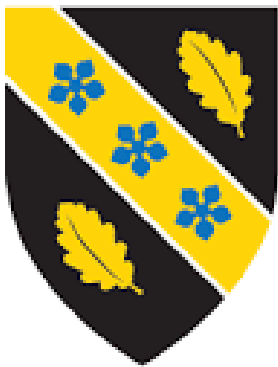


Lowri Williams

2014479

Structural & Fluid Analysis



Prifysgol Cymru

Y Drindod Dewi Sant

University of Wales

Trinity Saint David

ACMA6010

**Designing a Tank Propeller: Structural
Design**

Lecturer: Kelvin Lake

Contents Page

1.0	Introduction.....	Page 3
2.0	FEA optimisation techniques.....	Page 4 - 5
3.0	Creating a model in Design Studio.....	Page 6 - 9
4.0	Optimising the structure.....	Page 10 - 15
5.0	Development of the component.....	Page 16 - 18
6.0	Relating the design.....	Page 19 - 20
7.0	Conclusion.....	Page 21
8.0	References.....	Page 22 - 23

1.0 Introduction

Throughout this report, we'll be demonstrating the competence in the application of the suitable software package which is Design Studio. We'll be using this to investigate the engineering structural and the fluid issues, along with the cognitive skills, in the formulation of a problem with the chosen engineering specialism. Through the course studies, we've been discussing optimisation techniques that can be used within FEA. In this assignment, we will look at building on this and showing the knowledge we've gained throughout. The skills which will be show are optimisation, use of Design Studio and furthering knowledge by researching on optimisation.

2.0 FEA optimisation techniques

Throughout this section, we'll be discussing FEA optimisation techniques and reference them from appropriate sources. We'll also be presenting how they've developed historically and discussing how they may be developing in the future paths. We'll also discuss at a point of how they improve the design processes.

Optimisation is an engineering design methodology which uses a mathematical formula of a design issue to support selection of an optimal design with many alternatives. This is the "greatest degree or best results obtained or obtainable under specific conditions" (K, Lake., 2022).

A FEA optimisation technique is the **GTAM/GSAM ANYSYS Optimisation Software**. This is a topology optimisation software with a GTAM and ANSYS structural optimisation that has GSAM. These are "Two fully integrated ACT extensions enhancing ANSYS Workbench with the advanced structural and topology optimisation capabilities of OmniQuest Genesis" (Advanced Engineering., 2022). This software allows the users to access the entire suite of optimisation capabilities within the market today. This allows users to look at new designs, identify issues and resolve them and reduces the mass and costs of material of designs that already exist. This then guides any engineers to the most structurally effectual use of materials. A programme version of the genesis which has far more capabilities for optimisation is **Genesis Design Studio**. This software allows the user to display FEA (Finite Element Analysis) models and allows them to create GENEDIS data designs. This also allows the user to display analysis and optimisation results. This software is easy and fast to create Genesis datas, fast to post processes and helps create reports and presentations for the user to evaluate. Optimisation has a fundamental improvement on design processes. IT can give you clarity on designs and you can comply with the laws and regulations throughout. It can also optimise the way you use CAD. For example, when design specific parts on CAD you can then optimise the part to make sure it will function correctly and not fail within an assembly.

GTAM offers exportations to VR&D which is the Vanderplaats Research & Development, Inc, the leading global provider for the optimisation technologies and services. They specialise in varieties of engineering optimisation software to solve complex client's problems by providing solutions. This then enables the ANYSYS users to access extended optimisation techniques which include Topometry, Topography, Shape and Sizing methods and techniques. Furthermore, below are the different optimisation techniques and how they improve the design process:

- **Topology Optimisation** is a method that spatially optimises the distribution of a material with a method of constraints which are established by minimising a predefined cost function.

- **Topography Optimisation** is an optimisation capability which allows the user to find the shape and location of the beaded patterns to allow the panels to be stiffened.
- **Shape Optimisation** finds the best possible way of looking at the geometry of the structure, such that the desired behaviour is improved while the constraints are considered.
- **Sizing Optimisation** is an optimisation capability which permits the user to look for the best dimensions of a designable element for example like composites, bars, and shells. This is typically per group of elements. Sizing optimisation was developed in the 1980's.
- **Freeform Optimisation** is a new type of optimisation that allows the user to look at the best location and shape of the patterns that would stiffen the structures. This type can also find the best location of the grid for any type of optimisation.
- **Topometry Optimisation** is an exclusive optimisation capability which allows the user to find the 'optimal distribution' of the sizing dimensions which rules over the structure. The thickness of each material is a design variable. This is like topology as it can be found to look for the most optimal spaces. Then the difference it has to topology is that this optimisation technique allows the user to find the best places to insert the additional materials. This is a new optimisation process.

What backs up the historical development is the 'Advances in computing power and in computer-aided engineering (CAE) software now make it possible to create virtual prototypes of potential designs prior to building and testing expensive physical prototypes' (R, Averill., 2011). Previously, the history of optimisation is that it was only successful due to it being relied heavily on limitations of a human's intuition and their experience. Therefore, the users would need to have incredibly good knowledge on the systems as it's not as straight forward as tutorials/training would be in the present day.

Looking into the future for optimisation, it's inevitable that someday there will be a hybridization of optimization tools. Over the last decade or so, problems have become even more increasingly complex so there has been more time needed to solve these issues. Therefore, there are some solutions that may be taken into consideration in the future such as a "fully integrated optimization solver that smoothly hybridizes the main optimization technologies: constraint programming (CP), Boolean satisfiability (SAT), mixed integer programming (MIP), mixed integer non-linear programming (MINLP), local search (LS), and dynamic programming (DP)" *et al MG de la Banda*.

3.0 Creating a model in Design Studio

In this section, a model will be created of the blade with the correct material properties in Design Studio. This is to be laid up with 25 plies of the UD.

To align the material properties, we need to assume the force to enable us to optimise the structure on Design Studio. The force in which I will be using is:

$$L = C_L \times D \times V^2 / 2 \times A$$

Lift = lift coe x density x velocity of water x propeller area

$$\text{Lift} = 0.75 \times 1026 \text{ kg/m}^3 \times 35.62 \text{ m/s} \times 8.4 \text{ m}^2$$

For the lift coefficient, assume the angle of attack is 30 from reference (X, Yang., 2019) therefore being 0.75. This angle of attack had the lowest experimental error, therefore it's a more reliable source.

The velocity of water is from assignment 1 and the wing propeller area was calculated from the solid works model from the first assignment.

Therefore, the above calculation results are;

$$\text{Lift} = 4100.58 \text{ KN}$$

To conclude the equation lift is equal opposite to force and the propeller is submerged in the water. Even though the conditions are different, we're only looking at the ratio of pressure distributions on the blade.

Below, 3 loads have been added to the propeller blade. These are the forces in each area. These forces have been worked out to be 33% in each section and then to be multiplied by the ratios.

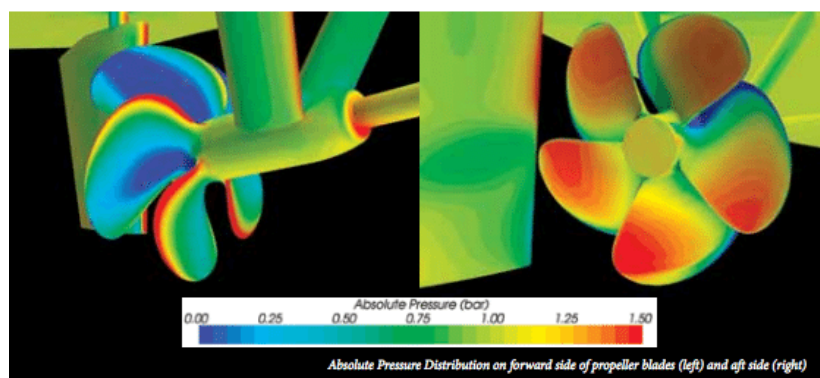


Figure 1 (B, Stockdill., 2012)

1224 is the number of grids in each section multiplied by the ratios as per above figure 1.

$$\text{Green area} = 1224 \times 0.75 = 918 \text{ KNs}$$

$$\text{Yellow area} = 1224 \times 101 = 1346.4 \text{ KNs}$$

Red area = $1224 \times 1.5 = 1836$ KNs

For the grids;

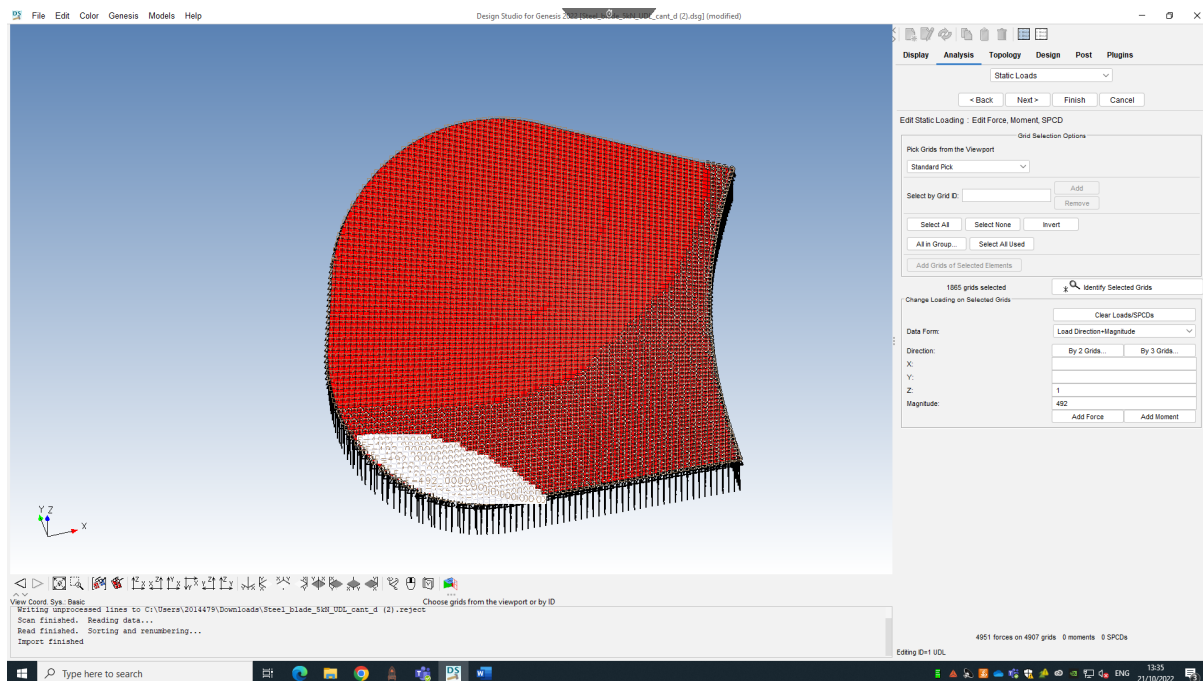
Force/Nodes x 1000 for Newtons;

$1836/1656 = 1108$

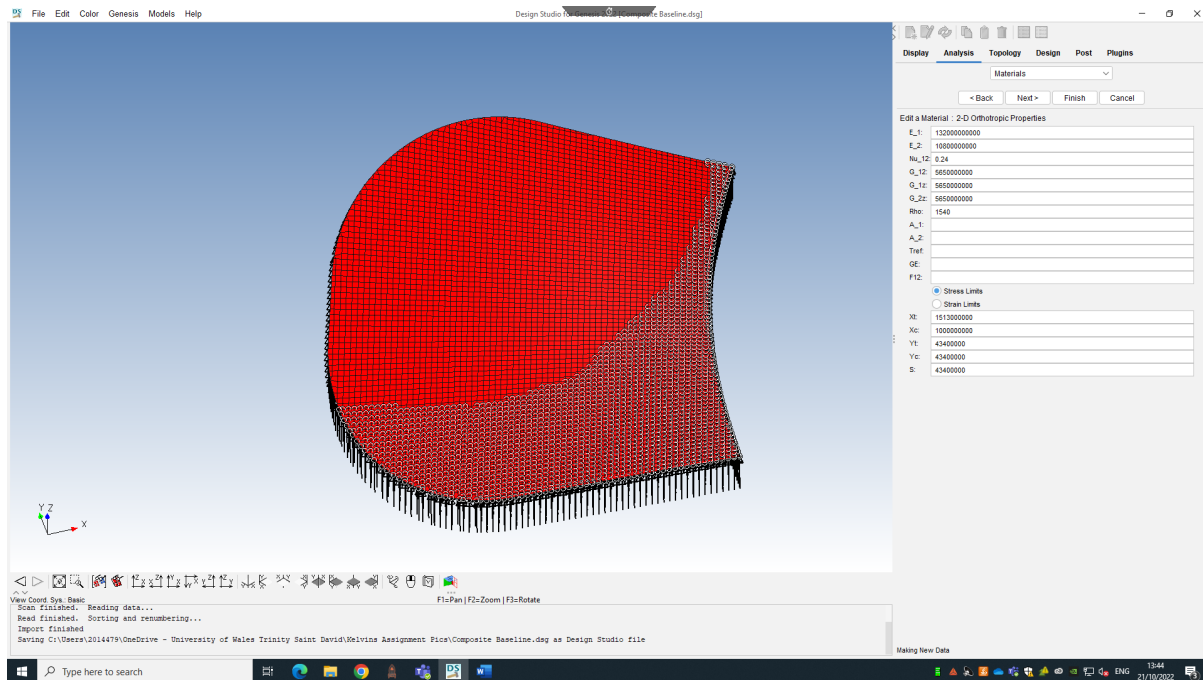
$1346.4/1430 = 941$

$918/1865 = 492$

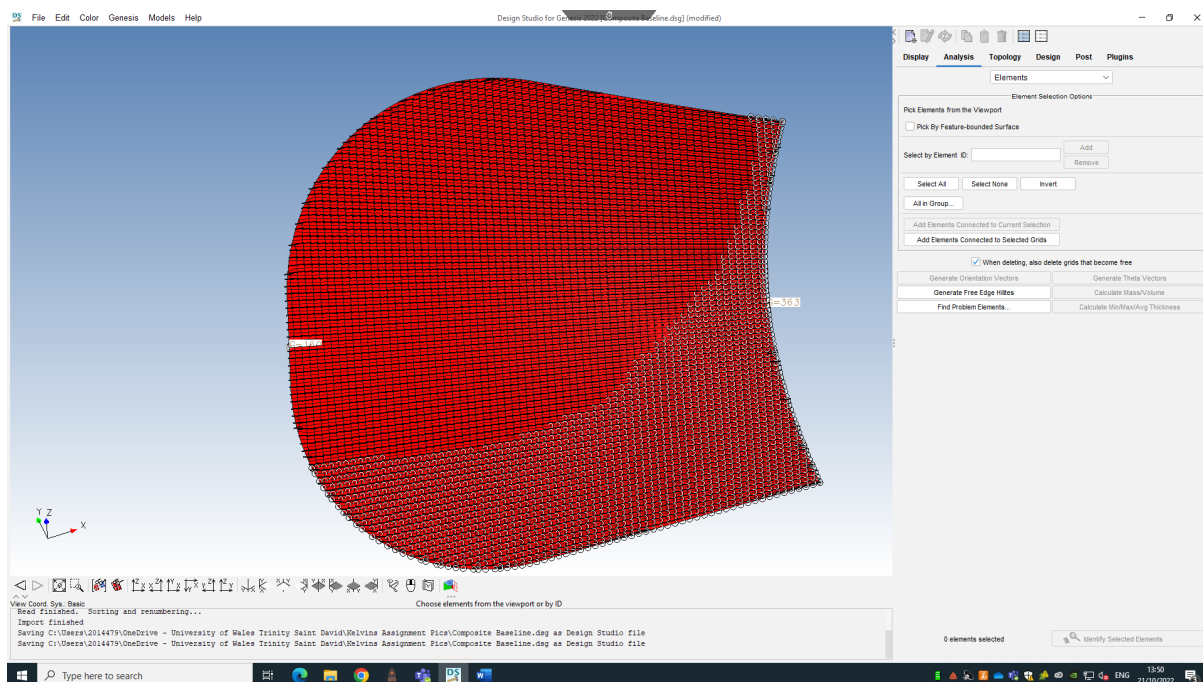
Below is an example of how I applied the loads via analysis.



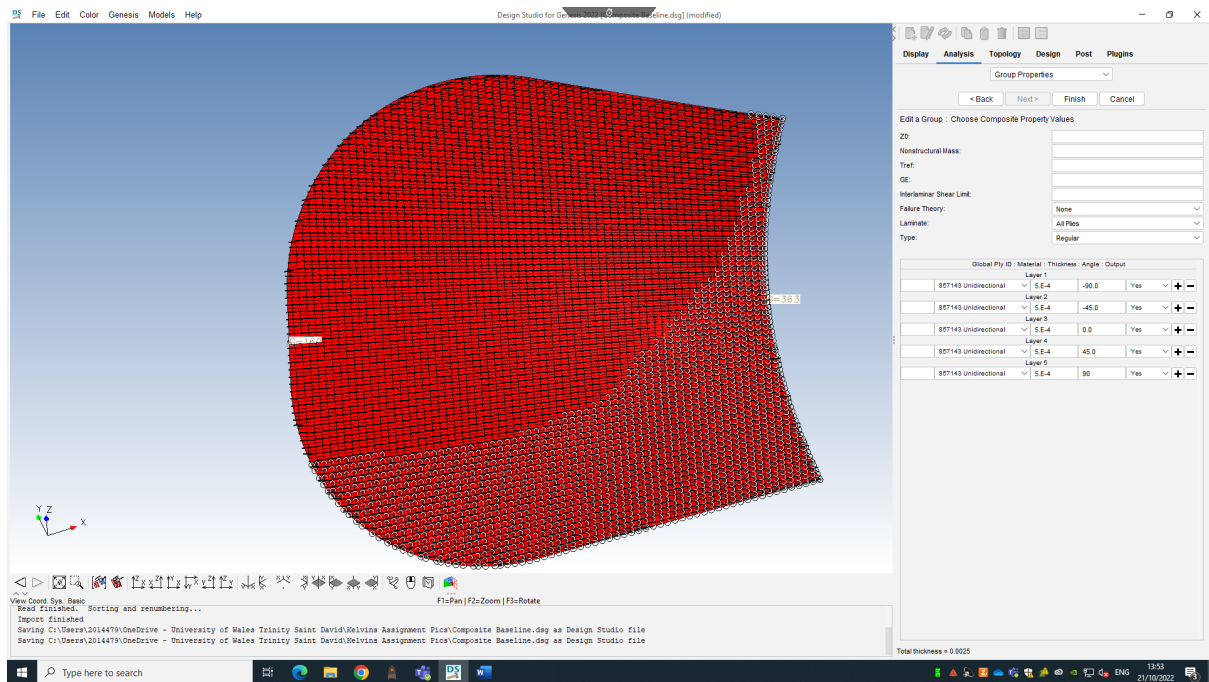
Below is the material properties aligned correctly as per assignment.



Assumption, the section of blade above is not fixed and it's passed the fillet/weld beam.



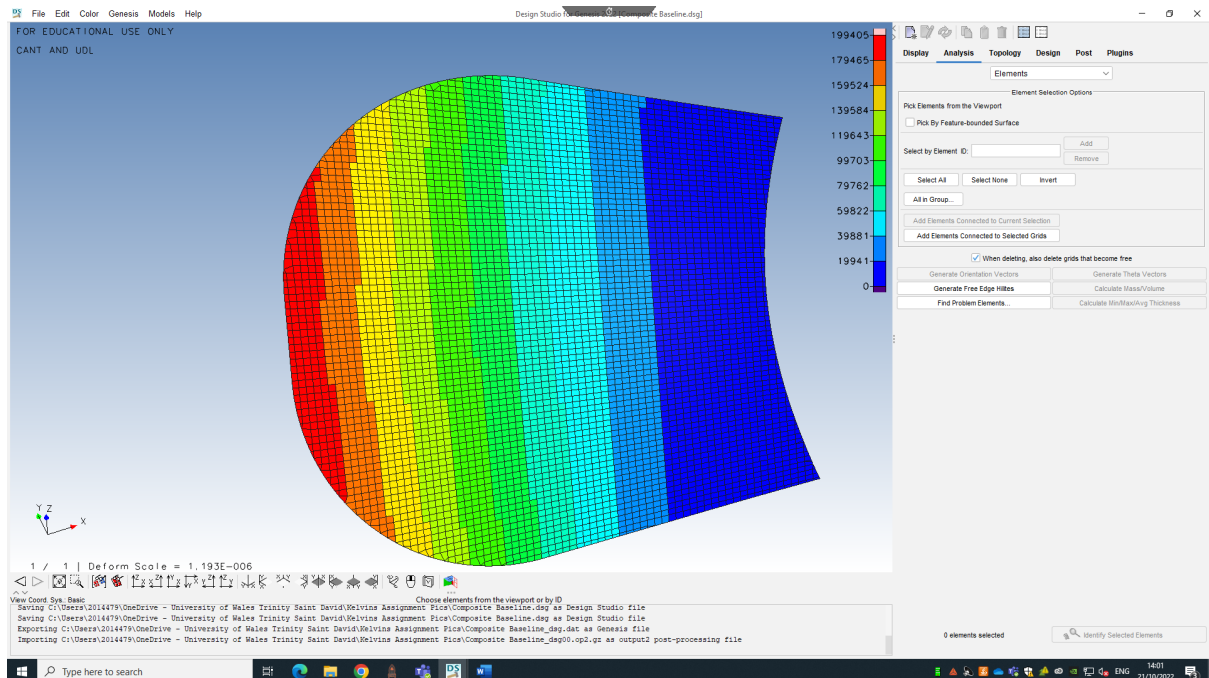
The Theta vectors have now been selected above.



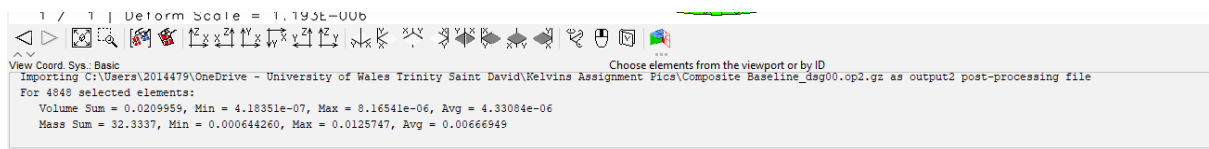
Then, the Plies have been applied to the blade. Each ply is 0.1mm.

4.0 Optimising the structure

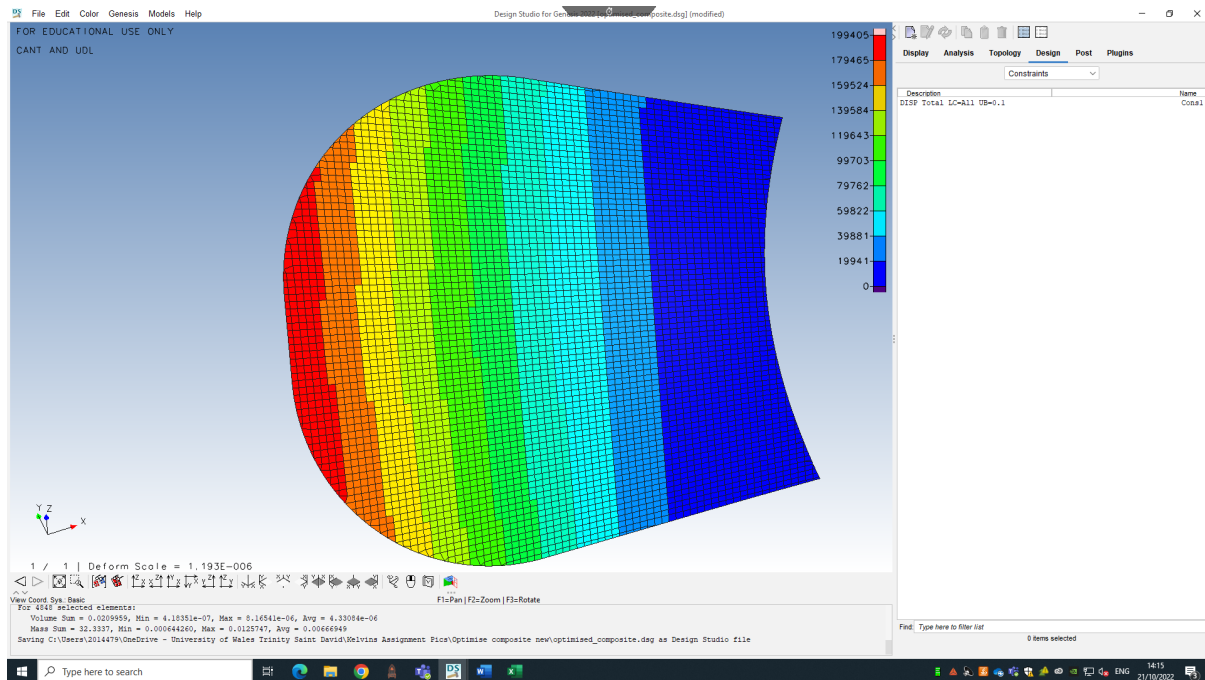
In this section, the optimisation of the structure to minimise the mass of the plate when meeting the displacement will occur. The variables that'll be selected are the number of plies in each orientation. Below is the start of the optimisation process.



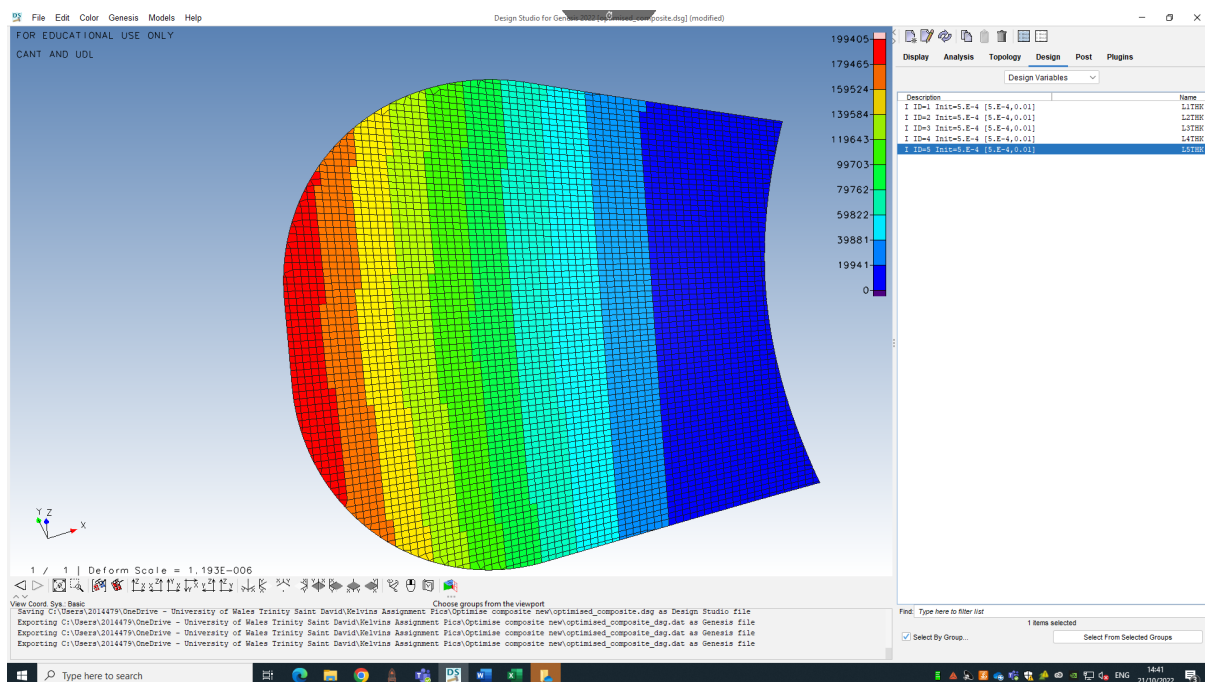
Above is the propeller blade before the optimisation takes place.



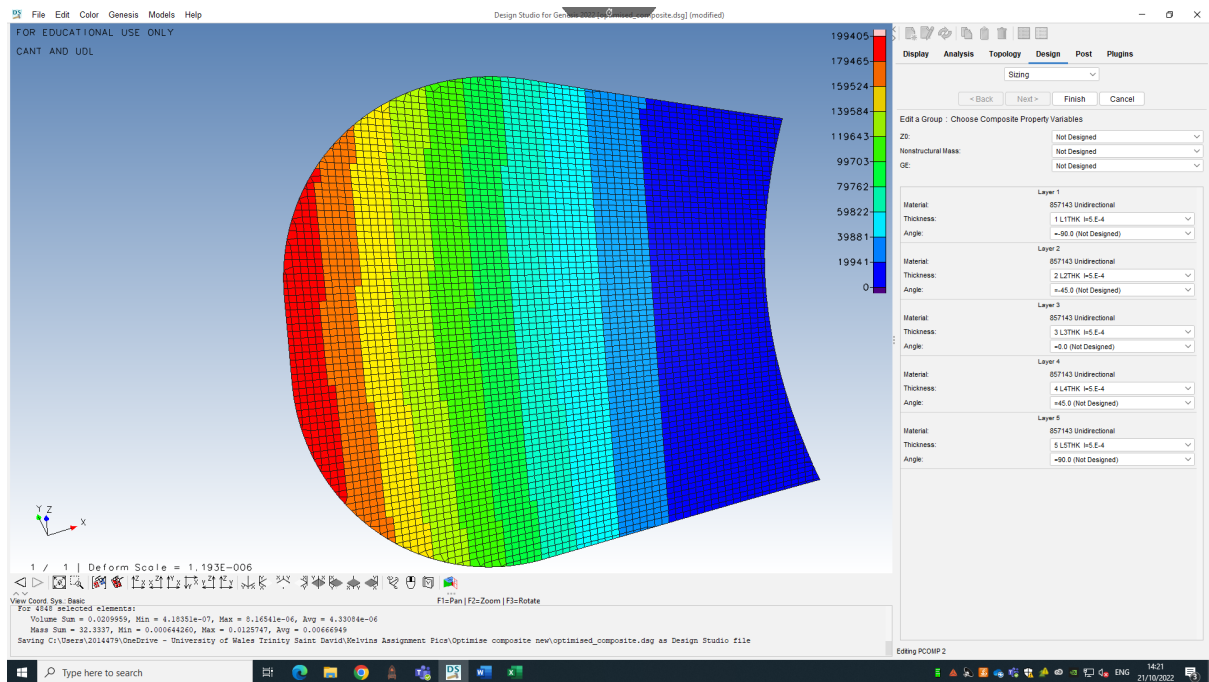
The mass of the blade is 32kg.



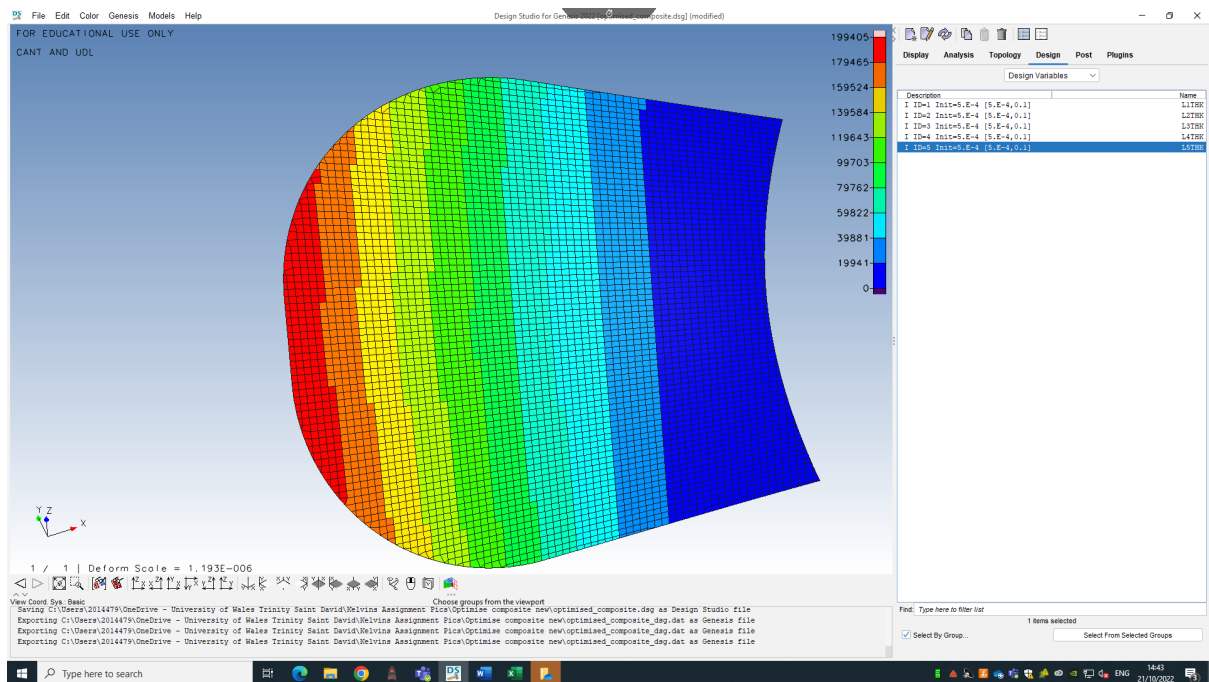
The upper bound has been set to 100mm as per the assignment brief.



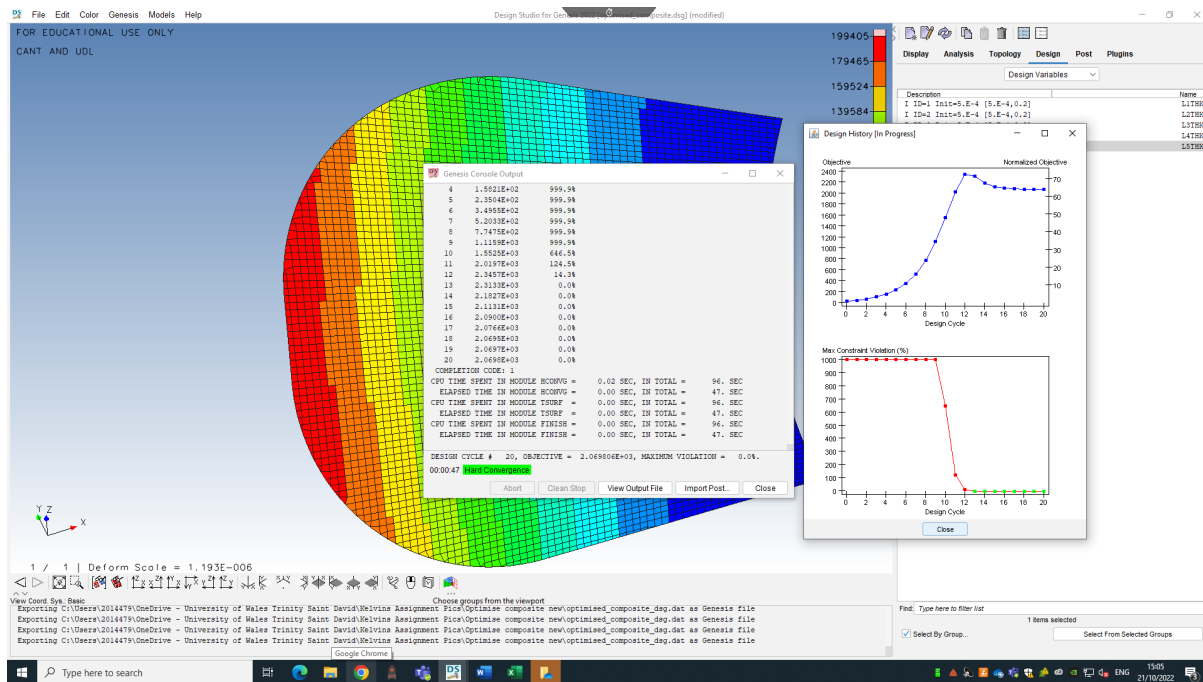
We used the same design variables for all the plys selected for each layer. A minimum of 0.5mm for the 5 plys was needed.



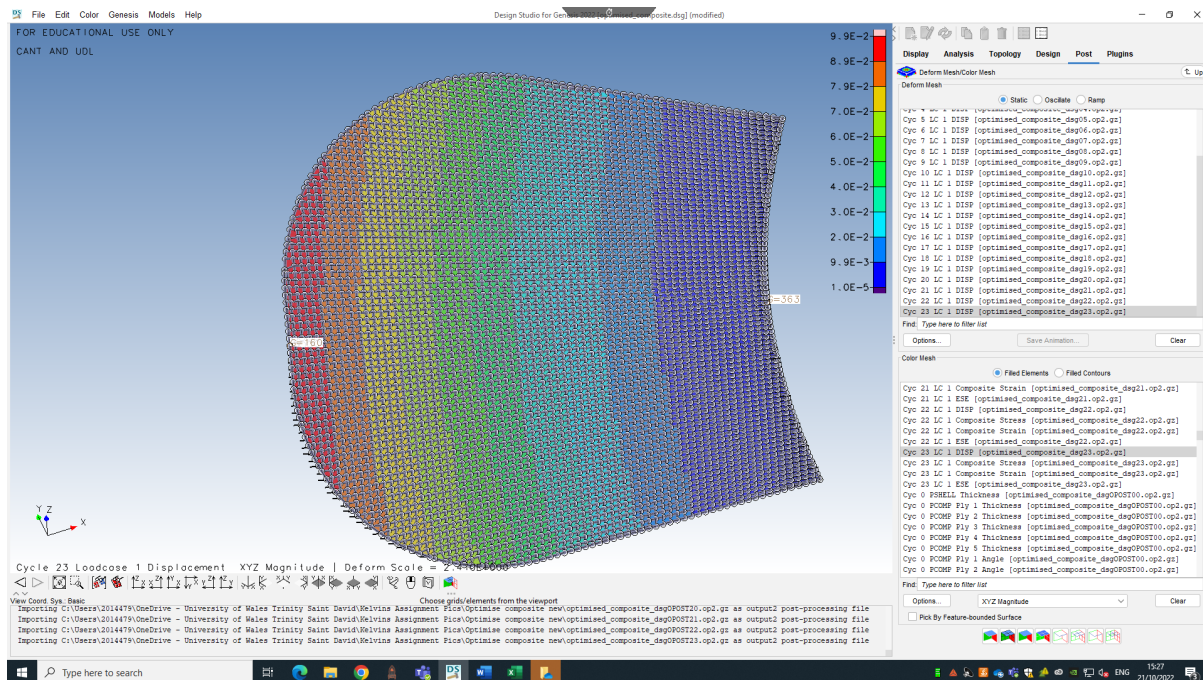
The sizing has now been implemented on all the different layers along with the orientation.

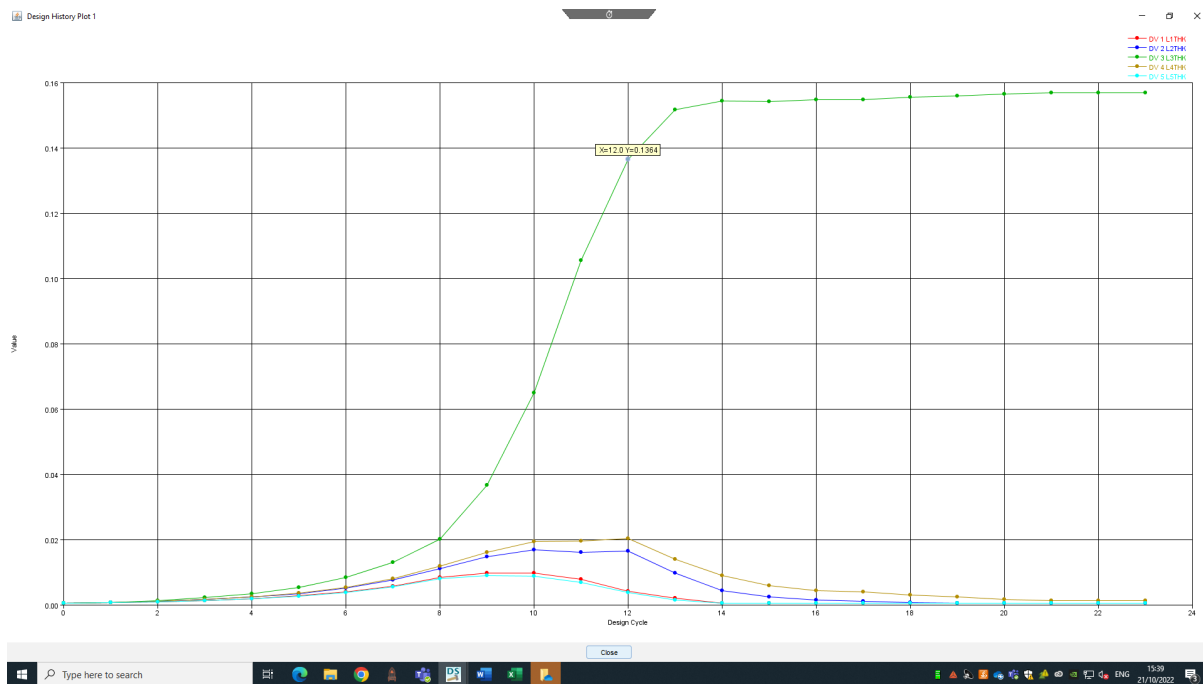


Above are the new constraints for the 5-ply thickness. This is to allow for thicker plys.



After applying a few constraints, this is correctly optimised within constraint violations at 0.2 plys.





This is a graph to show the design history. As you can see, the design variables started at 0.

Now, we need to get the results of the stiffness which is the force/deflection. The results are below:

139	DESIGN CYCLE #	23,	OBJECTIVE =	2.064667E+03,	MAXIMUM VIOLATION =	0.0%.
140	DESIGN VARIABLE #	1 =	5.009677E-04	L1THK		
141	DESIGN VARIABLE #	2 =	5.045052E-04	L2THK		
142	DESIGN VARIABLE #	3 =	1.568583E-01	L3THK		
143	DESIGN VARIABLE #	4 =	1.272453E-03	L4THK		
144	DESIGN VARIABLE #	5 =	5.012530E-04	L5THK		
145	COMPLETION CODE: 1	254	0			
146						

Normal text file length: 8,749 lines: 146 Ln: 144 Col: 56 Pos: 8,711 Windows

So, the mass = 2064.6kg

For thickness, there is $0.5 + 0.5 + 156.85 + 1.272 + 0.5$. So, therefore the thickness of the propeller blade is 159.622mm.

127	DESIGN CYCLE #	21,	OBJECTIVE =	2.066769E+03,	MAXIMUM VIOLATION =	0.0%.
128	DESIGN VARIABLE #	3 =	1.565000E-01	L3THK		
129	DESIGN VARIABLE #	4 =	1.800000E-03	L4THK		
130	DESIGN VARIABLE #	5 =	5.000000E-04	L5THK		
131	DESIGN VARIABLE #	6 =	5.000000E-04	L1THK		
132	DESIGN VARIABLE #	7 =	5.000000E-04	L2THK		
133	COMPLETION CODE: 1	256	0			
134						

Normal text file length: 8,023 lines: 134 Ln: 132 Col: 56 Pos: 7,985

The objective has increased to 2066.7KG and the plys are suggested to be laid out as follows:

-90 degrees = 0.5mm = 5plys

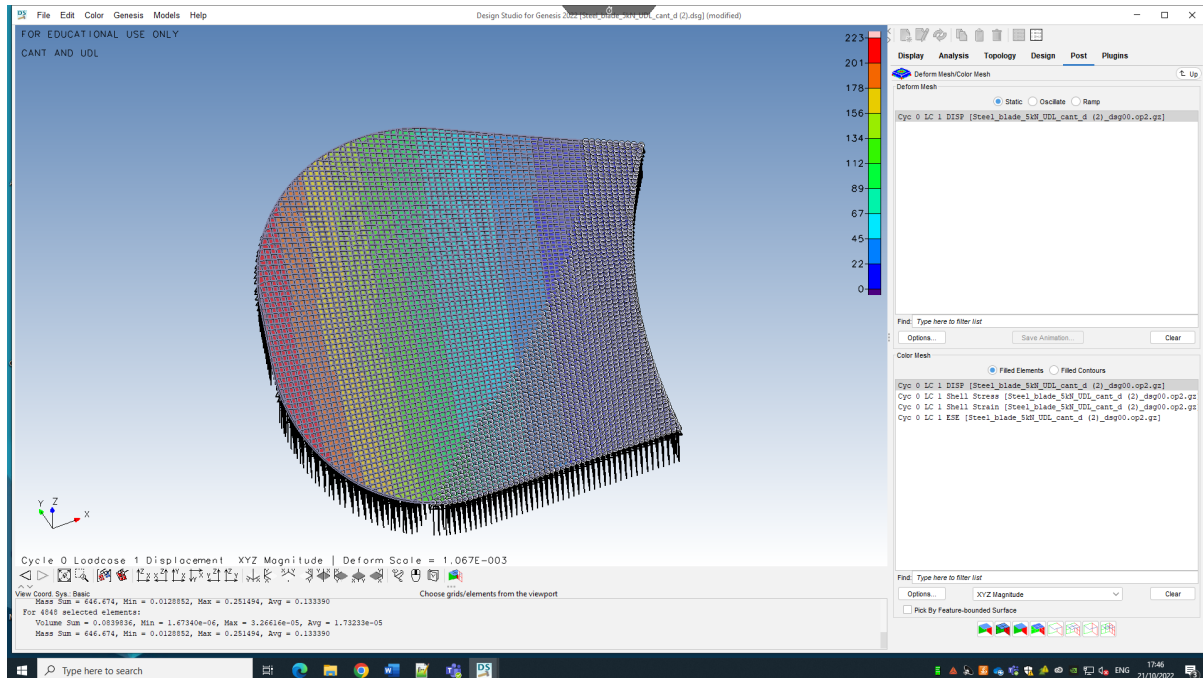
-45 degrees = 0.5mm = 5 plys

0 degrees = 156.5mm = 1565 plys

45 degrees = 1.8mm = 18 plys

90 degrees = 0.5mm = 5 plys

Total = 1598 plys



Above is the steel mass and deflection calculated.

To summarise, below is the table of results that has been able to be generated from the ongoing results that've been calculated via Design Studio optimisation results.

Run	Material	Thickness	Deflection	Mass	Load	Stiffness	Stiff/Weight
Composite Baseline	Composite	2.5mm	199405mm	32.33kg	4100.58	20.56 n/mm2	0.064 kg
Optomised Composite	Composite	159.622mm	99.9mm	2064.6kg	4100.58	41046.8 n/mm2	2.02 kg
Descrete Composite	Composite	159.8mm	100mm	2066.7kg	4100.58	41046.8 n/mm2	2.026 kg
Run Steel Composite	Steel	10mm	223000mm	646.6kg	4100.58	18.38 n/mm2	2.9 x 10-3 kg

The steel to the composite base line is similar, but the composite materials have a better stiffness but a similar deflection.

5.0 Development of the component

In this section, we'll be discussing how we think a test should be carried out to understand the deformation of the propeller blade when subject to forces. Also, it needs to correlate to the simulation carried out in the previous task. Propellers are regularly tested in 'open water tests' to determine the wake and relative rotative efficiency. The way that we would test the propeller is in a confined environment, so we can understand its thrust, torque, and its performance characteristics. Open water tests are preformed in an ideal flow condition to get these design parameters, and this is done by having two possibilities. These two are a 'Towing Tank' and a 'Cavitation Tunnel' and each facility has its own limitations. The towing tank is a long thin swimming pool where we can control all parameters and we can tow propellers down there to show their performance. The cavitation tunnel is effectively like a wind tunnel with a circle of water where we can push it around at different speeds. When the propeller is then subject to the water, we can determine its performance characteristics. The most fundamental form of a cavitation number is defined as the cavitation number = static pressure head / dynamic pressure head.

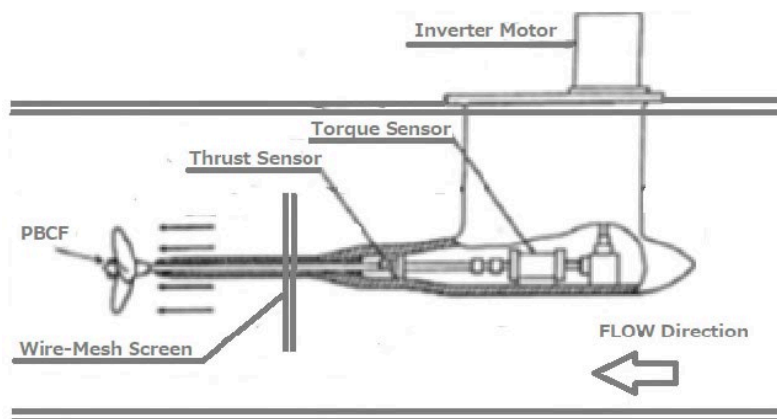


Figure 2 (K, Kimura., 2018)

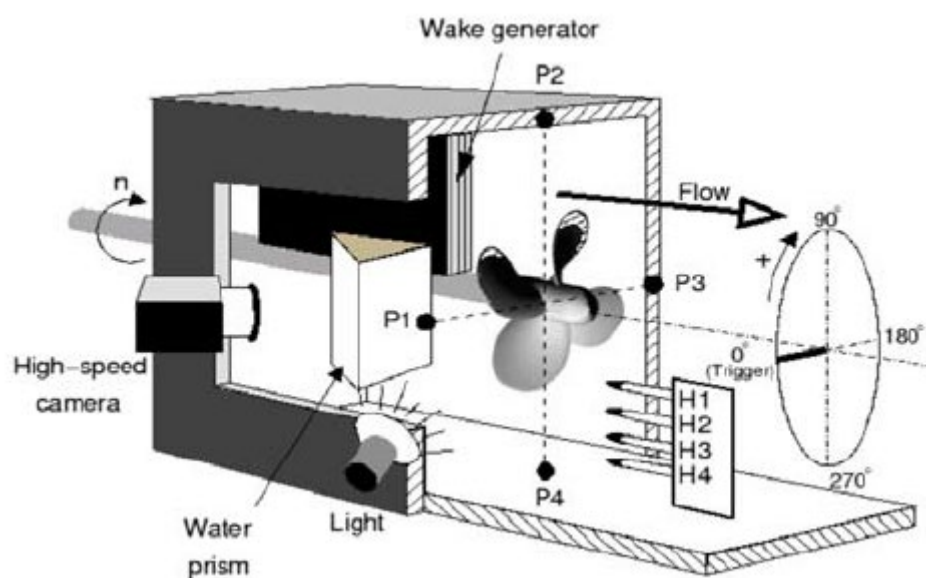
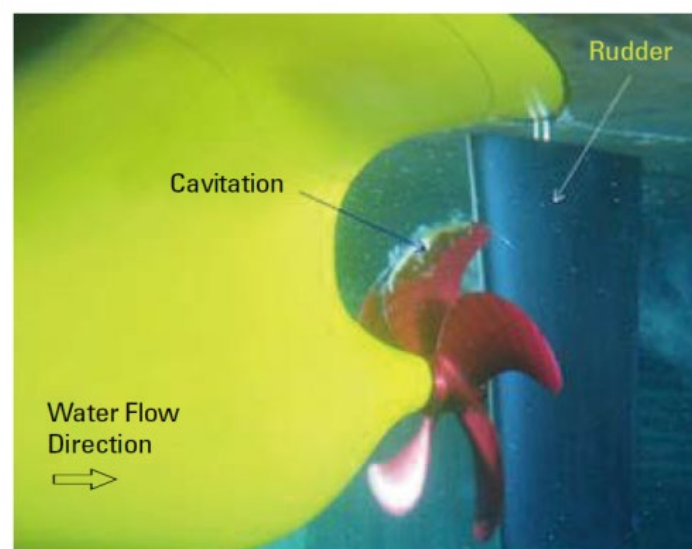


Figure 3 (F, Salvatore., 2006)

For this experiment, we will choose the cavitation tunnel. So, to conduct this experiment the propeller is mounted in the centre of the cavitation tunnels measuring section as seen in figure 3. This is then driven by a shaft from upstream. For the start of the test, it's been said by *UKEssays*. (November 2018) that "The cavitation number and the velocity of the incoming fluid are set before the test". A non-rotational smooth transition from the upstream shaft and propeller hub is settled. At the open water test, we measure the thrust and torque at a range of different advance numbers (which is measured in Joules) and the cavitation numbers (in omega) by differentiating the shafts speed and the tunnels pressure at constant velocity. Cavitation tunnels are "equipped with stroboscopic lights that illuminate the propeller intermittently such that propeller blades are always seen at the same position" (V, Bertram., 2012). There may be some limitations in the test, which include the measuring system requiring a lower velocity. What we can obtain from the tests is any combination of ahead or astern conditions with either a positive or negative thrust/torque can be found. For example, this can be tested in all four quadrants of the blades to get an average answer. For the controlled pitch propeller, the procedure for this is repeated for different pitch settings. The different water velocities are used to investigate the effect of the Reynolds Number. We measure the thrust, torque, and rotations per second by using an instrument called a dynamometer. The dynamometer is run with a dummy hub to back out the non-blade related thrust and torque. When the test is running, as the speed increases, the torque and thrust created by the propeller will decrease. In the test, you'll be able to see the rotational speed of the propeller is varied during the until the cavitation can be seen visually on the face and the back of the propeller.

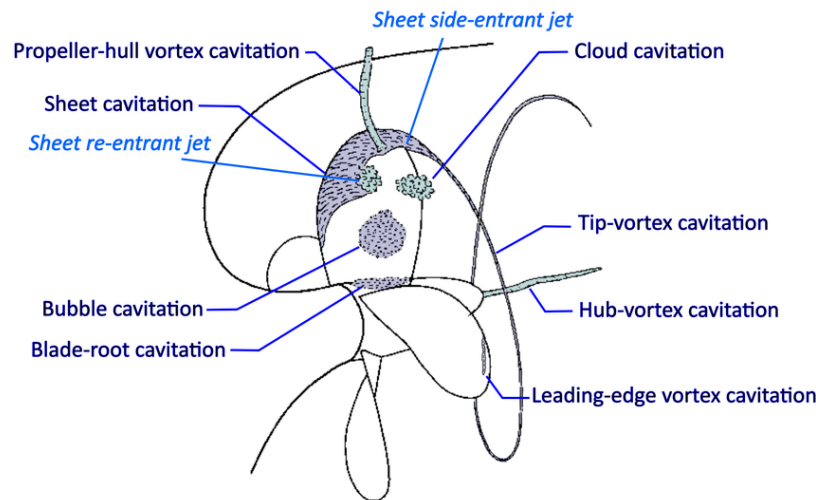


A test of observing propeller cavitation in a large cavitation tunnel. (Installation condition : model ship +propeller +rudder)

Picture to show the propeller blade being set up in a real-life cavitation test to back up the experiment considered above for our open water test.

Figure 4 (Digital Buyers Guide., 2016)

The results of the test are then presented in a diagram showing the non-dimensional thrust and the torque coefficients, the symbols are K_T and K_Q . For the open water efficiency, its known as η_0 which is a function of the advance number J which symbolises the cavitation numbers and pitch settings. Once the test has been complete and we evaluate, we can then determine the “influence of the limited size of the cross section on the flow velocity or the thrust and torque of the propeller” (SVA., 2015).



This is a diagram to show the illustration of the cavitation patterns on the ships propeller when being tested in the cavitation test.

Figure 6 (J, Bosschers., 2018)

Below, is a graph of results to show the results of a cavitation test that has previously taken place with joules v omega (cavitation number). This test was run via SVA in Germany. This gives us a real-life visual conception.

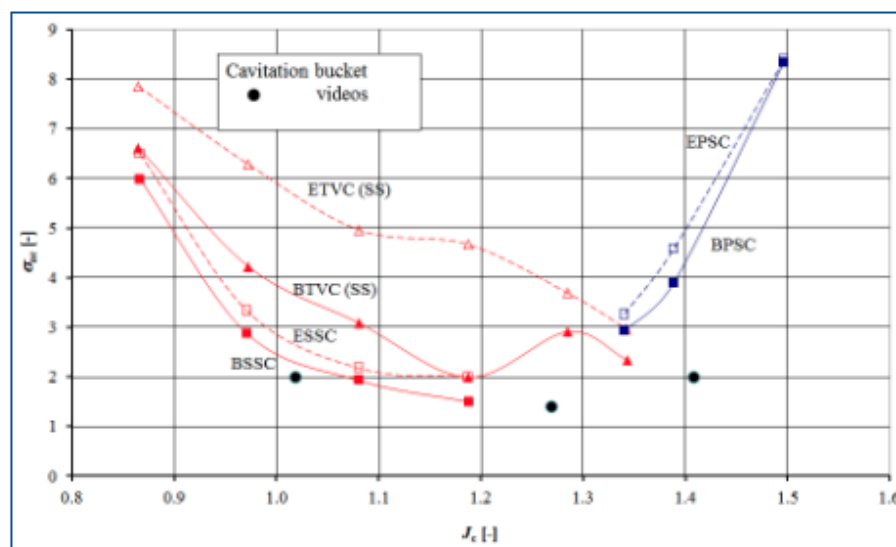


Figure 7 (SVA., 2011)

6.0 Relating the Design

Now the tests on Design Studio and suggestions for real life testing have been determined, we can now relate the design to technical literature and standards which cover the component.

To relate to industry standards, we will investigate ships and marine technology. What relates to the analysis we've conducted; we can investigate the propeller shaft revolution indicators. This ISO standard is "ISO 22554:2015 Ships and marine technology — Propeller shaft revolution indicators — Electric type and electronic type". This investigates the construction, performance requirements and methods of testing. This standard defines the propeller shaft revolutions, which is what we researched in relation to the cavitation testing. Throughout the cavitation test, this ISO standard would need to be taken into consideration to make sure the propeller is achieving the correct number of revolutions. Today, marine propellers remain the propulsion mechanism standard for underwater vehicles of surface ships. As Prof. A. H. Techet., 2005 says "We still need propellers to generate adequate thrust to propel a vessel at some design". There are multiple standards that relate to our design. These include some standards researched bullet pointed below:

- ISO 3715:1978 Shipbuilding – ship screw propellers. This gives us the correspondent in several languages which relates to the ship's propellers.
- ISO 22555:2002 Ships and marine technology – Propeller pitch indicators. This investigates the construction and performance methods. It also includes the tests which are required for testing the pitch propeller indicators.
- ISO 484-1:2015 Shipbuilding-ship screw propellers-Manufacturing tolerances. Part 1: Propellers of a diameter greater than 2.5m. This determines the deviations of tolerances that are permitted in some cases subject to discretion of customers.
- ISO 1303-218:2004 Industrial automation systems and integration- Product data representations and exchanges. Part 218: Application protocols: Ship Structures. This standard specifies the use of integrated sources for the scope of requirements of the product. This gives us the information of a ships structural systems.

Looking into the material selections of a propeller, composite propellers are the preferred material for ship propellers. They are usually made from a fibre composite which acts like glass or carbon fibres infused with high strength resins like polyimide or epoxy. As researched, Y. Hong., 2019 technical literature paper on the composite characteristic's states "the rich material and flexible moulding provide a good foundation for the diversification of composite propeller structures". As tested in task 3.0, its evident that the composite material preforms better than the steel baseline. So, as proven, we can rate to the statement above by Y. Hong. Investigating how we would change our design; composite skins could have a band of metal around the edge to stop them being able to delaminating. This could then mean that the X grams are added to the weight of the blade and will have FEA complications.

When we've been optimising the blade in Design Studio, there is papers to relate to how we've conducted the results. Engineering Design Optimisation (EDO) is the product that's created to achieve the best solutions. To back this up we relate to R, Roy., 2008 stating "A classification of the EDO problem is necessary to select the right approach for a given problem". As we look to review optimisation, it's evident that its "revolutionary in that it aids both the efficiency and creativity of a designer, improving the quality of a design itself" (H, Kim., 2002). We can agree with this statement as the introduction of having computer packages has developed, the design analysis process has simplified due to the power of processing. Because of this, the influence of engineering designing has and will continue to expand as we've experienced throughout this assignment.

7.0 Conclusion

To conclude this report, it's evident throughout the optimisation task that the steel to the composite base line is similar, but the composite materials have a better stiffness but a similar deflection. We've consolidated the optimisation techniques by in depth researching and using technical skills to overcome the task assigned in Design Studio. We successfully designed the lay-up of the composite material and applied the correct forces through calculation and application. We made sure we used as little material as possible, so the weight of the propeller was reduced. Demonstration of competence in applying the suitable software package so that we investigated engineering structural and fluid issues was addressed and the cognitive skills. If we were to optimise a structure again in design studio, we would use a range of materials to get an even better end analysis so we could get a better range of results.

8.0 References

- K, Lake., 2022. OPTIMISATION Fluids and Structures. University of Trinity St. David.
- Advanced Engineering., 2022. GTAM/GSAM – ANSYS Optimisation Software. [GTAM/GSAM – ANSYS Optimisation Software – Advanced Engineering Birmingham \(advancedengineeringuk.com\)](https://advancedengineeringuk.com)
- X, Yang., 2019. Numerical study on the hydrodynamic performance of the semi-spade rudder and propeller; Advances in mechanical engineering. [Numerical study on the hydrodynamic performance of the semi-spade rudder and propeller \(sagepub.com\)](https://www.sagepub.com)
- Bart Stockdill, M.A.Sc., P.Eng., Mechanical Engineer., 2012. Propeller Cavitation Analysis with Computational Fluid Dynamics. <https://gcaptain.com/propeller-cavitation-analysis/>
- R, Averill., 2011. A brief history of optimization. SEIMENS. <https://www.redcedartech.com/blog/410-a-brief-history-of-optimization>
- MG, de la Banda. The Future of Optimization Technology. <https://people.eng.unimelb.edu.au/pstuckey/papers/position.pdf>
- K, Kimura., 2018. (Figure 2). Investigation on Full Scale Performance of the Propeller Boss Cap Fins (PBCF). Semantic Scholar. <https://www.semanticscholar.org/paper/Investigation-on-Full-Scale-Performance-of-the-Boss-Kimura-Ando/00c5435e4f59782764493648123cf34e1a437c2c>
- F, Salvatore., 2006. Experimental set-up in the cavitation tunnel for the analysis of a propeller in behind-hull conditions. Research Gate. https://www.researchgate.net/figure/Experimental-set-up-in-the-cavitation-tunnel-for-the-analysis-of-a-propeller-in_fig3_259672073
- V, Bertram., 2012. 2.5.1 Cavitation Tunnels. Practical Ship Hydrodynamics (Second Edition), Propellers. [https://www.sciencedirect.com/topics/engineering/open-water-test#:~:text=Propeller%20tests%20\(open%2Dwater%20tests,in%20the%20lower%20horizontal%20part.](https://www.sciencedirect.com/topics/engineering/open-water-test#:~:text=Propeller%20tests%20(open%2Dwater%20tests,in%20the%20lower%20horizontal%20part.)
- SVA., 2012. Open Water test. Hamburg, Germany. <https://www.sva-potsdam.de/en/open-water-test/>
- UKEssays. November 2018. Open Water Propeller Characteristics Testing Engineering Essay. [online]. Available from: <https://www.ukessays.com/essays/engineering/open-water-propeller-characteristics-testing-engineering-essay.php?vref=1>
- Y, Hong., 2019. Marine Composites. 13.2 The characteristics of composite propeller. Propulsion and propellers. <https://www.sciencedirect.com/topics/materials-science/propeller>

- Prof. A.H. Techet., 2005. Hydrodynamics on Marine Propellers. version 3.0 updated 8/30/2005.
<http://web.mit.edu/2.016/www/handouts/2005Reading10.pdf>
- Digital Buyers Guide., 2016. Environment-friendly propeller cavitation performance control technology. KOREAN-MACHINERY.COM. <https://korean-machinery.com/2016/03/17/environment-friendly-propeller-cavitation-performance-control-technology/>
- J, Bosschers., 2018. Propeller Tip-Vortex Cavitation and its Broadband Noise. Research Gate. Maritime Research Institute Netherlands.
https://www.researchgate.net/figure/Illustration-of-possible-cavitation-patterns-on-ship-propellers-Adapted-from-ITTC_fig2_330244472
- R, Roy., 2008. Recent advances in engineering design optimisation: Challenges and future trends. CIRP Annals - Manufacturing Technology.
<https://reader.elsevier.com/reader/sd/pii/S0007850608001923?token=C41EE39C48F9C549EE3AB9A9845109B6A1EEE6263FF7984E697D0F41090B316128FB329B9419A313DD60D51ADDF5D14C&originRegion=eu-west-1&originCreation=20221029085540>
- H, Kim., 2002. On the development of structural optimisation and its relevance in engineering design. Design Studies. Volume 23, Issue 1, January 2002, Pages 85-102.
<https://www.sciencedirect.com/science/article/pii/S0142694X01000175>
- ISO 3715:1978 Shipbuilding – ship screw propellers.
https://www.iso.org/search.html?q=Ship%20propeller&hPP=10&idx=all_en&p=0&hFR%5Bcategory%5D%5B0%5D=standard
- ISO 22555:2002 Ships and marine technology – Propeller pitch indicators.
https://www.iso.org/search.html?q=Ship%20propeller&hPP=10&idx=all_en&p=0&hFR%5Bcategory%5D%5B0%5D=standard
- ISO 484-1:2015 Shipbuilding-ship screw propellers-Manufacturing tolerances.
https://www.iso.org/search.html?q=Ship%20propeller&hPP=10&idx=all_en&p=0&hFR%5Bcategory%5D%5B0%5D=standard
- ISO 1303-218:2004 Industrial automation systems and integration- Product data representations and exchanges. Part 218: Application protocols: Ship Structures.
https://www.iso.org/search.html?q=Ship%20propeller&hPP=10&idx=all_en&p=0&hFR%5Bcategory%5D%5B0%5D=standard