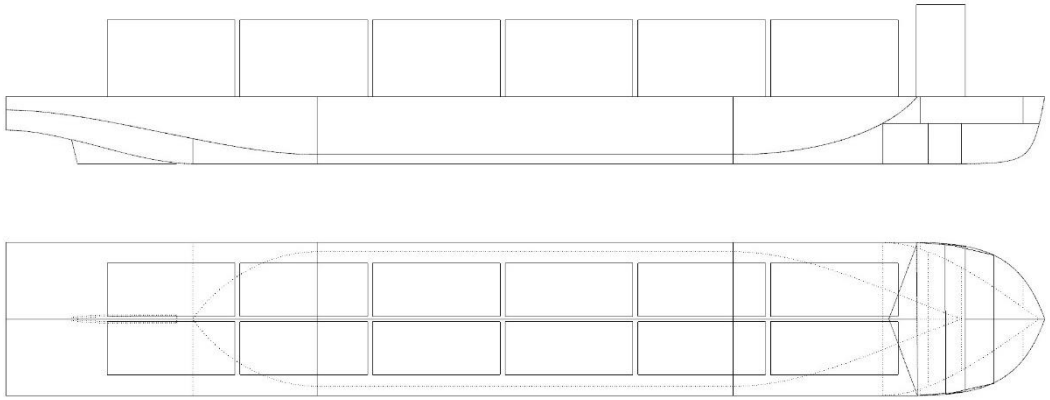
Multi-objective optimisation of a multi-purpose heavy cargo ship

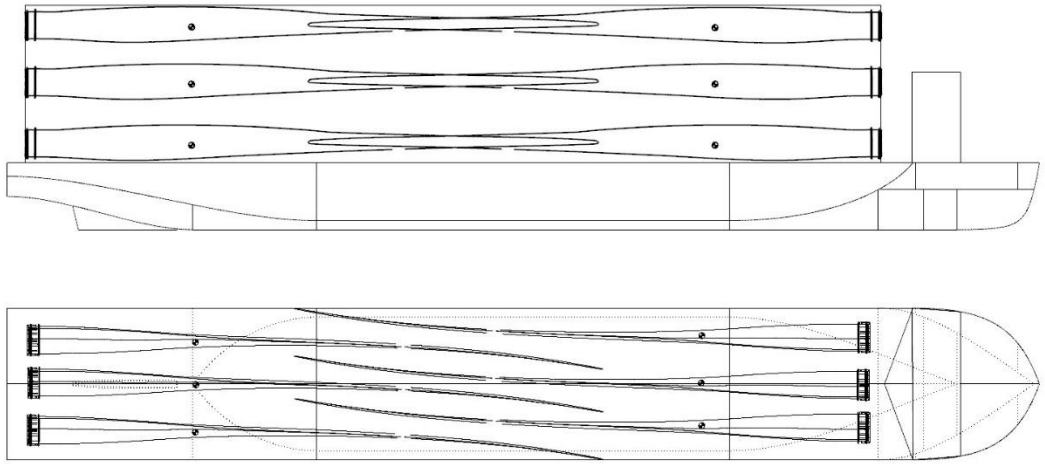
Anna-Sophia Büscher | TU Berlin | CAESES User Conference | 11.September 2024

Multi-purpose deck-carrier



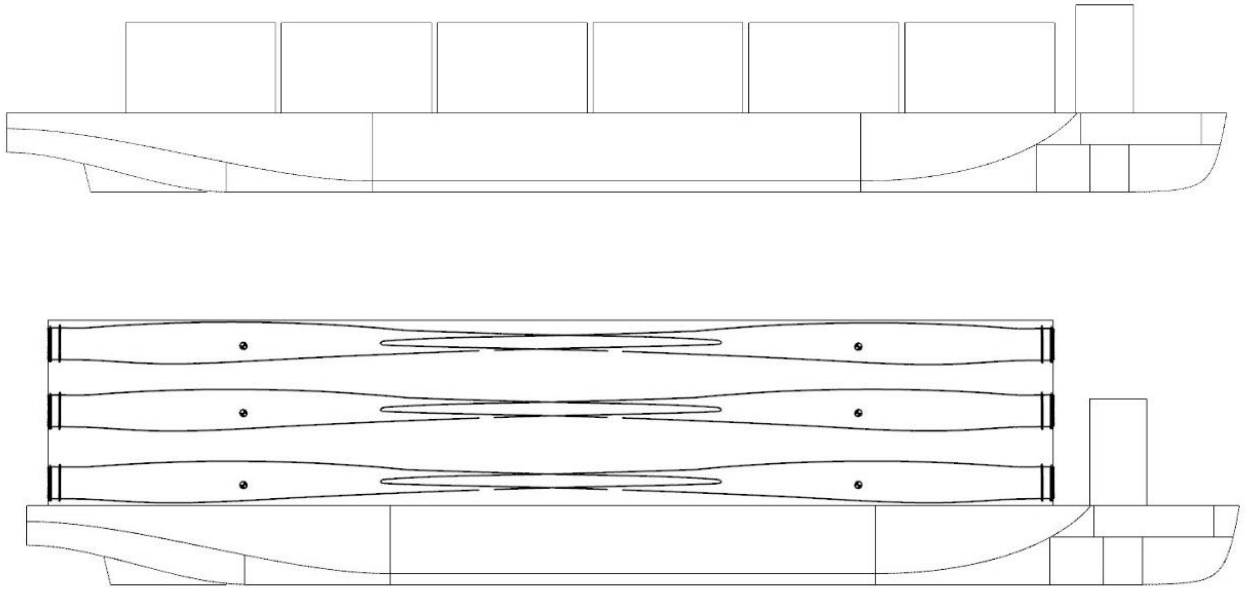
Lenght over all	165 m
Beam	26 m
Draught	5,1 m/6,1 m
Depth	11.3 m
Lightship weight	8000 t
Design Speed	15 kn

	Blades	Nacelles
Length	100 m	20.9 m
Height	7.0 m	12.5 m
Width	4.5 m	8.7 m
Weight	100 t	750 t
Weight total	1800 t	9000 t

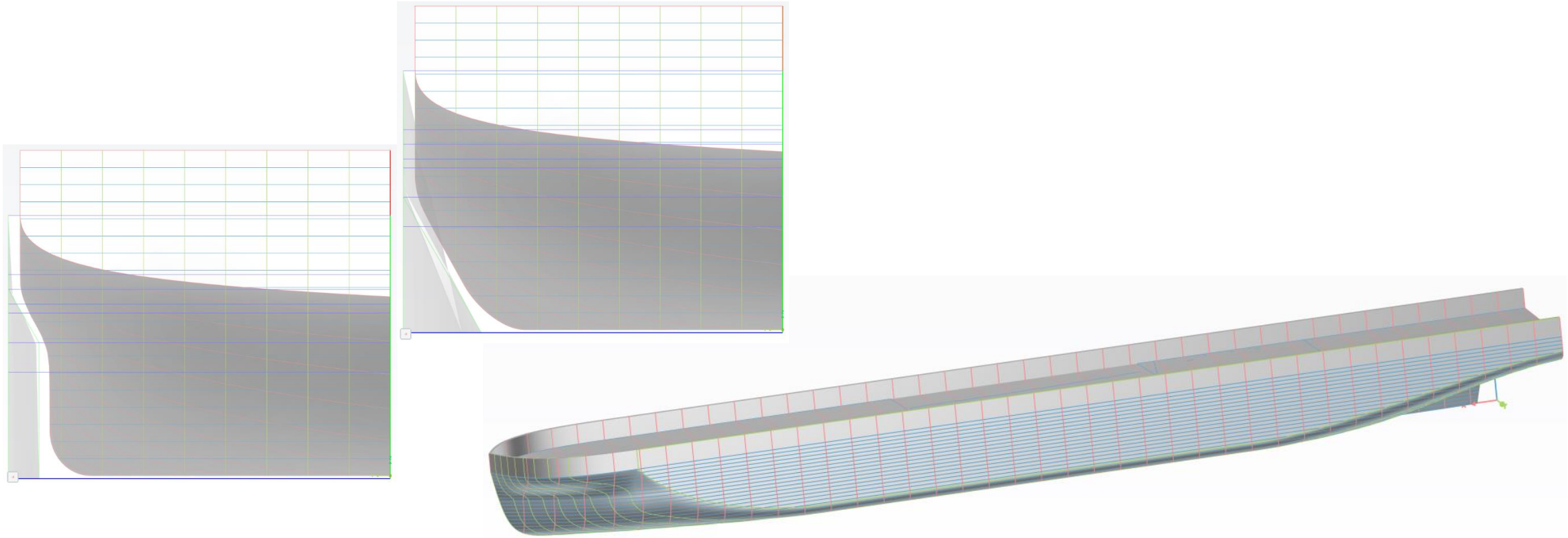


Optimisation Problem

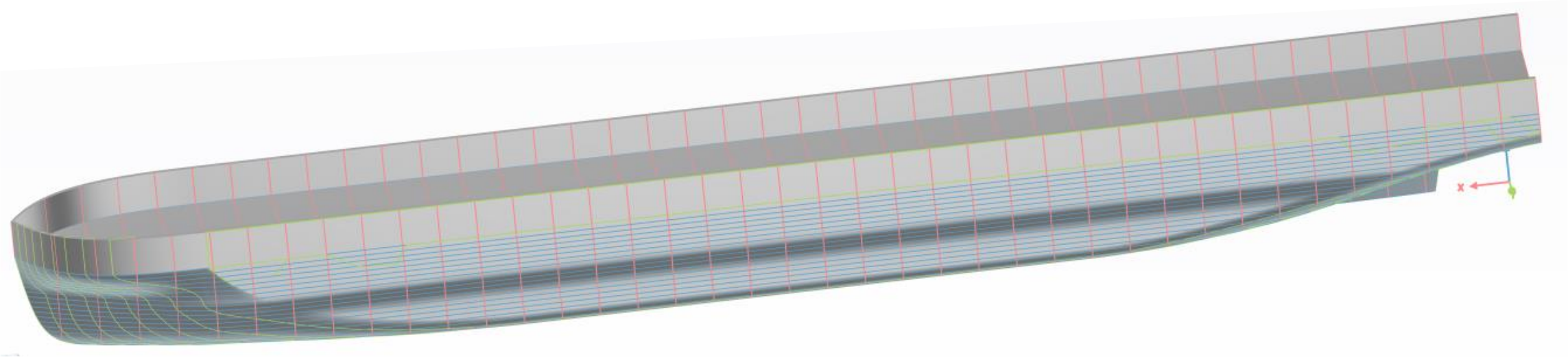
- More stability for nacelles
- Less stability for blades
- Minimise resistance for both



Hull Adjustments: Slanted Sides + „GZ boxes“



Baseline Hull



Optimisation

- Objectives:
  - Minimise resistance
  - Optimise stability (minimise GM)
- Variables:
  - Geometry parameters
  - Ballast variables
- Constraints:
  - Intact stability criteria
  - Minimum GM for damage stability
- Algorithm:
  - NSGA-II
    - Generations: 50
    - Population: 52

Stability Features

- Intact stability critera according to IMO 2008 Code on Intact Stability

$$\int_0^{30} A(\varphi)\, d\varphi \geq 0.055 \,\text{metre-radians}$$

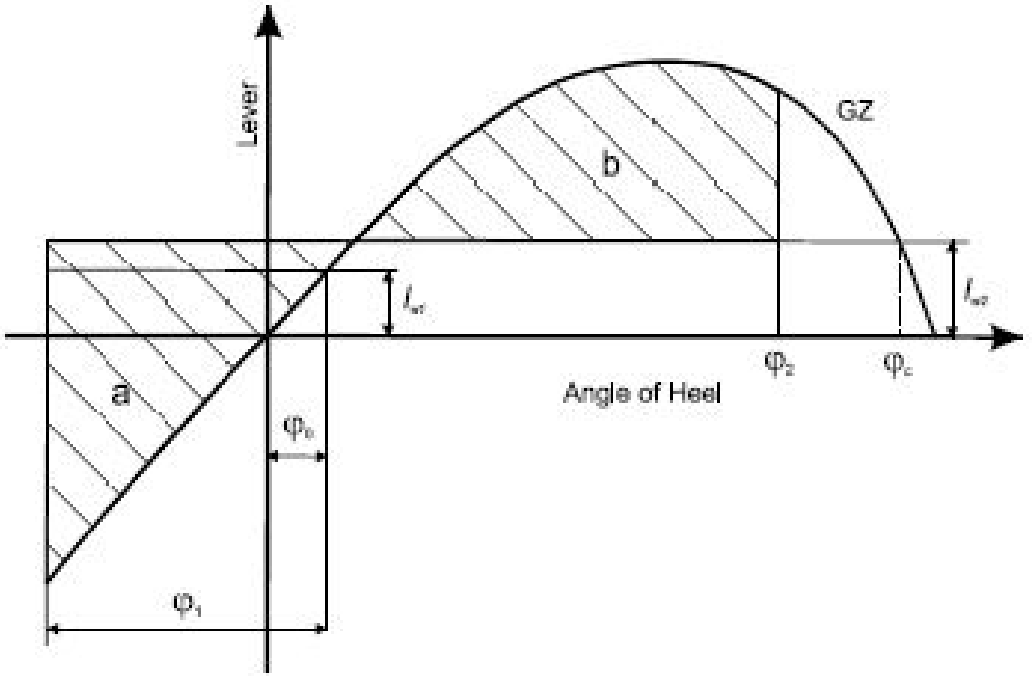
$$\int_0^{min(40,\varphi_f)} A(\varphi)\, d\varphi \geq 0.09 \,\text{metre-radians}$$

$$\int_{30}^{min(40,\varphi_f)} A(\varphi)\, d\varphi \geq 0.03 \,\text{metre-radians}$$

$$GZ \geq 0.2m \text{ for at least one } \varphi \geq 30$$

$$GZ_{max} \text{ at } \varphi \geq 25 \text{ with possible exeptions}$$

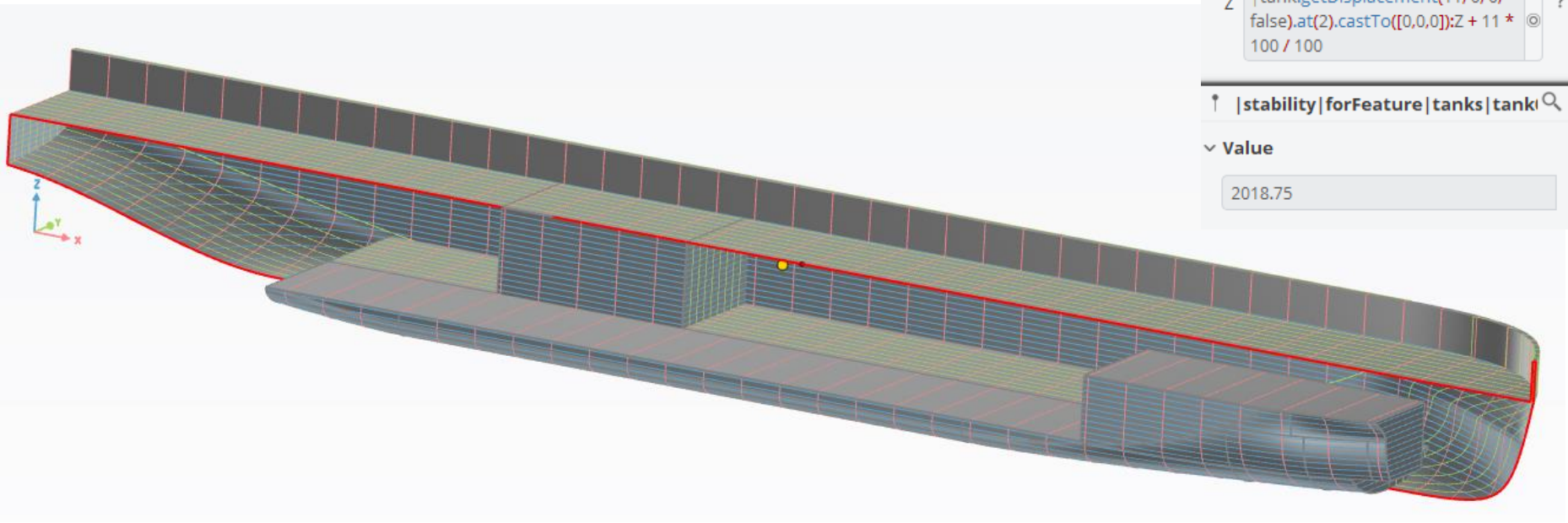
$$GM_0 \geq 0.15m$$

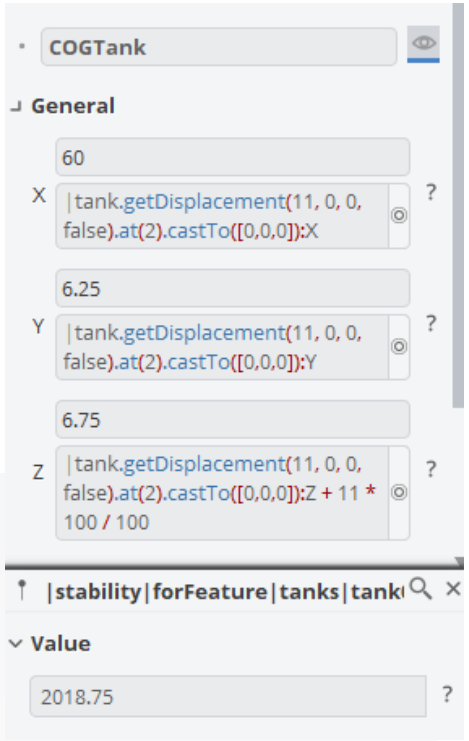


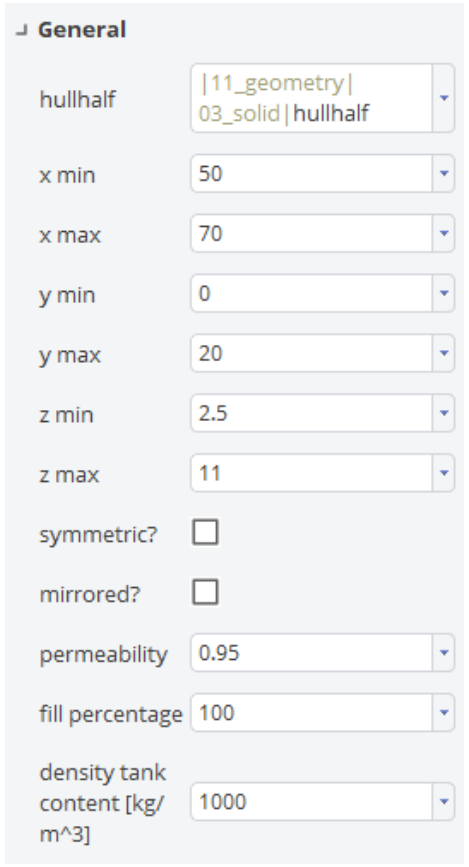
Stability Features – Tank Feature

Input:
- Tank limits
- Density
- Fill percentage

Output:
- Weight
- CoG
- FSM

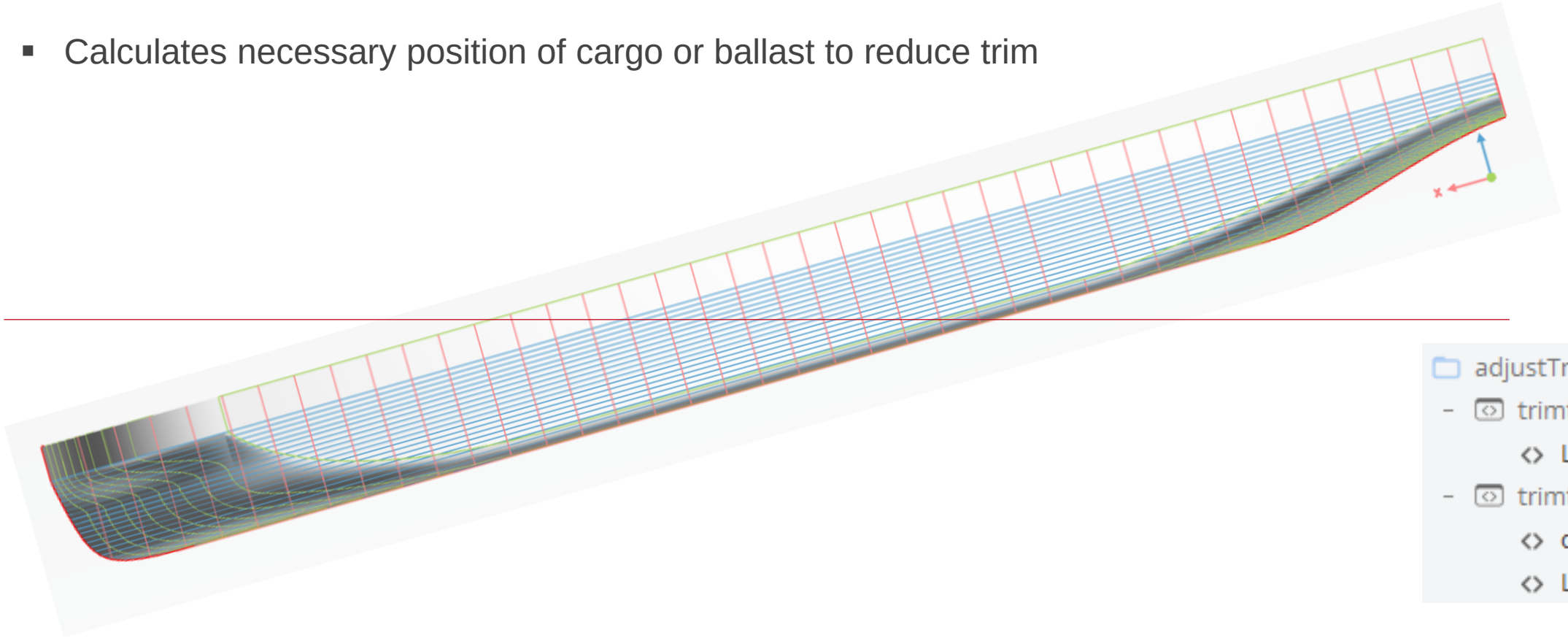






Stability Features – Trim Adjustment Feature

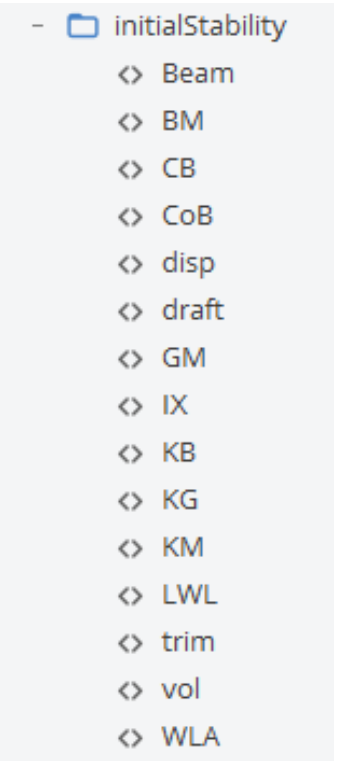
- Calculates necessary position of cargo or ballast to reduce trim

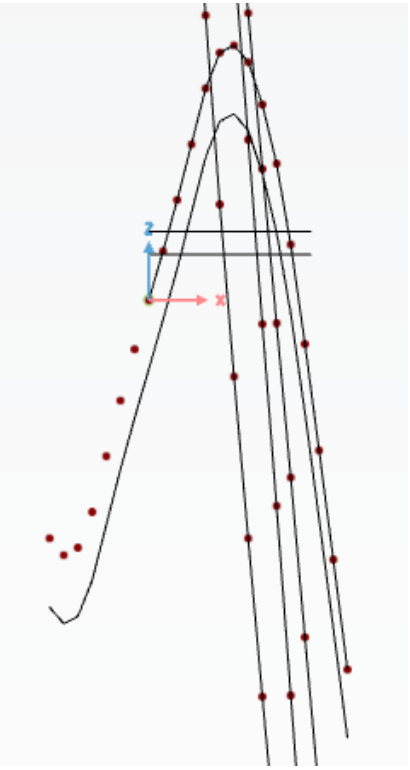


Stability Features – Intact Stability Criteria Feature

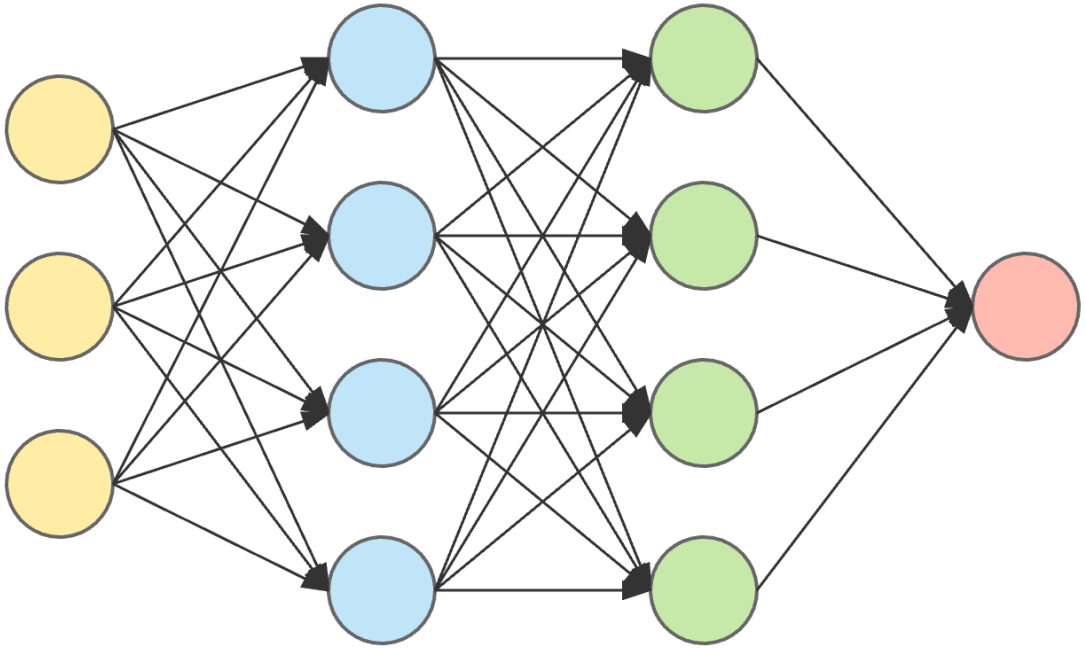
1. Righting lever curve calculation
2. Initial stability (Trim, draught, GM etc.)
3. Weather criterion
4. Stability criteria evaluation

Input:
- Hull Brep
- CoG
- Weight
- Wind Profile





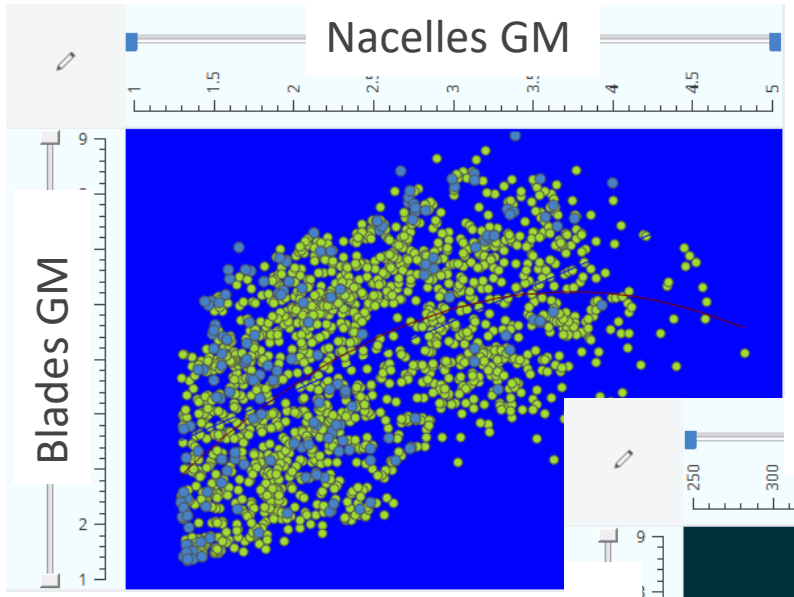
Resistance Evaluation

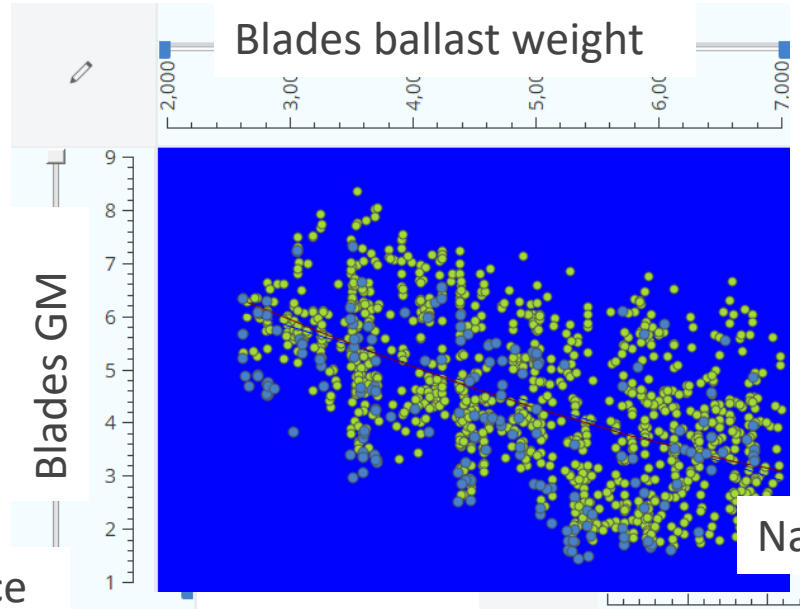


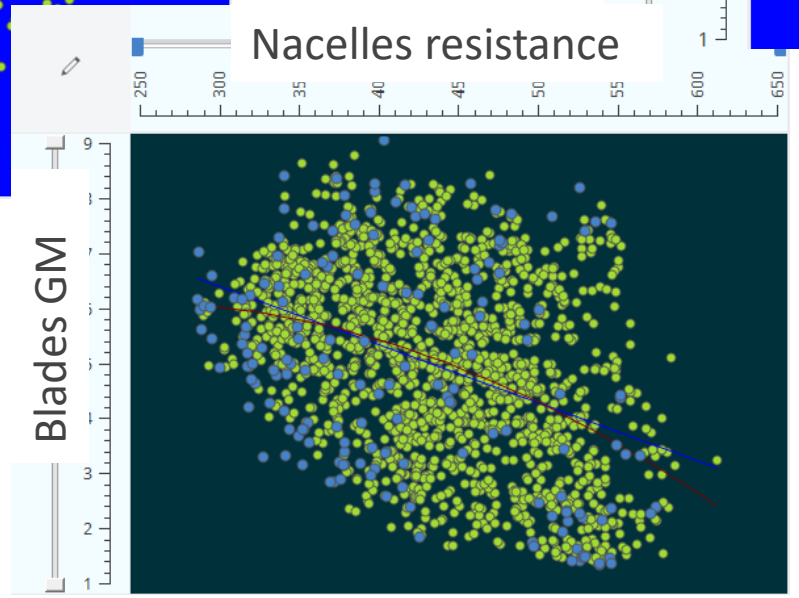
input layer hidden layer 1 hidden layer 2 output layer

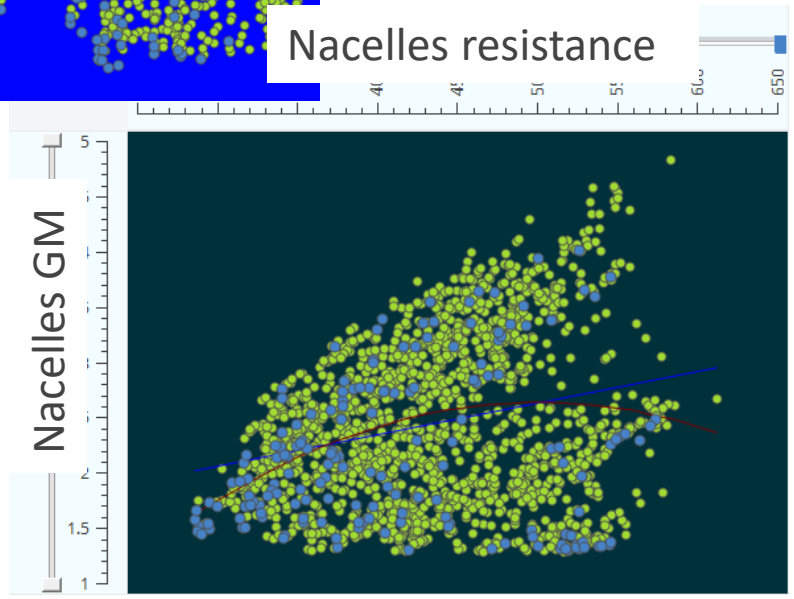
name	resBla	Tbla	resNac	Tnac
des0142	346.089	4.5	411.738	6.35
des0098	364.85	4.5	415.272	6.42
des0191	353.841	4.5	421.04	6.29
des0123	371.217	4.5	422.189	6.33
des0038	366.451	4.5	422.862	6.36
des0042	401.239	4.5	441.374	6.41
des0059	371.168	4.5	448.566	6.28
des0099	418.152	4.5	454.395	6.30
des0020	423.157	4.5	479.632	6.41
des0021	446.28	4.5	493.812	6.30

Optimisation Results

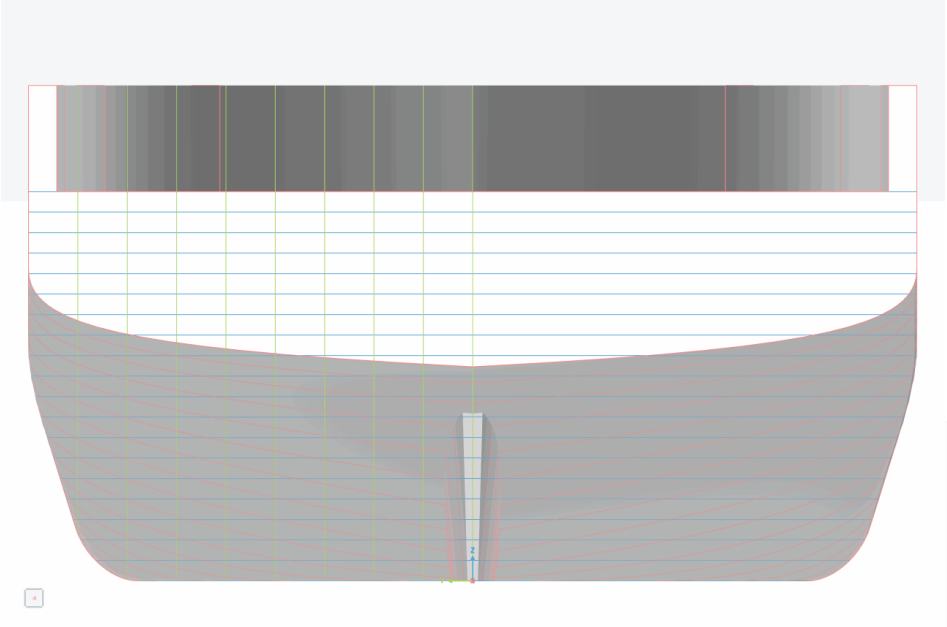


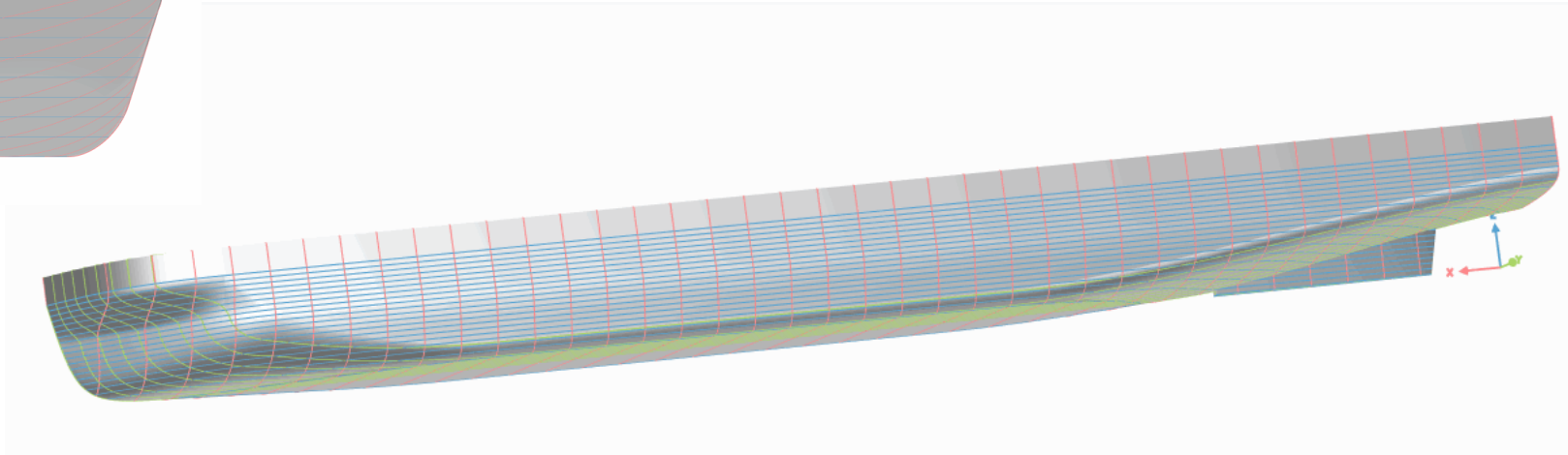




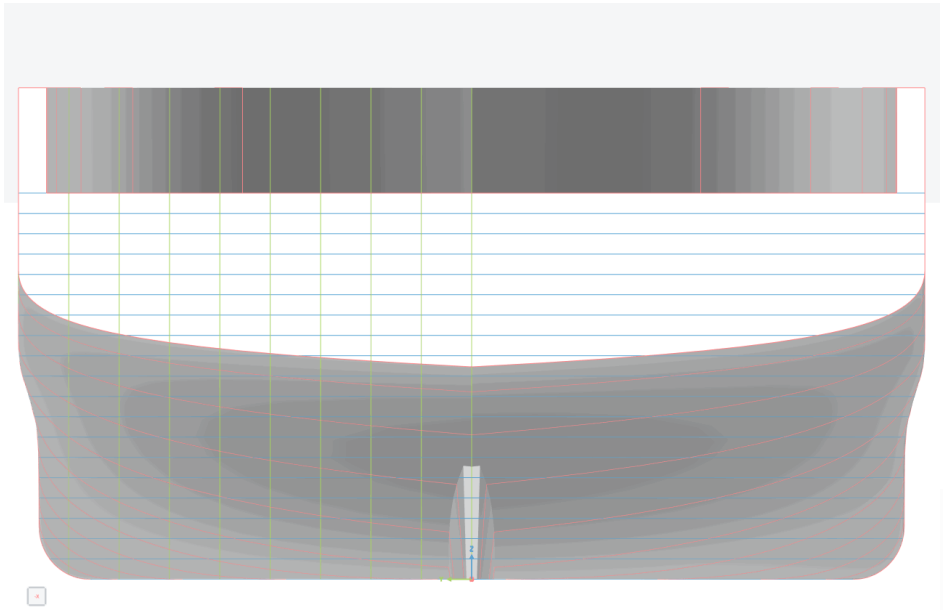


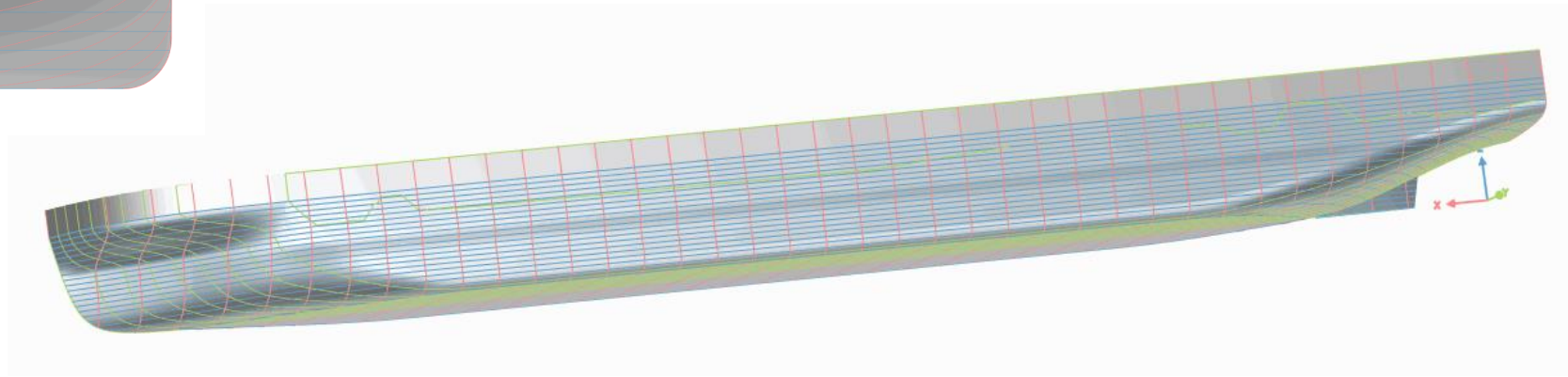
Optimisation Results





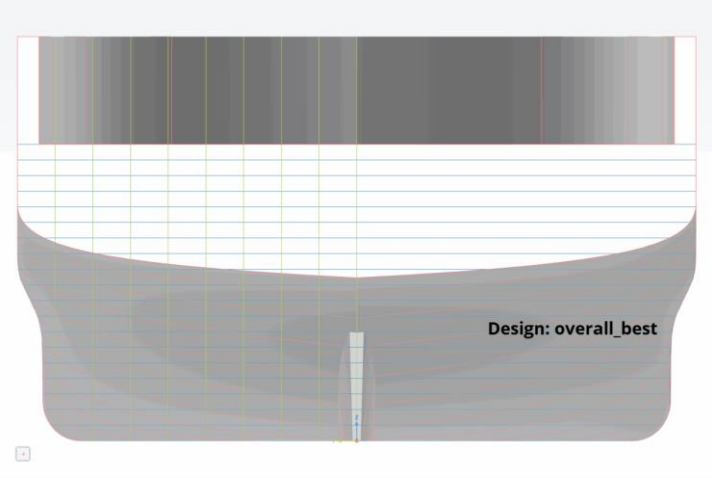
Optimisation Results

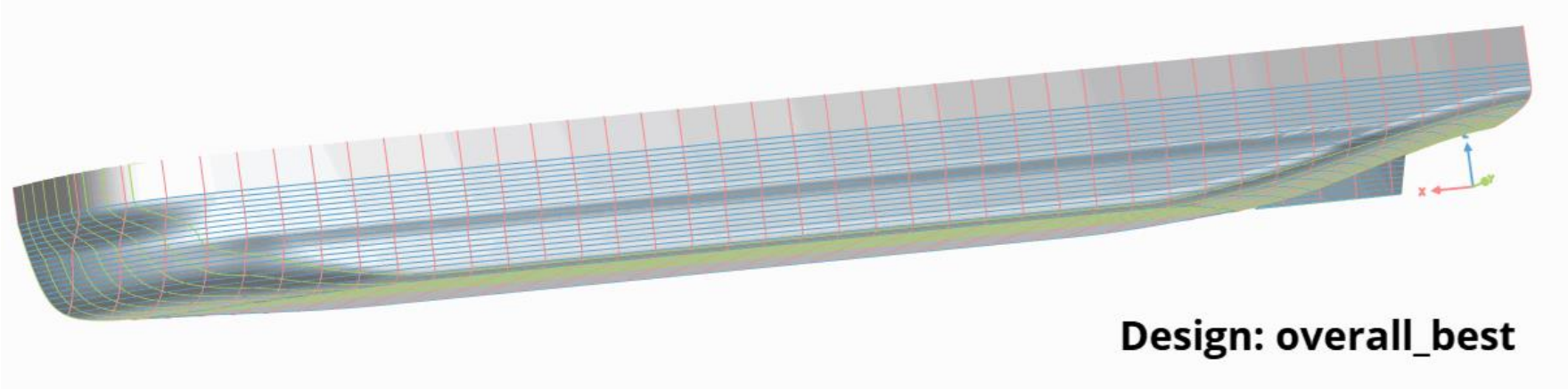




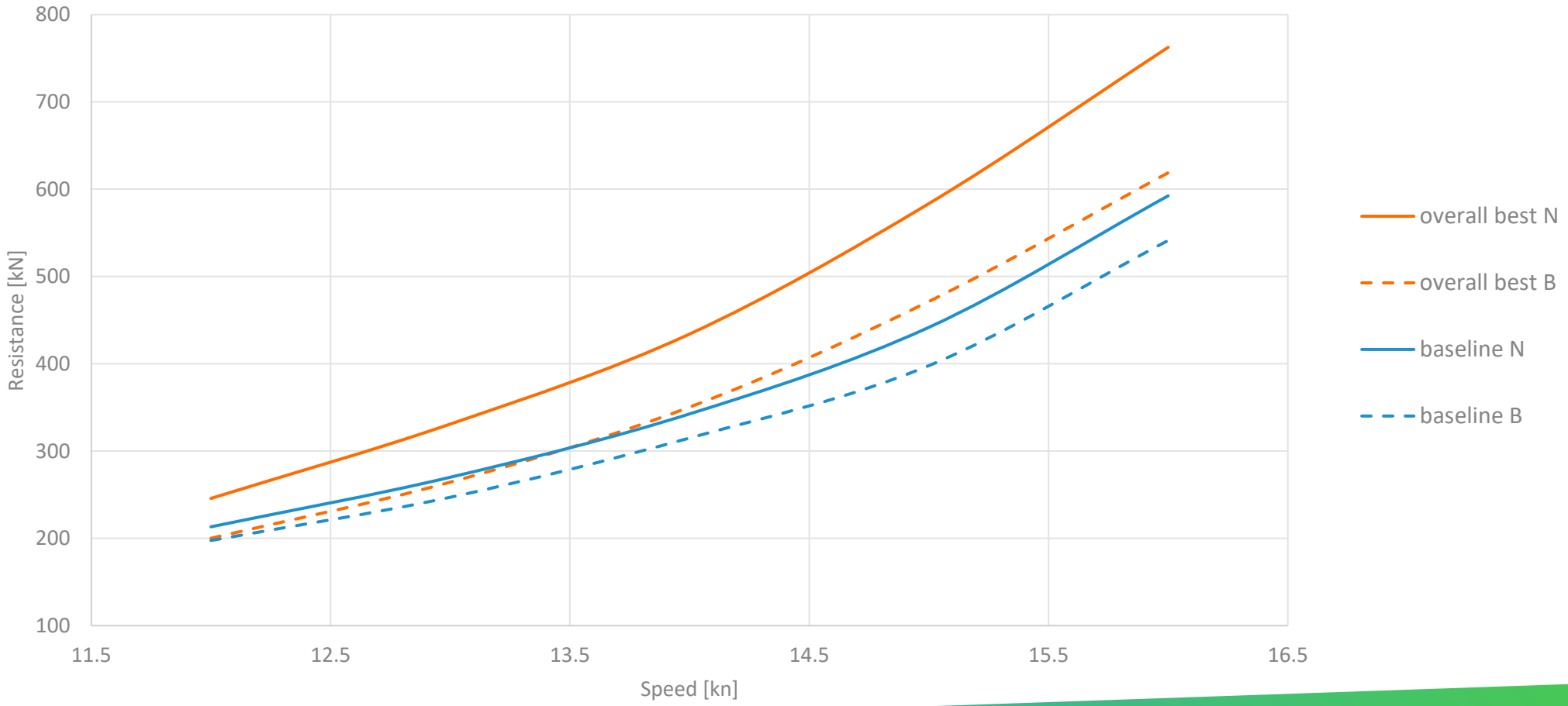
Optimisation Results

Design	Upper Slant Angle [°]	Lower Slant Angle [°]	Res N [kN]	BW B [t]	GM N [m]	GM B [m]	Improve-ment [%]
Baseline	30.0	0.0	470	6000	1.37	1.81	---
Overall best	28.3	0.1	538	5149	1.34	1.36	6.5





Optimisation Results



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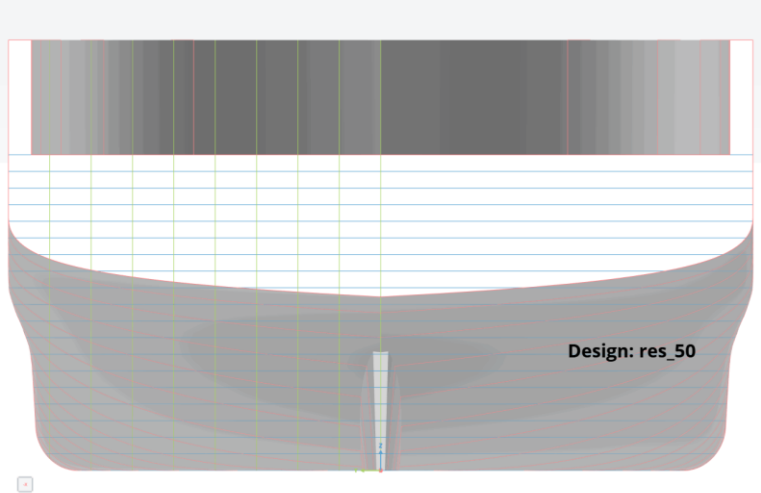
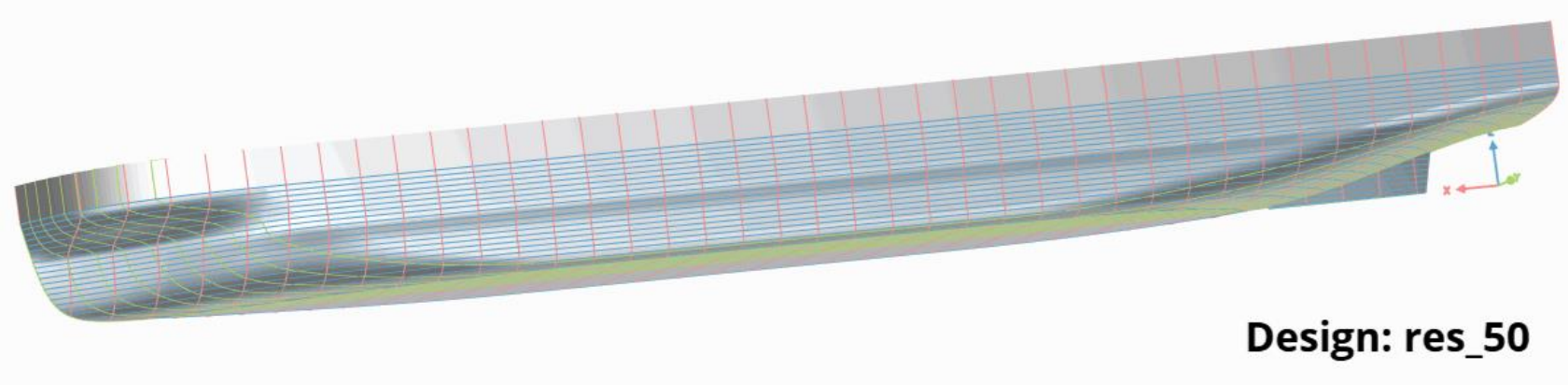
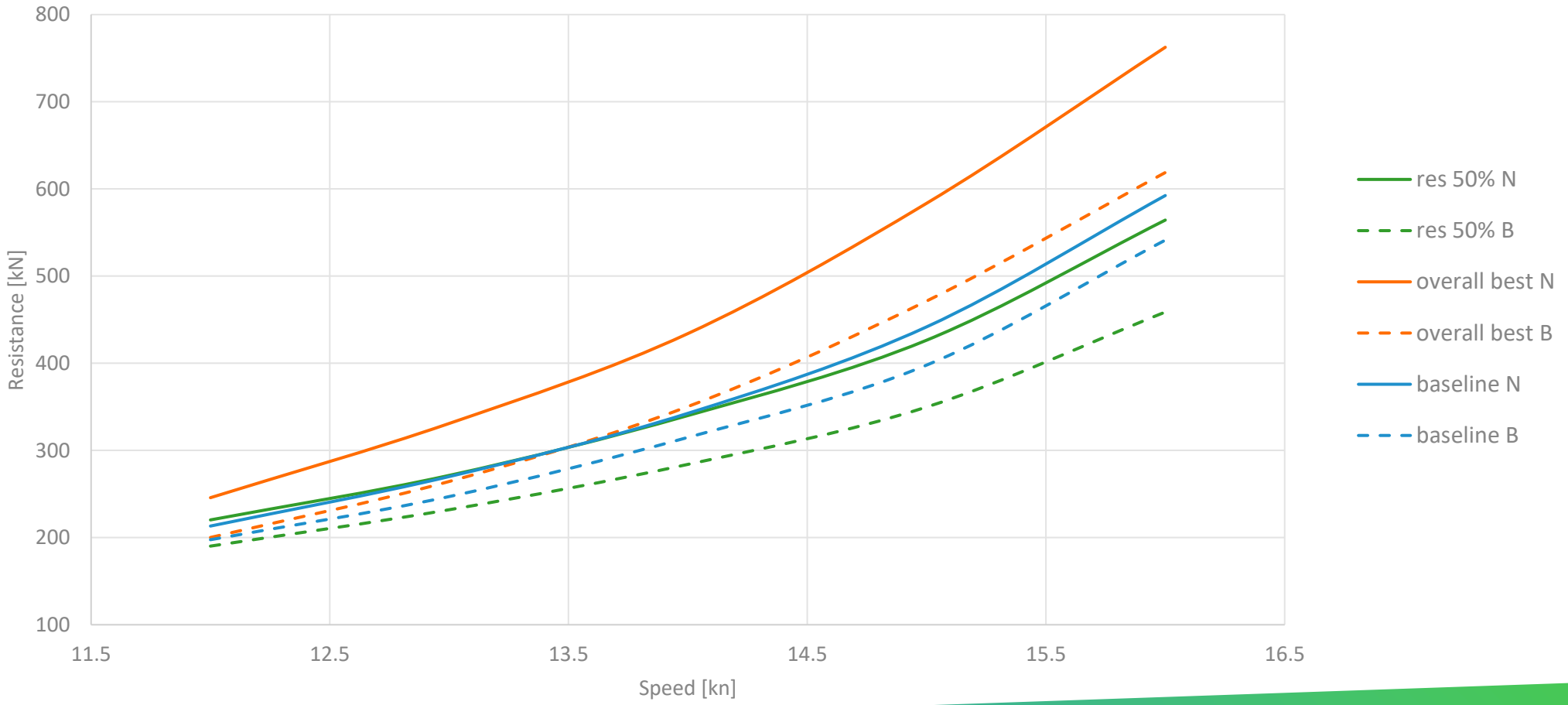
Resistance 50%	24.5	3.1	443	5591	1.56	1.71	0.9





Optimisation Results



Optimisation Results

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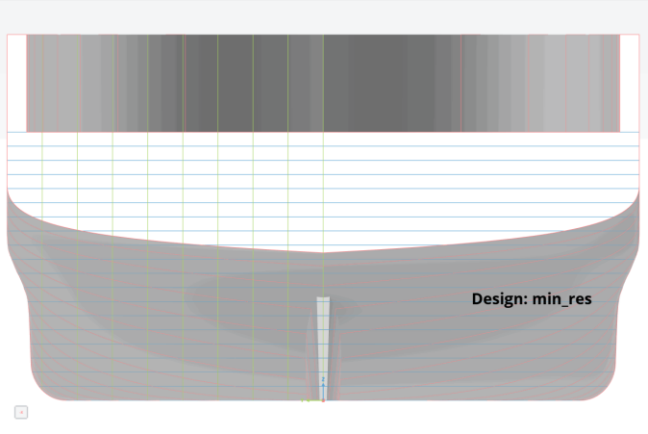
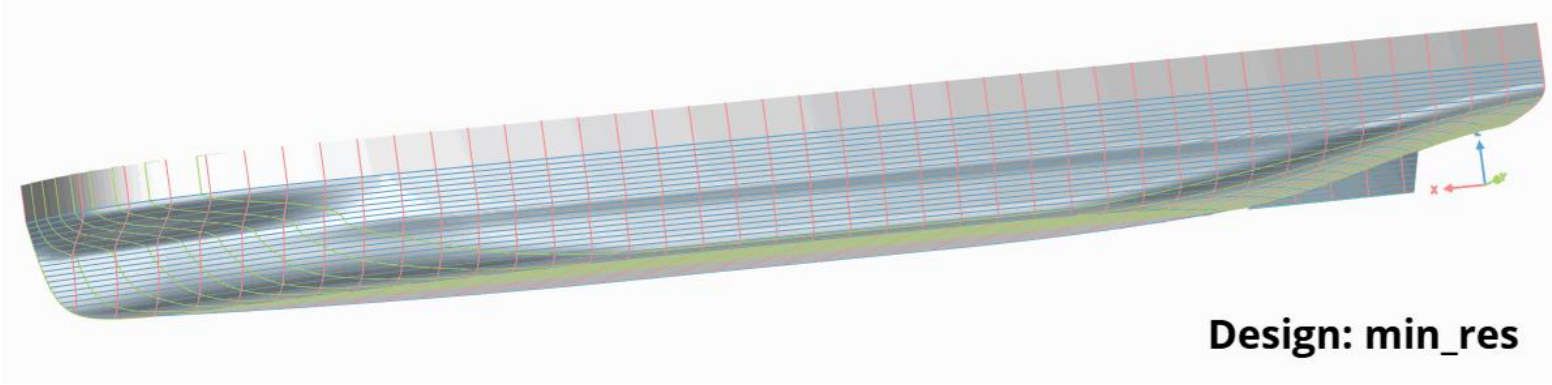
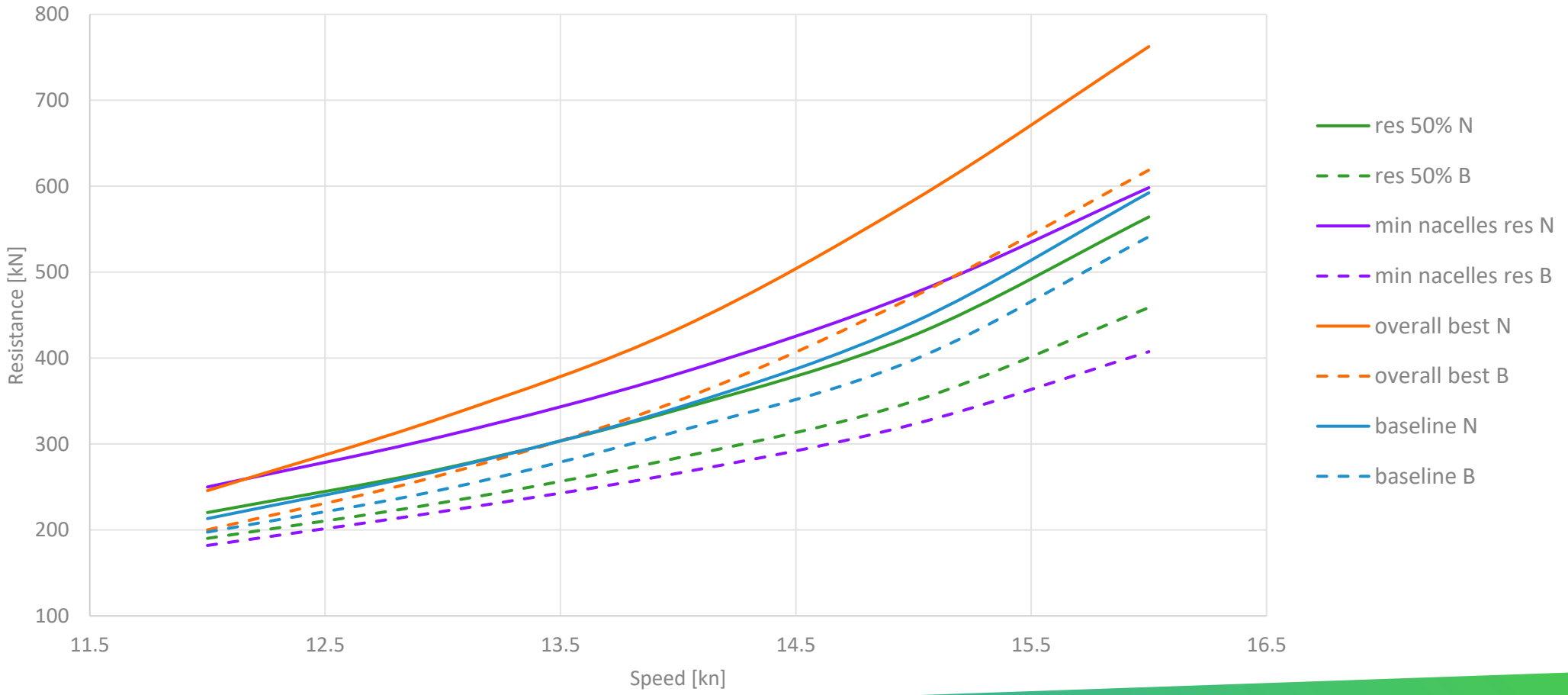
Resistance 50%	24.5	3.1	443	5591	1.56	1.71	0.9
Min resistance	26.8	1.9	424	5589	1.78	1.94	-5.2





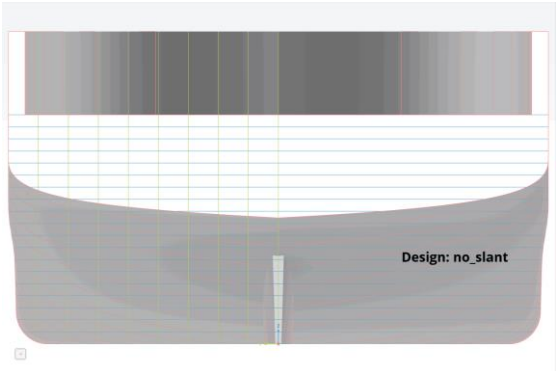
Design: min_res

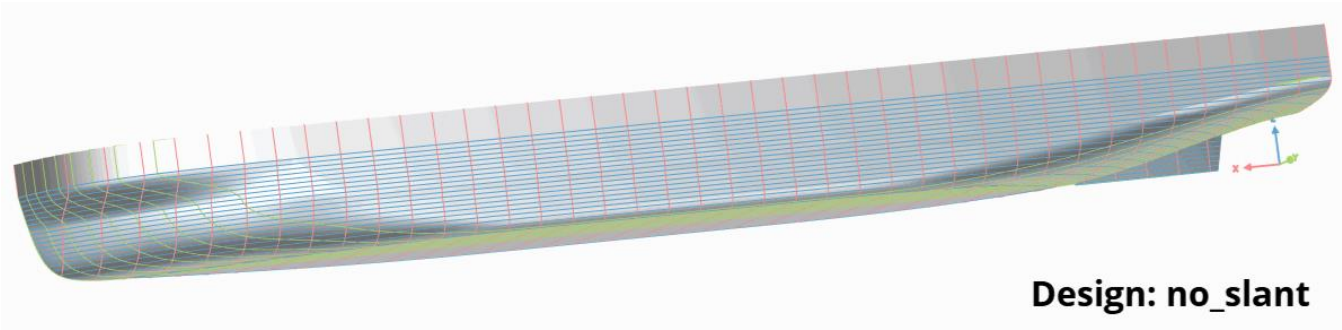
Optimisation Results



Optimisation Results

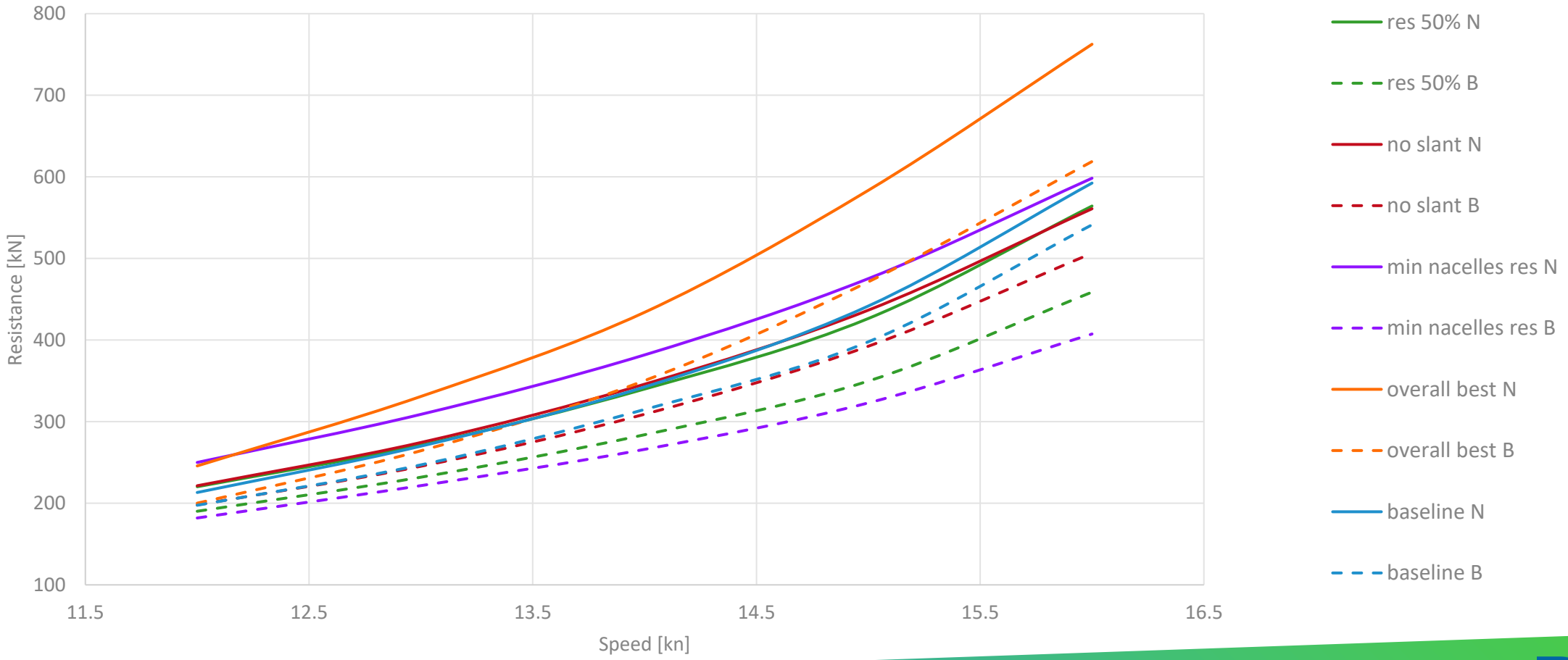
Design	Upper Slant Angle [°]	Lower Slant Angle [°]	Res N [kN]	BW B [t]	GM N [m]	GM B [m]	Improve-ment [%]
Baseline	30.0	0.0	470	6000	1.37	1.81	---
Overall best	28.3	0.1	538	5149	1.34	1.36	6.5
Resistance 50%	24.5	3.1	443	5591	1.56	1.71	0.9
Min resistance	26.8	1.9	424	5589	1.78	1.94	-5.2
No slant	10.0	1.4	427	6542	1.65	1.91	-6.5



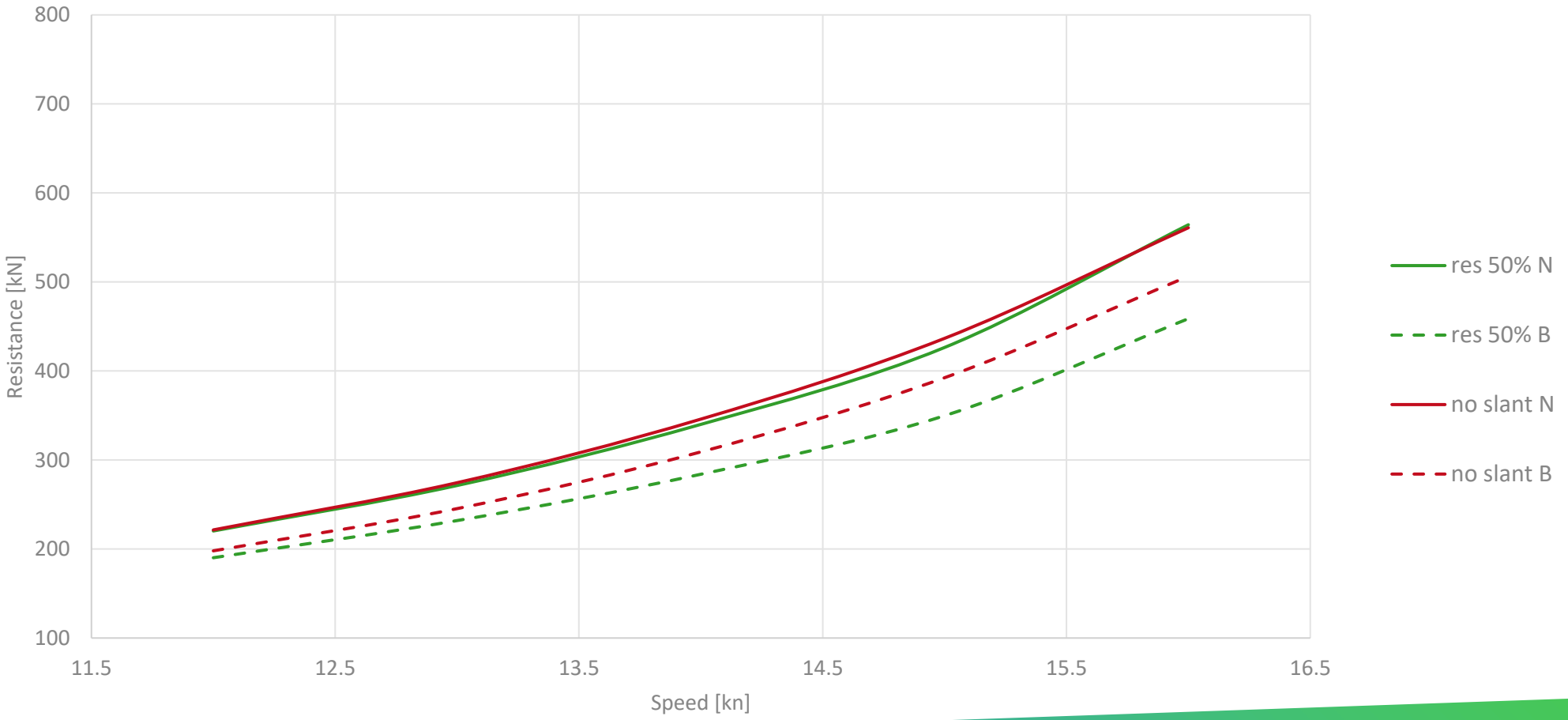


Design: no_slant

Optimisation Results



Optimisation Results



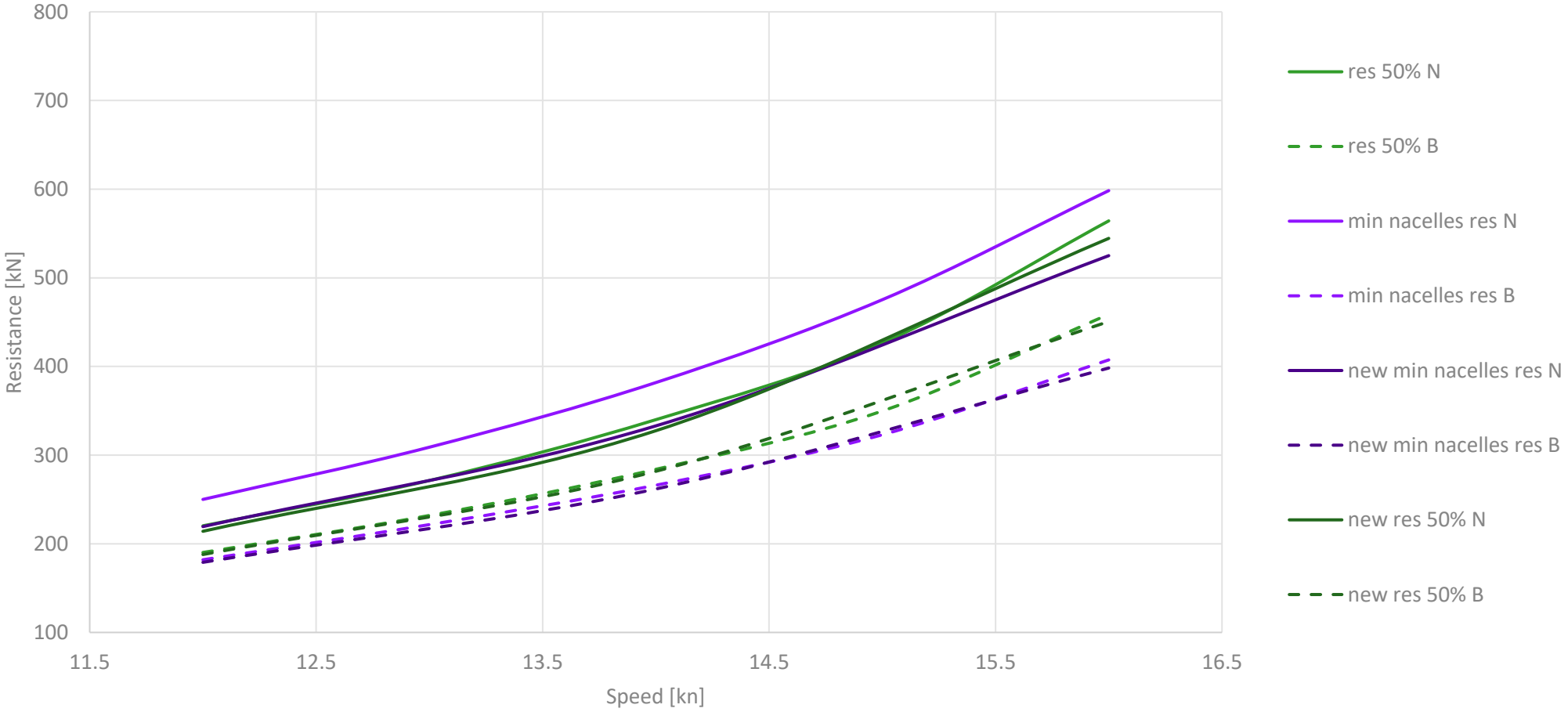
Optimisation Results

Design	Upper Slant Angle [°]	Lower Slant Angle [°]	Res N [kN]	BW B [t]	GM N [m]	GM B [m]	Improve-ment [%]
Baseline	30.0	0.0	470	6000	1.37	1.81	---
Overall best	28.3	0.1	538	5149	1.34	1.36	6.5
Resistance 50%	24.5	3.1	443	5591	1.56	1.71	0.9
Min resistance	26.8	1.9	424	5589	1.78	1.94	-5.2
No slant	10.0	1.4	427	6542	1.65	1.91	-6.5

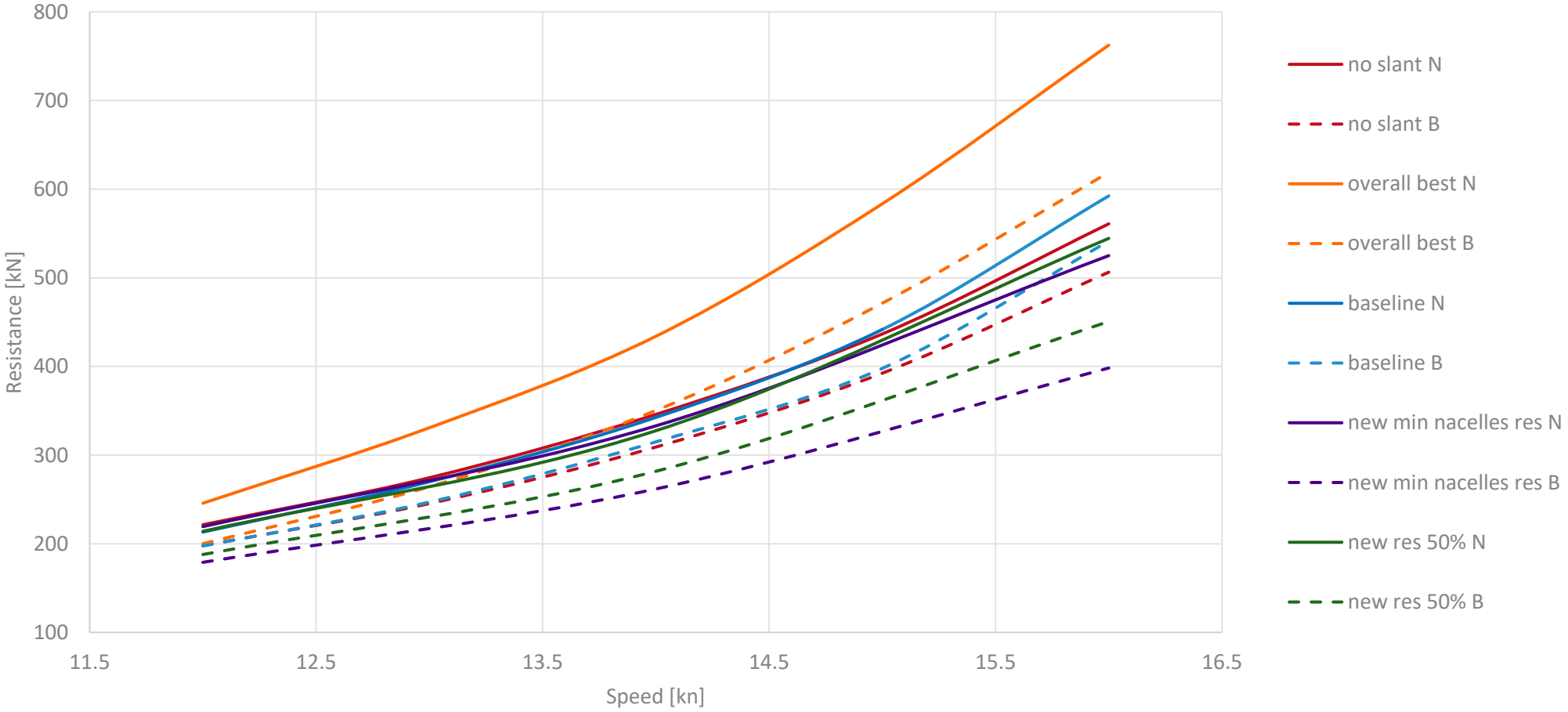
Optimisation Results

Design	Upper Slant Angle [°]	Lower Slant Angle [°]	Res N [kN]	BW B [t]	GM N [m]	GM B [m]	Improve-ment [%]
Baseline	30.0	0.0	470	6000	1.37	1.81	---
Resistance 50%	24.5	3.1	443	5591	1.56	1.71	0.9
Resistance 50%	30.0	0.0	437	5000	1.34	1.49	10.8
Min resistance	26.8	1.9	424	5589	1.78	1.94	-5.2
Min resistance	30.0	0.0	395	4750	1.36	1.75	10.1

Optimisation Results

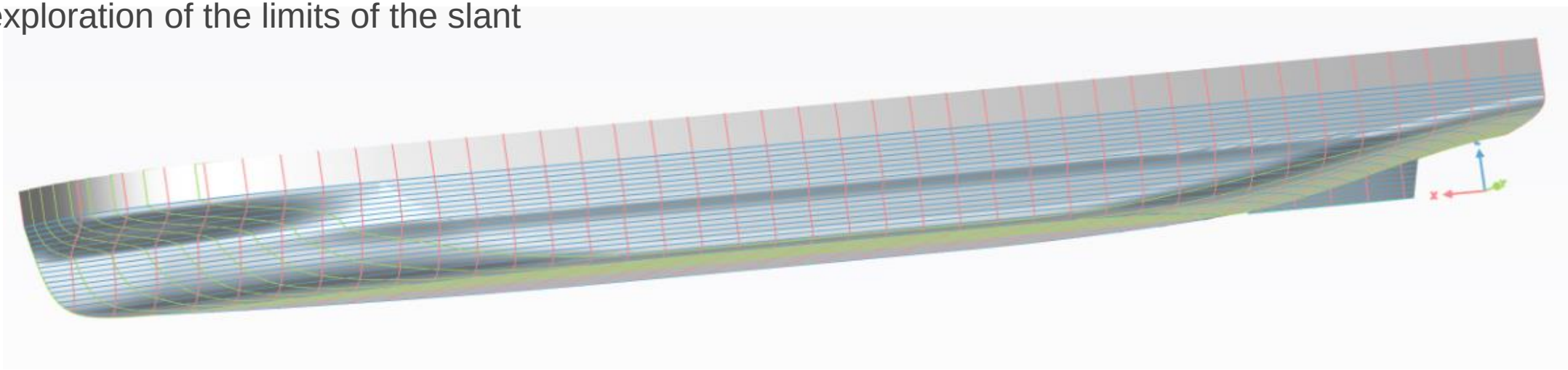


Optimisation Results



Conclusion and Outlook

- Stability feature is a good method for (preliminary) stability evaluation
- Slanted sides improve not only stability, but also resistance
- Regarding slant, the baseline was already a good solution
- Further exploration of the limits of the slant



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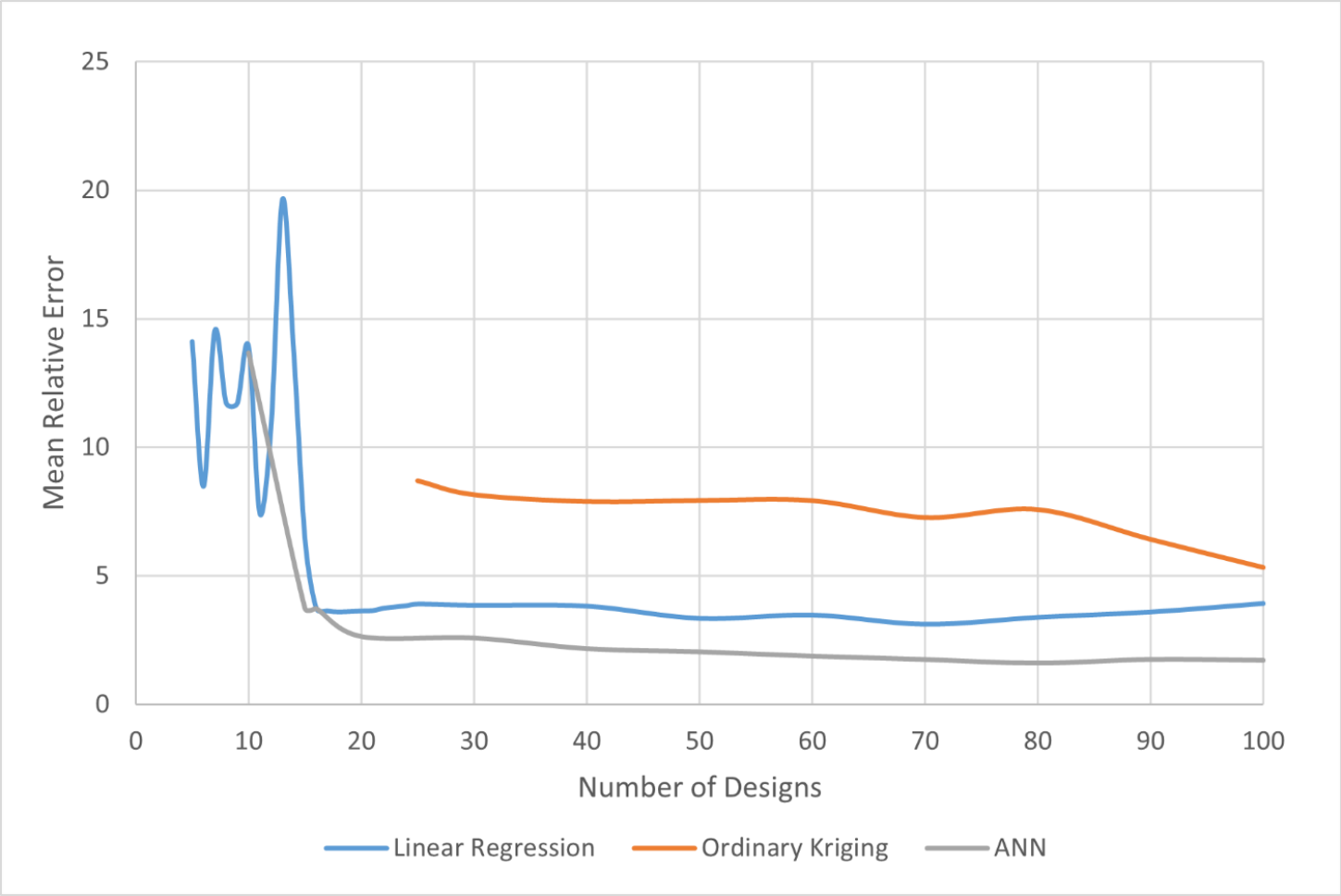
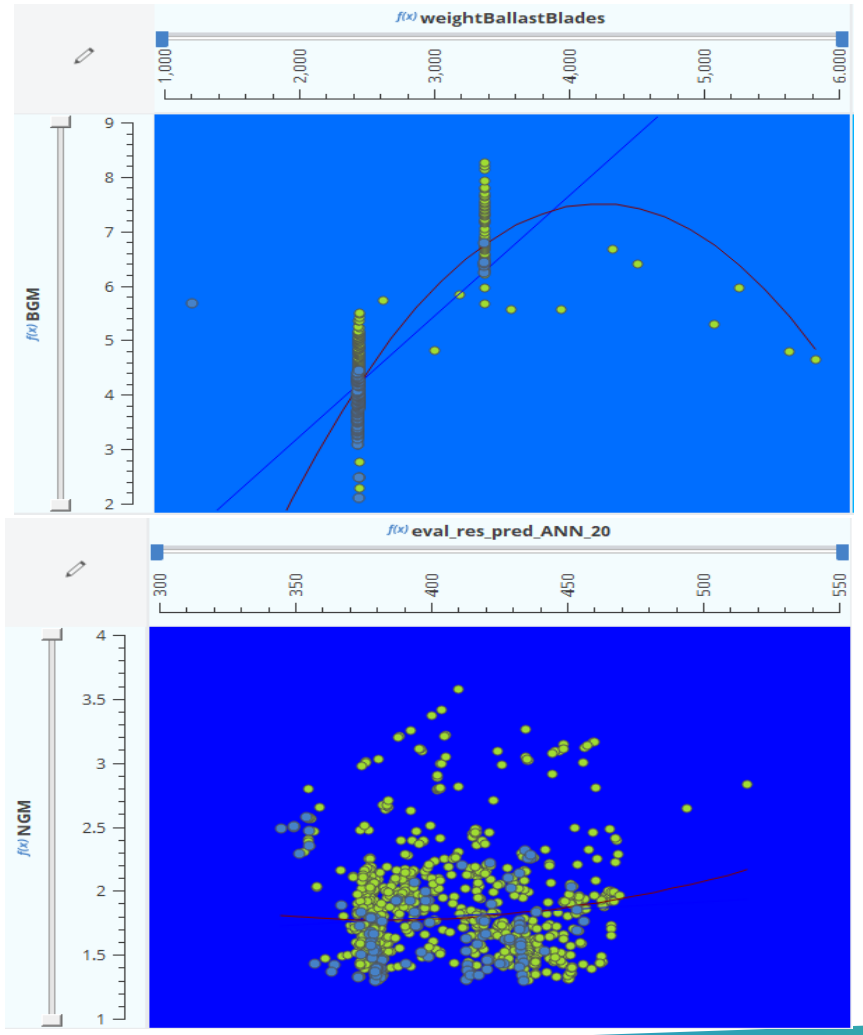
DEK MARITIME

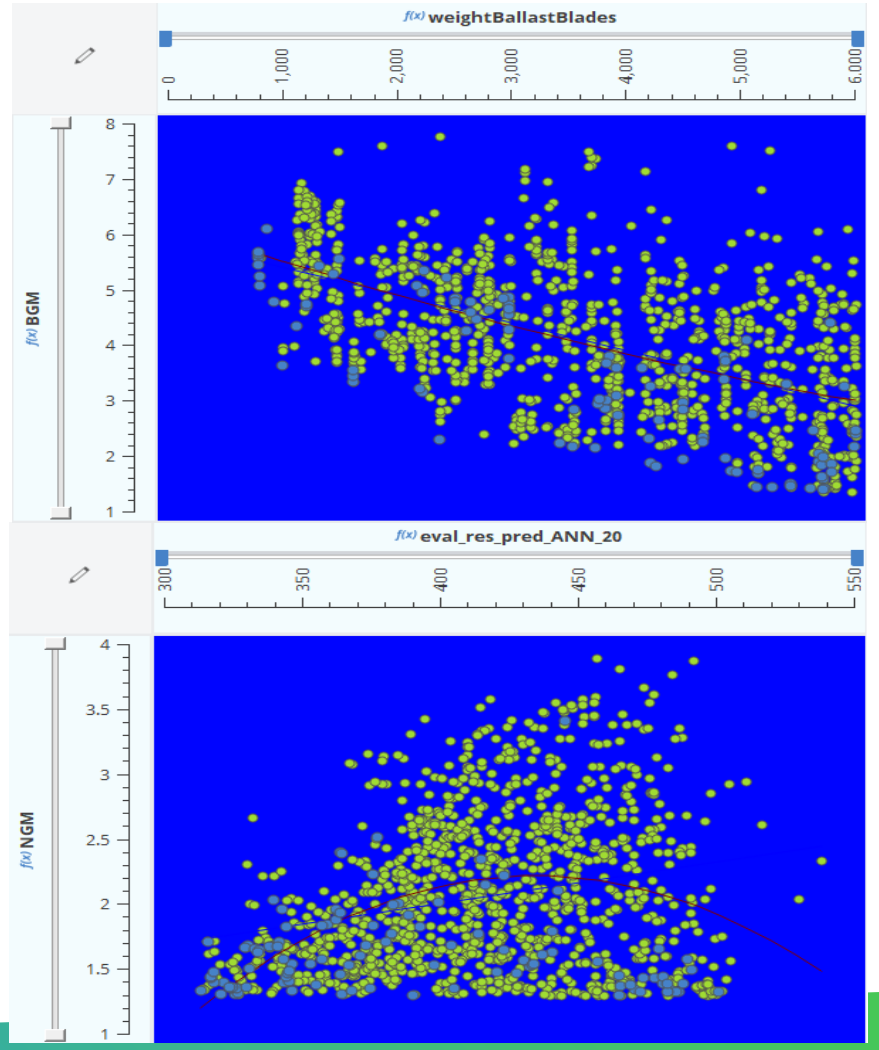
Resistance Surrogate



Optimisation Algorithms

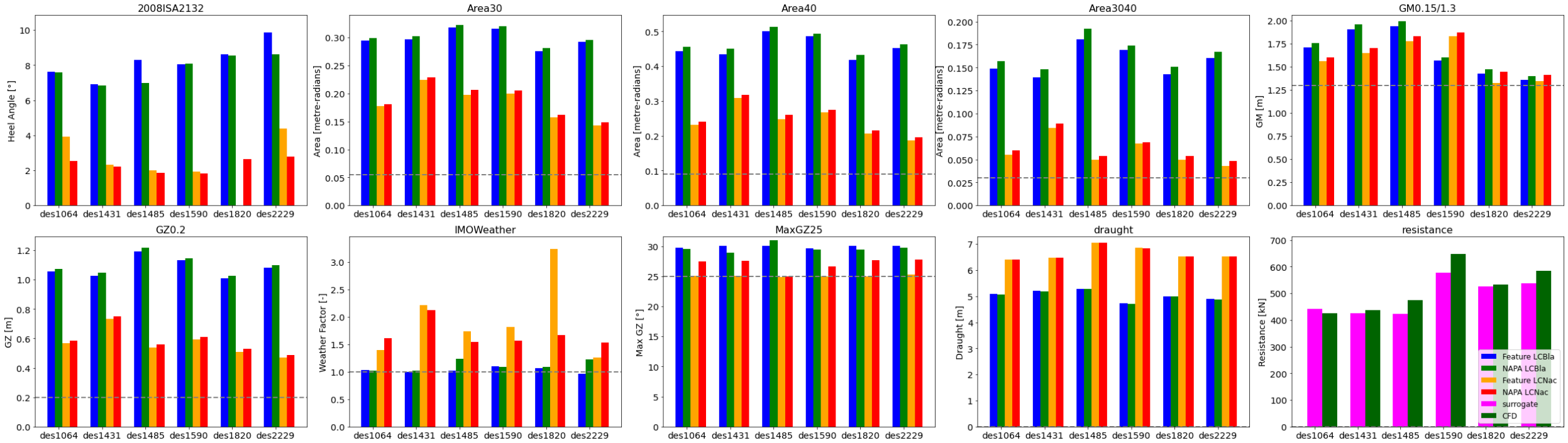


MOSA



NSGA-II

Validation


2008ISA2132
Heel Angle [°]
Area30
Area [metre-radians]
Area40
Area [metre-radians]
Area3040
Area [metre-radians]
GM0.15/1.3
GM [m]
GZ0.2
GZ [m]
IMOWeather
Weather Factor [-]
MaxGZ25
Max GZ [°]
draught
Draught [m]
resistance
Resistance [kN]
des1064 des1431 des1485 des1590 des1820 des2229
Feature LCBla
NAPA LCBla
Feature LCNac
NAPA LCNac
surrogate
CFD

Optimisation Results

		baseline	des2229	des1820	des1485	des1590	des1064	des1431
			min BGM	min NGM	min res	min BT/BW	res 50%	
upper slant angle	[°]	30	28	23	27	29	25	10
z Tanktop	[m]	1.20	1.78	1.79	2.20	2.33	1.50	1.78
rel Height Ballast	[-]	0.90	0.86	0.91	0.83	0.87	0.97	0.99
w Ballast	[t]	6000	5149	5501	5589	4622	5591	6542
B GM	[m]	1.80	1.36	1.43	1.94	1.56	1.71	1.91
B draught	[m]	5.09	4.89	5.00	5.28	4.71	5.08	5.20
N GM	[m]	1.37	1.34	1.32	1.78	1.83	1.56	1.65
Resistance	[kN]	470	538	526	424	578	443	427
Impr. ballast	[%]	0	6.45	5.15	-5.20	-5.15	0.94	-6.51
Impr. draught	[%]	0	3.90	3.54	-7.84	-9.05	-0.73	-4.83