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**Designing a Kiteboard: Structural Design**

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# Abstract

Building on the previous report, which focused on the fluid flow around a kiteboard, FEA optimisation techniques are investigated for optimising a kiteboard based on the forces it may endure. Optimisation techniques have significantly developed, from on-paper math equations to multidisciplinary force analysis using computational methods. Topology, shape, and size optimisation developments are discussed, highlighting historical and future developments, including AI, cloud-based networking, and advances in material science. While modern-day optimisation offers significant benefits to industries such as automotive, aerospace and civil engineering, costs are highlighted as disadvantages.

For the analysis of the kiteboard using 'Desing Studio by GENESIS', the dynamic load force of a rider is calculated at 1222.84N. FEA simulations were conducted on a baseline steel kiteboard model under an estimated dynamic load of 1222.84 N, resulting in a maximum displacement of 50 mm, a stiffness of 24.56 N/mm, and a strength-to-weight ratio (SWR) of 0.31 N<sup>2</sup>/mm. This steel model served as a benchmark for subsequent analyses with carbon fibre-reinforced polymer (CFRP), targeting a similar displacement constraint while capitalising on CFRP's superior strength-to-weight ratio. The CFRP model achieved a 50% reduction in mass compared to the steel version but showed a 10% increase in displacement, necessitating further optimisation.

Through iterative optimisation using independent design variables (IDVs), the CFRP model was refined to achieve a target displacement of 50 mm, resulting in a 29.38% weight reduction to 2.86 kg and an improved SWR. To ensure manufacturability, a second optimisation was conducted using discrete design variables (DDVs), resulting in a final CFRP model with a 48 mm displacement and mass of 3.56 kg. This optimised DDV model exhibited a 57% increase in SWR and a 56% reduction in mass compared to the baseline steel model, though its thickness increased by 2.4 mm.

The report proposes an experimental procedure for prototype testing to validate the FEA results. A hydraulic press will simulate distributed load across the board's surface to measure displacement under controlled conditions. Displacement data will be collected using high-accuracy laser measurement sensors or mechanical dial test indicators (DTIs) as a cost-effective alternative. This experimental data will be compared to the FEA results through force-displacement curves and calculated stiffness and SWR values, identifying discrepancies to refine the FEA model's parameters. Calibration of all measurement devices is included to ensure data validity, with potential sources of error considered in both the experimental and simulated setups.

This study illustrates the application of FEA-based optimisation in achieving mass and performance improvements for a kiteboard through material selection and structural refinement. While optimisation techniques present challenges in computational demand and manufacturability, the insights gained highlight the use of FEA for performance-driven design and the necessity of validating simulations with experimental data to align simulated predictions with real-world behaviour.

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*Equation 1 – Weight force of a rider*

*Equation 2 – Inertial force*

*Equation 3 – Dynamic Force*

*Equation 4 – Stiffness*

*Equation 5 – Strength-to-weight ratio*

# 1. Introduction

The Structural and Fluid Analysis assignment Part 1 examined the fluid flow around a kiteboard. The report also explored composite materials, specifically Carbon Fibre Reinforced Plastic (CFRP). Composite materials have profoundly impacted design engineering, enabling the creation of lightweight, high-performance structures (Gay, 2015). CFRP has become preferred for applications requiring an excellent strength-to-weight ratio (Gibson, 2016).

A kiteboard is subjected to various forces, some of which were estimated in Part 1. Finite Element Analysis (FEA) is a modelling technique designers use to optimise structures (Rajasekaren, 2008). FEA simulations can model the forces acting on a structure, identifying areas that may require reinforcement.

In this report, FEA software 'Design Studio' will simulate the forces acting upon the kiteboard discussed in Part 1. The optimisation process will be documented, ensuring the design meets the deflection constraints equivalent to a 2mm steel board.

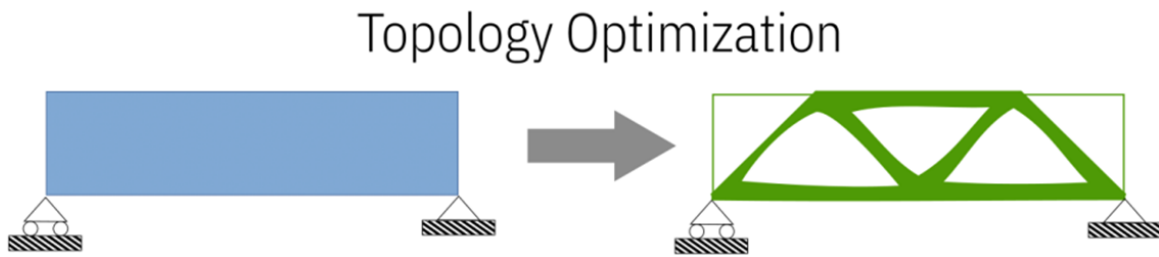
## 2. Optimisation Literature Review

This section will explore optimisation techniques, highlighting past advancements, future developments, and their advantages in the design process. These techniques enhance structural performance, reduce material usage, and improve design efficiency, making them valuable in aerospace, automotive, and civil engineering (Davim, 2017).

### 2.1. Topology Optimisation

Topology optimisation aims to efficiently distribute material within a design space to enhance performance by maximising stiffness or strength while minimising weight and material use (Da, 2020). Figure 1 illustrates a topology study on a rectangular structure.

Figure 1- Illustration of Topology Optimisation (SDCverifier, 2024)



Ogawa, Yonekura, and Suzuki (2023) emphasise that topology optimisation reduces material costs through efficient material distribution. In contrast, Liu and To (2017) argue that while material costs may decrease, expenses can rise due to complex designs and the costs of FEA software. Additionally, topology promotes sustainability by minimising material use and weight (Strambach and Pflitsch, 2020).

#### 2.1.1. Developments of Topology Optimisation

Topology concepts date back to the 1870s, when Georg Cantor introduced set theory (Scoville, 2012). Its formal use in structural design began in the 1980s after Martin Philip Bendsøe and Nobuhiro Kikuchi's (1988) paper on optimal topologies using a homogenisation method.

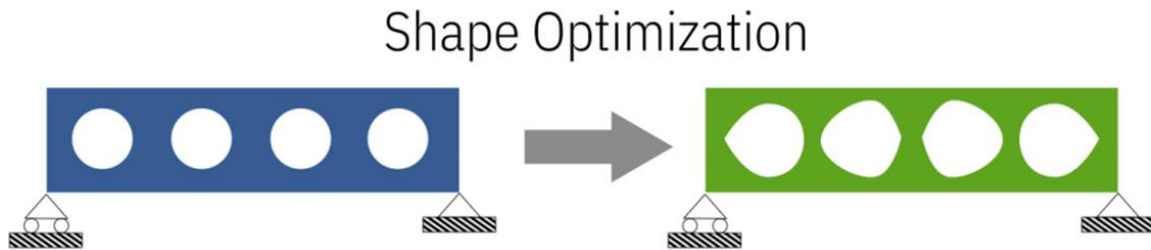
The homogenisation method transformed continuous materials into composites with solid and void regions, allowing efficient material distribution for structural integrity (Hassani and Hinton, 2012). This paved the way for developing the Solid Isotropic Material with Penalisation (SIMP) method in the 1990s, which simplified continuous material distribution into a discrete material allocation problem (Ferrer, 2019). Advancements in computational power and the use of additive manufacturing further widened the application of topology, proving it to be a useful technique, especially in industries such as biomedical, aerospace and automotive (Wang et al., 2020).

Integration of artificial intelligence with topology is a potential future development that could drastically enhance this technique. AI's ability to learn from previous tasks could result in a more adaptive and efficient design process, reducing computational time by predicting optimal designs based on previous iterations (Garrelts, 2021).

## 2.2. Shape Optimisation

Shape optimisation involves modifying the external geometry of a structure to enhance performance under specific constraints (Duan and Sheppard, 2002). Unlike topology optimisation, which adjusts internal material distribution, shape optimisation focuses on the outer surfaces of a component, as shown in Figure 2.

*Figure 2 - Illustration of Shape Optimisation (SDCverifier, 2024)*



This technique encourages innovative designs, creating non-intuitive shapes that are difficult to develop using conventional design methods (Breuß, Bruckstein, and Maragos, 2012). Shape optimisation enables designers to enhance performance metrics by effectively managing aerodynamics and stress, allowing for improved functionality and efficiency across various applications (Daxini and Praiapati, 2017).

### 2.2.1. Developments of Shape Optimisation

Early shape optimisation developments are linked to the Euler-Bernoulli beam theory, developed in the 18<sup>th</sup> century. This theory laid the foundational work by focusing on how beams could be shaped to effectively perform under specific load conditions (Tian, Zhang, and Sun, 2014).

The development of the finite element method (FEM) advanced shape optimisation, enabling its application for complex structures (Alves, Belinha and Pais, 2021). With advancements in computer-aided design (CAD) and computational power, shape optimisation became an essential tool for engineers. In the late 20<sup>th</sup> century, gradient-based optimisation techniques like sequential quadratic programming and adjoint methods were developed, allowing for efficient shape optimisation by focusing on performance goals such as weight reduction while maintaining structural integrity (Pugachev, 2013).

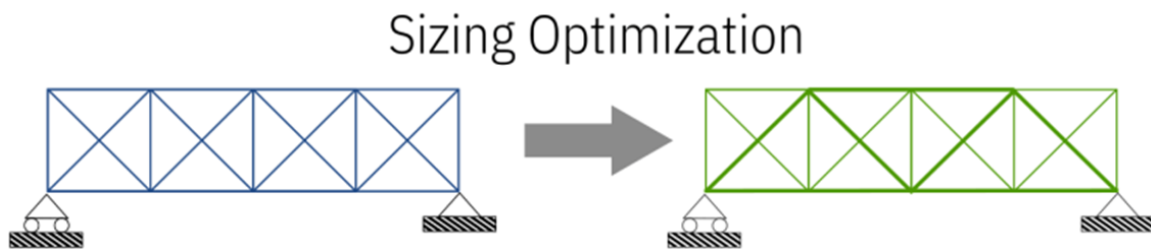
Advancements in cloud computing, allowing stakeholders to collaborate on models, could be a significant future development for shape optimisation. By using cloud-based platforms for

optimisation, multiple stakeholders can work on projects simultaneously, sharing insights and improving efficiency (Perri, Simonetti, and Gervasi, 2022). While this may substantially benefit efficiency, Zhong (2024) highlights that data security is a concern, and that careful consideration is required to mitigate data breaches and protect sensitive information.

## 2.3. Size Optimisation

Size optimisation focuses on adjusting the dimensions or thickness of individual structural elements to enhance performance. It is typically applied after the main load paths within a structure are defined (Kaveh and Ghazaan, 2017). For instance, the length and position would already be set for a cantilever beam, but the cross-sectional area remains to be optimised for improved performance, as depicted in Figure 3.

*Figure 3 - Illustration of Sizing Optimisation (SDCverifier, 2024)*



Applying this technique to structures with pre-defined load paths can refine them by optimising dimensions or thicknesses, resulting in efficient material usage. This technique is useful in the construction industry, where beams can be optimised to ensure they can perform under specific loads, promoting safety within the design.

### 2.3.1. Developments of Size Optimisation

Like shape optimisation, size optimisation emerged from classical mechanics, where early 20th-century engineers sought optimal dimensions for load-bearing structures like trusses and beams. Techniques were based on manual calculations using theories like Euler-Bernoulli, primarily for simple structures (Makavandi and Ochsner, 2020).

The introduction of numerical methods, such as the FEM, made size optimisation feasible for more complex designs. FEM enabled detailed analysis of stress and strain, guiding dimension

adjustments to improve performance (Chillet, Fonseca and Pugsley). By the late 20<sup>th</sup> century, advancements in CAD and FEA had integrated size optimisation into design workflows. Techniques such as Sequential Quadratic Programming (SQP) and gradient-based methods allowed engineers to optimise dimensions more precisely (Bastien and Christensen, 2015).

Advancements in material science could be a promising development for size optimisation, allowing for a broader range of materials with diverse properties such as strength, flexibility, and thickness (Packwood, 2017). Although breakthroughs in material science will benefit size optimisation, Sankaran and Venkataraman (2021) highlight that more sophisticated computational tools may be required when analysing new materials, increasing costs at the design stage.

In summary, various optimisation techniques are available today, including topology, shape, and size optimisation. These methods trace their origins to 19th-century mathematical foundations. Advancements in computational methods have greatly accelerated their development, improved efficiency, and made them widely accessible to designers. Future innovations, such as AI, cloud-based platforms, and material science advancements, could expand the scope of these techniques, making them even more powerful and versatile. These future developments are applicable across all three optimisations, potentially further revolutionising design processes.

Optimisation enhances structural performance while reducing material usage, lowering costs, and promoting sustainability. It often leads to innovative, complex designs, which may restrict manufacturing to additive methods, increasing production costs. Modern FEA techniques offer multidisciplinary optimisation with faster, automated results, improving design efficiency but sometimes at the expense of higher computational and manufacturing expenses.

### 3. Analysis of a Kiteboard in Design Studio

In this section, the structural performance of a kiteboard will be evaluated using Design Studio by GENESIS. The analysis will begin by assigning the board with 2mm thick steel material properties to establish a baseline for maximum displacement under applied forces, previously estimated in the initial kiteboard report. Following this, CFRP will be applied as the primary material, and the simulation will be re-run to observe any changes in displacement. Finally, an optimisation process will be conducted, targeting the desired performance metrics observed in the steel model while benefiting from CFRP's superior strength-to-weight ratio.

### 3.1. Simulation of the Kiteboard with Steel Properties

The initial report considered and estimated the rider's force on the board using the following equation.

$$W_{rider} = \text{Mass of rider} \cdot \text{Gravity} \quad (1)$$

$$W_{rider} = 75 \cdot 9.81 = 735.75N$$

To improve this calculation, the total dynamic load of the board can be calculated. To do this, the static weight load of the rider and board must be considered in addition to the inertial force.

Using equation 1, where the mass of the board in design studio is 8.1kg,

$$W_{board} = 8.10176 \cdot 9.81 = 79.48N$$

Therefore, the total static weight is estimated by adding the rider's weight force, which amounts to 815.23N (2.d.p.).

When the rider meets the water from the air, the inertial forces are added to the baseline static load forces. Gravity and lift forces from the kite impact the board's acceleration from the air back to the water's surface. This estimation assumes that the kite reduces the acceleration by 50%, giving  $4.905 \text{ m/s}^2$ . If the acceleration was greater, the overall force on impact would also be greater.

Therefore, using equation 2,

$$F_{inertial} = W_{total} \cdot a \quad (2)$$

Where,

$W_{total}$  = Is the weight of the rider and board (83.10176)

$a$  = Acceleration ( $4.905 \text{ m/s}^2$ )

$$\therefore F_{inertial} = 83.10176 \cdot 4.905 = 407.61N \quad (2.d.p)$$

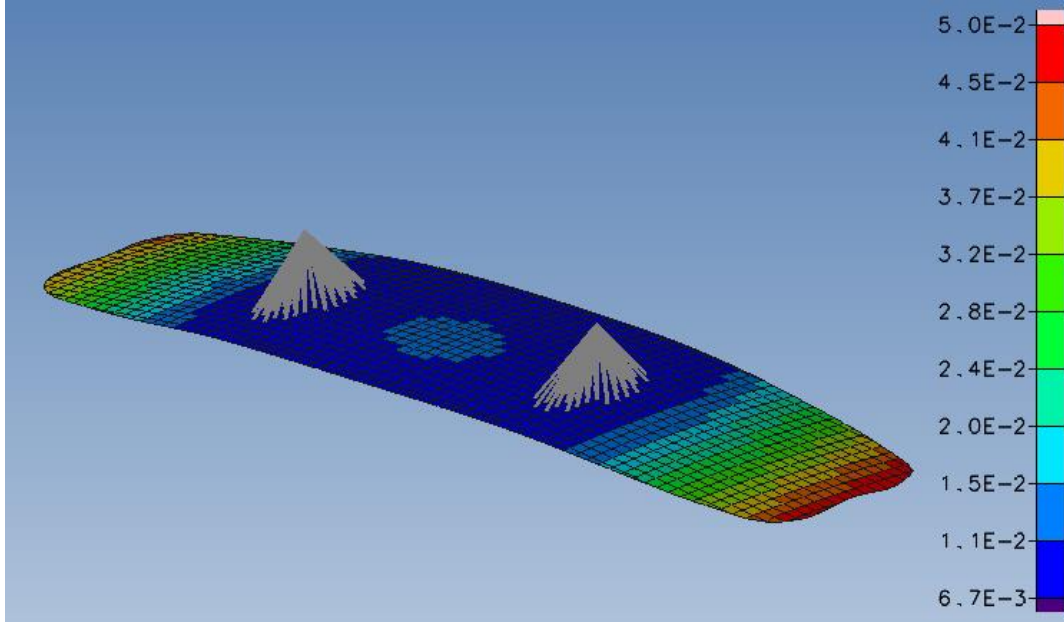
Using equation 3, the dynamic load force is then calculated,

$$F_{dynamic} = W_{rider} + W_{board} + F_{inertial} \quad (3)$$

$$\therefore F_{dynamic} = 735.75 + 79.48 + 407.61 = 1222.84N$$

In design studio, all 1464 grids are selected, and a magnitude of 0.835N at each grid is applied in the positive Z axis (Downward).

Figure 4 - Steel kiteboard displacement under load



The simulation shows the steel model's maximum displacement when considering the estimated dynamic load is 50mm.

The stiffness of the steel model is calculated using Equation 4,

$$k = \frac{F}{x} \quad (4)$$

Where,

K = Stiffness (N/mm)

F = Force applied (1222.84N)

x = Displacement (50mm)

$$\therefore k = \frac{1222.84}{50} = 24.56 \text{ N/mm (2.d.p)}$$

The strength-to-weight ratio (SWR) of the steel model is calculated using Equation 5,

$$SWR = \frac{k}{w} \quad (5)$$

Where,

SWR = Strength-to-weight ratio ( $N^2/mm$ )

k = Stiffness (24.56N/mm)

W = Weight of board (79.48Kg (2.d.p))

$$\therefore SWR = \frac{24.56}{79.48} = 0.31 N^2/mm \text{ (2.d.p)}$$

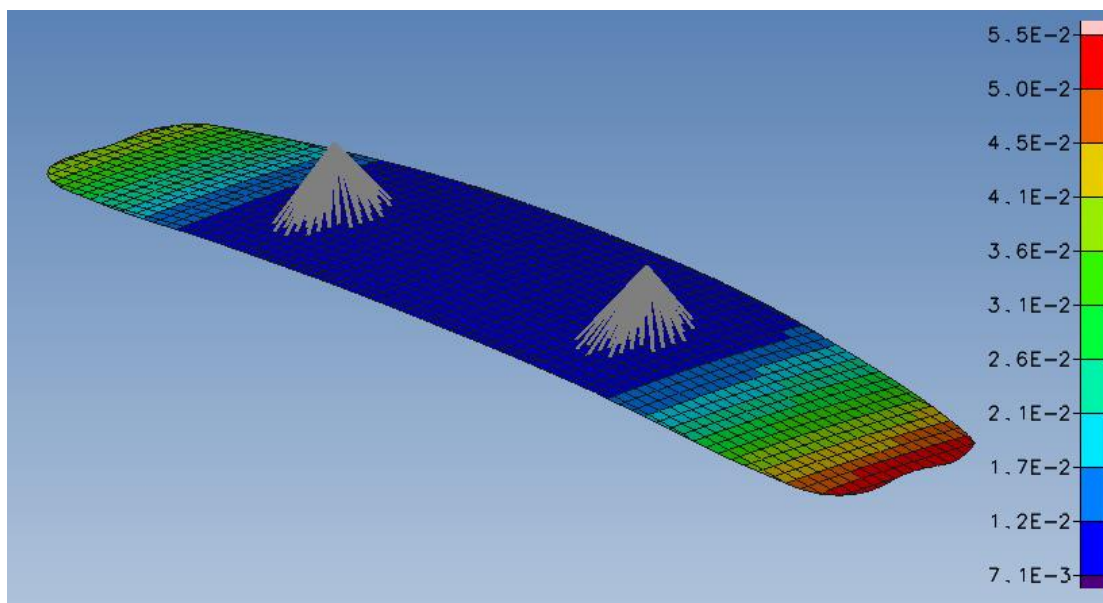
These values will be used to compare them against a CFRP board in the following section.

### 3.2. Simulation of the Kiteboard with CFRP Properties

The steel kiteboard model exhibited a maximum displacement of 50mm. This figure is now the target for the maximum displacement of the CFRP board. In addition to achieving a lower displacement, the board must also be lighter than the Steel kiteboard.

The structure is set up with the material properties in the assignment brief and the fibres are aligned correctly. The simulation is run with the same resultant force as calculated in section 3.1 and the results are displayed in Figure 5.

*Figure 5 - CFRP kiteboard displacement under load*



The simulation shows that the maximum displacement of the board when considering the estimated dynamic load is 55mm, a 10% increase in displacement compared with the steel

material. The overall mass of the CFRP model is 4.05Kg, a 50% reduction when compared with the steel model.

Using equation 4 to calculate the stiffness,

$$k = \frac{1222.84}{55} = 22.23N/mm \text{ (2. d. p)}$$

Using equation 5 to calculate the SWR,

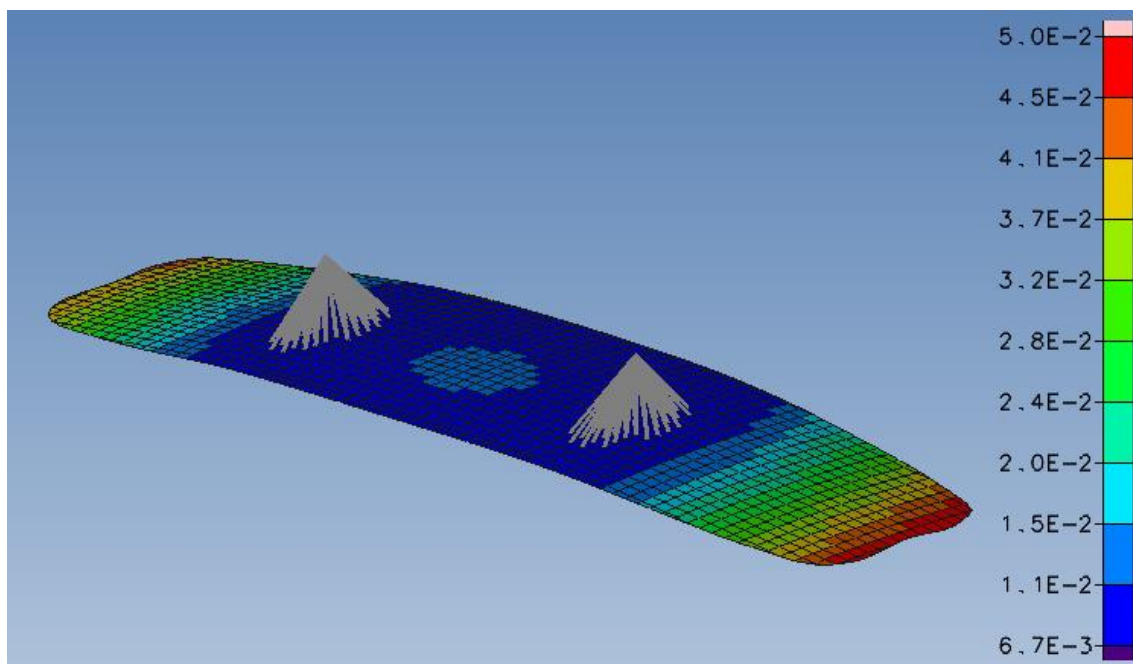
$$\therefore SWR = \frac{24.56}{39.73} = 0.62N^2/mm \text{ (2. d. p)}$$

### 3.2.1. Optimisation of the CFRP Model

Optimising the board requires setting objectives and constraints. The objective of this optimisation task is to minimise weight, and the constraint is to have a maximum displacement of 50mm. Five independent design variables (IDV) are set for the thickness so that the lower limit is 0.2mm and the upper limit is 3mm.

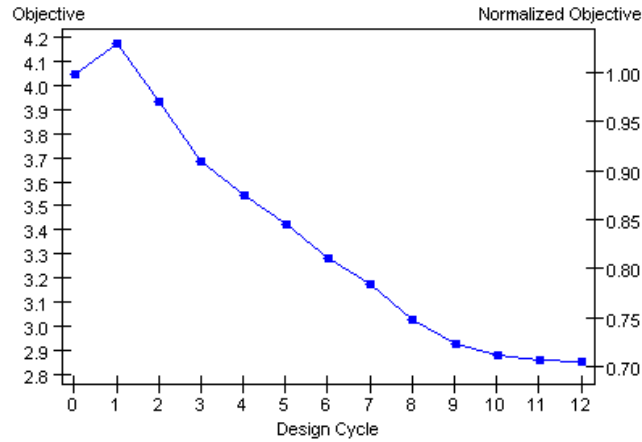
Genesis optimisation is run for the CFRP model and is fully optimised within 12 cycles, as depicted. Figure 6 shows the deform mesh/colour mesh for the model with IDV.

*Figure 6 – Optimised CFRP kiteboard displacement under load using IDV*



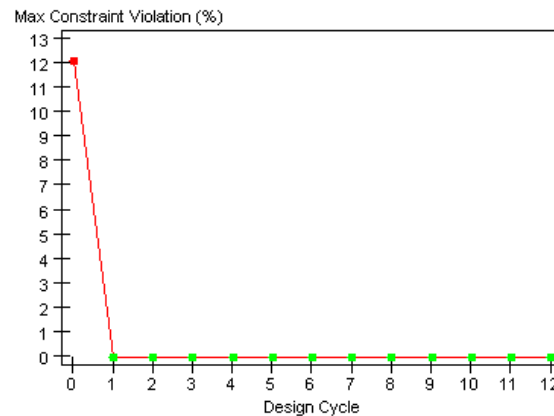
The CFRP displacement has been optimised to meet the constraint set and minimise mass. Graph 1 shows the mass optimisation against each design cycle.

*Graph 1 – Optimised CFRP Board with IDV Objective*



The CFRP model's weight decreased by 29.38% to 2.86 kg. The constraint violation was initially 12% but was resolved to 0% by design cycle 1, as seen in Graph 2 below.

*Graph 2 – Optimised CFRP Board with IDV Constrains violation*



The displacement was reduced to 50mm within the constraint set.

Using equation 4 to calculate the stiffness,

$$k = \frac{1222.84}{50} = 25.46 \text{ N/mm (2.d.p)}$$

Using equation 5 to calculate the SWR,

$$\therefore SWR = \frac{25.48}{28.06} = 0.91N^2/mm \text{ (2.d.p)}$$

Accessing the history file, which is produced through optimisation, allows one to know the thicknesses of each layer. The thicknesses for each design variable are shown in Figure 6.

Figure 7 - Thicknesses of each IDV

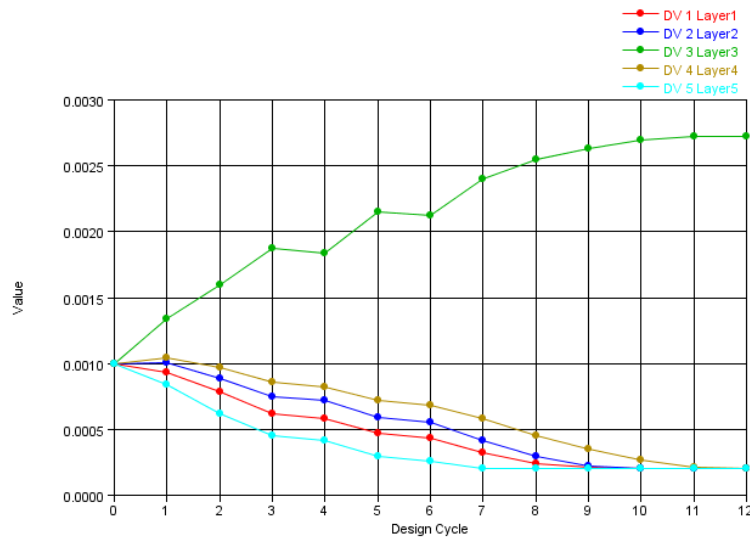
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DESIGN CYCLE #    12, OBJECTIVE = 2.855529E+00, MAXIMUM VIOLATION = 0.0%.
DESIGN VARIABLE #      1 = 2.000000E-04 Layer1
DESIGN VARIABLE #      2 = 2.000000E-04 Layer2
DESIGN VARIABLE #      3 = 2.724581E-03 Layer3
DESIGN VARIABLE #      4 = 2.000000E-04 Layer4
DESIGN VARIABLE #      5 = 2.000000E-04 Layer5

```

A graphical depiction of the optimisation of each design variable is shown in Graph 3.

Graph 3 - CFRP Optimisation of the IDV



The overall thickness of the board by design cycle 12 is 3.52mm (2.d.p). The thickness of 1 ply of CFRP can vary; for the following calculations, we will assume that the thickness is 0.2mm per ply.

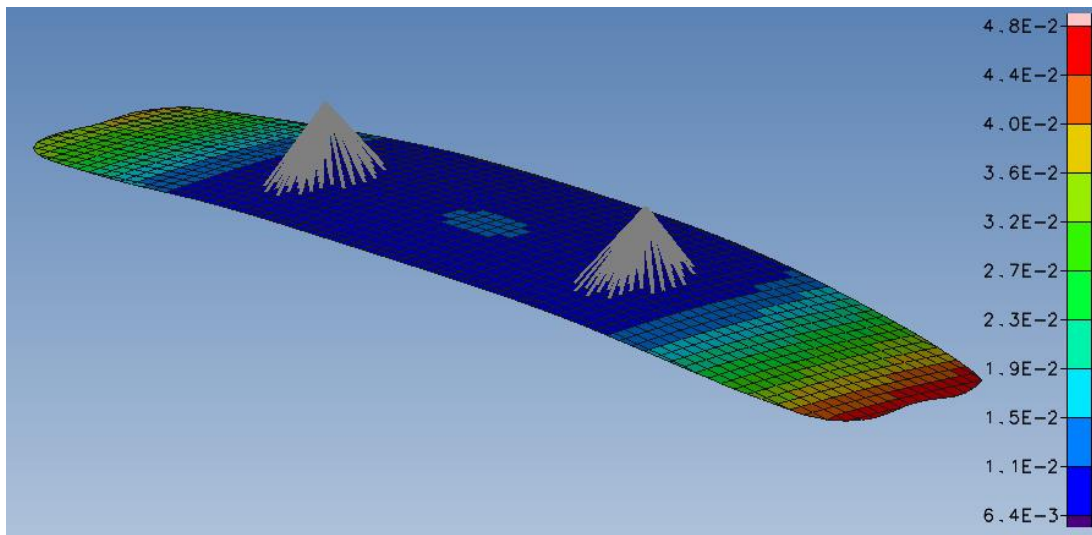
Therefore,

- Layer 1 = 1 Ply

- Layer 2 = 1 Ply
- Layer 3 = 13.62 Plies (2.d.p)
- Layer 4 = 1 Ply
- Layer 5 = 1 Ply

The total number of plies is 17.62. For manufacturability, the number of plies must be a discrete value with a specific thickness. In the design studio, the five design variables are then set to discrete design variables (DDV), and the model is optimised again, producing the results shown in Figure 8.

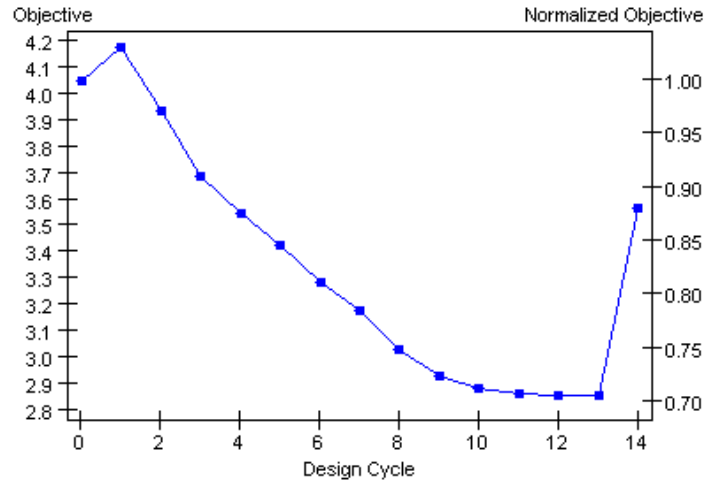
*Figure 8 - Optimised CFRP kiteboard displacement under load using DDV*



The maximum displacement observed is now 48 mm, sufficient to achieve the optimal mass with a maximum displacement constraint of 50mm using DDV.

Graph 4 shows the optimisation of the mass against each design cycle.

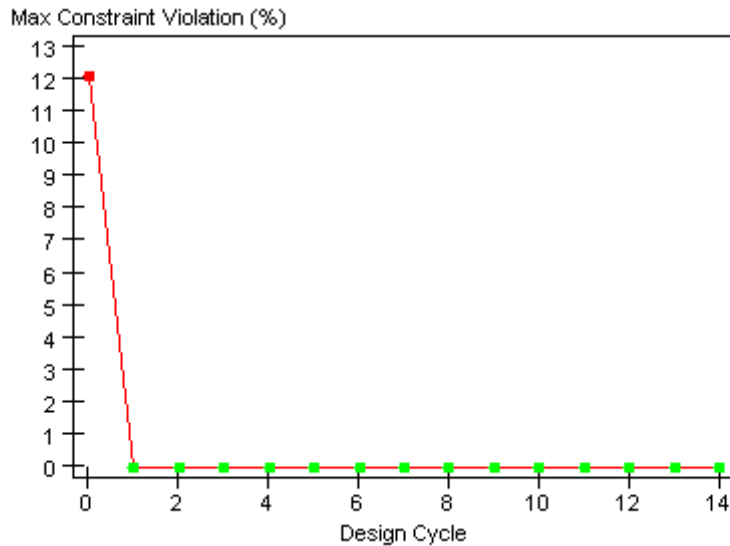
Graph 4 – Optimised CFRP Board with DDV Objective



To achieve DDV, the overall mass increased to 3.56 kg (2.d.p), an increase of 24.48% compared to the IDV-optimised CFRP model. An increase in mass was seen from design cycles 13 to 14; this is likely due to adjustments made to achieve DDV.

Like Graph 2, the constraint violation was initially 12% but was resolved to 0% by design cycle 1, as seen in Graph 5 below.

Graph 5 – Optimised CFRP Board with IDV Constrain violation



The maximum displacement constraint was resolved in design cycle 1.

Using equation 4 to calculate the stiffness,

$$k = \frac{1222.84}{48} = 25.47 \text{ N/mm (2.d.p)}$$

Using equation 5 to calculate the SWR of the optimised CFRP model,

$$\therefore SWR = \frac{25.47}{34.92} = 0.73 \text{ N}^2/\text{mm (2.d.p)}$$

The thicknesses of each layer are known by accessing the history file, which is produced through optimisation. The thicknesses for each design variable are shown in Figure 9.

Figure 9 - Thicknesses of each DDV

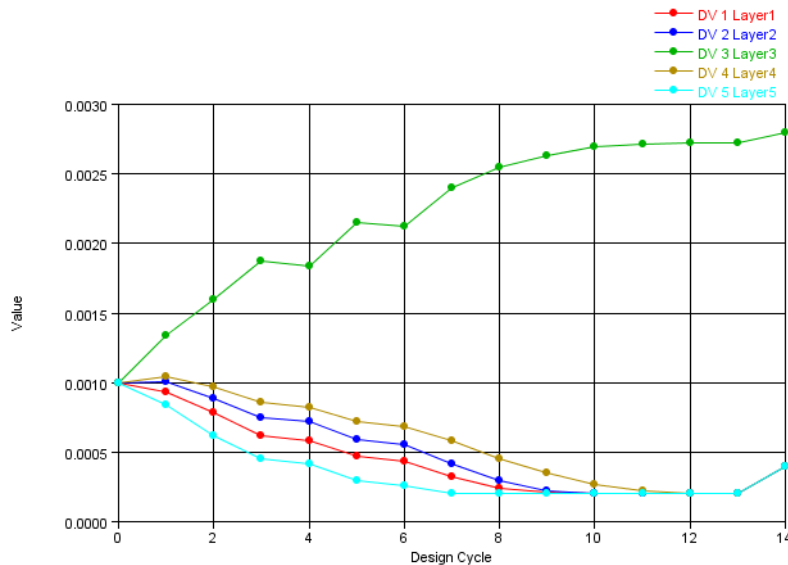
```

DESIGN CYCLE #   14, OBJECTIVE = 3.564772E+00, MAXIMUM VIOLATION = 0.0%.
DESIGN VARIABLE #    1 = 4.000000E-04 Layer1
DESIGN VARIABLE #    2 = 4.000000E-04 Layer2
DESIGN VARIABLE #    3 = 2.800000E-03 Layer3
DESIGN VARIABLE #    4 = 4.000000E-04 Layer4
DESIGN VARIABLE #    5 = 4.000000E-04 Layer5

```

A graphical depiction of the optimisation of each design variable is shown in Graph 6.

Graph 6 - CFRP Optimisation of the DDV



The overall thickness of the board by design cycle 14 is 4.4mm (2.d.p).

The number of plies per layer is;

Therefore,

- Layer 1 = 2 Ply
- Layer 2 = 2 Ply
- Layer 3 = 14 Plies
- Layer 4 = 2 Ply
- Layer 5 = 2 Ply

The total number of layers is 22, all discrete variables, so this optimised model is manufacturable.

### 3.3. Summary of the Kiteboard Design Studio Analysis

Table 1 below summarises the simulations run in the design studio.

*Table 1-Summary of data collected from design studio*

| Run                       | Material | Board Thickness (mm) | Number of plies | Maximum Displacement (mm) | Mass (Kg) | Stiffness (N/mm) | Strength-Weight Ratio $N^*2/mm$ |
|---------------------------|----------|----------------------|-----------------|---------------------------|-----------|------------------|---------------------------------|
| Steel Baseline            | Steel    | 2                    | N/A             | 50                        | 8.1       | 24.56            | 0.31                            |
| Composite Baseline        | CFRP     | 2                    | N/A             | 55                        | 4.05      | 22.23            | 0.62                            |
| Optimised Composite       | CFRP     | 3.52                 | 17.62           | 50                        | 2.86      | 25.46            | 0.91                            |
| Optimised Composite (DDV) | CFRP     | 4.4                  | 22              | 48                        | 3.56      | 25.47            | 0.73                            |

Overall, the optimised discrete CFRP model has seen an increase in SWR of 57% and a reduction in mass of 56%. The optimised IDV model has a greater SWR; however, for manufacturability, discrete variables are required, which causes an increase in mass and a resultant decrease in SWR. The final thickness of the optimised board was 4.4mm, 2.4mm greater than the composite baseline.

## 4. Prototype Testing and Data Acquisition

In the brief for this report, it is requested that a laboratory experiment be proposed for a prototype of the kiteboard. This experiment will correlate to the simulations in the design studio so that data can be compared. The following sections will outline a suitable experiment, including how the data will be obtained and compared to the simulation.

### 4.1. Experimental Procedure

In the design studio, the rider's force was applied across the entire upper face of the board. Although this may be an unrealistic representation of this force, as a rider would typically be in

contact with a small area of the board, the experiment will also simulate the force spread across the same area for fair comparison.

Multiple kiteboard prototypes will be used, matching those observed in the design studio simulations, which used steel and CFRP as the primary materials.

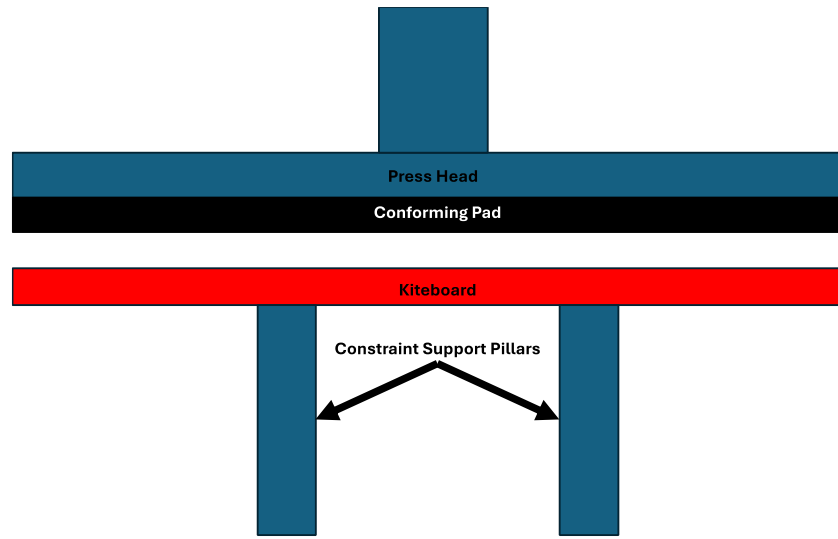
As illustrated in Figure 6, a hydraulic press is best suited to simulate a force across the entire surface of the board.

*Figure 10 - Laboratory hydraulic press (FOMM, 2023)*



Matching the experiment, the board will be constrained at the binding locations. This will be done by fixing the board to two support pillars underneath it. Fixing the board from underneath allows the press head to have complete contact. As it is known that the board will flex under load, a conforming pad will be used to ensure uniform load distribution across the board as displacement occurs. Figure 7 shows a diagram of the experimental setup.

Figure 11 - Illustration of the experimental set-up



The press head's application force will be controlled and monitored using a computer, gradually increasing force to identify the force-deformation relationship.

The correct safety measures must be implemented in case of machine or material failure. This includes the use of PPE, such as safety goggles and protective barriers and correct safety controls, such as emergency stops, all in guidance of the Provision and Use of Work Equipment Regulations 1998 (HSE Gov, 2014).

## 4.2. Data Acquisition

Displacement was analysed as the critical data in the simulation. As seen in Figure 8, a laser sensor would be the most accurate measurement tool for this experiment.

Figure 12 - Laser measurement sensor (Fortop, 2023)



Multiple sensors set up at various locations underneath the board will collect data as the board flexes towards the sensor, providing an accurate measurement for displacement without contacting the board. Although this method will give the most precise measurement, sensors can be costly and require training and software, which can also accumulate costs. A more cost-effective method would be to use mechanical DTI gauges at various locations under the board and record each load at peak force. However, this method is manual, and the risk of errors is greater.

Equipment calibration is critical for validating the results. The sensors will require calibration by a specialist before the experiment to ensure accurate measurements. The press head can be calibrated using a series of load sensors, ensuring that the applied load matches the data collected from the load cells.

### 4.3. Data Comparison

Both experimental data and FEA data will be extracted to form two force-displacement curves. Overlaying the curves will highlight areas of alignment and divergence. The maximum deflection can be compared as a percentage difference. A larger percentage difference could indicate that material properties, boundary conditions, or layer orientations may need refinement in the simulation model (Beisbart and Saam, 2019).

The stiffness and SWR for the experimental model can also be calculated using the same equations as above. Then, the FEA model can be compared, and the percentage difference can be calculated.

Potential sources of error should be evaluated in both the experiment and the FEA. In the experimental setup, errors may arise due to sensor calibration issues or alignment inaccuracies. For the FEA model, errors could stem from assumptions regarding boundary conditions, material properties, or the distribution of applied loads.

In summary, the data collected from both experiment and simulation can be directly compared using force-displacement curves, highlighting discrepancies and points of similarity. The equations in section 3 will also be used to calculate the experiment's stiffness and SWR. The root-mean-square-error (RMSE) method, which was discussed in the initial report, could also be utilised for this experiment to quantify the overall error of magnitude, highlighting how well the FEA Model approximates real-world behaviour (Li et al., 2020).

## 5. Conclusion

The development of optimisation techniques dates back centuries to early developments in mathematics. Advancements in computational methods significantly accelerated the development of various optimisation techniques, broadening their application in today's industries. Future developments in optimisation include advancements in AI, the use of cloud-based platforms and material science advances. Topology, shape and size optimisation techniques are beneficial in enhancing the performance of a structure, reducing material usage and lowering costs. Although optimisation techniques have many benefits, modern FEA optimisation techniques require high computational power and can often result in complex designs, leading to higher manufacturing costs.

The analysis of the steel kiteboard model with a force of 1222.84N across the upper surface of the board resulted in a maximum displacement of 50mm. This was used as an upper constraint for the CFRP models, which showed over half a reduction in weight and over double an increase in SWR. However, the discrete optimised CFRP model increased in thickness by 2.4mm.

An experiment using a hydraulic press to apply a known force to the board could provide real-world data on how the kiteboard will behave under load. Setting up the experiment to match the exact set-up in the design studio is difficult. Instead, small modifications can be made to the FEA model, such as constraint locations, to ensure the comparison is similar. Data acquisition of the displacement is best done through laser measurement sensors due to their high accuracy and non-contact measuring method. If cost is an implication, it is possible to measure displacement using several DTI gauges, which are considerably cheaper than laser measurement sensors. The calibration of the equipment is critical to validating the data collected. The data can be compared to the FEA data through graphical and statistical methods, highlighting discrepancies between results. These discrepancies may highlight that modifications of the FEA simulation are required to simulate real-world behaviours.

## 6. Limitations and Recommendations for Further Work

Further exploration into more optimisation techniques was limited due to report size restrictions. Researching alternative optimisation techniques, such as parametric optimisation (Zhang et al., 2023), will be valuable in providing a broader understanding of optimisation techniques and how they benefit the design process. In design studio, the forces were applied to the entire board surface, which is not an accurate representation of a real-world scenario.

With further training in the design studio, it is recommended that the simulation be improved by applying the force to two smaller areas representing the rider's feet. It is expected that if the force is applied in two areas towards the centre of the board, the maximum displacement will also be located at the centre, which is different from what was observed during the initial simulations. Simulations could also incorporate the calculations of additional forces, such as lift and drag

The forces on the board are calculated using several assumptions, which, if different, will change the overall force figure. To mitigate some of the assumptions made, a board could be equipped with load sensors and subjected to real-world testing, where data could be collected. This could be done using a dummy in a wave tank, where variables such as water density, weight, height, etc. are all known.

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