Study of the hydrodynamic flow around a 70m sailing boat for powering, wave pattern and propeller efficiency prediction

Romain Baudson

Supervisor: Prof. Dario Boote (UNIGE)

External Reviewer: Prof. Pierre Ferrant (Ecole Centrale de Nantes)

Gdynia, 18th of February 2013

Contents

- Introduction
- Star-CCM+ & Physical models
- Resistance prediction study
- Propeller performances study
- Conclusions

Introduction

- Resistance of Sailing Boats
  - Typical Decomposition: $R_{Tot} = R_{Up} + R_{Side} + R_{Heel}$
  - Present case: Motoring conditions
    - $R_{Tot} = R_{Up} = R_{Wave} + R_{Viscous\ Pressure} + R_{friction}$
- Study of Resistance
  - Effective Power prediction
    - $\mathbf{P_e = R_t \times V_s}$ with R_t the resistance in calm water without propulsive equipment and V_s the ship velocity
  - Linked to the Propulsion analysis
    - $\mathbf{P_e = \eta \times P_B}$
    - P_B = Brake power (Engine characteristics)
  - Hull shape design
    - L_{WL}/B_{WL} , B_{WL}/T , Cp , LCB , L_{WL}/∇^1/3

Optimization Loop

Optimization Loop

Introduction

- Propeller Performances
  - Common power used: $P_T = T \times V_A$
    - T = Thrust, measured in propulsion tests usually > R_T
    - $t = 1 - R_T/T$
  - Wake: inflow of the Propeller
    - Influenced by: fluid properties and waves
    - $w = 1 - V_A/V_S$
  - Hull efficiency
    - $\eta_H = P_E/P_T = (1-t)/(1-w)$

Introduction

- Propeller Performances
  - Present case: Study of the shaft line and brackets impact
  - Wake generation

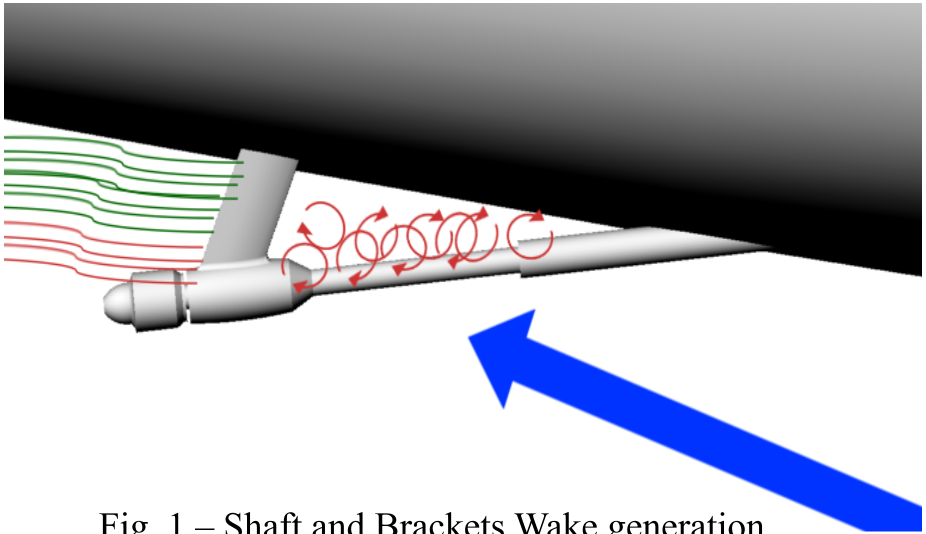

Fig. 1 – Shaft and Brackets Wake generation

Star-CCM+ & Physical models

- Computational Fluids Dynamics software
  - Use of the NS equations and as fluid/air considered here Newtonian fluid model

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{v}) = 0$$

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla.(\rho \vec{v} \vec{v}) = -\nabla p + \nabla.(\bar{\bar{\tau}})$$

$$\bar{\bar{\tau}} = \mu\left[(\nabla \vec{v} + \nabla \vec{v}^T) - \frac{2}{3}\nabla.\vec{v} I\right]$$

- RANS Closure Models
  - Requires closure governing equations
    - Model type: Eddy-Viscosity model
    - Most used for this type of study:
      - k-epsilon realizable all y+
      - k-omega SST

Star-CCM+ & Physical models

- Additional Features:
  - Free surface solving: Volume Of Fluids model
    - Volume control contains interface of fluids
    - New set of equations balanced by volume fraction solved
  - Body forces
    - Used to compute the resistance and assess convergence
    - Decomposed into Pressure, Shear and Gravity forces
  - DFBI feature
    - Computes fluids/structures interactions using structure inertia and fluids forces
    - Used for heave and pitch determination

Resistance Prediction

- Studied Hull
  - 70 m sailing boat from Perini Navi
  - Retractable keel for motoring sailing
  - Dimensions

Table 1 – Hull Dimensions

Characteristic	Symbol	Value
Length Overall	LOA	70 $[m]$
Length at DWL	LDWL	62.669 $[m]$
Length between Perpendicular	LBP	60.789 $[m]$
Maximum Breadth	Bmax	13.238 $[m]$
Draft	TDWL	4.54 $[m]$
Freeboard at Midship	amidFB	2.360 $[m]$
Displacement at DWL	Δ	927 $[t]$

Fig.2 - 70m Perini Navi Boat

S/Y 70m PERINI NAVI DESIGN

PERINI NAVI

Resistance Prediction

- CAD model for CFD computations
  - Built from rendering file using Rhinoceros software (real scale)
  - Takes into account only the hull and its appendices
- Domain of simulation
  - Build with CAD features of Star-CCM+
  - Common dimensions used for length, breadth and depth
  - Symmetry along x-axis used (symmetry plane)

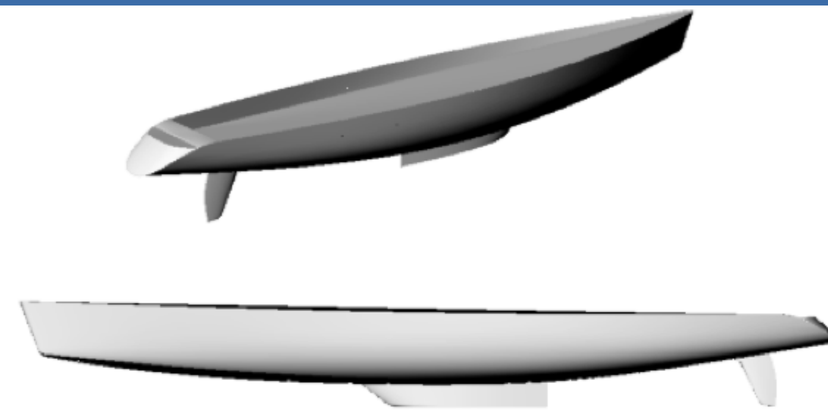

Fig.3 – CAD hull model

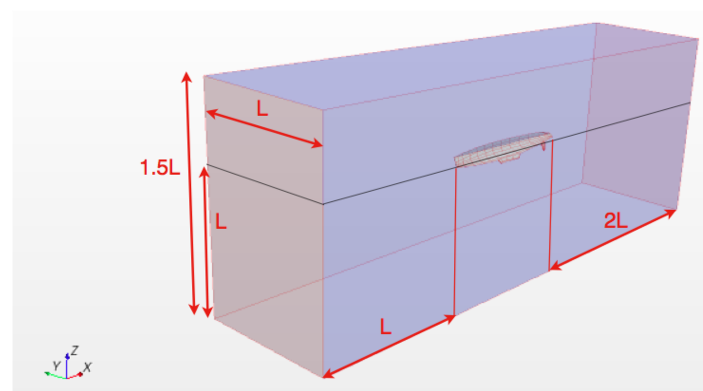

Fig.4 – Domain of simulation (resistance study)

Resistance Prediction

- Mesh generation
  - Hull divided into several parts for better mesh generation
  - Free surface refinements
    - Depth
    - Along predicted wave pattern

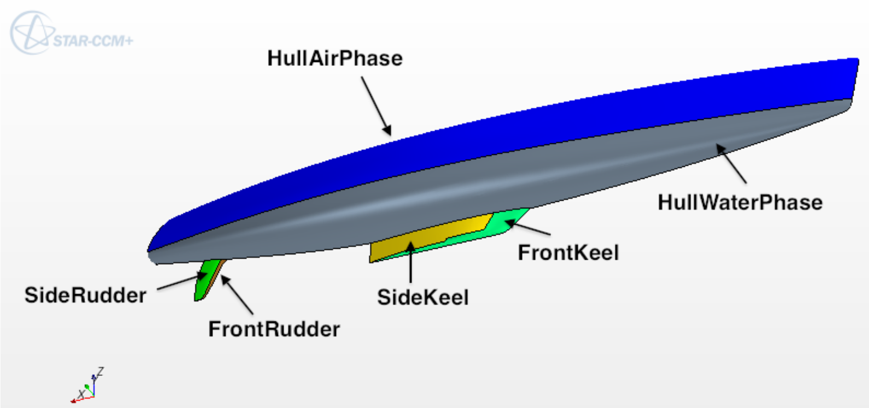

Fig.5 – Hull parts

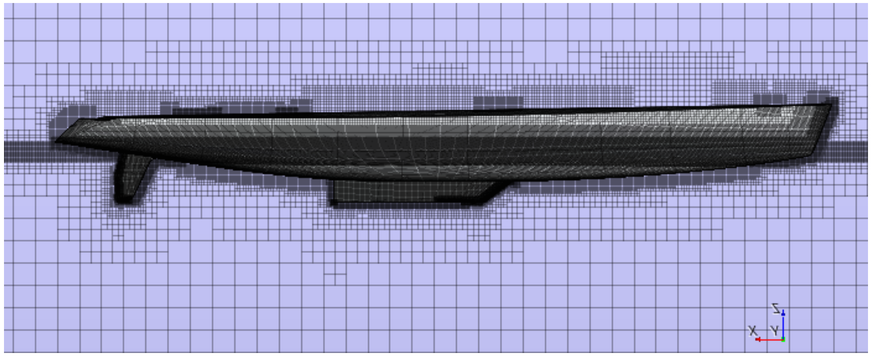

Fig.6 – Hull mesh

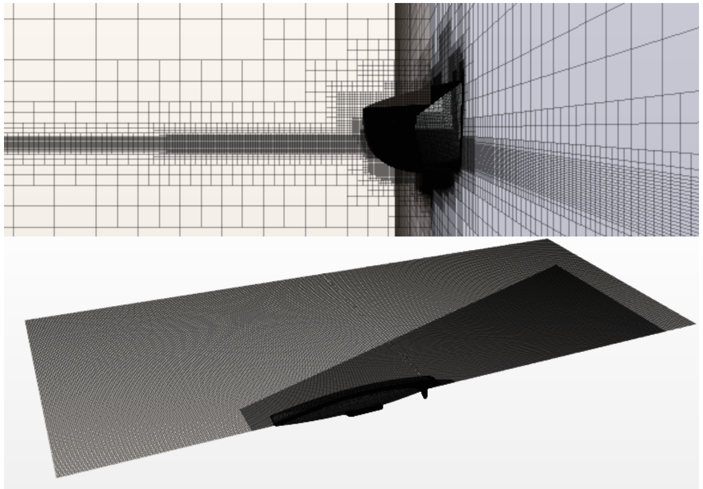

Fig.7 – Free surface refinements

Resistance Prediction

- Mesh generation
  - Prism layer mesh
    - layer thickness computed by formulas
    - 12 cells used
  - Same mesh for all the studies except for the prism layer
- Simulations
  - Performed on an Intel Core i7 3770K 3,4 GHz (4 cores) with 16 Gb RAM
  - Choice of speeds
    - Minimum and Maximum speeds: dictated by the company
    - Interval speeds: according simulations time and available time
  - Model: Implicit unsteady
  - Important assumption: heave and pitch only considered for maximum speed

Resistance Prediction

- Results
  - Resistance vs. Speed Curve
  - Validity of the results ?
    - Comparison with Wolfson VPP method (architect office)
    - Comparison with Guerritsma formulas

Table 2 – Perini hull coefficients and Guerritsma's range study

	Perini Hull	Guerritsma's study ranges
L_{WL}/B_{WL}	5.12	2.76 - 5.00
B_{WL}/T_{hull}	4.53	2.46 - 19.32
$L_{WL}/\nabla^{1/3}$	6.57	4.34 - 8.50
L_{CB}	-6.49	0.0 - -6%
C_p	0.54	0.52 - 0.60

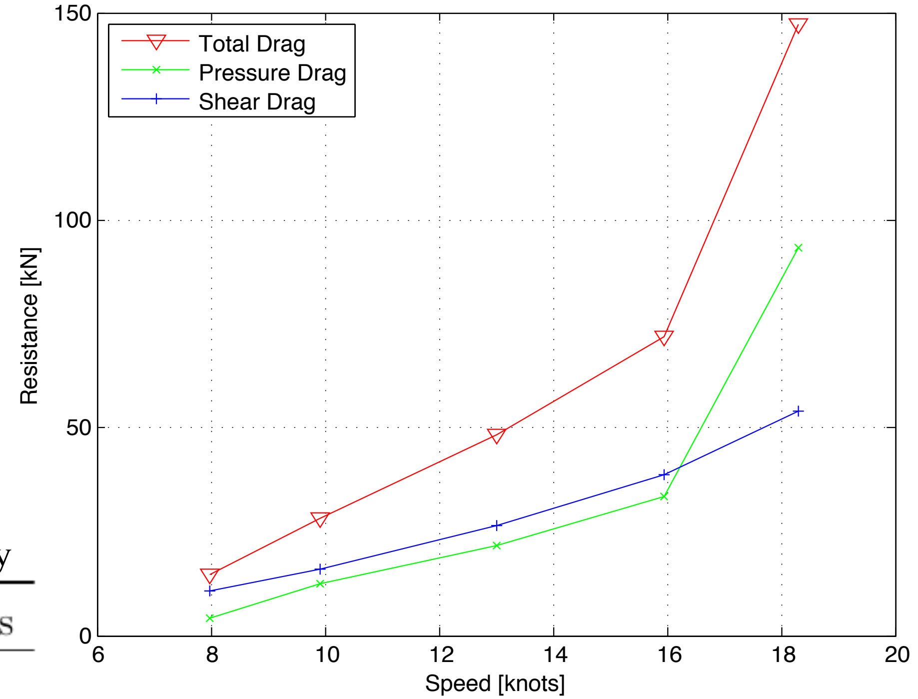

Fig.8 – Resistance [kN] as function of the Speed [knots]

Resistance Prediction

- Results
  - Comparison with Guerritsma model

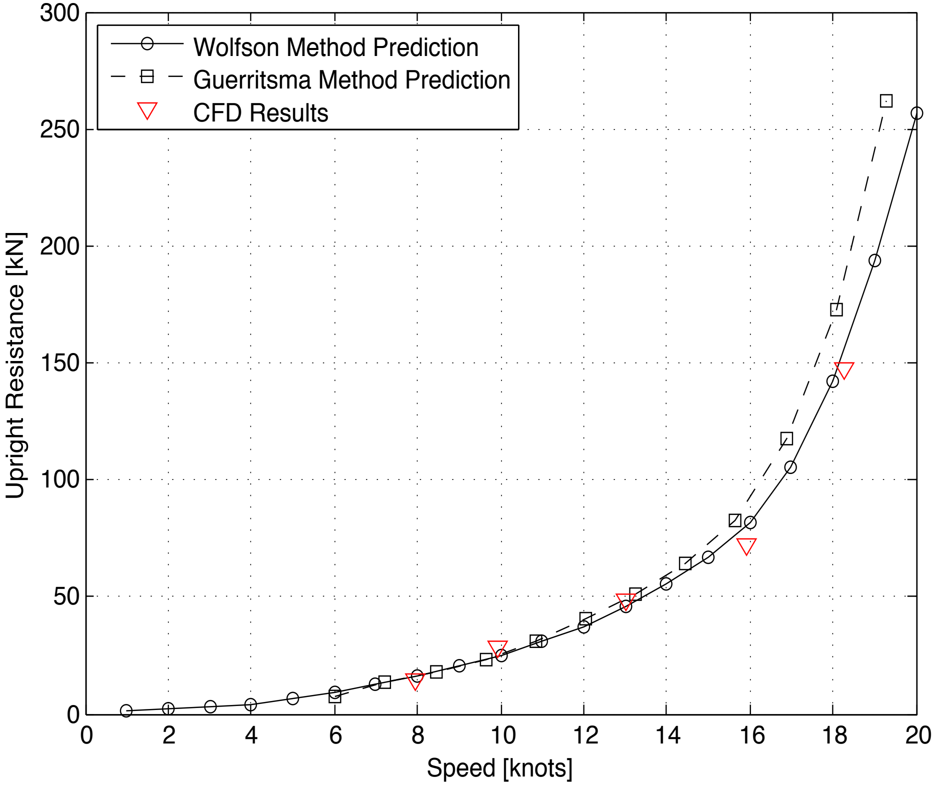

Fig. 10 – Upright resistance [kN] as function of the Speed [knots]

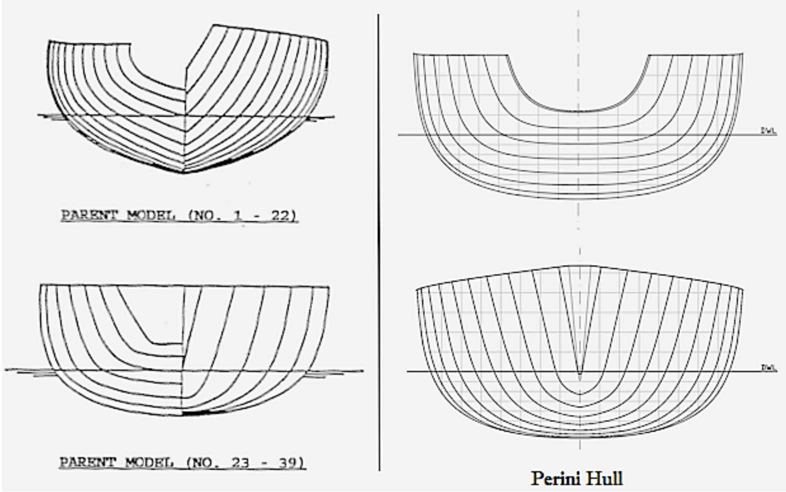

Fig. 9 – Guerritsma parent hull an Perini Navi hull

⇒ Same Range ✓

Resistance Prediction

- Results
  - Example of results obtained (Wave field and pattern).

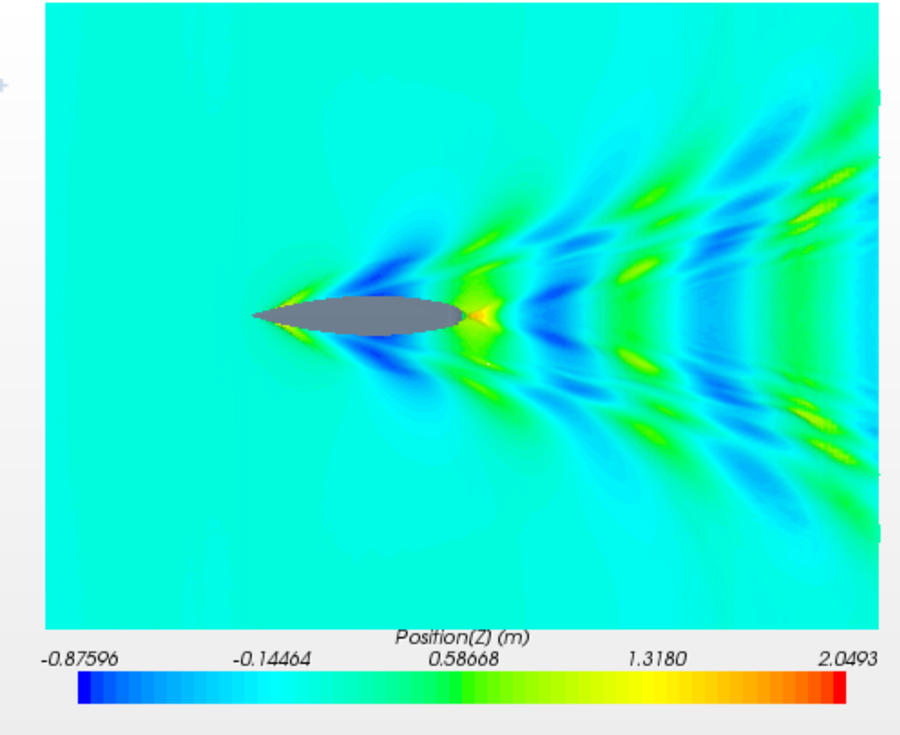

Fig. 11 – Wave field (18.3 knots)

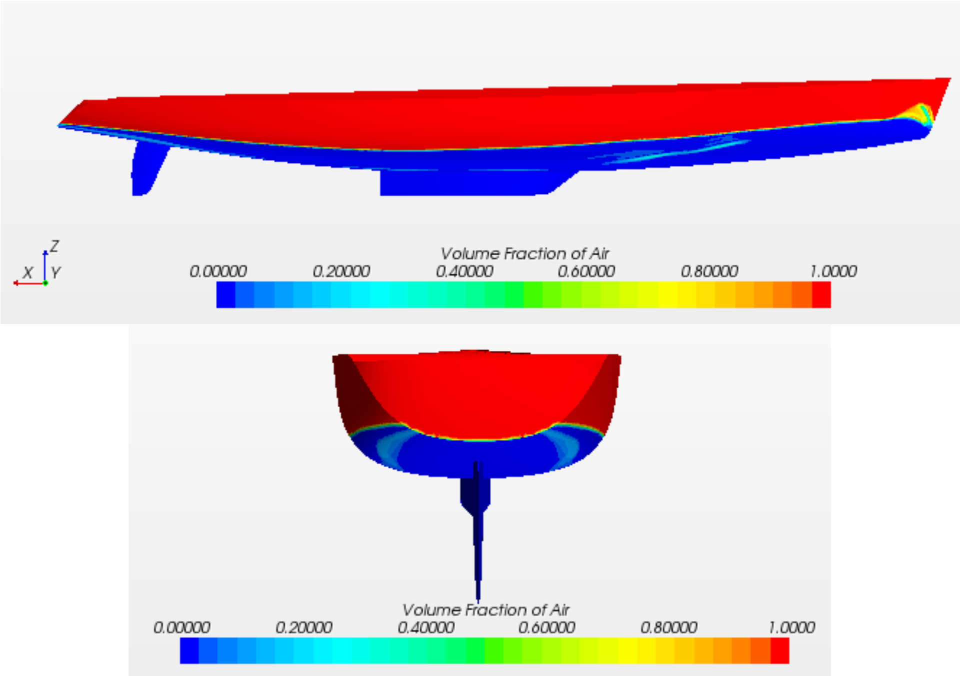

Fig. 12 – Wave pattern along the hull (18.3 knots)

Propeller Performances

- Problematic
  - Qualitative study of the shaft line and brackets impact on the propeller inflow
- Geometry
  - Build using company plans and CAD software Rhinoceros (real scale)

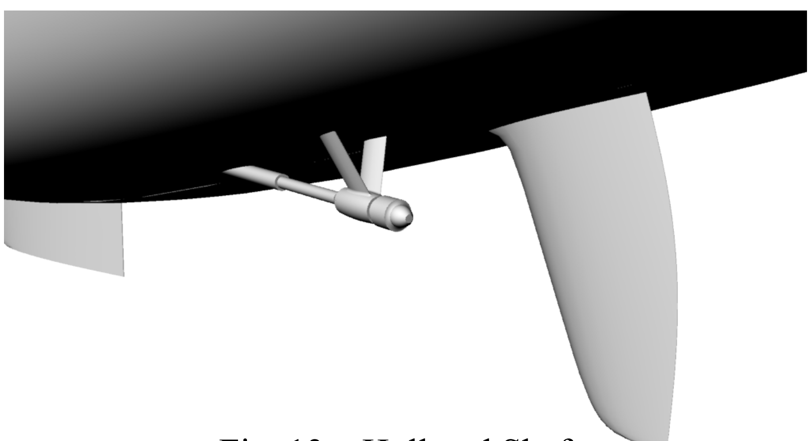

Fig. 13 – Hull and Shaft

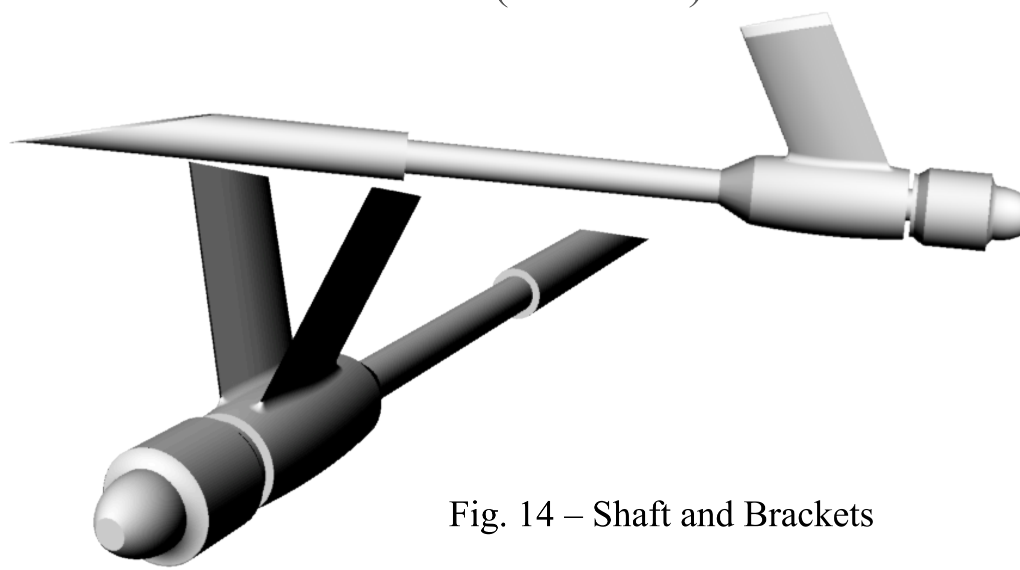

Fig. 14 – Shaft and Brackets

Propeller Performances

- Domain of simulation
  - Built using Rhinoceros
  - Use of the double hull assumption: top ends at free surface level (symmetry plane)
- Mesh generation
  - Hull and Shaft line divided into different parts
  - Volume shapes for local refinements

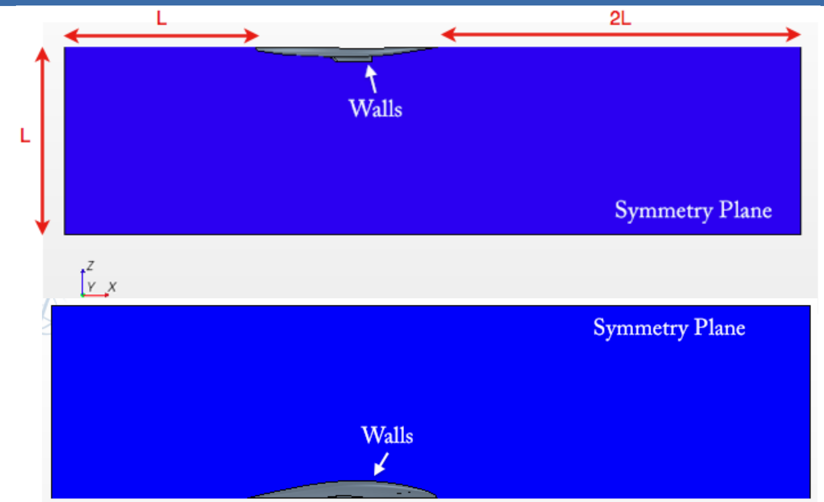

Fig. 15 – Domain of simulation (propeller performances study)

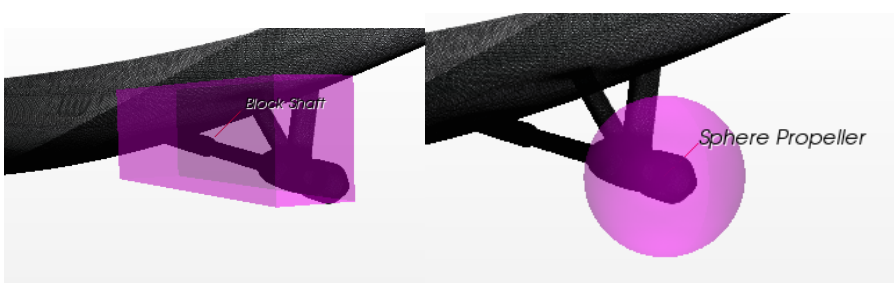

Fig. 17 – Volume shapes

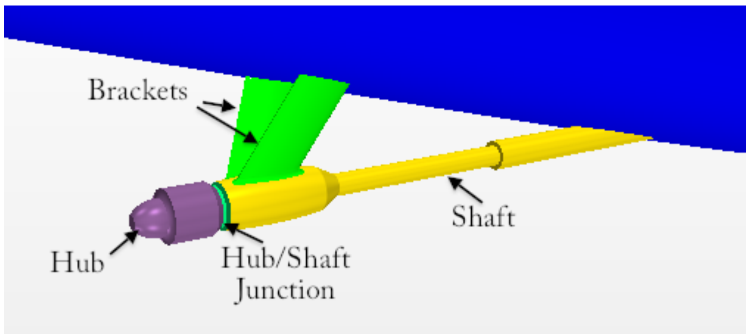

Fig. 16 – Shaft line parts

Propeller Performances

- Mesh generation
  - Prism layer mesh
    - layer thickness computed by formulas
    - 20 cells used

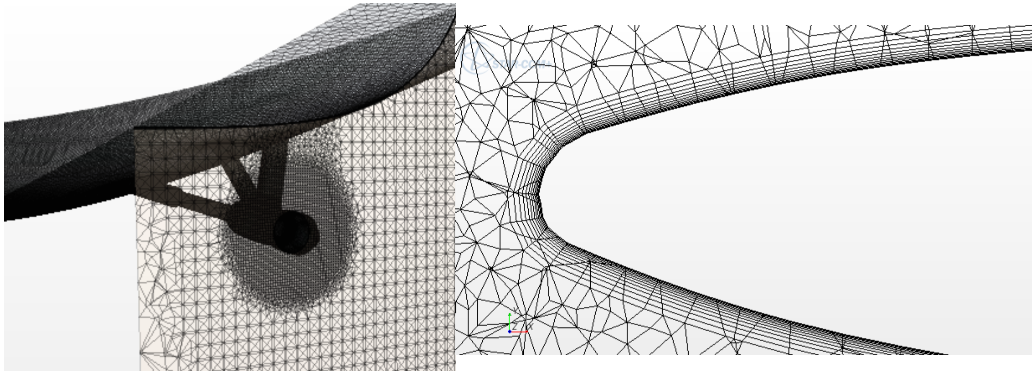

Fig. 18 – Mesh refinement and prism layer

- Simulation
  - Performed on 8 cores 2.4GHz with 32Gb RAM
  - At maximum speed
  - Model: Steady
    - First part of the simulation in laminar (to have good initial solution for turbulent simulation
    - Then k-epsilon Realizable

DLTM DISTRETTO LIGURE delle TECNOLOGIE MARINE

Propeller Performances

- Results
  - Analysis on 14 plans (6 vertical & 8 horizontal)
  - Vertical planes: shaft influence propagation

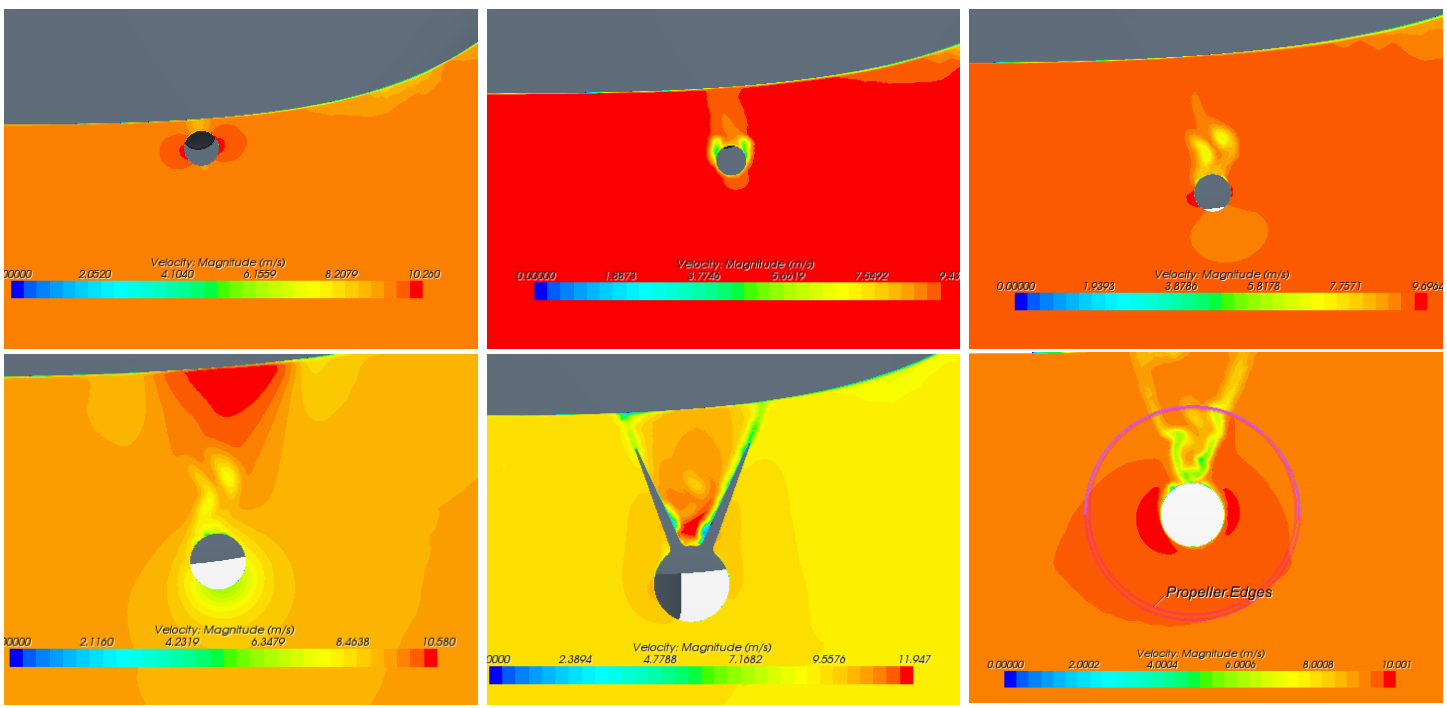

Fig. 19 – Shaft line wake steps

Propeller Performances

- Results
  - Horizontal planes: brackets influence

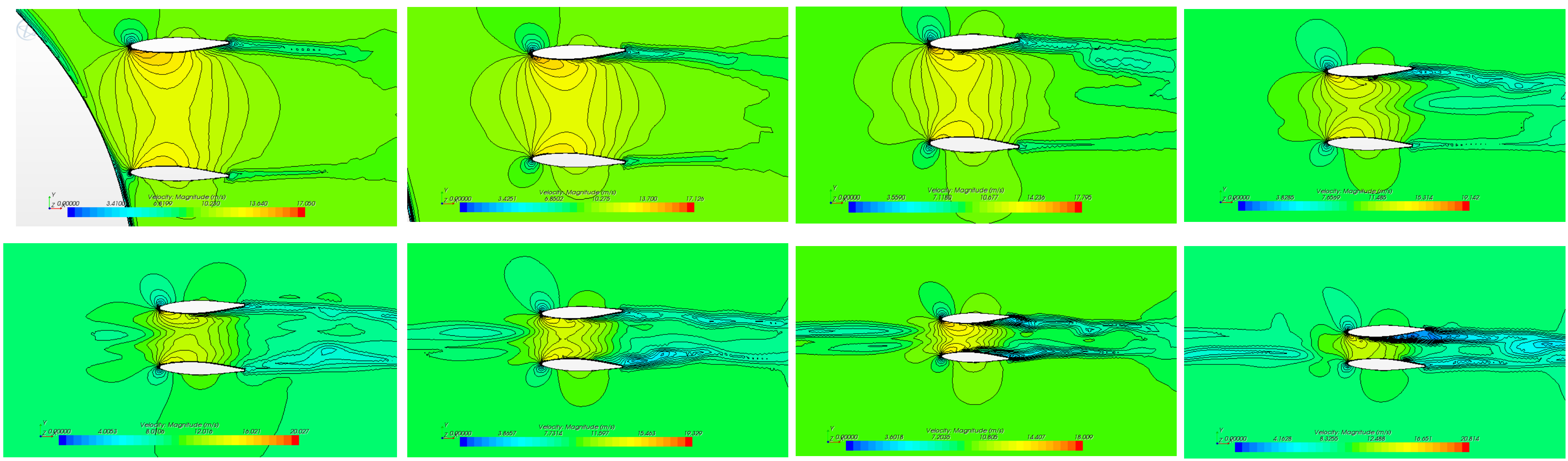

Fig. 20 – Brackets influence

Propeller Performances

- Results
  - Propositions mainly on the brackets design/configuration
    - Orientation of the brackets
    - Trailing edge form: curved in order to reduce turbulences and so vibrations
    - Bracket distance

➢ Company choice: Bracket orientation

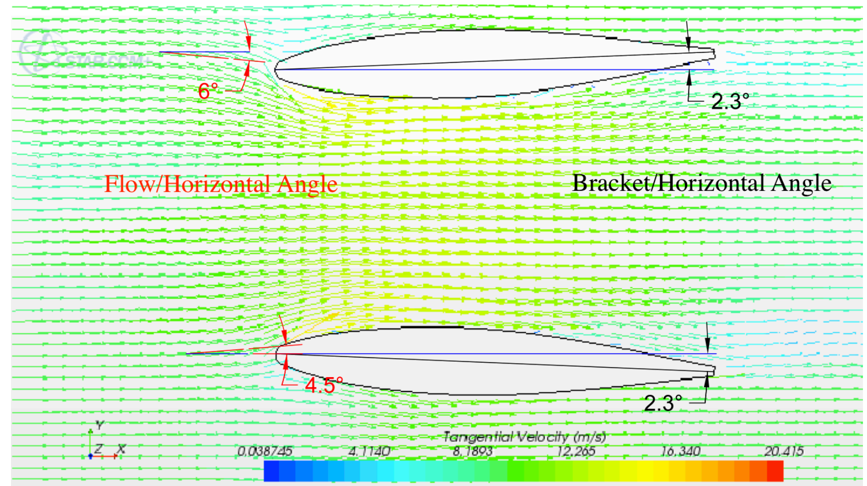

Fig. 21 – Bracket orientation

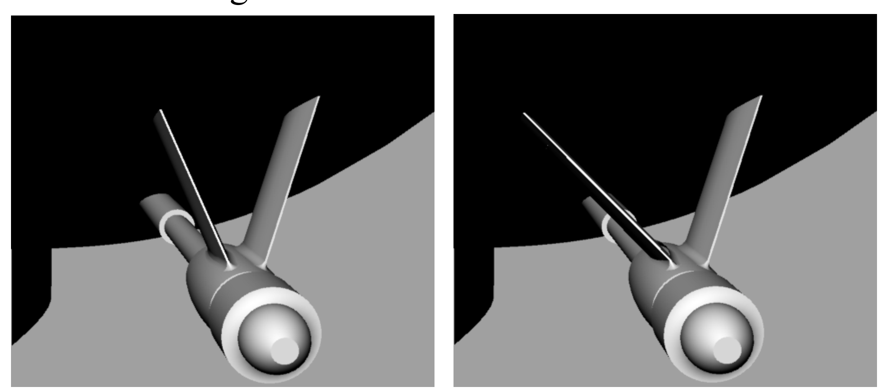
Fig. 22 – Bracket configuration proposition

Conclusions

- Resistance study
  - Good agreement with statistical method results
  - Helps for exhaust gas pipe location
- Propeller performances
  - Better understanding of the wake creation
  - Analysis of the geometry design
  - Modification to improve the performances

Thank you for your attention

Questions ?