



**Prifysgol Cymru**  
Y Drindod Dewi Sant  
**University of Wales**  
Trinity Saint David

**University of Wales Trinity Saint David**  
**School of Engineering**

# **Designing a Kiteboard: Structural Design (Part 2).**

**Simon Marc Harris**  
**(2116866)**

**BEng (Hons) Mechanical and Manufacturing Engineering**

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## Abstract.

In preparation for this report, academic research was conducted on optimisation techniques, including shape, size, and topology optimisation, as well as the historical development of these topics. The study also examined the structural simulation of a kiteboard and the optimisation of materials when constructed from a carbon-fibre-reinforced polymer (CFRP). The goal was to enhance the CFRP to achieve a stiffness-to-weight ratio equal to or surpassing that of a steel-based board. A testing setup was also developed to validate the simulation results against real-world test outcomes.

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# 1 Finite Element Analysis and Optimisation.

Finite Element Analysis, also known as FEA, enables engineers to simulate and evaluate complex systems that would be difficult or impossible to analyse using manual calculations alone. Utilising FEA, engineers can divide a complex system or structure into smaller, more manageable elements (Figure 1) and then apply numerical methods to analyse the behaviour of each element. These individual element analyses are then combined to provide an overall solution for the entire system (Combden, 2023).

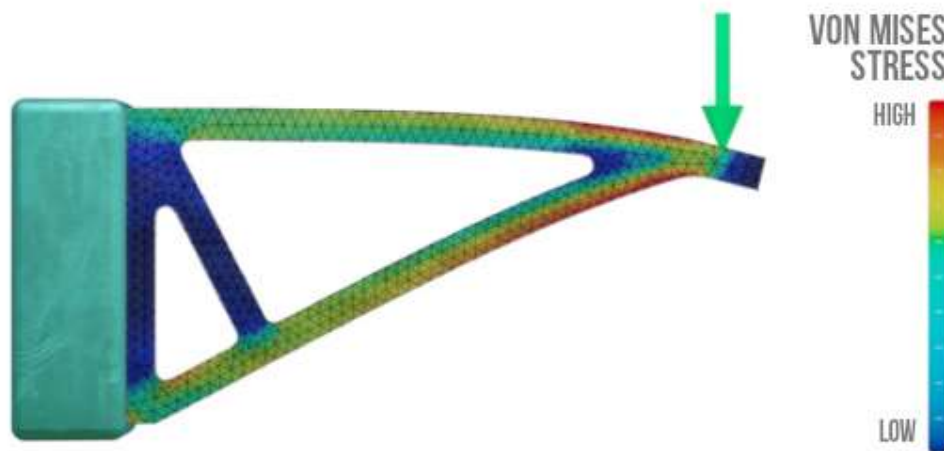


*Figure 1 - FEA Applied to a Simple Bracket (Efficientengineer, 2023)*

## 1.1 Simulation and Improvement.

Finite Element Analysis (FEA) simulates structures or systems under various conditions to understand their response, while optimisation aims to improve designs (Simscale, 2024).

FEA optimisation techniques employ various methods to enhance engineering design processes' efficiency, accuracy, and performance. This is achieved by refining the FEA model to meet specific performance criteria, such as minimising weight, maximising strength and stiffness, and optimising material usage (Ishchuk, 2024).

There are two options to optimise a design: parametric and non-parametric. With the parametric approach, the software automatically finds the most efficient shape suitable for the product being considered. One advantage of this approach is that you can start modelling without an original design. To choose the best design, you need to pick several important parameters or design variables and define a range for each (Rishabheng, 2024).

A parametric approach varies each parameter within the permissible range to find the optimal design while minimising the final volume (Rishabheng, 2024).

## 1.2 Optimisation History.

In 1638, Galileo Galilei presented the initial ideas about the most efficient shapes for structural elements in his work "Discourses and Mathematical Demonstrations." He studied brittle fracture processes and designed bodies based on their locally considered strengths (Phelipecostapde, 2018).

In 1870, Clerk Maxwell focused on civil engineering problems and proposed designing bridges with as little material as possible, using elasticity theory to find the ideal material distribution through the principal stress field. Following this work, A. G. M Michell continued Maxwell's studies to create optimal structures. Michell's work (Figure 3) was considered too difficult to manufacture in this period and was only considered a reference for future studies (Carpentieri, et al., 2015).

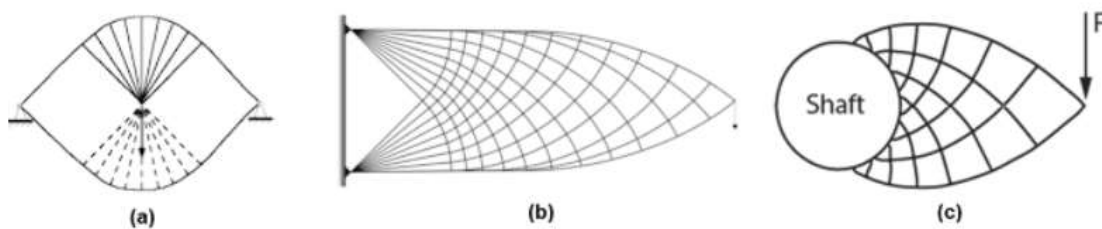


Figure 2 - a & b - frame bridge structure, c - optimal crank structure (Phelipecostapde, 2018)

In 1971 & 1972, George Rozvany and fellow researchers published papers extending Michell's theory to beam systems. Based on these papers, William Prager and Rozvany formulated the first general topology optimisation, termed "optimal layout theory" (Logo & Ismail, 2020).

In 1988, an influential paper from M.P. Bendsoe and N. Kikuchi, received intrigue from engineers; the paper presented a numerical technique for the homogenisation method and illustrated the practical applicability of earlier theoretical methods for optimisation (bham, 2001).

## 1.3 Computer-Based Optimisation.

As computer processor power advanced, the concept of optimisation evolved to benefit from software-based tools; these innovative software technologies converted previously difficult-to-apply methods into practical, everyday engineering tools (Jenkins, 2016).

These tools encompass optimisation and combine various optimisation techniques into one system, including software programs such as Ansys, Fusion 360, Genesis, Inspire, MSC Nastran, Generate-NX, TopShape & VirtualPyxis. It has also been integrated into existing CAD software, SolidEdge, Inventor, Nastran, SolidWorks & Catia (Phelipecostapde, 2018)

## 2 Optimisation Techniques.

Optimisation in finite element analysis can be divided into methods that focus on optimising grid locations (known as shape optimisation and topology), geometric properties (referred to as sizing optimisation), or material properties (referred to as material optimisation) (Ishchuk, 2024).

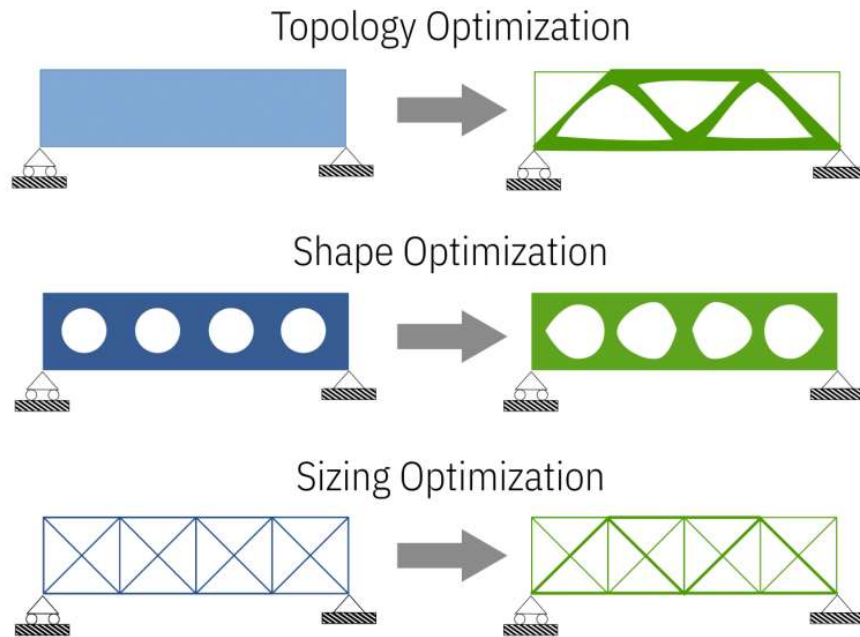


Figure 3 - Optimisation Techniques (Ishchuk, 2024)

### 2.1 Parameters.

To achieve successful optimisation, various parameters are required before optimisation can commence.

#### 2.1.1 Objectives.

An optimisation objective is the desired outcome that optimisation aims for, considering constraints and design variables. For example, an objective could be to minimise a component's weight while also maximising its strength-to-weight ratio by considering its displacement.

#### 2.1.2 Design Variables.

The design variables are the factors that influence the result of the optimised object. These may involve pressures, forces, material properties, geometric dimensions, angles, curves, and other related factors (pdesign, 2024).

### 2.1.3 Constraints.

Certain constraints need to be met during the optimisation process. These constraints relate to material properties, manufacturing limitations, or safety requirements. The optimisation algorithm must ensure that the suggested outcome complies with these constraints.

## 2.2 Topology Optimisation.

Topology optimisation is the efficient arrangement of material within a specified design space. By setting boundary conditions and constraints like loads, users can achieve objectives such as maximising the stiffness (nTop, 2020) and reducing unnecessary weight from a design, as shown in Figure 4. As a result, the aerospace and automotive industries frequently utilise this software in their designs (Engineering.com, 2019).

The SIMP (Solid Isotropic Material with Penalization) mathematical method pioneered initially by Rozvany & Prager, then developed by Bendsoe & Kikuchi, has emerged as the widely adopted standard approach for most commercial topology optimisation software in today's software (Phelipecostapde, 2018).



Figure 4 - Volume Removal Example (Engineering.com, 2019)

### 2.3 Generative Design.

Generative design is the latest iteration of the optimisation genres; it involves an advanced, algorithm-driven process, sometimes incorporating AI, to investigate numerous design options that adhere to specific criteria established by engineers or designers (Autodesk, 2024).

Generative design can be introduced at the start of the design process to eliminate boundaries and encourage new ideas, in contrast to topology optimisation, which uses a model that is already partially defined for its purpose in a more advanced stage of the design process (Neuralconcept, 2023).

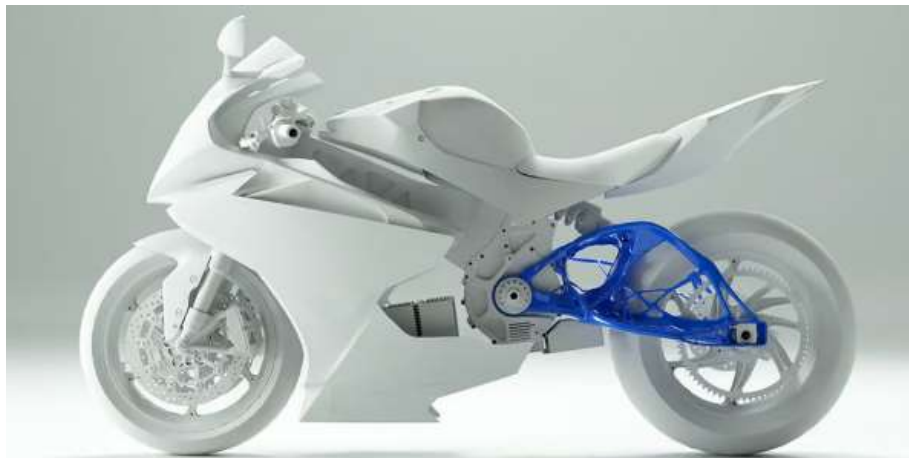


*Figure 5 - Rear axle of a motorcycle optimised with generative design (Autodesk, 2024).*

Generative design software allows engineers to input their requirements and preferences, such as materials and manufacturing methods, and then automatically generate a design ready for manufacturing.

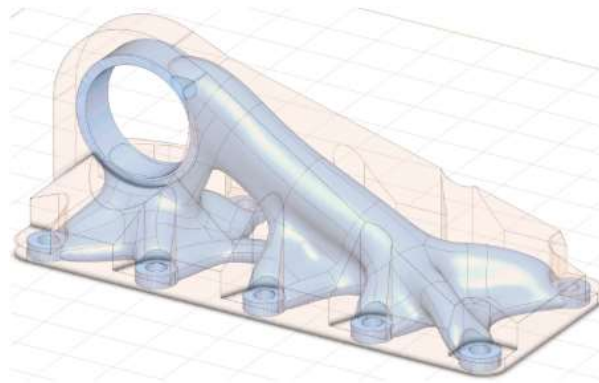


*Figure 6 - Typical Generative Design Organic Shape Comparison to Original Part*

## 2.4 Size Optimisation.

Lightweight structures play a crucial role in numerous industries' designs. Where discreet section sizes are used to construct an assembly, optimisation of these sections is necessary to achieve the design objectives, e.g., minimising weight and cost (Yokota & Frangopol, 2020).

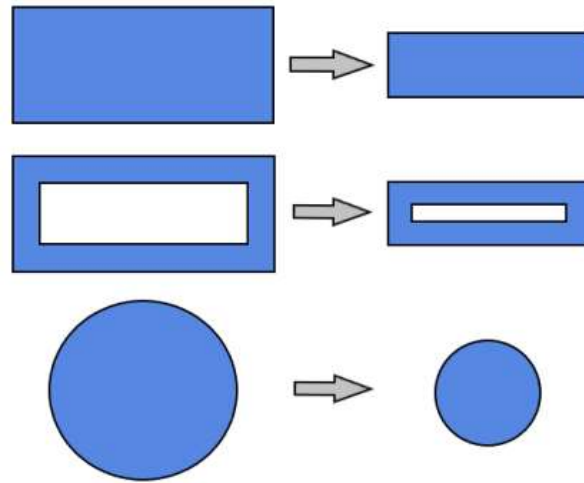


*Figure 7 - Size Optimisation.*

Size optimisation requires user input and constraints to determine the optimum section sizes, gage thickness and cross-sectional shapes to achieve the designated design objectives for deflections, stresses and strains. This optimisation can reduce the weight and cost of assemblies while adhering to the design's load requirements (Ishchuk, 2024).

## 2.5 Shape Optimisation.

Shape optimisation involves determining the best shape for a structure or object that meets specific performance criteria. The aim is to determine the object's geometry that minimises or maximises a particular outcome while meeting various constraints. This method is commonly used in the structural design, heat transfer and aerodynamics fields (Krishnamurthy, 2019).

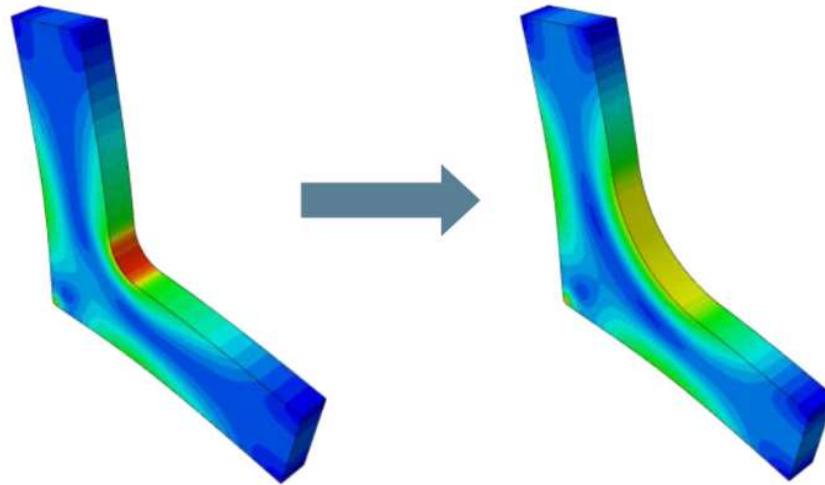


*Figure 8 - Shape Optimisation Example*

### 3 Design Studio Simulation.

#### 3.1 Steel Simulation.

Utilising Design Studio software, a task was set to optimise a kiteboard made from 2mm thick steel to be made from unidirectional CFRP and achieve the same deflection value as the steel kiteboard while minimising the weight. The following steps were carried out to achieve this objective:

A pre-modelled board was imported into Design Studio with the steel properties applied and two load cases located where the kiteboard clips would be positioned (Figure 9)

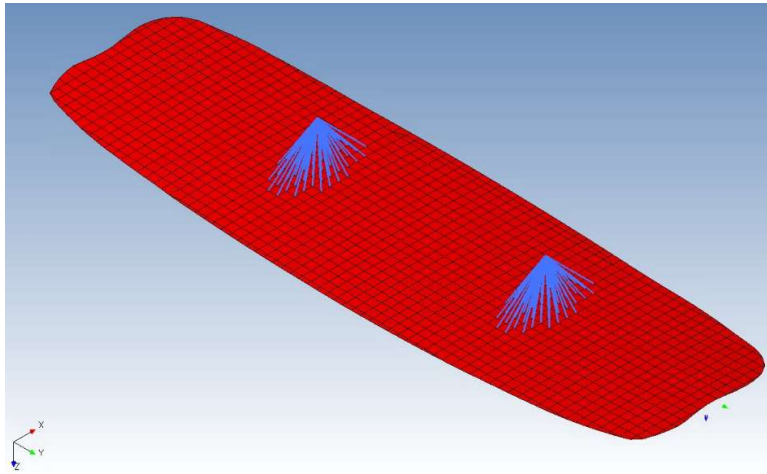


Figure 9 - Baseline Board

A UDL was to be applied to the board; calculated forces from a previous report were requested to be applied to the UDL.

*Due to the unrealistic thickness of the baseline board, the calculated impact force of **64.7 KN** would have resulted in an unrealistic deflection on the steel baseline material with a thickness of 2mm; this baseline deflection required minor deflections for the final optimisation to be compared. Design Studio uses linear solvers, which can result in unrealistic outcomes for outputs like stress, strain & displacement, as there is no failure function.*

This was considered, and a UDL of **1464 N** (Figure 10) was applied to the underside of the board (Figure 11). This load was the weight of an average board user with a safety factor of 2 applied.

0 grids selected Identify Selected Grids

Change Loading on Selected Grids

Clear Loads/SPCDs

Data Form: Load Direction+Magnitude

Direction:

X: By 2 Grids... By 3 Grids...

Y: 0

Z: 0

Magnitude: -1

1

Add Force Add Moment

1462 forces on 1462 grids 0 moments 0 SPCDs

Editing ID=2 UDL

Figure 10 – UDL Values

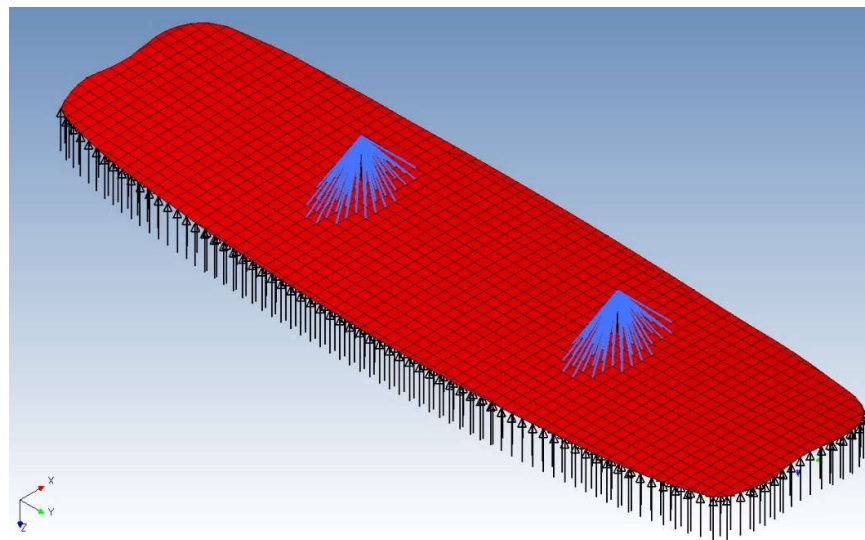


Figure 11 - UDL Visualisation

The model was analysed using the single analysis function; a deflection of 59mm and a mass of 8.1kg were observed (Figures 12 and 13).

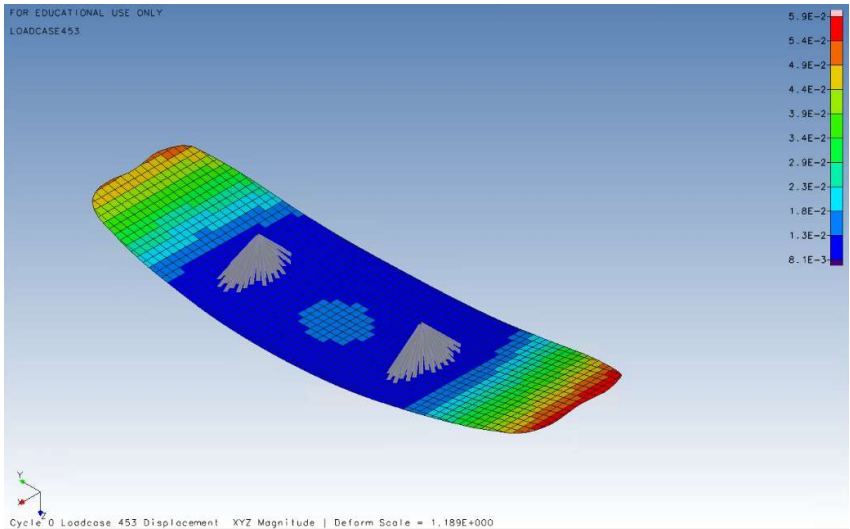


Figure 12 - Steel Deflection

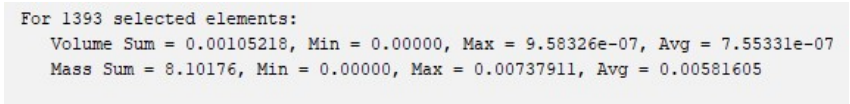


Figure 13 - Steel Mass

These figures were tabulated, and the stiffness-to-weight ratio was calculated (Table 1) first using the formula for stiffness:

$$stiffness(k) = \frac{f \text{ (load)}}{x \text{ (deflection)}}$$

Then, the ratio was calculated using:

$$\frac{k}{(mass \times gravity)}$$

Table 1 - Steel Values.

| Simulation      | Material | Thickness (mm) | Deflection (mm) | Mass (kg) | Load (N) | Stiffness (N/mm) | Stiffness/Weight Ratio (N <sup>2</sup> /mm) |
|-----------------|----------|----------------|-----------------|-----------|----------|------------------|---------------------------------------------|
| Steel_Kiteboard | Steel    | 2.00           | 59              | 8.1       | 1462     | 24.8             | 0.31                                        |

### 3.2 CFRP Simulation.

After the baseline values for the steel material were determined, the CFRP material properties (Figure 14) and layer thicknesses and orientations were added to Design Studio. Five layers were added to the group properties, and each layer was assumed to have five plies at 0.1 mm thick (Figure 15).

The plate comprises 25 plies (5 at -90, 5 at -45, 5 at 0, 5 at 45, and 5 at 90), totalling 2.5 mm thick.

Display Analysis Topology Design Post Plugins

Materials

< Back Next > Finish Cancel

Edit a Material : 2-D Orthotropic Properties

E\_1: 132E9  
E\_2: 10.8E9  
Nu\_12: 0.24  
G\_12: 5.65E6  
G\_1z: 5.65E6  
G\_2z: 5.65E6  
Rho: 1540  
A\_1:  
A\_2:  
Tref:  
GE:  
F12:

☒ Stress Limits  
☐ Strain Limits

Xt: 1513E6  
Xc: 1000E6  
Yt: 43.4E6  
Yc: 43.4E6  
S: 43.4E6

Figure 14 – CFRP Properties

Display Analysis Topology Design Post Plugins

Group Properties

< Back Next > Finish Cancel

Edit a Group : Choose Composite Property Values

Name: Laminate

Z0:  
Nonstructural Mass:  
Tref:  
GE:  
Interlaminar Shear Limit:  
Failure Theory: None  
Laminate: All Plies  
Type: Regular

Global Ply ID : Material : Thickness : Angle : Output

| Global Ply ID | Material         | Thickness | Angle | Output |
|---------------|------------------|-----------|-------|--------|
| Layer 1       | 857143 CFRP (UD) | 1.E-4     | -90.0 | Yes    |
| Layer 2       | 857143 CFRP (UD) | 1.E-4     | -45.0 | Yes    |
| Layer 3       | 857143 CFRP (UD) | 1.E-4     | 0.0   | Yes    |
| Layer 4       | 857143 CFRP (UD) | 1.E-4     | 45.0  | Yes    |
| Layer 5       | 857143 CFRP (UD) | 1.E-4     | 90.0  | Yes    |

Figure 15 – Layer Inputs

The vector direction for this analysis was modified to be the length of the board along the y-axis, which was assumed to be 0° (Figure 16).

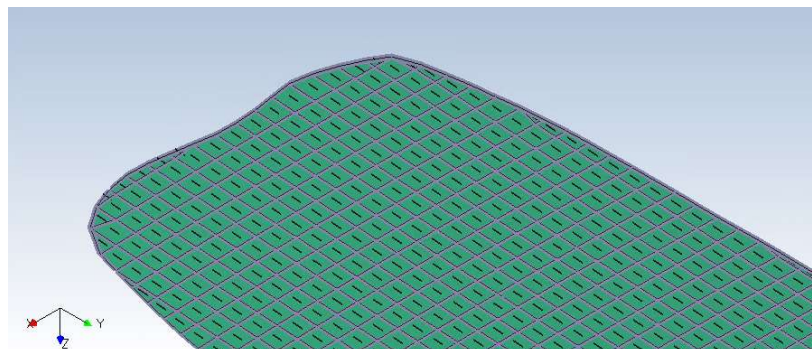


Figure 16 - Vector Orientation

After applying the CFRP properties and layer configuration, a second analysis was run, and a deflection of 230mm and a mass of 2kg were determined (Figures 17 and 18).

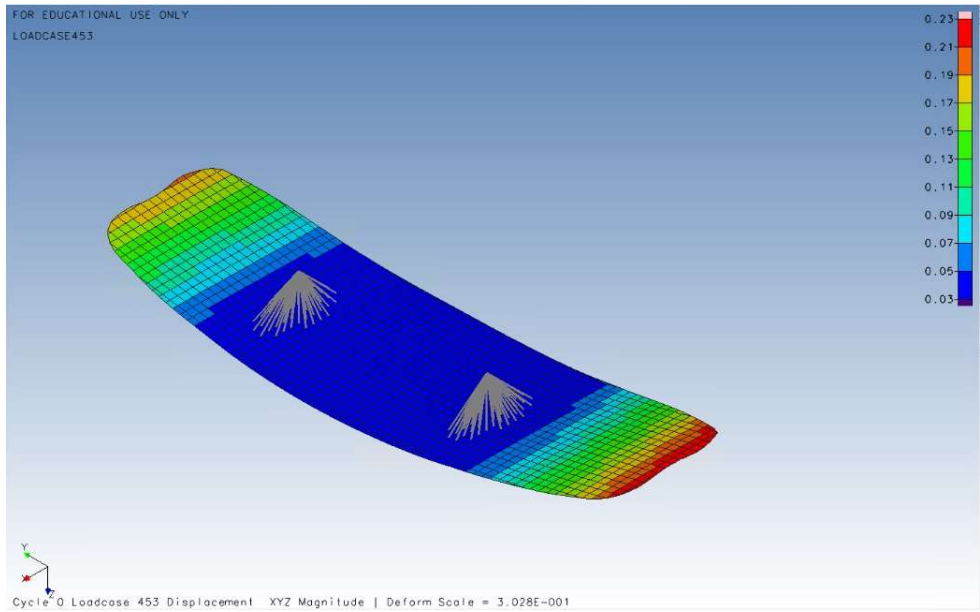


Figure 17 - CFRP Optimised Deflection.

For 1393 selected elements:  
 Volume Sum = 0.00131522, Min = 0.000000, Max = 1.19791e-06, Avg = 9.44164e-07  
 Mass Sum = 2.02544, Min = 0.000000, Max = 0.00184478, Avg = 0.00145401

Figure 18 - CFRP Mass

### 3.2.1 Analysis.

The figures were tabulated, and the stiffness-to-weight ratio was calculated and compared to the baseline steel material (Table 2).

Table 2 - CFRP Optimisation Values

| Simulation      | Material | Thickness (mm) | Deflection (mm) | Mass (kg) | Load (N) | Stiffness (N/mm) | Stiffness/Weight Ratio (N <sup>2</sup> /mm) |
|-----------------|----------|----------------|-----------------|-----------|----------|------------------|---------------------------------------------|
| Steel_Kiteboard | Steel    | 2.00           | 59              | 8.1       | 1462     | 24.8             | 0.31                                        |
| CFRP_Kiteboard  | CFRP     | 2.50           | 230             | 2.03      | 1462     | 6.4              | 0.32                                        |

As can be seen in the results, the CFRP has achieved a 75% reduction in weight, but this has resulted in a 290% increase in the deflection. A comparison of these figures highlights that CFRP has no stiffness-to-weight ratio advantage over the steel kiteboard.

Further review of Figure 17 highlights that the deflection occurs at one end of the board due to the restraints (foot clips) being slightly off-centre, which is confirmed by the number of grids on either side of the simulated restaurants.

It was anticipated that the thickness of the material would be increased and allocated to the plies in the y-axis ( $0^\circ$ ) using optimisation to reduce the deflection in line with the steel deflection.

### 3.3 CFRP Optimisation One.

Optimisation of the CFRP layers was completed by orientating the thickness of each layer efficiently to achieve a better stiffness-to-weight ratio.

The following parameters were stipulated:

**Objective:** Minimise mass. **Constraint:** Limit deflection to 59mm. **Design Variables:** Apply design variable to 5 layers (Figure 19).

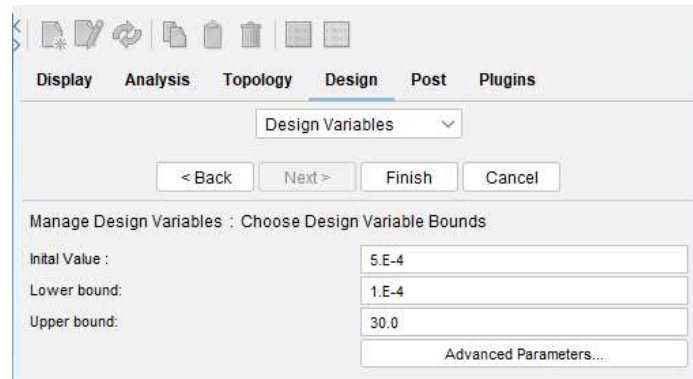


Figure 19 - Layer Variables

The optimisation was run on the CFRP kiteboard with all the optimisation parameters set, the third analysis produced a deflection of 57 mm (Figure 20), and a mass of 2.72 KG were achieved.

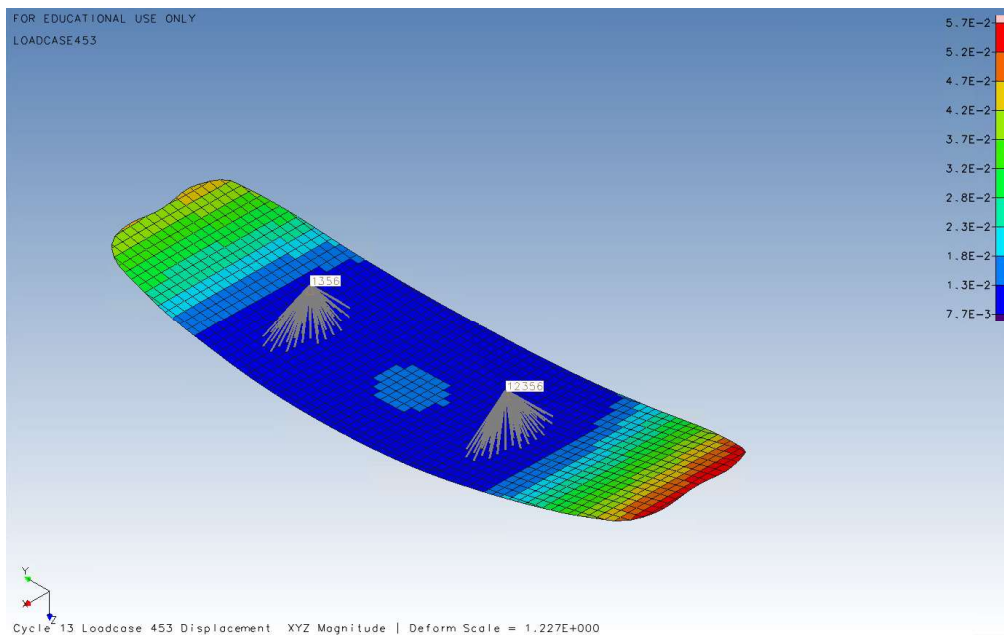


Figure 20 -

### 3.3.1 Analysis.

The figures were tabulated, and the stiffness-to-weight ratio was calculated and compared to the baseline Steel material (Table 3).

Table 3 – Optimisation One.

| Simulation           | Material | Thickness (mm) | Deflection (mm) | Mass (kg) | Load (N) | Stiffness (N/mm) | Stiffness/Weight Ratio (N <sup>2</sup> /mm) |
|----------------------|----------|----------------|-----------------|-----------|----------|------------------|---------------------------------------------|
| Steel_Kiteboard      | Steel    | 2.00           | 59              | 8.1       | 1462     | 24.8             | 0.31                                        |
| CFRP_Kiteboard       | CFRP     | 2.50           | 230             | 2.03      | 1462     | 6.4              | 0.32                                        |
| CFRP_Kiteboard_Opt_1 | CFRP     | 3.35           | 57              | 2.72      | 1462     | 25.6             | 0.96                                        |

Optimisation 1 achieved a 200% increase in stiffness-to-weight ratio by reducing the deflection by 75% while raising the initial CFRP weight by 33%, a slight increase considering the steel weight of 8.1 KG.

As can be seen from the information outputs (Figures 21 & 22), the optimisation violated the constraint initially at design cycle 0, when the mass was at its base value; as mass was added to the material via extra thickness, the constraint was returned to its goal of 0% violation at cycle 2. The fibres were then optimised over cycles 2-13 to reduce the mass to its final value of 2.7 kg.

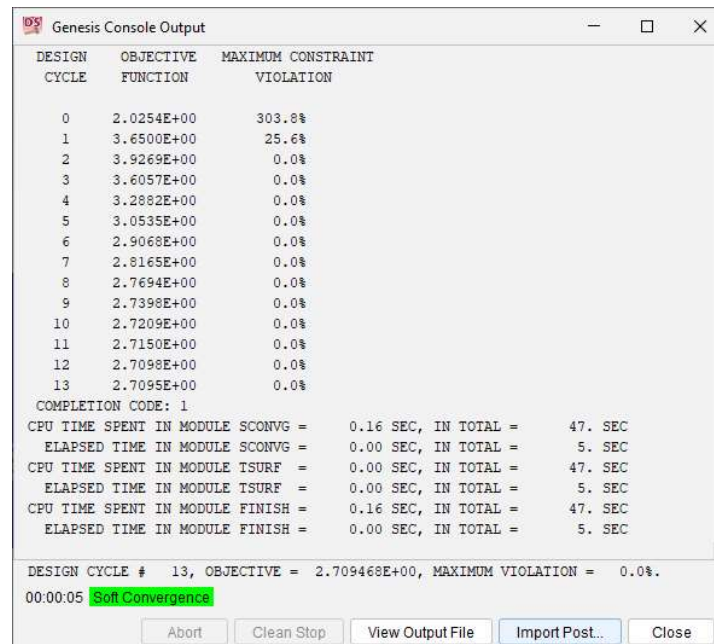


Figure 21 - Optimisation Report.

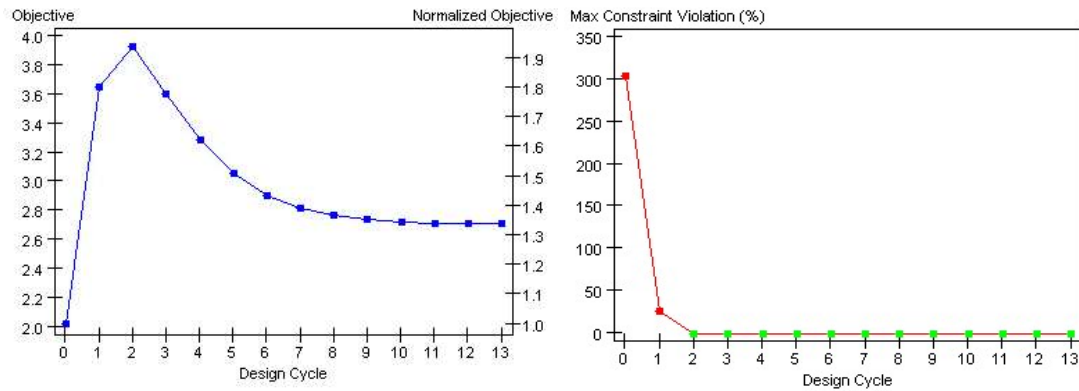


Figure 22 - Objective & Constraint Graphs.

As shown in Figure 23, all plies started at 0.5mm. The plies highlighted in green are positioned at  $0^\circ$ , which is lengthwise along the board in the y-axis. This orientation requires more stiffness compared to other orientations. As a result, the plies at  $0^\circ$  have increased in thickness to approximately 2.9 mm, while all other orientations have decreased to a minimum.

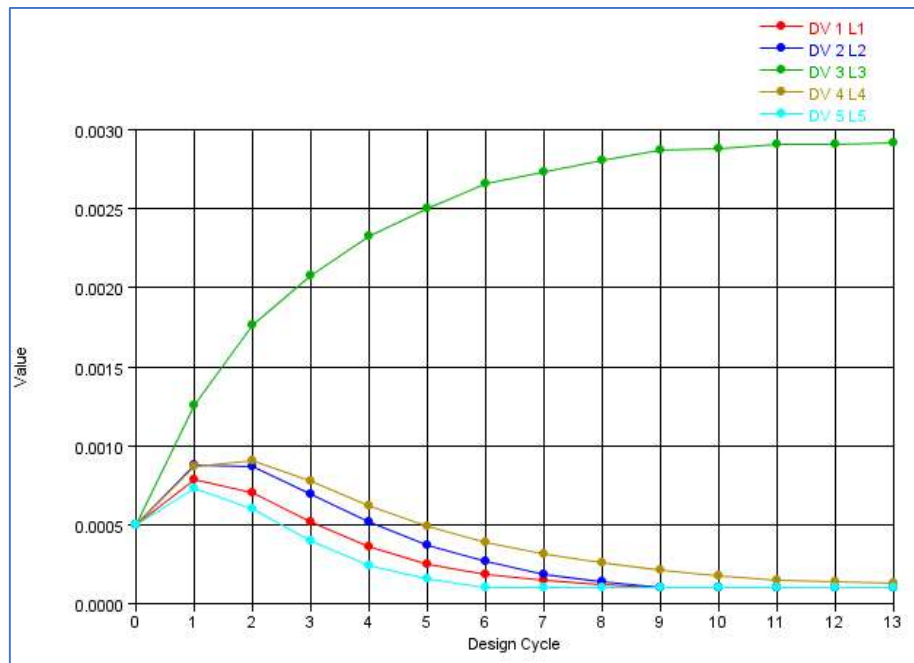


Figure 23 - Design History

Design studio outputs contain a history file that can be evaluated to analyse the design variables, objectives, and constraints in depth at each cycle.

Design cycle 0 (Figure 23) shows that the maximum violation to the deflection constraint was 303.8%, the minimise weight objective was as per the pre-optimisation weight, and each layer measured 0.5mm thickness.

```

DESIGN CYCLE #      0, OBJECTIVE =  2.025439E+00, MAXIMUM VIOLATION = 303.8%.
DESIGN VARIABLE #    1 =  5.000000E-04      L1
DESIGN VARIABLE #    2 =  5.000000E-04      L2
DESIGN VARIABLE #    3 =  5.000000E-04      L3
DESIGN VARIABLE #    4 =  5.000000E-04      L4
DESIGN VARIABLE #    5 =  5.000000E-04      L5

```

*Figure 24 - Design Cycle 0.*

Design cycle 13 (Figure 25) shows the objective has increased, but the violation has returned to 0% and now matches the steel baseline displacement. To achieve these results, design cycle 13 has attributed 2.9mm thickness to layer 3, where the fibres are orientated down the length of the board in the y-axis. The total thickness of the layers = 3.35 mm (0.1+0.1+2.92+0.13+0.1)

```

DESIGN CYCLE #      13, OBJECTIVE =  2.709468E+00, MAXIMUM VIOLATION =   0.0%.
DESIGN VARIABLE #    1 =  1.000000E-04      L1
DESIGN VARIABLE #    2 =  1.000000E-04      L2
DESIGN VARIABLE #    3 =  2.918582E-03      L3
DESIGN VARIABLE #    4 =  1.257157E-04      L4
DESIGN VARIABLE #    5 =  1.000000E-04      L5

```

*Figure 25 - Design Cycle 13*

To determine the amount of ply's in each layer, the following results were gathered:

```

DESIGN VARIABLE #    1 = 1.000000E-04  L1 = 1 ply @ -90°
DESIGN VARIABLE #    2 = 1.000000E-04  L2 = 1 ply @ -45°
DESIGN VARIABLE #    3 = 2.918582E-03  L3 = 29.2 ply's @ 0
DESIGN VARIABLE #    4 = 1.257157E-04  L4 = 1.3 ply's @45
DESIGN VARIABLE #    5 = 1.000000E-04  L5 = 1 ply @90

```

Analysis of these results highlighted a significant issue with optimisation 1: the CFRP material chosen in this simulation comprises 0.1mm thick ply's. As seen in layers 3 and 4, the optimisation has selected unrealistic thicknesses for these layers, which could not be manufactured using 0.1mm ply's. To alleviate this issue, a second optimisation was run using discrete values for the layer thicknesses.

### 3.4 CFRP Optimisation Two.

Using the discrete design variable settings (Figure 26), the layer thicknesses could be restricted to increments of 0.1mm, allowing manufacturable layer thickness to be output in the optimisation. Objectives and constraints were kept at the original values.

The screenshot shows the 'Design Variables' dialog box in a software interface. The 'Design' tab is selected. The 'Design Variables' dropdown is set to 'Design Variables'. The 'Manage Design Variables : Choose Discrete Variable Bounds' section is active. It includes fields for 'Initial Value' (5.E-4), 'Lower bound' (1.E-4), and 'Upper bound' (30.0). There are buttons for '< Back', 'Next >', 'Finish', and 'Cancel'. Below these are sections for 'Generate Discrete Values' with fields for 'First Discrete Value', 'Increment', and 'Num. of additional values', and a 'Generate & Add Values' button. A list of discrete values is shown, ranging from 1.E-4 to 0.0015. The 'Number of Discrete Values' is 30. The status bar at the bottom indicates 'Editing ID=1 L1 I=5.E-4'.

| Discrete value: | Value  | Remove |
|-----------------|--------|--------|
| Discrete value: | 1.E-4  | -      |
| Discrete value: | 2.E-4  | -      |
| Discrete value: | 3.E-4  | -      |
| Discrete value: | 4.E-4  | -      |
| Discrete value: | 5.E-4  | -      |
| Discrete value: | 6.E-4  | -      |
| Discrete value: | 7.E-4  | -      |
| Discrete value: | 8.E-4  | -      |
| Discrete value: | 9.E-4  | -      |
| Discrete value: | 0.001  | -      |
| Discrete value: | 0.0011 | -      |
| Discrete value: | 0.0012 | -      |
| Discrete value: | 0.0013 | -      |
| Discrete value: | 0.0014 | -      |
| Discrete value: | 0.0015 | -      |

Figure 26 – Discret Design Variables.

Optimisation two produced a deflection of 49 mm and achieved a mass of 3.0 KG (Figure 27),

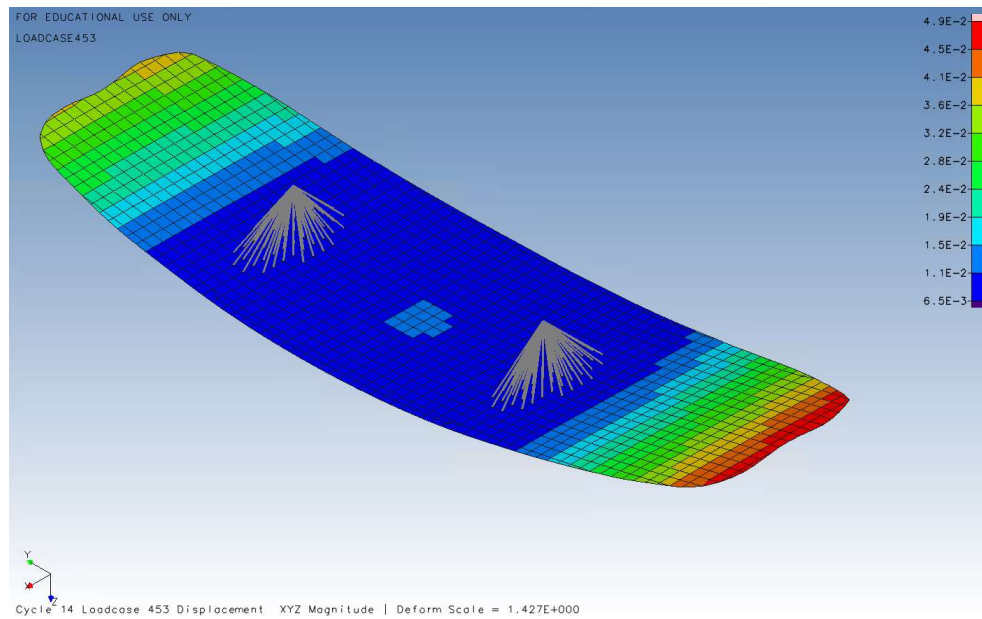


Figure 27

### 3.4.1 Analysis.

The figures were tabulated (Figure 4) and compared with optimisation one.

Table 4 – Optimisation Two.

| Simulation           | Material | Thickness (mm) | Deflection (mm) | Mass (kg) | Load (N) | Stiffness (N/mm) | Stiffness/Weight Ratio (N <sup>2</sup> /mm) |
|----------------------|----------|----------------|-----------------|-----------|----------|------------------|---------------------------------------------|
| Steel_Kiteboard      | Steel    | 2.00           | 59              | 8.1       | 1462     | 24.8             | 0.31                                        |
| CFRP_Kiteboard       | CFRP     | 2.50           | 230             | 2.03      | 1462     | 6.4              | 0.32                                        |
| CFRP_Kiteboard_Opt_1 | CFRP     | 3.35           | 57              | 2.72      | 1462     | 25.6             | 0.96                                        |
| CFRP_Kiteboard_Opt_2 | CFRP     | 3.70           | 49              | 3         | 1462     | 29.8             | 1.01                                        |

The board weight has increased by 10 %, resulting in a 14% decrease in the deflection. The

The optimised CFRP board now exhibits a stiffness-to-weight ratio of 1.0 N<sup>2</sup>/mm.

Figures 28 and 29 show that the objectives and constraints have been met. The board weight is 3 kg, and deflection has been reduced to 49mm through optimisation.

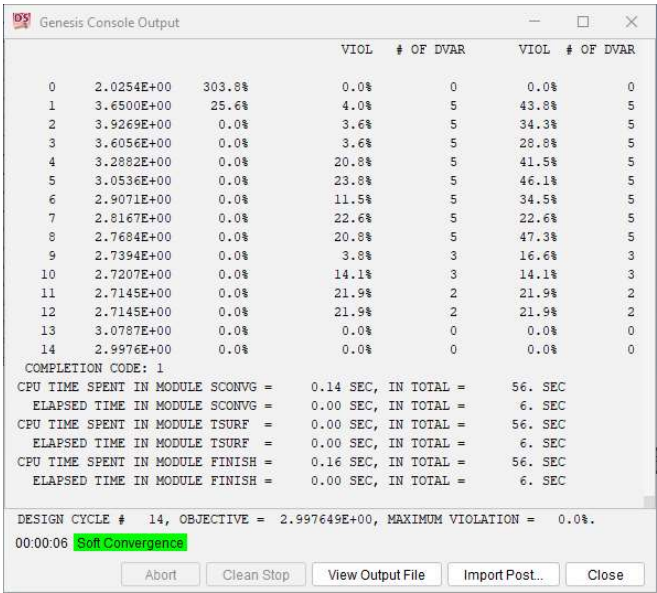


Figure 28 - Optimisation Report.

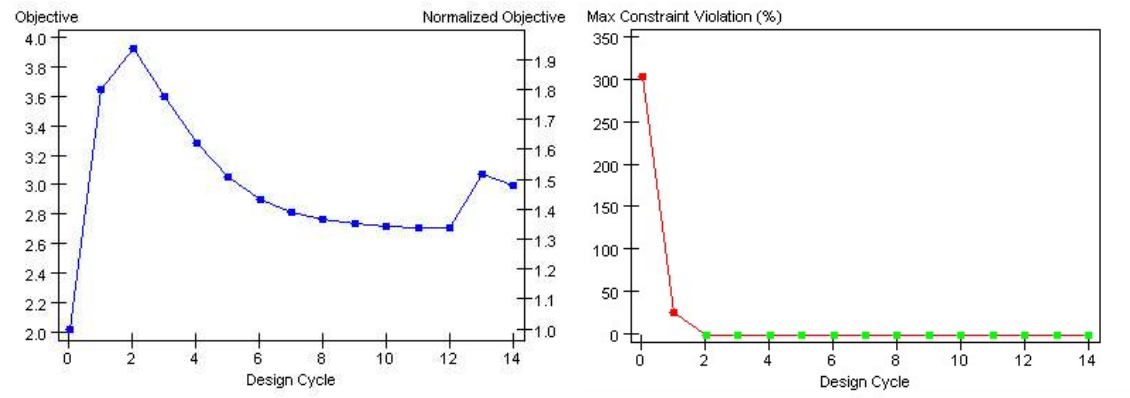


Figure 29 - Objective & Constraint Graphs.

Further analysis of the history file shows the lay-up of the plies:

```
DESIGN CYCLE # 14, OBJECTIVE = 2.997649E+00, MAXIMUM VIOLATION = 0.0%.
DESIGN VARIABLE # 1 = 2.000000E-04 L1
DESIGN VARIABLE # 2 = 2.000000E-04 L2
DESIGN VARIABLE # 3 = 2.900000E-03 L3
DESIGN VARIABLE # 4 = 2.000000E-04 L4
DESIGN VARIABLE # 5 = 2.000000E-04 L5
COMPLETION CODE: 1 12 0
```

The lay-up now consists of:

DESIGN VARIABLE # 1 = 2.000000E-04 L1 = 1 ply's @ -90°

DESIGN VARIABLE # 2 = 1.000000E-04 L2 = 1 ply's @ -45°

DESIGN VARIABLE # 3 = 2.900000E-

03 L3 = 29 ply's @ 0

DESIGN VARIABLE # 4 = 2.000000E-04 L4 = 2 ply's @45

DESIGN VARIABLE # 5 = 2.000000E-04 L5 = 2 ply's @90

The total thickness of the layers is 3.7 mm (0.2+0.2+2.9+0.2+0.2), and the discrete design variables have now enabled the optimisation to output manufacturable ply thicknesses.

The overall comparison of results shows that optimisation one was theoretically more desirable. Despite manufacturing constraints, optimisation two still achieved a 226% increase in the stiffness-to-weight ratio for the CFRP board.

## 4 Simulation Validation Testing.

A testing method was devised to validate the simulation results output by Genesis Design Studio; the test will record the results for displacement and strain exerted on the board after a UDL of 1464 N is applied; the data collected will be used to analyse and compare to the simulation results:

### 4.1 Testing Specification.

**Kiteboard:** Dimensions and material properties to match simulation properties.

**Supports:** A purpose-made structure is to be fabricated to support the kiteboard at foot clip locations.

**Force/Loading:** A UDL (uniformly distributed load) is to be evenly distributed across the board.

Simulation force = 1464 N

1 N = 0.1019716213 KG F

Therefore, the load requirement = 149 KG F

**Deflection Measurement:** Digital or mechanical measurement instruments to capture test measurements.

**Data Collection Software:** Collect data electronically from the strain gauges and deflection sensors.

**Data Analysis:** Compare data collected from testing to simulation using a computer.

### 4.2 Support Structure:

Construct a steel structure using steel sections to effectively withstand the forces of the uniform distributed load (UDL). Ensure the structure has a sufficient foundation to guarantee stability. Add support beams at the kiteboard clip locations to counteract the UDL and provide the necessary reaction forces (Figure 32).

### 4.3 Load Application.

Application of the UDL to be applied by either of the following methods:

#### 4.3.1 Sandbags:

Applying purpose-made sandbags that mimic the UDL across the board shall be suitable for a lower-budget test. A potential issue is the uneven distribution of load, which could affect results.

#### 4.3.2 Airbags:

Using an airbag system to achieve a more even load distribution will have cost implications and further complicate the support structure to incorporate the airbag unit.

#### 4.4 Measurement.

The central aspect of the test is measuring the deflection, which shall be carried out using either of the following methods.

##### **Deflection Gauges**

Deflection gauges should be placed at the outer edges and centre of the board. This method may limit the measurement range.



Figure 30 - (Epsilontech, 2024)

##### **Optical Displacement Sensor Node**

Optical sensor nodes shall be used for high-accuracy displacement measurement. This method can increase the cost of the test.



Figure 31 - (Senceive, 2024)

#### 4.5 Data Analysis.

Results shall be collected electronically through digital measurement, as listed previously and linked to a computer where they will be recorded.

All data shall be tabulated into a spreadsheet to compare the results to the simulation.

#### 4.6 Proposed Setup.

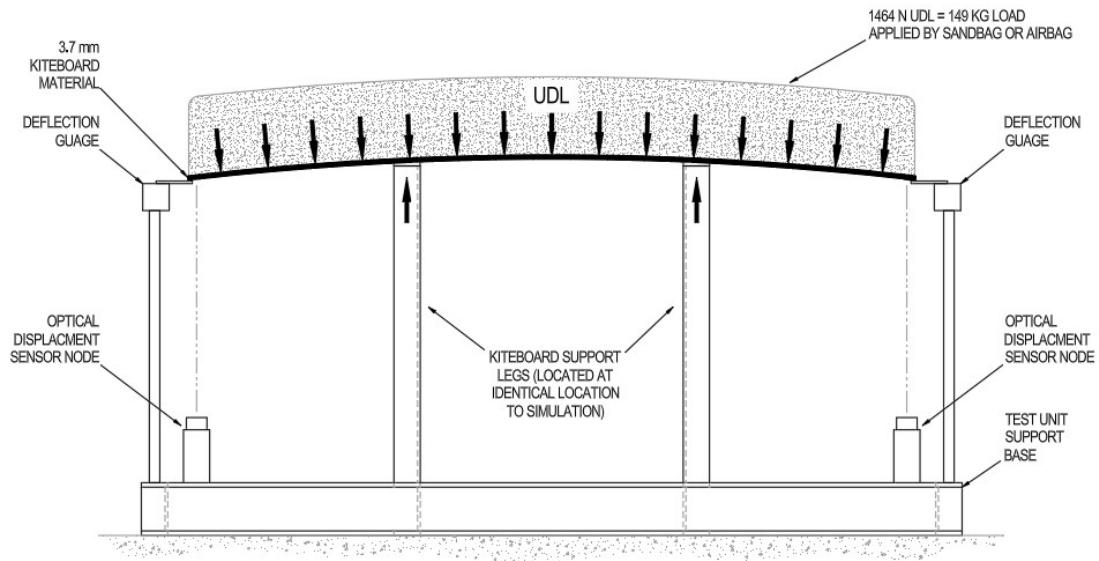


Figure 32 - Test Unit Setup

## 5 Conclusion.

Design optimisation has become a widely used tool for enabling product designers to maximise performance goals while minimising material usage and cost. Optimisation can give designers insight into how different parameters affect a design and where the balance in the final product properties lies.

Optimisation can present several challenges. If the inputs used during the optimisation process are inaccurate or not well-defined, the resulting designs may not be feasible for production through traditional manufacturing methods. This can increase production costs, as adjustments or alternative methods may be required to make the designs viable. In the most severe cases, it is possible to create an entirely impractical design that cannot be manufactured at all. This emphasises the importance of careful input selection and thorough evaluation during the optimisation process to ensure that designs are not only innovative but also manufacturable in the real world.

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