H1 Unlimited: Designing a Surface-Piercing Propeller for Speeds of over 300 km/h

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Motivational Background

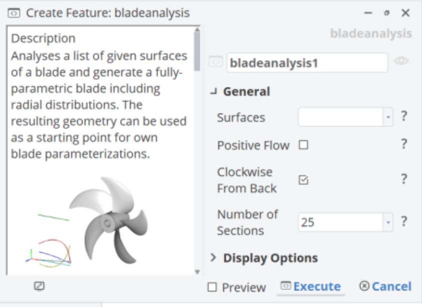
- H1 Unlimited: Premier high-speed hydroplane racing series
- Boats exceeding 300 km/h
- Go3 Racing Team: Known for piston-powered hydroplanes
- B-84 Propeller: 3-Bladed model
- Enhance efficiency
- Prevent blade cracking

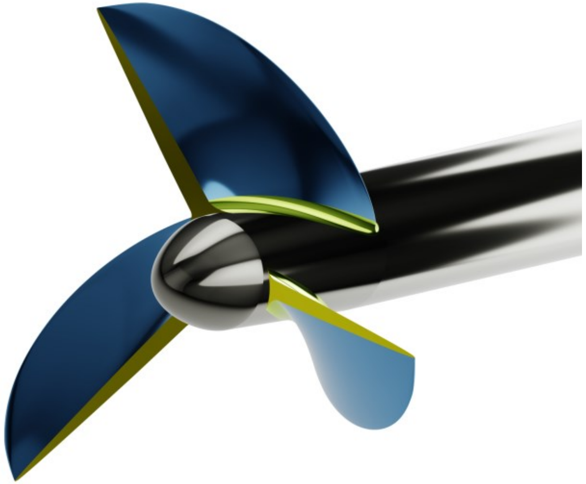
Go 3 Racing Boat (Video)

Goals of this Project

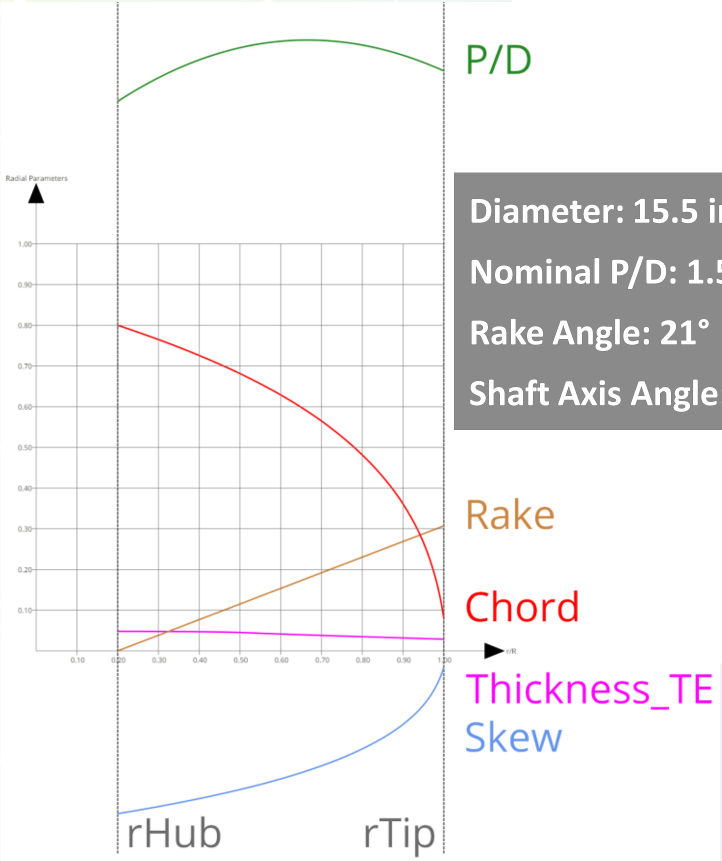
- CAD Model B-84 Propeller
- Parametric Model in CAESES
- Set up a CFD methdology using CONVERGE
- Surface-piercing propeller for high speeds
- Automated Integration of CONVERGE with CAESES
- Preliminary results on two different propeller geometries

Reverse Engineering

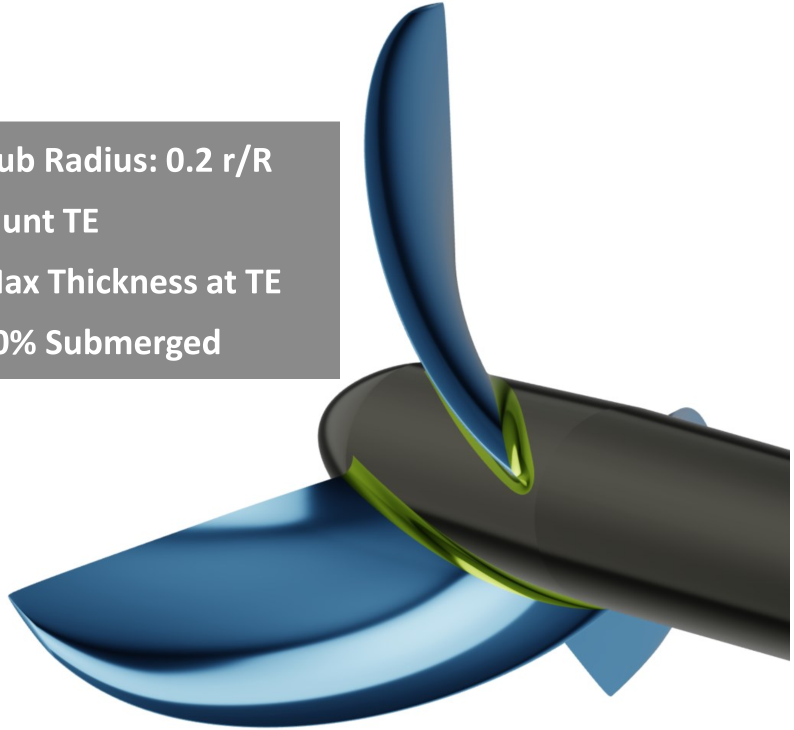




Radial Functions & Propeller Model in CAESES



Diameter: 15.5 in	Hub Radius: 0.2 r/R
Nominal P/D: 1.59	Blunt TE
Rake Angle: 21°	Max Thickness at TE
Shaft Axis Angle: 6°	50% Submerged



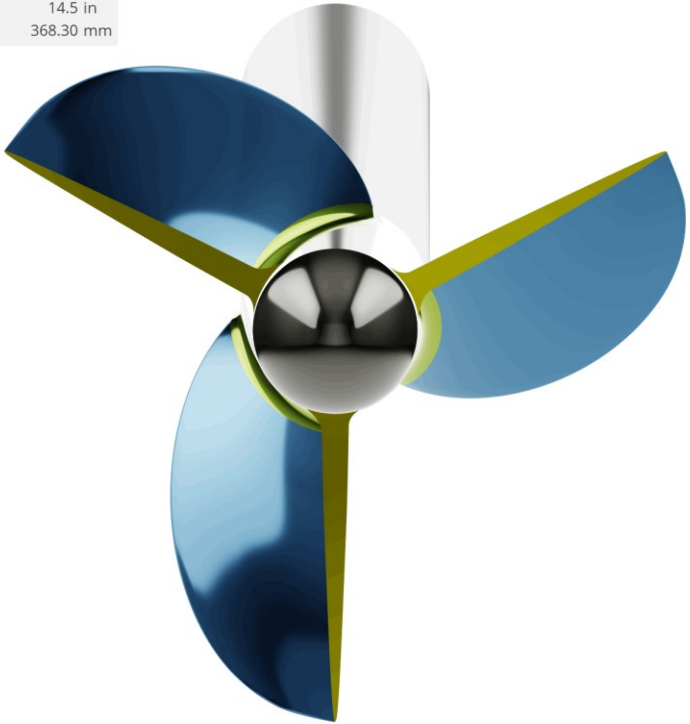
Design Variables of the Parametric Model

Parameter	Range	Effects
Diameter	[14.5 in, 15.5 in]	Thrust & Drag
Rake Angle	[20°,25°]	Lift & Efficiency
Nominal P/D	[1.5, 1.7]	Angle of Attack
TE Thickness	[0.03, 0.06]	Durability
Fillet Radius	[7 mm, 13 mm]	Strength & Stress

Parametrization of Diameter

Parameters

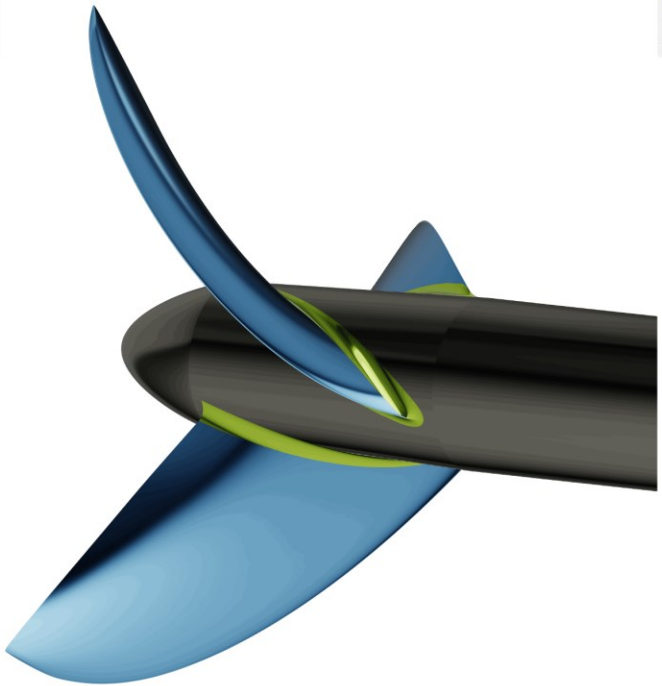
D	14.5 in
D	368.30 mm



Parametrization of Nominal Pitch Ratio

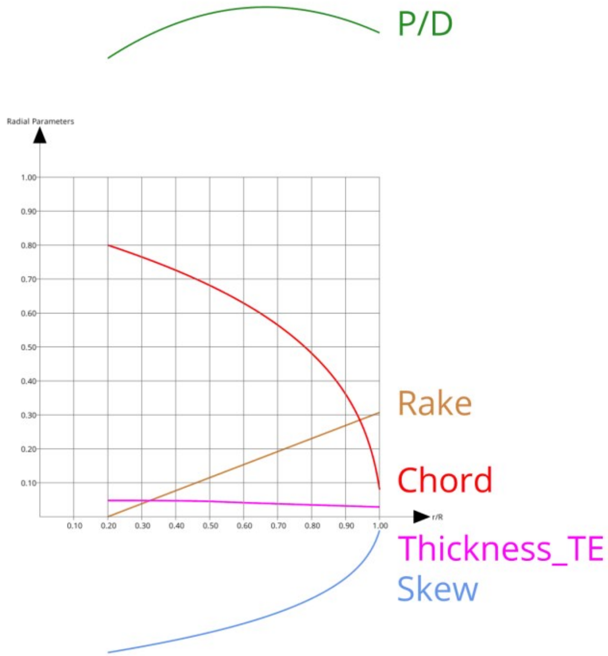
Parameters

nominalP_D 1.50

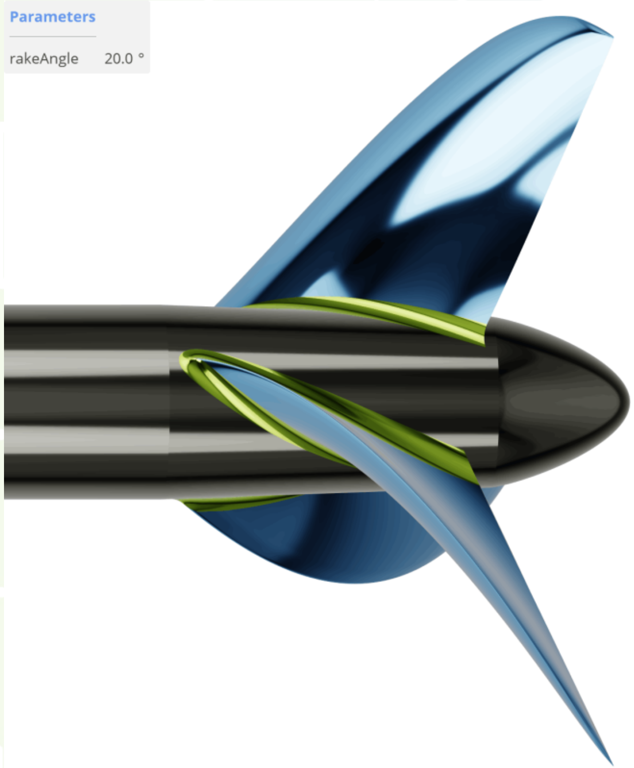


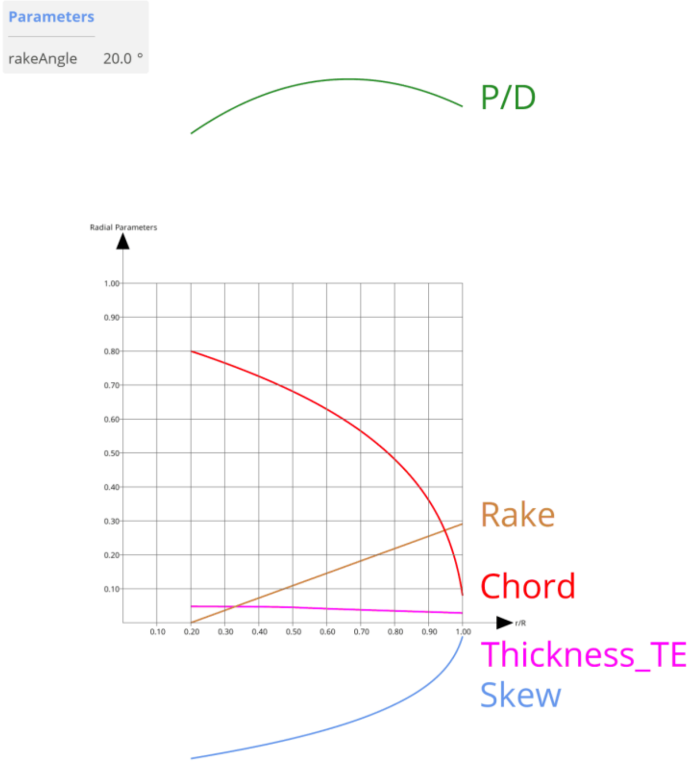
Parameters

nominalP_D 1.50



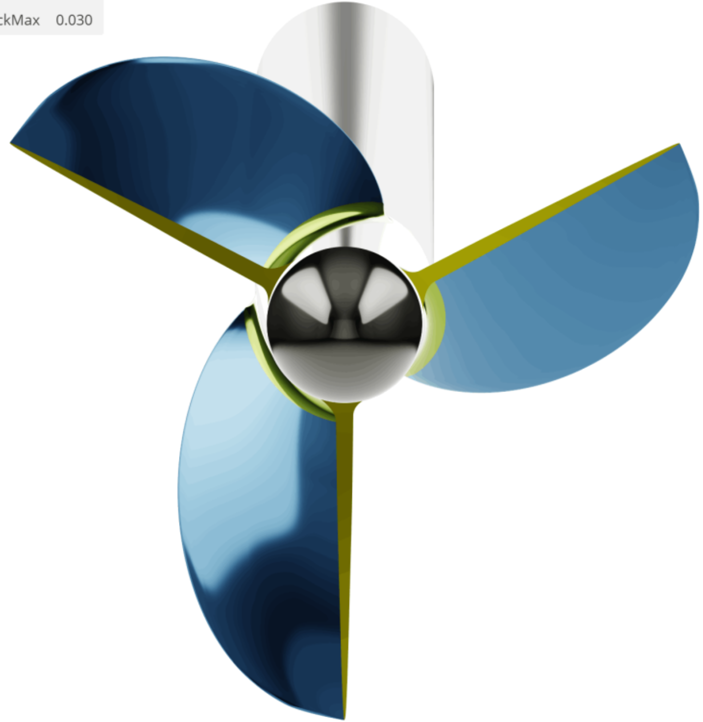
Parametrization of Rake Angle





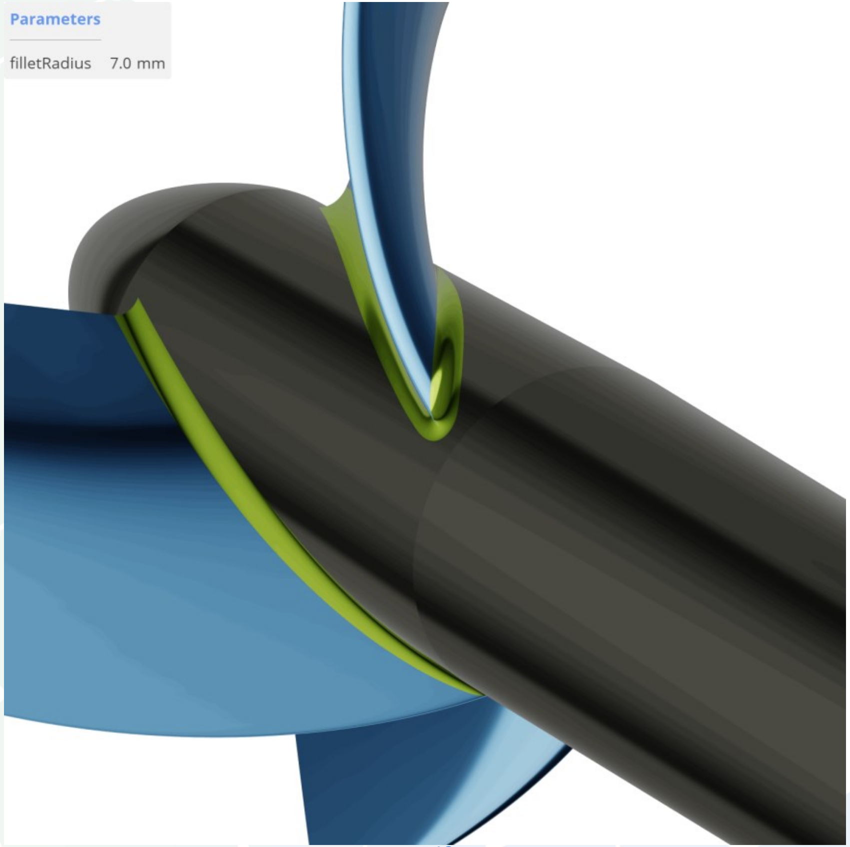
Parametrization of Trailing Edge Thickness

Parameters	
teThickMax	0.030



Parameters	
teThickMax	0.030

Parametrization of Fillet Radius



CONVERGENCE CFD Software

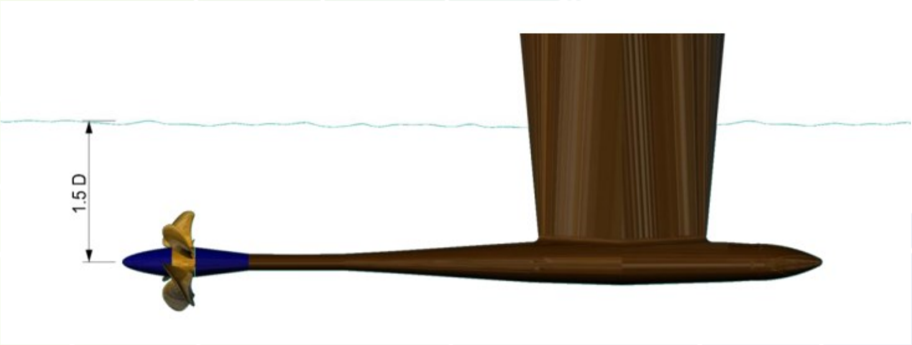
- Convergent Science
- CFD software
- Simulating 3D fluid flow
- Autonomous meshing
- Complex moving geometries
- Adaptive Mesh Refinement
- State-of-the-art physical models

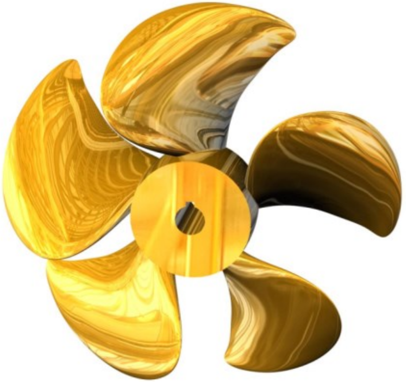
CONVERGE CFD SOFTWARE

PPTC – Open Water Tests

- SVA Potsdam controllable pitch propeller VP1304
- Constant rotational speed of 15 rps
- Thrust and torque of the blades were measured
- Open water tests for various advance coefficients
- Dimensioless coefficients

- Measuring T, Q, n
- Advance coefficient: $J = \frac{V}{n \cdot D}$
- Thrust coefficient: $K_T = \frac{T}{\rho \cdot n^2 \cdot D^4}$
- Torque coefficient: $K_Q = \frac{Q}{\rho \cdot n^2 \cdot D^5}$
- Propeller efficiency: $\eta_0 = \frac{J}{2\pi} \cdot \frac{K_T}{K_Q}$

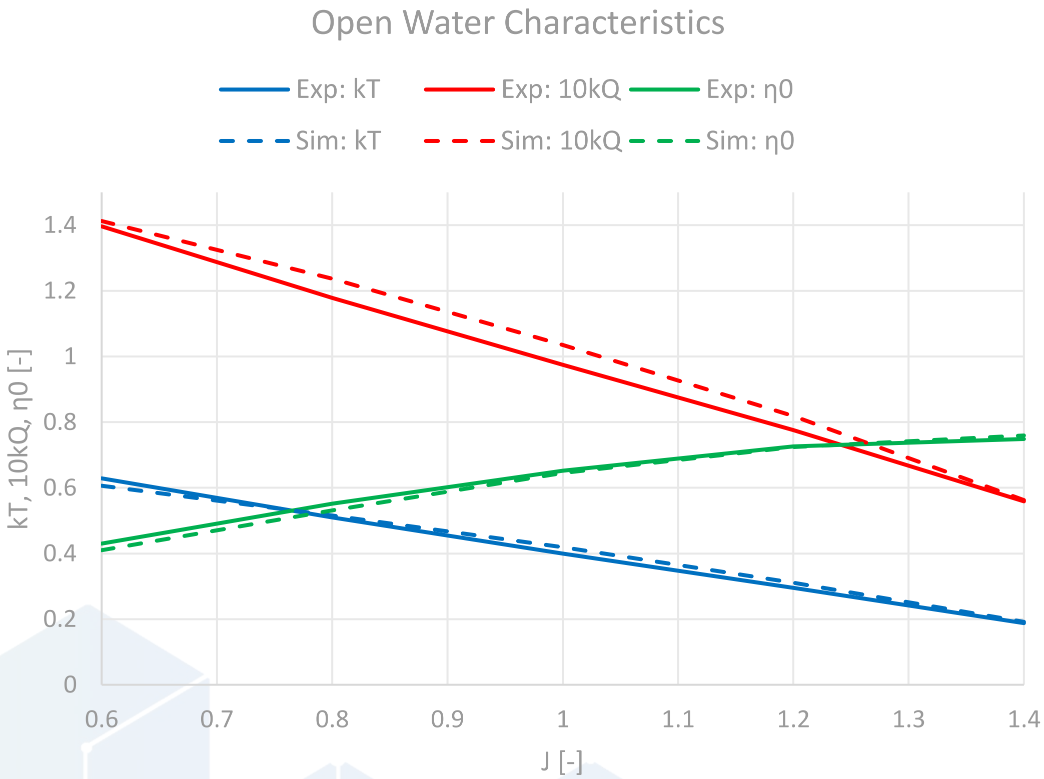




Barkmann, U.H., "Potsdam Propeller Test Case (PPTC): Open Water Tests With the Model Propeller VP1304," Schiffbau-Versuchsanstalt Potsdam GmbH Report 3752, 2011.

PPTC open water – results

J	K_T Exp.	K_T Sim.	ΔK_T	ΔK_T [%]
0.6	0.6288	0.6063	-0.0225	-3.5830
0.8	0.5100	0.5156	0.0056	1.1000
1.0	0.3994	0.4192	0.0198	4.9599
1.2	0.2949	0.3104	0.0155	5.2560
1.4	0.1878	0.1917	0.0039	2.0767
J	$10K_Q$ Exp.	$10K_Q$ Sim.	$\Delta 10K_Q$	$\Delta 10K_Q$ [%]
0.6	1.3964	1.4125	0.0161	1.1508
0.8	1.1780	1.2369	0.0589	5.0000
1.0	0.9749	1.0347	0.0598	6.1309
1.2	0.7760	0.8187	0.0427	5.5052
1.4	0.5588	0.5625	0.0037	0.6675
J	η_0 Exp.	η_0 Sim.	$\Delta\eta_0$	$\Delta\eta_0$[%]
0.6	0.4300	0.4099	-0.0201	-4.6791
0.8	0.5512	0.5308	-0.0204	-3.7083
1.0	0.6520	0.6448	-0.0072	-1.0982
1.2	0.7258	0.7241	-0.0017	-0.2356
1.4	0.7487	0.7593	0.0106	1.4185



Vangö, M., "CFD Validation of a Controllable Pitch Marine Propeller Using a Truly Autonomous Mesh Generation With Adaptive Mesh Refinement," ECCOMAS Congress 2022, Lillestrøm, Norway, Jun 5–9, 2022.

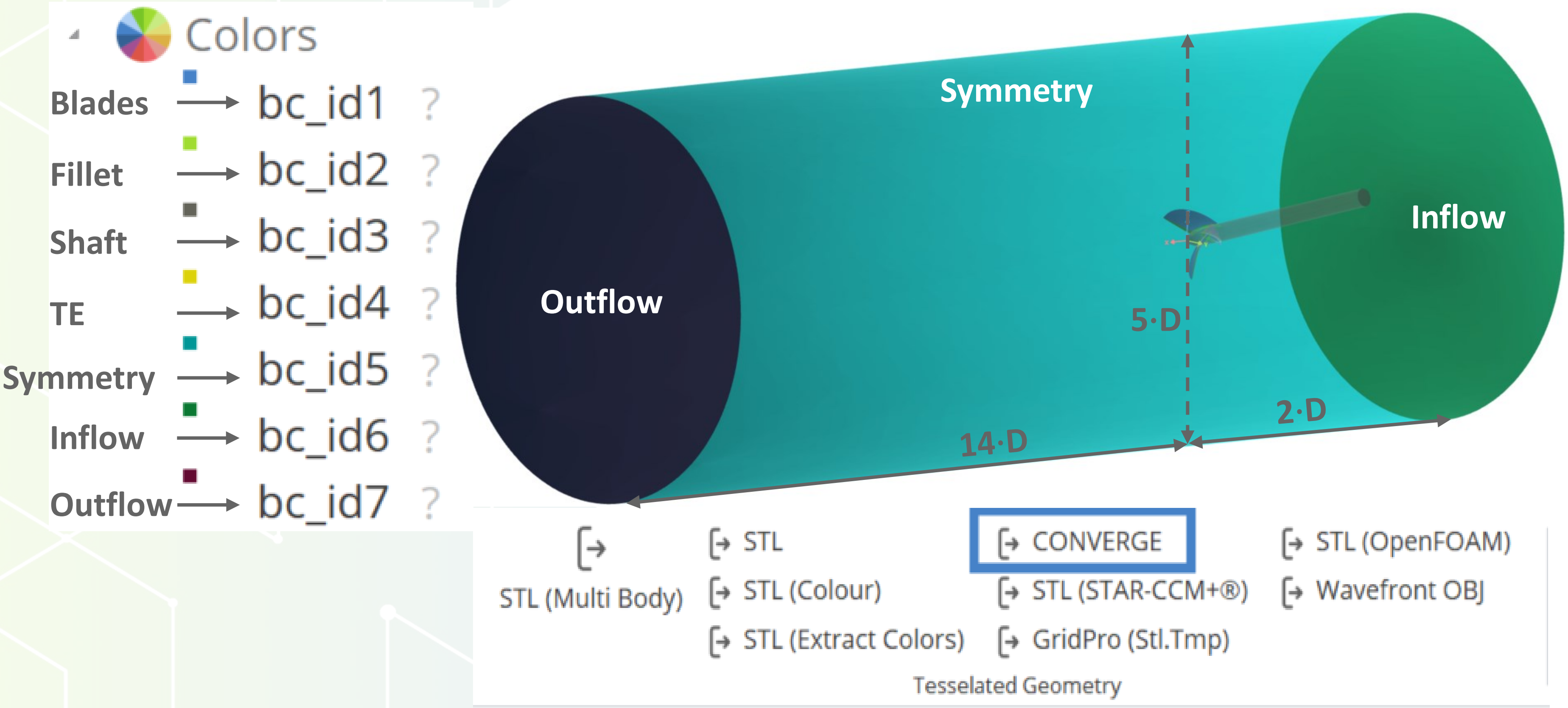
Challenges from a CFD perspective

- Complex hydrodynamics phenomena
- Ultra high speeds & Air/ Water
- Validation at these conditions?
- A grid convergence study
- Effect of the number of revolutions
- High priority: Low computational times

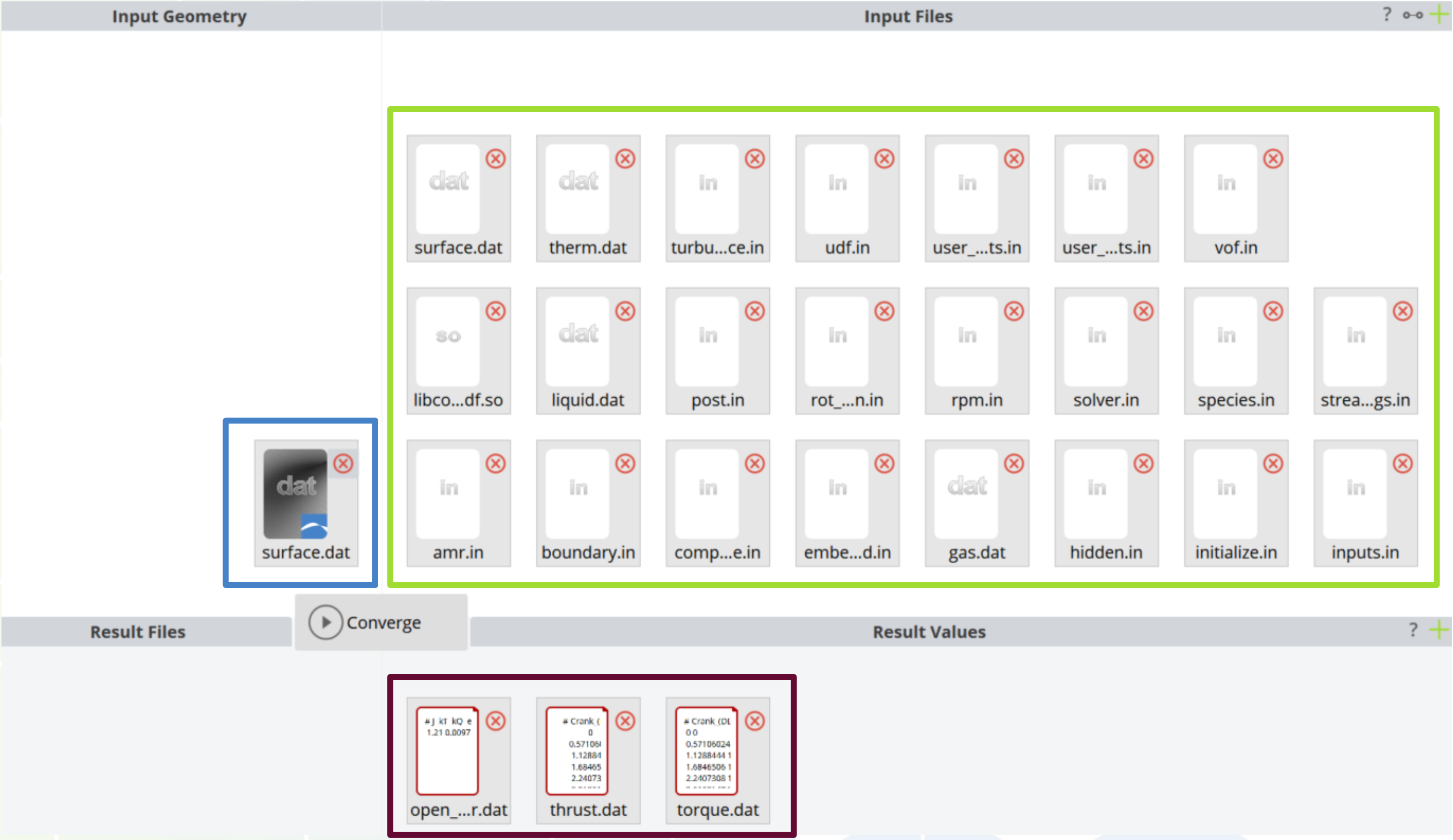
Simulation setup

Parameter	Value
Simulation Type	Transient
Rotation Methodology	Fully Moving Geometry – Continuously Regenerated Grid
Turbulence Model	Realizable k-ε
Number of Grid Elements	~0.8 million
Multiphase Modeling	Volume of Fluid (VOF) Approach
Adaptive Mesh Refinement	✓, based on velocity and void fraction
Incoming Flow	Open Water, Incompressible
Cavitation and Ventilation	Not Included
Number of Revolutions	Four

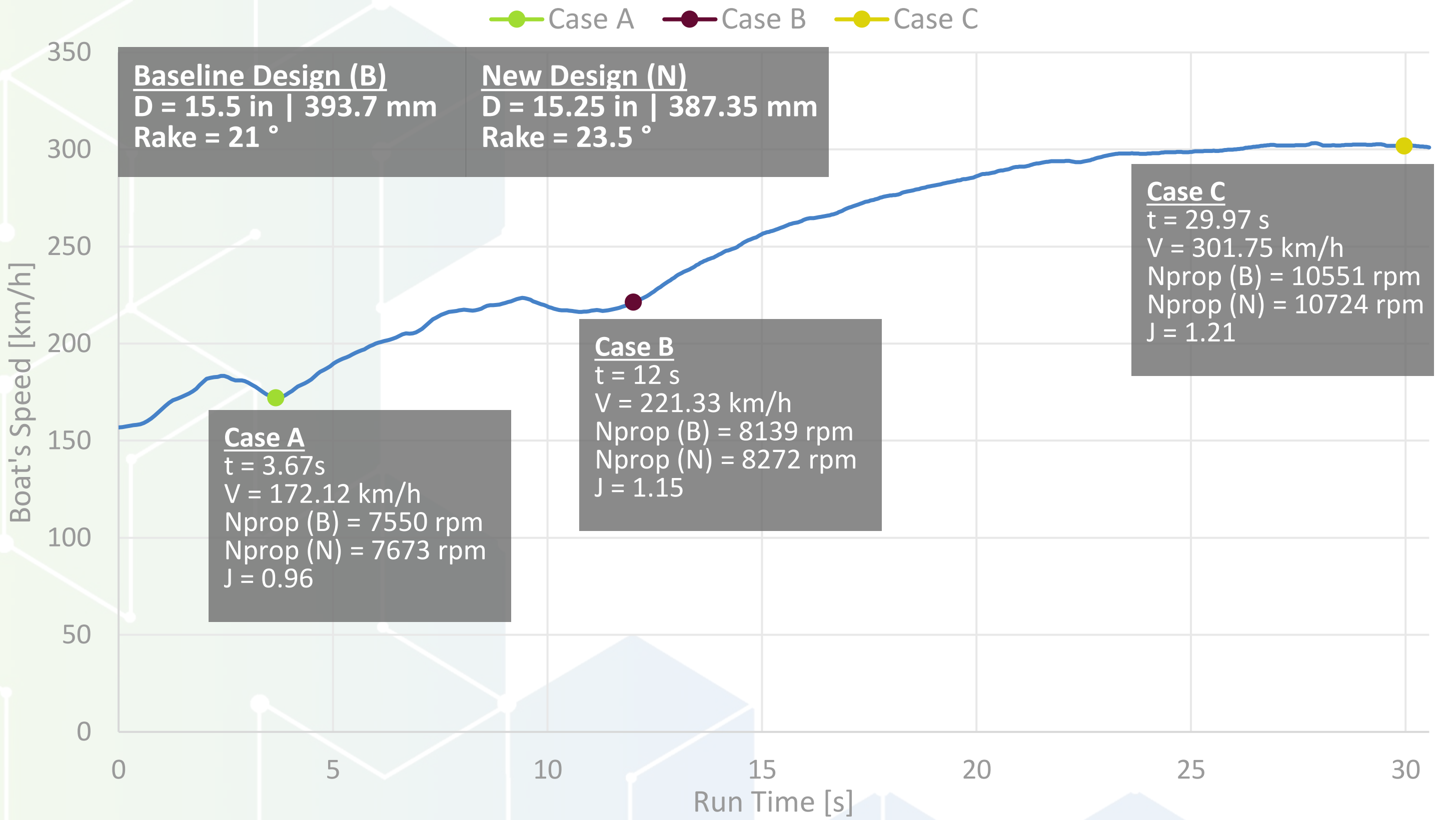
Computational Domain



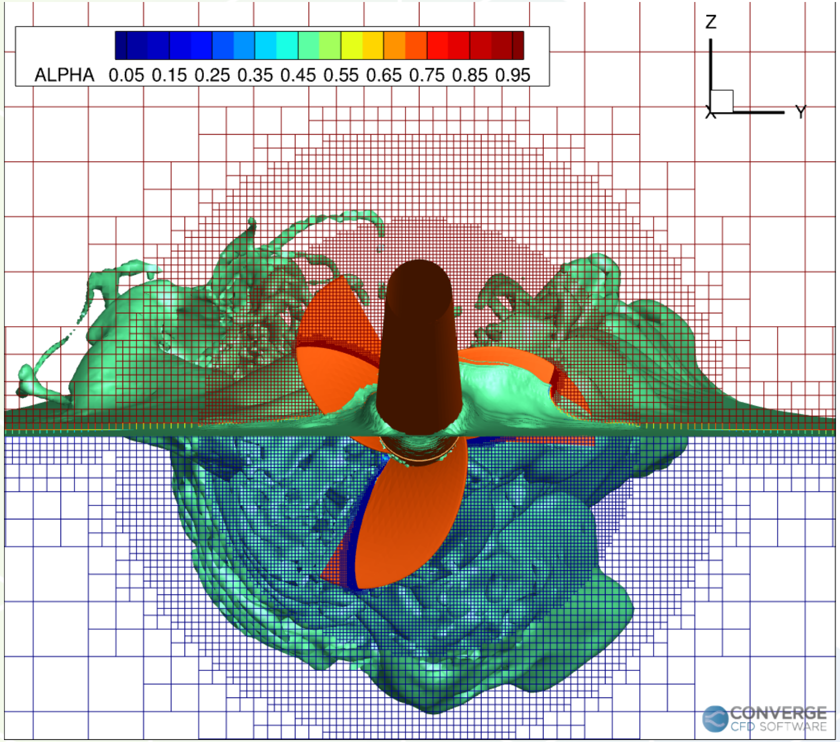
Integration CONVERGENCE with Caeses

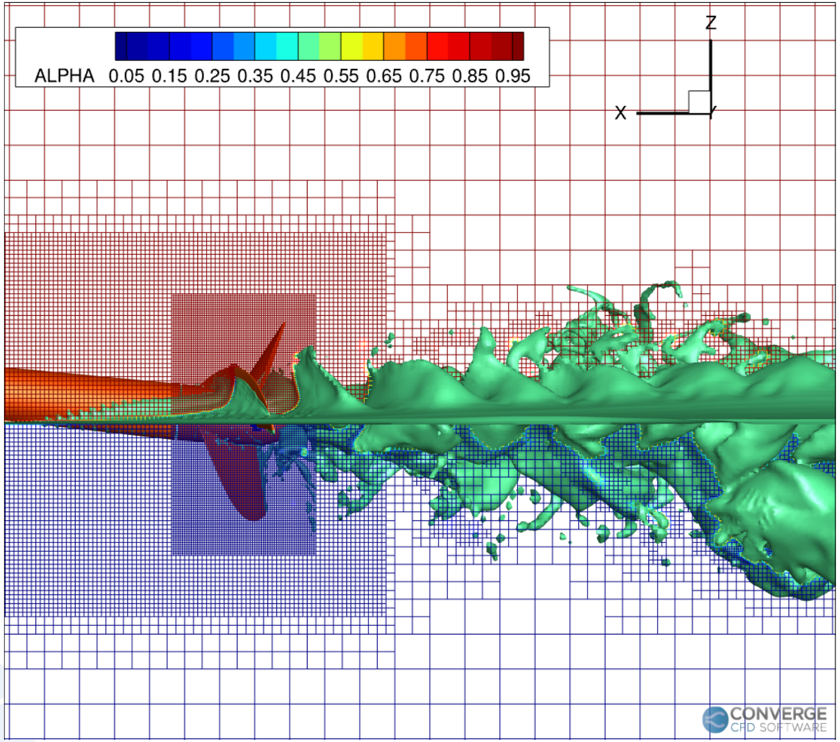


Acceleration Run - Test Cases



Computational Model Overview (VOF Approach)



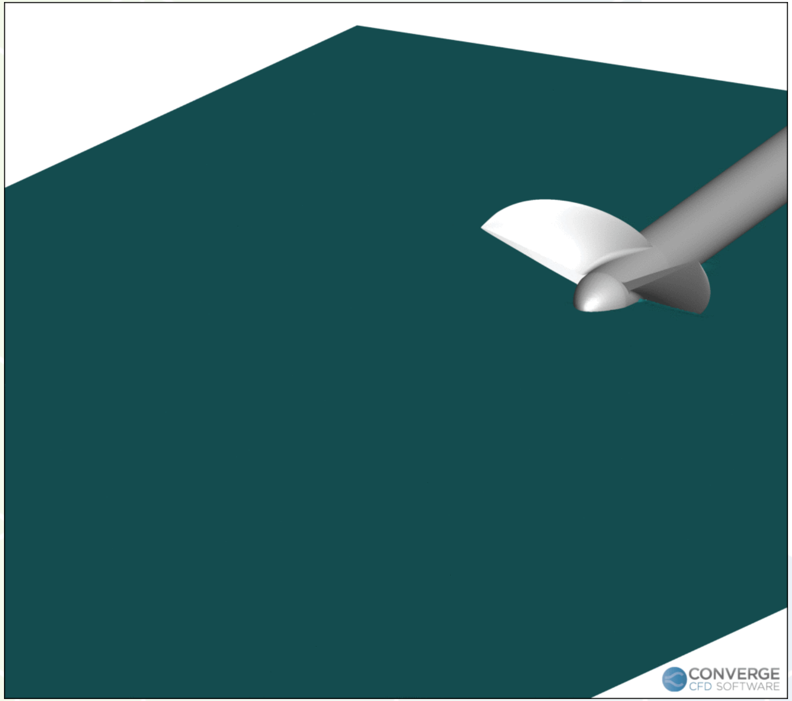


Preliminary Results

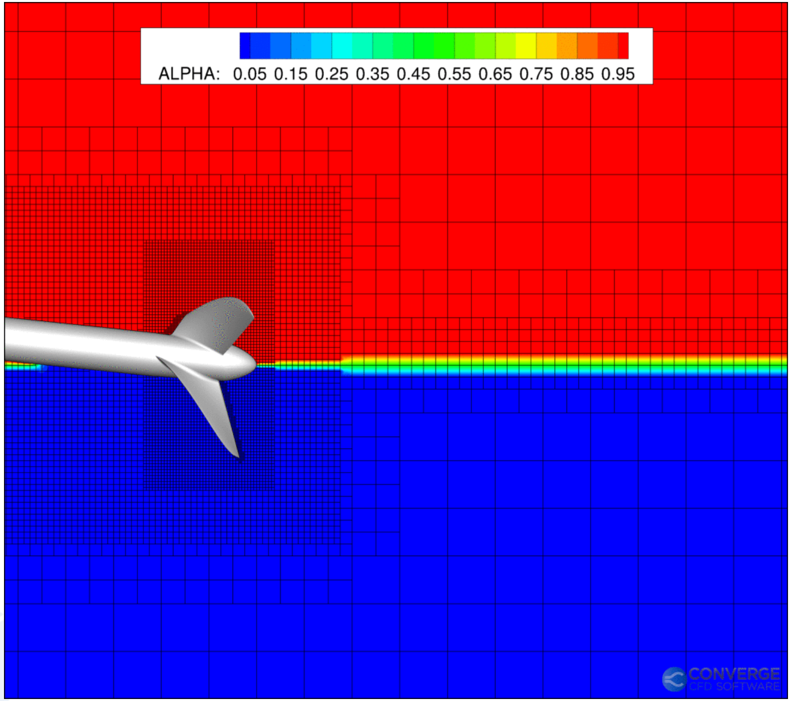
Baseline, Case C, J = 1.21

Simulation runtime: ~2.5 h per simulation on 112 cores

Iso-surface representing the air-water interface



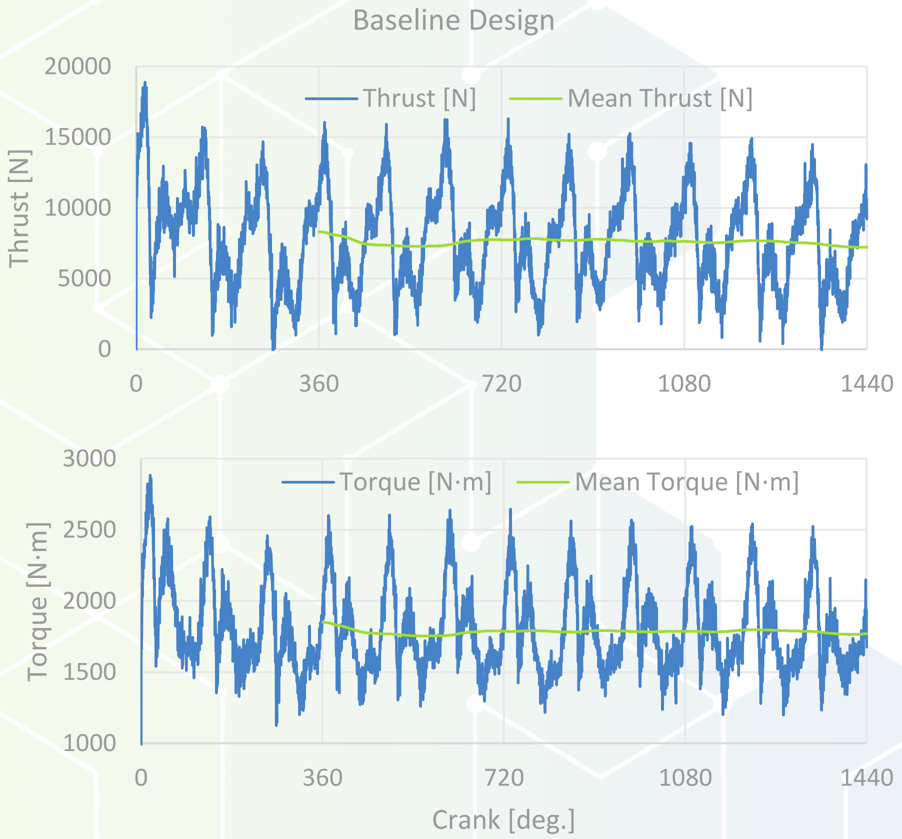
Slice visualizing the interface with mesh

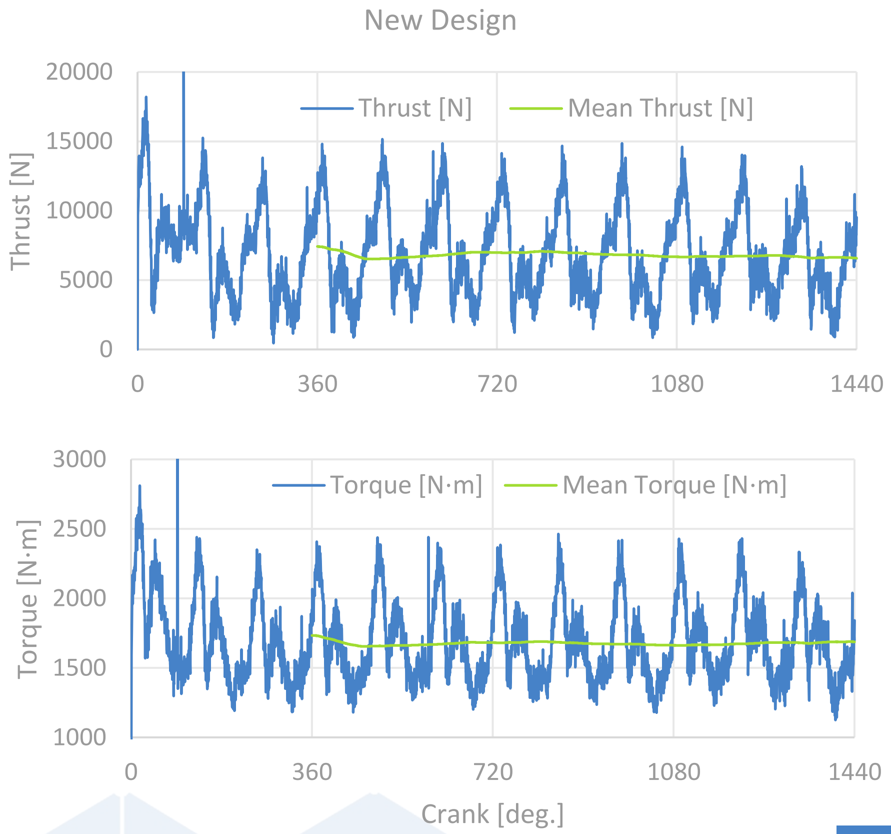


Note the coarse mesh used!

Thrust & Torque

Case C, J = 1.21



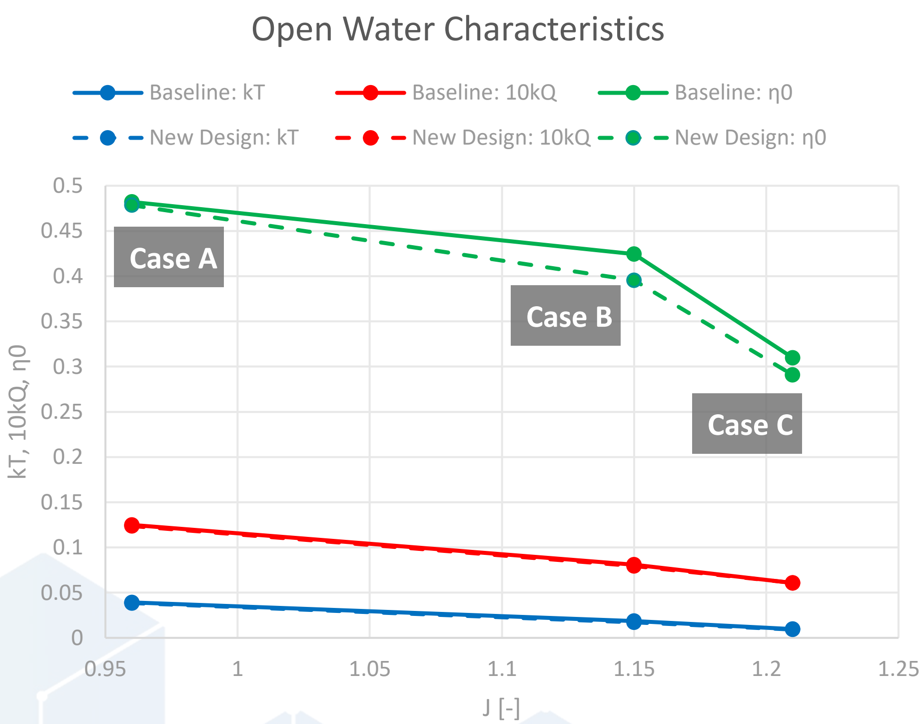


Open Water Characteristics

J	K_T Baseline	K_T New design
0.96	0.0392	0.0385
1.15	0.0187	0.0171
1.21	0.0097	0.0092

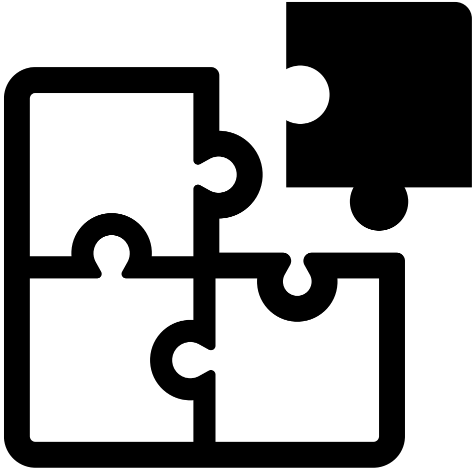
J	$10K_Q$ Baseline	$10K_Q$ New design
0.96	0.1249	0.1237
1.15	0.0809	0.0794
1.21	0.0607	0.0608

J	η_0 Baseline	η_0 New design
0.96	0.4821	0.4785
1.15	0.4245	0.3954
1.21	0.3097	0.2908



Key Accomplishments

- Remodel Surface Piercing Propeller in CAESES
- Development of Parametric Model
- CFD Ready Export
- Automated Integration with CONVERGE
- CFD Setup
- Challenging Cases
- 2 Propellers Tested



Next Steps

- Optimization of B-84 Propeller
- Surrogate Model Development
- FEM Simulation for Stress Analysis
- Include Cavitation and Ventilation
- Wake Adapted Simulation

Thank you for your attention!

Q&A Session

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