HYDROFOILING IN THE NAVAL FIELD:

AERONAUTICAL PRINCIPLES, ANALYSIS AND FLUID-DYNAMIC APPLICATIONS

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05/12/2025

A FUTURE ON SOLID ROOTS

BLUE Engineering was founded in 1993 in northern Italy by O.**B**erkol, D. **L**azzeri, P.**U**slenghi, M.**E**id.

As of 2025, the main company stakeholder is the biggest railway manufacturer in the world, CRRC.

The company HEADQUARTER is located in Turin, the 2008 World Design Capital and the Italian car design hometown.

The subsidiary is located in Naples, close to the aerospace southern district.

BLUE is a leading benchmark in Automotive, Railways, Aerospace and Maritime engineering and design, promoting also eco-friendly first- and last-mile connectivity solutions for smart cities.

With strong multidisciplinary know-how and deep specialization in numerical analysis we maximize speed, quality, and efficiency throughout the development process: concept & styling, design, engineering, virtual prototyping simulation, testing validating and ICT

EXCELLENCE IS OUR MISSION

Located in the core region of Europe and with its advantages in terms of technology, market, talent and scientific research, BLUE has been engaged in the technical service of transportation products for the last 29 years.

AUTOMOTIVE | AERONAUTICS | AEROSPACE | RAILWAY | MARINE | TEST BENCH & ITC | R&D

WHAT WE DO

- TURN-KEY DEVELOPMENT
- PLATFORM MANAGMENT
- CONTRACTOR COORDINATION
- ISSUING OF SPECIFICATION
- TECHNICAL DOCUMENTS
- COST ANALYSIS

PLUS

- IDEAS OF INNOVATION
- OPTIMIZATION IN QUALITY/CHARGE RELATIONSHIP
- EFFECTIVE PROCESSING METHODS
- PERFECT KNOWLEDGE OF NEW CAD/CAE SYSTEMS
- HIGLY SKILLED TEAM
- TOP FLEXIBILITY OF SERVICE

IDEA OF DESIGN

- TO GIVE EACH PRODUCT ITS PERSONALITY
- TO BE THE POINT OF CONTACT BETWEEN DESIGN AND TECHNOLOGY
- TO IMPROVE CONSUMERS' QUALITY OF LIFE
- TO REPRESENT THE BASIC FEATURE OF PRODUCT SUCCESS
- TO ACT A LEVER OF ECONOMIC DEVELOPMENT GIVEN THAT IT IS COMPETITIVE AND INNOVATIVE
- TO EXPRESS CULTURAL VALUES

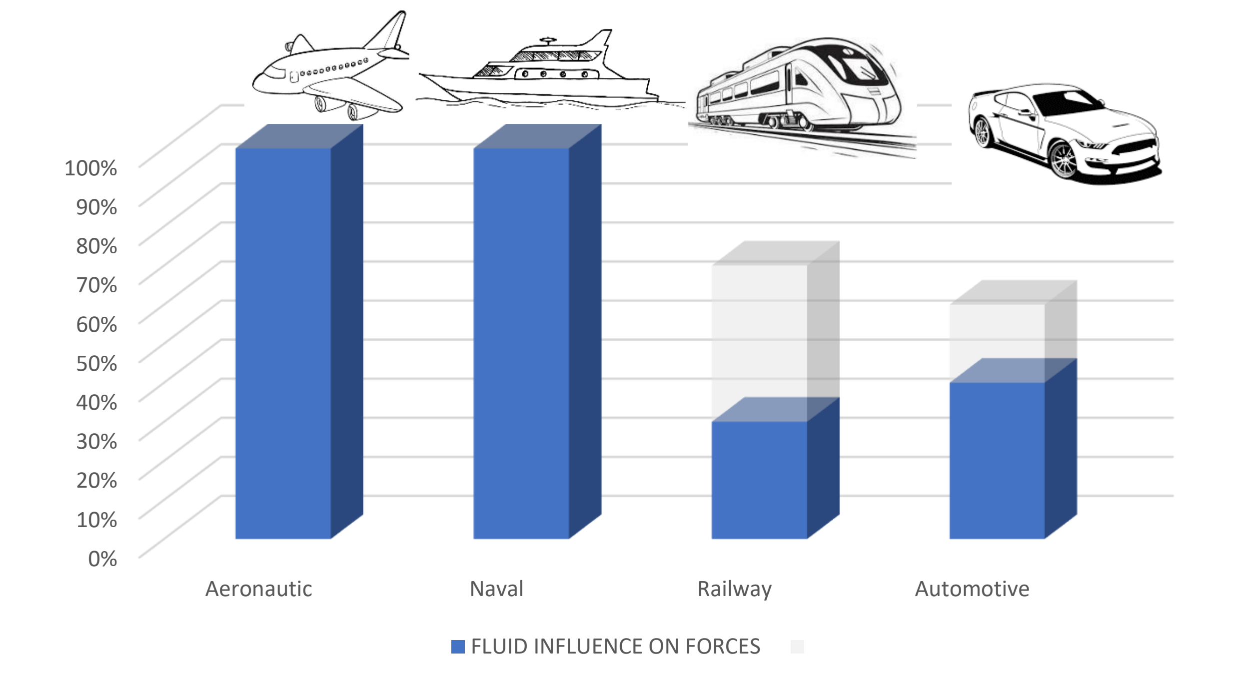
Fluid-Driven Design: The Fundamental Force

- **AERONAUTIC and NAVAL**

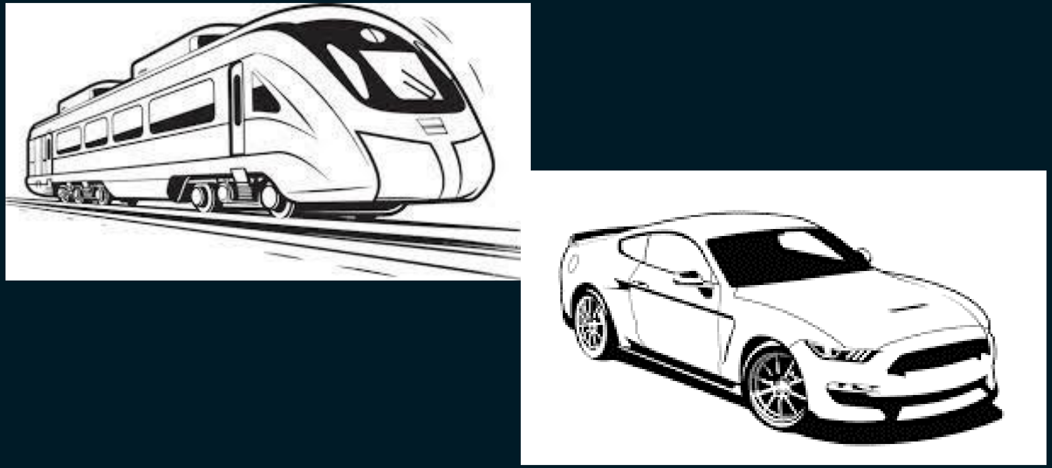
The shape *is* mainly the function of the fluid. The goal is to generate lift/buoyancy and minimize drag. The dominant forces (Lift/Drag/Thrust) originate from fluid interaction.

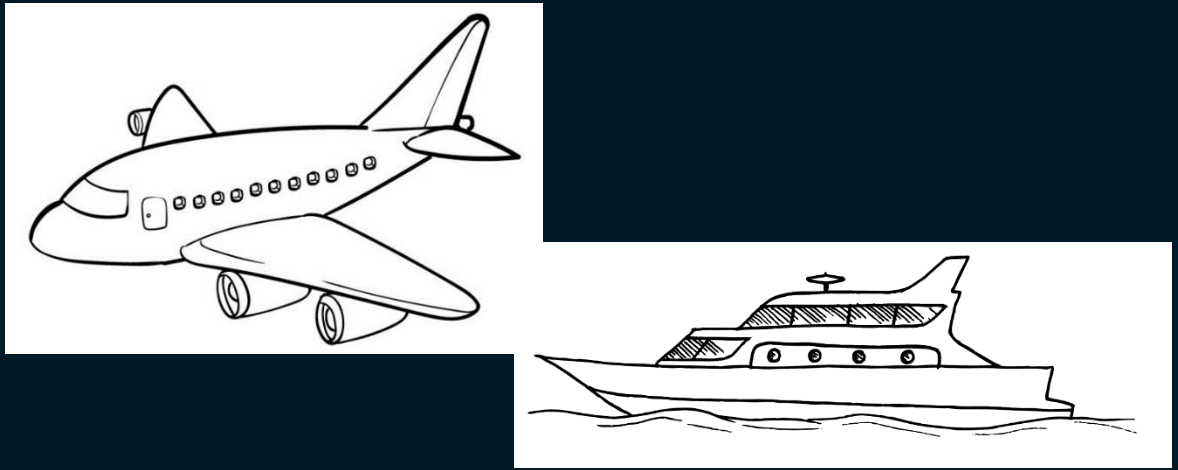
- **RAILWAY and AUTOMOTIVE**:

The shape is a compromise. The fluid (air) is an obstacle to mitigate, not the primary force supporting or guiding them. Dominant forces are friction and ground reaction.



Fluid-Driven Attitude: Mastering the Environment





Attitude is primarily a function of mechanical systems

- Constrained by Design:

Suspensions, springs, and physical contact with rails or road are the dominant factors.

- Fluid as Disturbance:

Aerodynamics is largely a disruptive force (drag, cross-winds) to be managed, not the primary medium for control or support. This concept stands generally, with some exception (e.g. the downforce in high performance vehicle).

For both aeronautic and marine field, attitude is fundamentally dictated by fluid dynamics.

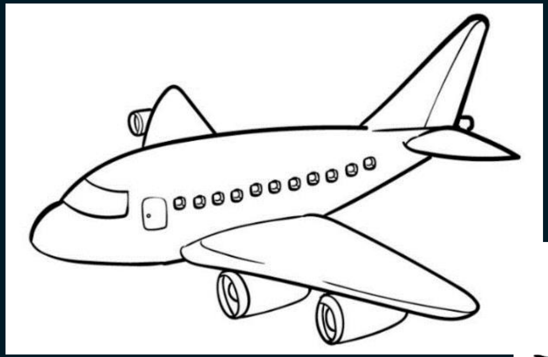
- Active Control:

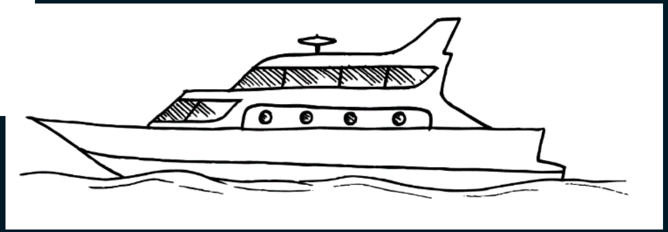
Surfaces like ailerons, elevators and rudders manipulate airflow and water flow to induce and control pitch, roll, and yaw.

- Passive Stability:

The inherent design of wings and hulls generates stabilizing forces (lift, buoyancy, righting moment), making the fluid itself a core component of attitude stability.

Fluid-Driven Attitude: Absolute Fluid Mastery





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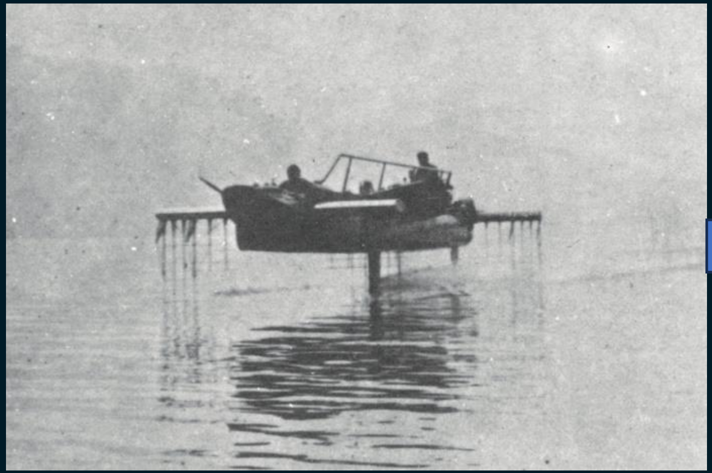
HYDROFOILING – Concept and Application

The hydrofoil concept, pioneered over a century ago by Enrico Forlanini (1911), utilizes submerged wings to generate lift.

The concept has been widely adopted in naval engineering and has since been successfully applied across various maritime sectors.



Forlanini’s Hydroplane

Seabubbler Taxi (FR)

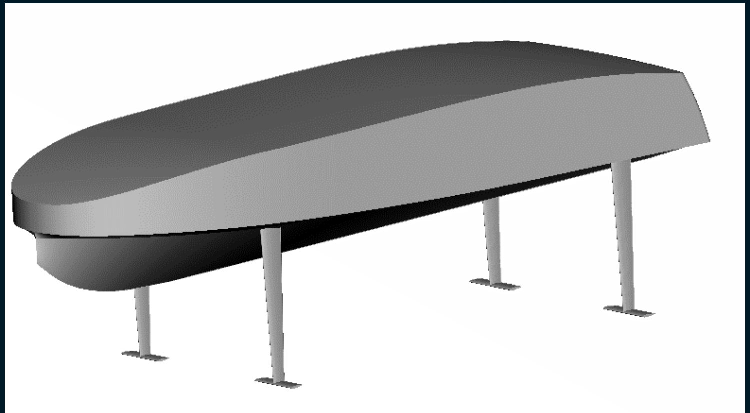
U.S. Navy foiling boat (USA)

SEAir (FR)

The fundamental principle involves a transition from hydrostatic buoyancy at rest to hydrodynamic lift in motion. As speed increases, the foils produce an upward force that elevates the hull, significantly reducing the wetted surface area and consequent hydrodynamic drag.

This drag reduction enables two primary advantages: achieving higher top speeds or maintaining equivalent speeds with reduced propulsive power. Lift can be actively controlled by adjusting the foil's angle of attack, ensuring optimal boat balance and performance across various operating conditions.

HYDROFOILING – Case Study



This activity was part of a broader research project exploring the application of shape-memory materials in marine engineering.

The project aimed, given a yacht with a pre-existing hull design, to develop and integrate geometries to enable foiling capability at the lowest possible speed threshold.

The proposed solution involved integrating four independent hydrofoils into the yacht's hull—a typical configuration with two forward and two aft foils to ensure pitch and roll stability.

The key innovation is the foil morphing capability. The design hypothesis proposed that these foils would be engineered to actively deform, optimizing performance.

Lenght [m]	17
Width [m]	5
Height [m]	3
Center of gravity (from stern) [m]	6
Weight [kg]	25000

Case Study – Foil Design

INPUT DATA:

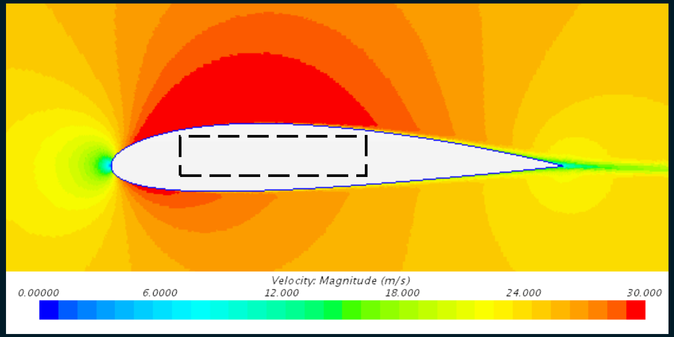
- Hull geometry and weight
- Center of gravity
- Foil positioning -> lift distribution between front and rear
- Minimum foil main section for manufacturing constraints

DESIGN VARIABLES:

- Airfoil shape
- Foil dimensions

- **STEP 1: airfoil choice**

The selection of the optimal foil geometry was based on 2D Computational Fluid Dynamics (CFD) simulations performed in water.



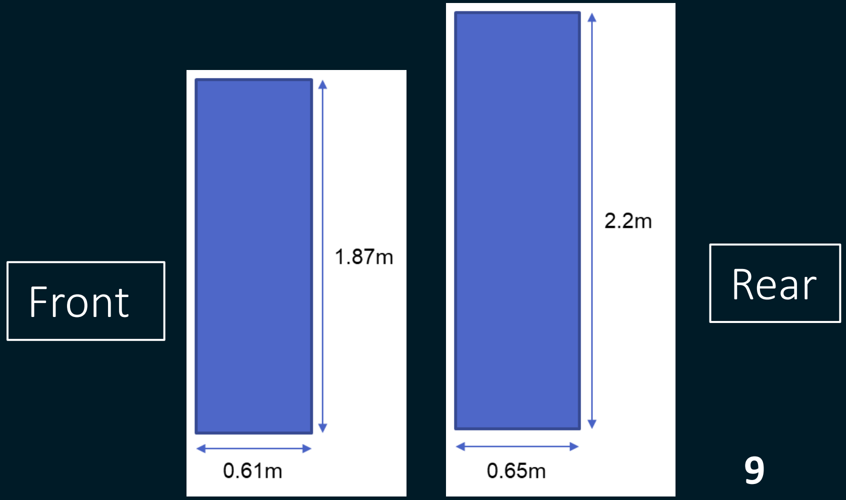
- **STEP 2: Surface area evaluation**

Given the wanted lift distribution and the lift coefficient obtained from CFD simulations of airfoils, for a certain velocity it is possible to obtain the surface area needed.

$$L = \frac{1}{2}\rho V^2 S C_L$$

- **STEP 3: Foil dimensions**

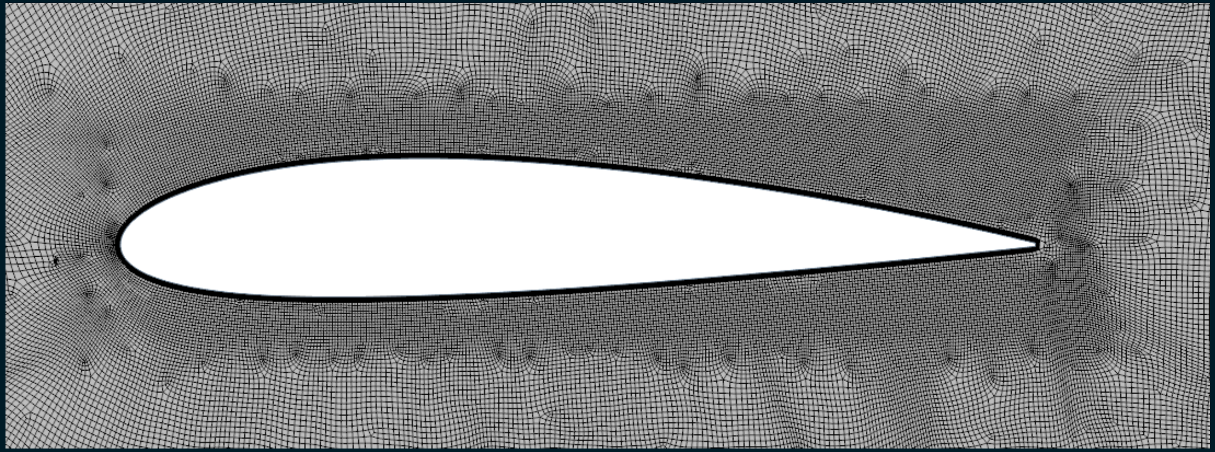
For front and rear foils, given the surface value previously obtained the foil dimensions have been evaluated.

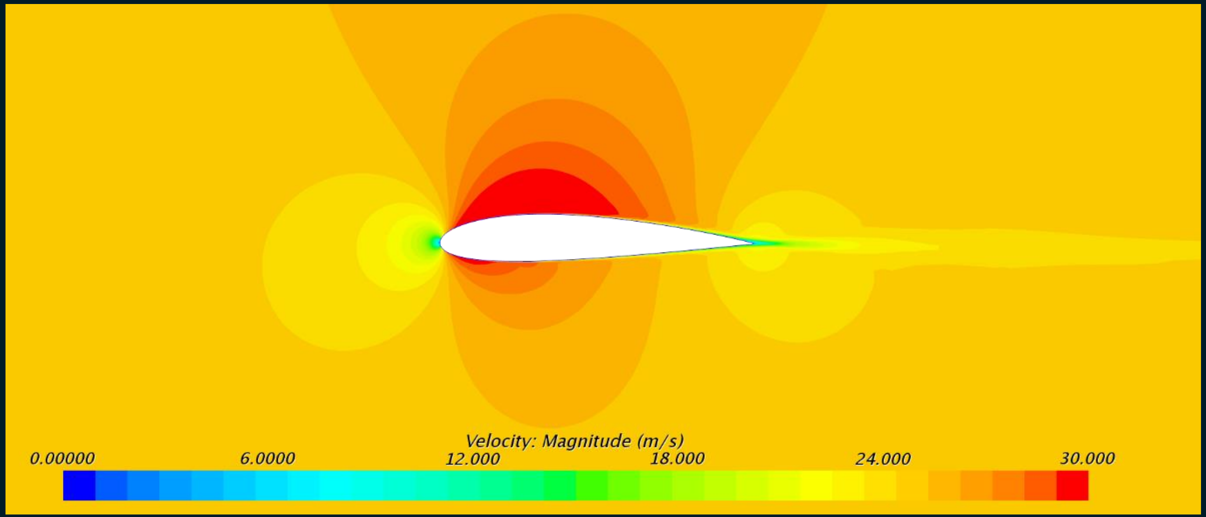


Case Study – Foil Numerical Setup

SIMULATION PARAMETER:

- RANS
- Steady
- Two-Dimensional
- Reynolds number ~ $2 \cdot 10^7$
- Constant density (Water properties)
- Fully turbulent
- Turbulence model: SST K-ω
- All y+ wall treatment
- Inlet velocity: 25 m/s
- Cells count: ~200000



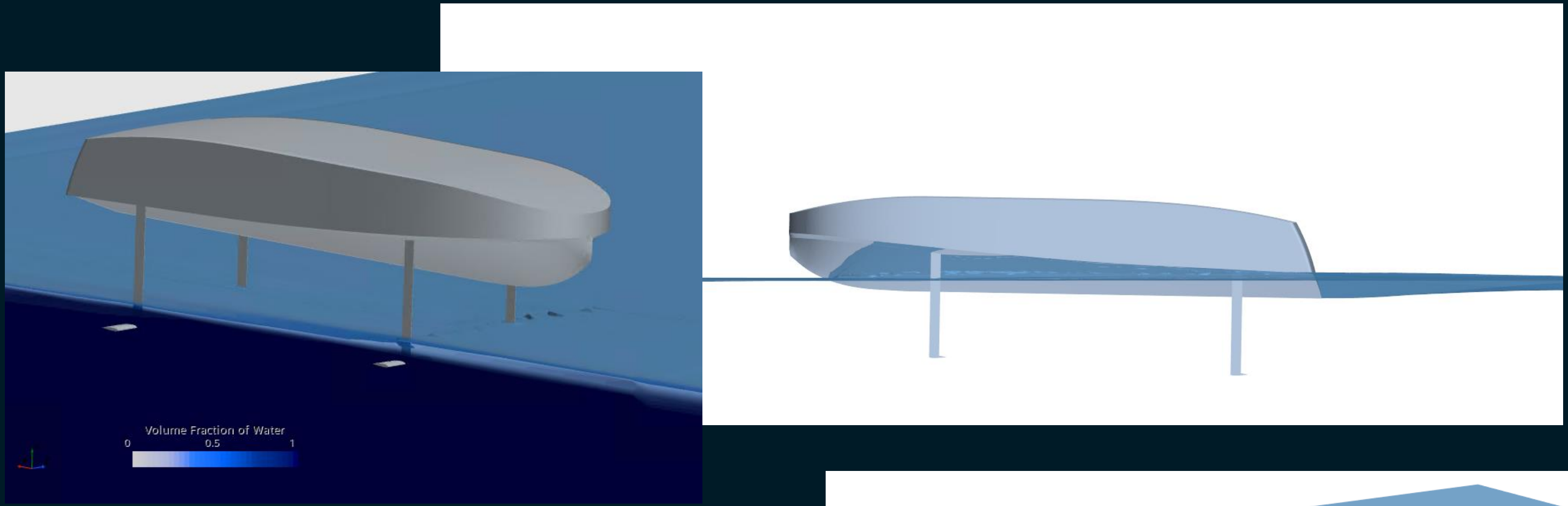


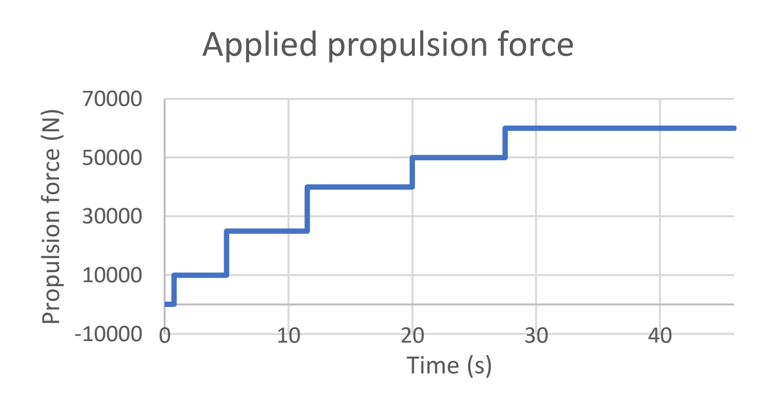
Case Study – Complete simulation setup

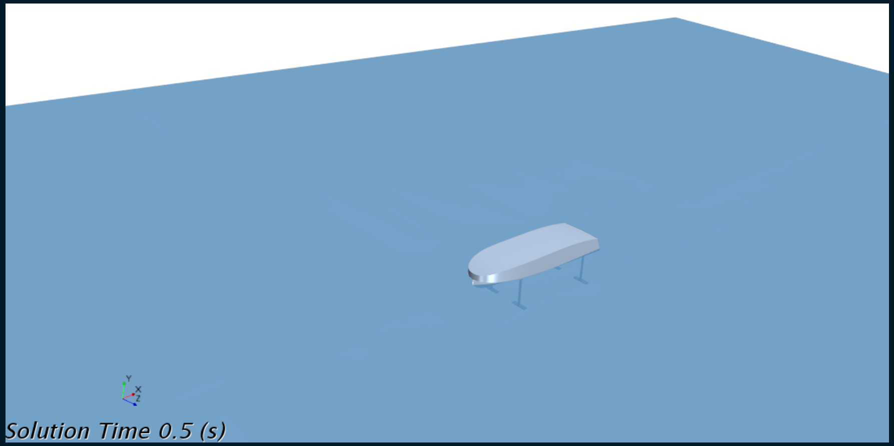
The obtained geometry has been simulated on the complete boat to verify the results from the two-dimensional simulations.

SIMULATION PARAMETER:

- RANS
- Unsteady
- Three-Dimensional
- Multiphase Eulerian Flow
- Turbulence model: SST K-ω
- All y+ wall treatment
- VOF (volume of fluid)
- DFBI (Dynamic Fluid Body Interaction) – 6DOF Body
- Applied propulsion force: see graph
- Cells count: ~10 mln





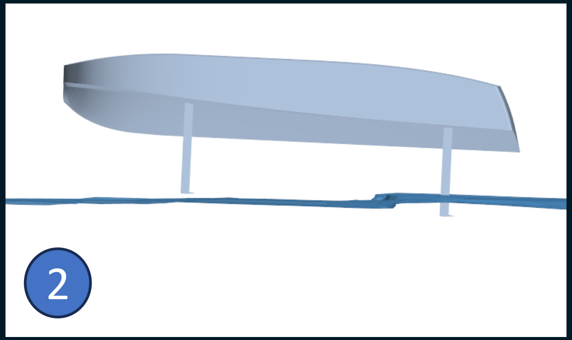


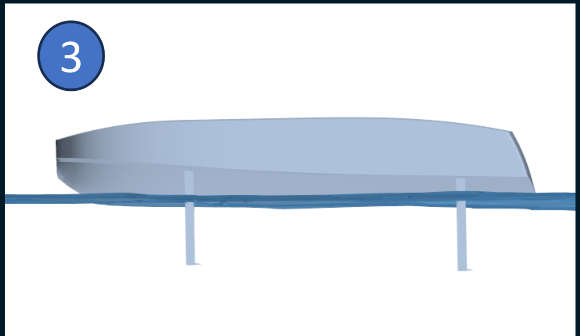
Case Study – Complete simulation results

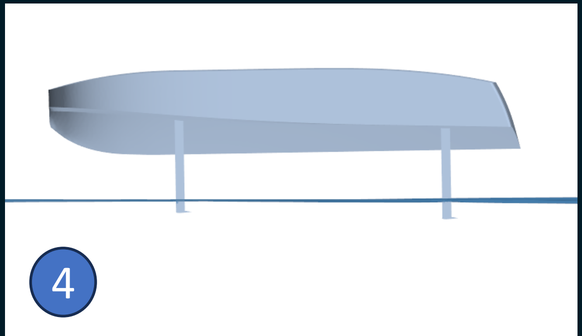
Verified foiling phenomena ✅

Foiling results:

Foiling start velocity	27 m/s (42 knots)
Applied propulsion force	60000N
Foiling start time	34 s







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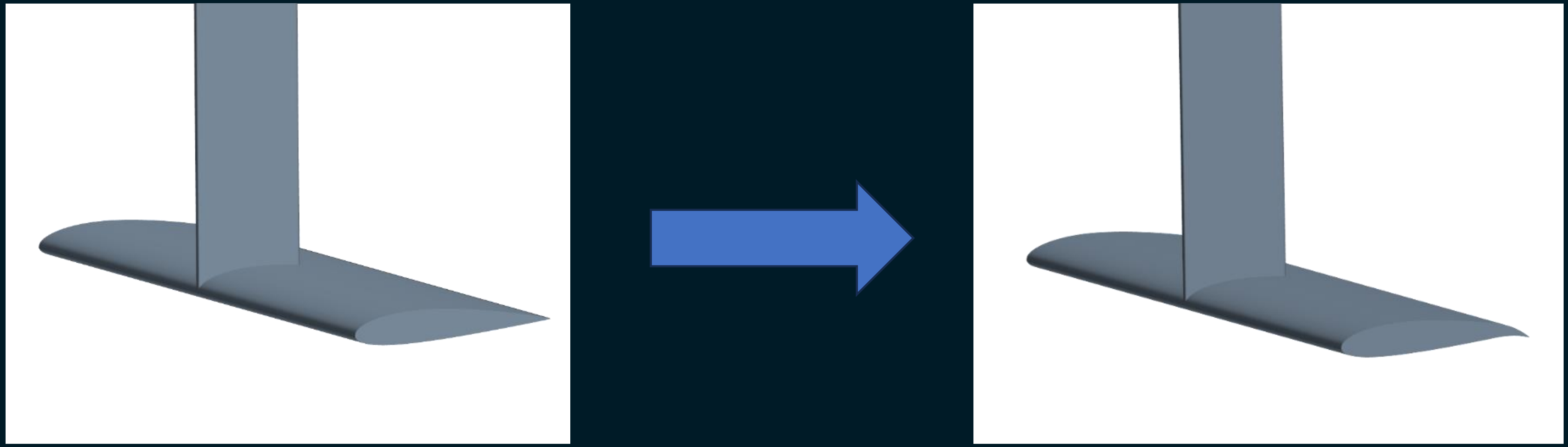
Case Study – Morphed foils

The simulation on the complete boat showed the hydrofoiling starting at 42 knots.

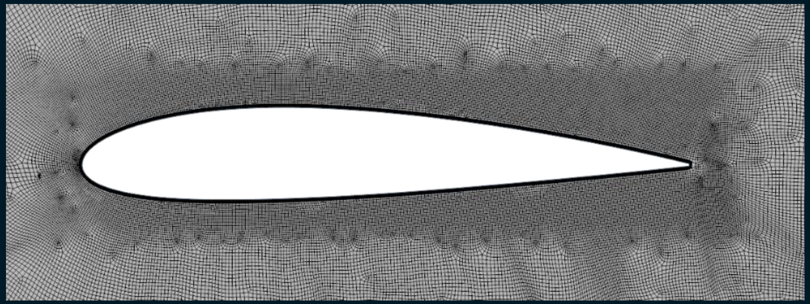
The aim of the study was to introduce the hydrofoiling also in different conditions, e.g. low speed.
The best way to achieve the target is to increase the lift produced from the foil, with solutions "stealed" from aeronautical concepts.

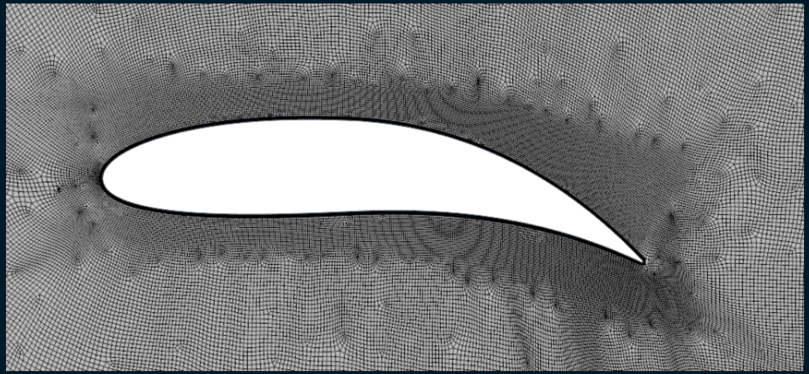


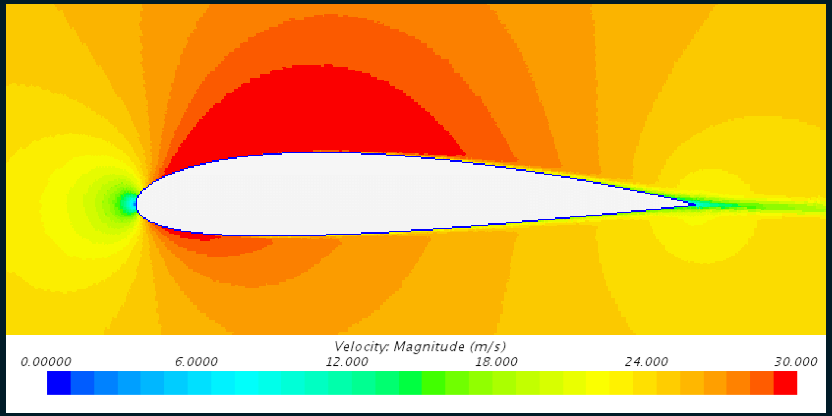
Case Study – Foil Morphing Simulation Setup

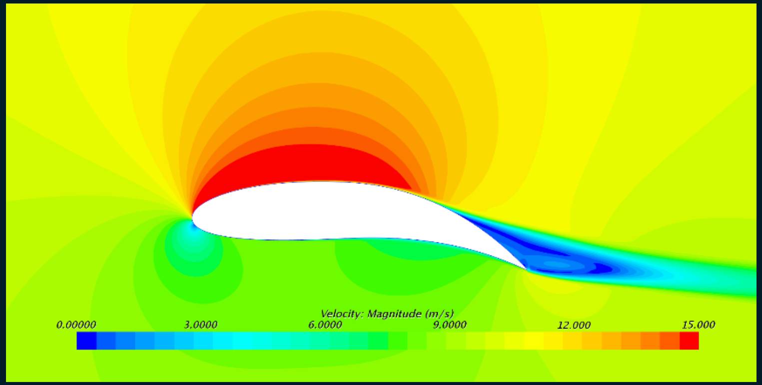
SIMULATION PARAMETER:

- RANS
- Implicit Unsteady
- Two-Dimensional
- Reynolds number ~ $7 \cdot 10^6$
- Constant density (Water properties)
- Fully turbulent
- Turbulence model: SST K-ω
- All y+ wall treatment
- Mesh morpher
- Airfoil hinge point: 40% chord
- Inlet velocity: 10 m/s
- Cells count: ~200000



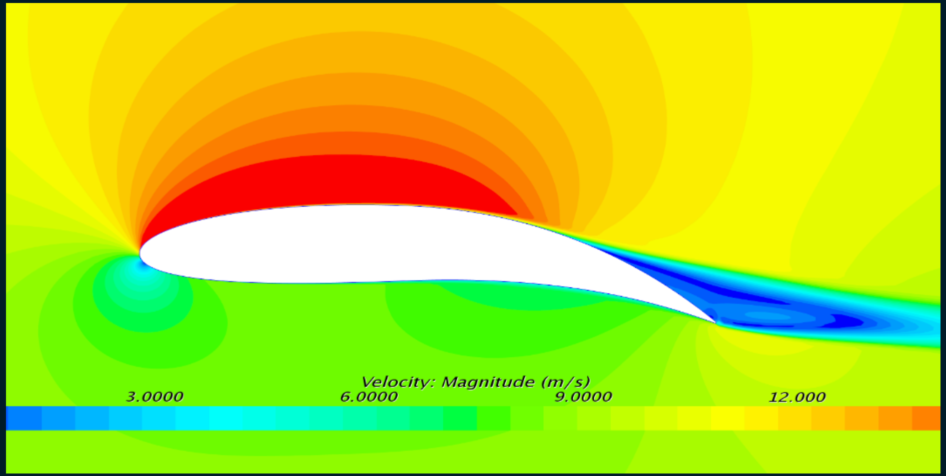




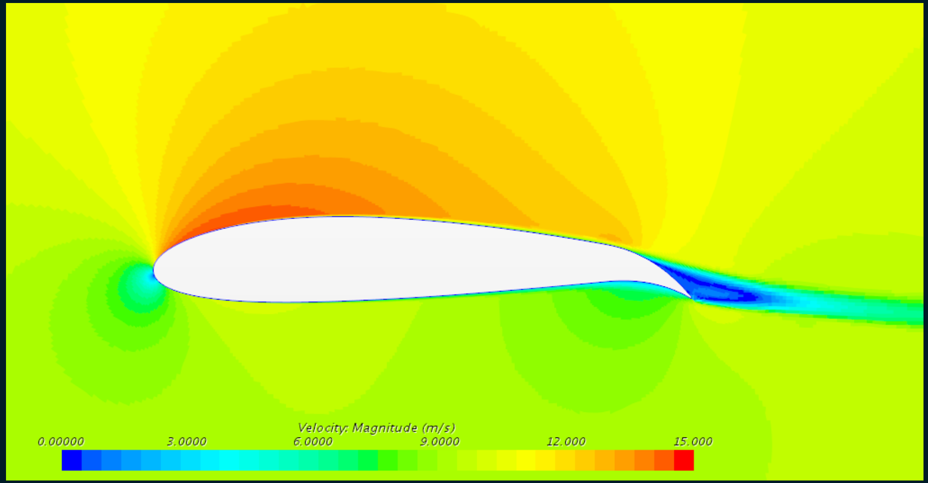


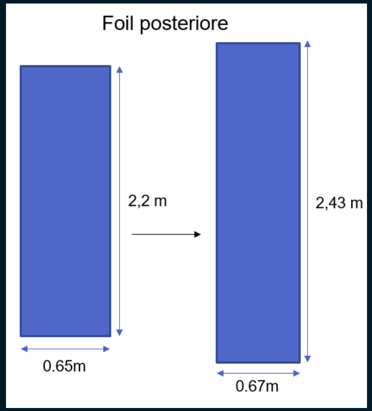
Case Study – Foil Morphing Feasibility

The obtained morphed geometry theoretically enabled foiling at approximately 10 knots using the same foil dimensions. However, a feasibility check determined that the hinge point needed to be relocated to 80% of the chord, significantly reducing the achieved performance.



-45% LIFT





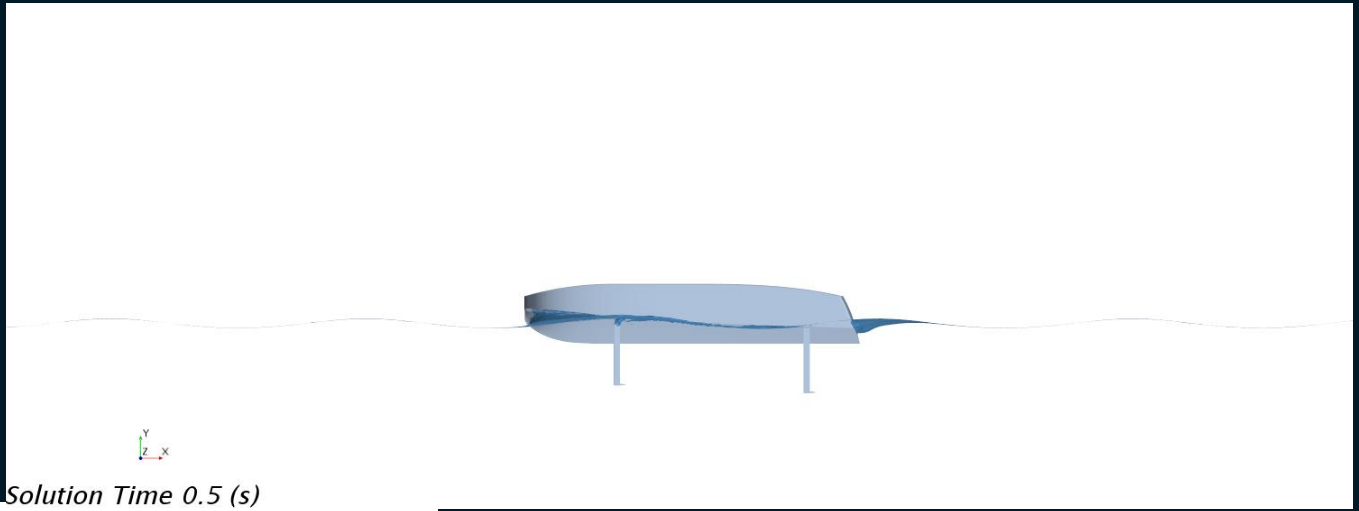
Thus, a compromise between performance and foil dimension has been achieved. Foils have been increased in their size as much as possible, still not reaching the same performances of the first morphing hypothesis.

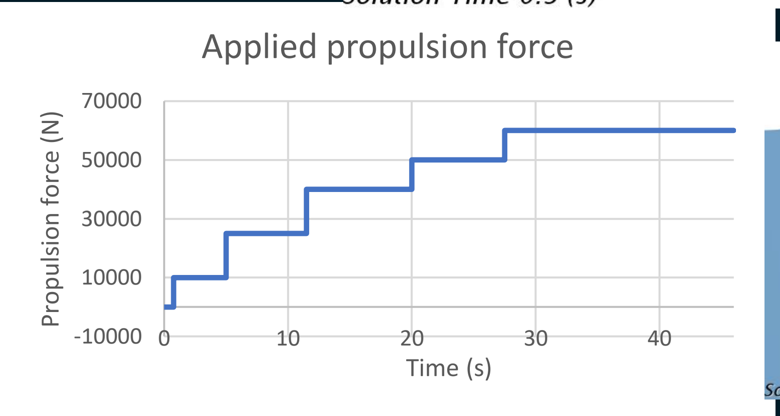
Case Study – Complete optimized simulation setup

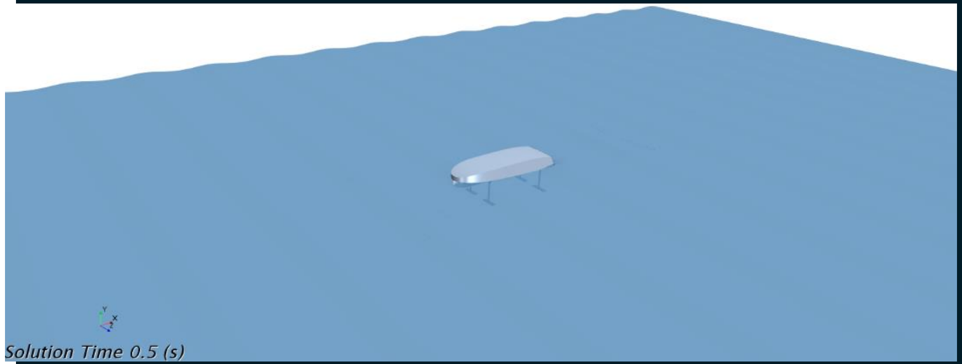
The obtained geometry has been simulated on the complete boat to verify the results from the two-dimensional simulations.

SIMULATION PARAMETER:

- RANS
- Unsteady
- Three-Dimensional
- Multiphase Eulerian Flow
- Turbulence model: SST K-ω
- All y+ wall treatment
- VOF (volume of fluid)
- DFBI (Dynamic Fluid Body Interaction) – 6DOF Body
- Applied propulsion force: see graph
- Cells count: ~10 mln
- VOF waves modelling







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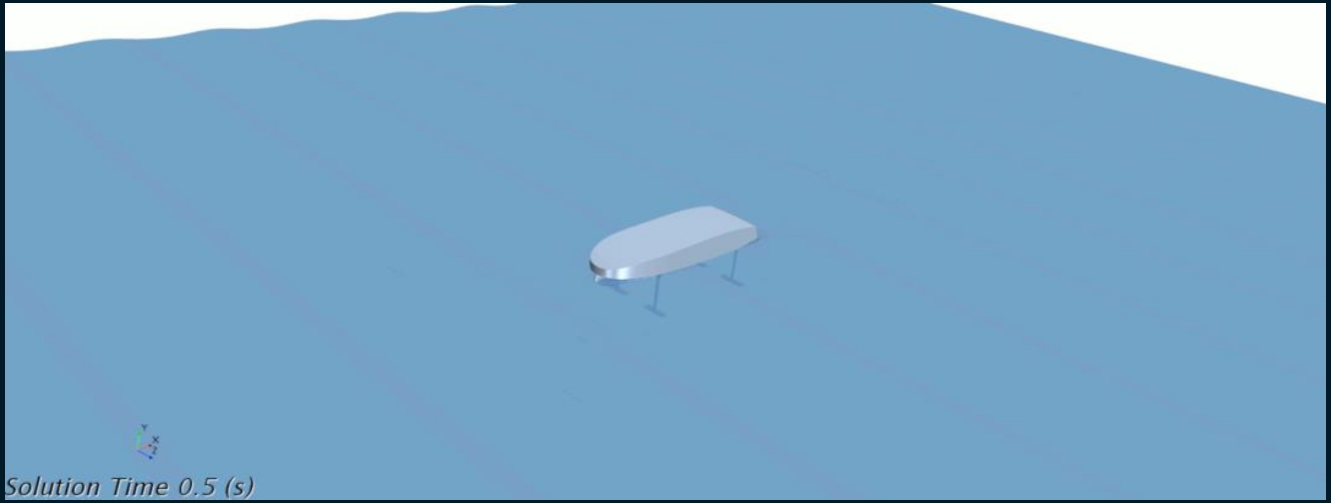
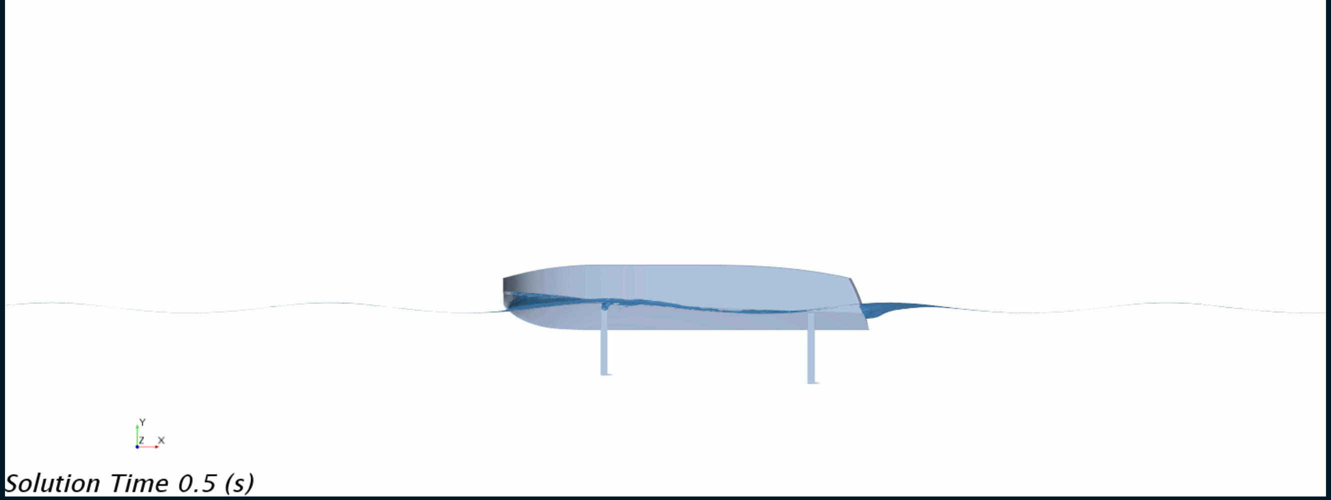
Case Study – Complete optimized simulation results

Verified foiling phenomena





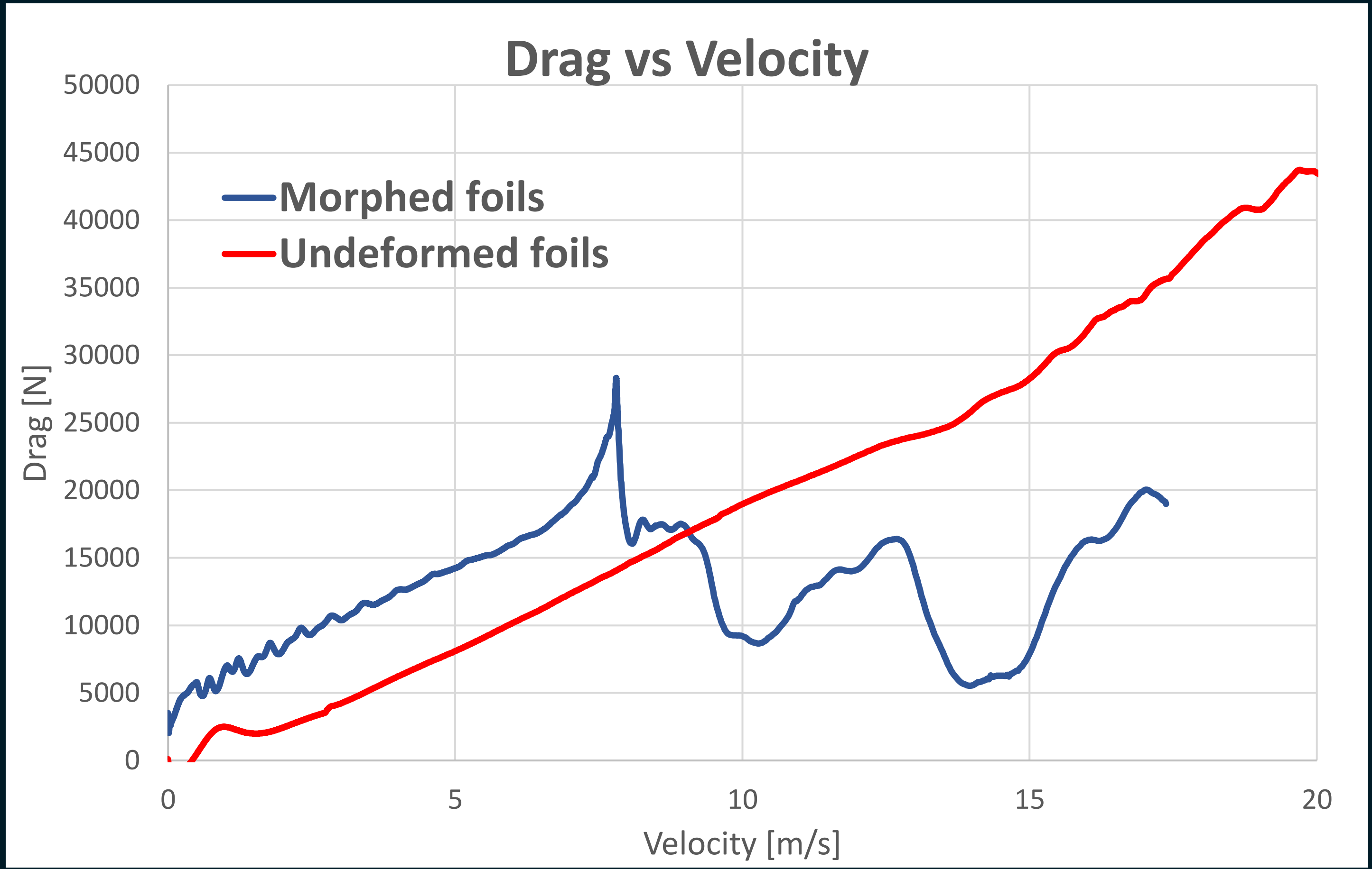
Foiling results:

Foiling start velocity	8 m/s (15 knots)
Applied propulsion force	30000N
Foiling start time	18 s

Case Study – Complete optimized simulation results

Comparing the two complete simulations:

- At start, when the foiling phenomenon has not happened in both cases, the boat with morphed foils presents higher drag values (due to the greater lift generated by the morphed foils)
- After foiling phenomenon (8m/s), the drag drastically reduces and stop increasing in morphed foil configuration, while still increasing at the same speed in the undeformed foils configuration (foiling phenomenon happens at higher speed).



Conclusions

- **A Unified Fluid-Dynamic Principle:**

This study successfully demonstrated that the fundamental principles of aerodynamics are directly transferable to marine engineering. The hydrofoil acts as a "wing in water," generating lift to elevate the boat’s hull, thereby drastically reducing drag.

- **Proof of Concept: High-Speed Foiling Achieved.**

Our initial design, equipped with four foils, conclusively proved the foiling phenomenon, achieving full hull elevation at a speed of 42 knots. This validated our computational models and the application of aeronautical science.

- **Innovative Morphing for Enhanced Performance.**

The key innovation lies in the morphing of the foil profiles. By optimizing the airfoil shapes for different regimes, we successfully extended the foiling capability to lower speeds. This allows the boat to achieve the foiling phenomenon at 15 knots, reaching a 65% reduction of foiling speed.