

University of Wales Trinity Saint
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School of Engineering

Designing a Kiteboard Hydrofoil
Wing – Fluid Flow

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1 Introduction and Context

This report assesses the fluid flow around a kiteboard hydrofoil wing, with emphasis on Reynolds number effects, boundary layer behaviour, force generation, material implications and suitable modelling approaches. The objective is to critically appraise the assumptions used in the structural design and establish a more physically representative understanding of the hydrodynamic loading. Seawater at 0 °C is assumed as a conservative operating condition due to higher fluid density in comparison to freshwater thus increasing fluid pressure and force generation. The analysis is intentionally preliminary due to limited geometric definition in the brief, and focuses on order-of-magnitude reasoning and engineering judgement rather than detailed optimisation.

The report is structured to follow the six tasks defined in the assignment brief, progressing from flow regime characterisation through to modelling, force estimation and experimental validation.

2 Reynolds Number Analysis

2.1 Reynolds Number

Reynolds number (Re) governs boundary layer development, transition and separation behaviour, and is therefore a primary parameter controlling lift, drag and sensitivity to surface roughness for hydrofoils (Munson, et al., 2013; Saldana, et al., 2024):

Representative geometric and operating parameters were selected based on typical recreational hydrofoil configurations. Commercial surf, kite and e-foil wings commonly exhibit chord lengths in the range 0.30–0.75 m, with mid-span chord values around 0.45 m being typical (Marchaj, 1980; Williams, 2026; Boone, 2024). Operating speeds vary with discipline and rider input; however, published data indicate characteristic velocities between 5 and 15 m/s, with approximately 10 m/s representative of powered recreational use (Larsson & Eliasson, 2000; Crouch, 2025). Seawater properties were taken as $\rho = 1028 \text{ kg/m}^3$ and $\mu = 1.88 \times 10^{-3} \text{ Pa}\cdot\text{s}$, consistent with standard values at 20°C (Zubair, et al., 2010).

Substituting these values into the chord Reynolds number yields $Re \approx 1.6 \times 10^6$.

Equation 1 - Reynolds Number for Characterising Flow Regime.

$$Re = \frac{\rho v L}{\mu} = \frac{(1028)(10)(0.45)}{1.88 \times 10^{-3}} \approx 2.46 \times 10^6 \text{ Fully Turbulent}$$

This places the flow firmly in the turbulent regime. At these Reynolds numbers, transition typically occurs close to the leading edge and the majority of the chord experiences fully turbulent boundary layer behaviour (Schlichting & Gersten, 2017; White, 2006).

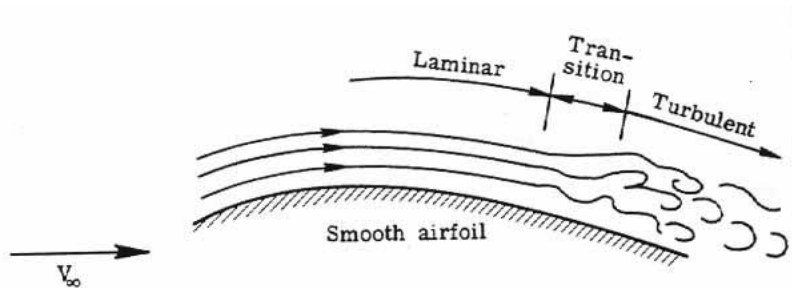


Figure 1 – Schematic of boundary-layer development on an aerofoil: adapted from NASA; reproduced via U.S. Centennial of Flight Commission.

For this hydrofoil, this implies that skin-friction drag is dominated by turbulent behaviour and that the boundary layer possesses higher near-wall momentum, increasing resistance to separation. This supports the use of thin, streamlined sections to delay stall and maintain high lift-to-drag ratios under operating conditions where rider power is limited (Hoerner, 1968; Anderson, 2011; Katz & Plotkin, 2012).

The analysis assumes steady, uniform inflow. In practice, unsteady effects due to wave action, rider input and speed variation will cause fluctuations in Reynolds number, and the calculated value should therefore be regarded as a nominal operating condition rather than a constant (Bethwaite, 2008).

3 Boundary Flow, Separation and Turbulence

3.1 Boundary Layer & Application to the Hydrofoil

At high Reynolds numbers, viscous effects are confined to a thin boundary layer adjacent to the hydrofoil surface, with the outer flow behaving effectively inviscid (Anderson, 2011).

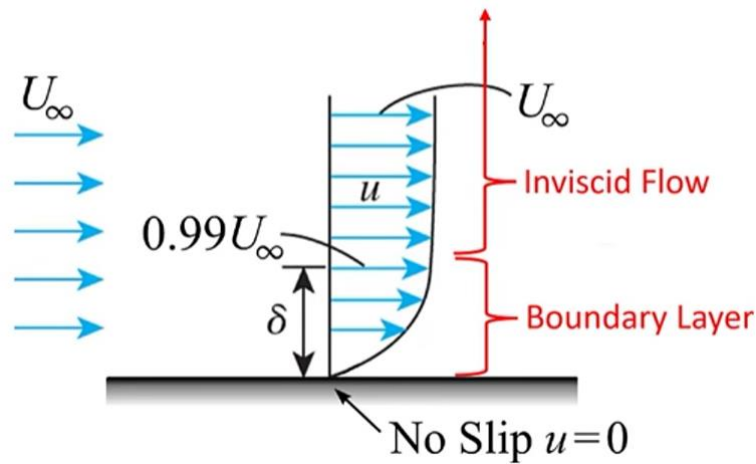


Figure 2 - Illustration of uniform free-stream flow U_{∞} passing over a flat plate, adapted from the presentation in <https://www.youtube.com/watch?v=K8t1D9t0QXY>

Turbulent flat-plate correlations provide a first-order estimate of boundary layer thickness of the order of a few millimetres at the trailing edge:

Equation 2 – Turbulent boundary-layer thickness for flow over a smooth plate, expressed as a function of distance from leading edge and local Reynolds number.

$$\delta \approx 0.16 \frac{x}{Re_x^{1/7}} = 0.16 \frac{0.3}{(1.6 \times 10^6)^{1/7}} = 6.236 \times 10^{-3} m (\approx 6mm)$$

This confirms that viscous effects are localised and that the overall flow field is inertia dominated (Cengel & Cimbala, 2006; Fox, et al., 2004).

3.1.1 Shape rationale & drag mechanisms

The hydrofoil geometry is therefore designed to promote attached flow and minimise pressure drag through gradual pressure recovery. In contrast to bluff bodies, which experience large, separated wakes and high form drag, streamlined hydrofoils maintain narrow wakes and low pressure drag when flow remains attached (Schlichting & Gersten, 2017).

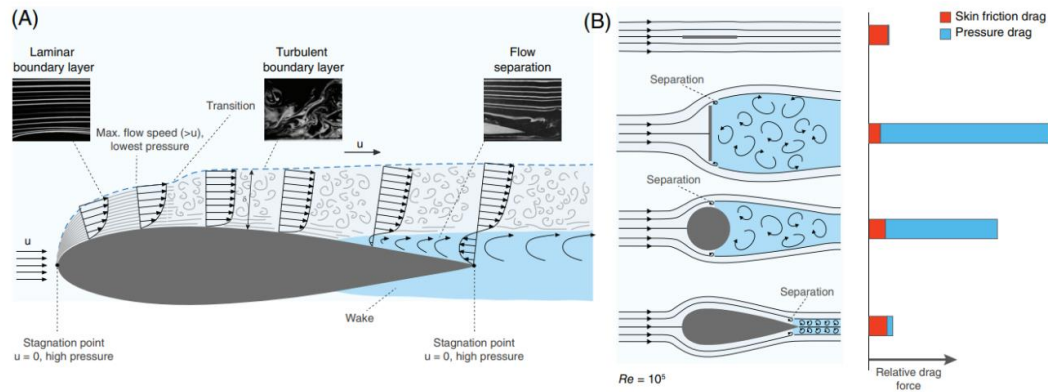


Figure 3 – Illustration of how boundary layer develops along a streamlined body such as hydrofoil and how the flow regime influences relative drag forces of different bodies adapted from (Gutarra & Rahman, 2021).

For this application, the turbulent boundary layer's resistance to separation enables operation at moderate angles of attack without large-scale flow breakdown, improving lift-to-drag ratio and efficiency (Anderson, 2011; Katz & Plotkin, 2012). The resulting section shape represents a compromise between thin profiles for low drag and sufficient thickness to maintain structural stiffness, as excessive deflection would degrade hydrodynamic performance (Abbott & Doenhoff, 1968; Hodges & Pierce, 2011).

4 Critical Appraisal of Applied Forces

4.1 Background Assumptions & Compare with realistic distributed loading

In Assignment 1, the hydrofoil wing was analysed using a simplified loading condition of 500 N applied vertically at the centre of each side of the wing as concentrated point loads. While this provides a convenient and conservative structural test case, it does not reflect the physical mechanism by which hydrodynamic loads are generated (Hoerner, 1968).

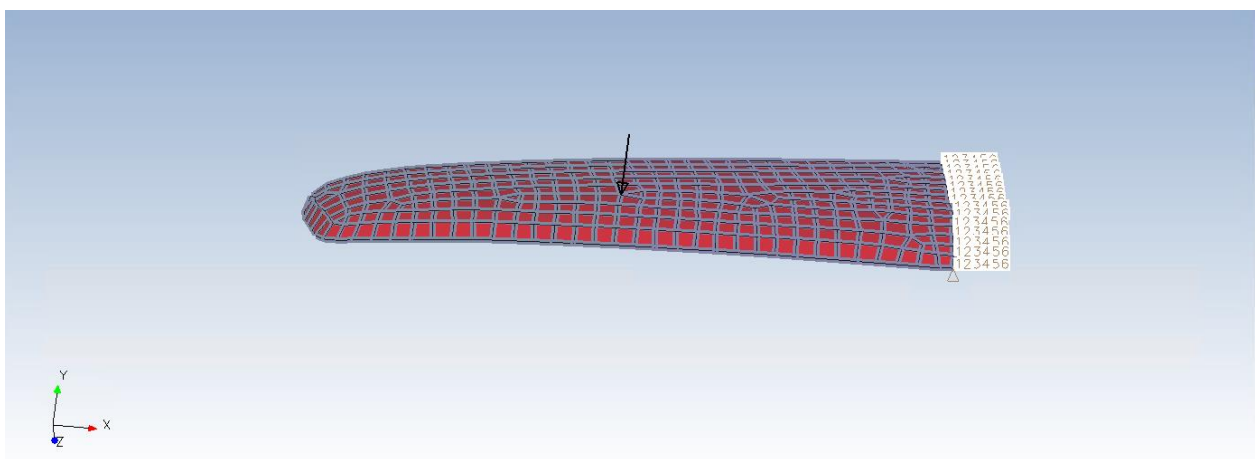


Figure 4 - Discretised hydrofoil geometry represented using a surface mesh showcasing the 500N force applied, originally developed for structural finite element assignment created by document owner.

In reality, lift on a hydrofoil arises from a distributed pressure field acting over the wetted surface. This pressure distribution varies along both chord and span, producing not only a resultant vertical force but also significant bending and pitching moments. Representing this complex load system as a pair of concentrated point loads neglects the true load path and may artificially increase local stresses while misrepresenting global bending and torsion (Hoerner, 1968; Gudmundsson, 2014).

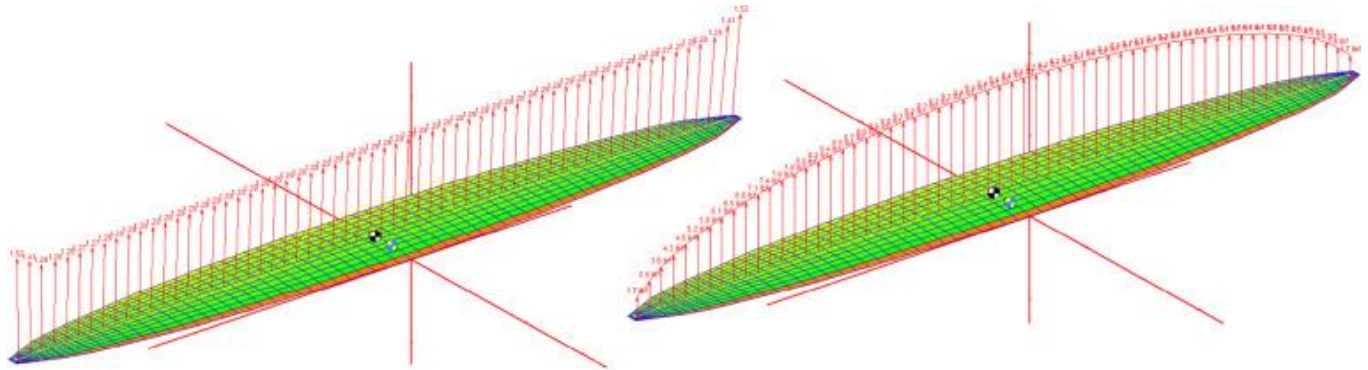


Figure 5 - Comparison of spanwise lift distributions for rectangular (left hand side) and elliptical wings (right hand side). In *General Aviation Aircraft Design* (Gudmundsson, 2014).

4.1.1 Alternative Approach

For a lifting surface, the vertical forces arise primarily from lift, which can be expressed in first-order terms as:

Equation 3 – Aerodynamic lift equation.

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

Using representative bounded values ($V = 5 - 15$ m/s (Crouch, 2025), $C_L = 0.4 - 0.8$ (Airfoiltools, 2024), $S = 0.05 - 0.08$ m² (Boone, 2024)) by using NACA published datasets and bounded values enables a physically consistent model without unduly constraining future design intent (Abbott & Doenhoff, 1968), the resulting lift forces are of the order of 600 N to over 3000 N. These values indicate that the assumed 500 N point load is not necessarily conservative when viewed against plausible operating conditions. More importantly, the distribution of this load is fundamentally different: lift acts continuously along the span, with higher loading near the mid-span and reduced loading towards the tips (Gudmundsson, 2014). In the context of CFRP this is key as Laminate lay-up for these loading conditions would be fundamentally different also (Mallick, 2007).

Table 1 - Preliminary hydrofoil lift load estimates under representative operating conditions

Load Case	Velocity (m/s)	V	Lift Coefficient C_L	Representative Planform Area S (m ²)	Dynamic Pressure q (kPa)	Distributed Pressure p (kPa)	Total Lift L (N)
A Conservative	8		0.4	0.05	32.896	13.158	657.9
B Nominal	10		0.6	0.05	51.4	30.840	1542
C Upper bound	10		0.8	0.08	51.4	41.120	3289.6

Where:

Equation 4- Kinetic Energy / Dynamic Pressure Equation, Distributed Pressure Equation, Aerodynamic lift equation

$$q = \frac{1}{2} \rho V^2, \quad p = q C_L, \quad L = p S$$

A more physically defensible representation is therefore a distributed pressure load acting over the planform area. This allows bending moments, torsion and support reactions to be captured in a manner consistent with the actual hydrodynamic behaviour. In addition, the pressure distribution produces a pitching moment about the quarter-chord, which is entirely absent in a simple point-load model (Anderson, 2011; Abbott & Doenhoff, 1968).

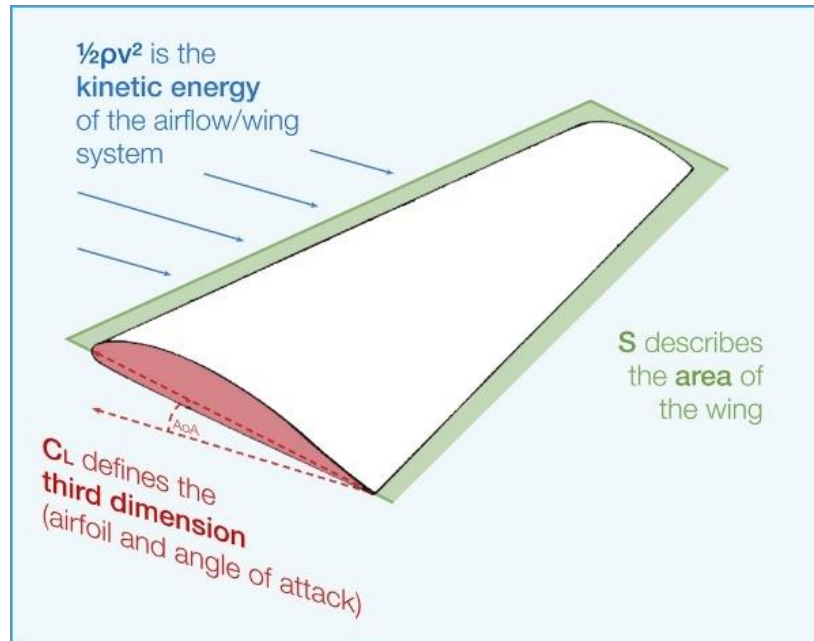


Figure 6 - Illustration of the lift equation and contributing parameters (dynamic pressure, wing area, and lift coefficient).
Source: (Airscape Magazine, 2015).

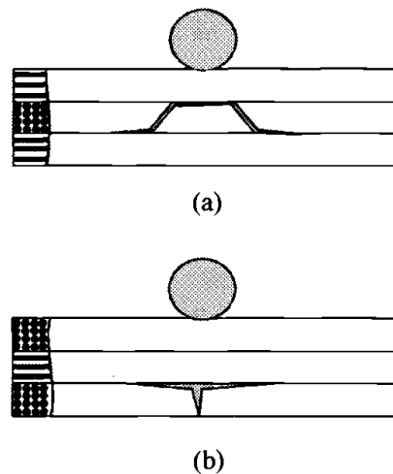
4.2 Effects of Unsteady Flow, Uncertainty and Design Implications

The 500 N assumption may still be useful as a bounding case, particularly for structural screening or proof testing. However, it should be explicitly justified as a conservative design load rather than implicitly treated as representative operating loading. Recasting the applied loads as distributed lift and drag, with clearly stated coefficients and assumptions, provides a more realistic basis for structural assessment and aligns the structural model with the underlying fluid mechanics (Newman, 1977; Sumer & Fredsøe, 2006).

Unsteady effects further complicate the picture. Wave action, rider movement and transient speed changes introduce time-varying loads and potential dynamic amplification (Bethwaite, 2008; Marchaj, 1980). These should be accounted for through load factors or transient load cases applied to the distributed model, rather than through unrealistic point load representations.

5.3 Fatigue, Damage Tolerance, and Marine Environment

CFRP also introduces challenges in impact tolerance and damage detectability. Localised impacts may cause internal delamination without visible surface damage, reducing residual strength (Abrate, 2005).



Two types of matrix cracks: a) tensile crack, b) shear crack.

Figure 9 - Schematic illustration of barely visible impact damage (BVID) in a CFRP laminate, showing extensive subsurface delamination beneath an apparently undamaged surface adapted from (Abrate, 2005).

In regulated aerospace and industrial applications, such risks are managed through formal damage tolerance design and routine non-destructive inspection (DoD , 2002; NASA , 1989). However, for recreational hydrofoil applications, it is unrealistic to assume specialist inspection capability or rigorous maintenance discipline.

Consequently, damage tolerance must be addressed through conservative laminate design and robust material selection. In addition, moisture ingress and environmental degradation can reduce matrix-dominated properties if protective coatings are compromised (Daniel & Ishai, 2006). These factors necessitate conservative safety margins in recreational hydrofoil structures.

5.4 Historical, Current and Future Development its Implications

Historically, hydrofoils were constructed from metals and wood composites. Advances in composite manufacturing have led to widespread adoption of CFRP in modern foiling craft, driven by performance demands. Current practice increasingly integrates numerical optimisation of laminate layup alongside hydrodynamic design (Marchaj, 1980; Mouritz, et al., 2001).

Relevant industry guidance is provided by standards such as ISO 12215, the ASM Composites Handbook and MIL-HDBK-17, which emphasise load cases, safety factors and failure mode control (BSI , 2019; DoD , 2002; ASM International, 2001). Future developments are likely to focus on improved damage tolerance through toughened resins, hybrid laminates and thermoplastic matrices. Structural health monitoring techniques offer potential for in-service damage detection, although their application in recreational equipment remains limited (Yao, et al., 2019; Rhead, et al., 2015; Di Sante, 2015).

5.5 Overall Evaluation

Overall, CFRP is a technically justified choice for hydrofoil construction, offering significant performance advantages provided that its limitations in damage tolerance and inspection are addressed through design conservatism and appropriate manufacturing quality.

6 Modelling, Simulation Techniques and Force Estimation

6.1 Candidate Modelling Approaches

The hydrodynamic force arises from a distributed pressure field that process a resultant L lift, D drag, and a pitching moment M about the foil (often referenced near the quarter-chord). Modelling approaches range from low-fidelity analytical methods to high fidelity CFD and coupled fluid structure interactions (FSI). The appropriate choice depends on the design stage, available geometric detail, and the required accuracy (Anderson, 2011; Katz & Plotkin, 2012).

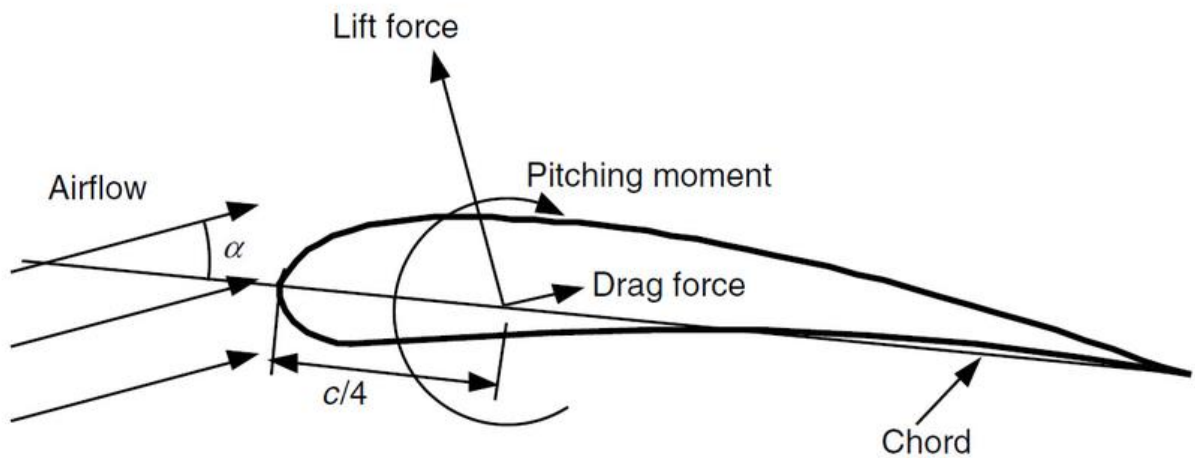


Figure 10 – Schematic representation of hydrodynamic forces and moments acting on a hydrofoil section, showing lift, drag, angle of attack (α), chord length, quarter-chord location, and pitching moment about the aerodynamic centre. Adapted from (Kulkarni, et al., 2016).

6.1.1 Analytical / Semi-Empirical Estimates (hand methods)

At a preliminary stage, the hydrodynamic forces on a hydrofoil can be estimated using the standard lift and drag relations:

Equation 5 – Aerodynamic lift & Drag equations.

$$L = \frac{1}{2}\rho V^2 C_L S, \quad D = \frac{1}{2}\rho V^2 C_D S$$

At this lowest level, analytical lift and drag relations using representative coefficients provide rapid, transparent estimates and are well suited to early-stage bounding calculations. Their limitation lies in sensitivity to assumed coefficients and inability to capture separation or unsteady effects (Anderson, 2011; Katz & Plotkin, 2012).

6.1.2 Potential-Flow Panel / Lifting-Line Methods (Inviscid)

Lifting-line methods offer improved fidelity by accounting for finite-span effects and spanwise lift distribution. They are computationally efficient and useful for structural sizing, but remain inviscid and require empirical corrections for viscous drag and stall behaviour (Reid & Hunsaker, 2016; Katz & Plotkin, 2012).

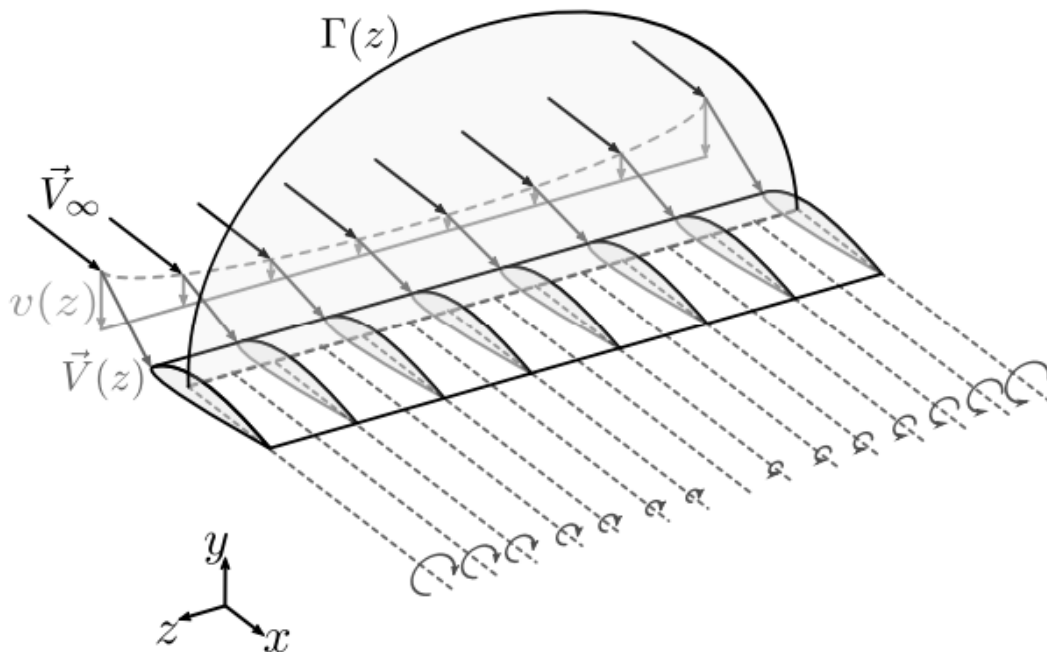


Figure 11- Lifting-line model of a finite hydrofoil showing the bound vortex, trailing vortex sheet, and resulting induced velocity field that gives rise to downwash and induced drag. Adapted from (Reid & Hunsaker, 2016).

6.1.3 Coupled inviscid + boundary-layer tools (e.g., XFOIL-type approach)

Coupled inviscid boundary-layer methods, such as XFOIL-type tools, provide section-level pressure distributions, lift, drag and transition prediction at modest computational cost. However, their two-dimensional nature limits accuracy for three-dimensional flows and strongly separated conditions (Drela, 1989). As a result, XFOIL-type approaches continue to serve as effective screening tools for section optimisation and early-stage load estimation prior to higher-fidelity CFD or experimental analysis (Katz & Plotkin, 2012).

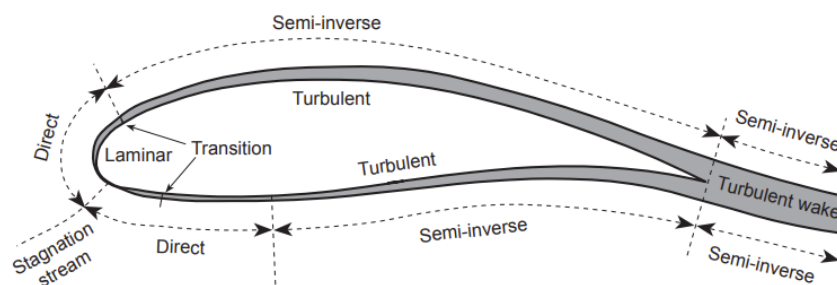


Figure 12 - Flow past an aerofoil diagram showcasing XFOIL-Type section level approach for boundary layer inviscid flow coupling adapted from (Zienkiewicz & Taylor, 2000).

6.1.4 CFD (RANS / URANS / LES)

At the high Reynolds numbers typical of hydrofoil operation, direct numerical simulation (DNS) is computationally infeasible, and Reynolds Averaged Navier Stokes (RANS) methods are therefore most widely used in practice. CFD using Reynolds Averaged Navier Stokes (RANS) offers full three dimensional, viscous flow prediction and is the most appropriate tool for detailed hydrofoil analysis. Unsteady RANS or Large Eddy Simulation may be required where vortex shedding or dynamic effects are significant, albeit at higher computational cost. Fluid structure interaction methods are relevant where structural flexibility influences the flow (Ferziger, et al., 2020).

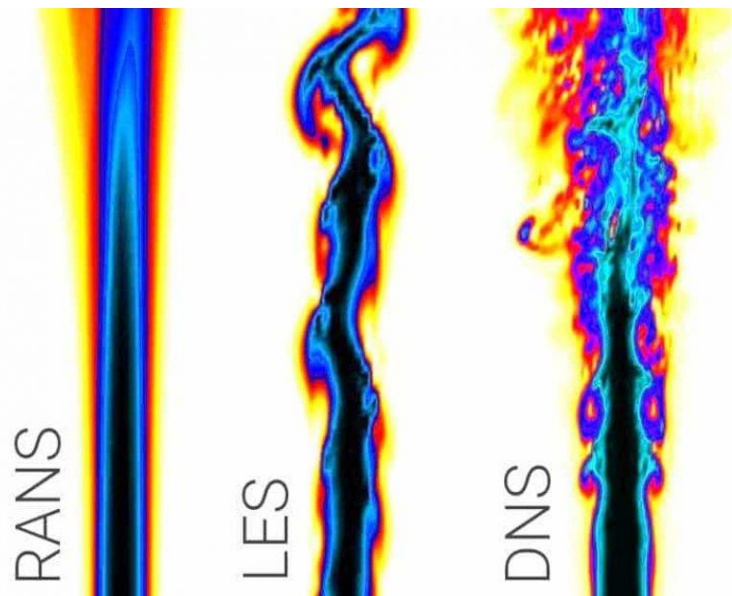


Figure 13 – CFD modelling of a turbulent jet using different approaches adapted from (idealsimulations, n.d.)

6.2 Recommended Strategy

Given the limited geometry and operating envelope in the brief, a stage approach is most defensible:

- Stage 1 Bounding / scoping (this study): Use analytical and semi-empirical estimates (lift/drag relations) to bound plausible loads and to test whether structural assumptions (e.g., 500 N point loads) are physically reasonable and not over-constraining.
- Stage 2 Section polars (when AoA/Re/section are defined): Generate 2D polars using an inviscid boundary-layer method (XFOIL/XFLR5-type) at the Reynolds number established in Stage 1, then apply finite-span corrections (e.g., lifting-line) to obtain spanwise lift distribution, induced drag, and resultant forces/moments.
- Stage 3 (CFD): RANS / URANS CFD to model flow to build upon the fidelity done in stage 2 and more accurate turbulence modelling, unsteady flows and 3D effects.
- Stage 4 – Verification & Validation (final confidence building): Verify the numerical solution (mesh/time-step independence, residual/monitor convergence) and validate predictions against experimental datasets where available. If the hydrofoil section differs from published experimental profiles, a defensible approach is to run a benchmark case using a well-documented aerofoil section under the same solver settings and compare predicted polars against experimental data to quantify systematic bias.

This approach is recommended as published comparisons show that “higher fidelity” methods (e.g., RANS CFD) can still deviate from experiments if separation/transition is mis-modelled, while lower-order methods (e.g., XFOIL-type) can match well in attached-flow regimes as shown in figure 14. Therefore, tool choice should be paired with explicit validation & verification rather than assuming fidelity guarantees accuracy (American Institute of Aeronautics and Astronautics (AIAA), 2002; American Society of Mechanical Engineers, 2009; International Towing Tank Conference, 2024).

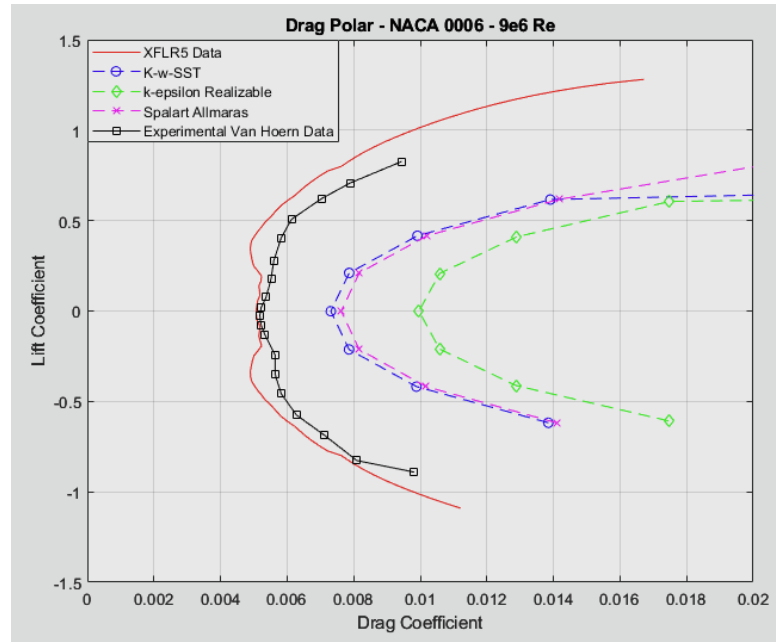


Figure 14 - Lift–drag polar comparison for a NACA 0006 aerofoil at high Reynolds number ($\sim 9 \times 10^6$), showing XFLR5/XFOIL predictions versus RANS CFD turbulence models (e.g., $k-\omega$ SST, $k-\epsilon$) and experimental reference data. Adapted from (Samandi, 2023)

6.3 Force Estimation

The purpose of this section is to synthesise the preceding hydrodynamic analysis into a representative range of forces acting on the hydrofoil wing. This is achieved without over-defining geometry or operating conditions, consistent with the limited design brief, and is intended to provide a physically realistic basis for preliminary structural interpretation rather than a final design load case.

6.3.1 Planform Area and Chord Selection

Planform area and chord length ranges were adopted from published dimensions for low, mid and high aspect recreational hydrofoil wing (Table 2). This anchors the analysis in real-world hardware and avoids speculative geometry. The primary limitation is that planform shape, taper and twist are unknown. A more rigorous approach would use manufacturer CAD data, but this is unavailable at the conceptual stage.

Table 2 - Planform Area Range created using information from (Williams, 2026; Boone, 2024).

Category	Planform Area Range (m ²)	Wing Length c (m)	Primary Use Case
Low Aspect	0.11 – 0.16	0.550 – 0.630	Beginners, and slow-speed carving
Mid Aspect	0.08 – 0.14	0.450 – 0.590	General Freeride, all-around performance
High Aspect	0.05 – 0.10	0.350 – 0.500	Racing, high-speed efficiency and maximum glide

6.3.2 Coefficients Ranges

Lift coefficients between 0.4 and 0.8 were selected to represent nominal, moderate, and upper pre-stall operating conditions. This is consistent with published section data and the attached turbulent flow regime established earlier. Actual values will depend on angle of attack and section geometry. Section polars generated using XFOIL or CFD would provide greater accuracy, but are unjustified without defined geometry (Abbott & Doenhoff, 1968).

Drag coefficients were selected consistent with streamlined hydrofoil operation and increased with lift coefficient to reflect induced and profile drag growth. Surface roughness and fouling are not explicitly modelled. High-fidelity CFD could capture these effects but would be highly sensitive to unknown geometry and surface condition (Anderson, 2011; Hoerner, 1968).

Quarter chord pitching moment coefficients were adopted from empirical NACA data for sections with comparable camber to low, mid and high aspect recreational foils (Table 4). This provides a defensible representative value to put together estimate torsional loading values. Actual values depend on detail pressure distribution and chamber line shape. Direct extraction from CFD pressure fields would be more accurate but are not justified or possible at this stage of development (Abbott & Doenhoff, 1968).

Table 3 - Representative Quarter-Chord Pitching Moment Coefficients for Analogous NACA Sections in the Linear Lift Regime taken from data provided by (Airfoiltools, 2024).

Wing Type	Comparable NACA	Reynolds No. based upon table 2 wing length	Representative C_m (Empirical)
Low Aspect 5 m/s	NACA 23012 (Reflexed)	1.72×10^6	-0.001
Low Aspect 10 m/s	NACA 23012 (Reflexed)	3.44×10^6	0.01
Low Aspect 15 m/s	NACA 23012 (Reflexed)	5.17×10^6	0.015
Mid Aspect 5 m/s	NACA 2412 (Moderate Camber)	1.61×10^6	-0.045
Mid Aspect 10 m/s	NACA 2412 (Moderate Camber)	3.23×10^6	-0.05
Mid Aspect 15 m/s	NACA 2412 (Moderate Camber)	4.54×10^6	-0.055
High Aspect 5 m/s	NACA 4412 (High Camber)	1.37×10^6	-0.090
High Aspect 10 m/s	NACA 4412 (High Camber)	2.73×10^6	-0.095
High Aspect 15 m/s	NACA 4412 (High Camber)	4.10×10^6	-0.100

6.3.3 Load Case Definition

Three load cases were defined for each wing category, combining largest bounded planform area and chord length for each respective wing category:

- Case A is representative of low speed manoeuvring a high C_L & C_D were adopted with the logic being loading would governed by initial take-off / acceleration, carving when manoeuvring and transient loading.
- Case B is intended to model normal cruising taking the view that hydrofoil would be in free glide operation with limited drag and moderate lift thus representative C_L & C_D were adopted.
- Case C for high-speed movement had the lowest bounded value for C_L and moderate C_D adopted to represent increased dynamic pressure and represent powered kitesurfing or upper bounds professional kitesurfing runs.

These cases represent physically plausible operating points rather than artificial worse-case combinations potentially over estimating forces and over constraining future design work. These

operating models however do not model highly transient events (e.g. wave slam or wave breaching). To model these time-accurate URANS/LES simulation of unsteady transient wave conditions would be needed. Such analysis however is prohibitively computationally expensive and outside the scope of preliminary design study (Bethwaite, 2008; Marchaj, 1980). For each case, forces were calculated using:

Equation 6 - Hydrodynamic force equations for Dynamic Pressure, Lift, Drag and Moment

$$q = \frac{1}{2} \rho V^2, \quad L = qSC_L, \quad D = qSC_D, \quad M = qScC_m$$

These relations arise directly from integration of pressure and shear stresses over the lifting surface and are standard in hydrodynamic analysis. Unsteady effects and structural deformation are not included; FSI would be required for full coupling but is outside the scope of this study due to it's preliminary nature (Anderson, 2011). The forces from these calculations are represented here in this graph for the reference tables please see appendix A.

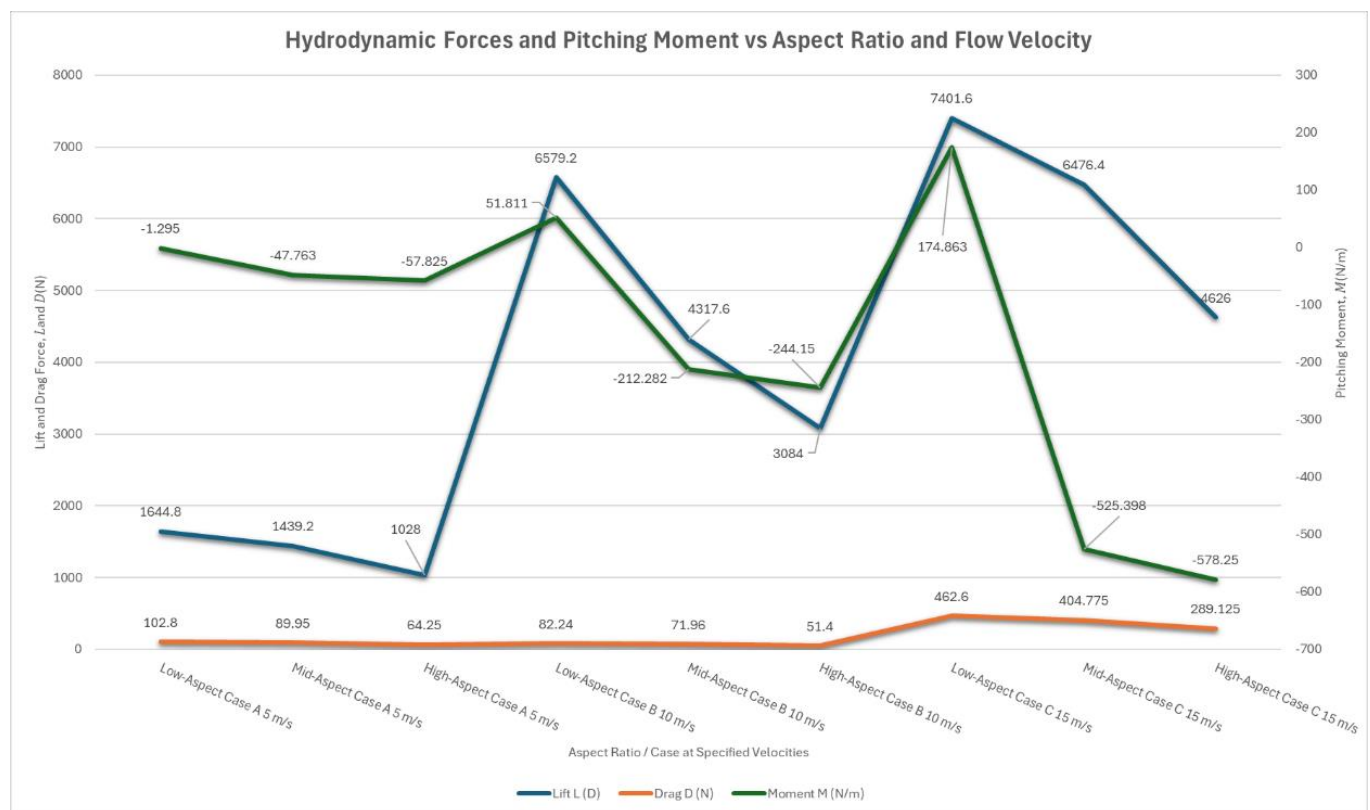


Figure 15 - Hydrodynamic Force Graph from calculated values created by document owner.

6.3.4 Interpretation

The results show that lift is the dominant loading component acting on the hydrofoil, typically in the range of 1–15 kN depending on aspect ratio and flow velocity. Drag is consistently secondary and approximately an order of magnitude lower, contributing less significantly to structural demand. Pitching moments are non-negligible, particularly for mid- and high-aspect-ratio wings, and are a key driver of torsional loading. For low aspect ratio wings, structural demand is governed primarily by bending due to lift, whereas for mid and high aspect ratio wings torsion associated with pitching moment becomes increasingly significant.

Lift and drag are derived from semi-empirical analytical relations, while pitching moment is based on representative empirical section data due to the absence of defined geometry and angle of attack. As a result, a direct proportional relationship between lift and pitching moment is not enforced.

Despite this, the results robustly demonstrate that hydrofoil structures are governed by combined bending and torsional loading, and that modelling distributed pressure effects provides a more realistic basis than simplified point-load assumptions.

7 Experimental Testing and Data Correlation

7.1 Prototype Testing and Simulation Correlation Methodology

A recirculating water tunnel is proposed for prototype testing of the hydrofoil wing seen below in figure 16. This facility provides controlled and repeatable inflow conditions, enabling precise regulation of free-stream velocity and angle of attack. A motorised inclination system will be used to vary angle of attack, allowing the generation of lift, drag and pitching moment polars over the operating envelope (Tran, et al., 2015).

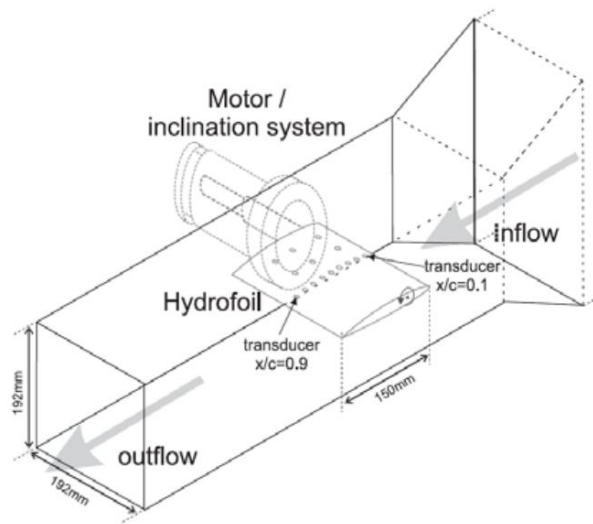


Figure 16 – Hydrofoil Experimental Test Setup Adapted from (Tran, et al., 2015)

The experiment will measure lift, drag and pitching moment using a multi-axis force balance sensor. These quantities will be reduced to their non-dimensional coefficients using:

Equation 7 - Hydrodynamic force equations reduced to their co-efficients

$$q = \frac{1}{2} \rho V^2, \quad C_L = \frac{L}{qS}, \quad C_D = \frac{D}{qS}, \quad C_m = \frac{M}{qSc}$$

Testing for coefficients rather than raw forces provides the most defensible basis for comparison with simulation, as it removes scale and speed dependence and isolates the underlying hydrodynamic behaviour (Anderson, 2011; White, 2006). Discrepancies between experiments and CFD can then be attributed to modelling assumptions (e.g. turbulence, transition), flow regime differences, or experimental interference, rather than simple dynamic pressure effects.

Reynolds number based on chord length, will be recorded to ensure consistency with the turbulent external flow regime assumed in the simulations. In addition, the tunnel internal-flow Reynolds number based on hydraulic diameter will be monitored to verify the stable inflow conditions within the tunnel (Fox, et al., 2004).

Equation 8 - Reynolds Number Equation for Internal non-Circular Ducts

$$Re = \frac{\rho v D_h}{\mu},$$

While Reynolds number alone does not fully characterise turbulence intensity, it provides a first-order check that experimental flow regime is comparable to the modelled case (Schlichting & Gersten, 2017). The cavitation number,

Equation 9 - Cavitation Number Equation

$$\sigma = \frac{p_\infty - p_v}{\frac{1}{2} \rho V^2},$$

Will also be monitored to ensure that test remains in a non-cavitating regime. Cavitation would fundamentally alter the flow physics and invalidate the direct comparison with incompressible simulations. As recreational hydrofoils are not typically intended to operate in cavitating conditions, any residual cavitation flow risk is more appropriately managed through conservative structural safety factors rather than explicit experimental modelling (Brennen, 2014; Kermeen, 1956; Parkin & Kermeen, 1957).

Flow behaviour will be assessed using qualitative visualisation and where available, particle image velocimetry (PIV) at selected operating points to identify separation onset, wake development and vortex structure. Structural response will be measured using strain gauges and deflection/twist monitoring the sensing locations would be directed by finite element modelling from the previous CFD concentrating in areas where high strain or strain gradients are predicted (Davis, et al., 2015). Similar in principle to the set up shown in figure 17.

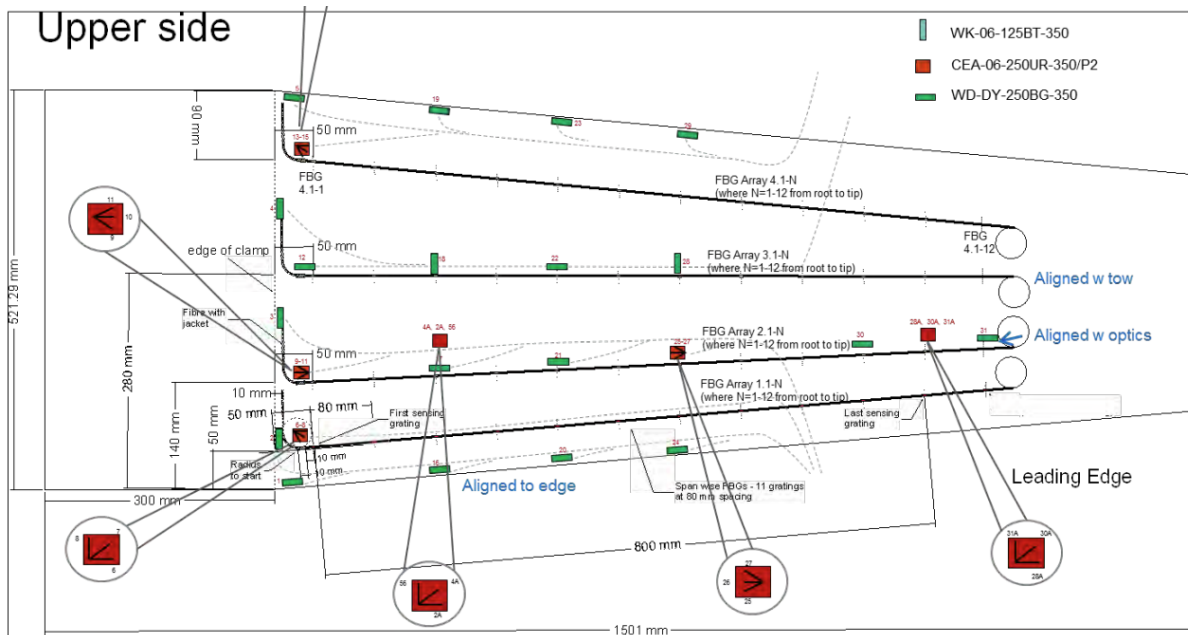


Figure 17 - Schematic drawing of an upper surface of a hydrofoil showing locations of strain gauges, Bragg gating sensors and their associated wiring adapted from (Davis, et al., 2015)

Experimental $C_L(\alpha)$, $C_D(\alpha)$, and $C_m(\alpha)$ curves will be compared directly with simulation predictions at matched Reynolds number (Kermeen, 1956). Agreement in pre-stall regions and correct trend capture near stall will be used as primary validation criteria, with flow visualisation supporting interpretation of any discrepancies. This staged approach provides a robust and practical framework for validating the numerical models without incurring the cost and complexity of full-scale open-water testing or high fidelity unsteady FSI at the prototype stage (Malalasekera & Versteeg, 1995).

8 Discussion and Integration & Conclusion

This study has developed a physically grounded preliminary assessment of a composite hydrofoil wing, integrating fluid mechanics, structural loading, and material considerations within the constraints of a limited design brief. By progressing from Reynolds number and boundary layer analysis through drag, lift, and pitching moment estimation, the work has demonstrated that hydrofoil loadings is dominated by distributed lift and associated torsional moment with drag effects acting as secondary. The resulting load cases indicate forces in the order of 1-15kN, confirming that the structure is fundamentally bending and torsion driven and that concentrated point-load assumptions are not fully representative of the true physics.

The material evaluation confirmed that CFRP is a technically justified choice for high-performance hydrofoils, offering optimal balance of stiffness, strength and low mass. The coupling between structural stiffness and hydrodynamic efficiency was highlighted, as excessive deformation would degrade the section shape, alter effective angle of attack and reduce lift-to-drag ratio.

A key outcome of this work is the demonstration that bounded analytical and semi-empirical methods, when used with engineering judgement, can provide reliable guidance for future works. The study therefore establishes a robust preliminary framework upon which higher-fidelity modelling and testing can be built.

Future work should focus on defining hydrofoil geometry to enable section polar generation and lifting-line analysis, followed by 3D CFD to capture pressure distribution and separation behaviour. The prototype experimental programme outlined should then be used to validate and calibrate the numerical models. Final development should included detailed laminate design, fatigue assessment, and impact tolerance evaluation.

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10 Appendix A – Data Tables for Hydrodynamic Forces Estimate

Table 4 – Representative combined lift, drag, and pitching moment load cases for a low-aspect recreational hydrofoil wing based on bounded hydrodynamic coefficients and empirical geometry ranges.

Load case	V (m/s)	q (Pa)	S (m ²)	c (m)	C_L	C_D	Representative C_m at given Re	Lift L (N)	Drag D (N)	Moment M (N/m)
Case A (low speed / during manoeuvres)	5	12850	0.16	0.630	0.8	0.05	-0.001	1644.8	102.8	-1.295
Case B (Normal Cruising)	10	51400	0.16	0.630	0.6	0.01	0.01	6579.2	82.24	51.811
Case C (high speed)	15	115650	0.16	0.630	0.4	0.025	0.015	7401.6	462.6	174.863

Table 5 – Representative combined lift, drag, and pitching moment load cases for a mid-aspect recreational hydrofoil wing based on bounded hydrodynamic coefficients and empirical geometry ranges.

Load case	V (m/s)	q (Pa)	S (m ²)	c (m)	C_L	C_D	Representative C_m at given Re	Lift L (N)	Drag D (N)	Moment M (N/m)
Case A (low speed / during manoeuvres)	5	12850	0.14	0.590	0.8	0.05	-0.045	1439.2	89.95	-47.763
Case B (Normal Cruising)	10	51400	0.14	0.590	0.6	0.01	-0.05	4317.6	71.96	-212.282
Case C (high speed)	15	115650	0.14	0.590	0.4	0.025	-0.055	6476.4	404.775	-525.398

Table 6 – Representative combined lift, drag, and pitching moment load cases for a high-aspect recreational hydrofoil wing based on bounded hydrodynamic coefficients and empirical geometry ranges.

Load case	V (m/s)	q (Pa)	S (m ²)	c (m)	C_L	C_D	Representative C_m at given Re	Lift L (N)	Drag D (N)	Moment M (N/m)
Case A (low speed / during manoeuvres)	5	12850	0.10	0.500	0.8	0.05	-0.090	1028	64.25	-57.825
Case B (Normal Cruising)	10	51400	0.10	0.500	0.6	0.01	-0.095	3084	51.4	-244.15
Case C (high speed)	15	115650	0.10	0.500	0.4	0.025	-0.100	4626	289.125	-578.25