SINTEF OCEAN BENCHMARK BULK CARRIER "SOBC-1"

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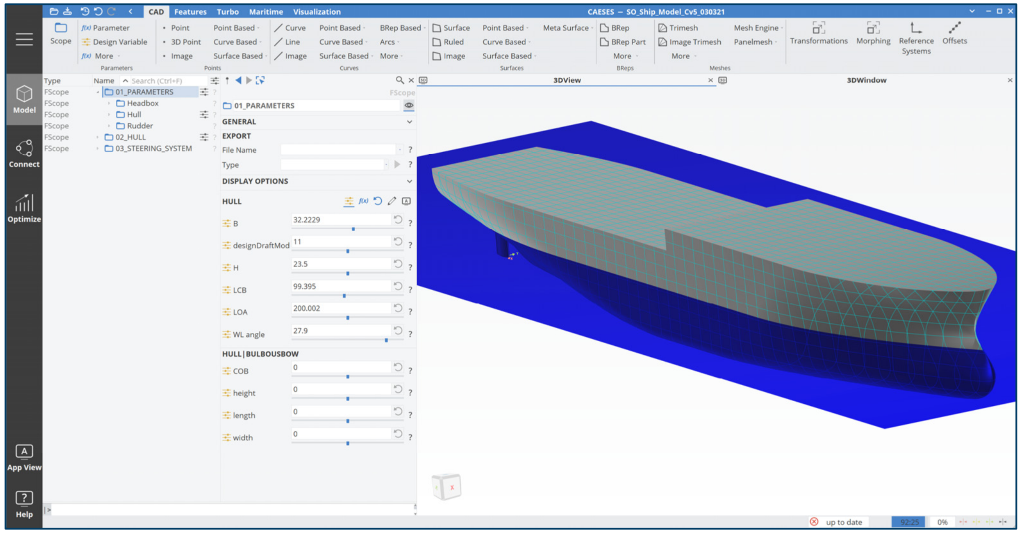
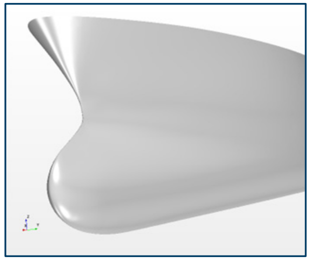
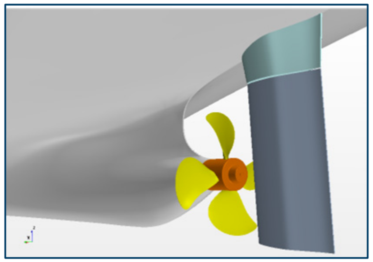
Abstract

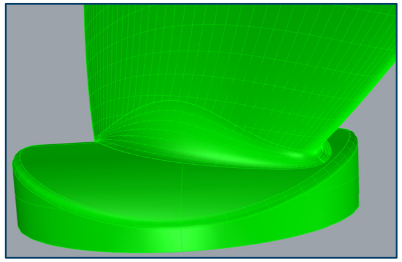
Achievement of historical targets set by IMO with regards to decarbonization of shipping requires novel ship concepts, which use clean fuels and sustainable energy sources, and which are highly optimized for their mission. Ship energy efficiency is one of the principal levers in the transition of the shipping industry to a climate neutral status. Design of an energy efficient ship is an interdisciplinary problem where propulsion efficiency plays a crucial role. The solution of this problem requires design tools appropriate for the task. Validation of methods employed by the design tools and creation of an open-access database of reference ships are therefore essential.

With support from the Research Council of Norway, SINTEF Ocean has produced the design of the "SINTEF Ocean Bulk Carrier" (SOBC-1). The design is conceived to be representative of the class of medium-size, single-screw tank/bulk carriers for short- to medium-range shipping. It features unconventional main dimensions originating from the feasibility studies conducted in the Centre of Research-based Innovation "Smart Maritime programme" (http://www.smartmaritime.no/) in 2019, and it implements state-of-the-art solutions regarding the hull lines, controllable pitch propeller and high-efficiency rudder. The SOBC-1 is intended to serve as testbed and demonstrator – physical and numerical – for various energy efficiency solutions and innovative "low-"/"zero-" emission technologies. Within the first phase of model test campaign, both the conventional and wind-assisted propulsion tests have been conducted. Some of the tests have been replicated by numerical simulations, including high-fidelity CFD. Presently, the SOBC-1 case is used in several ongoing research projects with the focus on further improvements in ship's hydrodynamic performance, using the methods of CAE simulation driven design.









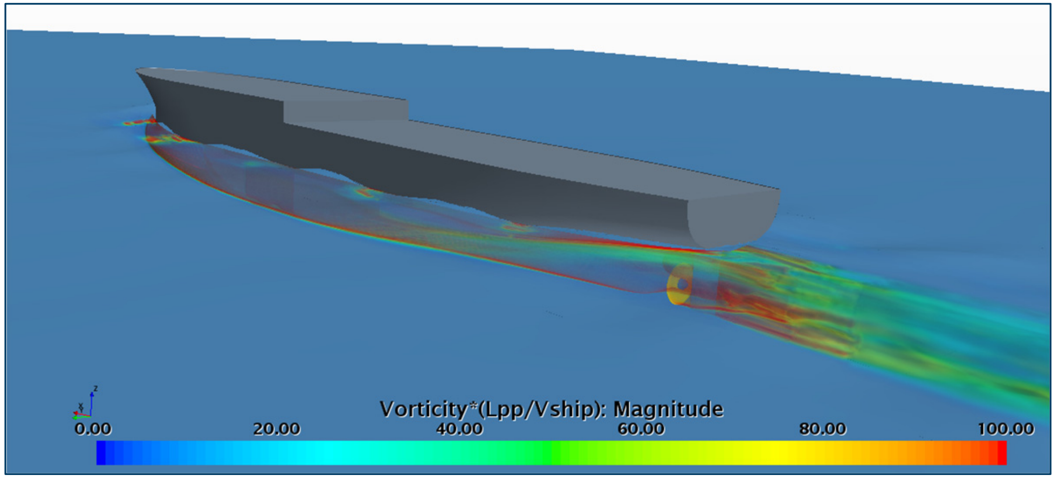
Contents

1) Concept and current design of the SOBC-1

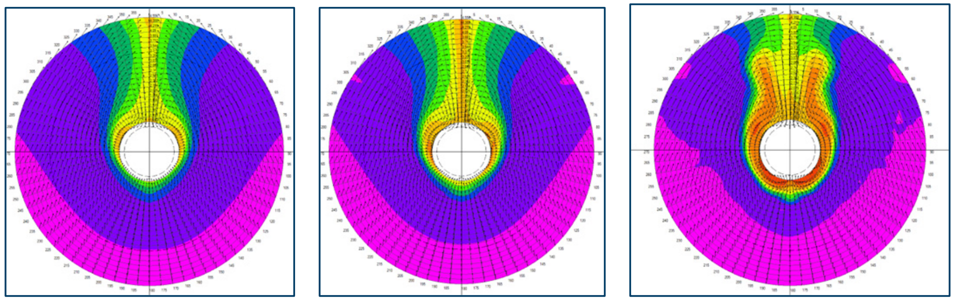
Overall concept of the SOBC-1

- Develop an in-house open geometry demonstrator which is representative of a realistic class of vessels and which incorporates state-of-the-art design trends;
- Use the designed ship as a testbed (physical in model scale and numerical in both the model scale and full scale) for various energy efficiency solutions and innovative "low-"/"zero-" emission technologies;
- Create a continuously updated, open-access validation database using the results of model tests and numerical simulations;
- Demonstrate the benefits of CAE simulation driven approach to ship performance optimization;
- Build a digital twin of the reference ship using the Open Simulation Platform (OSP) framework

Full-scale LES CFD simulation of SOBC-1 in self-propulsion condition



Time-average nominal wake field at propeller plane computed by CFD



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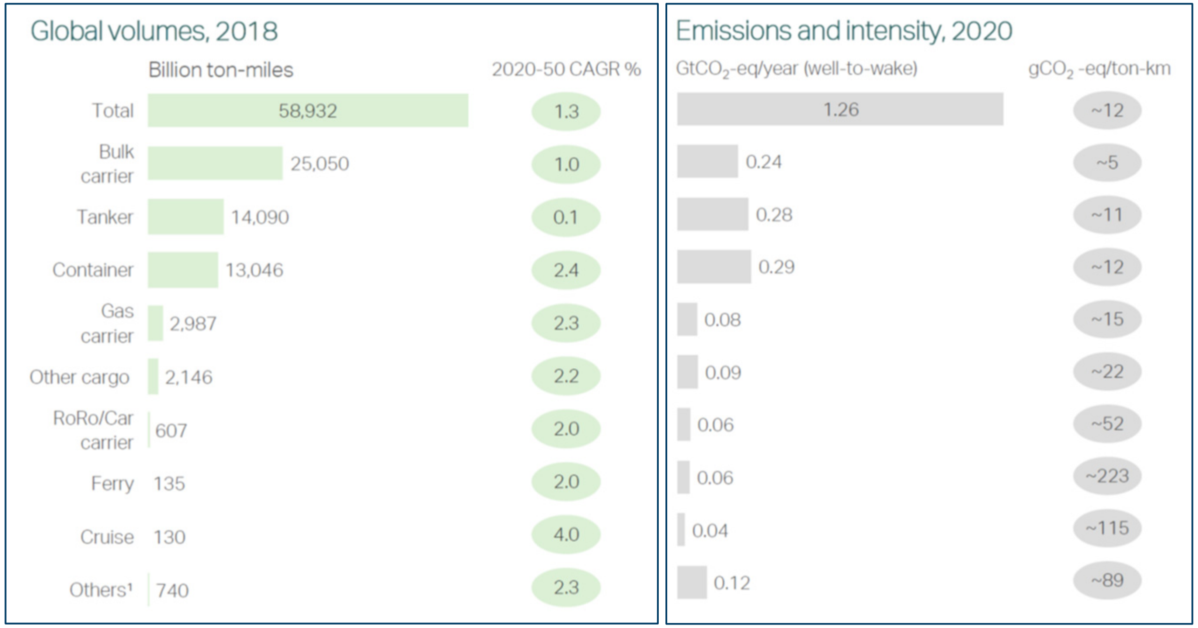
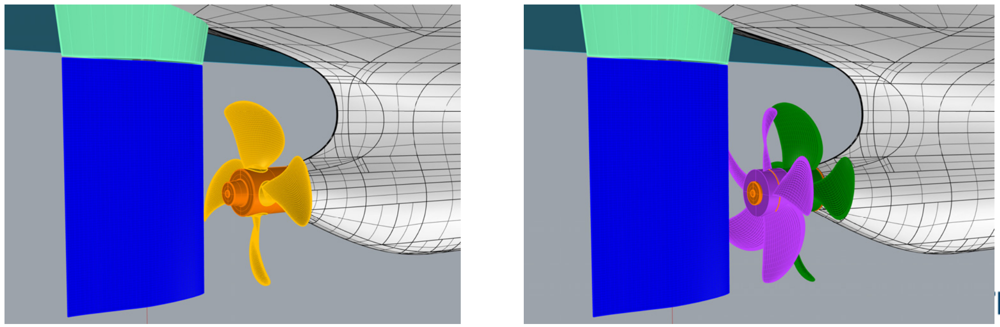
Background for choosing the vessel

- Generic medium-size, medium range, single-screw tank/bulk carrier, but having unconventional main dimensions
- This type of vessel is representative of a significant part of the global transport fleet, and it is regarded as one of the priority targets for the application of Green Shipping technologies
- An improved hydrodynamic design of the ship can demonstrate the benefits of choosing unconventional main dimensions in a fairly conservative market, as well as capabilities of simulation driven design approach for multi-objective optimization
- This vessel type is relevant for the demonstration of the following aspects:
    - Main dimensions optimization
    - Reduction of added resistance in waves
    - Requirements regarding minimum available power and vessel manoeuvrability in adverse sea conditions
    - Use of Controllable Pitch Propeller (CPP) to optimize powering in heavy seas and improve efficiency in moderate to rough seas
    - Wind propulsion (+ CPP propeller + ESDs)
    - Air lubrication
    - Energy Saving Devices (ESD) and high-efficiency propellers
    - Holistic optimization of GA, hull form and propulsion arrangement

Source: Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (2021): Industry Transition Strategy, October.



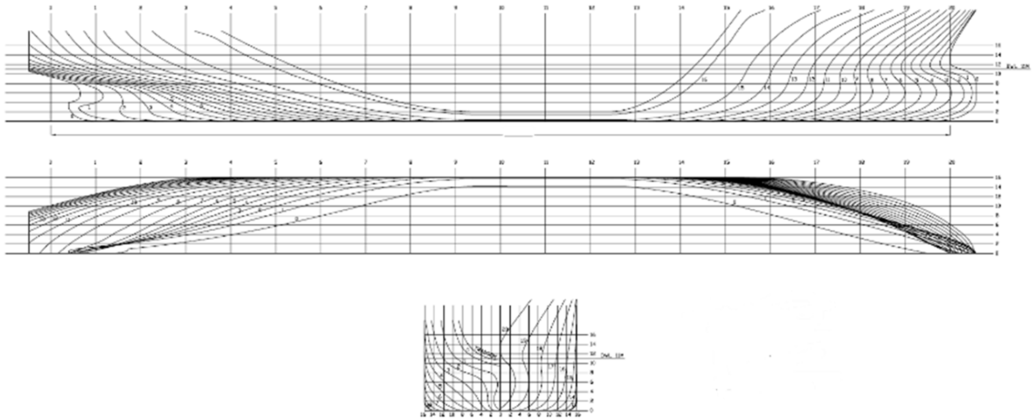
One of the ongoing activities: Designing innovative CRP system for SOBC-1



Main particulars and design conditions

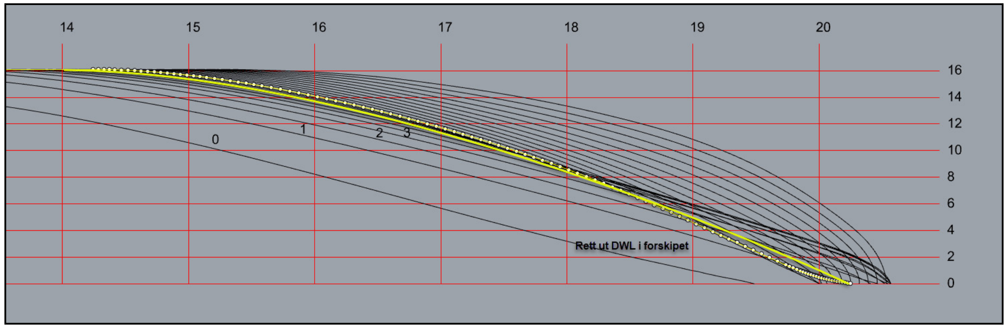
Feasibility studies conducted in the SFI Smart Maritime in 2019, Deep sea case

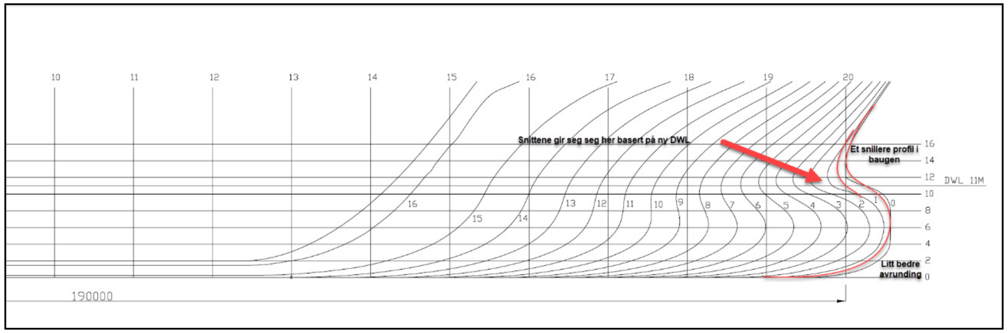
Main particulars	Value	Dimension
Length between perpendiculars , Lpp	190	(m)
Breadth, B	32.2	(m)
Height, H	23.5	(m)
Draught design, T_DWL	11	(m)
Draught at ballast, T_BWL	7.7	(m)
Displacement, Δ	50.218	(tonnes)
Block coefficient, CB	0.726	(-)
Prismatic coefficient, CP	0.730	(-)
Operation speed range	6-15(17)	(knots)
Propeller Diameter, D	6.75	(m)
Propeller type	CPP, moderate skew	
Number of blades, Z	4	
Rudder type	Spade rudder with headbox, rectangular, high-efficiency profiles	

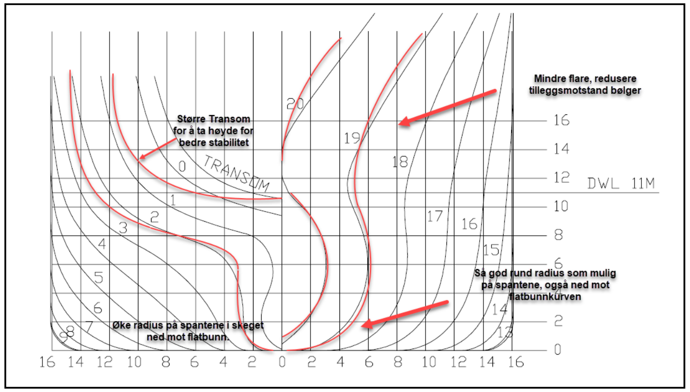


Design parameters	Value	Comments
Design speed, Vs (knots)	15	Assigned for a higher speed range; at lower speeds CPP can be utilized
Installed power, PB (kW)	8500	"Mean value" resulting from the power requirements studies using statistical data on tankers and bulk carriers in head seas
Hull resistance, Rts (kN)	510.16	Estimated in ShipX for a database vessel with similar dimensions
Axial wake fraction, WT	0.26	Estimated in ShipX for the same database vessel as Rts, but "t" is corrected according to CFD calculations for similar ships
Thrust deduction factor, t	0.215	
Relative rotative efficiency, η_r	1.007	
Distribution of *effective* axial wake, Ux(r)		Scaled from CFD calculations done in earlier projects

Hull design iterations







Feasibility studies conducted in the SFI Smart Maritime in 2019, Deep sea case provided input to the selection of prototype design and choice of the main particulars. The hull line were further optimized in the design process of SOBC-1.

Design considerations

- Hull shape optimized for resistance in calm water may appear sub-optimal for operation in waves.
- Optimization of hull lines from the standpoint of resistance should be considered along with the requirements of stability.
- Slimmer aftship configuration is beneficial for reduction of resistance, but it results in lower hull efficiency $\eta_H = \frac{1-t}{1-W_T}$, and therefore may have adverse effect on propulsion performance; it also reduced potential gains from the installation of pre-swirl ESDs.
- Bow bulb cannot be optimized for one "design" speed and draught if the vessel should operate efficiently under off-design conditions. When optimizing the bulb shape one also needs to ensure its smooth integration with hull to avoid knuckles of small radius and other areas of large surface gradients.
- Increase of propeller D (and reduction of RPM) is advantageous from the standpoint of propeller efficiency, but one needs to observe a reasonable tip clearance at 12 o'clock to ensure acceptable level of pressure pulses on the hull, as well as sufficient margin between blade tip at 6 o'clock and base plane to mitigate risk of propeller damage at grounding.
- Placing rudder closer to propeller improves the hull efficiency, but it increases unsteady loads and risk of cavitation on the rudder at non-zero rudder angles.

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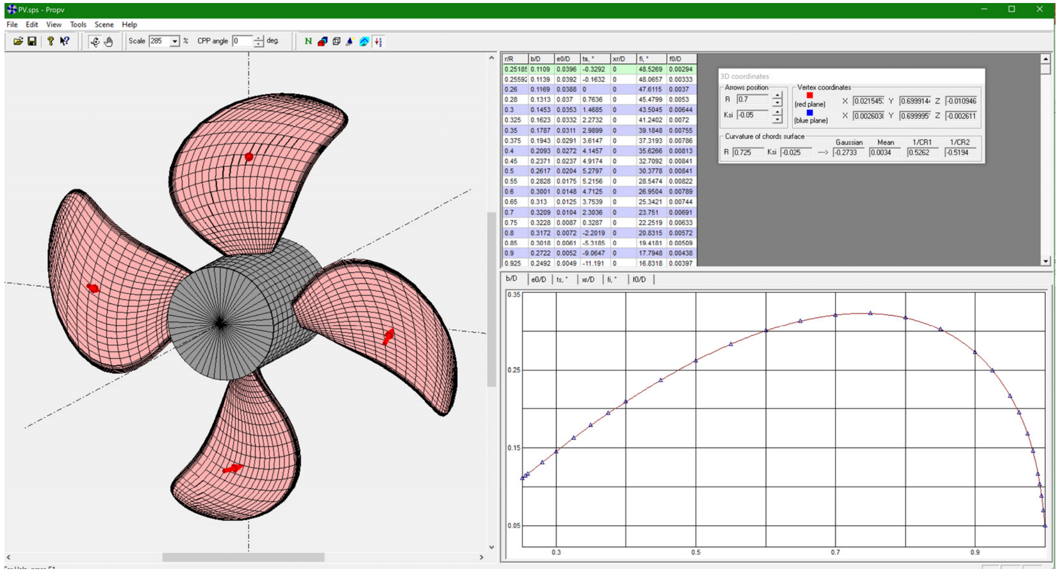
Propeller design workflow

Input
- Design parameters and constraints
- Vs, Rts, available kW
- Prop. Factors: WT, t, η_r
- Propeller type, D_init, rh
- First database estimations for RPM, P/D, $\eta 0$, ηD

Preliminary design

PPD
- Variation of propeller D and RPM
- Choice of Z, Ae/Ao
- Preliminary blade design
- Blade strength check against class rules

Propeller model in AKPA



Detailed design of wake-adapted propeller

CFD database
- Assumption about effective wake on propeller

AKPD *(lifting surface)*
- Variation of propeller RPM in wake
- Optimum pitch and camber distribution for wake adapted propeller

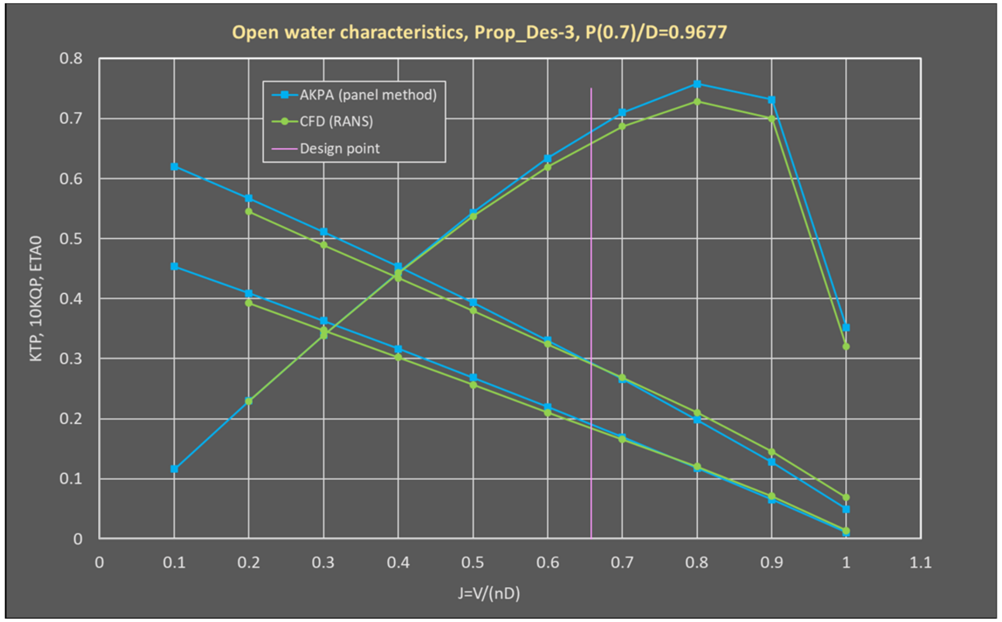
AKPA *(panel method)*
- Verification of propeller performance at design point: Thrust, Power, Cavitation margins
- Elaboration of blade geometry
- OW characteristics

Design verification and elaboration by CFD

CFD *(RANS)*
- Final check of propeller performance in OW
- Elaboration of hub design

Prediction of propeller OW characteristics and estimation of cavitation margins

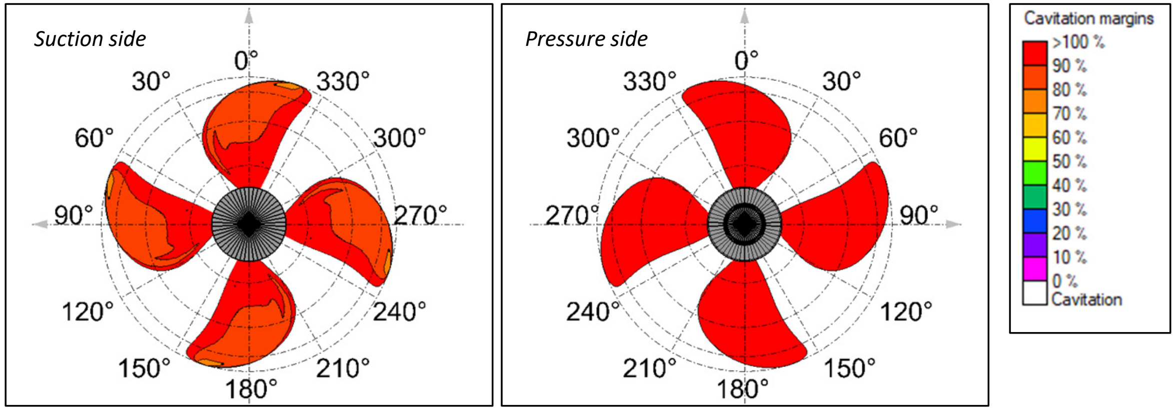
Predicted open water characteristics



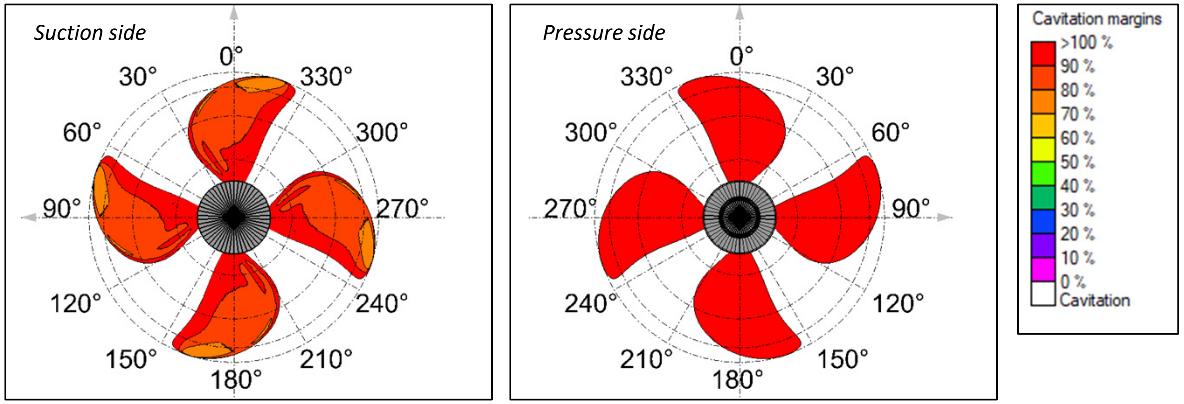
Comparison of propeller open water characteristics at the estimated "effective" design J_A=0.658

	Panel method	CFD | RANS
Thrust, KTP	0.19044	0.1844
Torque, KQP	0.02931	0.02915
Efficiency, ETA0	0.6807	0.6628
Spindle moment, KMY	-0.00029	-0.00025

Cavitation performance in average axial wake, Design WL



Cavitation performance in average axial wake, Ballast WL



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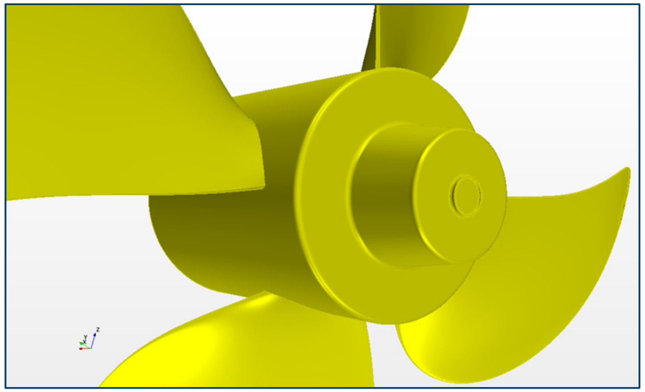
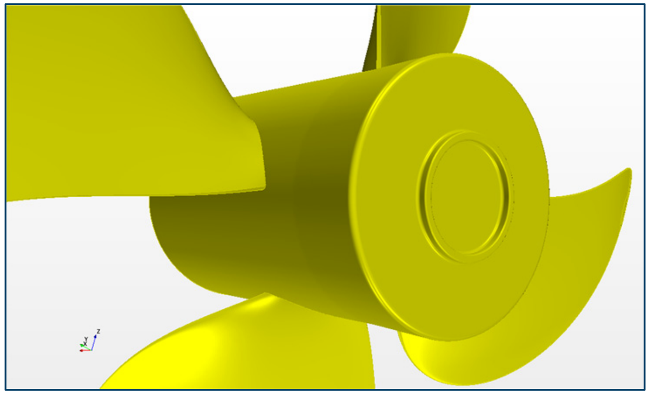
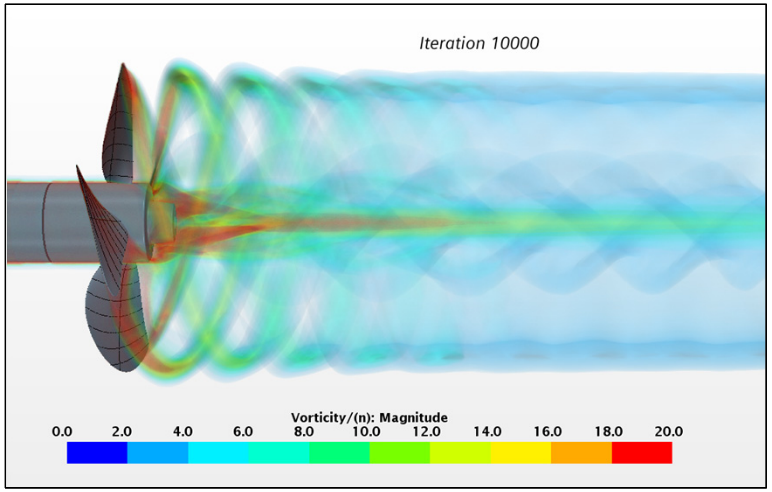
Propeller hub design

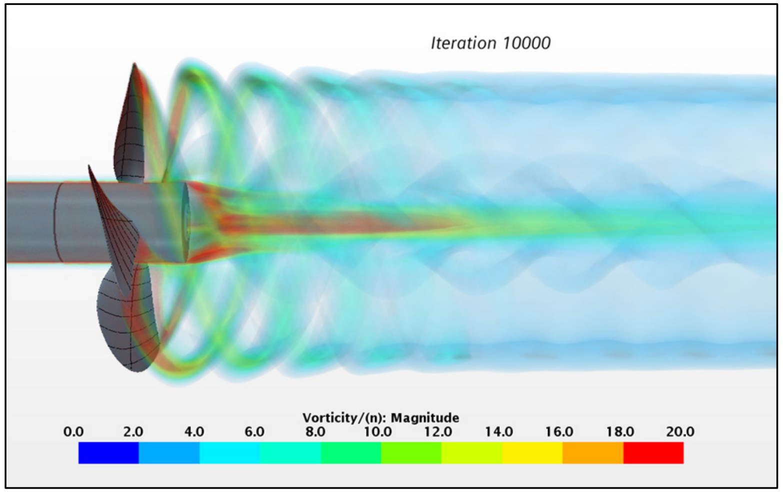
Hub-1



Hub-2







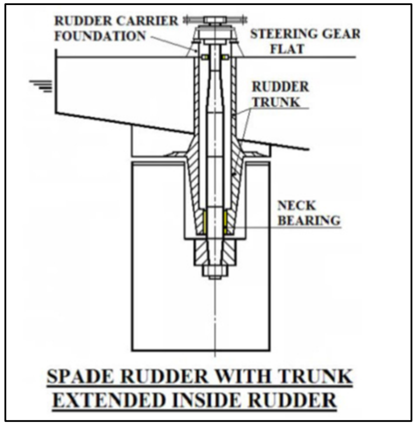
Installation of custom designed Propeller Boss Cap Fins (PBCF) is an effective measure to combat the axial hub vortex and at the same time improve propeller efficiency in behind hull conditions. For a CPP, the PBCF solution is not so straightforward, since the fins are normally optimized only for one pitch setting. Before more detailed design exploration studies on PBCF performance are conducted, one can consider simpler alternative solutions, for example truncated caps. The two configurations of a truncated cap (Hub-1 and Hub-2) have been evaluated through CFD (RANS) simulations.

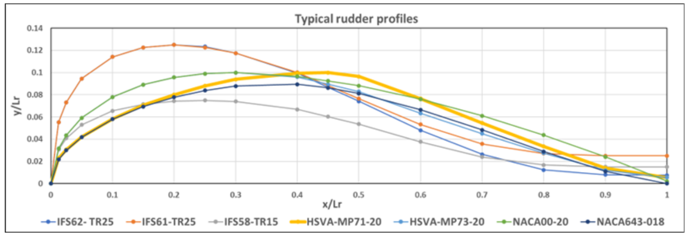
Both the hub cap configurations achieve the goal of reducing hub vortex strength compared to conventional hub caps. The configuration Hub-1 shows a slightly more dynamic picture of flow separation, but it results in lower overall vorticity magnitude, and lower hub resistance (KTH). In OW conditions, around the design point, the propeller equipped with Hub-1 has the efficiency about 0.5% higher compared to the same propeller equipped with Hub-2.

Additional measures to break vorticity separating from hub cap may included the installation of pins along the circumference of the cap outer radius.

Details of rudder design

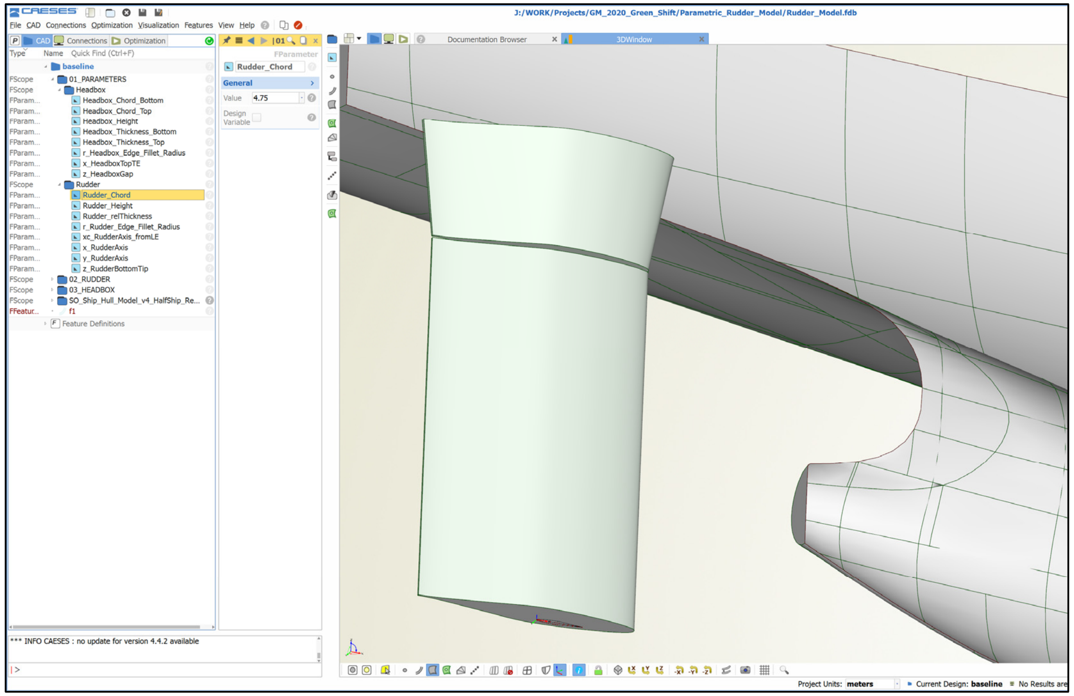
Rudder type according to DNV classification





Rudder profile: HSVA-MP71-10

Parametric models of Rudder and Headbox in CAESES



Main particulars of rudder	Value	Dimension
Rudder height, Hr	7.8	(m)
Rudder aspect ratio, Hr/Lr	1.642	(-)
Rudder projection area, Ar/(LPP*T_DWL)	0.0177 (*DNV – 0.0176*)	(-)
Distance between PP and rudder axis, Xp_ra/D	0.641 (*0.63÷0.65*)	(-)
Distance between PP and rudder LE, Xp_rLE/D	0.324	(-)
Max section thickness, tmax/Lr	0.20	(-)
Rudder shaft diameter, d_rsh	0.385 (*DNV – 0.3836*)	(-)
Rudder plane form	Rectangular	

The Rudder and Headbox models share the same section profile type. The Headbox model is developed from the considerations of streamlined shape and smooth integration between the rudder and hull, also allowing some distance from transom. The Headbox dimensions are chosen based on structural considerations for similar vessels and dimensions of rudder shaft and trunk.

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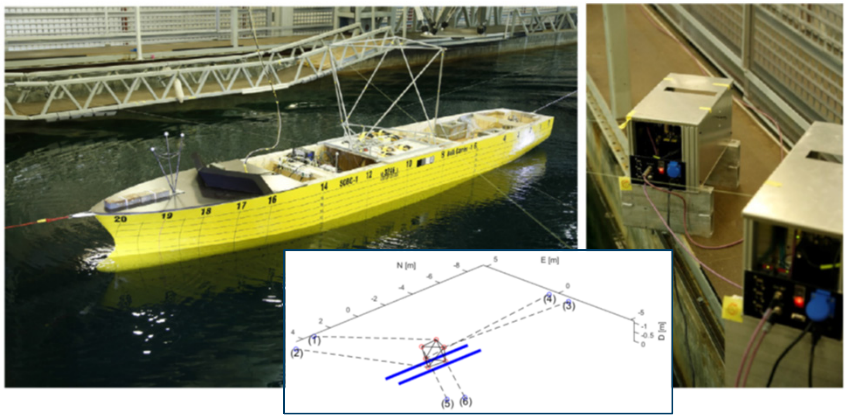
2) Model experiments and numerical simulations

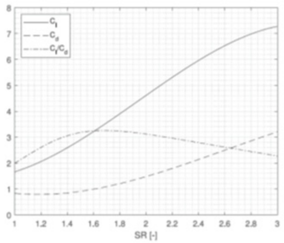
Model tests conducted with SOBC-1

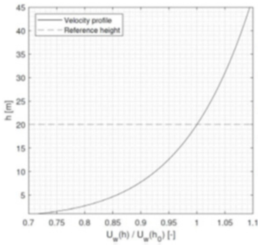
- Conventional propulsion test campaign in calm water
  - ✓ Towing resistance
  - ✓ Propeller open water
  - ✓ Self-propulsion
- Hybrid (cyber-physical) test campaign for wind-assisted propulsion
  - Ship is equipped with 4 Flettner rotors: height H_R=35(m), diameter d_R=5(m), spacing Δx_R=35(m); targeting 90% of required thrust, w/o interaction losses, at ship speed of 12(kn) in wind of 10(m/s) with TWA=110°, constant rotor speed of 180(rpm)
  - Wind field is described by an ABL power law profile (σ=9)
  - Optical motion capture system is used to control ship position
  - Aerodynamic rotor loads are calculated by a quasi-steady approach using a strip theory and polynomial representations of CL and CD computed by CFD, rotor-rotor interaction is neglected
  - Rotor loads are applied to the ship through a stiff frame mounted on the deck and connected by thin wires with six actuators mounted on the carriage
  - Free-running model with an autopilot acting on the rudder to ensure ship position at the centerline of the towing tank
  - Test matrix covers the range of TWS from 10 to 20 (m/s) and range of TWA from 30° to 150°, steady wind profiles.

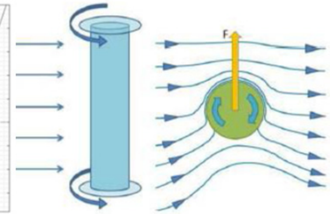
SOBC-1 Model: Scale 1:32, L_{PP}=5.938(m), D=0.21094(m), no tunnel thrusters, no bilge keels

Setup in the towing tank for hybrid wind-assisted propulsion tests







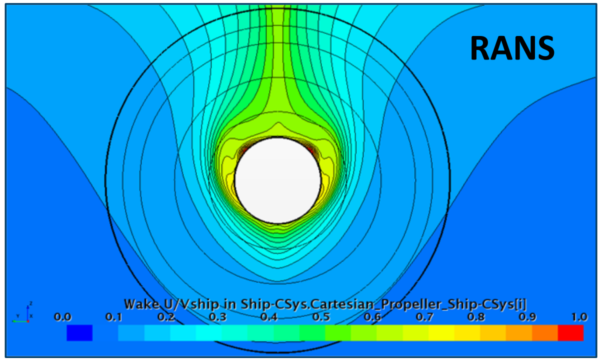


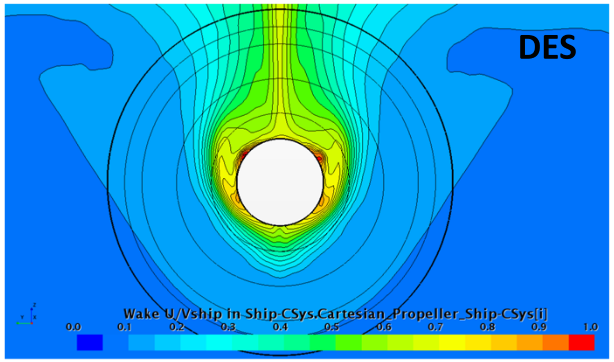
Ship towing resistance and nominal wake field predicted by different turbulence models

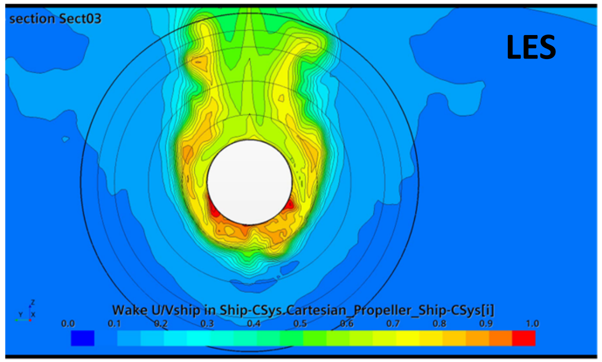
Towing resistance at design conditions: Vs=15(kn), T=11(m), full scale

	Cf_hull	Cp_hull	Ct_hull	Ct_rud	Ct_ship	Sink (m)	Trim (deg)
EXP, scaled	0.001670 (0.001485)				0.00227	-0.2521	0.167
RANS | kwSST | rough	0.001654	0.000522	0.002176	8.47E-05	0.002289	-0.2275	0.176
DES | IDDES | kwSST | rough	0.0017	0.00052	0.00222	7.84E-05	0.002328	-0.2273	0.1769
DES | IDDES | ke-EB | rough	0.00173	0.00051	0.00224	7.32E-05	0.002333	-0.2271	0.1756
LES | Smagorinsky | smooth	0.00142	0.000558	0.001978	7.19E-05	0.002064	-0.2257	0.1745

Axial nominal wake on control section in front of propeller, design conditions: Vs=15(kn), T=11(m), full scale

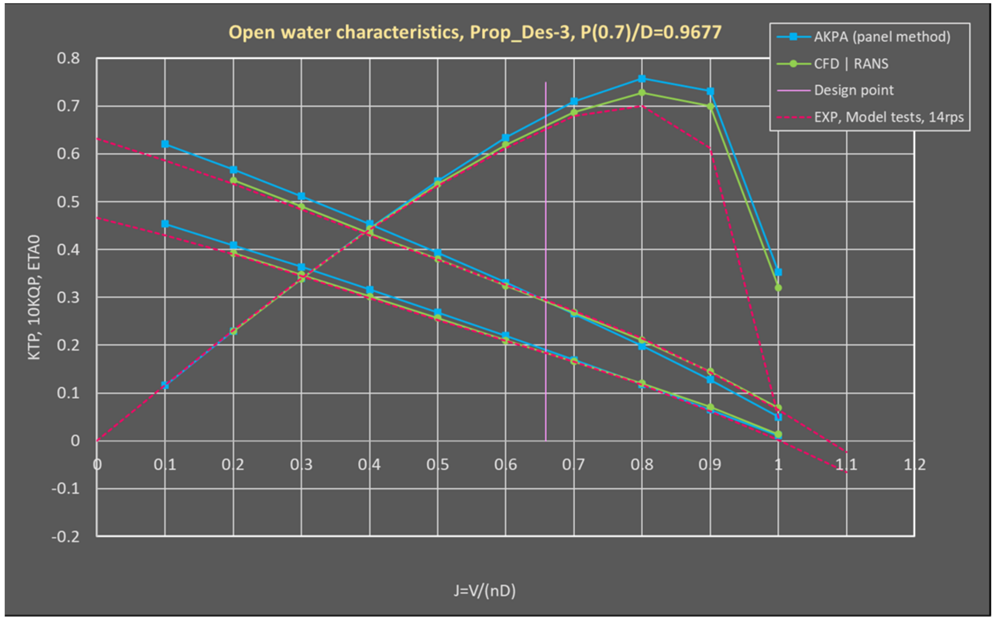




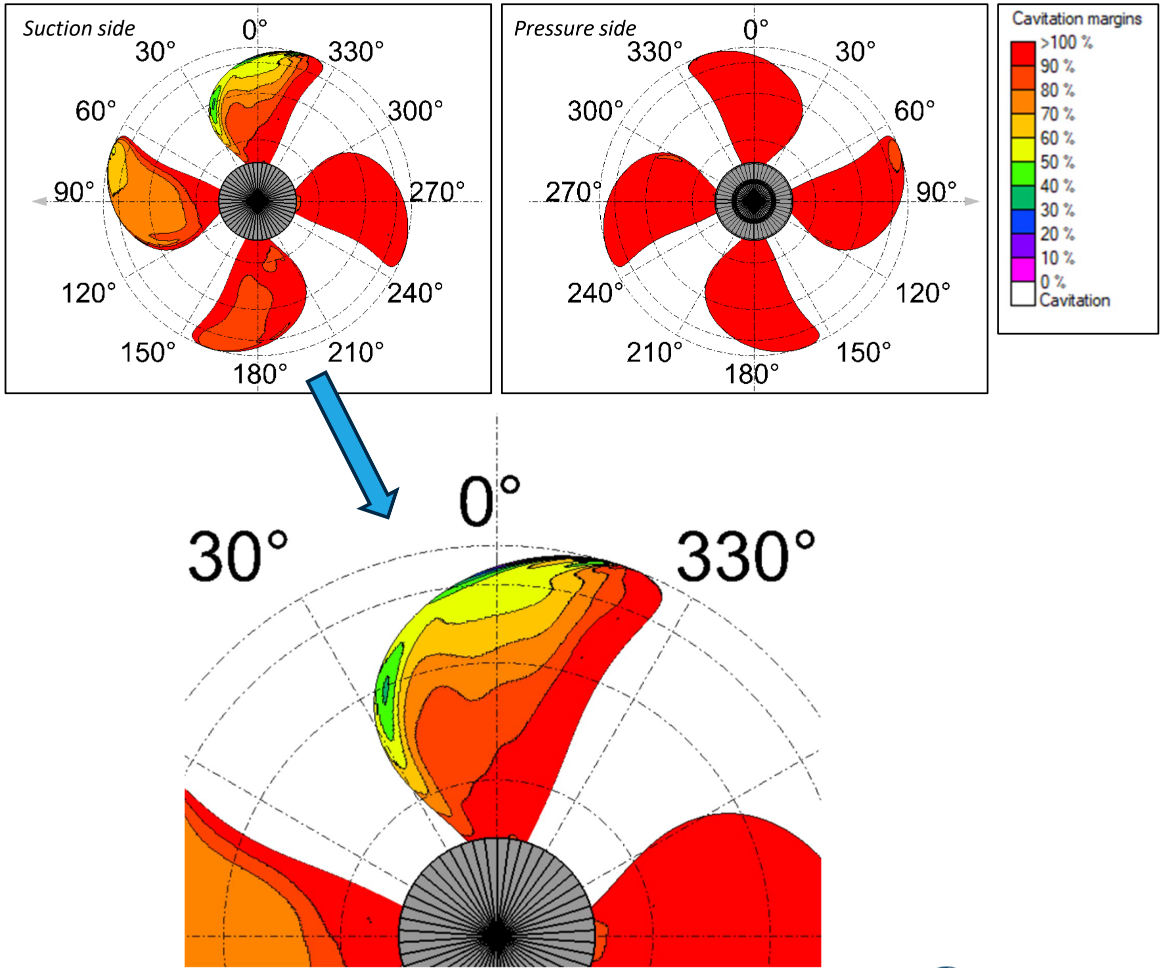


Comparison of propeller OW characteristics and analysis of cavitation in wake field

Computed open water characteristics in full scale vs Experimental results



Cavitation performance in effective wake obtained from CFD LES simulations, Design WL



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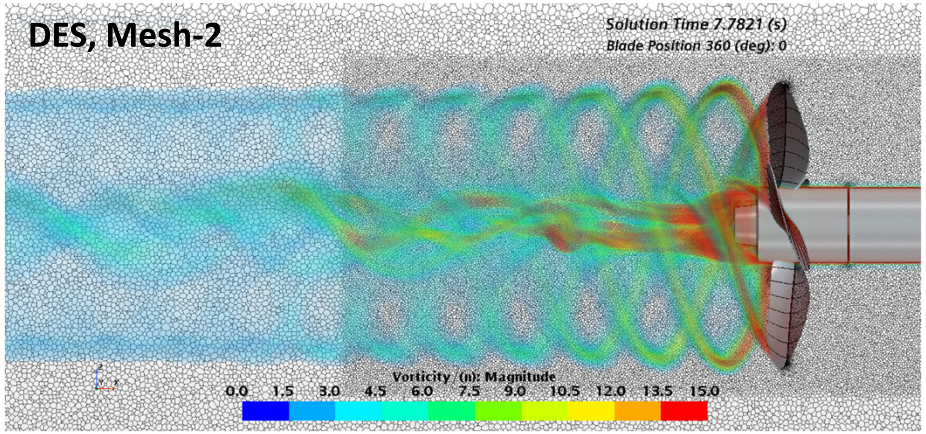
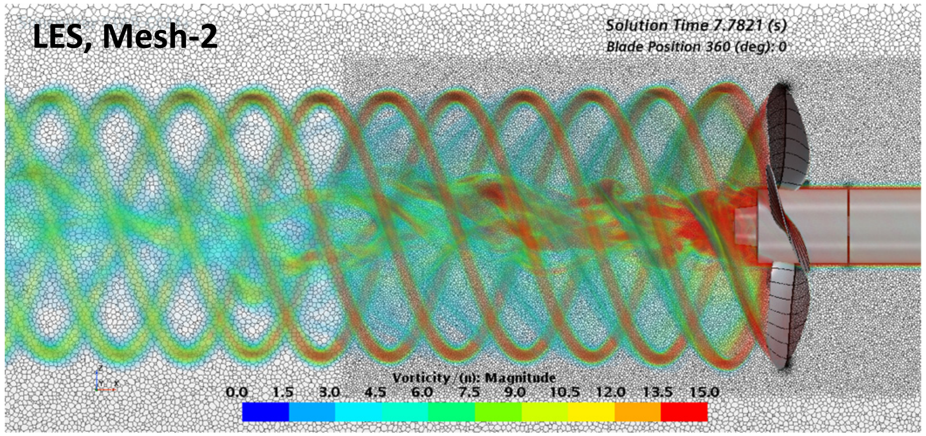
Assessment of Scale Resolving CFD simulation methods for propeller analysis

Open water characteristics at J=0.8 (max ETA0)

	Mesh (Cell count) / Cell size	KTP	10KQP	ETA0
EXP Model scale		0.117	0.214	0.700
RANS	Mesh-2 (14.6 mil) Δ/D=0.0075	0.1204	0.2104	0.7283
DES	Mesh-1 (11 mil) Δ/D=0.01	0.1168	0.2078	0.7159
DES	Mesh-2 (14.6 mil) Δ/D=0.0075	0.1175	0.2080	0.7191
DES	Mesh-3 (22.0 mil) Δ/D=0.005	0.1174	0.2079	0.7190
LES	Mesh-1 (11 mil) Δ/D=0.01	0.1167	0.2064	0.7197
LES	Mesh-2 (14.6 mil) Δ/D=0.0075	0.1166	0.2064	0.7194
LES	Mesh-3 (22.0 mil) Δ/D=0.005	0.1166	0.2064	0.7195

Vorticity field in propeller slipstream, J=0.8

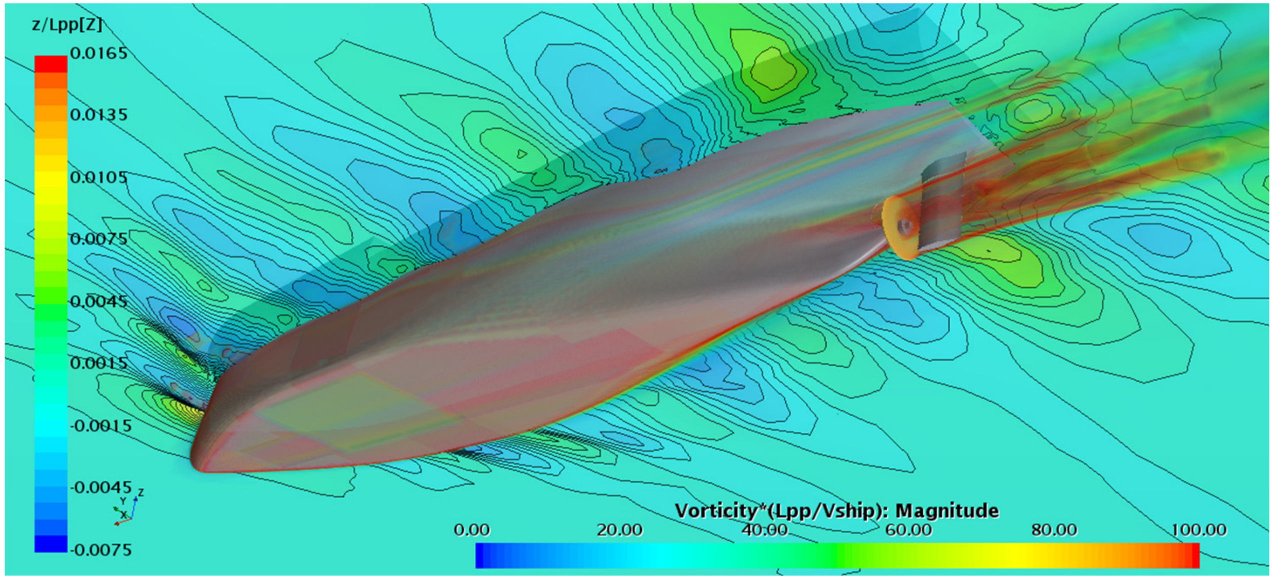




Prediction of vessel propulsion performance

Self-propulsion at design conditions: Vs=15(kn), T=11(m), full scale

	RPM	KTB	KQB	WT	t	PD (kW)	TB (kN)
EXP, scaled	77.8	0.186	0.0294	0.259	0.163	5796	666
CFD | LES / AD / Panel method	78.7	0.1854	0.0284	0.249	0.158	5779	679
Δ=(CFD-EFD)/EFD*100%	+1.16	-0.32	-3.40	-3.86	-3.07	-0.29	+1.95



3) Way forward – simulation driven design optimization for energy efficiency

Parametric model of SO Ship in CAESES

Principles:

- ✓ Simplicity at "designer" level, flexibility at "developer level;
- ✓ Physically meaningful parameters and design variables

Current models:

HULL

A partially parametric model that starts with initial CAD geometry of half-ship (e.g. from NAPA or another design tool)

STEERING_SYSTEM | RUDDER

A fully parametric model of a spade rudder with custom profiles

STEERING_SYSTEM | HEADBOX

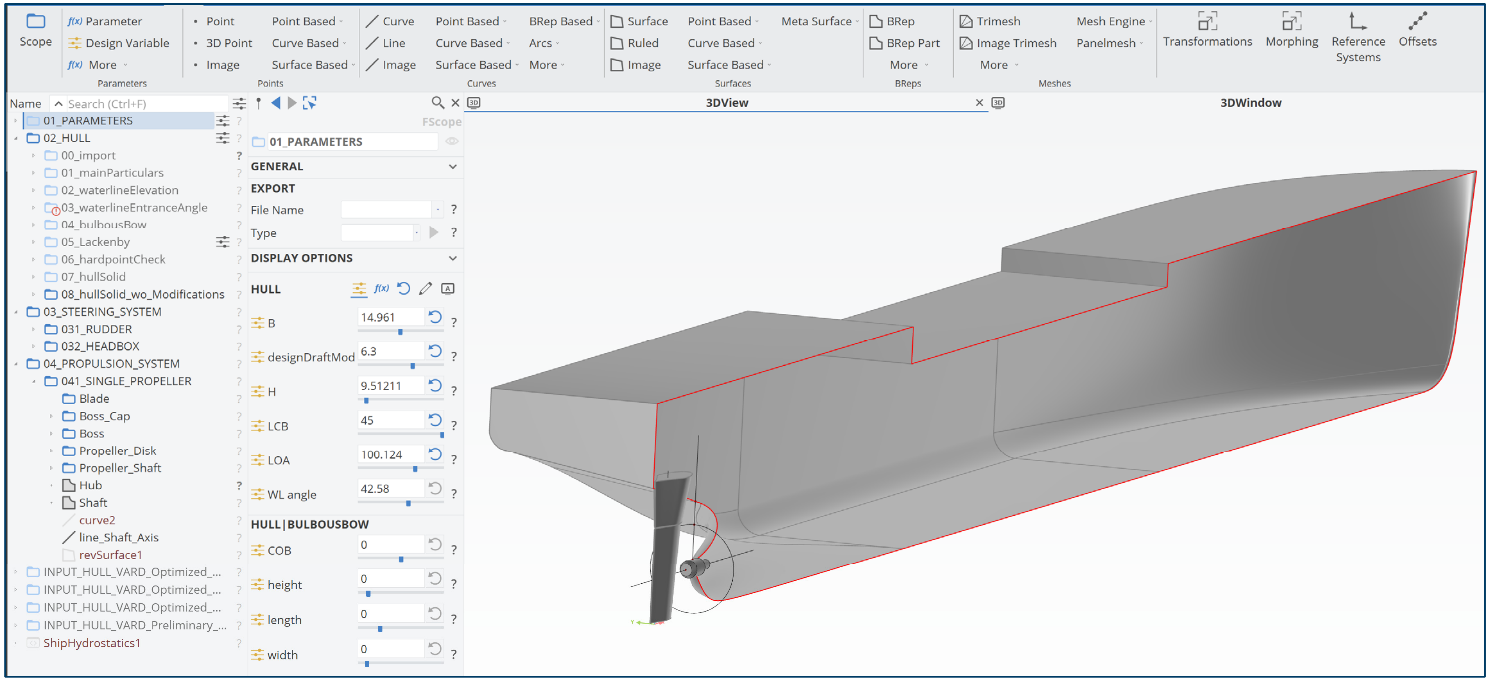
A fully parametric model of headbox associated with the rudder model

PROPULSION_SYSTEM | PROPELLER | *BLADE*

A fully parametric model of conventional propeller blade based on the AKPA model

PROPULSION_SYSTEM | PROPELLER | *HUB*

A fully parametric model of conventional elliptic and conical hubs



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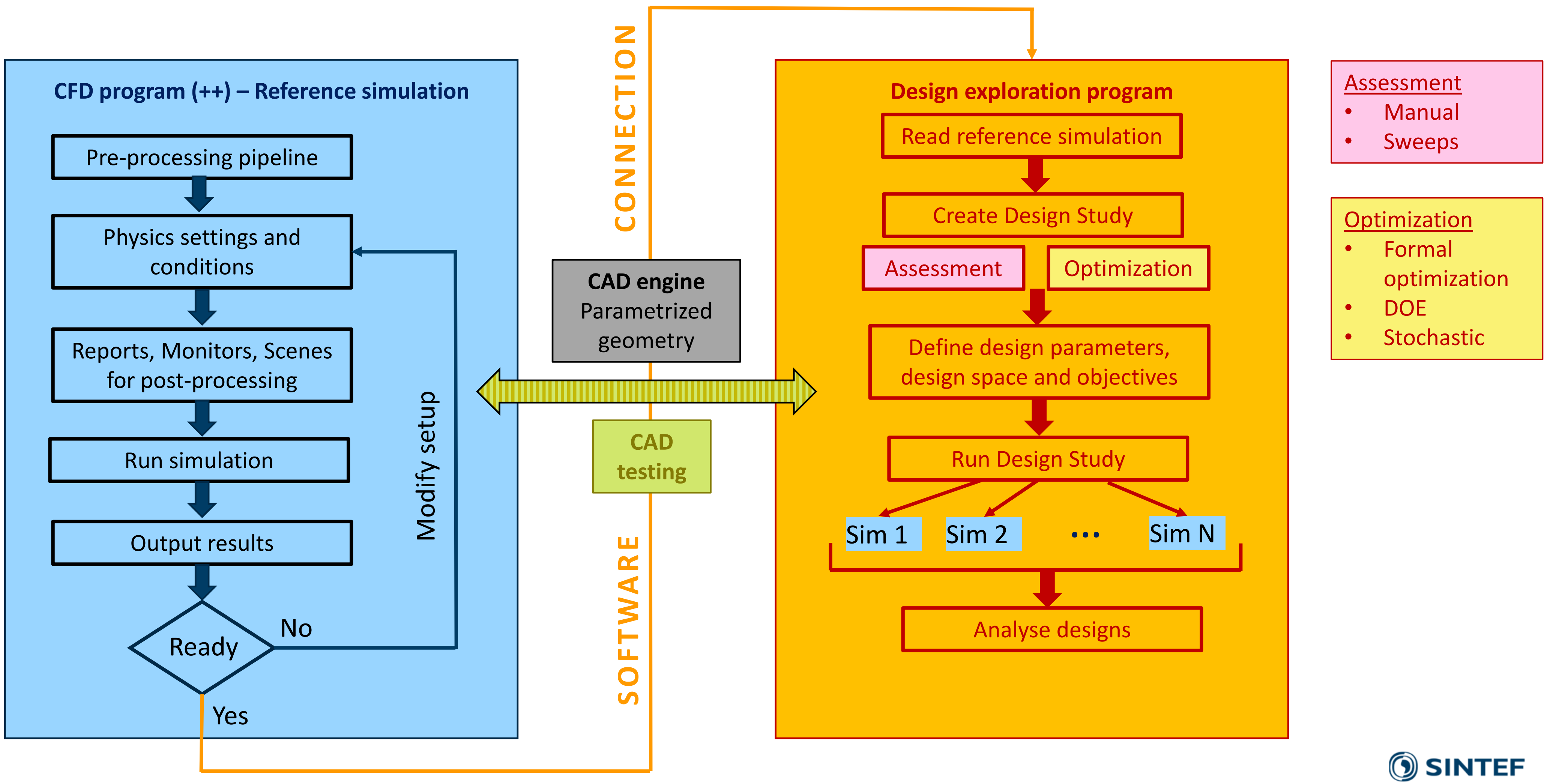
Principle diagram of the simulation driven design process involving a CFD code



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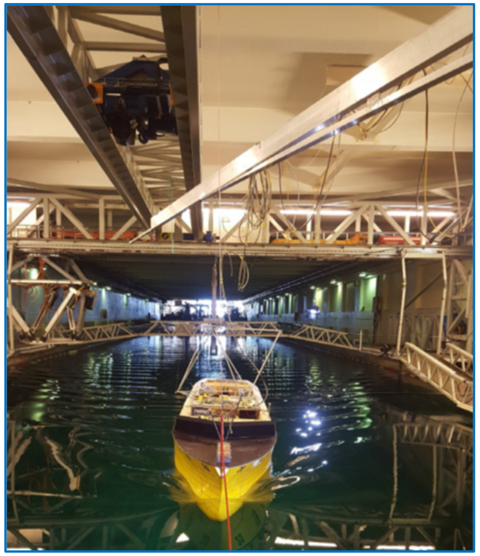
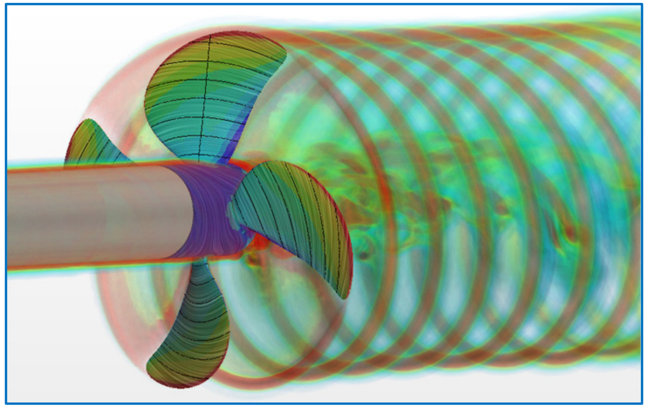
Changing mindset towards climate neutral shipping industry

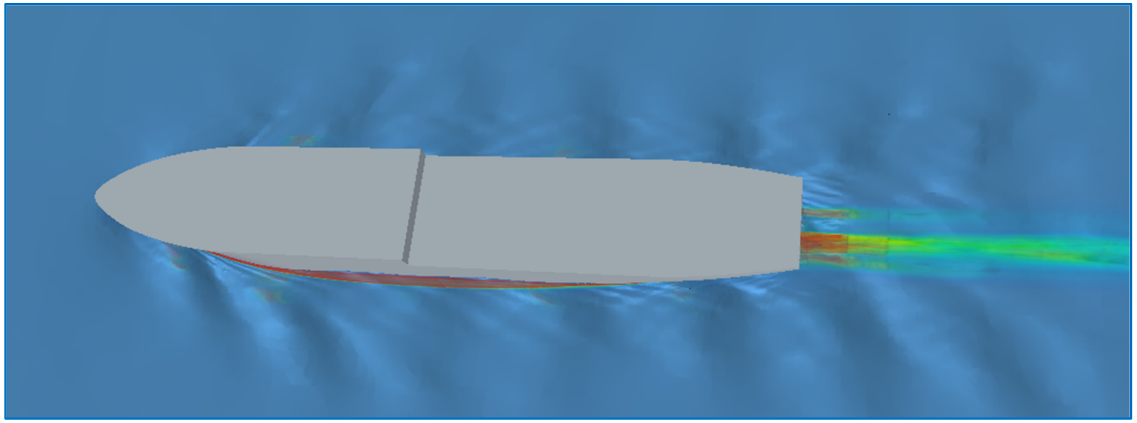
Critical industry transition levers

- Global policies and regulations
- Technical advancements in ship's energy efficiency
- Scale-up of alternative fuels for maritime industry
- Customer demand
- Mobilization of finance sector

Collective mindset







References

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (2021): Industry Transition Strategy, October. https://www.zerocarbonshipping.com/

Sauder, T. and Alterskjær, S.A. (2022): Hydrodynamic testing of wind-assisted cargo ships using a cyber–physical method, *Ocean Engineering* 243 (2022) 110206; https://doi.org/10.1016/j.oceaneng.2021.110206

Koushan, K., Krasilnikov, V.I., Nataletti, M., Sileo, L. and Spence, S. (2020): Experimental and Numerical Study of Pre-Swirl Stators PSS, *Journal of Marine Science and Engineering*, 2020, 8, 47; https://doi:10.3390/jmse8010047

Rambech, H.J. (2021): Calm Water Performance Tests, SOBC-1 (SINTEF Ocean Bulk Carrier no.1), SINTEF Report, Project No. 302006033-09, August 25.

The SINTEF Ocean Bulk Carrier SOBC-1 Benchmark Dataset is found at the shared location on Microsoft Teams Team **SINTEF Ocean Bulk Carrier SOBC-1 Benchmark Dataset**
https://teams.microsoft.com/l/team/19%3agYyG7I2k5aPzq-p-Lew3yXWYFvYGBVu7gmJHwLMHsEE1%40thread.tacv2/conversations?groupId=dfdc43f0-7f63-4a06-9aa5-353faf824a19&tenantId=e1f00f39-6041-45b0-b309-e0210d8b32af

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