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DESIGNING A KITEBOARD: STRUCTURAL DESIGN

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Abstract

This report focuses on the structural optimisation of a composite kiteboard using Finite Element Analysis (FEA) to enhance material efficiency while maintaining structural performance. The study involved the creation and analysis of a carbon fibre-reinforced plastic (CFRP) kiteboard, comparing its deflection and mass properties against a steel baseline model. Initial findings revealed significant weight reduction in the composite model but excessive deflection. A series of optimisation cycles were conducted, refining ply orientations, boundary conditions, and layer thicknesses to achieve a model that met the deflection criteria while maintaining manufacturability. The iterative optimisation process demonstrated that adjustments in composite layup can effectively balance weight, stiffness, and deflection.

Additionally, the study highlighted the evolution of FEA from its origins to present-day Artificial Intelligence (AI)-integrated tools, emphasising advancements in CAE approaches that reduce design times and errors. Practical validation of simulation results through controlled experimentation, such as three-point bending tests, is proposed to ensure alignment with real-world performance. The research underscores the importance of combining theoretical analysis with empirical validation to refine engineering models and optimise composite structures.

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Introduction

This report examines the structural optimisation of a composite kiteboard using Finite Element Analysis (FEA) methodologies to enhance material efficiency while maintaining performance standards. Building upon the preliminary analyses from prior coursework, this task requires modelling and optimising a kiteboard constructed from unidirectional carbon fibre-reinforced plastic (CFRP). The primary objective is to ensure that the board's deflection remains equivalent to that of a 2mm steel board under comparable load conditions, achieved through a strategic layup that minimises weight without compromising structural integrity. This assignment necessitates thoroughly applying FEA optimisation techniques, including accurately modelling boundary conditions, applied forces, and ply orientations. To support this, engagement is shown with both historical and contemporary optimisation methods in FEA, analysing their development and impact on the engineering design process and exploring future directions for this technology. Additionally, this report emphasises practical application through the iterative refinement of the model, culminating in an experimental validation phase to assess deformation under controlled laboratory conditions and compare these findings with simulation results.

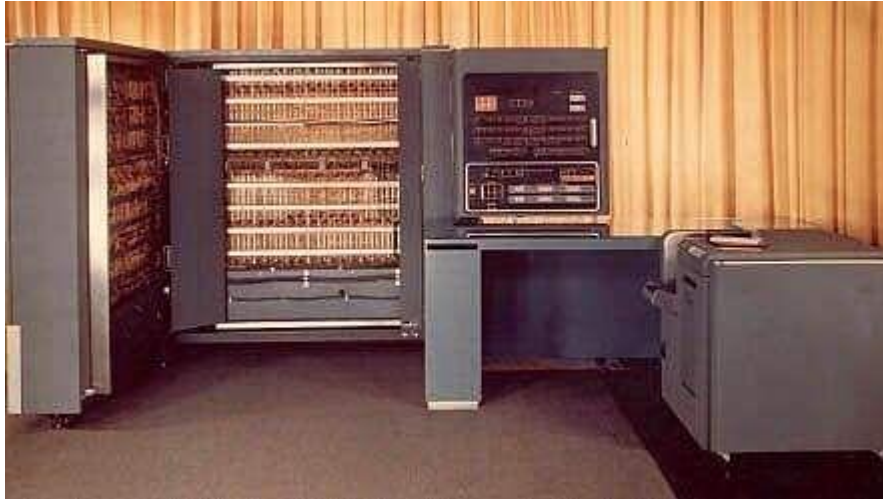
Finite Element Analysis optimisation techniques and their historical developments

FEA development 1940-1970's

Finite Element Analysis (FEA) optimisation techniques have significantly developed since their inception during the mid-20th century and are ever-evolving due to the need to address more complex engineering requirements. FEA optimisation aims to refine a component design to ensure the specification is met while optimising differing elements for efficiency (Mottram et al., 1996).

The mathematical foundation of FEA optimisation can be traced back to the 1940s with work by Alexander Hrennikoff and Richard Courant (Liu et al., 2022), where they posed alternate theories for solving structural mathematical problems by applying theoretical mesh structures to mechanical assemblies. Although this work influenced later research, it was not until the early 1950s that Ray Clough and John Turner applied FEA in the structural analysis of aircraft wings (Castro, 2016). Clough continued his research during the 1960s and developed a program to study FEA phenomena further (Mueller, 2024). Digital computers (as shown in Fig 1) were first used here, allowing for the opportunity to solve finite element problems using a matrix algebra program developed by Clough (Madier, 2024).

Figure 1 IBM 701 computer used by Ray Clough for FEM Calculations. Source- (Madier, 2024)



Between the mid-1960s and late 1970s, FEA optimisation software emerged, such as NASA Structural Analysis (NASTRAN)(Nagy, 2024), ANSYS(Mueller, 2024) and ABAQUS (Madier, 2024). These softwares provided engineers with a simulation solution for structural behaviour in applications such as the aerospace and automotive industries (Liu et al., 2022). They focussed primarily on fundamental sensitivity analyses of the component's structure (Mottram et al., 1996). This was achieved by manually modifying input parameters such as material properties, boundary conditions, and material loads, and the results of the calculations suggested possible design enhancements that could be achieved (Nam, 2010). This process would then involve creating a physical model of the component, testing it in real-world applications and then redesigning it on a trial-and-error basis (Altair, 2021).

FEA and Computer Aided Design (CAD) intergration 1980's-2000's

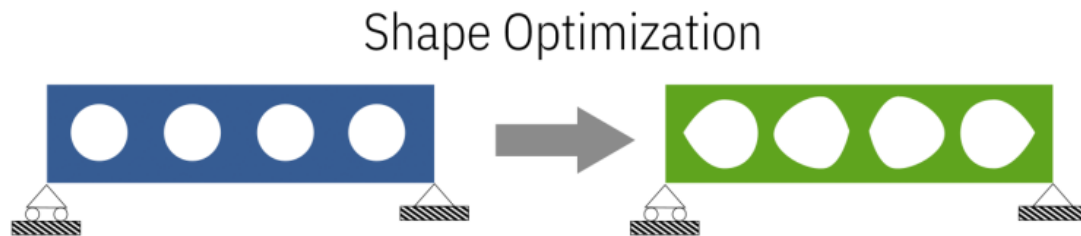
The 1980s saw the first introduction of Simulation FEA software sharing data transfer with CAD (Abbey, 2013) (as shown in Fig 2). This combination enabled breakthroughs in FEA optimisation, which expanded during the 1990s (Wu et al., 2021) (Bremicker et al., 1991), where algorithm-based optimisation techniques such as shape, topology, and size optimisation emerged. At this stage, optimisation was driven by CAD models, where designs were drafted before being optimised. These developments ultimately allowed engineers to automatically refine the geometry of components within specified boundaries to optimise elements of their structure.

Figure 2- Image of a digitising tablet used to create a nodal mesh for FEA CAD integration. Source- (Abbey, 2013)



Shape optimisation involves the selection of an optimal structural geometry to improve targeted mechanical performance within given constraints (Altair, 2021)(shown in Fig 3). Automated design optimisation tools enabled engineers to explore innovative solutions, particularly for problems involving numerous design variables (Burman et al., 2018). These tools evaluate the impact of modifying a wide array of design parameters, including simple dimensional adjustments and comprehensive shape changes. Shape optimisation integrates linear and nonlinear finite element analyses, providing adaptable solutions for complex design challenges(Duan and Sheppard, 2002).

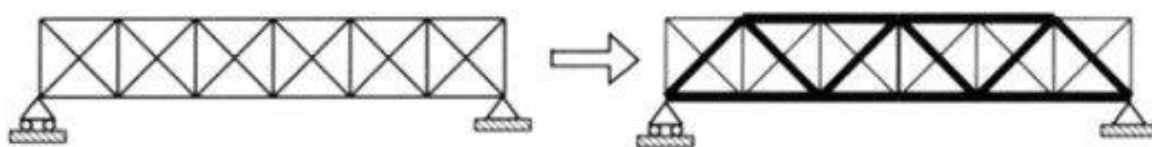
Figure 3- Representative example of changes possibly achieved using shape optimisation. Source- (Ishchuk, 2022)



Topology optimisation reduces the amount or redistributes material within component design while maintaining mechanical strength (Sehmi et al., 2018). Optimised structures typically offer lighter and stiffer structures (as shown in Fig 4) where the component structure is reinforced in areas where strain forces are concentrated (Tsavdaridis, 2015). Leveraging FEA to test optimised designs further with differing loads and boundary conditions allowed for effective determination of design feasibility.

Finally, size optimisation defines ideal component parameters, such as material values, cross-sectional dimensions and thicknesses (Nagy et al., 2010). It is used to determine the ideal thickness of a material based on the performance goals and the forces expected to be placed on the component during its life (Ishchuk, 2022). In an optimisation process, these tools estimate the effects of numerous modifications to the design parameters and suggest dimensional changes. Overall, this method effectively reduces the weight of the design while yielding manufacturable designs, contributing to cost-effective and high-performance solutions.

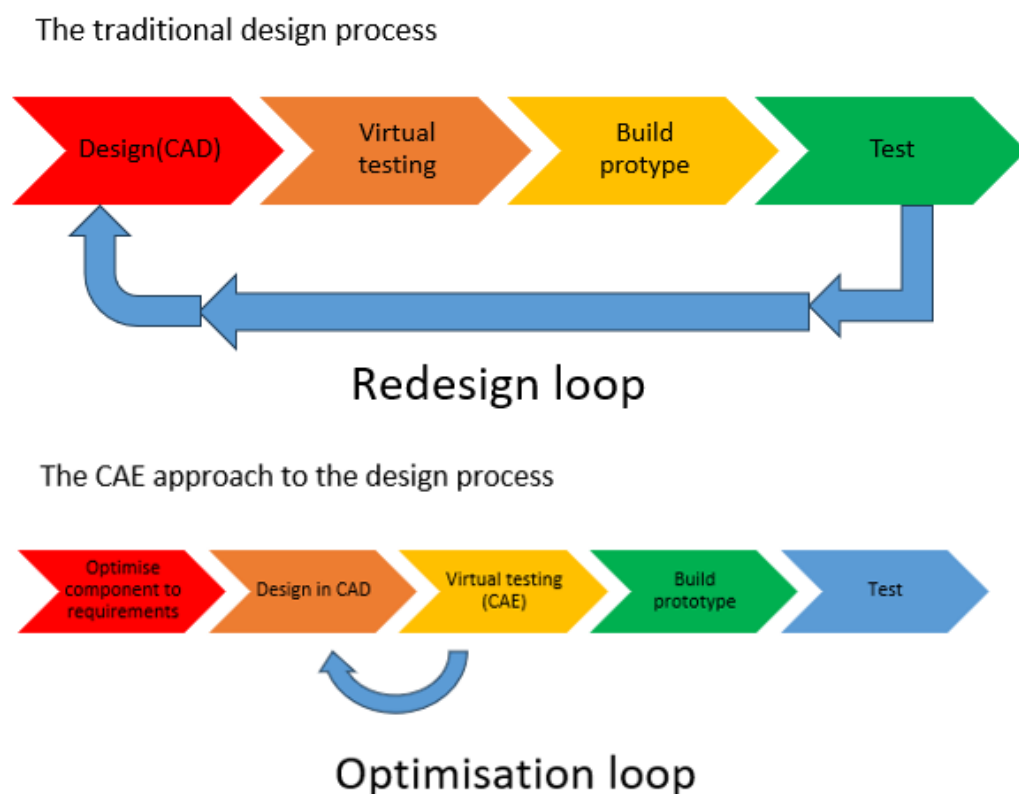
Figure 4- Representative display of changes in structural beam thicknesses after size optimisation. Source-(Tsavdaridis et al., 2015)



Computer Aided Engineering (CAE) approach 2000's- present day

Evidence suggests that the design process can be streamlined and sped up by using a CAE as opposed to a CAD-driven approach due to a reduced need for physical prototyping (Zitzewitz, 2017). Furthermore, it could be posed that a CAE-led approach to manufacturing can provide data-driven models that are more efficient than their CAD-led counterparts (VanLee, 2023). This is due to the fact that CAE can reduce errors and inefficiencies in designs, such as over-engineering, and the fact that the design and optimisation process is shortened (as shown in Fig 5).

Figure 5- A representative flow diagram of a traditional CAD-led design process versus a CAE approach. Adapted from source- (Altair, 2021)



In recent years, advancements in FEA software have incorporated artificial intelligence capabilities, such as generative design (Wu et al., 2019) and Machine Learning (ML) technologies (Kohar et al., 2021). These technologies enable the exploration of multiple design variations within constrained limits (as shown in Fig 6), allowing engineers to assess only the optimal designs, reducing the need for physical prototypes. This ultimately saves resources and time, thus improving productivity. By using optimisation techniques like these described, engineers can more effectively tailor designs to meet specific functional requirements, leading to safer, more durable, and more efficient structures.

Figure 6- Examples of generative designs of a component which have undergone topology optimisation. Source- (ProtoTechSolutions, 2022)



Looking forward, FEA optimisation is expected to continue to integrate even more closely with AI generative design (Bannerjee, 2023). Advances in cloud computing capabilities have reduced the computational load of the software, making it more accessible to engineers and encouraging wider adoption of the technology (Urankar, 2024). Additionally, cloud computing enables engineers to work together collaboratively (Modisane and Jokonya, 2021), allowing them to work concurrently on a model with engineers both nationally and internationally, further streamlining the design process.

Creating the model of the kiteboard in Design Studio

Assessing baseline kiteboard with steel characteristics

The baseline steel kiteboard model provided was first imported into the design studio to provide parameters to compare to the composite model board (shown in Fig 7). The force loadings of the board were not changed as dynamic loading was not considered correctly during the first assignment; therefore, it was decided that to gain more accurate results, the load case would remain the same. Furthermore, the results within the design studio are displayed in SI units, for clarity of results, the figures have been converted to mm. To gain the mass and the displacement of the board, a genesis analysis was run, which provided the required data, as shown in Fig 8 and 9. The analysis revealed that the displacement of the baseline steel model was 59mm and a mass of 8.1kg.

Figure 7- Image of steel baseline model of the kiteboard in design studio. Source-DesignStudio.

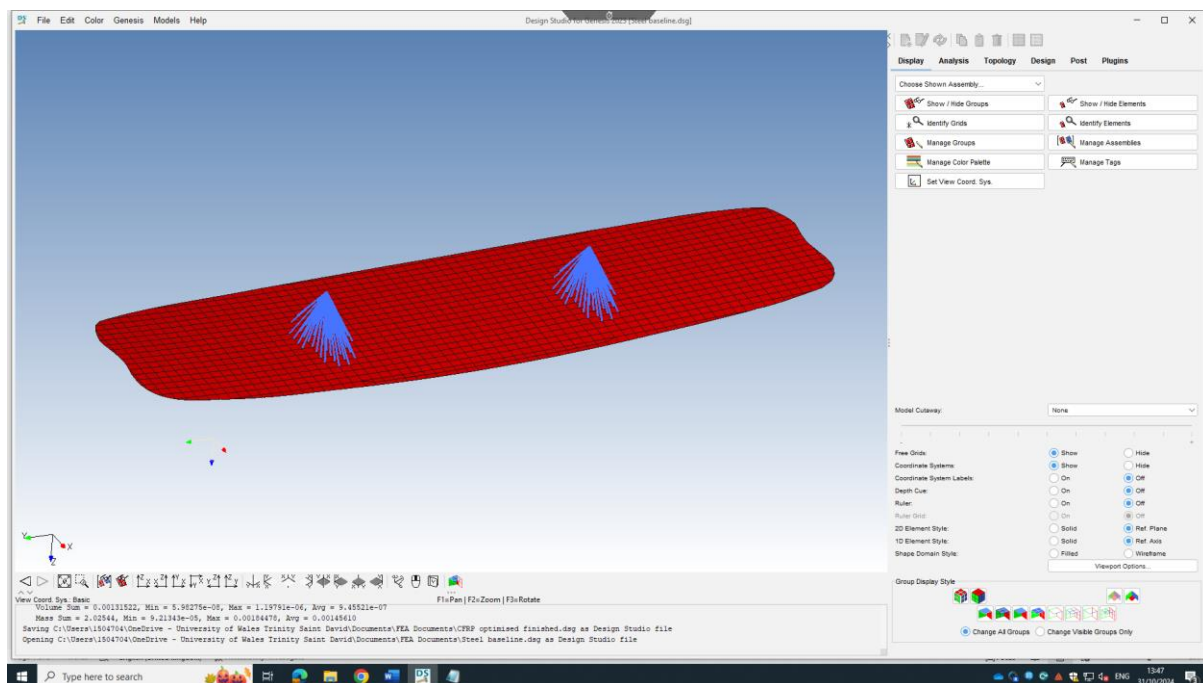


Figure 8- Image of deflection of the steel baseline kiteboard. Source-DesignStudio.

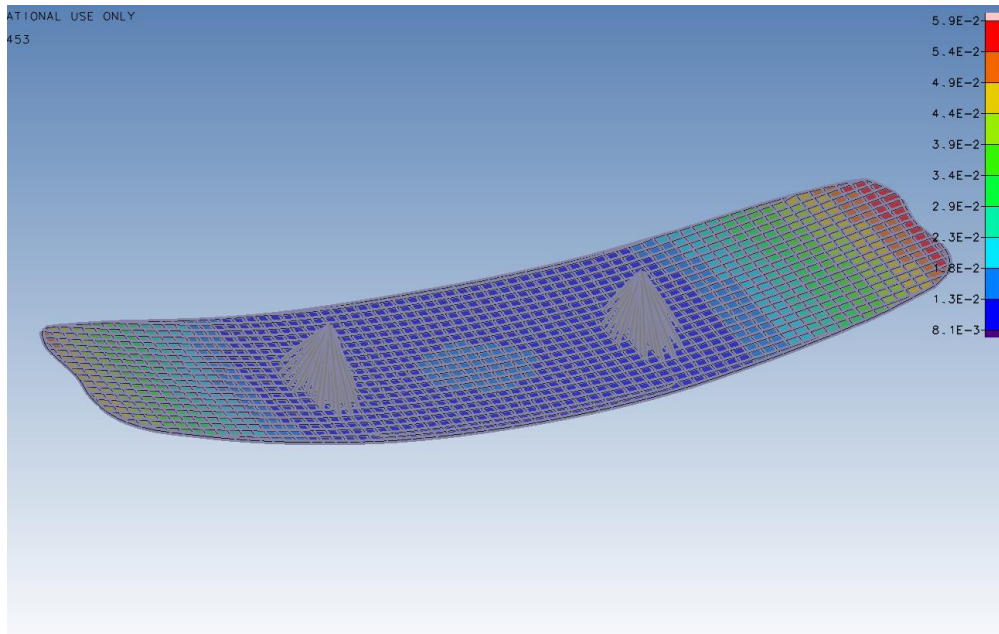


Figure 9-Image of the mass of the steel baseline kiteboard. Source-DesignStudio.

```
^ ^  
View Coord. Sys.: Basic  
Importing C:\Users\1504704\O  
For 1393 selected elements:  
    Volume Sum = 0.00105218,  
    Mass Sum = 8.10176, Min =
```

Creating a baseline kiteboard with composite characteristics

The baseline steel kiteboard was copied to allow for editing the material properties to satisfy the criteria of the baseline composite kiteboard, as shown below in Fig 10:

Figure 10-Material property requirements for orthotropic CFRP on design studio. Source-(Lake,2024)

Material properties	Relevant value
Young's Modulus in the longitudinal direction (E_1)	132 GPa
Young's Modulus in the lateral direction (E_2)	10.8 GPa
Poissons Ratio (ν_{12})	0.24
Inplane Shear Modulus (G_{12})	5.65 GPa
Transverse Shear Modulus (1-Z plane)(G_{1z})	5.65
GPa Transverse Shear Modulus (2-Z plane)(G_{2z})	5.65
GPa Mass Density (ρ)	1540 kg/m ³
Allowable longitudinal stress in tension (X_t)	1513 MPa
Allowable longitudinal stress in compression (X_c)	1000 MPa
Allowable transverse stress in tension (Y_t)	43.4 MPa
Allowable transverse stress in compression (Y_c):	43.4 MPa
MPa Allowable inplane shear stress (S)	43.4 MPa

A new orthotropic material was selected to satisfy the laminar criteria needed, then the data from Fig 10 was applied, as shown in Figures 11 and 12.

Figure 11- Image of selecting orthotropic material. Source- DesignStudio.

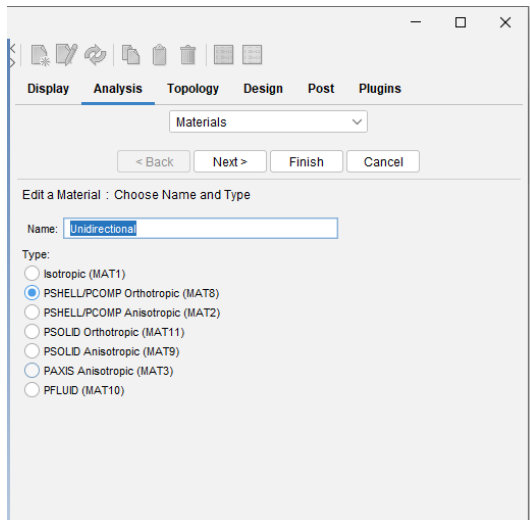
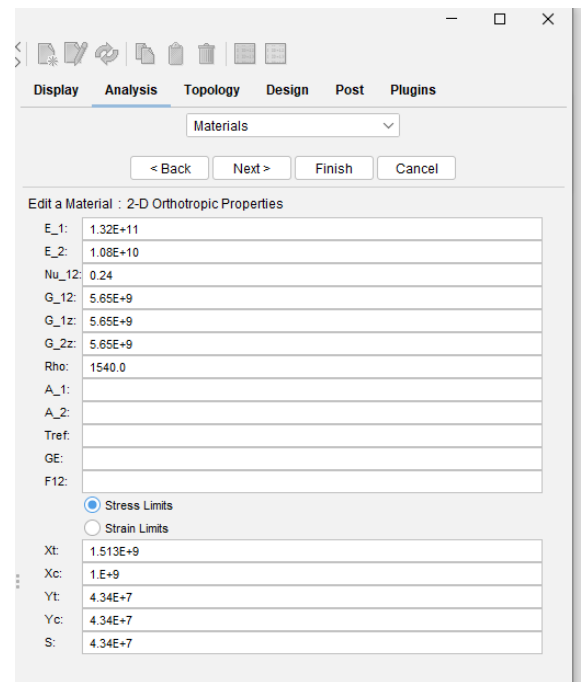


Figure 12- Entering CFRP material properties.



As the material is a laminate, it possesses differing material properties in different directions, the elements must be orientated to a relevant vector to suit the application of the kiteboard. As stipulated in the assignment brief, the vectors should be aligned at zero degrees in the longitudinal direction (Y-axis).

To achieve this, all elements of the mesh were selected, and theta vectors were generated. The global positioning default within design studio is set to the transverse direction (X-axis) (as shown in Fig 13). Two grids were selected, which can then be used to orient the elements correctly on the Y-axis.

To solve this, all elements of the mesh were selected, and theta vectors were generated. As the global positioning default within design studio is set to the transverse direction (X-axis), two grids must be selected, which can then be used to orientate the elements correctly in the Y-axis (as shown in Fig 14).

Figure 13- Image of elements misaligned. Source- DesignStudio

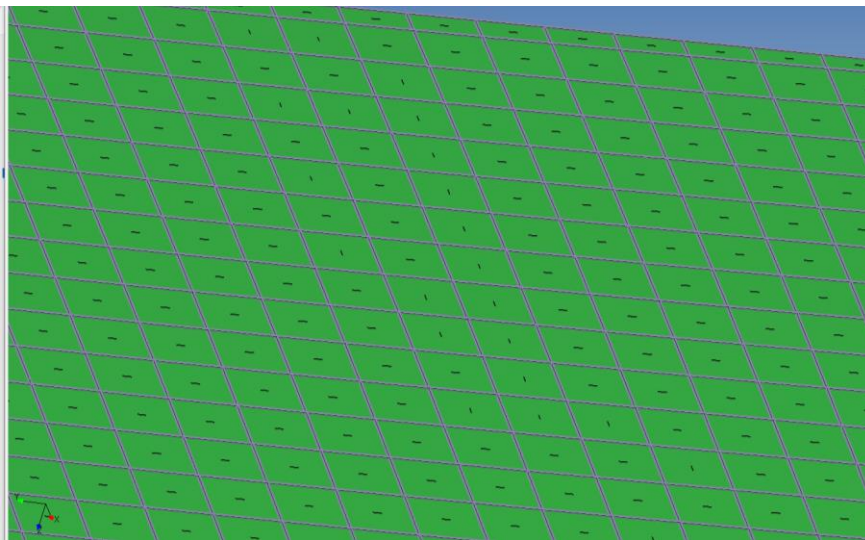
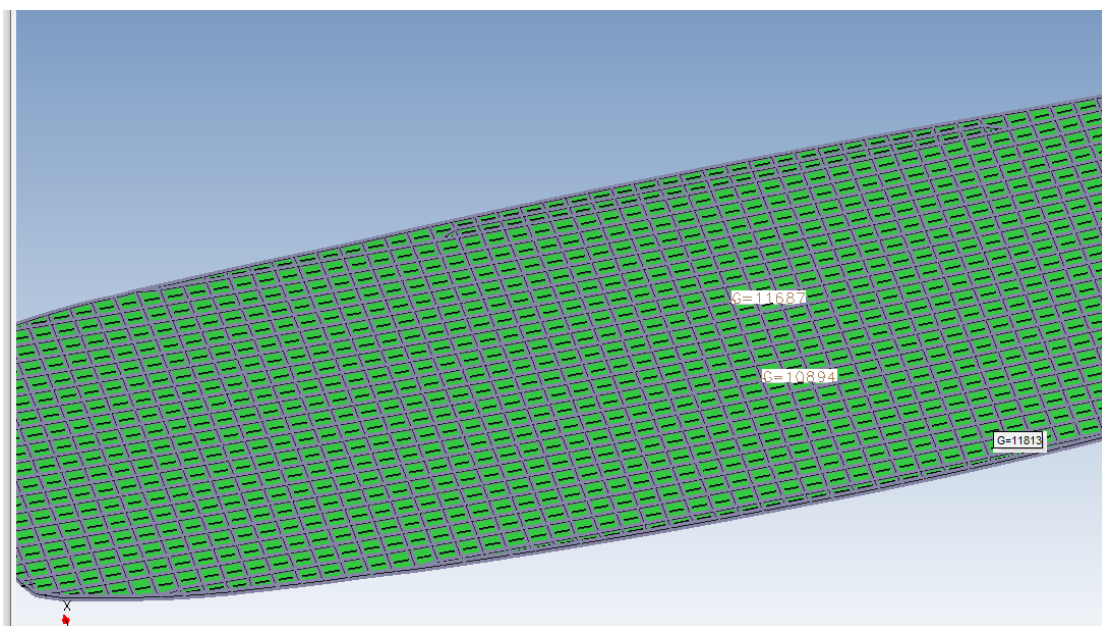


Figure 14- Image of theta vectors realigned to the Y-axis. Source-DesignStudio

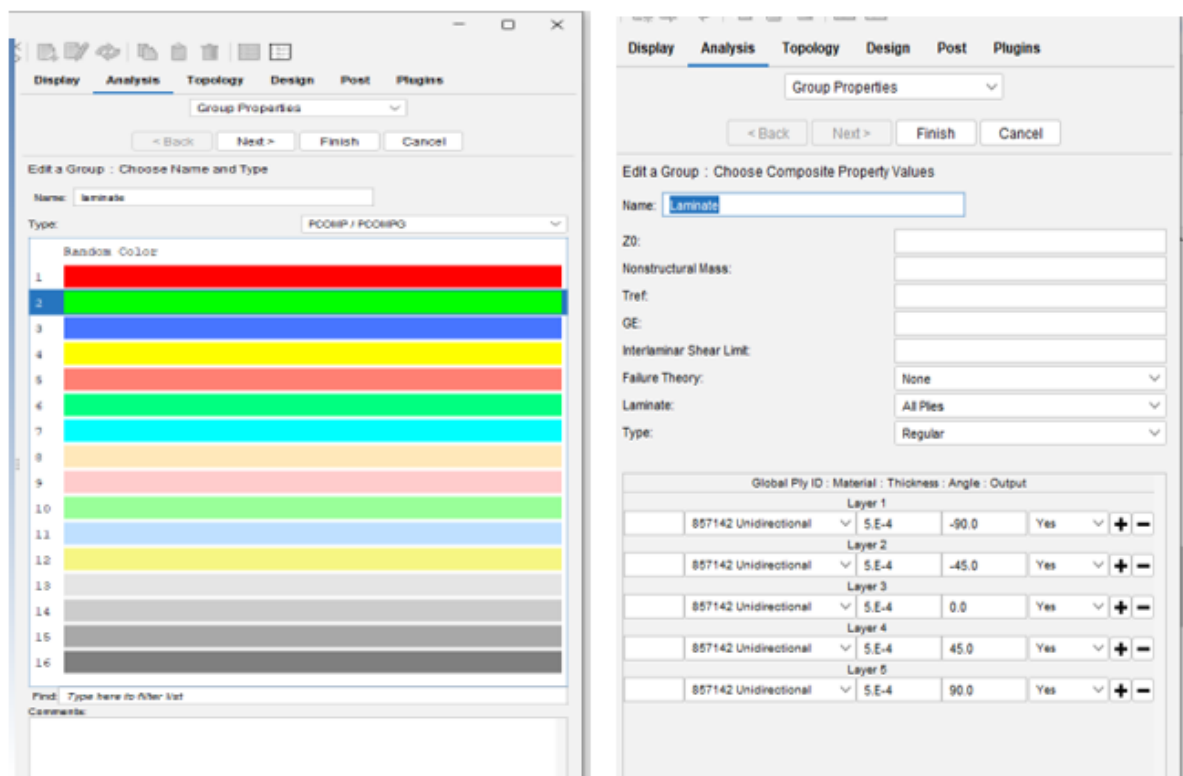


Creating the CFRP laminate layers

The next step involved setting up the laminate layers for the unidirectional material previously defined. A new group property, which is identified as a laminate, is set up (as shown in Fig 15).

This correct property type is listed as PCOMP/PCOMPG, and a colour can be selected at this point to colour the model mesh. Following this, the material for the laminate layers must be changed to unidirectional from the original steel baseline.

Figure 15- Setting up of PCOMP Laminate material. Source-DesignStudio.



The stipulated requirement of unidirectional layers is set out below in Fig 16:

Figure 16-Ply and Angular orientation criteria for CFRP kiteboard. Source (Lake,2024)

Number of plys in each layer	Layers angle of orientation with respect to the Y-axis
5	-90°
5	-45 °
5	0 °
5	45°
5	90°

At this point, the first layer properties were added. The thickness is defined as 0.5mm, as there are five plys at a thickness of 0.1mm in each laminar layer (as shown in Fig 17). The angle of layer one's orientation is changed to -90° to satisfy the requirements shown in Fig 16.

This process was then repeated four more times to set the remaining layers to their correct angular orientation, as depicted in Fig 18.

Figure 17- image of setting the parameters for the first laminate layer. Source-DesignStudio

Edit a Group : Choose Composite Property Values

Name:

Z0:

Nonstructural Mass:

Tref:

GE:

Interlaminar Shear Limit:

Failure Theory:

Laminate:

Type:

Global Ply ID : Material : Thickness : Angle : Output					
Layer 1					
	857142 Unidirectional	5.E-4	-90.0	Yes	+ -

Figure 18-Image showing the process being repeated for the remaining layers.Source-DesignStudio.

Edit a Group : Choose Composite Property Values

Name:

Z0:

Nonstructural Mass:

Tref:

GE:

Interlaminar Shear Limit:

Failure Theory:

Laminate:

Type:

Global Ply ID	Material	Thickness	Angle	Output
Layer 1				
	857142 Unidirectional	5.E-4	-90.0	Yes
Layer 2				
	857142 Unidirectional	5.E-4	-45.0	Yes
Layer 3				
	857142 Unidirectional	5.E-4	0.0	Yes
Layer 4				
	857142 Unidirectional	5.E-4	45.0	Yes
Layer 5				
	857142 Unidirectional	5.E-4	90.0	Yes

From here, the PCOMP is fully defined, although the loading elements of the PSHELL must be applied. This is to ensure that the relevant conditions, such as bending conditions, match that of the baseline steel model as provided. The original PSHELL file was then deleted as it was no longer needed to avoid possible confusion at the optimisation stage.

Analysis of the baseline composite kiteboard

A genesis analysis was applied to the model to ascertain the displacement and mass in comparison to the baseline steel kiteboard (as shown in Fig 19,20&21).

Figure 19-Image shows a completed genesis analysis. Source- DesignStudio.

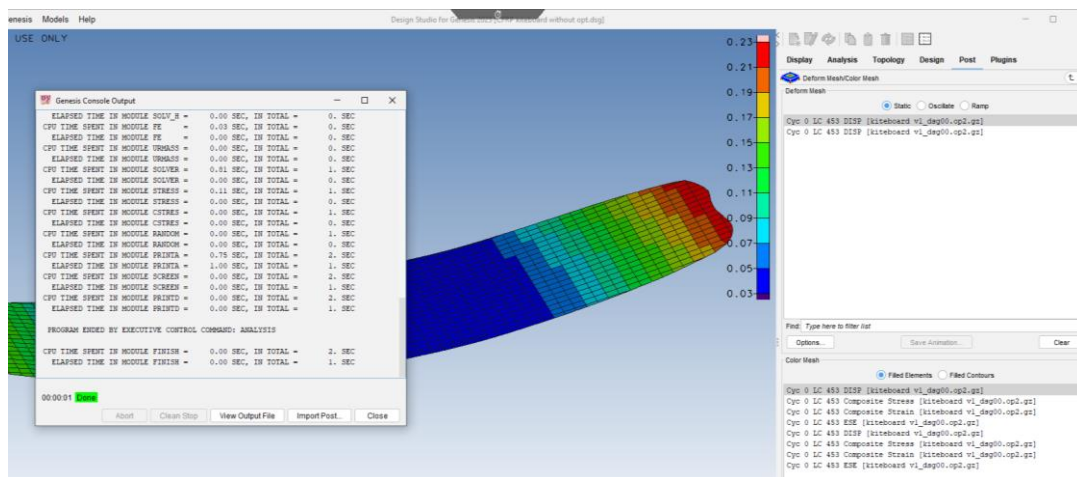


Figure 20- The image shows the deflection of the baseline composite board as 230mm. Source-DesignStudio

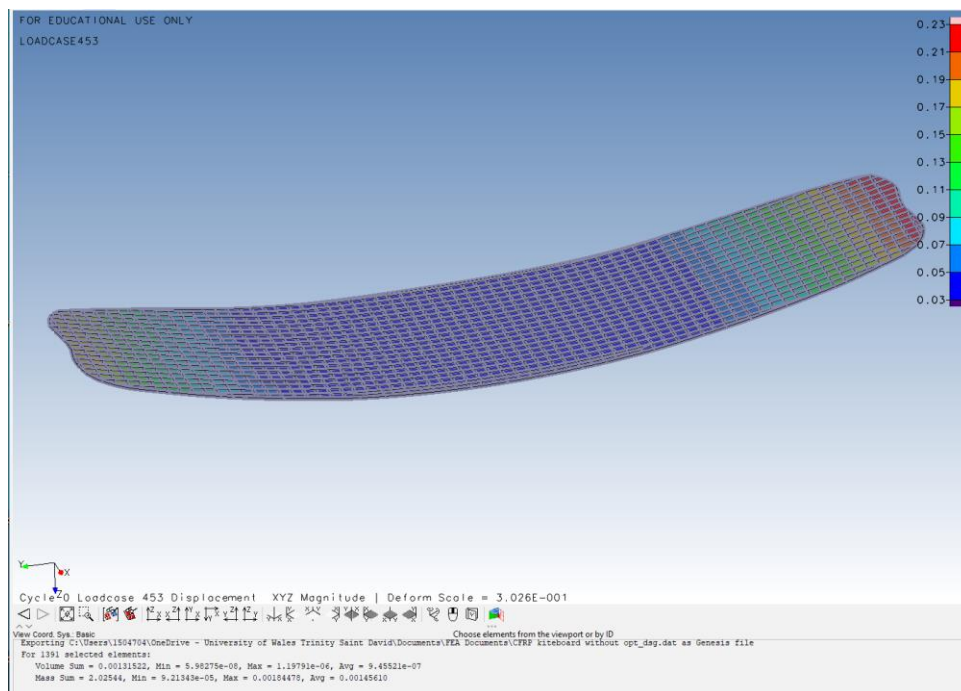


Figure 21-Image depicting the mass (2.03kg 2d.p's) of the baseline laminate kiteboard.

```
Exporting C:\Users\1504704\Documents\1504704\Baseline\Baseline.kib
For 1391 selected elements
Volume Sum = 0.00131
Mass Sum = 2.02544,
```

As shown in Fig 20, the displacement of the board is 230mm in comparison to the results gained from the steel baseline, where it deflected by 59mm. Although its displacement is far greater, there has been a significant reduction in the mass of the composite baseline against the steel model. As shown in Fig 9, the steel model's mass was 8.1kg, while the composite model comparatively weighs 2.03 kg (as shown in Fig 21). Further to this, fig 22 displays the calculations of the two baseline models' comparative stiffnesses and stiffness-to-weight ratios. As shown, the steel model is far stiffer than the composite board at this point at 24.80N/mm compared to 6.4 N/mm, although when adjusted for weight, both boards show negligible differences. Although the composite model's mass was primarily reduced, it did not fully satisfy the assignment specification applied in this case, where it was stipulated that the displacement should not exceed that of the steel baseline. For this reason, further optimisation of the model was needed.

Figure 22- table showing calculations of stiffness and stiffness/weight of the baseline steel and composite kiteboards

Component run	Material	Thickness(mm)	Deflection(mm)	Mass (Kg)	Load(N)	Stiffness(N/mm)	Stiffness/weight(N ² /mm)
Baseline Steel kiteboard	Steel	2	59	8.1	1462	24.77966102	0.311846831
Baseline composite kiteboard	CFRP	2.5	230	2.03	1462	6.356521739	0.319193833

Optimisation of the composite model using Design Studio

Setting parameters for the optimisation of the kiteboard

A copy of the baseline composite model was made to facilitate the creation of the optimised model.

An objective was set up within design studio to minimise the mass of the optimised model in comparison to the baseline composite model (shown in Fig 23). Also, a constraint was set to ensure that the displacement of the optimised kiteboard did not exceed 59mm as set out by the steel baseline model, as shown in Fig 24.

Figure 23- Image depicting the setup of an objective to reduce the mass of the kiteboard. Source-DesignStudio

Objectives

< Back Next > Finish Cancel

Edit Design Objective : Enter Name and Type

Name: Obj1

Response Type

☒ Mass Entire Model

☐ Volume Entire Model

☐ Strain Energy Entire Model

☐ Displacement

☐ Stress Selected Groups

☐ Grid Stress von Mises

☐ Failure Index Selected Groups

☐ Buckling Load Factor 1

☐ Frequency Mode Number 1

☐ Reaction Force (SPCF)

☐ Von Mises Index

☐ Synthetic Response

☐ More Response Types...

Objective Definition Switch

☐ Max

☒ Min

☐ Target 0.0

Weight 1.0

MinMax Param:

Figure 24- Image depicting setting a constraint to limit the displacement of the optimised kiteboard to 59mm

Constraints

< Back Next > Finish Cancel

Edit Design Constraint : Enter Name and Type

Name: Cons1

Response Type

- ☐ Mass
- ☐ Volume
- ☐ Strain Energy
- ☒ Displacement
- ☐ Stress
- ☐ Grid Stress
- ☐ Failure Index
- ☐ Buckling Load Factor
- ☐ Frequency Mode Number
- ☐ Reaction Force (SPCF)
- ☐ Von Mises Index
- ☐ Synthetic Response
- ☐ More Response Types...

Entire Model
Entire Model
Entire Model
Selected Groups
von Mises
Selected Groups
1
1

Constraint Bounds

Lower Bound
Upper Bound: 0.059
Bound Type: ☒ Actual ☐ Scale of Initial
Allowed Fail Probability: 0.0

To facilitate optimisation, design variables were applied within the software to set the upper and lower acceptable bounds of the layer thickness. These were set at 0.1mm at the lower bound and 3mm at the upper bound (shown in Fig 25), therefore limiting the minimum and maximum thickness of each layer of the composite within these ranges. These variables were then attached to PCOMP (shown in Fig 26) to ensure that each composite layer was correctly assigned the appropriate design variables.

To complete the setup ready for optimisation, it was necessary to increase the maximum number of design cycles within the genesis software to 30. This figure was chosen to ensure there would be enough study iterations to generate the optimised model within the design studio.

Figure 25- Image depicting setting bounds for layer thicknesses.Source-DesignStudio

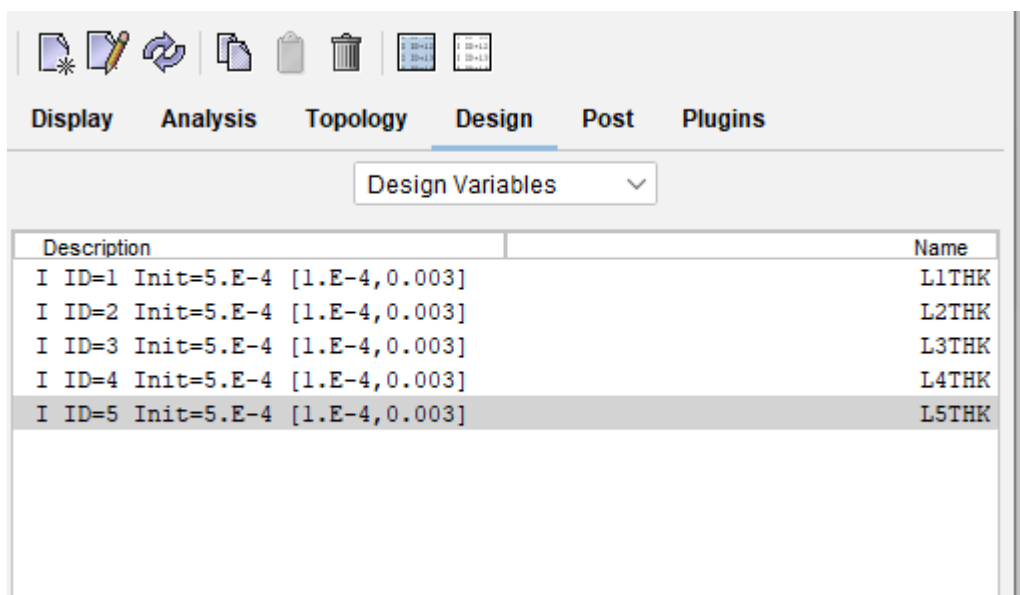


Figure 26- Image depicting layer thicknesses being set in PCOMP.

Sizing

< Back
Next >
Finish
Cancel

Edit a Group : Choose Composite Property Variables

Z0: Not Designed

Nonstructural Mass: Not Designed

GE: Not Designed

Layer 1	
Material:	857142 Unidirectional
Thickness:	1 L1THK l=5.E-4
Angle:	=-90.0 (Not Designed)
Layer 2	
Material:	857142 Unidirectional
Thickness:	2 L2THK l=5.E-4
Angle:	=-45.0 (Not Designed)
Layer 3	
Material:	857142 Unidirectional
Thickness:	3 L3THK l=5.E-4
Angle:	=0.0 (Not Designed)
Layer 4	
Material:	857142 Unidirectional
Thickness:	4 L4THK l=5.E-4
Angle:	=45.0 (Not Designed)
Layer 5	
Material:	857142 Unidirectional
Thickness:	5 L5THK l=5.E-4
Angle:	=90.0 (Not Designed)

Results from optimisation cycles

To gain the optimised data, a genesis analysis was run, revealing the results as shown in Fig 27, 28 and 29. As shown, the first design cycle at 0 gave a constraint violation of 302.9% against the displacement constraint set at 59mm. After 13 optimisation cycles, this is reduced to 0%, showing that the displacement criteria have been met.

The deformation of the board was checked (shown in Fig 29), and the deflection was reduced to 57mm. Also, the mass of the board, starts at 2.03kg (2 d.p's) and increases to 2.72kg (2 d.p's), showing an increase of 0.69kg. As shown in Fig 30, calculations revealed that although the weight of the optimised board increased, as did the stiffness, exceeding the steel baseline model by 1N/mm while still being 5.38kg lighter. To achieve this optimisation, Genesis needed to add more material to achieve the stipulated displacement. This has increased the stiffness and weight due to the fact that the thickness of the board has increased from 2.5mm to 3.35mm.

Figure 27- Image depicting the results of the first and last optimisation cycle. Source-DesignStudio

```
DESIGN CYCLE #    0, OBJECTIVE =  2.025439E+00, MAXIMUM VIOLATION = 302.9%.
DESIGN VARIABLE #      1 =  5.000000E-04    L1THK
DESIGN VARIABLE #      2 =  5.000000E-04    L2THK
DESIGN VARIABLE #      3 =  5.000000E-04    L3THK
DESIGN VARIABLE #      4 =  5.000000E-04    L4THK
DESIGN VARIABLE #      5 =  5.000000E-04    L5THK

DESIGN CYCLE #   13, OBJECTIVE =  2.716131E+00, MAXIMUM VIOLATION =   0.0%.
DESIGN VARIABLE #      1 =  1.000000E-04    L1THK
DESIGN VARIABLE #      2 =  1.000000E-04    L2THK
DESIGN VARIABLE #      3 =  2.916175E-03    L3THK
DESIGN VARIABLE #      4 =  1.363462E-04    L4THK
DESIGN VARIABLE #      5 =  1.000000E-04    L5THK
COMPLETION CODE: 1      1      0
```

Figure 28-Result graphs from genesis analysis of optimised kiteboard model

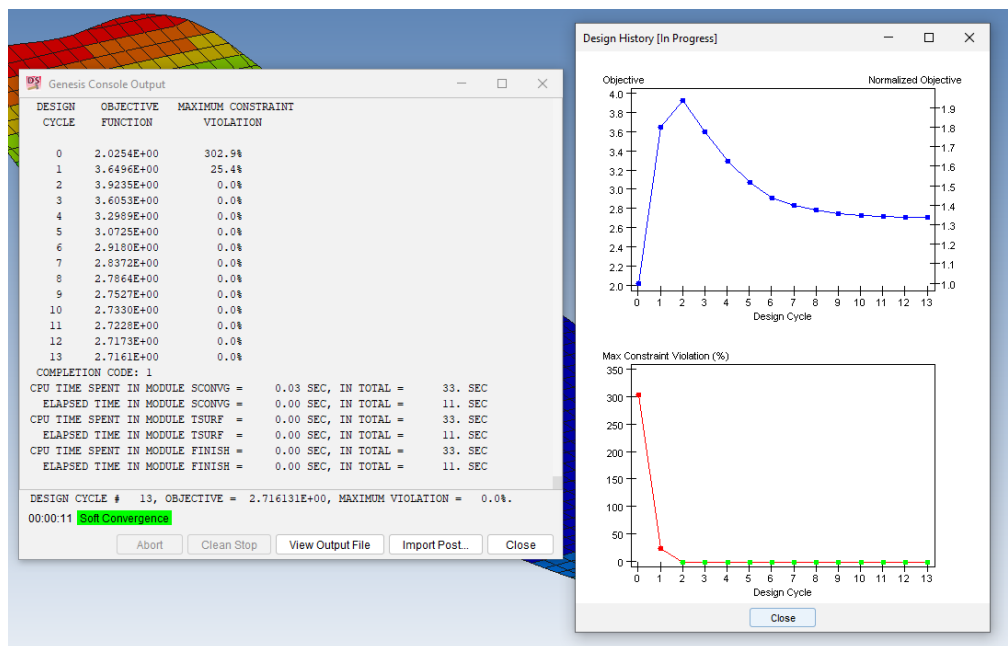


Figure 29- Image depicting the displacement of the optimised kiteboard(57mm) and the mass(2.72kg). Source-DesignStudio

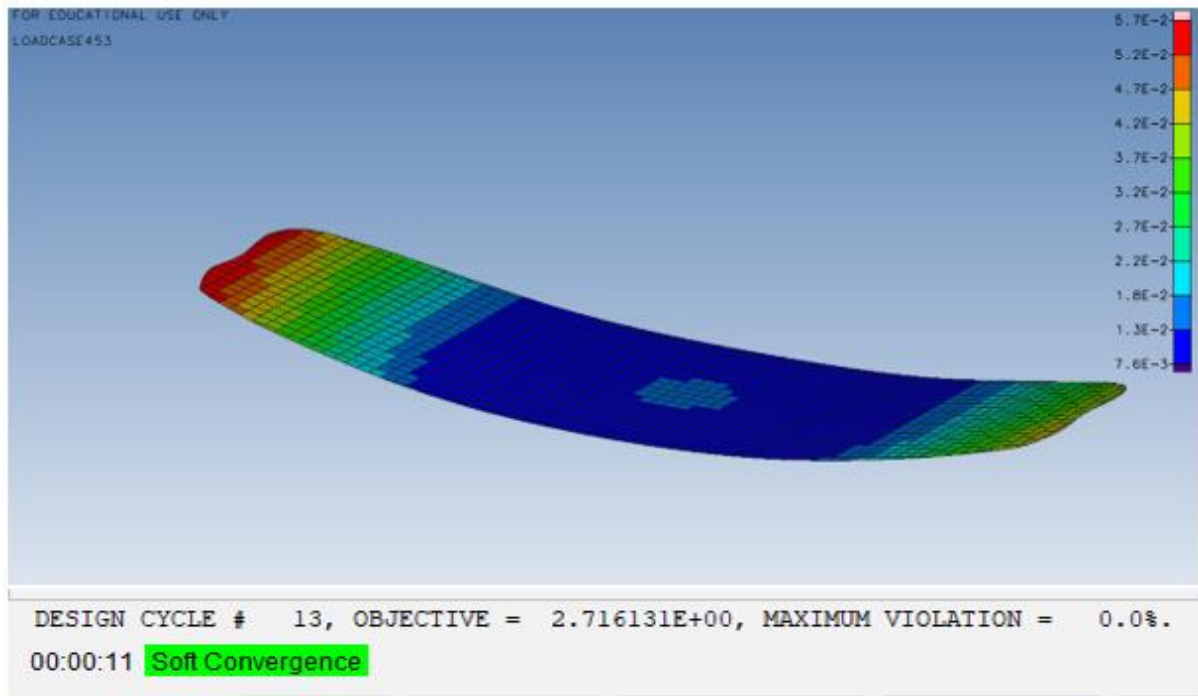


Figure 30-table showing calculations of stiffness and stiffness/weight of the baseline steel, baseline composite and first iteration of the optimised kiteboard.

Component run	Material	Thickness(mm)	Deflection(mm)	Mass (Kg)	Load(N)	Stiffness(N/mm)	Stiffness/weight(N ² /mm)
Baseline Steel kiteboard	Steel	2	59	8.1	1462	24.77966102	0.311846831
Baseline composite kiteboard	CFRP	2.5	230	2.03	1462	6.356521739	0.319193833
Optimised Kiteboard	CFRP	3.35	57	2.72	1462	25.64912281	0.961246133

Further optimisation for manufacturability

Although the optimised model at this point theoretically meets the criteria set out by the assignment brief, it is not practically possible to manufacture. Fig 27 shows the thickness of each layer. As previously stated, each ply is 0.1mm thick; therefore, it was not practically possible to achieve the thickness of each layer as the model has stated.

To solve this problem, the previous design variables were altered. As shown in Fig 33, the design variables were changed from independent to discrete values to limit the thickness of

each layer increment to be divisible by 0.1mm. 32 values were added, enabling the layer to have a maximum thickness of 3.2mm

A final optimisation cycle was run, which provided the results as shown in Fig 34. This revealed the final optimised result (shown in Fig 32), where the total weight of the kiteboard increased to 3.08kg. Furthermore, the layers were reorganised to the discrete values stipulated (as shown in Fig 33), ultimately solving the issue of manufacturability. Although the weight increased, the deflection of the board reduced from 57mm to 46mm due to an increase in stiffness to 31.8N/mm. Also, as shown in the calculations in Fig 31, the final iteration of the board had the highest stiffness to weight despite the increase in mass, suggesting that optimisation has been successful.

Figure 31-table showing calculations of stiffness and stiffness/weight for all iterations of the kiteboards.

Component run	Material	Thickness(mm)	Deflection(mm)	Mass (Kg)	Load(N)	Stiffness(N/mm)	Stiffness/weight(N ² /mm)
Baseline Steel kiteboard	Steel	2	59	8.1	1462	24.77966102	0.311846831
Baseline composite kiteboard	CFRP	2.5	230	2.03	1462	6.356521739	0.319193833
Optimised Kiteboard	CFRP	3.35	57	2.72	1462	25.64912281	0.961246133
Optimised for manufacture Kiteboard	CFRP	3.8	46	3.08	1462	31.7826087	1.051888766

Figure 32- The image depicts the results of the final optimised kiteboard for manufacture.Source-DesignStudio.

```

DESIGN CYCLE #    16, OBJECTIVE = 3.078667E+00, MAXIMUM VIOLATION = 0.0%.
DESIGN VARIABLE #      1 = 2.000000E-04    L1THK
DESIGN VARIABLE #      2 = 2.000000E-04    L2THK
DESIGN VARIABLE #      3 = 3.000000E-03    L3THK
DESIGN VARIABLE #      4 = 2.000000E-04    L4THK
DESIGN VARIABLE #      5 = 2.000000E-04    L5THK

```

Figure 33- Image depicting the setting of discrete values to constrain layer thicknesses further. Source-DesignStudio.

Figure 34- The image depicts an overview of design cycles in written and graphical form. Source-DesignStudio.

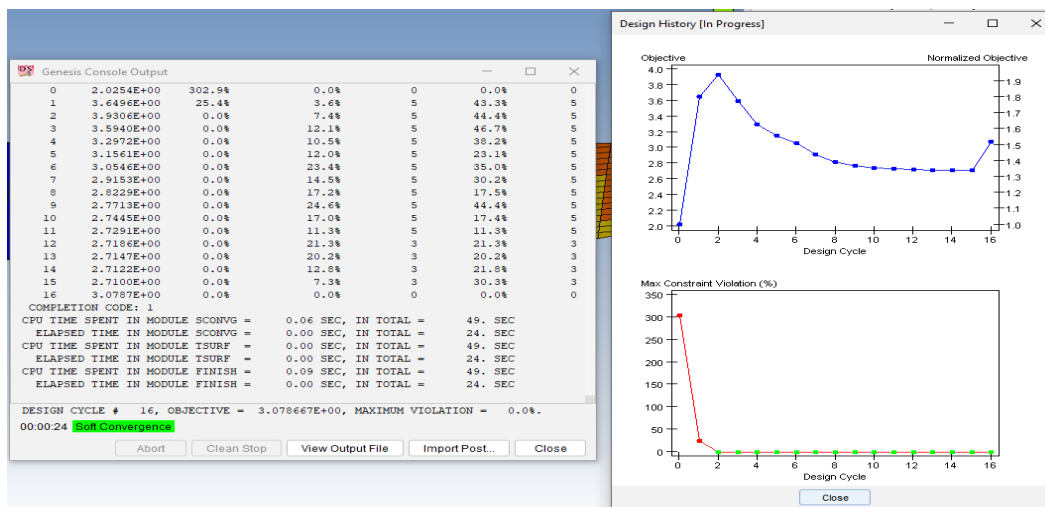
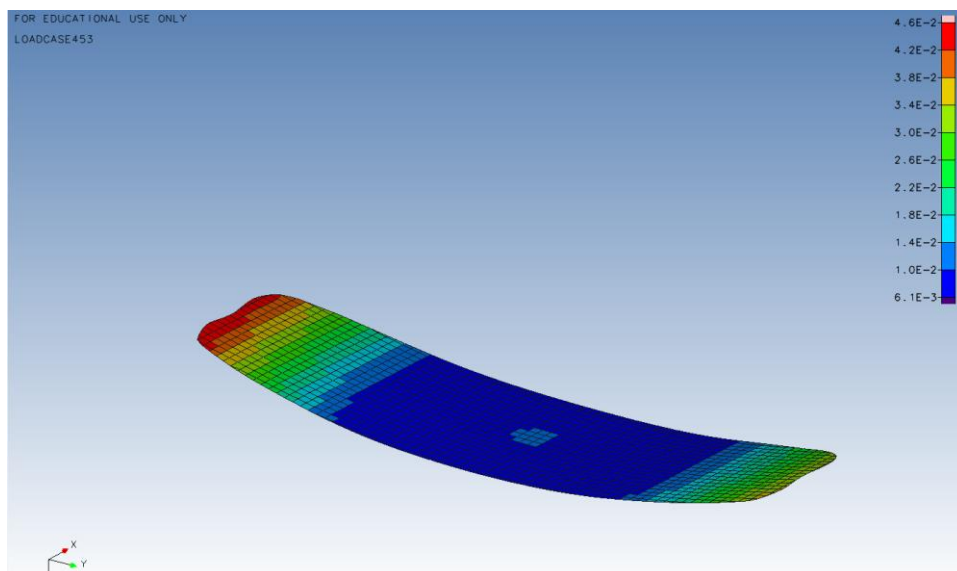


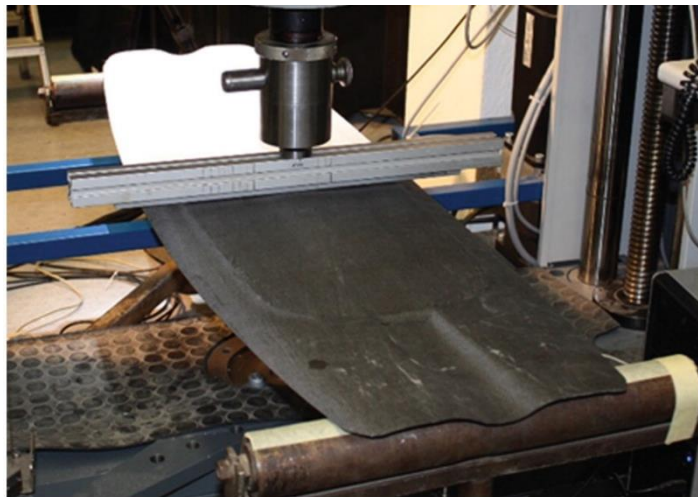
Figure 35- Image depicting deflection of the kiteboard optimised for manufacture (46mm). Source-DesignStudio.



Practical experimentation to validate FEA results

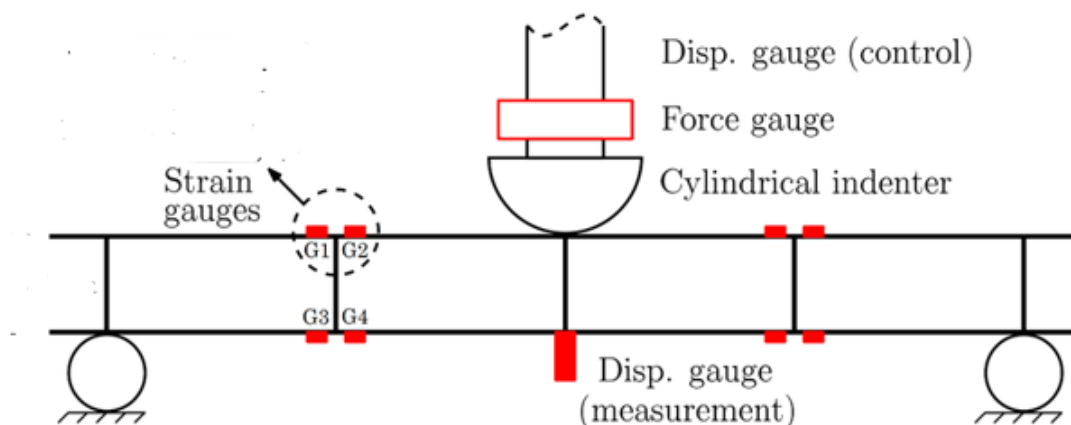
Several techniques can be applied to conduct the laboratory experiment to effectively understand the deformation characteristics of the kiteboard material and the associated stresses under load. Research suggests that a controlled three-point bending test would be suitable, as this approach enables a simulation of the loading conditions experienced by the board in real scenarios (Stier et al., 2015), (Poodts et al., 2013). This test is designed to replicate the criteria set within the FEA conducted using Design Studio.

Figure 36-Representative example of a 3-point bed test on a CFRP kiteboard. Source-(Stier et al., 2015)



The laboratory experiment requires a structured approach, beginning with the design of the experiment, setting up and calibrating necessary equipment, and ultimately recording and analysing the data. At the experiment's inception, it is necessary to define boundaries and establish which design elements need examination and what tests are required (Srinivas, 2020). For deformation assessment, specific loading conditions must be simulated. These should include various bending loads and force distributions applied according to the criteria set out through the FEA simulation. A range of sensors, such as strain gauges and displacement transducers (Instron, 2024), should be used to capture the material's response (Ramos et al., 2015). The sensors must be strategically placed to gather accurate strain data, which will then be recorded digitally for thorough analysis (as shown in Fig 37).

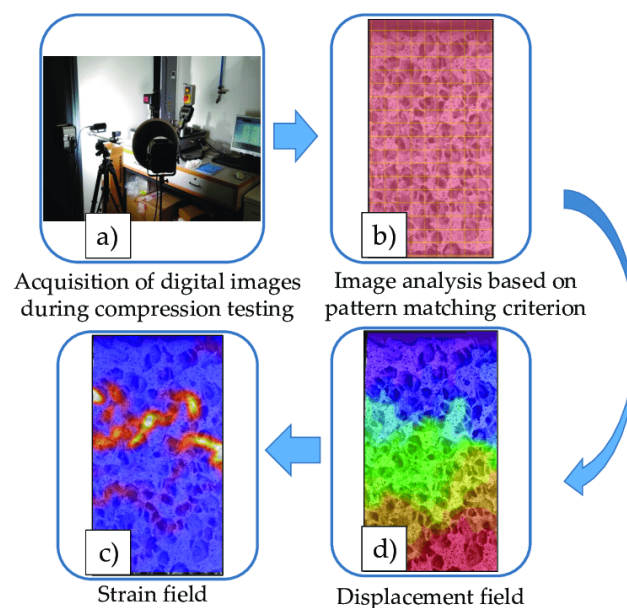
Figure 37-Representative diagram of strain gauge and displacement transducers. Adapted from source-(Karttunen et al., 2016)



Consideration should be given to the prototype of the kiteboard: determining whether a single design is sufficient or if multiple variations should be tested. Additionally, prototype dimensions are crucial, as testing a full-sized model can yield results closer to in-field conditions, though scaled models may reduce costs (Stier et al., 2015), (Sadeghi et al., 2019). When using a scaled model, efforts should be made to ensure it accurately represents the structural behaviour of the full-size kiteboard.

While visual inspection of material deformation is helpful, recording quantitative strain data is paramount for this experiment. Digital Image Correlation (DIC) techniques can be employed for visualising strain distribution (Choi et al., 2014), using a high-resolution camera system to capture displacement fields across the board's surface (McCormick and Lord, 2010). This data can provide both qualitative and quantitative insights.

Figure 38- Image string depicting the process of DIC. Source-(Belda et al., 2020)



After the testing, the results should be compared to the FEA data. This comparison will either validate or suggest modifications to the FEA simulation (Srinivas, 2020). Researchers should analyse any discrepancies, considering potential experimental errors or limitations in the FEA model, such as assumptions or simplifications that may not fully capture real-world conditions. This data can then be used to refine the FEA model for greater accuracy in future analyses (Cashin, 2023).

Finally, based on the discrepancies identified, modifications to the simulation model can be proposed. For example, if the experimental data shows that certain regions experience more deformation than simulated, adjusting the layup angles of the CFRP layers in the model or fine-tuning the material properties may better capture the real-world response of the board. This iterative process allows for a more accurate design by adjusting FEA parameters based on real-world performance.

Conclusion

In conclusion, this report has detailed the structural optimisation of a composite kiteboard through the use of Finite Element Analysis (FEA). The study demonstrated that while the initial composite baseline model significantly reduced the overall weight compared to a steel counterpart, it did not meet the required performance specifications due to excessive deflection. Subsequent iterations of optimisation refined the composite layup to achieve an optimal balance of weight reduction and structural integrity. This process incorporated comprehensive modelling, boundary condition adjustments, and iterative design cycles, which effectively reduced deflection whilst minimising the kiteboards mass.

Further, the research highlighted the progression of FEA techniques from manual calculations to contemporary AI-enhanced, cloud-based simulation platforms (Ari and Muhtaroglu, 2013), (VanLee, 2023). These advancements have been pivotal in enabling more sophisticated analyses and more efficient designs. The findings suggest that while theoretical models provide valuable insight into performance, practical constraints such as manufacturability must be incorporated to ensure feasibility. Laboratory experimentation using techniques like three-point bending tests (Stier et al., 2015) are essential to validate the FEA results and refine the simulation models. Overall, the integration of FEA with modern computational tools affirms its role in engineering design, driving for more innovative, lighter, and high-performing structures (Li et al., 2021).

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