CFD-assisted Hull Form Optimization for Sustainable Shipping

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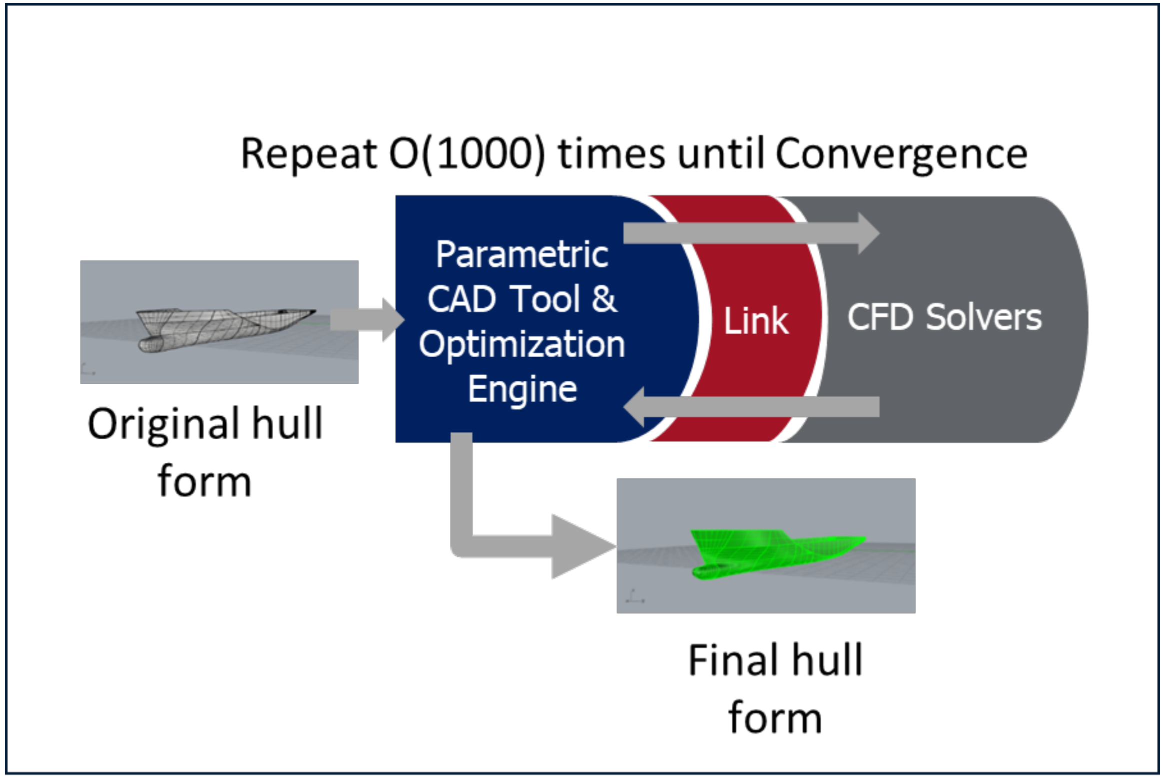
CFD-based Parametric Hull Form Optimization

Parametric Hull Form Optimization

- New technologies for more sustainable shipping are being developed
- Parametric hull form optimization guided by RANS CFD could help stakeholders find the optimal way to implement these technologies
- ABS has been assisting clients with this parametric hull form optimization framework

Optimization Framework



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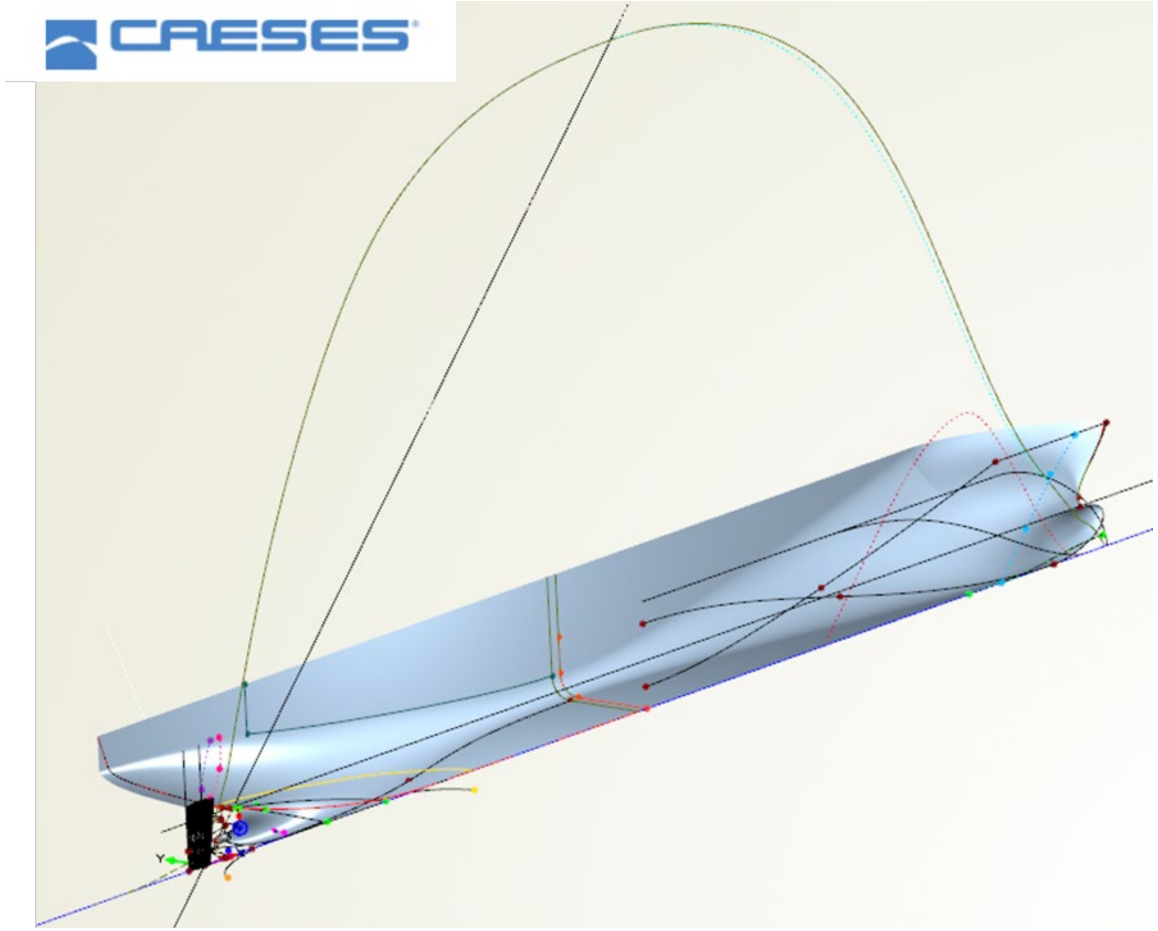
What is Parametric Hull Form Optimization?

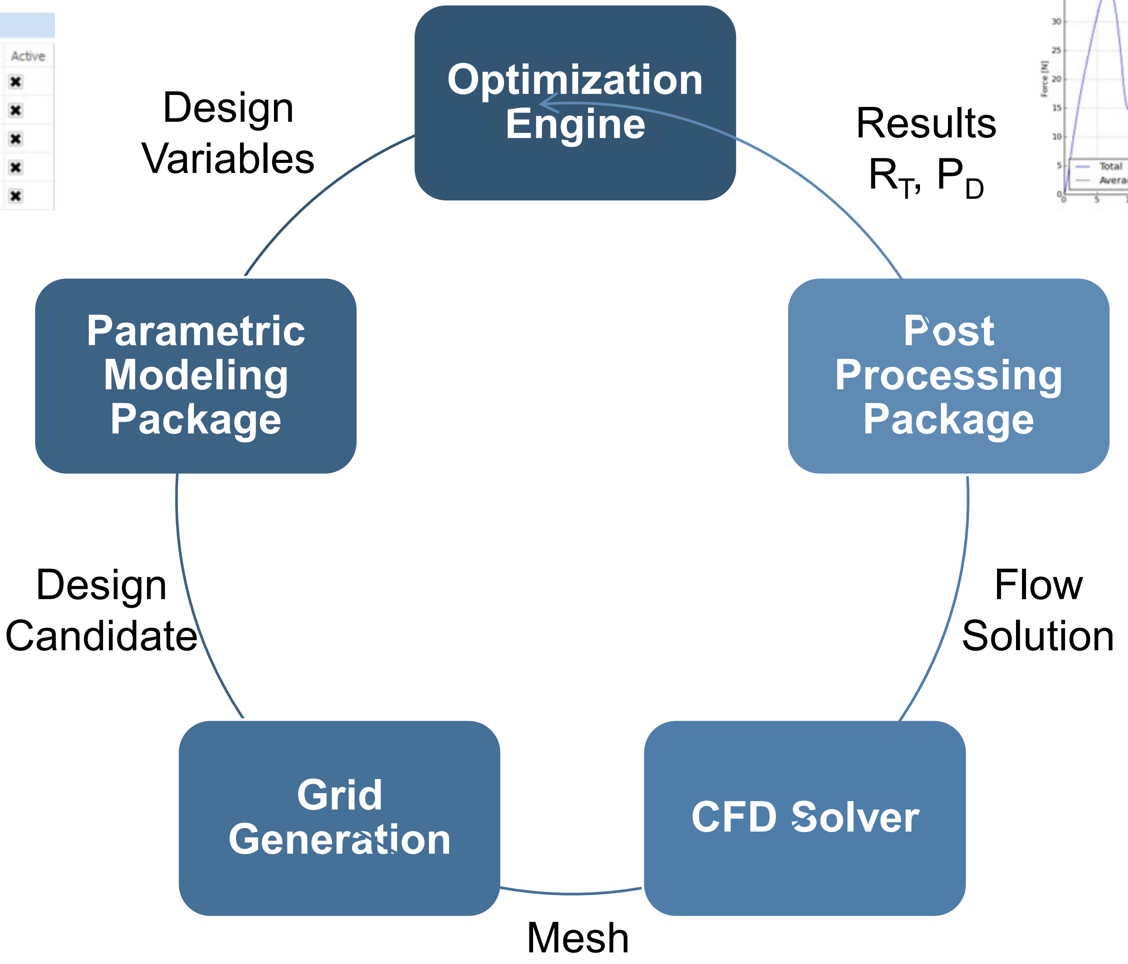
- Hull form is modeled by parameters (variables) using a parametric CAD modeling software
- Depending on the area of interest, relevant parameters (i.e., design variables) are optimized against given objective function(s)
- Each design variable produces a unique design candidate
- Objective functions (e.g., minimum power and/or maximum cargo capacity) associated with each design candidate is evaluated by CFD tool
- It often becomes a multi-objective nonlinear optimization problem with a set of design constraints

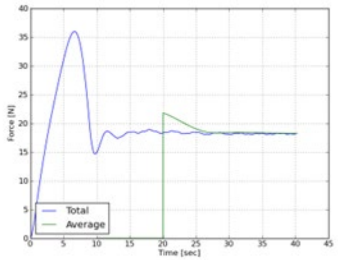


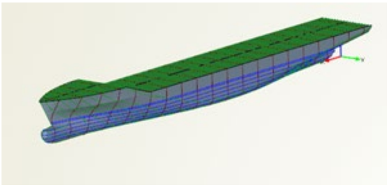
Hull Form Optimization Process

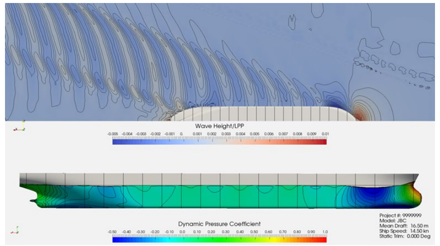
Design Variables

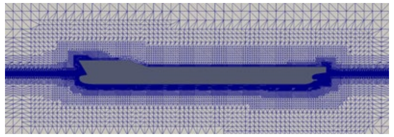
	Design Variable		Lower	Value	Upper	Active
1	maxBeam	▾	1.5	2.4	2.6	✖
2	SectionlowFullness	▾	0.65	0.74	0.85	✖
3	SectionuppFullness	▾	0.67	0.78	0.85	✖
4	xBulbTip	▾	234	237	240	✖
5	zBulbTip	▾	4	5.90193387	6.5	✖







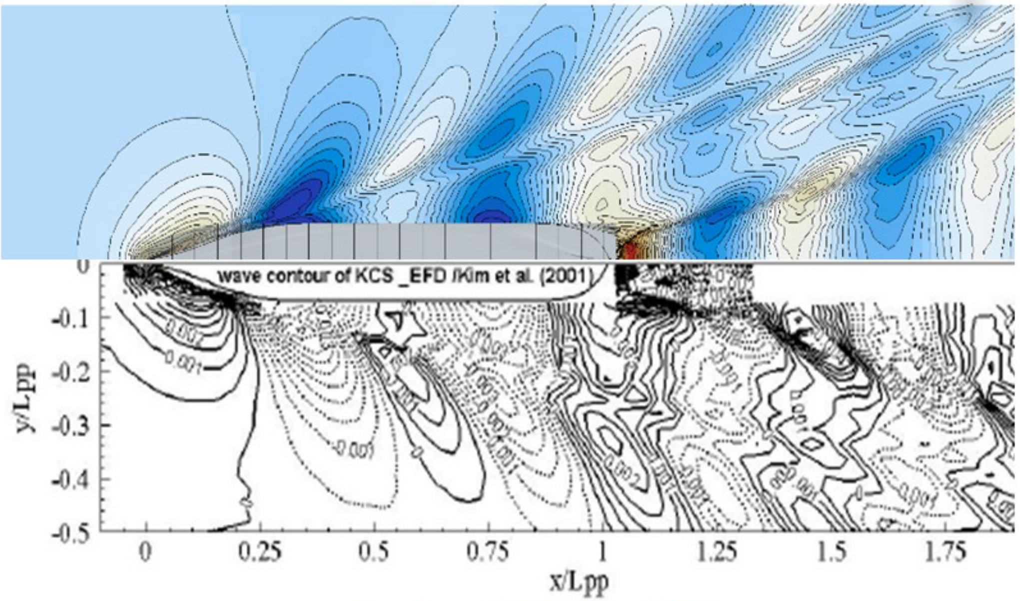




Example Accuracy of CFD Simulations

- Calm water resistance computed by CFD and compared to KCS model test results from "Gothenburg 2010: A Workshop on Numerical Ship Hydrodynamics"
- Average difference between CFD and experimental resistance values is 0.88%
- Good comparison in free surface wakes

KCS Benchmark							
Speed	[knots]	**10.0**	**14.0**	**18.0**	**20.0**	**24.0**	**26.0**
Froude Number		0.1083	0.1516	0.1949	0.2166	0.2599	0.2816
Dynamic Sinkage, CFD	[mm]	-1.552	3.610	-6.689	-8.656	-13.518	-16.907
Dynamic Sinkage, Exp.	[mm]	-0.900	-2.750	-5.990	-9.440	-13.040	-17.020
Dynamic Trim, CFD	[deg]	0.031	0.057	0.099	0.124	0.184	0.160
Dynamic Trim, Exp.	[deg]	0.170	0.053	0.097	0.127	0.169	0.159
C_{TM} x 10^3, CFD		3.741	3.674	3.506	3.477	3.663	4.478
C_{TM} x 10^3, Exp.		3.796	3.641	3.475	3.467	3.711	4.501
Delta CFD-Exp.	**[%]**	**1.44%**	**0.90%**	**0.90%**	**0.29%**	**-1.30%**	**-0.51%**



Experiment (MOERI, Kim et al. 2001)

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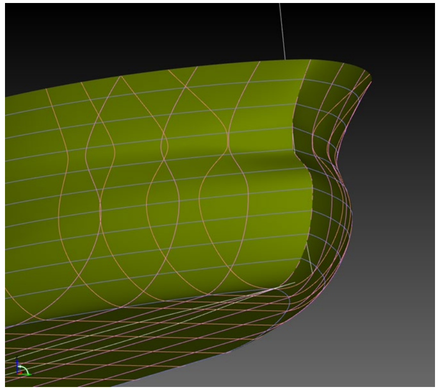
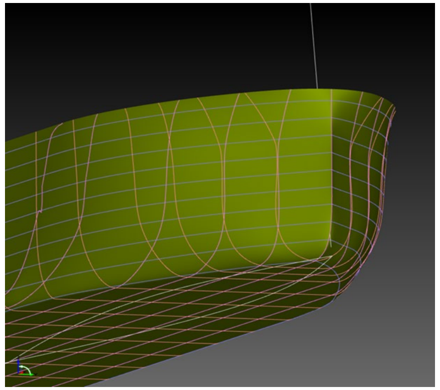
Case Study: Fully Parametric Approach

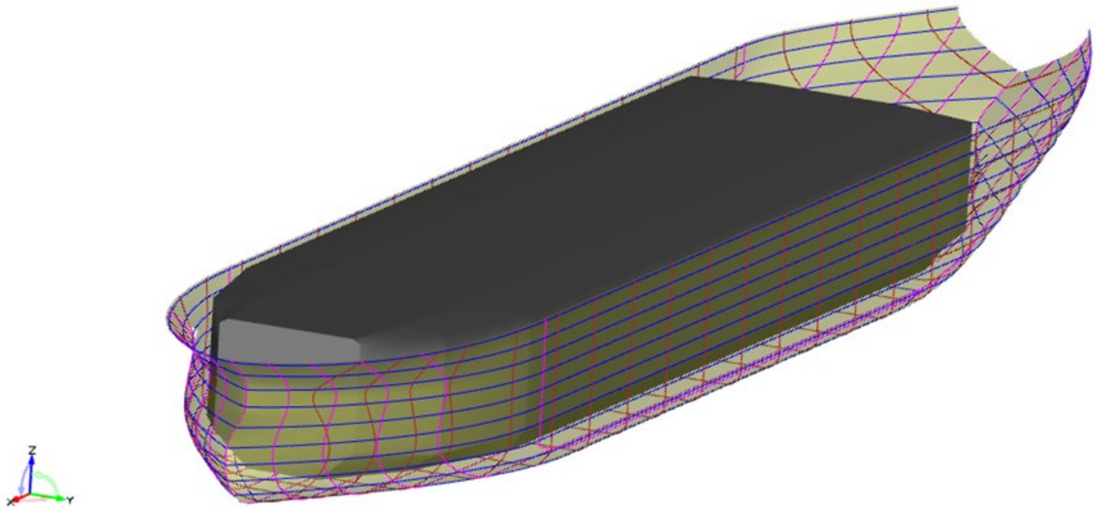
- Optimize the hull form for minimum delivered power over the operational profile (Design Draft: 60%, Ballast Draft: 40%) subject to the following constraints:
  - Cargo tank volume of 85,000 m^3
  - Hull maximum depth (15.0 m max. freeboard @ Midship and Ballast Draft)
  - Draft @ Aft-ship to ensure propeller immersion
  - Speed: 14.5 kn for both drafts



Bulbous Bow (BB)



Vertical Stem (VS)

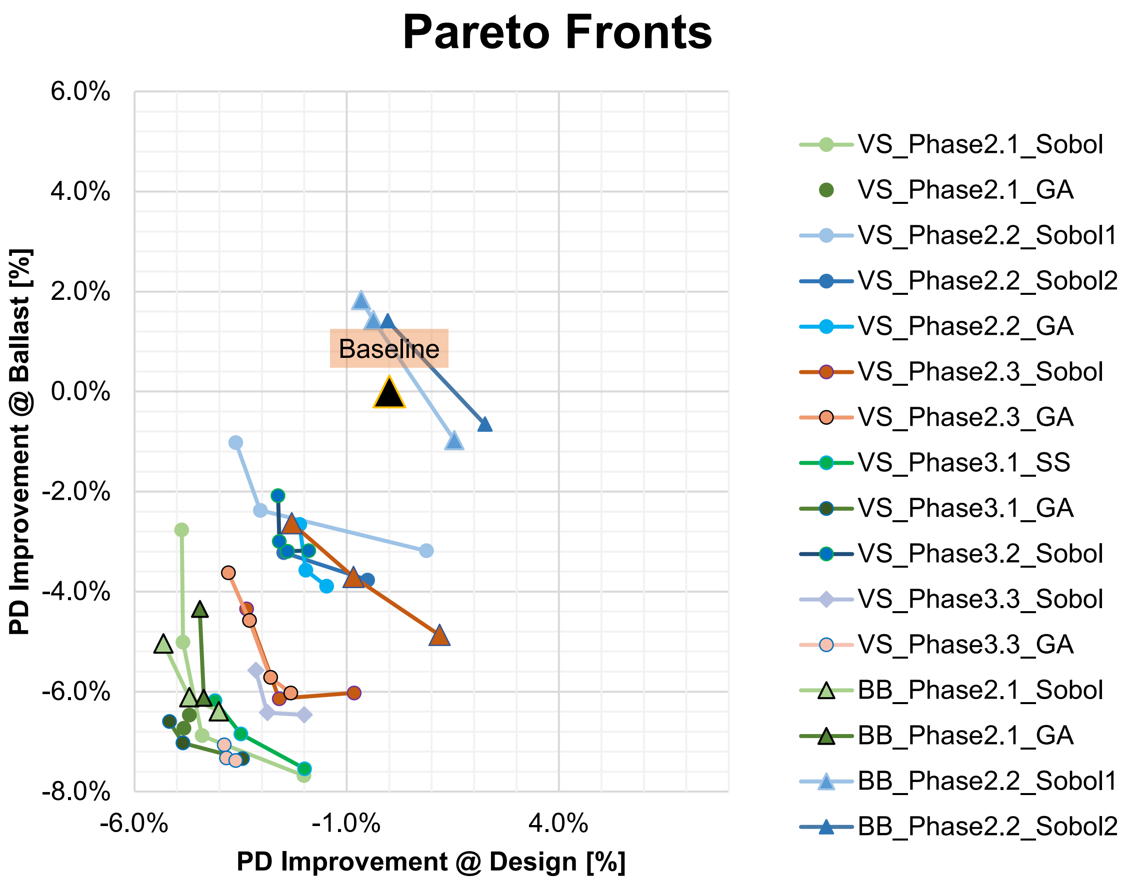


Modeling of Hull and Cargo Tank: As hull form changes, cargo tank also changes with a pre-defined clearance between Hull and Tank.

Case Study: Summary of Pareto Frontier

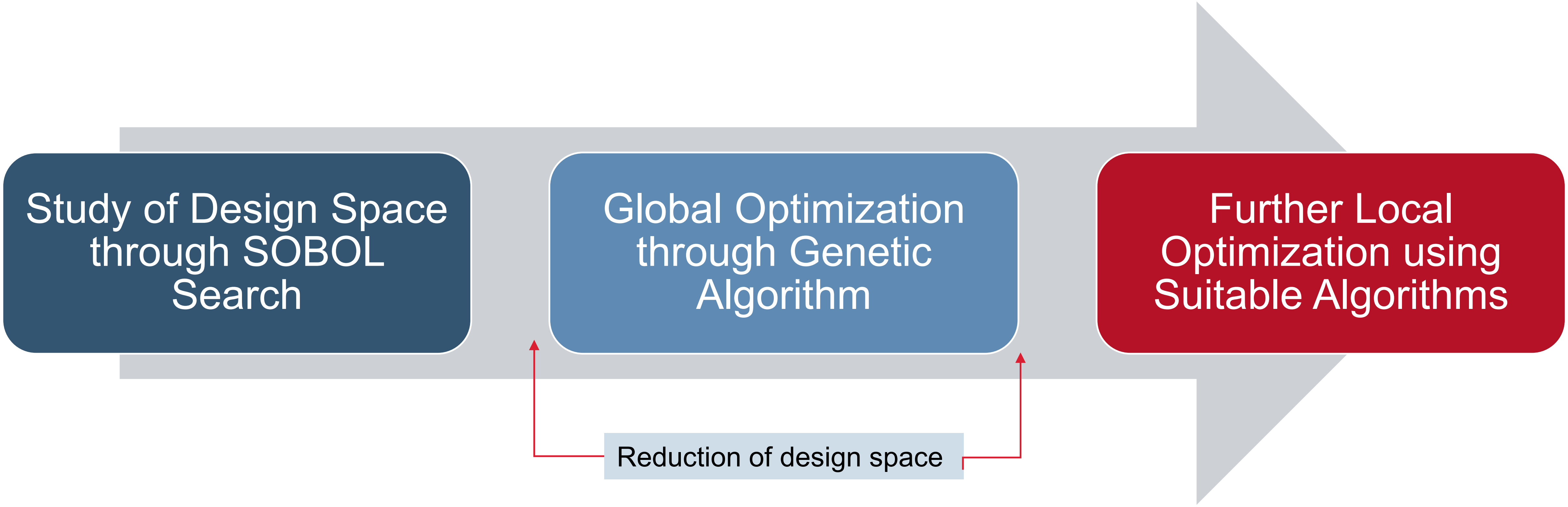
Summary:

- Optimization with Panamax beam and no limit on length have the best potential to push performance up
- Vertical stem bow type appears to have better performance compared to the bulbous bow type

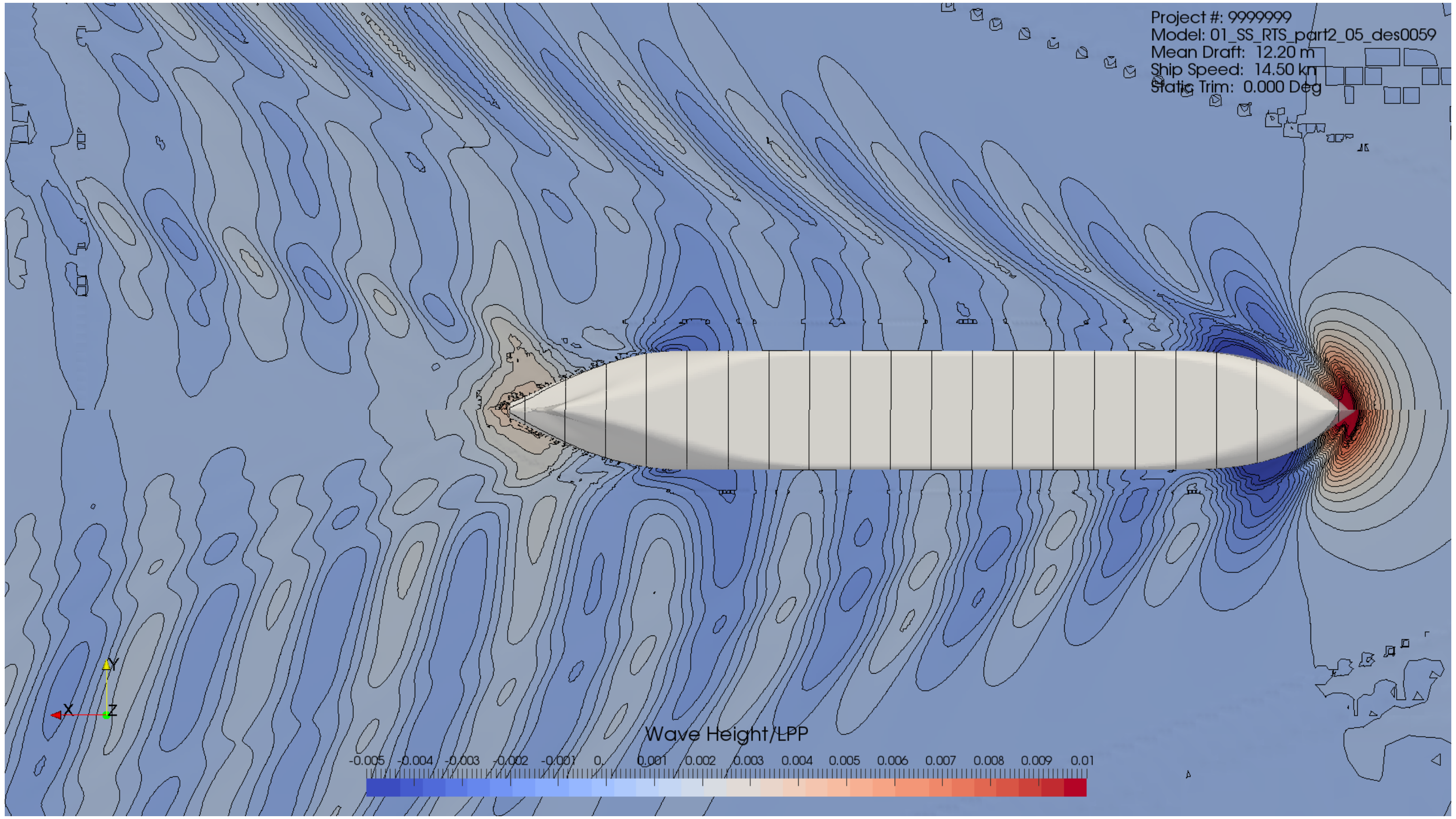


Example Procedure in Optimization

- Depending on the problem, different optimization algorithms will be used but in general, a multi-step approach is efficient.



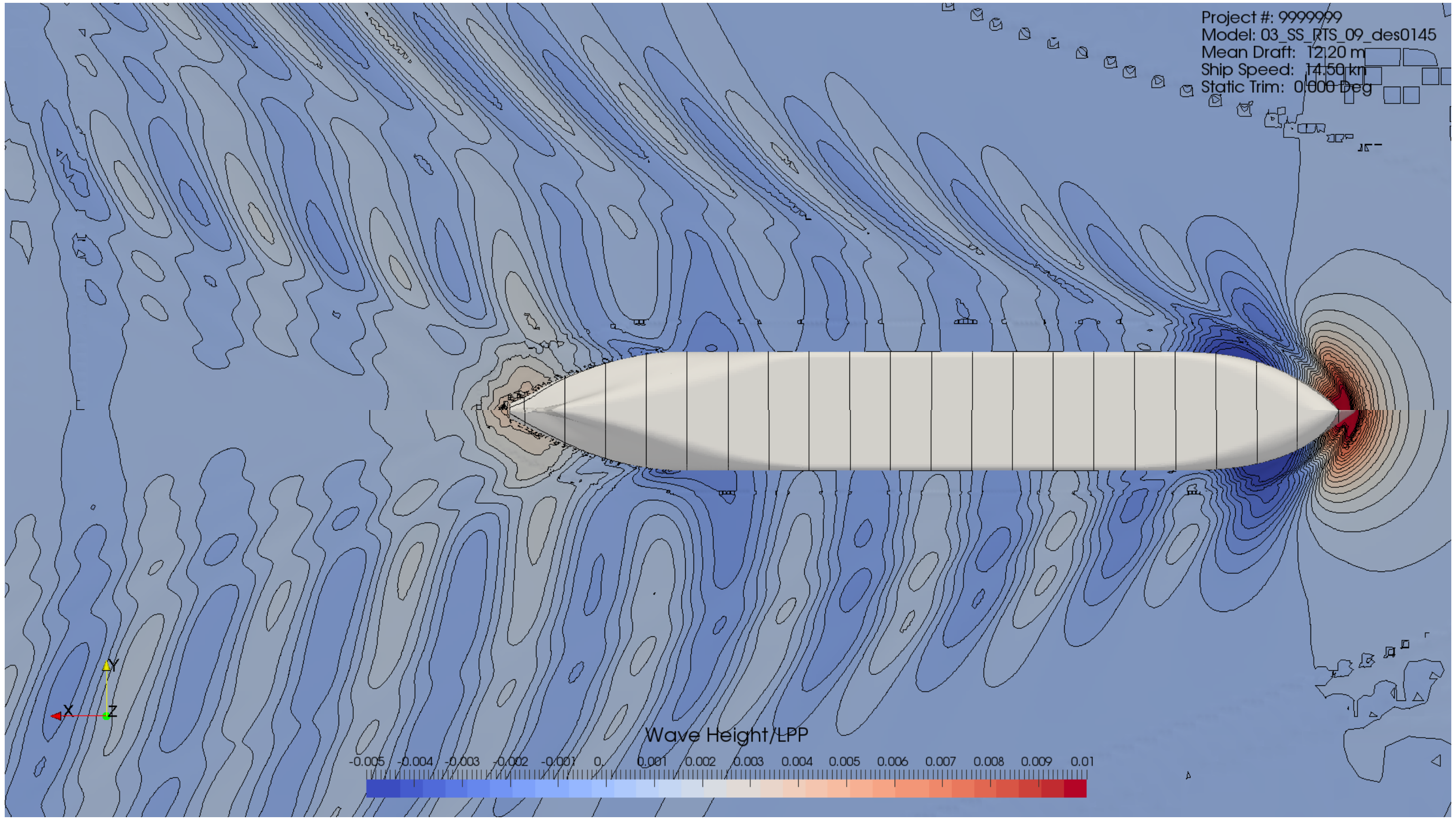
Wave Pattern Comparison



New Variant 1 (Bulbous Bow)

Baseline

Wave Pattern Comparison



New Variant 2 (Vertical Stem)

Baseline

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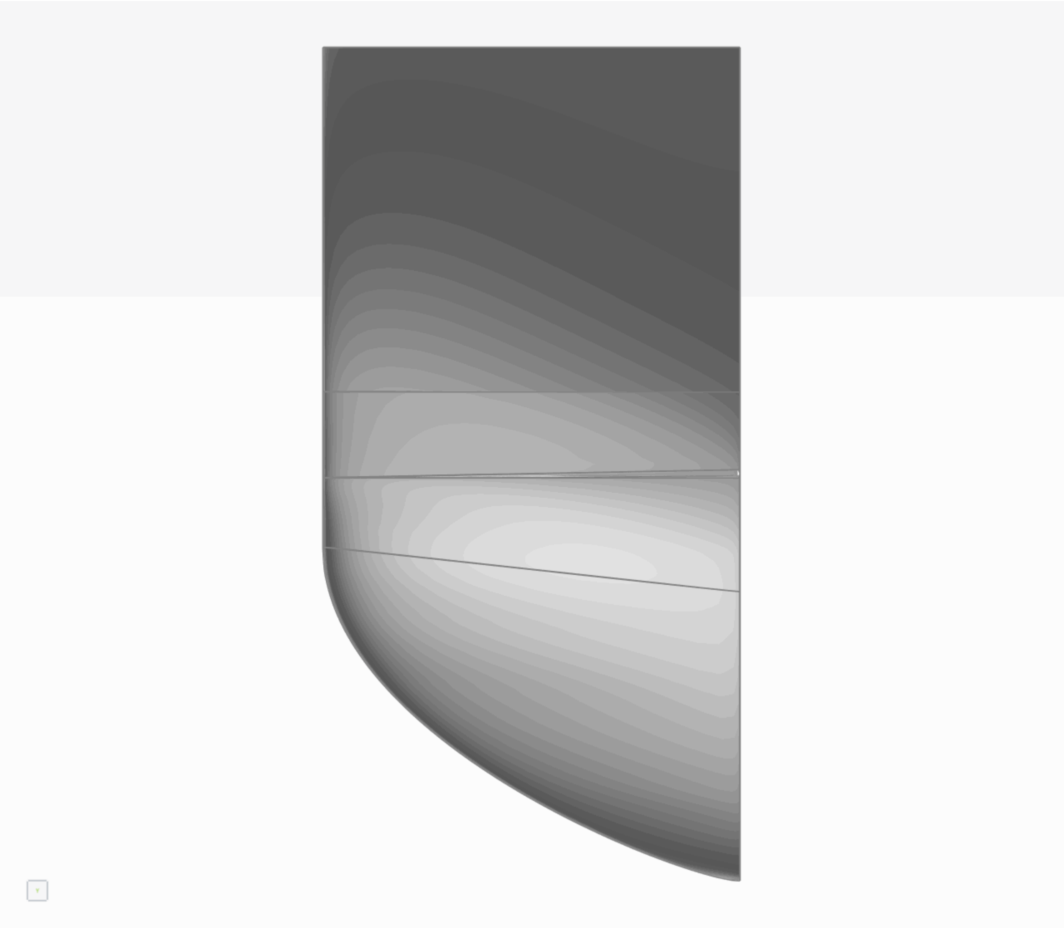
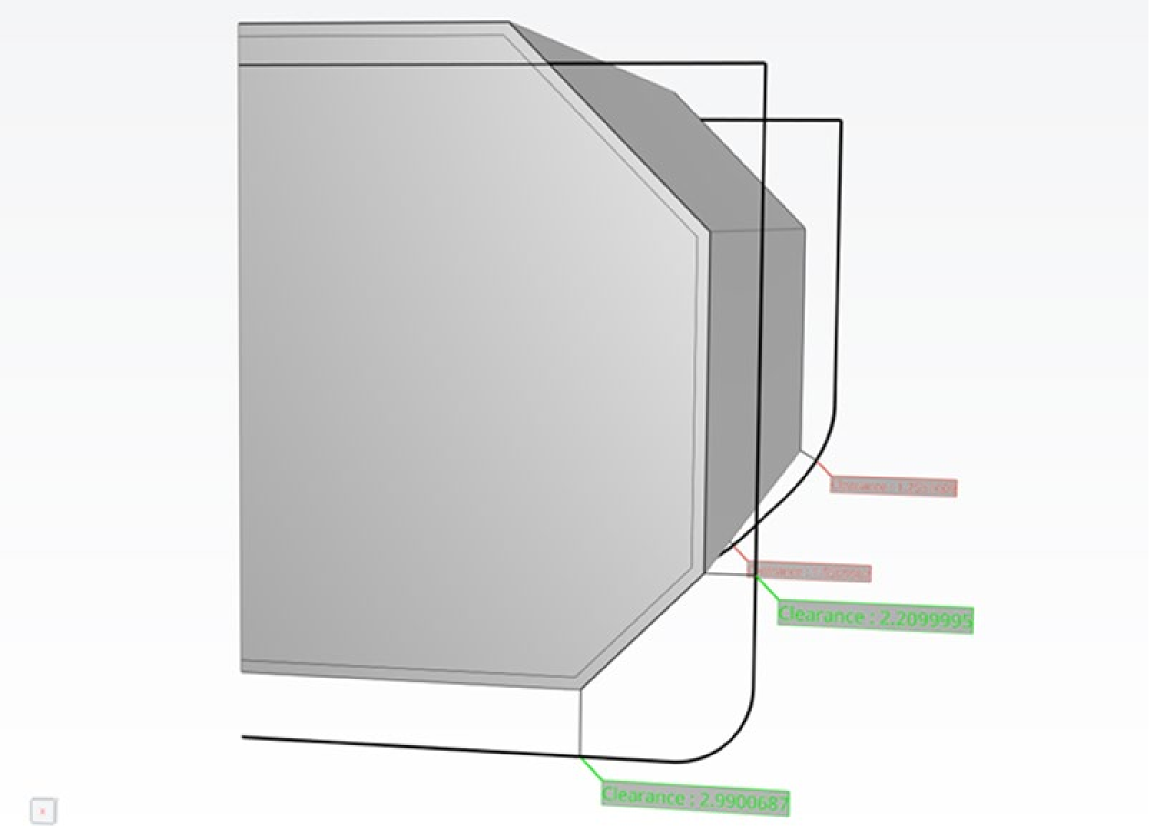
Building Flexible and Robust Parametric Model

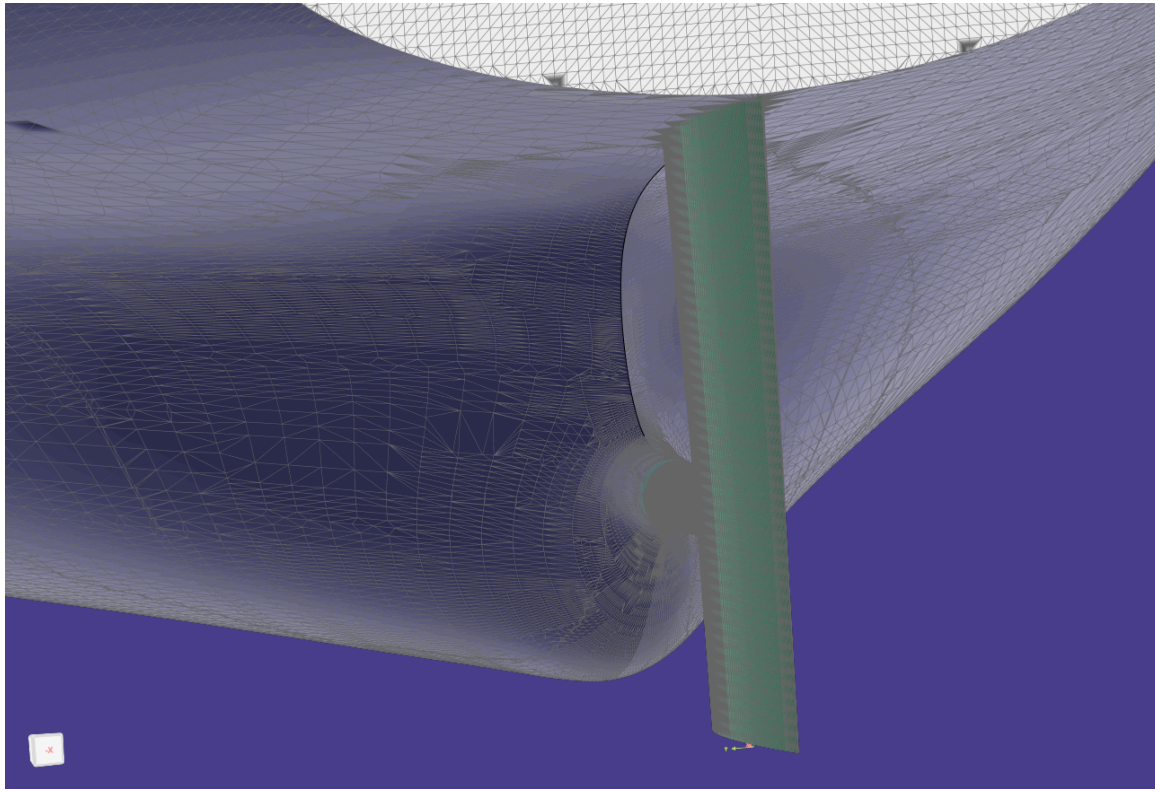


- It is possible to model not only vertical stem bow but also bulbous bow with a single parametric model.
- The efficiency of the design space investigation depends on how the parametric model is built (e.g., number of design variables).
- How to implement the constraints should also be considered in building parametric models.

Extension of Parametric Hull Modeling Approach



- Automatically checking the hull tank clearance to ensure constraints are met.



- Example of partially parametric model for asymmetric stern hull.

Summary

- CFD-based parametric optimization approach is feasible for hull form design and optimization
- Parametric optimization approach enables a more efficient investigation of design space with various constraints and multiple objective functions
- It requires knowledge and experience on:
  - Computational fluid dynamics (CFD)
  - Parametric CAD modeling
  - Nonlinear multi-objective optimization
  - Ship resistance, propulsion and powering (<u>or the physics of the problem</u>)
  - Ship design, construction and operation (<u>or practical considerations of the engineering problem</u>)

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