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Assignment 2

Structural and Fluid Analysis (ACMA6010)

Abstract

Section 2.0 discusses various optimisation techniques and looks into a proposed optimisation technique specifically for propellers and is based on a two-step model to more accurately predict the behavior of the blade.

Section 3.0 and 4.0 covers the production and optimisation of a proposed composite. The results show that the blade has a substantial stiffness value and to improve efficiency it is suggested that a stiffness constraint is set (based on technical literature) for the optimised run.

Section 5.0 proposes a segmented loading test for an accurate representation of the loading condition on the blade covered in section 3.0.

Section 6.0 gives insight into a helical ply layup that can significantly improve the propeller blades (from sections 3.0&4.0) structural characteristics and covers relevant standards and codes of practice.

Key Words

FEA – Finite element analysis

FEAO – Finite element analysis Optimisation

ITO – Isogeometric Topology Optimisation

CFD – Computational fluid dynamics

PCOMP – Ply Composite

DIC – Digital Image Correlation

ISO – International Organization for Standardization

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1.0 Introduction

Section 2.0 of this report gives a brief overview of historically and currently used optimisation methods in FEA and provides insight into methods that have been proposed for use in the future.

Section 3.0&4.0 covers creating and optimising a propeller blade model made of composite material and compares the results of 4 different runs.

Section 5.0 covers a proposed test method to correlate results with the simulation carried out in sections 3.0&4.0, and section 6.0 compares the blade design with the latest technical literature on propeller composites and discusses relative standards.

2.0 Task 1 Optimisation Techniques

2.1 Shape

Historically the first developed optimisation method was shape optimisation. In the 1980s, M.E. Botkin and N.kikuchi developed the first structural shape optimisation FEA for the automotive industry. This optimisation method was further developed in 1988 by creating an approach to finding the optimal shape of a structure under a specific load (Liu et al., 2022).

Problems are generally solved numerically via iterative methods meaning that it will continually evolve an initially specified shape until it becomes an optimal shape (Leiva, 2004). It involves using perturbation vectors as the design variable, which can almost take the form of any shape and is not limited to any type of element (Leiva, 2010).

2.2 Topology

The idea of efficiently using computing power to speed up the development of structures optimised typically for mass and stiffness led to the creation of topology optimisation. Altair's engineering consultancy further developed this method in the early 1990s (Schramm, 2020).

Topology optimisation involves removing material from a specified design space while allowing for a specific amount of material to be retained to create an ideal structure (LeapAustralia , 2014).

The main limitation of topology is that it can produce designs that are very difficult to manufacture and very expensive to manufacture (Velling, 2020).

2.3 Topography

For improved structural performance, topography optimisation can be utilised to alter the forms of shell structures by adding stamped beads. Topology optimisation software can recommend the location, shape, and orientation of these alterations, frequently surpassing a conventional layout. Local shape modifications can improve vibration characteristics (Pagadala, 2015).

Topology optimisation will identify the density of the required elements, whereas topography will strengthen a structure by applying bead parameters (Kong et al., 2016).

2.4 Topometry

Sizing optimisation has been generalised to include topometry optimisation. Each element is designed independently in topometry optimisation, unlike size optimisation where all elements that are connected to a property data entry are built with the same values. Topometry can give continuous variations of the dimensions of elements within a specified design region (Leiva, 2004).

2.5 Freeform Optimisation

The programme divides an existing perturbation vector into separate perturbations, resulting in a perturbation vector and design variable unique to each grid (Leiva, 2010). It takes advantage of both topography and shape optimisation and is currently a widely used method due to its versatility.

2.5.1 Freeform Optimisation compared to Other Optimisation methods

Freeform optimisation can produce greater variability in results than shape optimisation; however, it is more likely to distort the finite element meshes (Leiva, 2010).

Freeform can work with any element, whereas topography is mainly used for shells and solids. Freeform can also create beads of varying heights whereas topography beads are limited to a set height (Leiva, 2010).

Freeform can add more material outside specified borders, whereas topology cannot. However, topology optimisation has two main advantages over freeform; meshes cannot be distorted using topology, and it can produce interior cavities (Leiva, 2010).

2.6 Composite Optimisation

Composites are generally optimised using two main methods.

The first method involves optimising by using various algorithms and problems. Objective functions and design variables are used to define the optimisation problem. The algorithm is the process in which the design variables are optimised to achieve the objective function set by the user (Nikbakt et al., 2018).

The second method involves different constraints, design variables, objective functions and composite structures (Nikbakt et al., 2018).

2.7 How optimisation improves the design process

FEA identifies weaknesses within a designed component or structure and optimises the existing design to provide better solutions. Its efficiency in addressing structural and fluid flow problems has made it a staple tool for many industries (imaginationeering, 2020).

FEA allows the designer to predict the behavior/performance of a component before developing prototypes, which saves a significant cost as it reduces the number of prototypes that need to be produced and saves a company time, effort and resources that would otherwise be put into an ineffective design (Kanade, 2022).

Seeing how one change to a variable affects the optimal point for others allows the designer to see synergies between variables that would otherwise go unnoticed in traditional experiments. By creating a design space, it is possible to optimise the entire set of factors specific to an output while also pinpointing the process's boundaries of failure. This gives a more predictable production process with significant time and money savings (ManufacturingChemist, 2019).

2.8 Future of optimisation for propellers

The design of a propeller involves the evaluation and consideration of numerous factors.

Typical propeller constraints/considerations are as follows

- Dynamic and static blade stresses
- Cavitation
- Regulations on propeller efficiency and blade weight
- Arrangement of the blade, blade edges and blade collision

The hydrodynamic performance will also need to be analysed to give cavitation and power consumption values which are constrained to reduce blade erosion. Propeller-induced vibration and static strength must also be considered via FEM (Vesting, 2015).

All these multi-disciplinary evaluations are very time-consuming to account for. Therefore, automated optimisation can assist the designer in accomplishing this task faster and with a better quality of the final design (Vesting, 2015).

For the future of propeller design, a two-stage optimisation procedure was proposed, where the geometry is initially modified by parameterised geometry distribution curves to give additional information on the test case of the propeller. The first optimisation setup will depend on the gathered constraints, objectives and parameter algorithm selection. A second optimisation will be implemented to improve the design of the propeller by changing the local geometry based on the outcome of the first optimisation (based on the additional information gained from the first optimisation). This method has been shown to give designs comparable to a manually designed propeller (Vesting, 2015). This method is still under research for use with other algorithms to improve its efficiency.

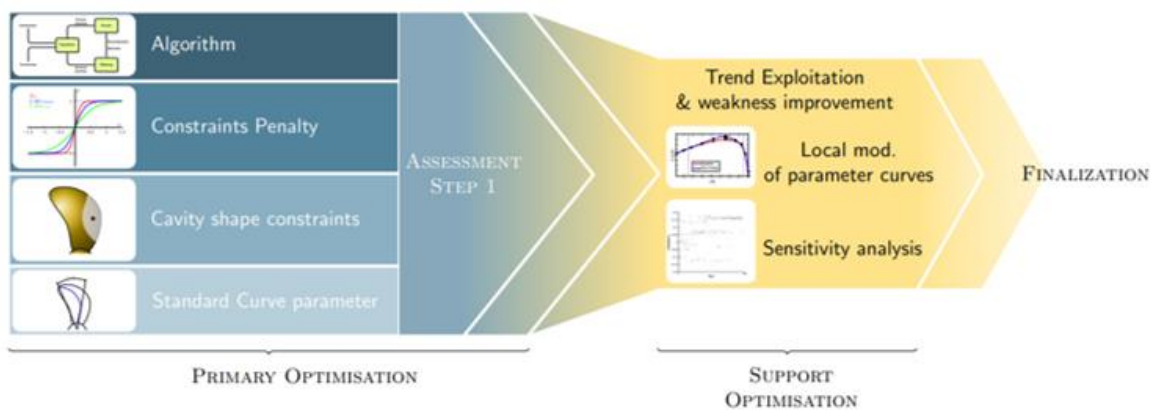


Figure 1 - Two stage optimisation procedure for marine propeller blade (Vesting, 2015)

2.9 Future Techniques that are in development

Many researchers believe that optimisation's future will gravitate towards combining different optimisation tools.

The combination of topology optimisation and other tools like FEM and shape optimisation has been experimented with to give optimum solutions. There are several mathematical methods in development, and by unifying and standardising these methods, new techniques can be developed (Calado, 2018).

2.9.1 FEAO

FEAO is an optimisation algorithm in development that solves the challenge of determining the global minima of a (nonlinear) objective function $f(x)$ specified on a bounded hyperspace (Ning et al., 2020).

FEAO convergence is deduced through an algorithm based on the discrete-time linear system theory. Simulation results have shown that it is practical and has the potential for use in fluid simulation applications in the future (Ning et al., 2020).

2.9.2 ITO

Isogeometric Topology Optimisation (ITO) has also gained traction as it can considerably reduce the computation cost of topology by unifying the CAD and CAE mathematical models. It can overcome the numerical deficiencies of FEM that negatively influence topology's efficiency and effectiveness (Gao et al., 2020).

3.0 Task 2 Design Studio Model

3.1 Assumptions made

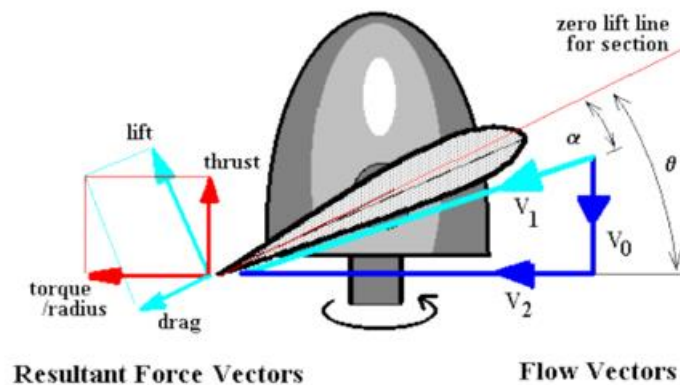


Figure 2- Force Vectors acting on a propeller blade (aerodynamics4students, 2015)

The illustration above shows the force vectors acting on a propeller blade. For this simulation, an assumption will be made based on Newton's third law that the equal and opposite force of the lift generated will be the total load acting on the blade face. This assumption may incur errors as the loading condition of propellers is very complex, and there may be more interactions that will not be considered that affect the lift of the blade.

$$L = C_L \times d \times \frac{V^2}{2} \times A$$

- L = Lift**
- C_L = Lift Coefficient**
- d = Density of Air**
- V = Velocity of Air**
- A = Wing Area**

Figure 3 - Lift Coefficient Formula for a helicopter (Ashish, 2022)

An assumption will be made that the above equation will calculate the lift on the propeller blade under water by substituting the density and velocity of water plus the area of the propeller blade. Hydrodynamic interactions are not taken into account in this formula which will increase the likelihood of non-correlation between the simulation and a physical underwater test.

The propeller blade model that is optimised is the section past the weld beam of the blade, so only the edge is fixed. This will affect the deflection of the blade as there is less of a fixed portion.

3.1 Assumptions made

Angle of attack (α)	Lift coefficient				
	C_y (CFD_Xiao)	C_y (CFD_Lars)	C_y (Exp.)	C_y (CFD_Xiao) and C_y (CFD_Lars) error (%)	C_y (CFD_Xiao) and C_y (Exp.) error (%)
10	0.326	0.346	0.374	-5.7	-12.8
20	0.598	0.573	0.623	4.4	-4.0
30	0.751	0.794	0.756	-5.4	-0.7
35	0.705	0.770	0.739	-8.4	-4.6

CFD: computational fluid dynamics.

Table 1 - Lift coefficient at different angles of attack (Yang et al., 2019)

In the absence of the lift coefficient, typically found experimentally, an assumption will need to be made based on technical literature. Above are experimental results on lift coefficient based on angles of attack. The 0.75 result has the closest correlation between the CFD model and the experiment. Therefore, 0.75 will be used for the lift coefficient, and the blade will be assumed to have an angle of attack of 30 degrees and will be validated experimentally as such.

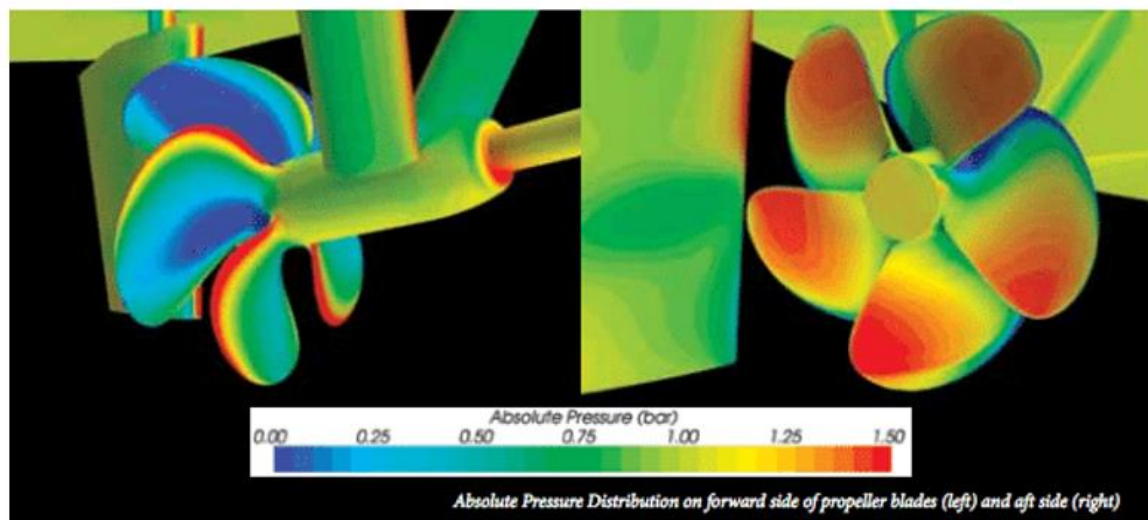


Figure 4 - Pressure distribution on propeller blade

The loading distribution of the blade will be in 3 areas of equal size and use the same ratio as the pressure shown above in the green, red and yellow areas from a cavitation analysis. Although the blades in the above illustration are under different conditions, which will introduce some errors in the results obtained, we are mainly interested in the distribution of pressure to simulate the loading on the blade face accurately.

3.2 Calculations

$$L = C_L \times d \times (V^2/2) \times A$$

$$C_L = \text{Lift Coefficient} = 0.75$$

$$d = \text{Density of Water} = 1026 \text{Kg/m}^3 \text{ (Ahmed, 2022)}$$

$$V = \text{Velocity of Water} = 32.34 \text{ m/s (Ahmed, 2022)}$$

$$A = \text{Area of Blade} = 8.4 \text{m}^2 \text{ (taken from model of propeller blade)}$$

$$\text{Lift} = 0.75 \times 1026 \times 32.34 \times 8.4 = 3380160 \text{Kg/s}^2 = 3380.16 \text{KN}$$

Assumption - Lift = Total Loading on Blade

Distribution of loading was split across 3 areas of approximately the same size. Loading was distributed based on the ratios found in the pressure distribution.

See calculations below

Green Area = 0.75 Ratio

Yellow Area = 1.1 Ratio

Red Area = 1.5 Ratio

Total = 3.35

Total calculated load on blade = 3380.16KN

To calculate the loading in each of the 3 areas the total load was divided by the total ratio and this value was then multiplied by each individual ratio to give the load in each area.

$$\text{Total Load} / \text{Total Ratio} = 3380.16 / 3.35 = 1009 \text{KN}$$

$$\text{Green Area Total Load} = 1009 \times 0.75 = 756.75 \text{KN}$$

$$\text{Yellow Area Total Load} = 1009 \times 1.1 = 1109.9 \text{KN}$$

$$\text{Red Area Total Load} = 1009 \times 1.5 = 1513.5 \text{KN}$$

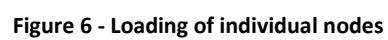
Now the loads for each area is divided by the number of nodes selected in each area to give the loading per node in each of the 3 areas.

$$\text{Loading per node, green area} = 756.75/1457 = 519 \text{N acting on each node}$$

$$\text{Loading per node, yellow area} = 1109.9/1617 = 686 \text{N acting on each node}$$

$$\text{Loading per node, red area} = 1513.5/1724 = 880 \text{N acting on each node}$$

Three different loading conditions were applied to the blade based on the calculations performed.



3.3 Model Creation

Display Analysis Topology Design Post Plugins

Materials

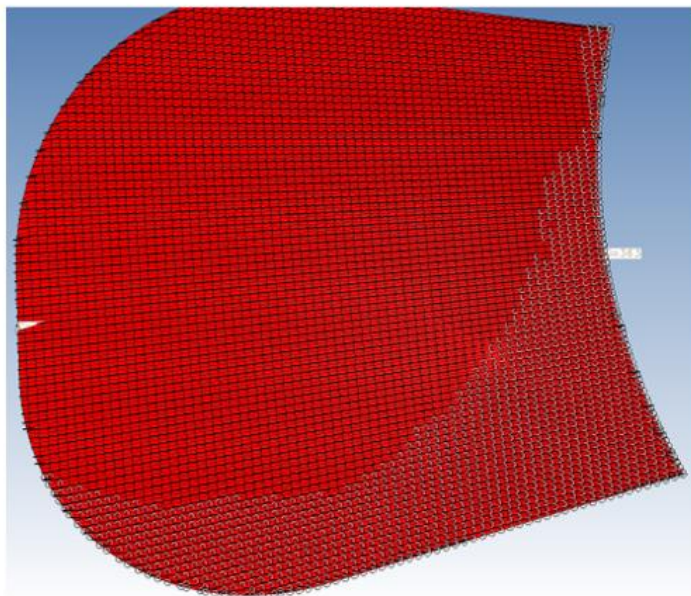
< Back Next > Finish Cancel

Edit a Material : 2-D Orthotropic Properties

E_1: 132000000000
E_2: 10800000000
Nu_12: 0.24
G_12: 5650000000
G_1z: 5650000000
G_2z: 5650000000
Rho: 1540
A_1:
A_2:
Tref:
GE:
F12:
☒ Stress Limits
☐ Strain Limits
Xt: 1513000000
Xc: 1000000000
Yt: 43400000
Yc: 43400000
S: 43400000

The material was first defined as unidirectional under MAT8 and these material properties were entered.

Figure 7 - Defining the Material Properties



Theta vectors were aligned so that they run 0 degrees radially out from the centre of the propeller.

Figure 8 - Alignment of Theta Vectors

3.3 Model Creation

Display Analysis Topology Design Post Plugins

Group Properties

< Back Next > Finish Cancel

Edit a Group : Choose Composite Property Values

Z0:

Nonstructural Mass:

Tref:

GE:

Interlaminar Shear Limit:

Failure Theory: None

Laminate: All Plies

Type: Regular

Global Ply ID	Material	Thickness	Angle	Output
Layer 1				
857143 Unidirectional	S.E-4		-90.0	Yes
Layer 2				
857143 Unidirectional	S.E-4		-45.0	Yes
Layer 3				
857143 Unidirectional	S.E-4		0.0	Yes
Layer 4				
857143 Unidirectional	S.E-4		45.0	Yes
Layer 5				
857143 Unidirectional	S.E-4		90.0	Yes

The material properties were defined as a laminate and under PCOMP/PCOMPG the material was chosen to be unidirectional with the ply layup shown. 0.1mm ply's with 5 ply's in each direction (-90, -45, 0, 45 and 90 degrees).

Figure 9 - Ply layup

4.0 Task 3 Design Studio Optimisation

4.1 Initial Optimisation

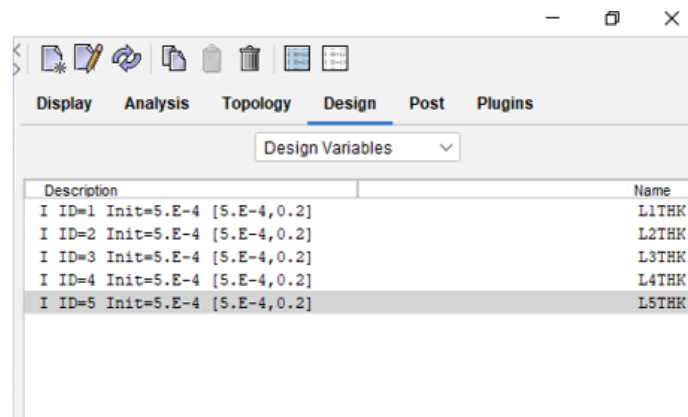
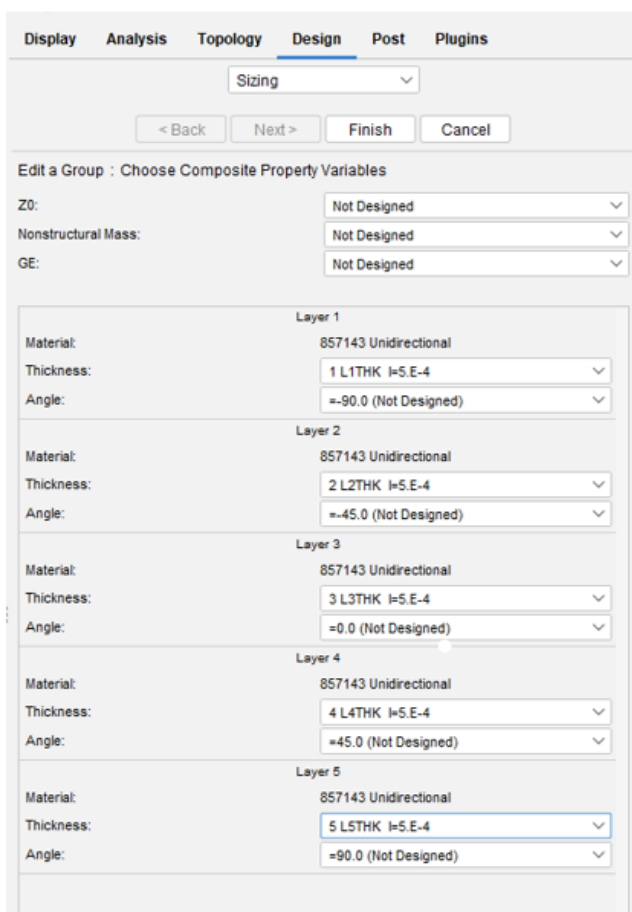


Figure 10 - Design Variables

The design variables were altered to allow a maximum thickness of 200mm in each direction (the number of ply's in each direction is the set variable). This was set to give a hard convergence during optimisation.



Sizing was implemented to attach the design variables to the PCOMP.

Figure 11 - Sizing of Composite

4.1 Initial Optimisation

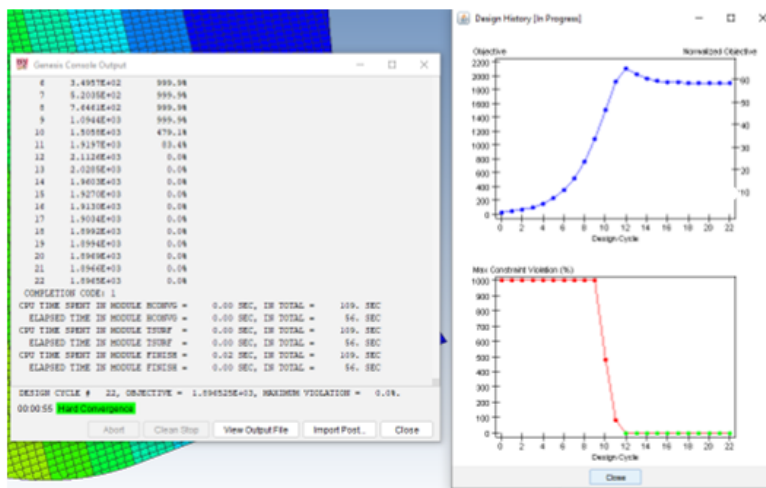


Figure 12 - Initial Optimisation

The optimisation gave a hard convergence within the set constraints. This optimisation's objective is to minimise the mass of the propeller whilst meeting the displacement constraint. The design graph shows for each cycle; the mass will increase until the displacement constraint is met and then will focus on decreasing the mass whilst still meeting the set constraint.

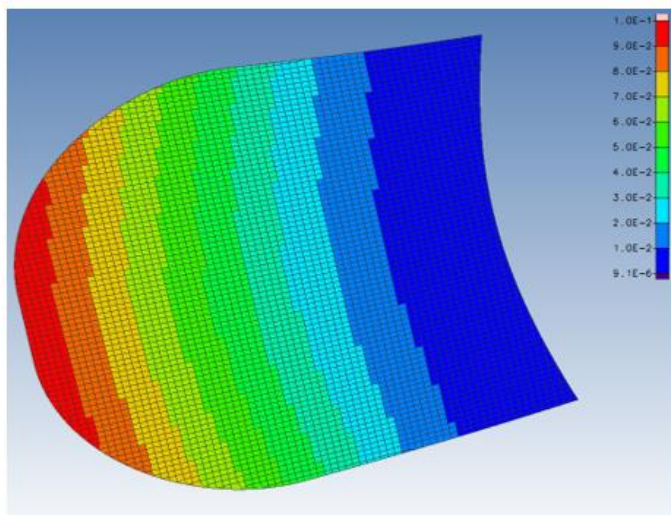


Figure 13 - Deflection of Blade after Optimisation

This image shows that the maximum deflection seen after optimisation is 100mm at the edge of the blade.

4.1 Initial Optimisation

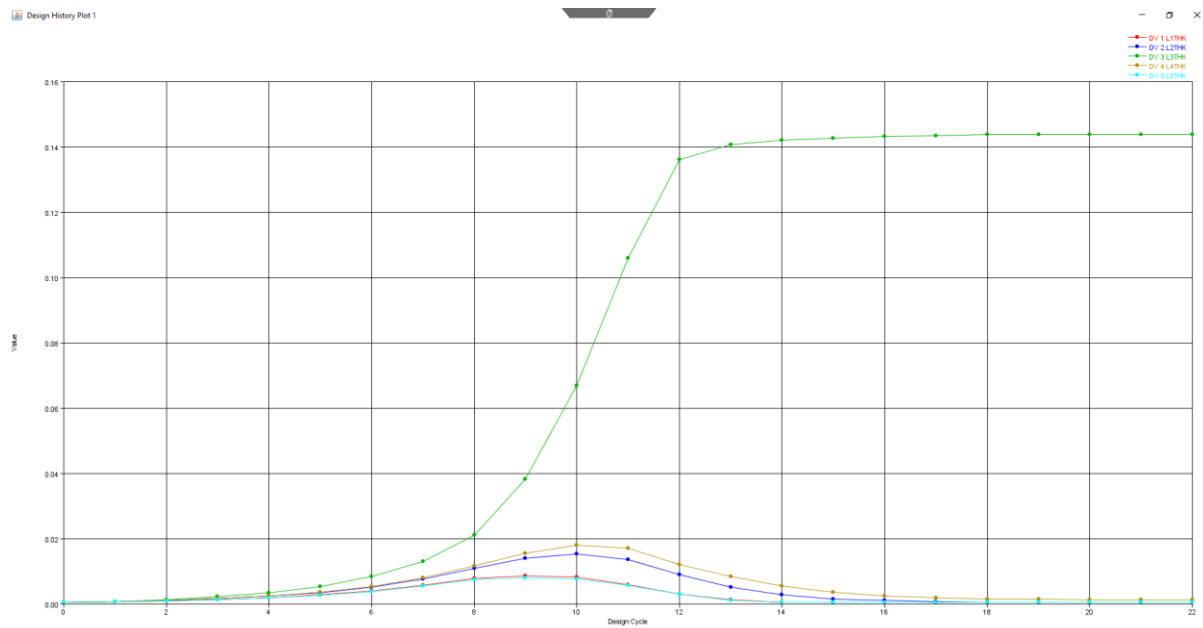


Figure 14 - Design History Graph

The design history graph above shows that the design variables started at 0 and then rose to the shown values. The maximum number of ply's were in the 0-degree direction, which correlates with how the part will be loaded as the maximum amount of force will be withstood in this direction.

```

133 DESIGN CYCLE # 22, OBJECTIVE = 1.896525E+03, MAXIMUM VIOLATION = 0.0%.
134 DESIGN VARIABLE # 1 = 5.003171E-04 L1THK
135 DESIGN VARIABLE # 2 = 5.013598E-04 L2THK
136 DESIGN VARIABLE # 3 = 1.438021E-01 L3THK
137 DESIGN VARIABLE # 4 = 1.332811E-03 L4THK
138 DESIGN VARIABLE # 5 = 5.003333E-04 L5THK
139 COMPLETION CODE: 1 254 0
140

```

Figure 15 - Ply thickness's and total weight of composite

Above are the optimised composite's total mass and ply thicknesses in each direction.

Mass= 1896.5KG

Total Thickness= $0.50+0.50+143.80+1.33+0.50=146.63\text{mm}$

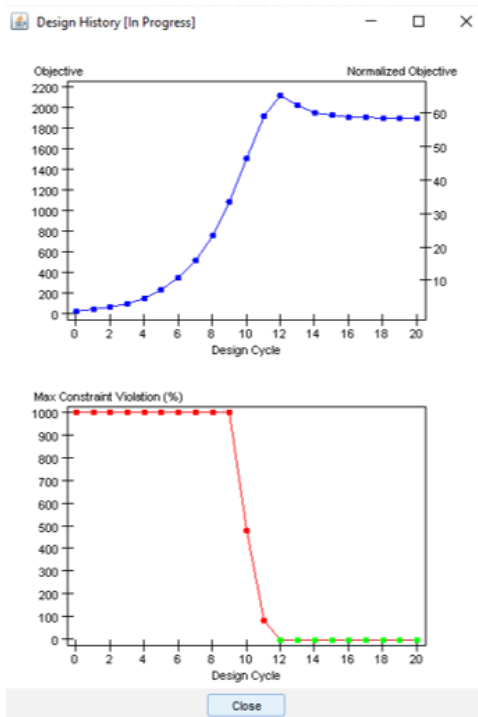
The thickness in the 45-degree direction is 1.33mm, and as each ply is 0.1mm thick, this would correlate to 13.3 ply's. This would be difficult to manufacture as there is such a tight tolerance for each ply and the fact that they are incredibly thin. Therefore, discrete variables will be set to give thickness values that correlate to whole ply's.

4.2 Optimisation with Discrete Variables



Discrete variables were implemented to improve manufacturability.

Figure 16 - Implementation of Discrete Variables



This run gave a hard convergence.

Figure 17 - Optimisation Run with Discrete Variables

4.2 Optimisation with Discrete Variables

```
DESIGN CYCLE #    20, OBJECTIVE =  1.901221E+03, MAXIMUM VIOLATION =   0.0%.
DESIGN VARIABLE #      1 =  5.000000E-04    L1THK
DESIGN VARIABLE #      2 =  5.000000E-04    L2THK
DESIGN VARIABLE #      3 =  1.438000E-01    L3THK
DESIGN VARIABLE #      4 =  1.700000E-03    L4THK
DESIGN VARIABLE #      5 =  5.000000E-04    L5THK
COMPLETION CODE: 1      256      0
```

Figure 18 - Ply thicknesses and weight after implementation of discrete variables

Above are the thickness results in each direction after implementing discrete variables.

The objective has increased to 1901.2Kg however the suggested ply layout is as follows:

-90 degrees – 0.5mm = 5plys

-45 degrees – 0.5mm = 5plys

0 degrees – 143.8mm = 1438plys

45 degrees – 1.7mm = 17plys

90 degrees – 0.5mm = 5plys

Total ply's = 1470plys

Although this part is not as efficient as the initial optimised run, the blade is now more manufacturable.

4.3 Optimisation Results Summary

Below is a table comparing the results between the original steel plate and the composite runs.

Run	Material	Thickness	Deflection	Mass	Load	Stiffness	Stiffness/Weight
Steel Baseline	Steel	10mm	168000mm	646.67kg	3380.16KN	20.12N/mm	$3.175 \times 10^{-3} \text{N}^2/\text{mm}$
Composite Baseline	Composite	2.5mm	156695mm	32.33Kg	3380.16KN	21.57N/mm	$0.0681 \text{N}^2/\text{mm}$
Optimised Composite	Composite	146.63mm	100mm	1896.5Kg	3380.16KN	33801.6N/mm	$1.819 \text{N}^2/\text{mm}$
Optimised Composite (using discrete variables)	Composite	147mm	100mm	1901.22Kg	3380.16KN	33801.6N/mm	$1.814 \text{N}^2/\text{mm}$

Table 2 - Design Studio Results Summary

It can be assumed that the blade has snapped for the steel baseline and the composite baseline, due to the deflection value seen (ply constraint not allowing the part to meet the specified max deflection). The composite baseline provides a large weight saving compared to the steel baseline for similar performance. The stiffness-to-weight ratio is significantly larger for the composite compared to the steel baseline, which is expected of a composite.

The composite's very high stiffness would result in reduced material flexibility, an essential factor for CFRP propellers for restraining cavitation inception and reducing pressure fluctuation. This stiffness may be acceptable for such a significant loading condition, but there needs to be more data that supports a set standard for composite propeller stiffnesses (Nakashima Propeller Co, 2015).

5.0 Task 4

5.1 Loading Test Method

The loading experiment discussed in this section will verify the elastic response of the blade, and the results can then be compared to the design studio simulation.

A point load experiment carried out by researchers involved the blade being loaded at two points with increasing magnitude to evaluate whether a propeller prototype based on an FEA design exhibited the predicted bend twist deformation. The elastic response was measured using DIC (digital image correlation) and strain gauges. Model predictions and experimental measurements were then compared, and the results correlated well in this case (Rokvam et al., 2021).

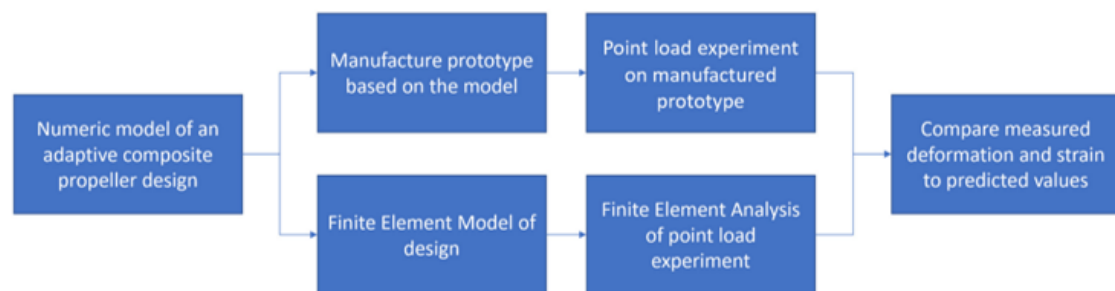


Figure 19 - Block Diagram of test method carried out in research paper (Rokvam et al., 2021)

The blade would have ideally been loaded with an operational periodic load case. However, this would be too complex to recreate experimentally, so a point load experiment was performed as an alternative (Rokvam et al., 2021).

5.1 Loading Test Method

The image below shows the experimental setup.



Figure 20 - Image showing loading of the blade (Rokvam et al., 2021)

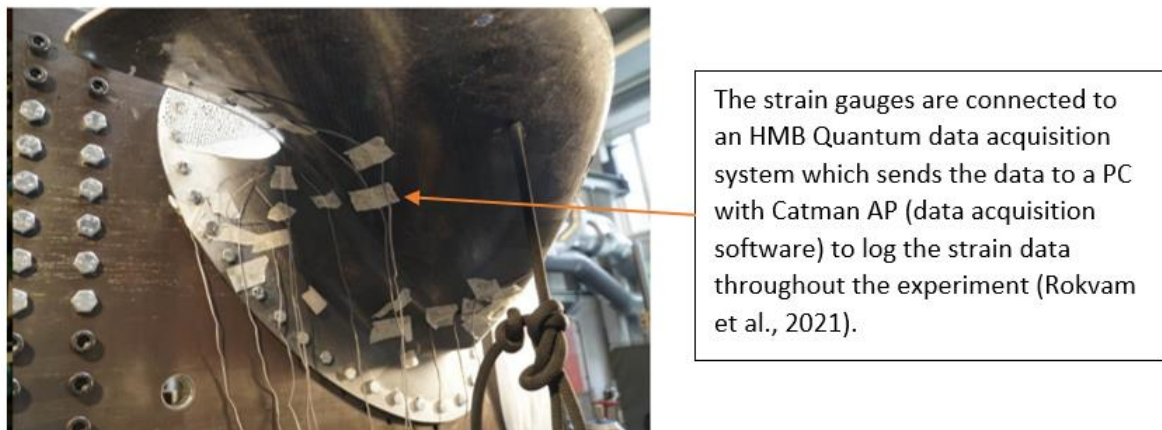


Figure 21 - Image showing strain gauges attached to the underside of the blade (Rokvam et al., 2021)

5.1 Loading Test Method

DIC snapshots were taken for each load case to measure the deformation of the blade. The DIC measured the visible 3D deformation of the blade on the pressure side (side facing upwards). Using the DIC cameras, measurements were taken with Vic-Snap 8 (software). Post-processing was then performed to calculate the deformation of the blade that was visible in the pictures via Vic-3D 8 (software) (Rokvam et al., 2021).

Below is an image showing the setup of these cameras.

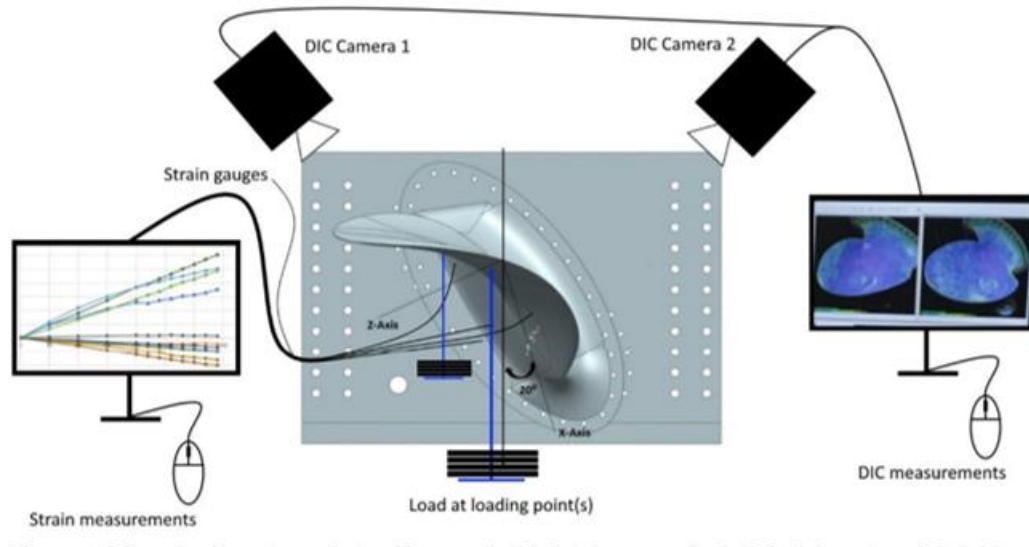


Figure 22 - Digital image correlation and strain gauge design schematic (Rokvam et al., 2021)

The results obtained can then be compared to the numerical predictions. The DIC measurements will be compared to the FEA and provide the user with results such as the deformation of the blade, bending deflection and twist of the blade. Strain measurements can also be extracted and compared to the FEA model (Rokvam et al., 2021).

5.1 Loading Test Method

The example below shows a scan of the prototype propeller, which can be compared to the 3D model.

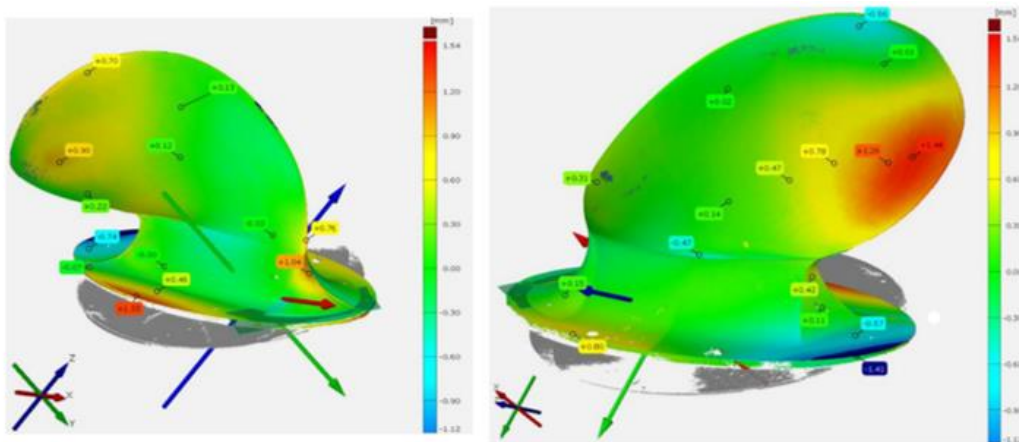


Figure 23 - 3D scan of propeller deflection (suction side on the left and pressure side on the right) (Rokvam et al., 2021)

A comparison of results from the DIC-measured deformation and the numerical predictions is shown below. The holes observed are the holes in the blade made for the hanging weights (Rokvam et al., 2021).

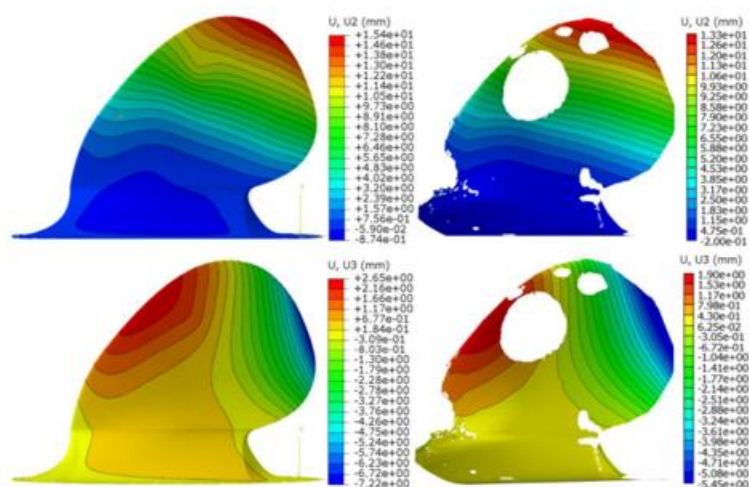


Figure 24 - Deformation plots, FEA plot on the left, experimental results on the right (Rokvam et al., 2021)

The results, when compared, can be tabulated to give a percentage correlation.

5.2 Proposed Experiment Alterations

Experimentally validating the propeller's loading conditions from section 3.0 is very difficult due to how complex the load case is. However, the experiment detailed in section 5.1 can be altered to improve the representation of the load case. The forces in sections 3.0&4.0 acted in the Z axis only and consisted of 3 different loads acting on three blade sections.

The image below shows a segmented loading test. This experimental setup, combined with the data acquisition method detailed in section 5.1, can prove to make a reasonably representative experiment to the loading case defined in section 3.0.



Figure 25 - Segmented loading test supporting structures (Kumar et al., 2019)



Figure 26 - Full view of segmented loading test (Kumar et al., 2019)

5.2 Proposed Experiment Alterations

If the segmented sections from figures 25 and 26 were altered to include a jig/chuck any desired shape can be inserted and loaded onto the propeller. This set-up will allow the loading case shown in section 3.0 to be more accurately represented and increases the likelihood of correlation between the simulation and experiment.



Figure 27 - Suggested alterations to segmented loading test involving a chuck (Sealy, 2007) and insert

As shown above, the setup can be altered to apply the loads in the desired areas. This would be very costly due to the size of the propeller; however, it would be a cost-effective solution compared to cavitation tunnel testing.

Lights will need to be inserted into the large fixtures so that the DIC cameras can take snapshots of the deformation of the bottom of the blade and around all sides of the blade to collect data on the maximum deflection and pressure at the loaded areas of the blade which can then be correlated to the simulation.

5.3 Experiment Alternatives/Suggestions

Due to the size of the blade, the model can be scaled down to decrease testing costs significantly. However, this will introduce more variables into the experiment and increase the likelihood of experimental error as fluid flow around a propeller blade is a very complex scenario. There are already many unknowns and induced errors due to assumptions.

Alternatively, the blade can be set up in a cavitation tunnel where the shaft velocity and stream velocity are specified. Alterations to the acquisition method, such as using an encoder that sends impulses to trigger strobe lights and cameras to collect test data that can be correlated to the simulation, will need to be made. This method would be much more costly as there are many unknowns to account for, such as the considerations detailed in section 2.8. This test method can also confirm the validity of the specified load case, as the loading can be measured based on the assumed parameters and then correlated (van de Sanden, 2020).

With the optimisation method described in section 2.8, many conditions of the propeller blade will be defined, and a more representative cavitation tunnel test can be performed.

6.0 Task 5

6.1 Latest Technical Literature on Composite Propellers

Several local impact events can occur to a propeller blade, such as collision with debris or other crafts. Impact with ice is a complex problem due to ice bodies' variable shape and size (Islam et al., 2022).

The latest technical literature on composite propellers focuses on low-velocity impact damage. Impact studies are conducted infrequently, and understanding composite propellers' impact behaviour and how to design them to resist impact damage is needed. The design of impact-resistant composites will be assisted by using domain-specific knowledge of impact damage responses (Islam et al., 2022).

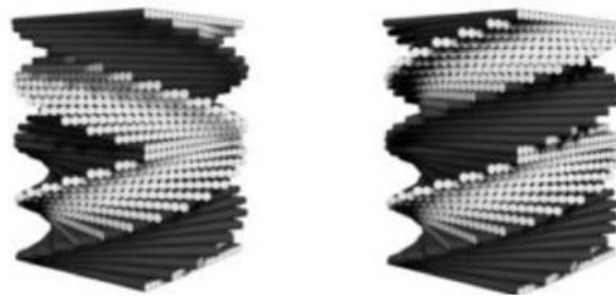


Figure 28 - Illustration of a symmetrical helicoidal structure (left) and helicoidal structure (right) (Islam et al., 2022)

Helicoidal structures have shown an improvement in the following over traditional cross-ply layouts:

- 'Fibre pull-out energy
 - Inter-laminar fracture toughness
 - Residual strength'
- (Islam et al., 2022)
- Impact resistance (Ghazlan et al., 2021)

Therefore, this type of laminate shows much promise for future use to improve the impact performance of composite marine propeller blades. This information, along with the new suggested optimisation technique for composites in section 2.8, can be combined to improve the propeller blade design from sections 3.0&4.0.

Note: Symmetrical helicoidal layups are used more often than single helicoidal layups to avoid warping but, as a compromise, have a lower short beam shear strength (Apichattrabrut & Ravi-Chandar, 2006).

6.2 Relative codes of practice and Standards

6.2.1 Fishing Vessels (Codes of Practice) Regulations 2017

For the design produced in this report, the ply layup must be in line with an applicable code of practice or specification of an EEA state other than the UK (Gov.UK, 2017). Therefore the product must be certified by an acceptable board if the helical ply layup (section 6.1) is prototyped for production.

6.2.2 ISO 20233-1:2018

This standard covers a model test method for propeller cavitation noise evaluation (ISO, 2018). If the cavitation tunnel test method is selected to validate the simulation carried out in section 5.0, then ISO 20233-1 should be followed for a cost-effective and simplified test method.

6.2.3 ISO 19030-1:2016

ISO 19030-1 discusses general principles for variable pitch propeller performance; one section covers ship efficiency (ISO, 2016). The main goal of this standard is to promote emission savings and reduce the carbon footprint of large vessels. The results of the optimisation run led to a high stiffness value that can negatively impact the efficiency of a composite propeller. Potentially setting a stiffness constraint backed by research on optimal stiffness values can improve the efficiency of the blade.

7.0 Conclusion

A proposed optimisation method for use with composites has shown promising results; it works on a two-step model that improves the optimisation of the composite by collecting additional data that would need to account for by external testing.

The optimisation of the blade composite has given results within the specified constraints, and discrete variables have been used to ensure the blade is manufacturable.

A segmented loading experiment will cover the main goals of comparing results between the simulation and experimental results; if there is little confidence in the assumptions made, a cavitation test can be performed to confirm the load case. However, this would be more costly.

Helical structures have shown promise to improve the design of the optimised composite, and standards relating to propeller efficiency will need to be considered as the optimised blade has a high stiffness value which will negatively impact the efficiency of a naval vessel.

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