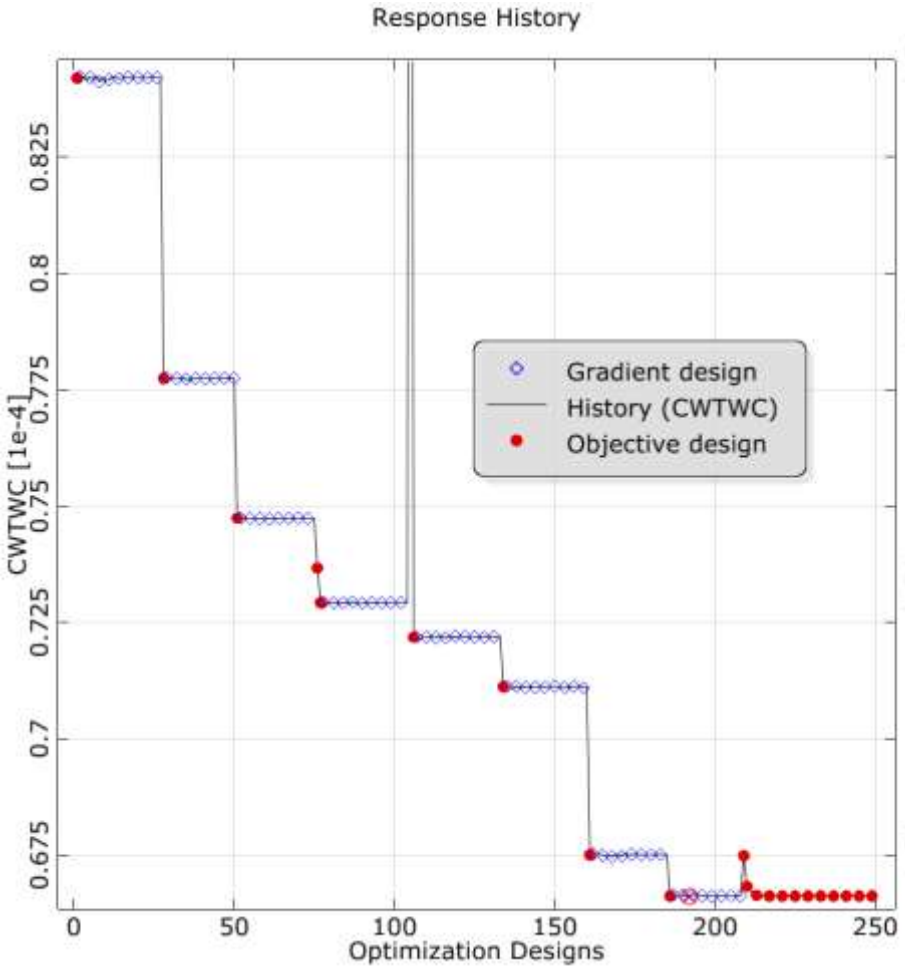
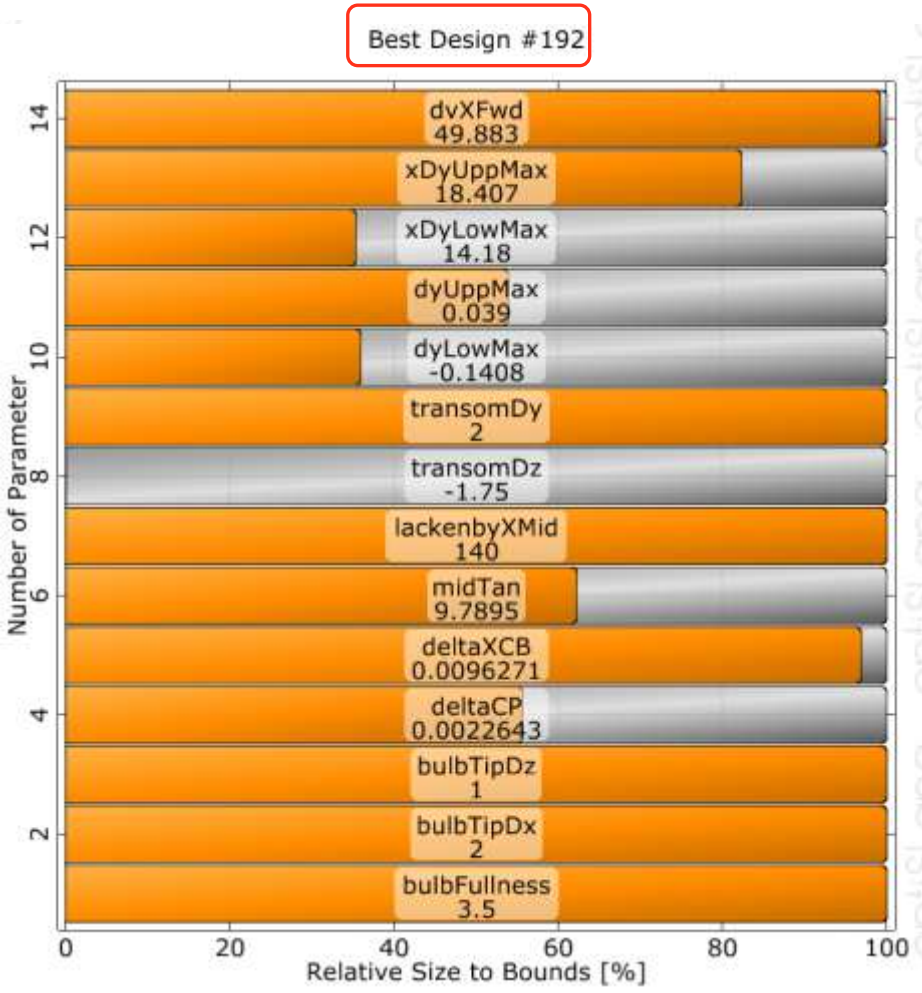
Nonlinear Optimization

Gradient-based optimization (SQP)





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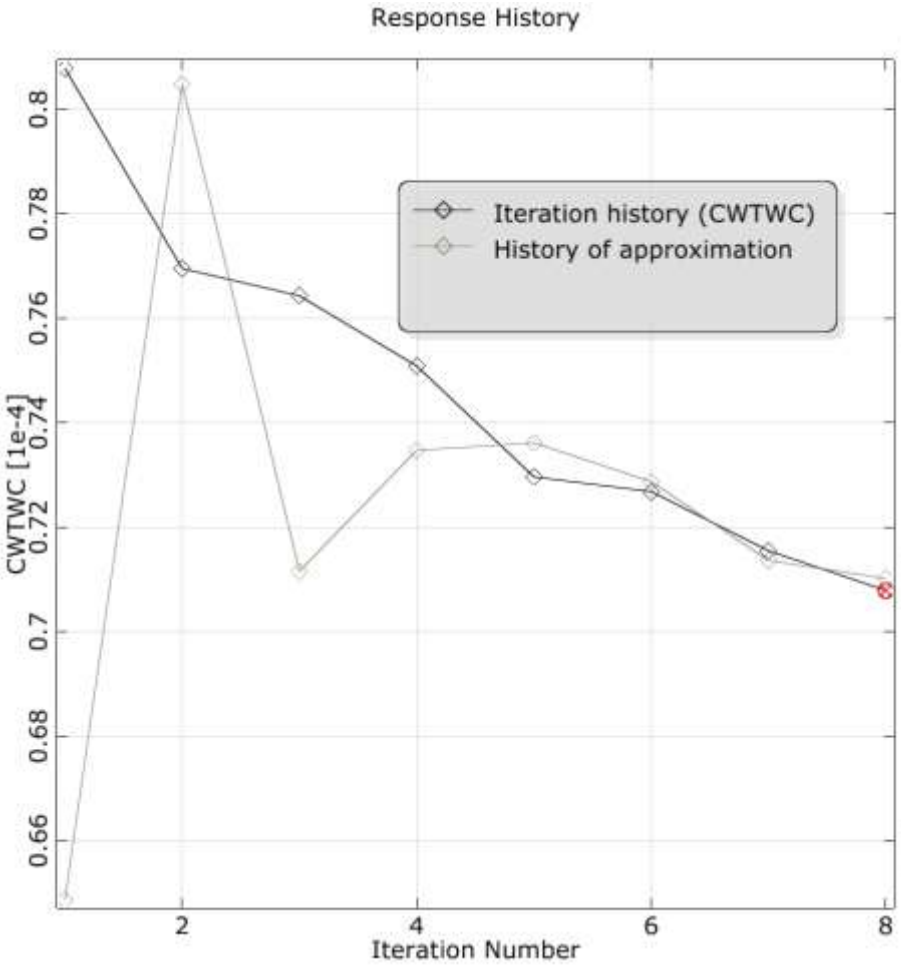
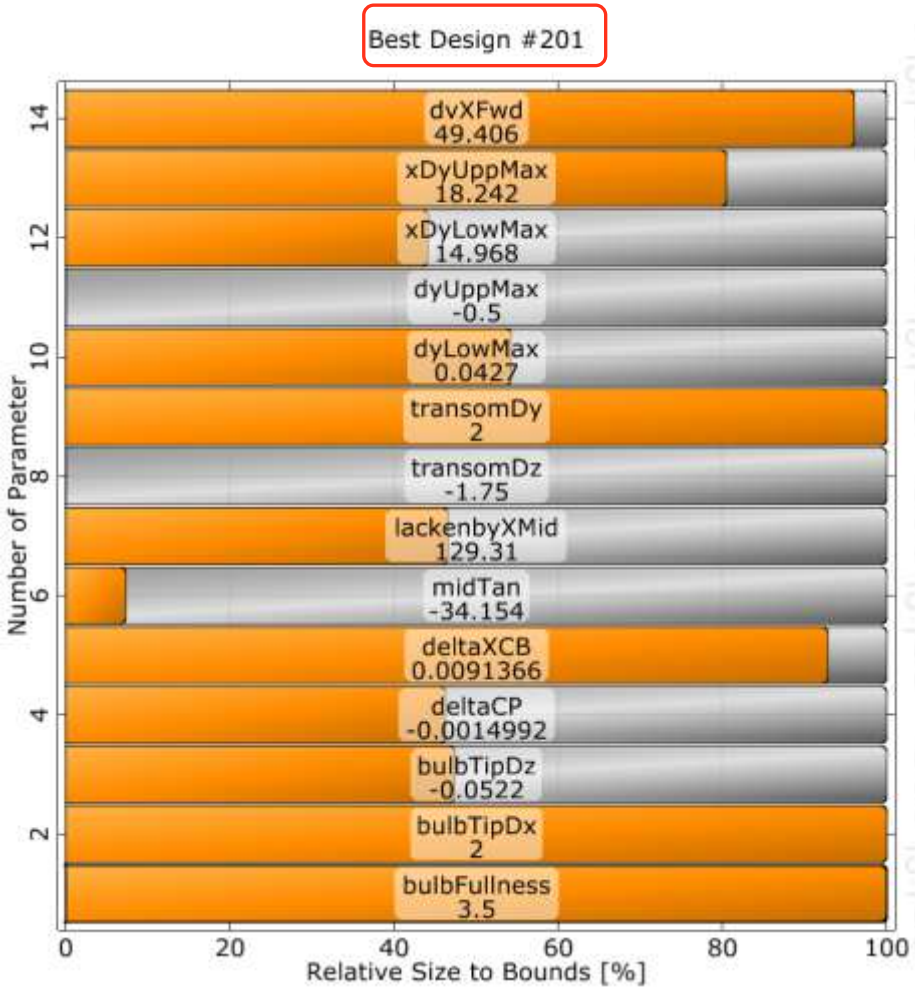
Nonlinear Optimization

Adaptive response surface (ARSM)





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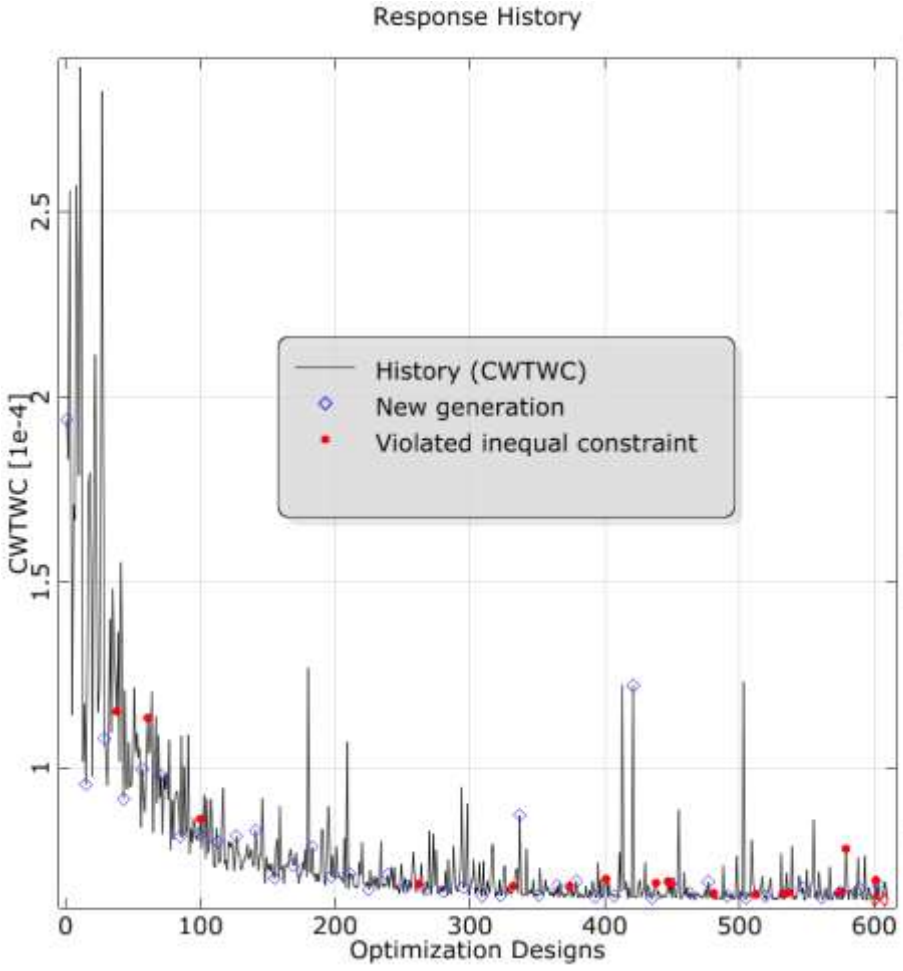
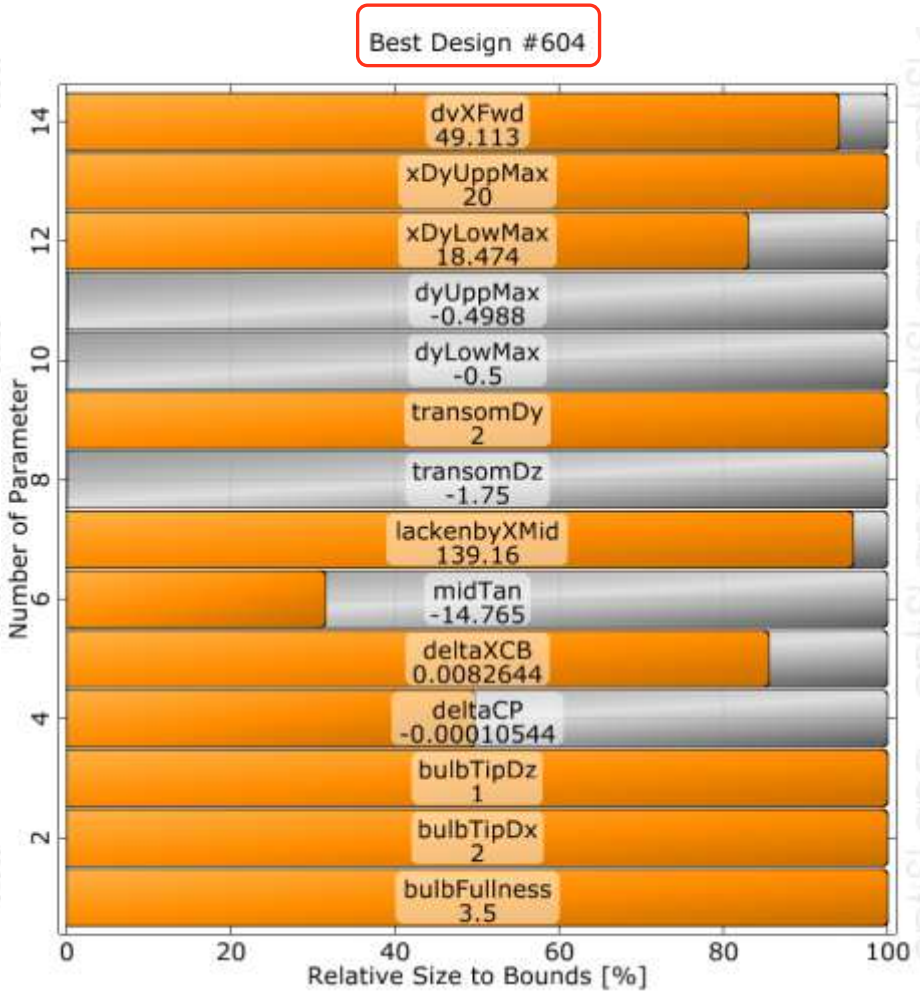
Nonlinear Optimization

Evolutionary algorithm





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Nonlinear Optimization
Summary

	Start	SA	MoP	SQP	ARSM	EA
CWTWC	$2.27 \cdot 10^{-4}$	$1.02 \cdot 10^{-4}$	$7.66 \cdot 10^{-5}$	$6.66 \cdot 10^{-5}$	$7.08 \cdot 10^{-5}$	$6.43 \cdot 10^{-5}$
	100%	45%	34%	29%	31%	28%
CF	$1.44 \cdot 10^{-3}$	$1.43 \cdot 10^{-3}$	$1.42 \cdot 10^{-3}$	$1.42 \cdot 10^{-3}$	$1.42 \cdot 10^{-3}$	$1.42 \cdot 10^{-3}$
	100%	99%	98%	98%	98%	98%
Design Evaluations	-	312 Total:	1 505	192	201	604

Design improvement considering uncertainties?

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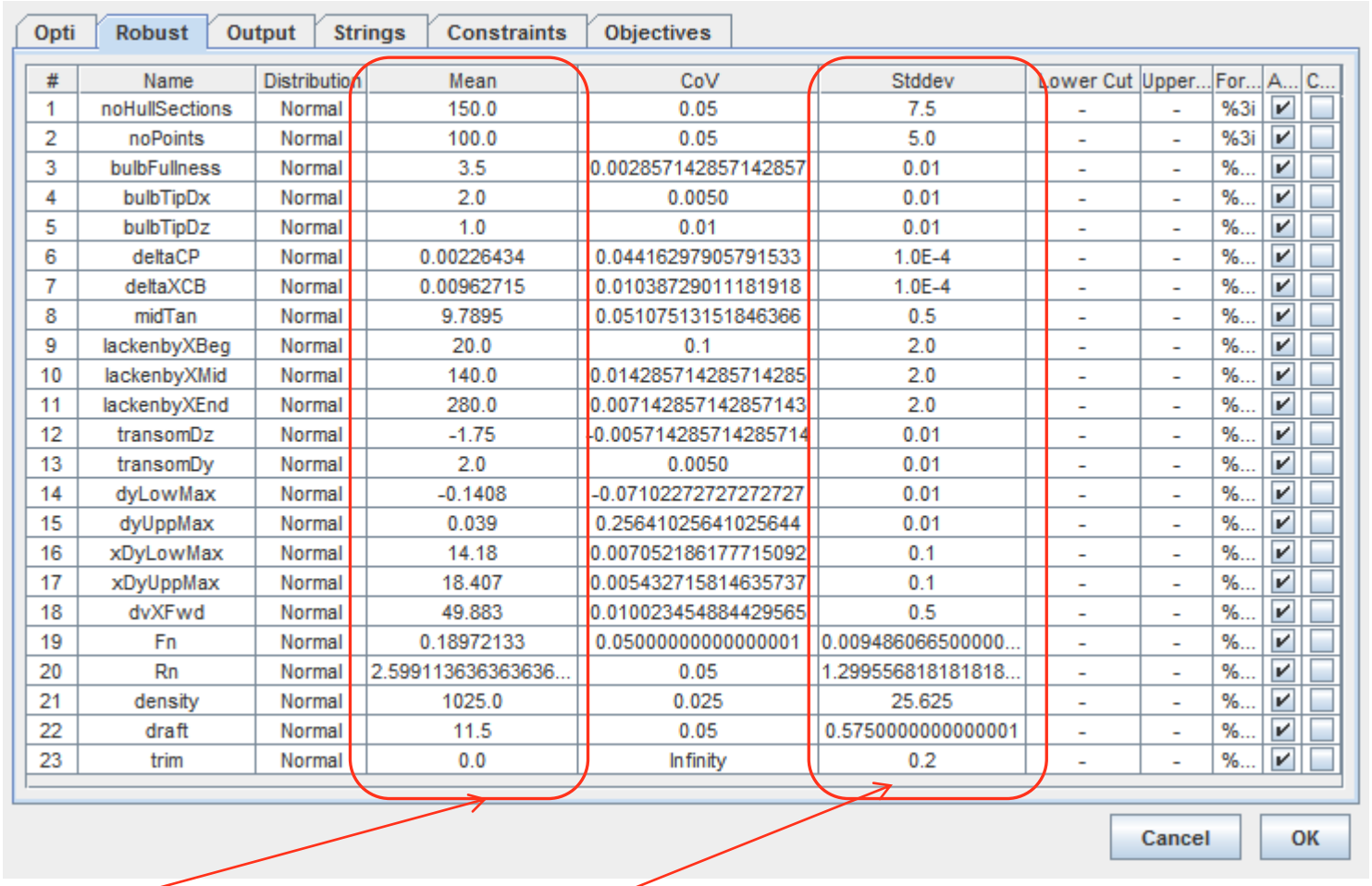
Robustness evaluation



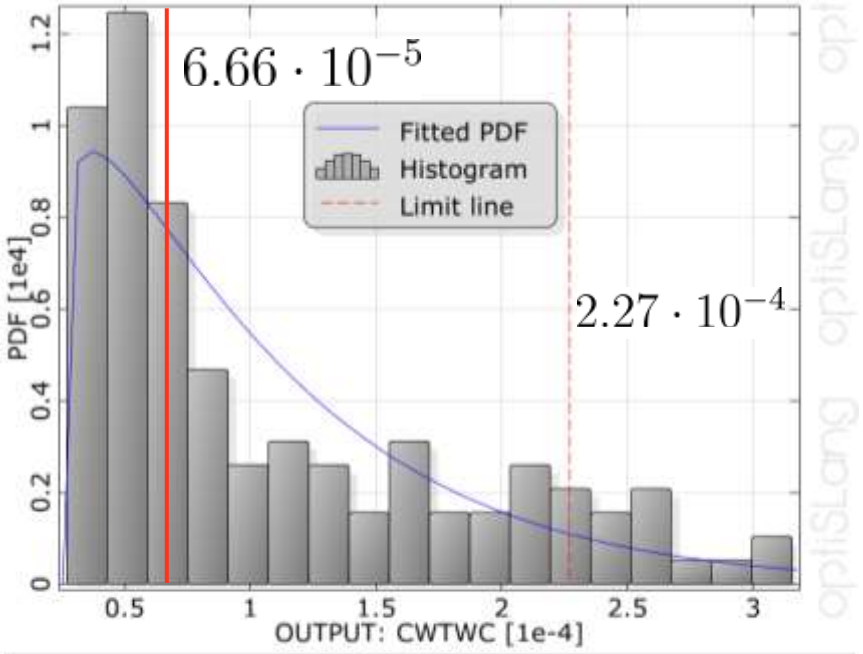
Opti | Robust | Output | Strings | Constraints | Objectives

#	Name	Distribution	Mean	CoV	Stddev	Lower Cut	Upper...	For...	A...	C...
1	noHullSections	Normal	150.0	0.05	7.5	-	-	%3i	✔	
2	noPoints	Normal	100.0	0.05	5.0	-	-	%3i	✔	
3	bulbFullness	Normal	3.5	0.002857142857142857	0.01	-	-	%...	✔	
4	bulbTipDx	Normal	2.0	0.0050	0.01	-	-	%...	✔	
5	bulbTipDz	Normal	1.0	0.01	0.01	-	-	%...	✔	
6	deltaCP	Normal	0.00226434	0.04416297905791533	1.0E-4	-	-	%...	✔	
7	deltaXCB	Normal	0.00962715	0.010387290111819 18	1.0E-4	-	-	%...	✔	
8	midTan	Normal	9.7895	0.05107513151846366	0.5	-	-	%...	✔	
9	lackenbyXBeg	Normal	20.0	0.1	2.0	-	-	%...	✔	
10	lackenbyXMid	Normal	140.0	0.014285714285714285	2.0	-	-	%...	✔	
11	lackenbyXEnd	Normal	280.0	0.007142857142857143	2.0	-	-	%...	✔	
12	transomDz	Normal	-1.75	-0.005714285714285714	0.01	-	-	%...	✔	
13	transomDy	Normal	2.0	0.0050	0.01	-	-	%...	✔	
14	dyLowMax	Normal	-0.1408	-0.07102727272727727	0.01	-	-	%...	✔	
15	dyUppMax	Normal	0.039	0.25641025641025644	0.01	-	-	%...	✔	
16	xDyLowMax	Normal	14.18	0.007052186177715092	0.1	-	-	%...	✔	
17	xDyUppMax	Normal	18.407	0.005432715814635737	0.1	-	-	%...	✔	
18	dvXFwd	Normal	49.883	0.010023454884429565	0.5	-	-	%...	✔	
19	Fn	Normal	0.18972133	0.05000000000000001	0.009486066500000...	-	-	%...	✔	
20	Rn	Normal	2.599113636363636...	0.05	1.299556818181818...	-	-	%...	✔	
21	density	Normal	1025.0	0.025	25.625	-	-	%...	✔	
22	draft	Normal	11.5	0.05	0.5750000000000001	-	-	%...	✔	
23	trim	Normal	0.0	Infinity	0.2	-	-	%...	✔	

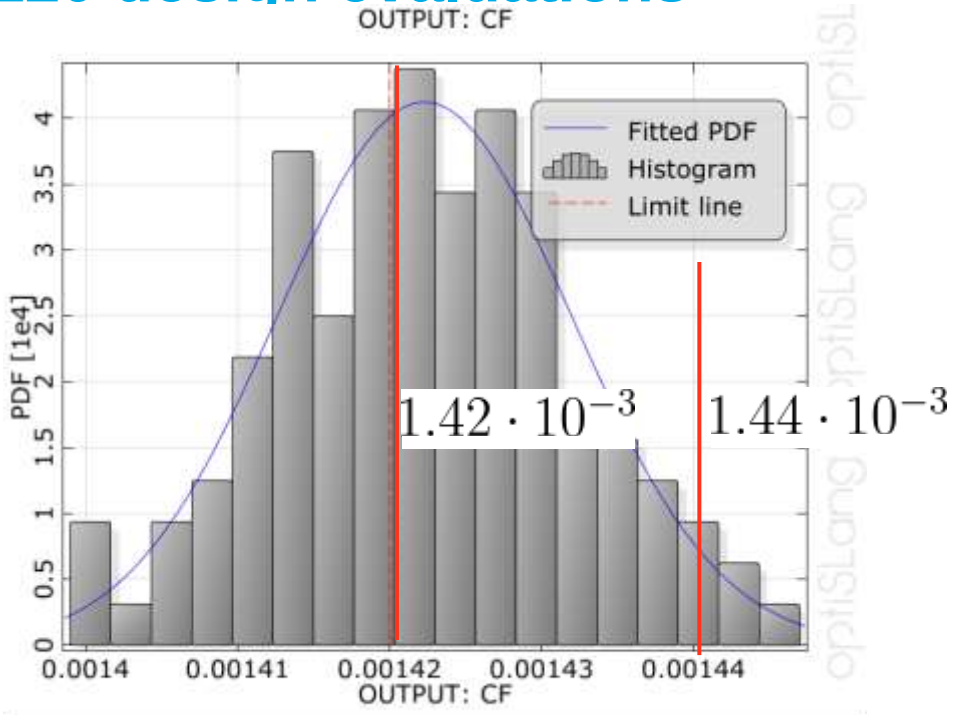
Cancel OK

Mean and modified standard deviation of the best design as result of the gradient-based optimization

Robustness evaluation with 120 design evaluations



Statistic data			
Min:	2.708e-005	Max:	0.0003155
Mean:	0.0001095	Sigma:	7.5e-005
CV:	0.6848		
Skewness:	0.986	Kurtosis:	2.757
Fitted PDF: Extreme Typ III (Max) Weibull			
Mean:	0.0001095	Sigma:	7.5e-005
Lower cut:	2.708e-005		
Limit x = 0.000227			
P_rel =	0.891667	P_fit =	0.921784
Probability P(X<x) = 0.95			
x_rel =	0.000265817	x_fit =	0.000258658



Statistic data			
Min:	0.001399	Max:	0.001447
Mean:	0.001422	Sigma:	9.671e-006
CV:	0.006799		
Skewness:	-0.02388	Kurtosis:	2.831
Fitted PDF: Normal			
Mean:	0.001422	Sigma:	9.671e-006
Limit x = 0.00142			
P_rel =	0.425	P_fit =	0.405673
Probability P(X<x) = 0.95			
x_rel =	0.00144	x_fit =	0.00143822

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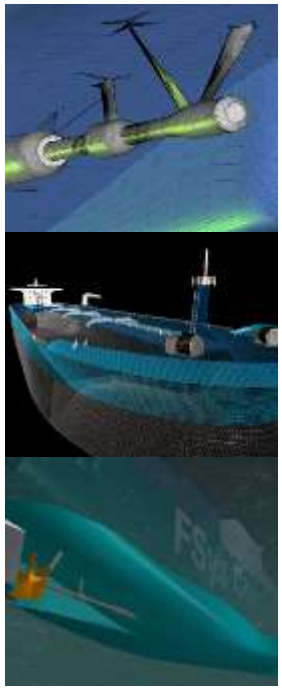
Institute of Modeling and High-Performance Computing

Thank you very much for your attention



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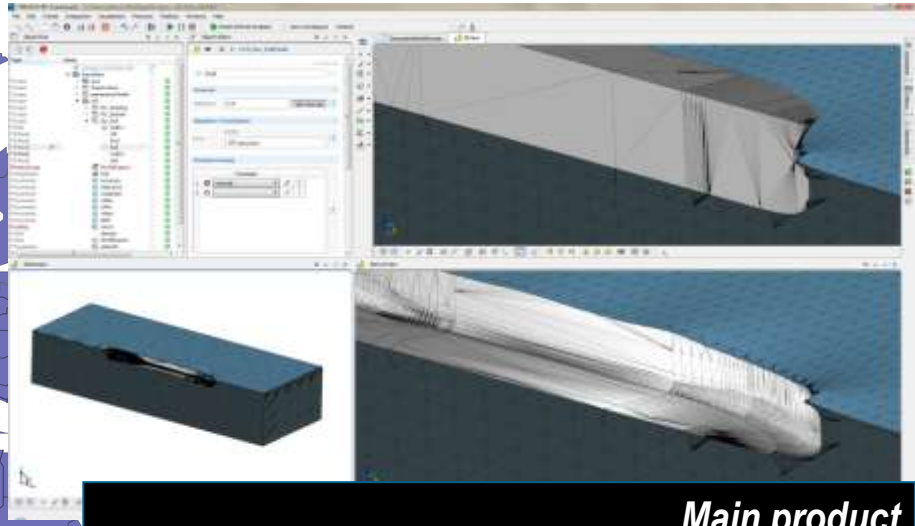

Main product

The FRIENDSHIP-Framework –
Software for simulation-driven design

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