CFD-based Hull Form Optimization for Improving Vessel Energy Efficiency

Dae-Hyun Kim | September 11, 2024

Who We Are

- ABS (American Bureau of Shipping) is a classification society, not a design firm. But ABS clients ask for assistance in making their ships more energy efficient and environmentally friendly.
- ABS Mission Statement:

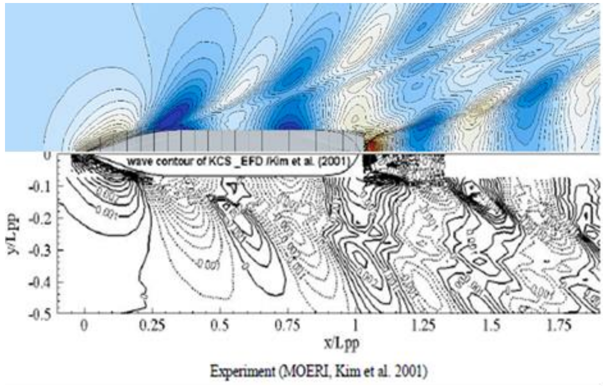
> *To serve the public interest as well as the needs of our members and clients by promoting the security of life and property and preserving the natural environment.*

- ABS Technology Americas has a CFD team that has been using CAESES for many years.
- Brief explanation of what ABS can provide our members and clients and an example of how ABS would use CAESES for a 210,000 m^3 twin-skeg (or twin-engine) LNG carrier will be presented.

Evaluation Capabilities

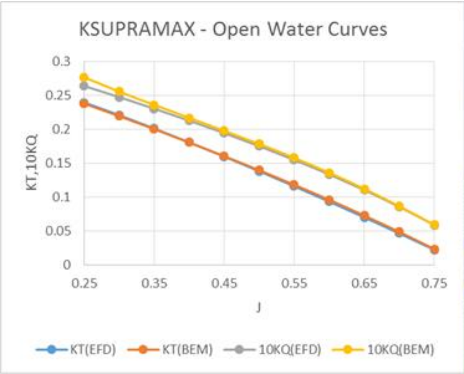
Hull Form Evaluation

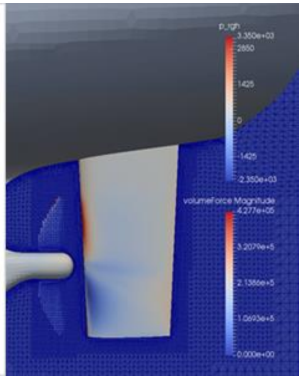
Dedicated HPC (High Performance Computing) center and highly automated simulation preparation make it possible to evaluate hundreds of hull forms daily using RANS (Reynolds-Averaged Navier Stokes) CFD tools. The computation results have been extensively verified and validated against experimental data.



Propeller Evaluation

CFD tools with various levels of fidelity can be utilized to evaluate the performance of a propeller in open water or behind hull. The available tools include RANS tools, Potential theory propeller tools, and coupling of RANS and Potential theory propeller tools.

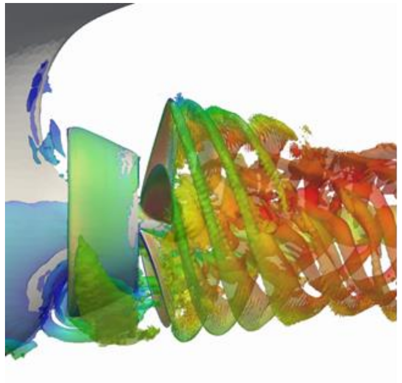


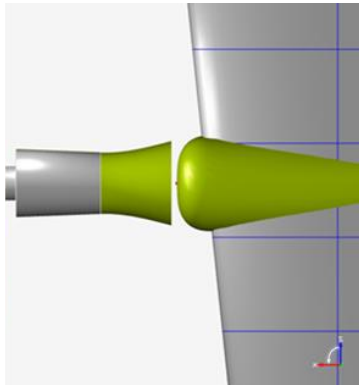


Experimental Results Courtesy of KTTC

ESD Evaluation

Evaluation of ESD (Energy Saving Devices) often requires the simulation of rotating propellers with the highest fidelity, but lower fidelity simulations are also used, such as body force propeller. The shape and alignment of different appendages such as rudder bulbs and bilge fins can also be evaluated.





Use of CAESES: Geometry Preparation, Fluid Domain Creation for Meshing, Automated Case Submission and Post-processing

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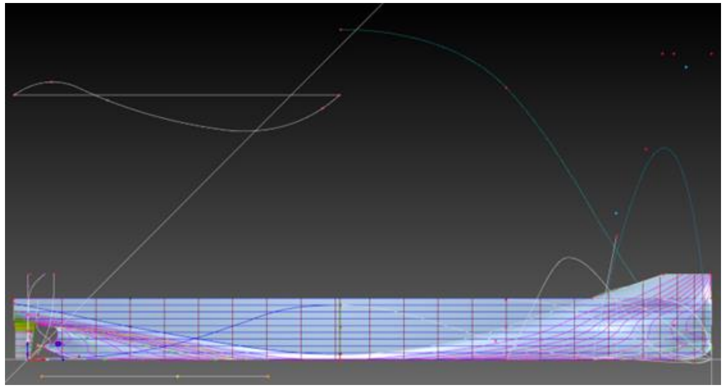
Optimization Capabilities

Global Hull Form Optimization

It has the advantage of reducing operating expenses and helping with regulatory compliance without any additional capital expenditure for new builds. RANS CFD tools are routinely used in model scale and full scale. A complex set of design constraints can be considered during the optimization.



Local Hull Form Optimization

This type of optimization can significantly improve the energy efficiency of a vessel with a relatively small investment in modifications. One example is a bulbous bow retrofit optimized for a new operational profile. Aftship optimization for improving propulsion efficiency is also routinely carried out.

Trim Optimization

Operating a vessel in the optimized trim could result in a significant fuel cost without any hull modification. The significant portion of saving comes from reduced residual resistance, because hull forms were often optimized for a design draft and speed.

Trim Optimization for power saving

	condition1	condition2	condition3	condition4	condition5	condition6
Trim1	-10.87%	-9.50%	-3.41%	0.18%	3.40%	4.15%
Trim2	-18.91%	-15.68%	-4.45%	1.90%	7.67%	9.38%

Use of CAESES: Full/Partial Parametric Modeling, Feature Programming, Automated Simulation Preparation, and Optimizers

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Importance of Getting Accurate CFD Results

- Calm water resistance computed by CFD and compared to JBC (Japanese Bulk Carrier) model test results from “2015 Tokyo CFD Workshop”.

JBC Benchmark (Fr = 0.142)					
	[knots]	**EFD**	**Coarse Grid**	**Medium Grid**	**Fine Grid**
Dynamic Sinkage	[mm]	-6.020	-6.339	-6.320	-6.294
Dynamic Trim	[deg]	-0.1031	-0.1098	-0.1094	-0.1085
C_{TM} x 10^3		4.289	4.258	4.245	4.294
(CFD-EFD)/EFD*100			**-0.72%**	**-0.82%**	**0.12%**

Experimental Results Courtesy of NMRI

- During optimization, relative difference between design candidates may be more important than absolute accuracy. But absolute accuracy itself is also important at the end of optimization.
- For high block coefficient vessel, the dynamic motions may not be that important. However, an accurate prediction of stern wake is important to ensure the accuracy.

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Case Study: Development of 210,000 m^3 Twin-Skeg LNG Carrier

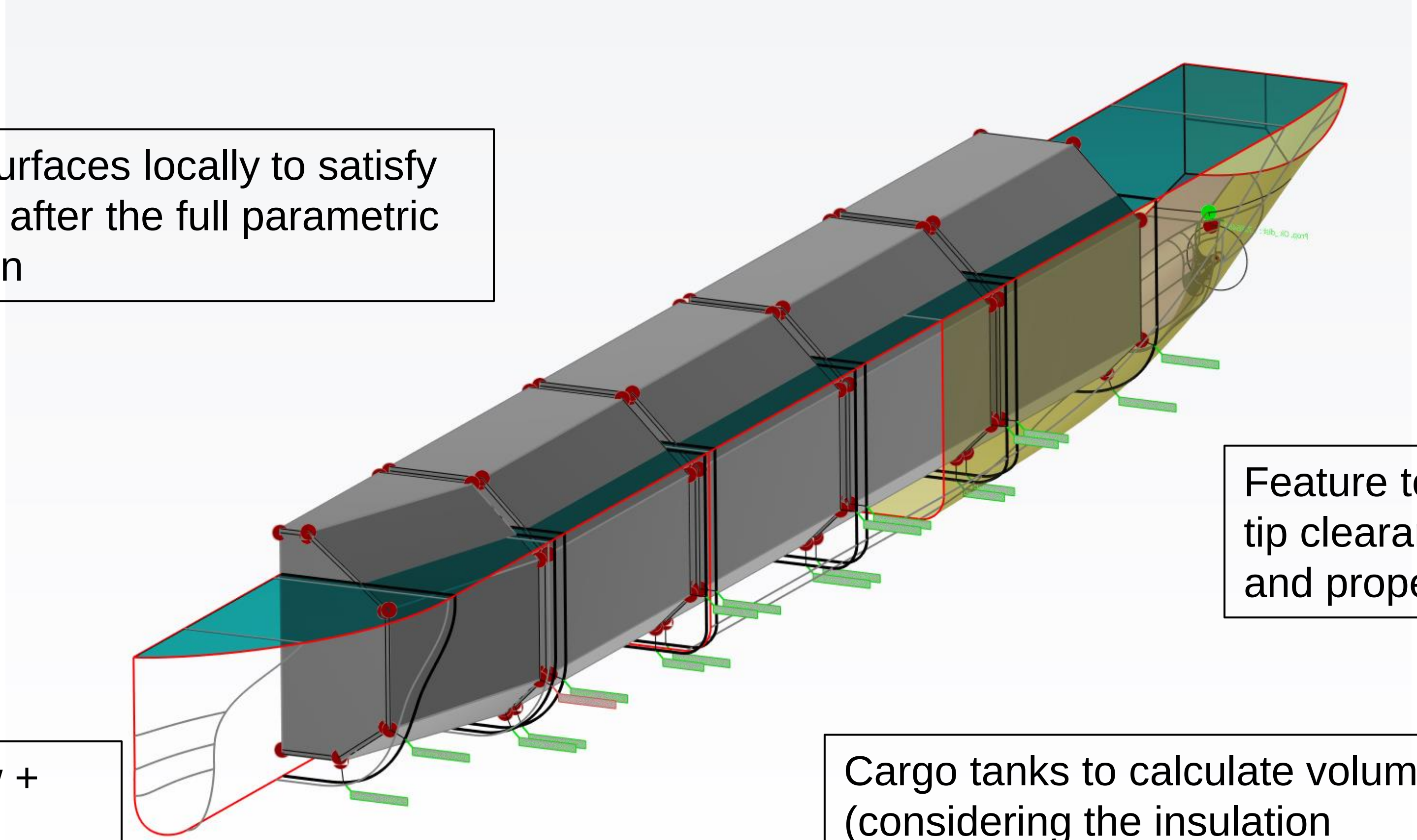
- Numerous questions may arise during the early stage of a new hull form development. Some of the questions might be as follows:
- *How much displacement can the vessel carry if the main dimensions (e.g., LBP, Beam) are to change from the reference hull? What's the total volume of cargo tanks?*
- *What's the optimal cargo tank arrangement and details considering the available information (e.g., tank section shape, tank length, cofferdam length, engine room size)?*
- *How much change in hydrodynamic performance should I expect? What's the maximum propeller diameter this vessel can have?*

Parametric Model of Twin-Skeg LNG Carrier can efficiently and practically address all these questions.

Parametric Model of Twin-Skeg LNG Carrier

Features to modify hull surfaces locally to satisfy all the design constraints after the full parametric modeling and optimization

Realistic way of modeling twin-skeg stern (asymmetry between inner and outer skeg surfaces)



Feature to calculate the propeller tip clearance between the hull and propeller tip

Parametric bulbous bow + shoulder with curves for sectional area curve, flat of side, flat of bottom, design waterline, and so on

Cargo tanks to calculate volume (considering the insulation thickness) and check the required clearance between hull and tank

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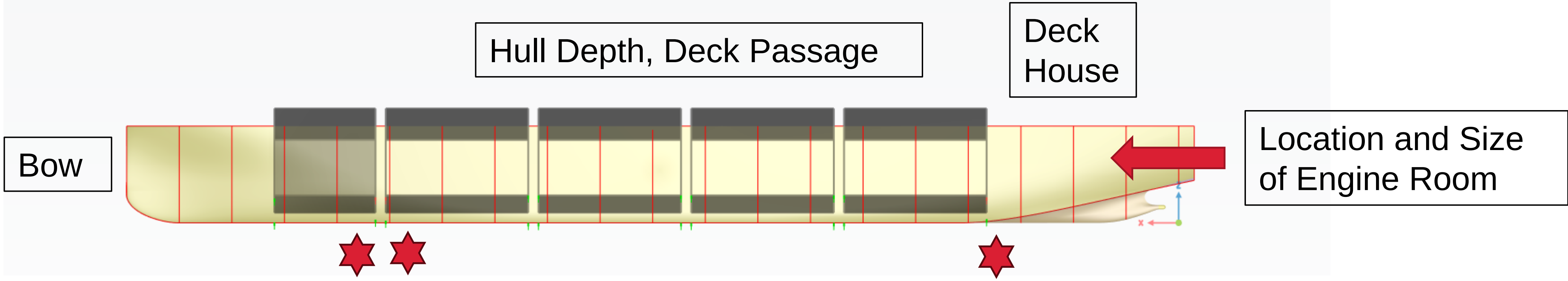
Parametric Model of Twin-Skeg LNG Carrier

Hyd. DesignDraft	
LPP	304.0000
Beam	50.0000
DesignDraft	11.8000
volumeDesign	138936.6747
wettedSurface	18610.2769
LCBDesign	147.7483
VCBDesign	5.5976

Hyd. Ballast Draft	
LPP	304.0000
Beam	50.0000
BallastDraft	9.5000
volumeBallast	109097.9895
wettedSurfaceBallast	16902.0604
LCBBallast	148.9927
VCBBallast	6.2023

Tank Dimension	
Tank1Length	29.2000
Tank2Length	41.2000
Tank3Length	41.2000
Tank4Length	41.2000
Tank5Length	41.2000
Cofferdam	2.9500
xTank5Start	55.5000

Tank Volume	
volume_value	27046.9637
volume_value	47527.1126
volume_value	47527.1126
volume_value	47527.1126
volume_value	47527.1126
volume_total	217155.4142
volume_target	217000.0000



Critical "hard points"

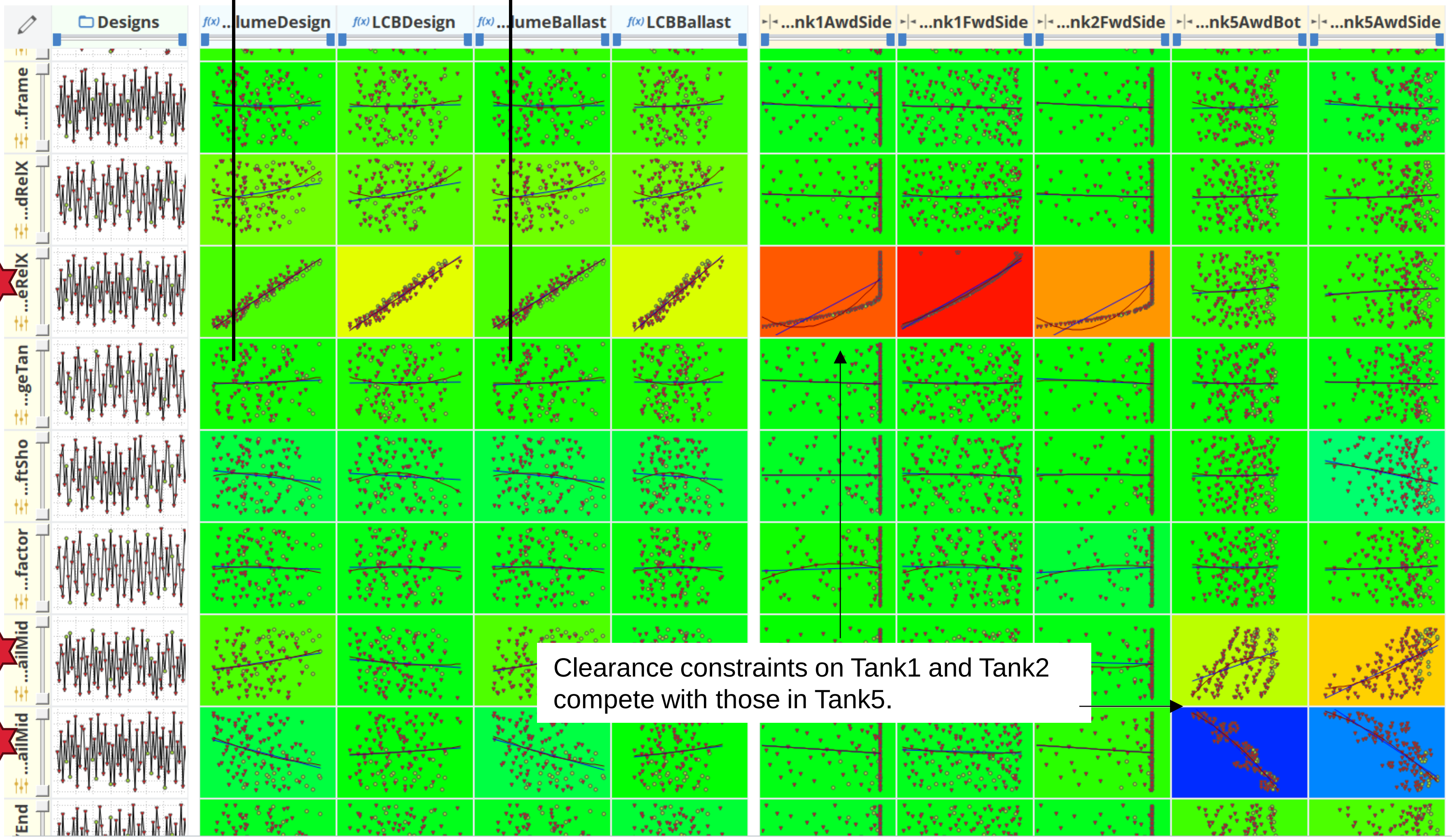
Competition, e.g., between tank volume and clearance between hull and cargo tanks (while minimizing required power) → Optimization Problem

Exploration of Design Space with Constraints

Target Vol at Design D

Target Vol at Ballast D

Monitoring Clearance on Tank1, 2, 5



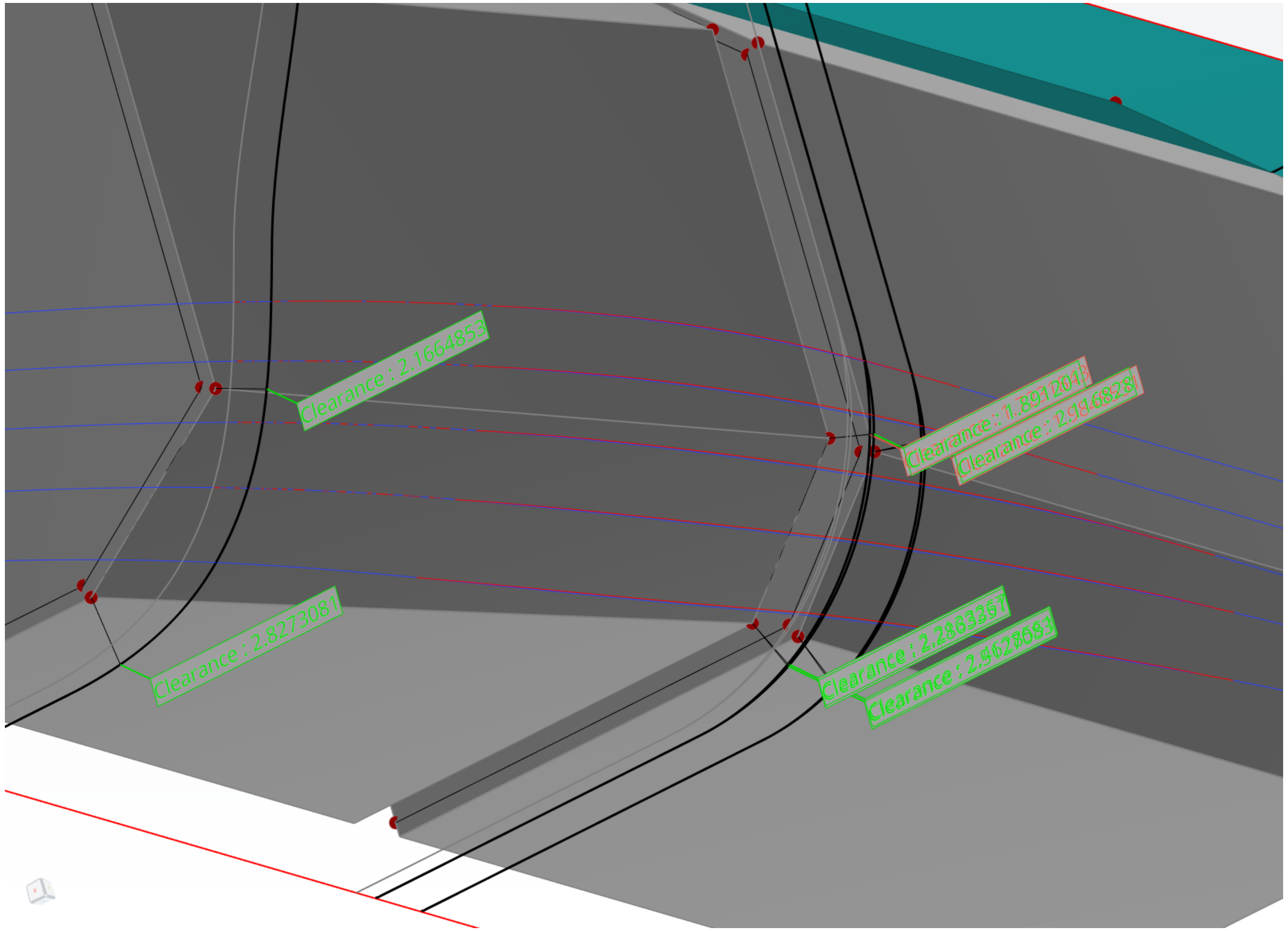
In this example, L, B, D and Tank Details (Size, Starting point, Cofferdam) are fixed. Also, a target displacement at design draft and ballast draft are known.

SOBOL results suggest the ranges of three parameters (marked with red six-pointed stars) may require adjustments.

From here, there are numerous paths. For example, if the designs all look reasonable, it also means that the L, B and D could be adjusted in a way that the displacements are reduced. Or the tank volume could be increased with the same L, B, and D.

By repeating this process several times, the answers to the previous questions could be addressed.

Partially Parametric Approach



The fully parametric model is a powerful tool. But it may not be easy to satisfy all the constraints while minimizing the changes in other areas.

Therefore, the model is equipped with various Features to modify the hull locally after the optimization is finished.

The waterlines in Red show the new surfaces that satisfy the tank clearance constraints, while the waterlines in Blue do not.

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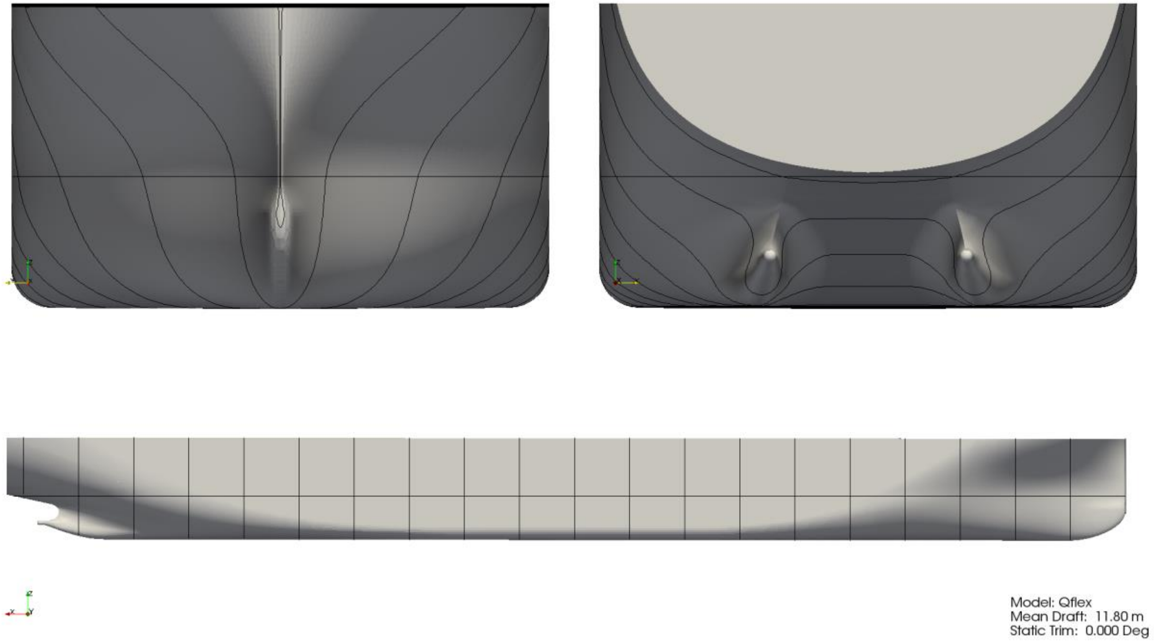
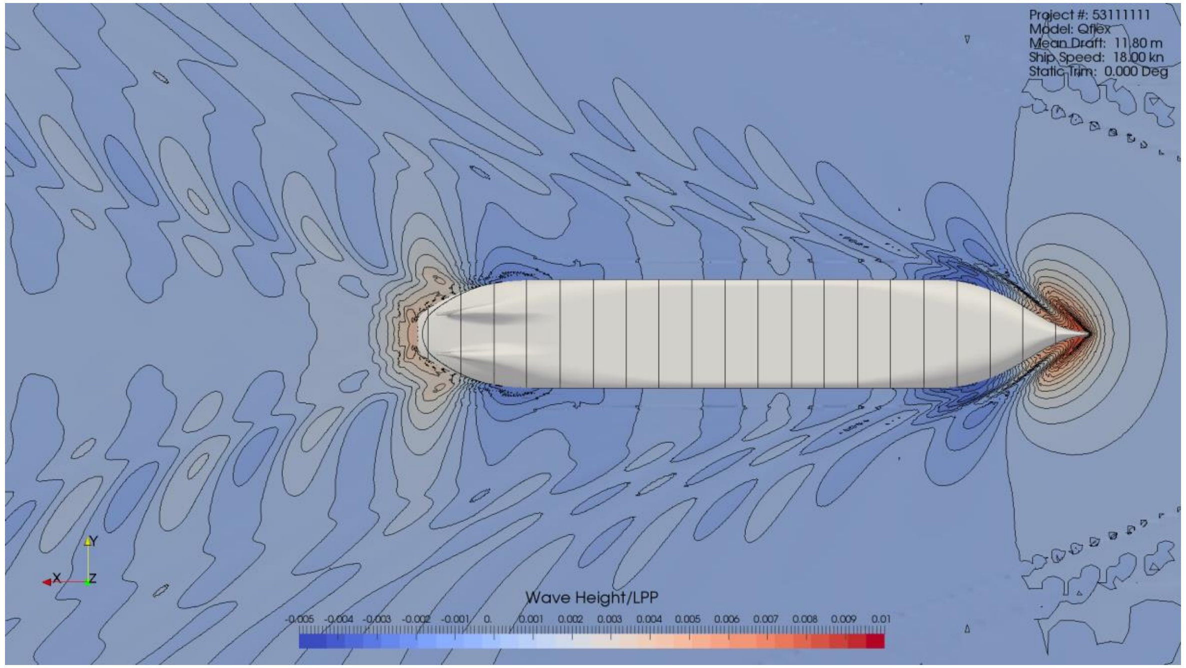
Example Baseline of 210,000 m^3 Twin-Skeg LNG Carrier

Geometry



Free Surface Wake



Optimization has NOT been carried out, but its estimated effective power is within 3-4% of a 210,000 m^3 hulls that had been built.

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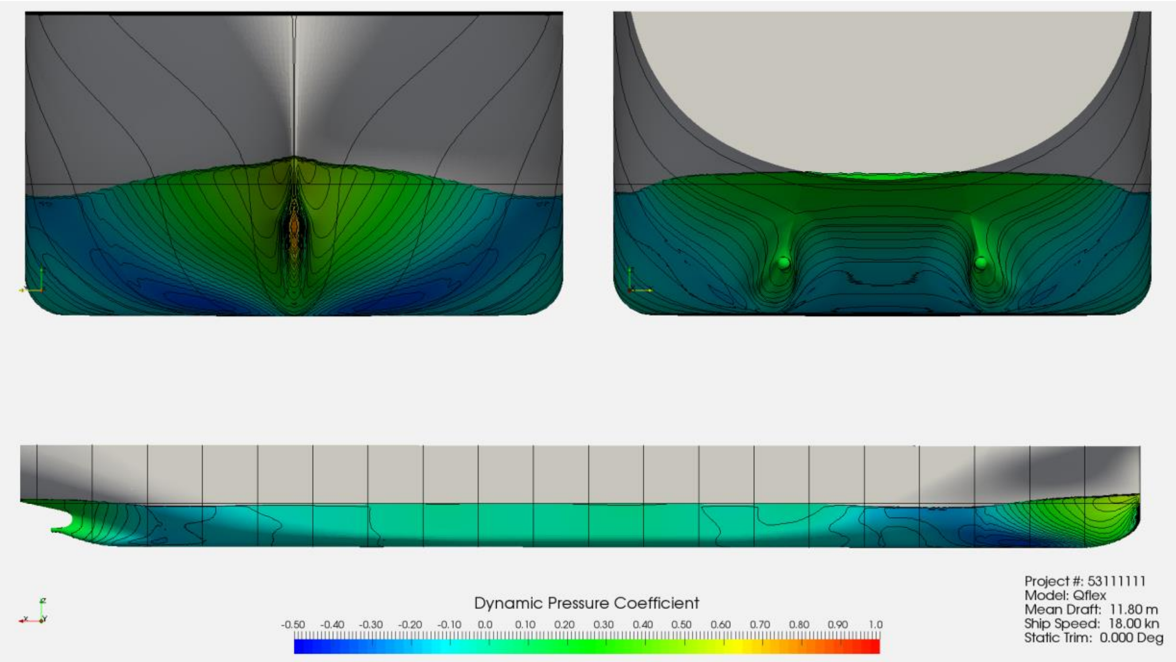
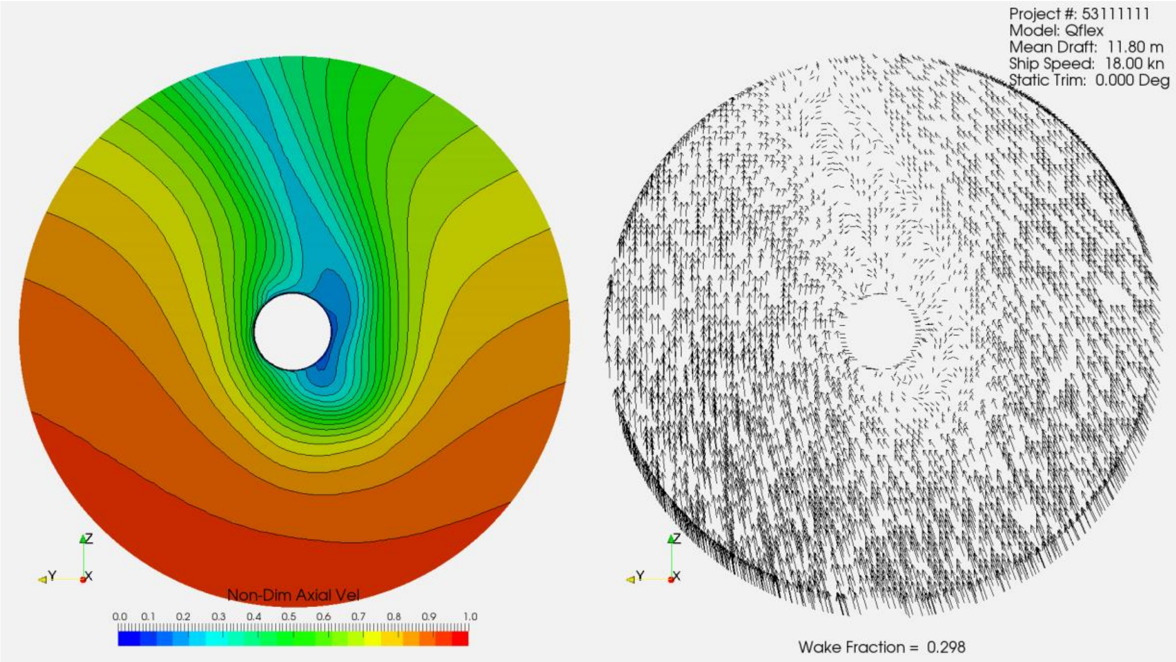
Example Baseline of 210,000 m³ Twin-Skeg LNG Carrier

Dynamic Pressure

Nominal Wake at Propeller Plane





This reference hull can accommodate a propeller with bigger diameter (about 15%) compared to a 210,000 m³ hull that had been built.

Summary

- ABS has been helping the marine industry to achieve better energy efficiency on new ships or existing fleet.
- CAESES software is critical for evaluating and optimizing the energy efficiency of ships with the ABS RANS-based CFD frameworks.
- Fully parametric models, including the twin-skeg LNG model shown in the current presentation, are available at ABS. These models have been successfully utilized for many industry projects.
- Today's presentation is a brief illustration on how ABS would use the fully parametric model to explore the design space at the early hull form development stage.

Thank You

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