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Designing a Kiteboard Hydrofoil:
Fluid Flow Assessment
Structural and Fluid Analysis (ACMA6010)

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Abstract

This report presents a critical analysis of the fluid interaction on a kiteboard hydrofoil wing. The investigation shows that the wing operates in a fully turbulent flow regime, which sustains flow attachment and lift generation. This hydrodynamic behaviour has a direct effect on the wing's high-aspect ratio and optimised profile. The study re-evaluates the force assumption made previously and demonstrates that complex distributed loads more accurately reflect real-world hydrodynamic loading compared to simplified point loads. Despite being susceptible to impact damage, carbon fibre reinforced plastic (CFRP) is recommended for its strength-to-weight ratio. The report concludes that CFD simulations and experimental towing tank tests must be combined to validate and improve design. A balanced integration of turbulent flow management, hydrodynamic form, and advanced composite materials produces peak hydrofoil performance.

1.0 Introduction

The sport of kiteboarding has undergone significant technological evolution, largely driven by the integration of hydrofoil systems. These systems increase lift and reduce hydrodynamic drag, improving performance. This report analyses fluid flow around a kiteboard hydrofoil wing. The study has six main goals: to perform a Reynolds number analysis, to examine boundary layer effects on wing design, to critically evaluate force assumptions from a previous study, to evaluate modelling techniques like CFD and carbon fibre composites, and to propose an experimental validation method. The report sequences these tasks to understand how fluid dynamics, structural design, and material science affect modern hydrofoil performance.

2.0 Task 1: Reynolds Number Analysis

- 2.1 Reynolds number

The Reynolds number (Re) is a dimensionless parameter defined as the ratio of inertial to viscous forces in a fluid flow, expressed as $Re = \rho VL/\mu$, where ρ is density, V is velocity, L is a characteristic length, and μ is dynamic viscosity (Saldana et al., 2024, Sec. 3.1). Its primary significance is characterising flow regimes: laminar flow ($Re < \sim 2000$), where viscous forces dominate and fluid moves in orderly layers; transitional flow ($\sim 2000 < Re < \sim 4000$); and turbulent flow ($Re > \sim 4000$), where inertial forces create chaotic, mixing motion (Saldana et al., 2024, Sec. 3.2). Re is a key part of this idea because it lets you guess how things will act and interact in different situations without having to solve the whole Navier-Stokes equations over and over again.

- 2.2 Relevance to Hydrofoil Performance

The Reynolds number (Re) directly affects the boundary layer and main drag sources, affecting hydrofoil performance. Hydrofoils exhibit a thick boundary layer that separates early from the surface at low Reynolds numbers, such as 1.4×10^5 (Wei et al., 2015). This significantly increases pressure drag and can cause the foil to stall at low angles of attack.

A higher Reynolds number thins the boundary layer, but pressure drag from flow separation and turbulent energy dissipation dominates, with skin friction playing a minor role (Guo & Wang, 2023). The angle of attack (α) is crucial for management of this separation. An increase in α causes the hydrofoil's flow separation to move forward, leading to stall and a larger wake size. To improve hydrodynamic efficiency, the hydrofoil must operate near the optimal angle of attack and manage pressure drag (Guo & Wang, 2023).

- 2.3 Estimation of Operational Reynolds Number

A kitesurf hydrofoil's performance is governed by its Reynolds number, which varies with equipment types and riding conditions. Different foil aspect ratios alter the characteristic chord length, consequently affecting the operational Reynolds number (Thekitesurfcentre, 2021).

The key parameters for this calculation are shown in the table below.

Parameter	In Fresh Water	In Salt Water	Source
Density (ρ)	1000 kg/m ³	1025 kg/m ³	The Open University (2018)
Dynamic Viscosity (μ)	1.002 × 10 ⁻³ Pa·s	1.088 × 10 ⁻³ Pa·s	IAPWS (2008); Sharqawy et al. (2010)
Characteristic Chord Length (c) Average	0.075 m – 0.2 m (Mean Geometric Chord ~0.15 m)	0.075 m – 0.2 m (Mean Geometric Chord ~0.15 m)	Martinez-Barbera et al. (2025); Wei et al. (2015); Lopes et al. (2019); Androuin (2022)
Benchmark Velocity (V) Average	~9 m/s	~9 m/s	Martinez-Barbera et al. (2025); Wei et al. (2015); Lopes et al. (2019); Androuin (2022)
[Table 1] Reynolds number parameters for fresh and salt water			

Due to its simplicity and ability to balance disciplines, the average chord was chosen. These factors, along with the standard speed of 9 m/s, determine kitesurf foils' Reynolds number range in fresh and salt water.

$$Re = \frac{\rho v L}{\mu}$$

$$Re \text{ (fresh water)} = \frac{1000 * 9 * 0.15}{1.002 \times 10^{-3}} = 1.35 \times 10^6$$

$$Re \text{ (salt water)} = \frac{1025 * 9 * 0.15}{1.088 \times 10^{-3}} = 1.27 \times 10^6$$

[Figure 1] Reynolds number calculations

- 2.4 Interpreting the results

The estimated Reynolds number of approximately 1.3×10^6 confirms a fully turbulent flow regime, where inertial forces dominate viscous forces (Tamburrino and Niño, 2025). This turbulence is characterised by significant velocity fluctuations and enhanced turbulent kinetic energy (Timoshevskiy et al., 2020). The hydrofoil must therefore be designed to withstand these unstable loads and prevent flow separation and vibration. Consequently, the wing's shape, particularly its aspect ratio, is optimised for lift, structural integrity, and stability in turbulent flow, ensuring consistent rider performance.

3.0 Task 2: Boundary Layer Flow and Wing Design

- 3.1 Boundary Layer Concepts

The boundary layer, a thin region of fluid adjacent to a hydrofoil's surface where viscous forces dominate, is critical to performance. Under specific conditions, a laminar boundary layer, characterised by orderly motion, reduced friction, and smaller thickness, can form at the leading edge (Xu et al., 2018). This laminar state can persist even at high Reynolds numbers, with transition to turbulence occurring further downstream (as cited in Ye, 2020).

As the flow moves across the foil, it encounters a negative pressure gradient. If sufficiently strong, this gradient causes the boundary layer to separate, creating a turbulent wake and unsteady flow (Schmidt et al., 2020). This separation directly compromises efficiency by significantly increasing pressure drag and causing lift loss. Consequently, the primary goal of parametric shape optimisation is to identify geometries that promote attachment flow, thereby maximising the lift-to-drag ratio (Schmidt et al., 2020).

- 3.2 Turbulence and Separation on the Hydrofoil

The high operational Reynolds number ($\sim 1.3 \times 10^6$) ensures that the flow around a kitesurf hydrofoil remains fully turbulent, which causes the boundary layer to transition almost instantly at the leading edge (Shi and Wang, 2021) and become highly mixed (Timoshevskiy et al., 2020). This turbulent state is key to managing flow separation. It is possible for laminar flow to separate and stall because of adverse pressure gradients (Schmidt et al., 2020). On the other hand, natural mixing in a turbulent boundary layer keeps the near-surface flow going by moving momentum from the faster outer stream. This process creates a more robust velocity profile that remains attached to the wing longer (Ye et al., 2024). Therefore, despite increasing skin friction, turbulence's primary advantage is its exceptional ability to delay large-scale separation, ensuring stable handling and preventing abrupt lift loss (Ye et al., 2024).

- 3.3 Critical Appraisal of the Wing Design

The hydrofoil wing is shaped specifically to perform efficiently in its fast, turbulent operating environment. Its long, narrow shape (high aspect ratio) is a common modern feature that helps it cut through the water with less drag from swirling wingtip vortices (Nestor, 2023). An elliptical, curved planform also helps to lessen these energy-sucking vortices.

The wing's unique curved profile keeps water flowing smoothly over its surface, preventing separation and the drag it creates. Engineers use complex computer simulations, like the multi-fidelity models described by Pehlivan Solak et al. (2024), to find the optimal shape for this; some designs achieve drag reductions of up to 17%. In these simulations, a dense mesh around the wing is essential, as it allows the computer to accurately simulate the complex flow right next to the surface, ensuring the final design produces steady and effective lift.

4.0 Task 3: Critical Appraisal of Assumed Forces

4.1 Review of Assignment 1 Force Assumption

Applying a 500N vertical point load at the centre of each side of the hydrofoil wing greatly simplified the structural analysis of the wing in Assignment 1. This assumption was helpful for making a baseline model and figuring out how basic structures act under a simple load. In practice, though, a hydrofoil is subject to much more intricate and dispersed forces.

4.2 Analysis of Real-World Force Distribution

Although a central point load is a helpful engineering simplification, it does not accurately represent the forces that a hydrofoil actually encounters while in use. In reality, lift forces vary along the foil's span (length) and chord (width), distributing them unevenly across the wing surface. According to Pozhidaev's thesis, the pressure field surrounding a hydrofoil is not constant and varies depending on the submersion depth, speed, and angle of attack (Pozhidaev, 2022). This indicates that certain parts of the wing are subjected to greater loads and pressures than others. Furthermore, hydrofoils in the real world experience more than just vertical lift. They also experience:

- Drag forces consisting of skin friction (from water flowing across the surface) and pressure drag (from the foil's shape);
- Side forces due to steering or cross-currents;
- Moments, like pitching and twisting, that can put a lot of stress on the structure (Pozhidaev, 2022).

According to Martínez-Barberá et al. (2025), the process by which these forces work together is called fluid-structure interaction (FSI). In this process, the flow of water affects the structure, and the structure's deformation, in turn, affects the flow.

Martínez-Barberá et al. (2025) emphasised that the precise modelling of this interaction is crucial for forecasting real-world performance and preventing unexpected failures.

4.3 Conclusion on Force Assumption

The 500N point load assumption is appropriate because it is simple to compare material options and general structural layouts in the early stages of design. Although it is not precise enough, it offers a helpful standard for stiffness and mass. This simplification has obvious limitations, though, when it comes to thorough performance analysis or final design validation. A distributed load model would probably display distinct stress patterns, particularly in the vicinity of the wing's root and leading edge, where Pozhidaev's research suggests peak stresses frequently occur (Pozhidaev, 2022). Point loads can miss important failure points, like the junction of bending and twisting, or understate localised stresses. While the point load model was useful in Assignment 1, it would be much more accurate to use a distributed load model, ideally one based on computational fluid dynamics (CFD), to help design a safer, more effective hydrofoil.

5.0 Task 4: Material Selection and Evaluation

- 5.1 Properties of Carbon Fibre Reinforced Plastic (CFRP)

Due to its superior mechanical properties, carbon fibre reinforced plastic (CFRP) is the preferred material for high-performance hydrofoils. Table 2 quantifies and compares its high specific stiffness and specific strength to aluminium, which are its most important properties.

Under heavy and fluctuating loads, CFRP's stiffness is necessary to maintain the hydrofoil's aerodynamic profile. The consistent lift and predictable handling depend on this dimensional stability under load. The low density of CFRP gives it a high strength-to-weight ratio, making it lighter without compromising structural integrity. Riders can move the board more easily due to this mass reduction.

Beyond static loads, CFRP has excellent fatigue resistance, allowing it to withstand waves and manoeuvres. Additionally, CFRP is corrosion-resistant in saltwater, unlike aluminium or steel, which makes the hydrofoil durable and reliable.

Property	CFRP Performance (high end value)		Aluminium (6061-T6) (High end value)	Source
Density (kg/m ³)	~1.7	[1]	2700	Thomasnet (2024) [1] Guo et al., (2022) [2] World Material (2020) [3]
Tensile strength (MPa)	~6,000	[1]	290	
Youngs modulus (GPa)	~600	[1]	68.9	
Stiffness-to-Weight (MN·m/kg)	~353	[1]	25.52	
Strength-to-Weight (MN·m/kg)	~3.53	[1]	0.107	
Fatigue Resistance	Very good	[2]	Moderate	
Corrosion Resistance	Excellent	[2]	excellent	

[Table 2] Properties of CFRP and Aluminium

- 5.2 Implications for Hydrofoil Performance

For high-performance kite-surfing hydrofoils, the use of carbon fibre reinforced polymer (CFRP) composites is essential because of their remarkable strength-to-weight and stiffness-to-weight ratios (Alam et al., 2019). CFRP's low weight directly improves the rider's experience by making the hydrofoil more responsive and easier to steer, which means they can control it quickly and accurately. Additionally, for the hydrofoil to maintain its precise aerodynamic shape under the dynamic loads experienced during kitesurfing, its high stiffness is essential for ensuring stable performance and effective lift (Alam et al., 2019; Zheng et al., 2022).

However, there are particular difficulties with this performance in a kitesurfing setting. According to Alam et al. (2019) and Zheng et al. (2022), the material's susceptibility to impact damage from floating debris or improper handling is a major concern because it can lead to internal cracks that compromise fatigue life and structural integrity. High production costs are also a result of the intricate manufacturing process, which is necessary to prevent defects that reduce strength (Alam et al., 2019). In conclusion, connections between CFRP and metal fittings in a corrosive marine environment may result in galvanic corrosion, where the carbon fibres hasten the metal's degradation and endanger its long-term durability (Alam et al., 2019; Liu et al., 2023).

5.3 Historical, Current, and Future Context

Early prototypes and components of the hydrofoil were made of conventional materials like wood, aluminium, and stainless steel, marking the beginning of its manufacturing history (Ng, 2025). Advanced composite materials, especially carbon fibre and fibreglass, changed everything. This shift improved performance and accessibility due to the need for stronger, lighter, and more tuneable structures (Yashchuck, 2023). Composites, the industry standard, enable today's sophisticated, high-performance hydrofoils.

Contemporary hydrofoil wings use advanced Carbon Fibre Reinforced Polymers (CFRP) that follow BSI guidelines. The BS EN ISO 12215 series provides the foundation for maritime composite part material integrity (BSI Group, 2025).

The field is ready for significant changes that go beyond what is currently being done. Future composites will include recyclable thermoplastics and bio-based resins to reduce environmental impact (Nehls, 2025). Team (2025) claims that additive manufacturing will enable complex topology and "smart" foils with real-time performance monitoring and structural health assessment from sensor systems integrated during layup. Ultra-high modulus carbon fibre, CFD with rider feedback loops, modular systems, and winglets promise a new generation of intelligent, effective, and environmentally friendly hydrofoiling technology (Team, 2025).

6.0 Task 5: Modelling Techniques for Fluid Flow

- 6.1 Overview of Potential Modelling Techniques

There are several different methods to simulate the fluid flow around a hydrofoil. The most thorough method is Computational Fluid Dynamics (CFD), which simulates viscous flow by numerically solving the Navier-Stokes equations. This enables a thorough examination of pressure distribution and wake turbulence, capturing intricate phenomena like boundary layer development, transition, and separation (Žic et al., 2021).

Potential flow techniques are very useful for early design phases where computational speed is a top concern. Techniques like the Vortex Lattice Method (VLM) simplify the physics by assuming an inviscid, irrotational fluid. According to

Nayem and Tarafder (2023), this simplification makes it possible to quickly estimate global parameters such as lift and moment coefficients, which makes it perfect for initial sizing and optimisation studies.

Finally, wind tunnel and towing tank testing validate all theoretical models. Reliable sources like Bertin and Smith (1998) show that these physical tests are essential for verifying computation results. High cost and long turnaround times limit physical prototypes' use for quick, iterative design cycles (Bertin and Smith, 1998).

- **6.2 Critical Evaluation of CFD**

- Advantages:

CFD offers significant benefits for hydrofoil analysis, including the ability to optimise complex 3D geometries without the need for costly physical prototypes (Li, 2022). Using software like STAR-CCM+ and ANSYS Fluent, engineers can visualise critical flow characteristics, such as pressure distribution, velocity fields, and wake turbulence, which helps increase the lift-to-drag ratio (Li, 2022; Žic et al., 2021). Furthermore, it accelerates the development of more reliable systems by enabling rapid design iterations through testing various angles of attack and flow conditions (Li, 2022).

- Disadvantages:

CFD also has some disadvantages. Li (2022) and Žic et al., (2021) found that: The results are greatly impacted by mesh quality, which makes costly independence studies necessary.

Even on supercomputers, the computational cost is high; simulations take hours. Realism is diminished by important simplifications, such as disregarding free-surface effects.

Complex geometries can cause convergence issues, and physical model testing is ultimately required to confirm the accuracy of all results.

- **6.3 Estimation of Forces on the Wing**

According to Li (2022), the NACA 63-412 foil's "even and smooth curve" makes it appropriate for hydrofoils, and its well-known efficiency and balanced performance led to its selection for this analysis. Comparative studies show how widely used it is

in research (Pattanashetti et al., 2020). These studies led to the angle of attack being set at 4 degrees, which is consistently found to be the foil shape's peak efficiency point and produces the best lift in relation to drag.

A lift-to-drag (L/D) ratio of 115–118 was determined using data from Aerofoil Tools (2025) and standard aerodynamic formulas. Higher values indicate greater efficiency. This ratio, known as "hydrodynamic efficiency" (Li, 2022), represents lift generated per unit of drag. Li's (2022) 3D CFD simulations demonstrated a 10.7% L/D improvement at 4 degrees, and Pattanashetti et al. (2020) verified that this angle yields maximum L/D in 2D analysis, so this result strongly supports independent research. This consistency demonstrates that the chosen parameters and computational methodology are sound.

Parameters	Value	Source
<i>Area of foil</i>	0.08m ² -0.1m ² (the mean optimum area for all round kitefoiling. = 0.09m ²	(Dan, 2025)
<i>Density (salt water)</i>	1025 kg/m ³	
<i>Density (fresh water)</i>	1000 kg/m ³	
<i>Velocity</i>	9 m/s	
<i>Lift coefficient (Cl)</i>	0.7902	(Airfoil Tools, 2025)
<i>Drag coefficient (Cd)</i>	0.0068	(Airfoil Tools, 2025)

[Table 3] Table of parameters used for lift/drag calculations.

The lift and drag forces are calculated below using $L = Cl\frac{\rho v}{2}A$ (Glenn Research Centre, 2024):

$$L \text{ (fresh water)} = 0.7902 \frac{1000 * 9}{2} 0.09 = 2880 \text{ N}$$

$$L \text{ (salt water)} = 0.7902 \frac{1025 * 9}{2} 0.09 = 2835 \text{ N}$$

$$D = C_d \frac{\rho v^2}{2} A$$

$$D \text{ (fresh water)} = 0.0068 \frac{1000 * 9}{2} 0.09 = 25 \text{ N}$$

$$D \text{ (salt water)} = 0.0068 \frac{1025 * 9}{2} 0.09 = 24 \text{ N}$$

$$\text{Lift/Drag ratio (fresh water)} = \frac{2880}{25} = 115.2$$

$$\text{Lift/Drag ratio (salt water)} = \frac{2835}{24} = 118.125$$

[Figure 2] Lift and drag calculations

7.0 Task 6: Experimental Testing and Correlation

• 7.1 Proposed Experimental Setup

Experimental testing gives us the real-world data we need to prove that a hydrofoil design works, going beyond just theoretical calculations and computer models. The best technique for this is a towing tank test.

The movement of a hydrofoil through water is replicated in a towing tank, which is a long, water-filled channel where a scaled model is drawn along by a moving carriage at regulated speeds (Varvne and Eriksson, 2024). With this configuration, forces can be directly measured in realistic flow conditions.

Similar to the model used by Liarokapis et al. (2025), a scaled model of the NACA 63-412 hydrofoil, potentially 3D-printed for accuracy, would be mounted to the carriage via a stiff strut connected to a force balance. This balance is the most critical component, as it accurately measures the lift and drag forces on the foil (Liarokapis et al., 2025). Flow visualisation would employ techniques like Particle Image Velocimetry (PIV), which determines water velocity and direction by tracking seeded particles illuminated by a laser sheet (Russell et al., 2018). Furthermore, cavitation inception and the resulting bubbly wake could be studied using

shadowgraphy, a backlighting technique that produces clear images of small bubbles and voids (Russell et al., 2018).

- **7.2 Data Acquisition and Measurement**

The lift (vertical force) and drag (horizontal force) that the hydrofoil experienced during each test run would be continuously recorded by the force balance, which is basically an advanced multi-directional load cell (Liarokapis et al., 2025). Lift and drag coefficients (C_L and C_D) can be computed from a thorough map of the foil's performance created by testing at various speeds and angles of attack.

The PIV system would simultaneously record the water's behaviour. It would show how the boundary layer, which is a major source of drag and lift loss, forms and where it may separate from the foil. The boundary layer is a thin layer of water slowed down by friction on the foil's surface.

Visualising the energy and structure of the vortex-filled wake behind the foil would also reveal induced drag (Varvne and Eriksson, 2024).

- **7.3 Correlation with Simulation**

Finally, the experimental data must be correlated with the Computational Fluid Dynamics (CFD) outcomes from Task 5. This process turns a good simulation into a useful tool for making predictions.

Following the method of Liarokapis et al. (2025), it is possible to make a direct comparison by plotting the experimentally derived C_L and C_D values against the angles of attack and overlaying the CFD-predicted curves. The correlation would also include looking at pressure distribution plots along the foil's surface and using Particle Image Velocimetry (PIV) data to check if the CFD model correctly predicts where the flow separates.

Differences between experimental data and CFD results are opportunities to improve the numerical model rather than failures. The choice of the turbulence model itself is a frequent source of inaccuracy. To illustrate the importance of model selection, Varvne and Eriksson (2024) showed that various RANS-based turbulence models can predict drag coefficients for the same hydrofoil with errors greater than 90%. Inaccuracies also arise in simulating cavitation; Dular et al. (2005) found that standard models incorrectly over-predict turbulent viscosity, which dampens the

development of key vortices and bubbles. More complex models, like the k-omega SST, which can better handle flow transitions, or targeted mesh refinement in crucial regions found by the PIV data are two ways to improve the CFD setup in order to address these problems (Dular et al., 2005).

8.0 Conclusion

This report has critically evaluated the fluid flow around a kiteboard hydrofoil. The analysis confirmed a highly turbulent flow regime ($Re \approx 1.3 \times 10^6$), where turbulence delays flow separation to ensure steady lift. This flow behaviour directly influenced the wing's optimised profile and high aspect ratio.

While the initial 500N point load provided a structural analysis baseline, a CFD-informed distributed load model is essential for accurate stress prediction. Carbon Fibre Reinforced Plastic (CFRP) was selected for its superior specific stiffness and strength, maintaining performance despite challenges like impact sensitivity and cost. Finally, correlating advanced CFD with towing tank validation was identified as the most effective method for ensuring simulation accuracy. In conclusion, hydrofoil performance is a direct result of the synergy between turbulent flow, an optimised structural form, and advanced material properties.

9.0 References

Airfoil Tools (2025) *NACA 63-412 AIRFOIL (n63412-il)* [online]. Available at: <http://airfoiltools.com/airfoil/details?airfoil=n63412-il> (Accessed: 19 November 2025).

Alam, P, Mamalis, D, Robert, C, Floreani, C and Ó Brádaigh, C M (2019) 'The fatigue of carbon fibre reinforced plastics - a review', *Composites Part B: Engineering*, [online] 166, pp.555-579. doi <https://doi.org/10.1016/j.compositesb.2019.02.016> (Accessed: 15 November 2025).

Bertin, J J and Smith, M L (1998) *Aerodynamics for engineers*. Upper Saddle River, N.J.: Prentice Hall.

BSI Group (2025) *BS EN ISO 12215 - small craft. Hull construction and scantlings* [online]. Available at: <https://landingpage.bsigroup.com/LandingPage/Series?UPI=BS%20EN%20ISO%2012215> (Accessed: 15 November 2025).

Dan (2025) *Kite foil buyers guide: how to choose the right setup - king of watersports* [online]. Available at: <https://www.kingofwatersports.com/blog/kite-foil-buyers-guide> (Accessed: 16 November 2025).

Dular, M, Bachert, R, Stoffel, B and Širok, B (2005) 'Experimental evaluation of numerical simulation of cavitating flow around hydrofoil', *European Journal of Mechanics - B/Fluids*, 24(4), pp.522-538. doi <https://doi.org/10.1016/j.euromechflu.2004.10.004> (Accessed: 20 November 2025).

Glenn Research Center (2024) *Lift equation* [online]. Available at: <https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/lift-equation/#lift-coefficient> (Accessed: 19 November 2025).

Guo, T and Wang, H-Y (2023) 'Analysis of hydrodynamic characteristics and loss mechanism of hydrofoil under high Reynolds number', *Ocean Engineering*, [online] 287, p.115892. doi <https://doi.org/10.1016/j.oceaneng.2023.115892> (Accessed: 7 November 2025).

International Association for the Properties of Water and Steam (2008) *Revised release on the IAPWS formulation 2008 for the viscosity of ordinary water substance* [online]. Available at: <http://www.iapws.org/relguide/viscosity.html> (Accessed: 14 November 2025).

Li, A (2022) *CFD optimization of hydrofoiling concept for a new era of sea transports master thesis report* [online]. Available at: <https://www.diva-portal.org/smash/get/diva2:1737350/FULLTEXT01.pdf> (Accessed: 19 November 2025).

Liarokapis, D, Sitorus, P E and Barlas, T K (2025) *Experimental and numerical evaluation of the hydrodynamic performance of a hydrofoil* [online]. Available at: https://www.researchgate.net/profile/Dimitris-Liatorokapis/publication/397525903_EXPERIMENTAL_AND_NUMERICAL_EVALUATION_OF_THE_HYDRODYNAMIC_PERFORMANCE_OF_A_HYDROFOIL/links/69143e3f4baee1659192510e/EXPERIMENTAL-AND-NUMERICAL-EVALUATION-OF-THE-HYDRODYNAMIC-PERFORMANCE-OF-A_HYDROFOIL.pdf (Accessed: 19 November 2025).

Liu, Y, Wang, H, Du, J, Lin, J, Cao, Y and Cheng, L (2023) 'Comparative experimental study on mechanical properties of CFRP subjected to seawater and hydrostatic pressure', *Composites Science and Technology*, 242, p.110193. doi <https://doi.org/10.1016/j.compscitech.2023.110193> (Accessed: 12 November 2025).

Martínez-Barberá, H, Calderon-Sanchez, J, Moulán, L and Souto-Iglesias, A (2025) 'Fluid forces on a hydrofoil for kitefoil and windfoil boards: experimental investigation on their dependence on the Froude number based on submergence', *Journal of Marine Science and Application*. doi <https://doi.org/10.1007/s11804-025-00708-2> (Accessed: 7 November 2025).

Menon, P (2025) *Hydrofoil technology in kiteboarding: a deep dive* [online]. Available at: <https://waveandwinds.com/articles/hydrofoil-technology-kiteboarding-guide/> (Accessed: 20 November 2025).

Nayem, A Z and Tarafder, M S (2023) 'Analysis of potential flow around a hydrofoil using vortex lattice method', *SSRN Electronic Journal*. doi <https://doi.org/10.2139/ssrn.4445146> (Accessed: 19 November 2025).

Nehls, G (2025) *Breton companies launch recyclable hydrofoil design project* [online]. Available at: <https://www.compositesworld.com/news/breton-companies-launch-recyclable-hydrofoil-design-project> (Accessed: 15 November 2025).

Néstor, A (2023) *Hydrofoil design for surfboard* [online]. Available at: <https://riunet.upv.es/entities/publication/92197240-3d0d-4e22-a8fa-9217d4413664> (Accessed: 12 November 2025).

Ng, C (2025) *Exploring wind surf hydrofoil: the evolution of surfing* [online]. Available at: <https://surfhavens.com/articles/exploring-wind-surf-hydrofoil-evolution/> (Accessed: 15 November 2025).

Pattanashetti, N, Mahadeva and Suresha, C N (2020) 'Behavior of NACA 4424, NACA 63(1)-412 & NACA 63(2)-615 airfoils subjected to subsonic flow at various angle of attacks using CFD', *International Research Journal of Engineering and*

Technology (IRJET), 7(7), pp.1367-1373. Available at:

<https://www.academia.edu/44300651/> (Accessed: 19 November 2025).

Pehlivan Solak, H, Wackers, J, Pellegrini, R, Serani, A, Diez, M, Perali, P, Sacher, M, Leroux, J-B, Augier, B, Hauville, F and Bot, P (2024) 'Optimising hydrofoils using automated multi-fidelity surrogate models', *Ships and Offshore Structures*, pp.1-12. doi <https://doi.org/10.1080/17445302.2024.2422518> (Accessed: 16 November 2025).

Pozhidaev, K (2022) *Hydrofoil fixture load analysis* [online]. Available at:

<https://www.theseus.fi/handle/10024/743908> (Accessed: 12 November 2025).

Russell, P S, Venning, J A, Brandner, P A, Pearce, B W, Giosio, D R and Ceccio, S L (2018) *Microbubble disperse flow about a lifting surface* [online]. 32nd Symposium on Naval Hydrodynamics, Hamburg, Germany, 5-10 August. Available at:

https://figshare.utas.edu.au/articles/conference_contribution/Microbubble_disperse_flow_about_a_lifting_surface/23099819?file=40829837 (Accessed: 19 November 2025).

Saldana, M, Gallegos, S, Gálvez, E, Castillo, J, Salinas-Rodríguez, E, Cerecedo-Sáenz, E, Hernández-Ávila, J, Navarra, A and Toro, N (2024) 'The Reynolds number: a journey from its origin to modern applications', *Fluids*, [online] 9(12), p.299. doi <https://doi.org/10.3390/fluids9120299> (Accessed: 7 November 2025).

Schmidt, J, Fleischmann, M, Ehemann, C, Kaufmann, J and Cebulla, H (2020) 'Parametric shape and manufacturing optimization of customized kitesurf hydrofoils', *Proceedings*, [online] 49(1), p.126. doi

<https://doi.org/10.3390/proceedings2020049126> (Accessed: 14 November 2025).

Sharqawy, M H, Lienhard, J H and Zubair, S M (2010) 'Thermophysical properties of seawater: a review of existing correlations and data', *Desalination and Water Treatment*, 16(1-3), pp.354-380. doi <https://doi.org/10.5004/dwt.2010.1079> (Accessed: 14 November 2025).

Shi, L and Wang, Y (2021) 'Numerical investigations on transitional flows around forward and reversed hydrofoils', *European Journal of Mechanics - B/Fluids*, [online] 85, pp.24-45. doi <https://doi.org/10.1016/j.euromechflu.2020.08.008> (Accessed: 16 November 2025).

Tamburrino, A and Niño, Y (2025) 'The universal presence of the Reynolds number', *Fluids*, 10(5), p.117. doi <https://doi.org/10.3390/fluids10050117> (Accessed: 14 November 2025).

Team, R (2025) *7 game-changing hydrofoil wing design advancements in 2025* [online]. Available at: <https://www.hydrofoiling.org/hydrofoil-wing-design-advancements/> (Accessed: 15 November 2025).

The Open University (2018) *The oceans* [online]. Available at: <https://www.open.edu/openlearn/science-maths-technology/the-oceans/content-section-3.2> (Accessed: 7 November 2025).

Thekitesurfcentre (2021) *Kite foils & hydrofoils for kitesurf hydrofoiling - the kitesurf centre* [online]. Available at: <https://www.thekitesurfcentre.com/hydrofoil> (Accessed: 7 November 2025).

Timoshevskiy, M V, Ilyushin, B B and Pervunin, K S (2020) 'Statistical structure of the velocity field in cavitating flow around a 2D hydrofoil', *International Journal of Heat and Fluid Flow*, [online] 85, p.108646. doi

<https://doi.org/10.1016/j.ijheatfluidflow.2020.108646> (Accessed: 14 November 2025).

Varvne, M and Eriksson, W (2024) *Scaling effects for hydrofoil testing: developing a methodology for hydrofoil performance measurement in towing tank* [online]. Available at: <https://odr.chalmers.se/handle/20.500.12380/307777> (Accessed: 19 November 2025).

Wei, Z, New, T H and Cui, Y D (2015) 'An experimental study on flow separation control of hydrofoils with leading-edge tubercles at low Reynolds number', *Ocean Engineering*, 108, pp.336-349. doi <https://doi.org/10.1016/j.oceaneng.2015.08.004> (Accessed: 7 November 2025).

Xu, L, Baglietto, E and Brizzolara, S (2018) 'Extending the applicability of RANS turbulence closures to the simulation of transitional flow around hydrofoils at low Reynolds number', *Ocean Engineering*, 164, pp.1-12. doi <https://doi.org/10.1016/j.oceaneng.2018.06.031> (Accessed: 14 November 2025).

Yashchuk, O (2023) *The history of foilboarding* [online]. Available at: <https://surftattoo.com/blogs/news/the-history-of-foilboarding> (Accessed: 15 November 2025).

Ye, C, Wang, F, Wang, C and van Esch, B P M (2020) 'Assessment of turbulence models for the boundary layer transition flow simulation around a hydrofoil', *Ocean Engineering*, 217, p.108124. doi <https://doi.org/10.1016/j.oceaneng.2020.108124> (Accessed: 14 November 2025).

Ye, C, Wang, Y, An, D, Chen, J, Yan, H, Zheng, Y, Kan, K and Bart, H (2024) 'Study of hydrofoil boundary layer prediction with two correlation-based transition models', *Journal of Marine Science and Engineering*, [online] 12(11), p.1965. doi <https://doi.org/10.3390/jmse12111965> (Accessed: 16 November 2025).

Zheng, H, Zhang, W, Li, B, Zhu, J, Wang, C, Song, G, Wu, G, Yang, X, Huang, Y and Ma, L (2022) 'Recent advances of interphases in carbon fiber-reinforced polymer composites: a review', *Composites Part B: Engineering*, 233, p.109639. doi <https://doi.org/10.1016/j.compositesb.2022.109639> (Accessed: 15 November 2025).

Žic, E, Černeka, P and Biluš, I (2021) 'Hydrodynamic analysis of the fluid flow around a symmetric hydrofoil', *Fluid Dynamics*, 56(4), pp.460-472. doi <https://doi.org/10.1134/s0015462821040133> (Accessed: 19 November 2025).

10.0 Appendices

Appendix 1: Image of the table of Lift (Cl) and Drag (Cd) coefficients taken from Airfoil

XFOIL version 6.96

Calculated polar for: NACA 63-412 AIRFOIL

1 1 Reynolds number fixed Mach number fixed

xtrf = 1.000 (top) 1.000 (bottom)
Mach = 0.000 Re = 1.000 e 6 Ncrit = 9.000

alpha	CL	CD	CDp	CM	Top_Xtr	Bot_Xtr
-13.750	-0.8332	0.05739	0.05518	-0.0594	1.0000	0.0096
-13.500	-0.8907	0.04486	0.04227	-0.0685	1.0000	0.0093
-13.250	-0.8936	0.04150	0.03881	-0.0705	1.0000	0.0094
-13.000	-0.8877	0.03884	0.03617	-0.0718	1.0000	0.0095
-1.750	0.5419	0.00591	0.00140	-0.0800	0.6091	0.7152
2.000	0.5702	0.00596	0.00146	-0.0800	0.5987	0.7231
2.250	0.5981	0.00603	0.00152	-0.0800	0.5877	0.7312
2.750	0.6539	0.00619	0.00166	-0.0801	0.5616	0.7469
3.000	0.6815	0.00629	0.00174	-0.0800	0.5465	0.7545
3.250	0.7088	0.00642	0.00184	-0.0799	0.5253	0.7626
3.500	0.7361	0.00655	0.00195	-0.0798	0.5069	0.7701
3.750	0.7633	0.00669	0.00206	-0.0798	0.4896	0.7781
4.000	0.7902	0.00685	0.00220	-0.0796	0.4696	0.7859
4.250	0.8168	0.00706	0.00234	-0.0795	0.4423	0.7942
4.500	0.8410	0.00747	0.00256	-0.0789	0.3899	0.8022
4.750	0.8630	0.00815	0.00292	-0.0782	0.3143	0.8112
5.000	0.8838	0.00893	0.00336	-0.0772	0.2368	0.8199
5.250	0.9050	0.00968	0.00380	-0.0764	0.1712	0.8293
5.500	0.9263	0.01037	0.00425	-0.0755	0.1177	0.8394

