



MODULE: STRUCTURAL &
FLUID ANALYSIS

ASSIGNMENT TITLE:
DESIGNING A TANKER
PROPELLER: STRUCTURAL
DESIGN.

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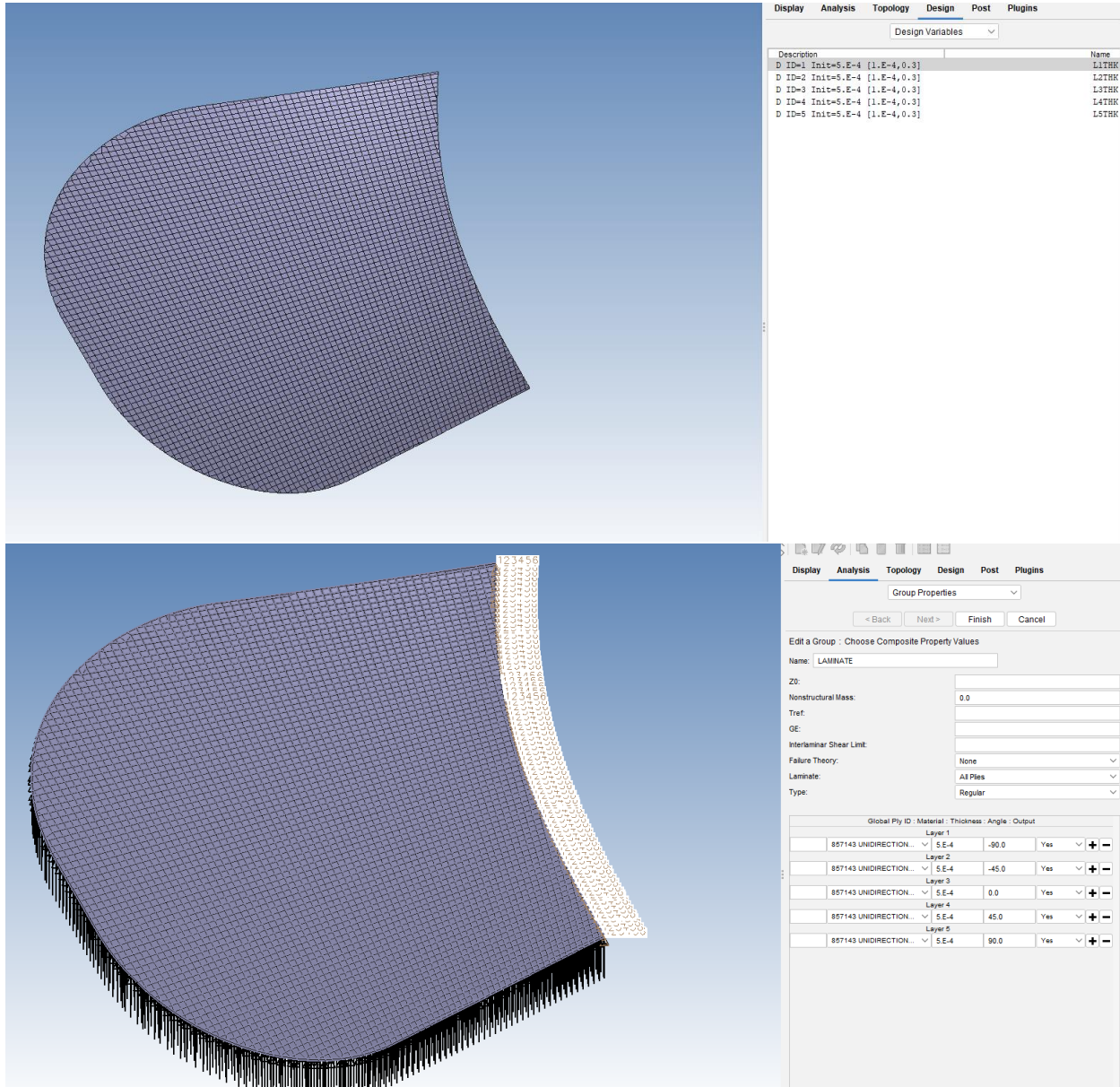
FEA OPTIMIZATION TECHNIQUES

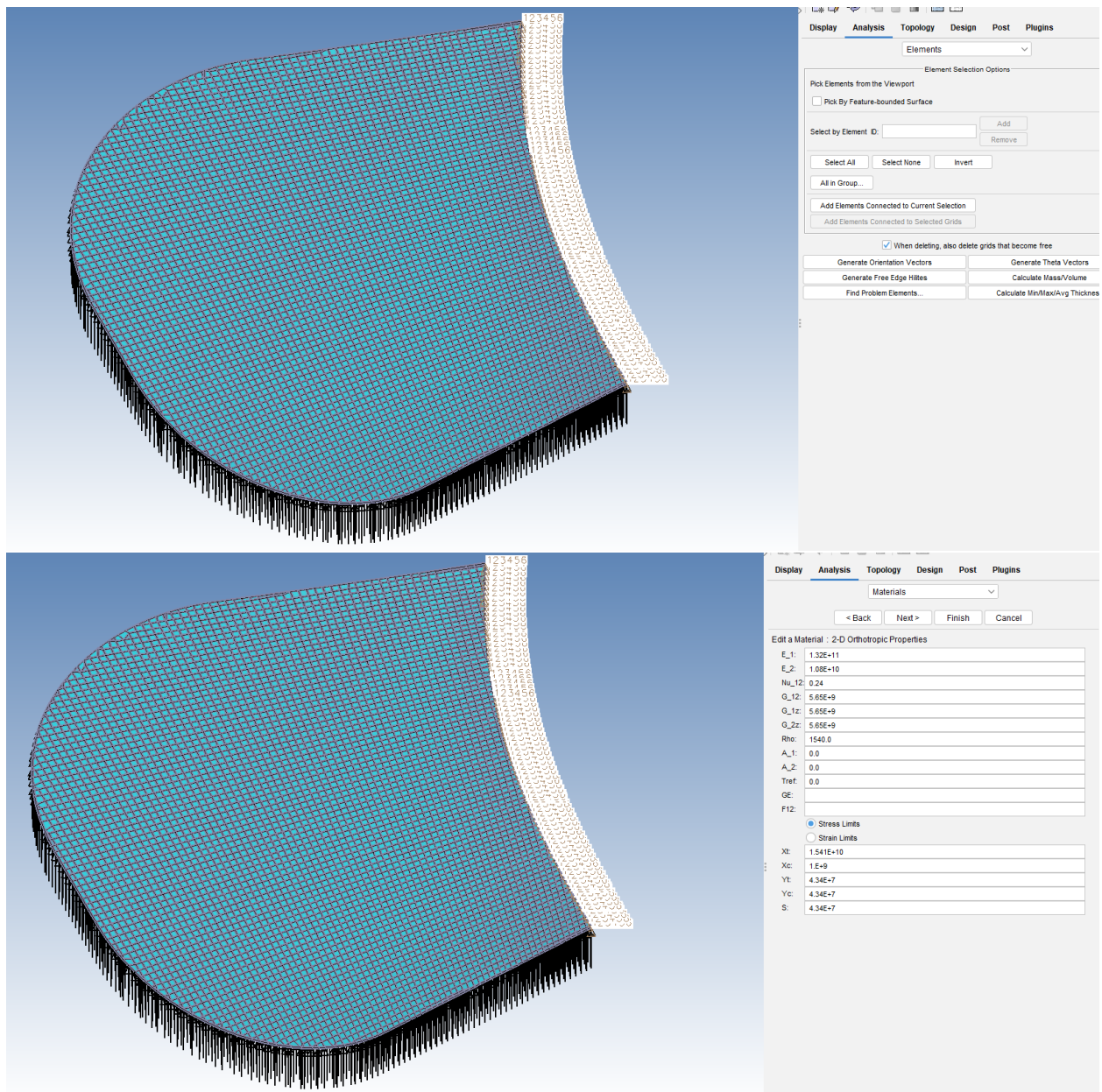
When compared to other common materials, carbon fiber composite stands out due to its superior strength, light weight, and resistance to corrosion in salt water. These qualities recommend it as a potential replacement for stainless steel in the production of maritime screw propellers. Despite these positives, pressures on blades due to the material's elasticity have a detrimental effect on hydrodynamic performance. Because of the lower stiffness and material anisotropy, hydrodynamic performance must be captured by a two-way coupled fluid-structure interaction analysis. Here, we conduct a computational study to analyze the performance of a composite marine propeller in open water circumstances from the perspective of hydro-elastic theory. Coupling a computational fluid dynamics solver based on the Reynolds-averaged Navier-Stokes Equation with a solver based on the finite element technique is the basis of the approach. The relationship between the thrust coefficient, the torque coefficient, and the open water efficiency is investigated as a function of the forward progress to propeller revolution ratio. This research contrasts the hydrodynamic performance and structural reactions of a typical steel propeller with those of a carbon fiber composite propeller. The composite propeller outperformed the metallic counterpart in hydrodynamic tests while maintaining structural integrity throughout all ranges.[1]

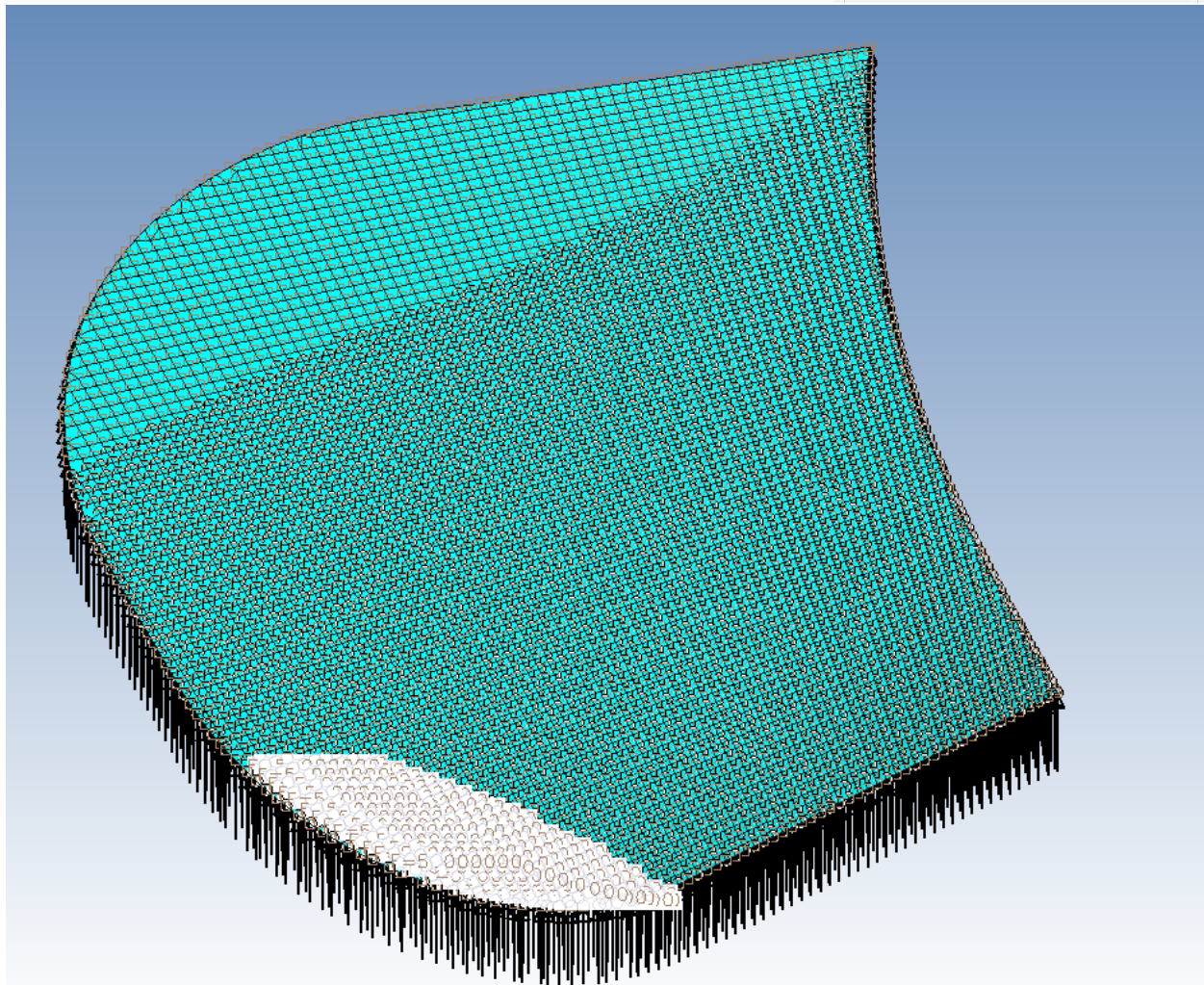
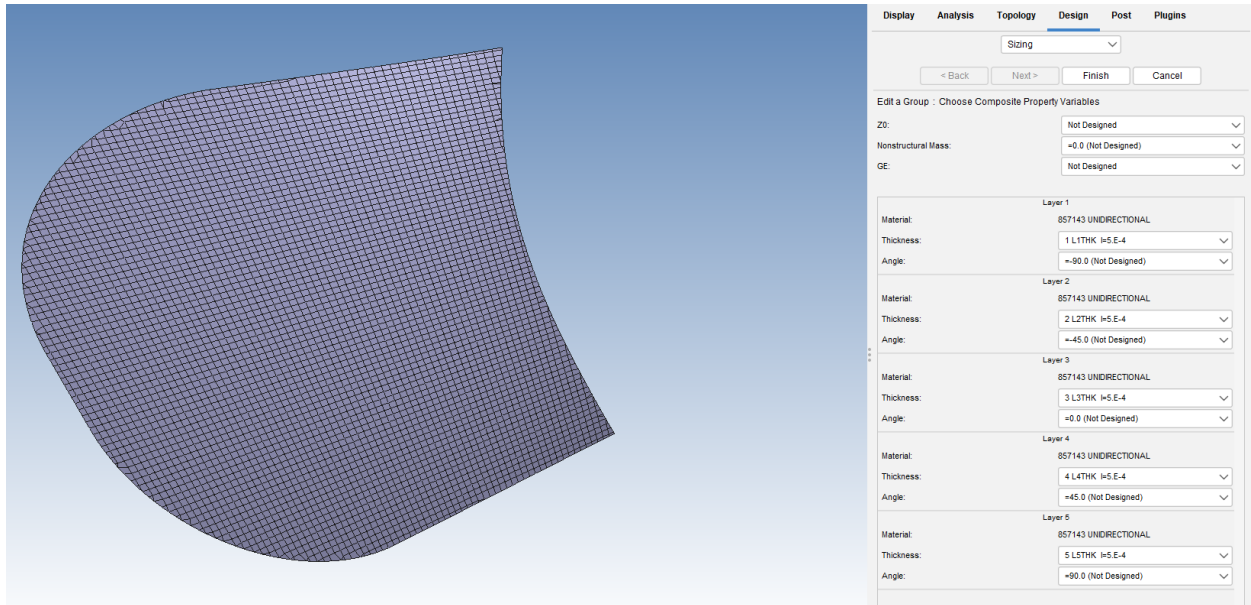
The purpose of marine propellers, which are hydrodynamic spinning components, is to produce thrust to overcome resistance. They usually have a set geometry and are quite stiff. The propellers' performance has been fine-tuned over the last several decades to maximize efficiency. Conventional maritime propeller materials include manganese-bronze, nickel-aluminum, and steel. Iron, aluminum, and steel are also used. They were effective at delivering the thrust, but they also showed several unfavorable properties, such as low specific strength (a measure of how effectively a material delivers its intended load), low fatigue cycles, vulnerability to cavitation and corrosion, and high noise and vibration levels. As a result, composite materials should be taken into account as a viable option to traditional materials for making maritime propellers. It boasts a number of benefits, including increased fatigue cycles, better acoustic characteristics, and increased specific strength. A variety of tests, including open water, self-propulsion, and cavitation, are used to assess the hydrodynamic performance of conventional propellers. Standard propellers are tested in this way on the premise that they are rigid bodies. Hydrodynamic performance must take into consideration the impact of structural deformation on hydrodynamic characteristics and vice versa for composite marine propellers, which have reduced flexural stiffness. Hydrodynamic efficiency is affected because the deformation alters the blade angle of attack. In addition to the already complicated physical factors at play, the heterogeneous character of the hull's wake causes the propellers to be exposed to very unstable forces. Accordingly, a two-way FSI study should be carried out to evaluate the propeller's hydrodynamic performance and structural reactions.[1]

MODEL OF THE BLADE WITH THE CORRECT MATERIAL PROPERTIES IN DESIGN STUDIO

Now made the propeller model in design studio with different design parameters



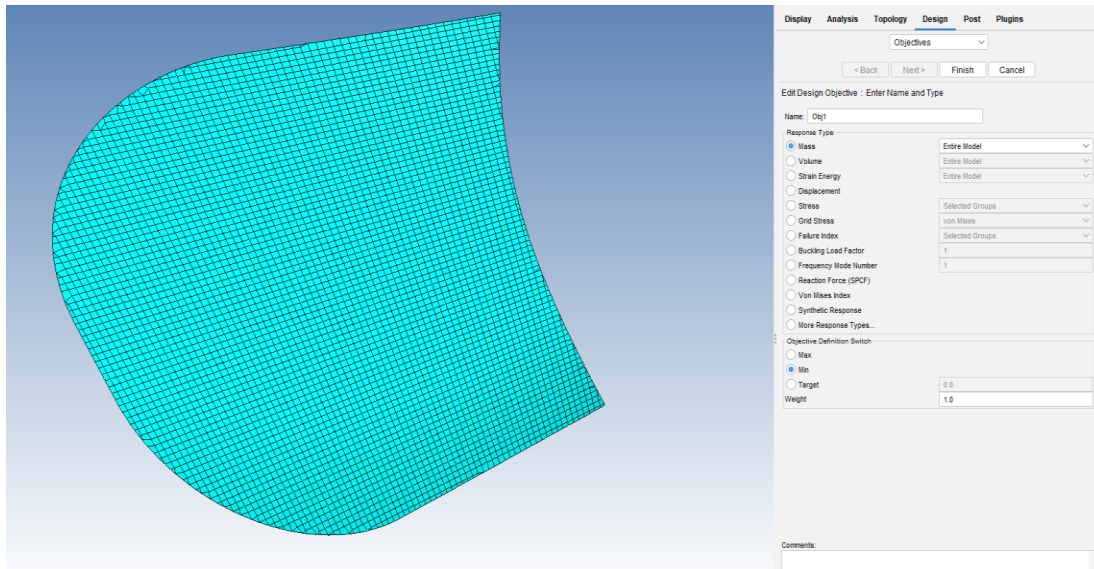
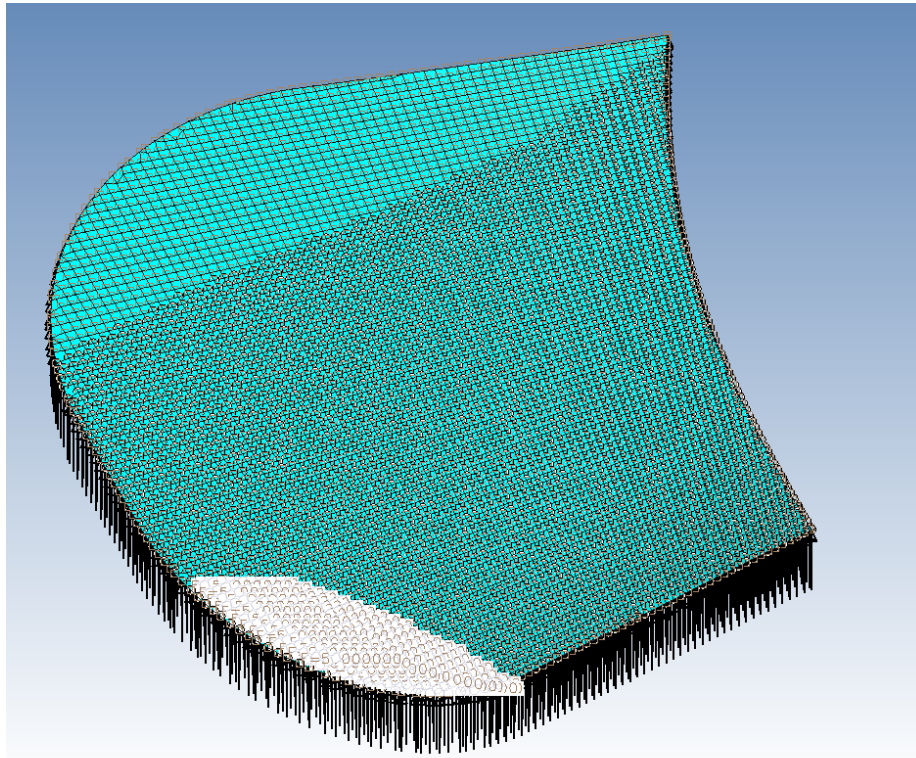


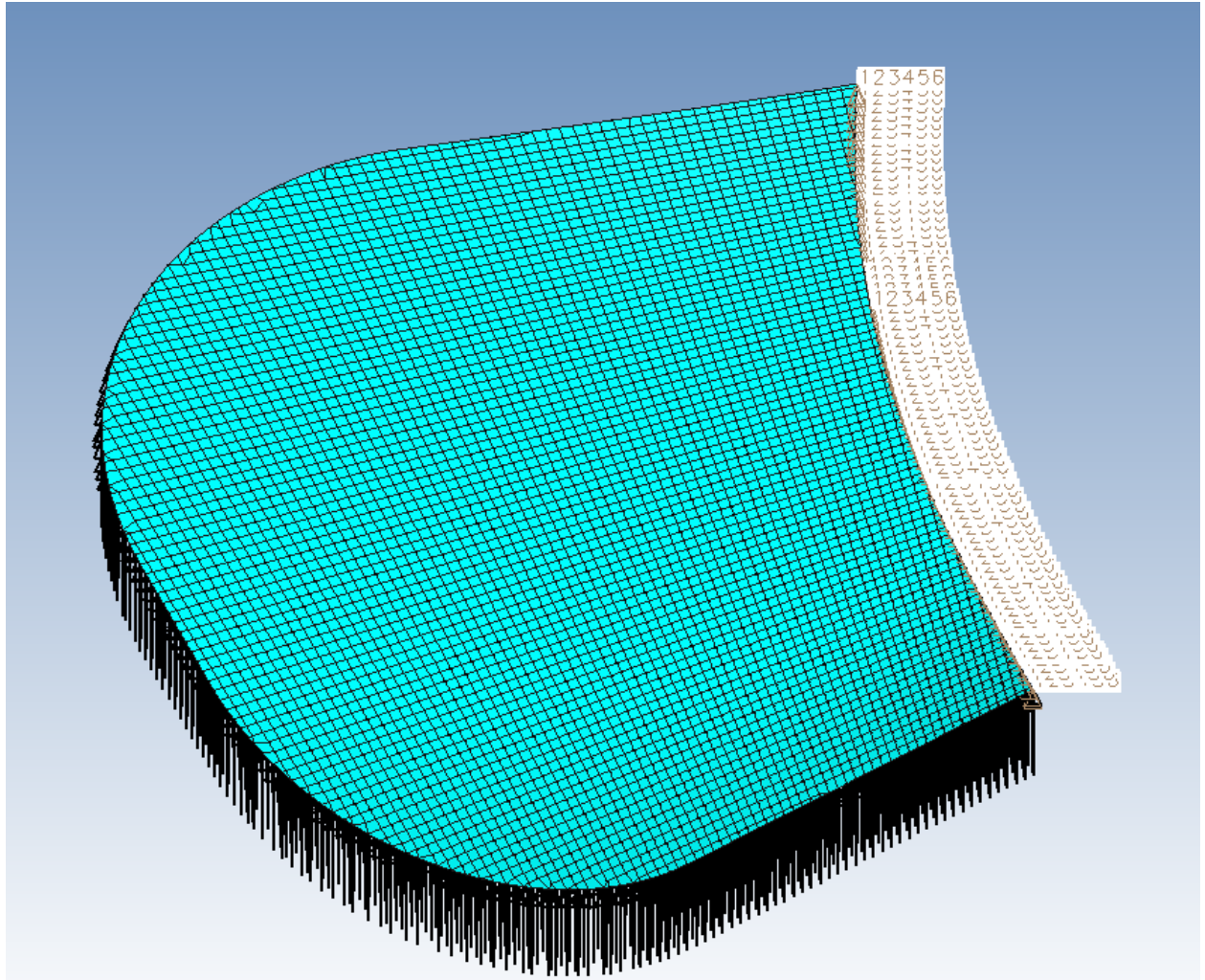


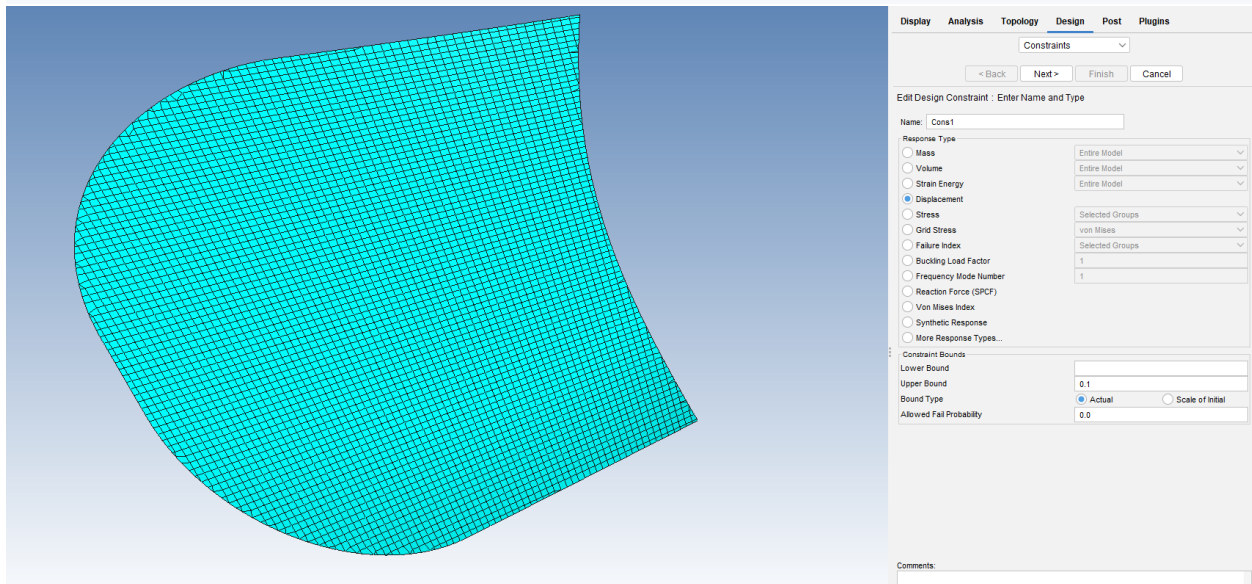
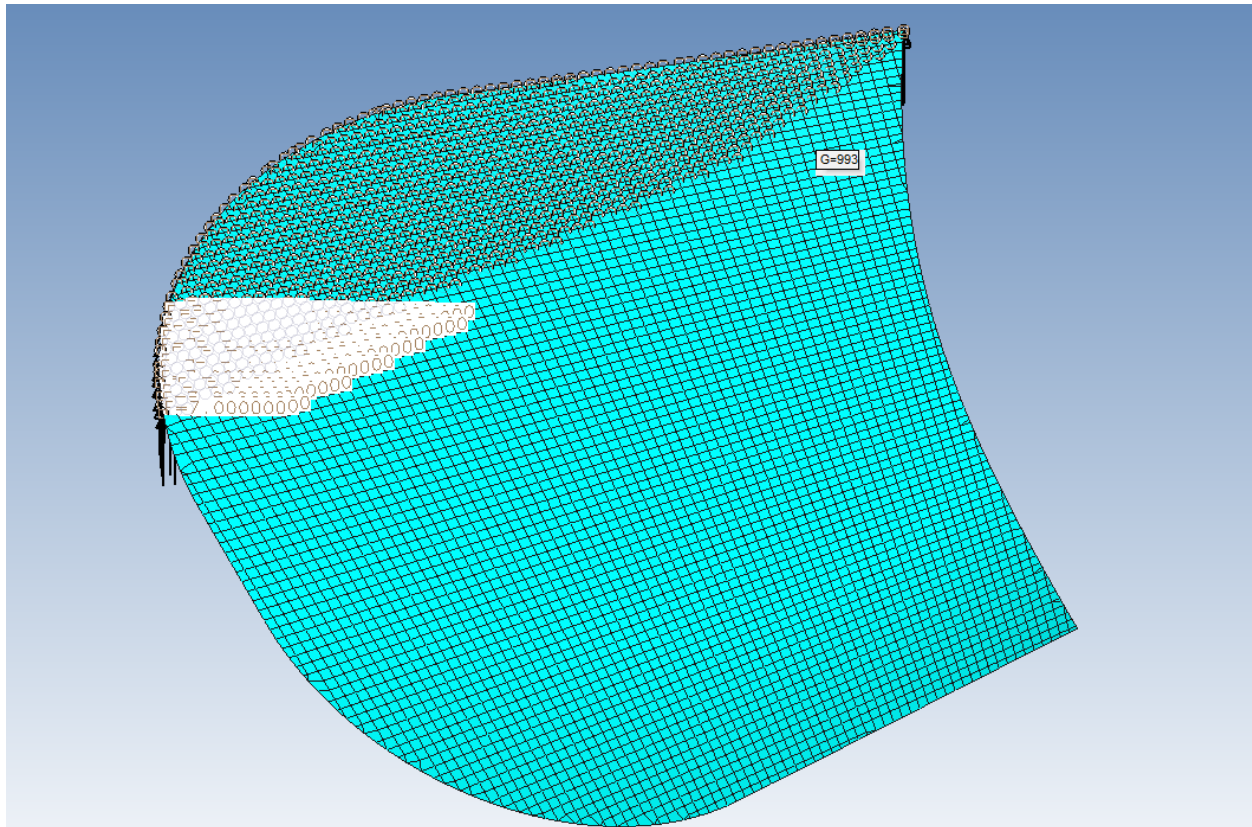


OPTIMIZATION IN DESIGN

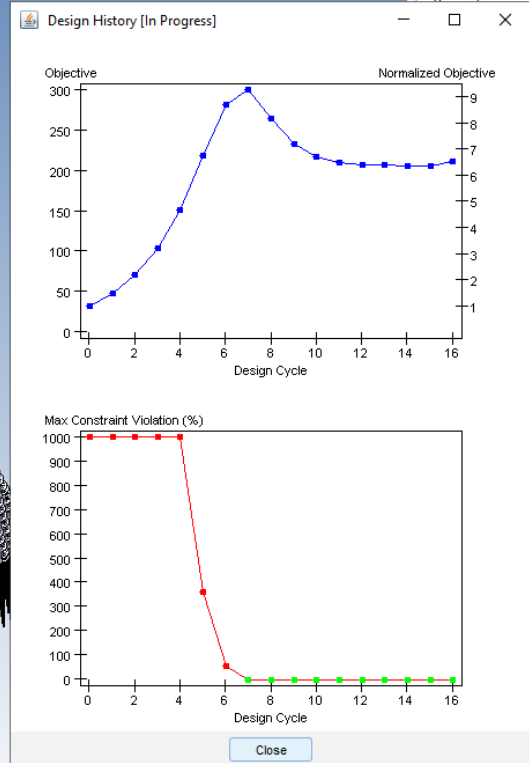
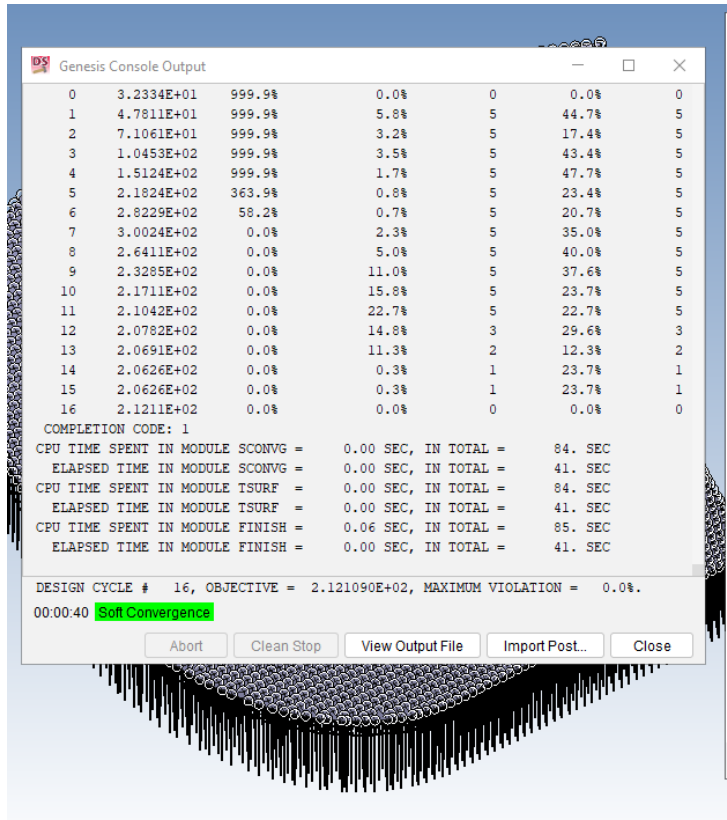
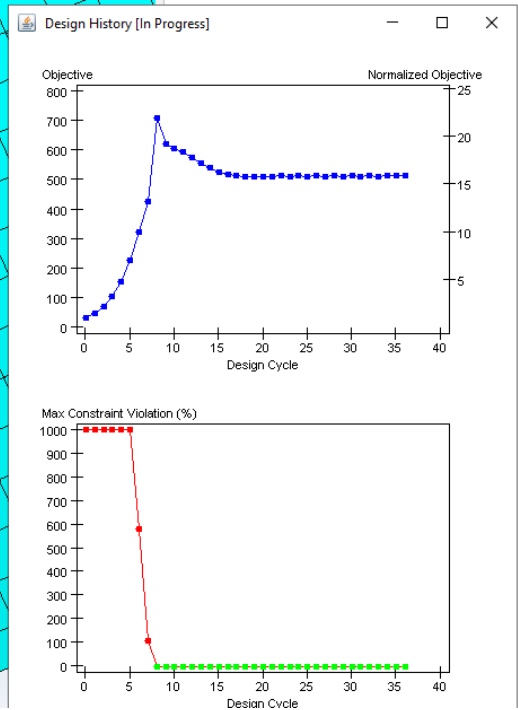
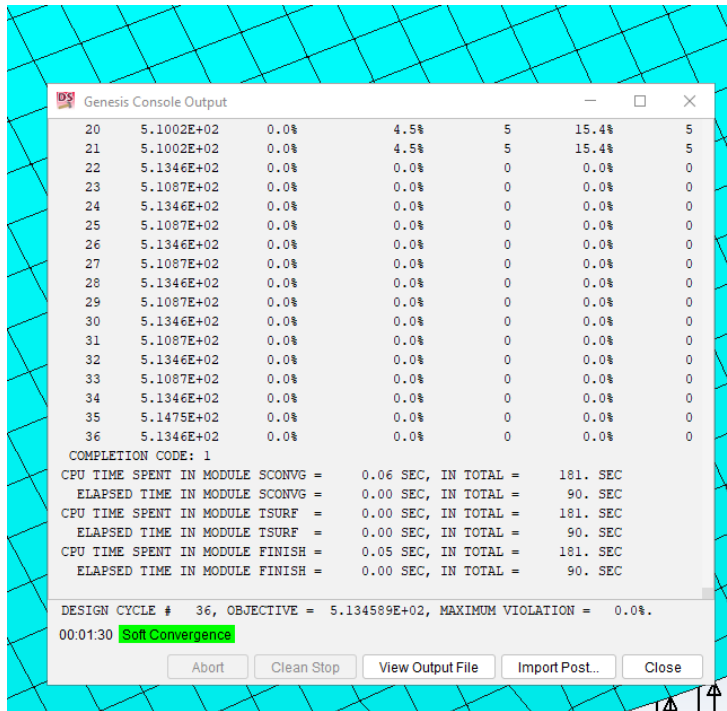
Now for the optimization of the design which is shown below.







Now for the optimization graph have been plotted to show the results of the design propeller.



RELATE TO THE LITERATURE

Mouritz et al. (2001) Early 1970s work on composites for a Soviet fishing vessel began in the early 1960s and included testing of propellers up to 6 meters in diameter. In order to conduct an inviscid FSI investigation of the hydrodynamic performance of a propeller, the structural solver might be paired with a number of flow-based solvers (including the boundary element approach and the lifting line method), as indicated by Young et al. (2017), thanks to advancements in computational methodologies. When analyzing a bendable propeller, Lin and Lin (1996) used the lifting surface theory with the finite element technique to arrive at a hydroelastic basis. Using nonlinear hydro-elastic analysis, Lin (2005) clarified the structural performance of the composite blade; he also took into account the impact of the fibre stacking sequence on propeller performance and failure scenarios. Recently, Young (2007, 2008) used the BEM combined with FEM to examine the performance of composite propellers in uniform and wake flow.[2]

It has been shown that propeller blades' hydrodynamic performance may be enhanced via the use of hydro-elastic tailoring. The propeller always runs in the viscous domain, therefore despite the fact that the potential flow techniques outlined above are comparatively simpler and yield pretty accurate faster answers than more fidelity approaches, it is vital to account the viscous effects. The wake of the ship compounds the difficulties already present. Popular viscous models include RANSE, LES, and a hybrid RANSE-LES that may be used to address difficult issues. Among them, RANSE is notable for being mostly based on the FVM and so being thought to be computationally inexpensive and effective in obtaining a pretty accurate solution. For example, Blasques et al. flexible.'s propeller uses RANSE-based design and discretization to customize the flexible laminate to control the deformation shape and, in turn, enhance the thrust (2010). Focusing on viscous effects including the laminar-to-turbulent transition and stall, Ducoin and Young (2013) used a commercial CFD solver to study the hydroelastic response and stability of a hydrofoil, and they corroborated their findings with tests. [2]

Akcabay and Young (2013) hydrofoil in two dimensions, using numerical analysis, to determine the impact of turbulence and cavitation. Incompressible URANSE equations with eddy-viscosity turbulence closure and a transport equation based cavitation model were used to simulate the fluid flow. Two studies that looked at the flexible propeller used the FVM-FEM coupling method: Ghassabzadeh et al. (2013) and Han et al. (2015). For 3D hydrofoils, Garg et al. (2015) created a CFD-based hydrodynamic shape discretization tool that takes cavitation and a broad variety of operating situations into account. Up to 210 design factors were explored in the research to get the best possible outcome. Garg et al. verified the accuracy of the aforementioned numerical technique (2018). Hydroelastic response of composite hydrofoils under steady state loading from bend-twist coupling effects was studied by Young et al. (2018). Maljaars et al. (2018) performed experimental testing on the composite propeller to evaluate performance and validate BEM and RANSE using FEM coupling methodologies.[3] Carbon fiber composite hydrofoils in viscous flow were studied by Liao et al. (2018), who

discovered that fiber orientation has a major influence in the vibration characteristics and load-dependent bend-twist coupled behavior of these structures. Kumar et al. (2018) and Kumar et al. (2018) tested two propellers with the same geometry in open sea (2019). Carbon fiber composite and homogenous isotropic metal was used to create the blades. The composite propeller was shown to be more hydrodynamic ally efficient than its metal counterpart. Each propeller's tip deflection was measured using static loading testing and finite element modeling (FEM). The two-way FSI analysis is crucial in the design of a carbon fiber composite propeller with ideal material properties and higher hydrodynamic performance in comparison to conventional marine propellers while maintaining the structural deformations below the safe limit. In order to develop a two-way fluid-structure interaction approach for composite marine propellers, this work uses the RANSE solver to compute the hydrodynamic performance and the FEM solver to determine the structural response.[3]

To achieve an advance ratio (J) of 0.5, two steel and two carbon fiber propellers were developed with the same geometry and constructed in the same way. Since this research serves as a precursor to an experimental examination, a steel propeller was investigated rather than nickel aluminum bronze because of the former's greater accessibility of material and the latter's inclusion of stiff qualities. The manufacturing process had no effect on the geometry while it was in a static state. For this FSI simulation, the finite element method (FEM) based commercial structural solver ABAQUS was combined with the RANSE based commercial CFD solver StarCCM+ to create a hybrid solution. The efficiency of the propeller was evaluated in open water with and without coupling, and the results were compared to a regression series. A comparison was made between the stress levels and blade tip deflection measured for the two materials.[4]

CAD-BASED MODEL PREP Parameters for the propeller were calculated from the shape of potential hull (an oil tanker) using suitable hull-propeller interaction components. Troost's (1938, 1940, 1951) standard series was utilized to build this widely used tool for propeller design. The Reynolds adjustment proposed by Oosterveld (1969); Oosterveld and van Oossanen (1971) is also included into the design (1975). The propeller has a D of 1.785 m, Z of 4, a P to D ratio of 0.826, and a rake angle of 15 degrees. Using empirical relations, radial sections are constructed and wrapped around the cylinder. The final blade geometry for the propeller was created in the 3D CAD program Rhinoceros. The CAD geometry of a propeller, as seen from the front and the side, is shown in Figure 1.[5]

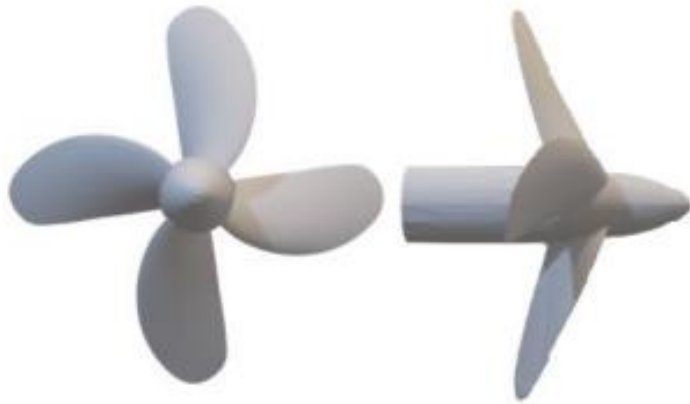


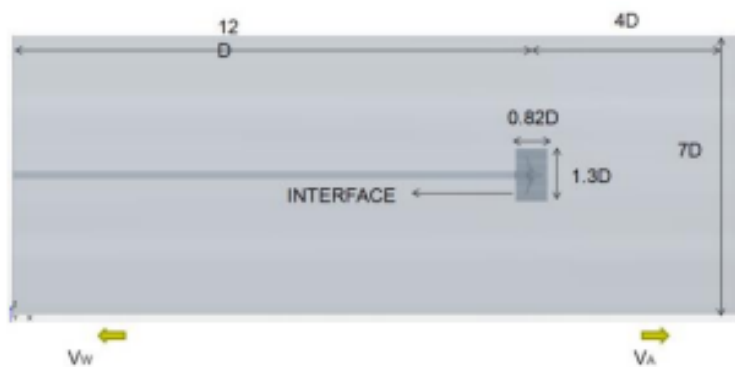
Figure 1 Front and side views of the propeller[2]

Inside the computational domain, StarCCM+ solves the governing equation, which is the continuity and Reynolds Averaged Navier-Stokes Equation. As water is the fluid of choice, it is believed that the flow is incompressible. Conditions of unsteadiness and turbulence apply to the flow.[2]

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U}) = 0 \quad (1)$$

$$\frac{\partial \rho \mathbf{U}}{\partial t} + \mathbf{U} \cdot \nabla \mathbf{U} = -\nabla p + \mu \nabla^2 \mathbf{U} + \rho \mathbf{g} \quad (2)$$

The fluid density is denoted by ρ , the velocity is denoted by $\mathbf{U}$ (where u , v , and w correspond to the x , y , and z components of velocity, respectively), p represents pressure, μ represents dynamic viscosity, and t represents time. In order to solve the governing equation inside the computing domain, the finite volume discretization approach was used. In this case, the computational domain is a cylinder, $7D$ in diameter and $16D$ in length, with the propeller located $4D$ from the intake. The issue is periodic; therefore the periodic boundary condition may be used to solve it in just one quadrant. The simulation can now be run on a reasonable amount of computing power. Computational domain with boundary conditions is shown in Figure 2.[6]



The computational domain is divided between a stationary outer zone and a revolving inner region that contains the propeller. When the propeller is placed in the center, the rotating inner area is a cylinder with a length of $0.82 D$ and a diameter of $1.3 D$. According to ITTC guideline 75-03-03-0 and in accordance with the literature [11,19], we settled on a suitable domain size. A non-conformal fluid-fluid interface links the two areas, allowing the flow amounts to be transmitted between them. There is no physical separation between the interface borders of two interconnected locations. The research used a moving reference frame (MRF) technique with periodic bounds. Here, we take into account the K- turbulence model and apply the y^+ treatment to walls with two layers. 50 is utilized as the value for wall Y^+ in the analysis.[2]

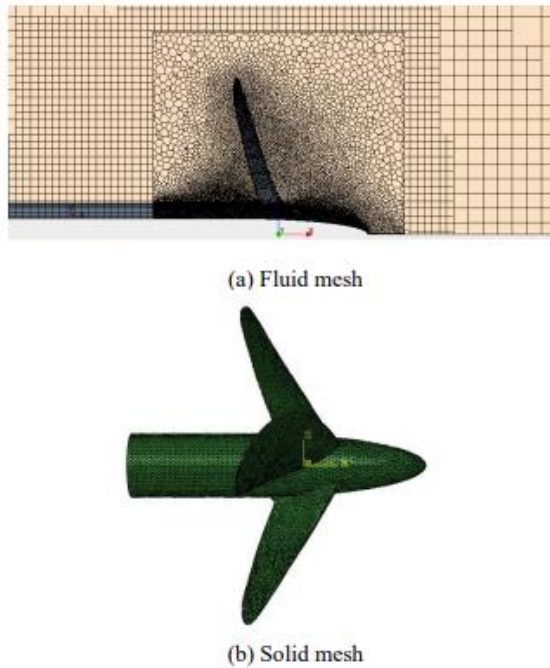


Figure 2 Mesh for fluid model (a) & solid model (b)

The outside, non-rotating section was meshed using hexahedral cells, while the inner, spinning portion was meshed using polyhedral cells. Six prism layers with a near-wall height of 6.8105 m and a growth rate of 1.2 were used to capture the boundary layer on the blades and the hub. From the blade, the cell size increases progressively. See Figure 3 for an illustration of the fluid model's mesh (a). At a constant rotational speed of 286 revolutions per minute, the full-scale propeller was simulated with varying advance ratios. The solver was given the properties of water, including its density (1025 kg/m^3) and dynamic viscosity (8.88104 Pas). It is assumed that the inlet velocity is 4.25 m/s ($J = 0.5$) while the system is in operation. Blade velocities for a composite propeller with a radial section ($0.7r$) under an operating state where denotes the enhanced angle of attack are shown in Figure 4.[6]

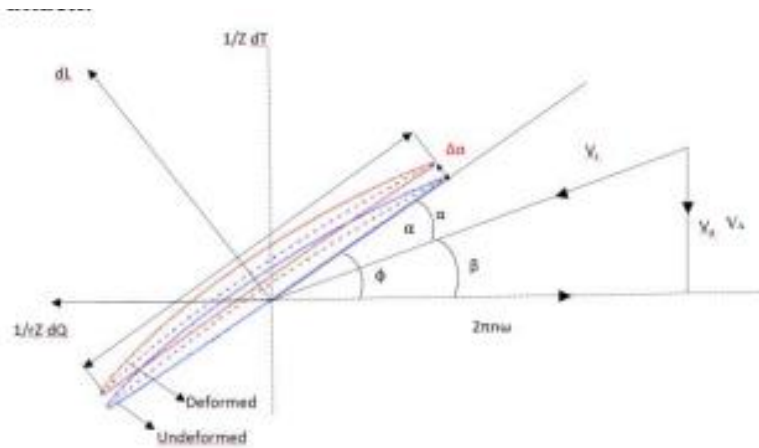


Figure 3 Figure 4 Blade velocity diagram[7]

Using the solid model, we can develop the following generic propeller blade motion equation.

$$a\ddot{x} + b\dot{x} + cx = F_T \quad (3)$$

Mass (a), damping (b), stiffness (c), acceleration (a), velocity (v), and displacement (x) are all matrices. Total external force (t. FT) An FEM model was used to calculate the propeller's structural behavior with the help of the commercial solver ABAQU. S. The solid solve models for both the steel and composite propellers. Homogeneous isotropic material is used to represent the steel propeller. Carbon fiber is modeled as an anisotropic material where the fiber direction is specified, on.[7]

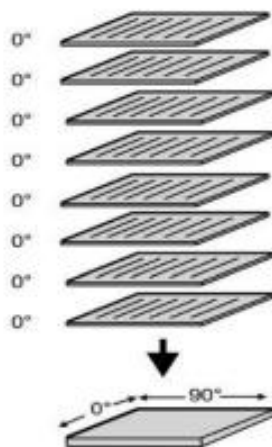


Figure 4 Stacking sequence in unidirectional style

Since this is an early stage investigation into the composite propeller, the fibre orientations were maintained as uniform throughout the thickness, as seen in Figure 4. Unstructured tetrahedral components were employed for the solid model because of the intricate geometry of the blade. The trailing edge of the blade always had at least three components. Figure 4 depicts the solid model's mesh (b). Table 1 (a) and (b) detail the steel and carbon fiber's relative material attributes. Boundaries are taken as being at the base of the propeller blades.[8]

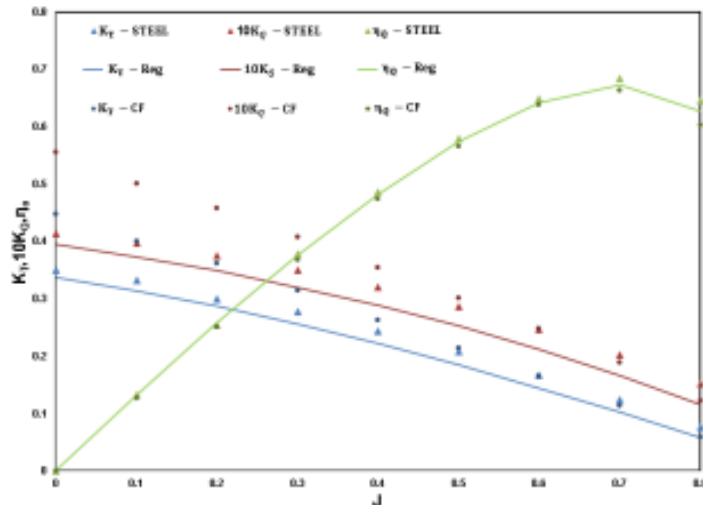
Table 1: Material properties of steel (a)

Description	Value
Density (ρ_s)	7850 kg/m ³
Poison ratio (ν)	0.3
Young's modulus (E)	210 GPa
Yield strength (σ_y)	450 MPa

Material properties of carbon fibre (b)

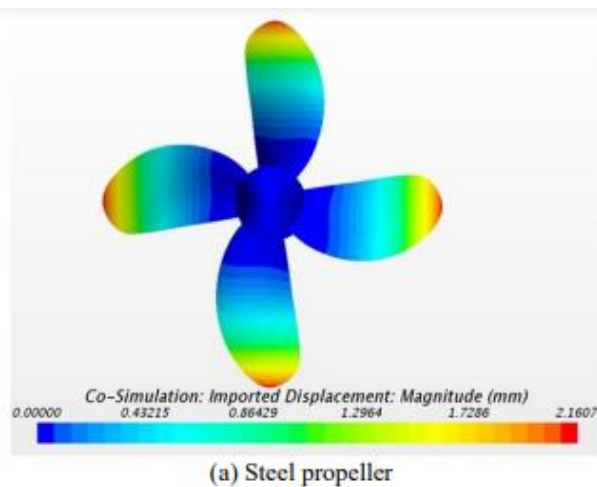
Description	Value
Density (ρ_s)	1600 kg/m ³
Young's modulus (E_{11})	149 GPa
Young's modulus (E_{22})	8.33 GPa
Young's modulus (E_{33})	8.33 GPa
Poison ratio (ν_{12})	0.342
Poison ratio (ν_{13})	0.342
Poison ratio (ν_{23})	0.35
Rigidity Modulus (G_{12})	5.38 GPa
Rigidity Modulus (G_{13})	5.38 GPa
Rigidity Modulus (G_{23})	2.98 GPa
Ultimate strength (σ_y)	2400 MPa

The propeller's thrust coefficient (KT), torque coefficient (KQ), and open water efficiency (η_o) were calculated using CFD modeling, which ignored the solid model (without FSI coupling). This was done in order to confirm the CFD results by comparing them to regression curves based on previously published experimental data. (Oosterveld and van Oossanen 1975). As can be seen, there is less than a four percent discrepancy between the numerical findings and the regression curves from the literature. When the material characteristics are taken into account, this approach provides strong evidence for the validity of CFD simulation. The cosimulation method was used to calculate the hydro-elastic based performance study of two distinct propeller materials. [8]



Hydrodynamic performance curves in open water condition for steel and carbon fibre propeller

Figure 5 displays the open water hydrodynamic performance data for both the steel propeller and the carbon fiber propeller, together with regression curves derived from the aforementioned literature. At working condition ($J = 0.5$), the carbon fiber composite propeller was found to have a 3.25 percent and 5.5 percent improvement in thrust and torque coefficient, respectively, compared to the steel propeller. Reduce J to see the thrust coefficient rise even more dramatically. Carbon fiber propellers have been shown to be superior than steel propellers in terms of both thrust and torque output at the bollard pull condition ($J = 0$). Thus, it is evident that, across the board, the thrust generation of a carbon fiber propeller is superior ($J = 0$ to 0.5).



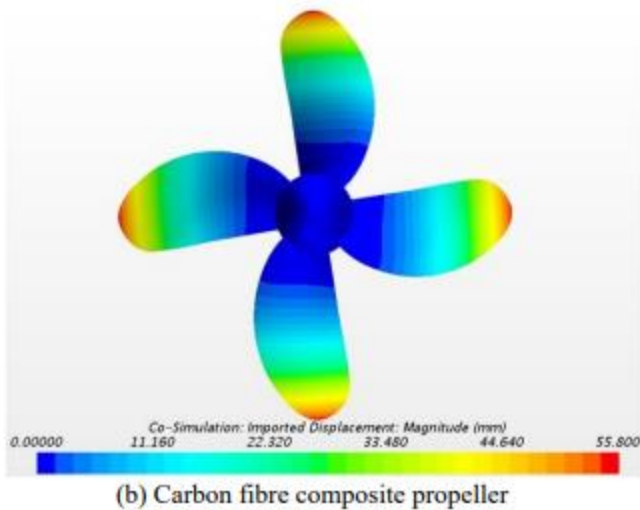


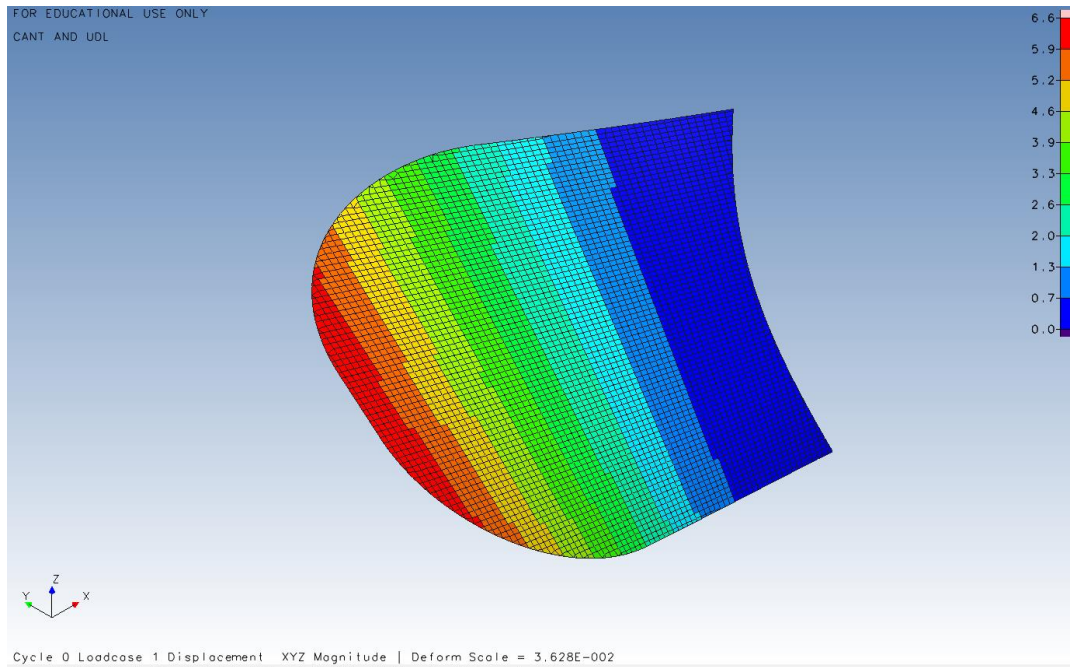
Figure 5 Contours of defection magnitude of steel and carbon fiber propellers at $J = 0.5$

The simulations were all ran for long enough that the measured tip deflection of the propeller reached a steady state. Figure 5 displays the defection magnitude contours for steel and carbon fiber propellers running at $J = 0.5$. Figure 11 illustrates the deformed and undistorted forms of the composite propeller when running at $J = 0.5$, confirming that both blades bend mostly in the positive x-direction.

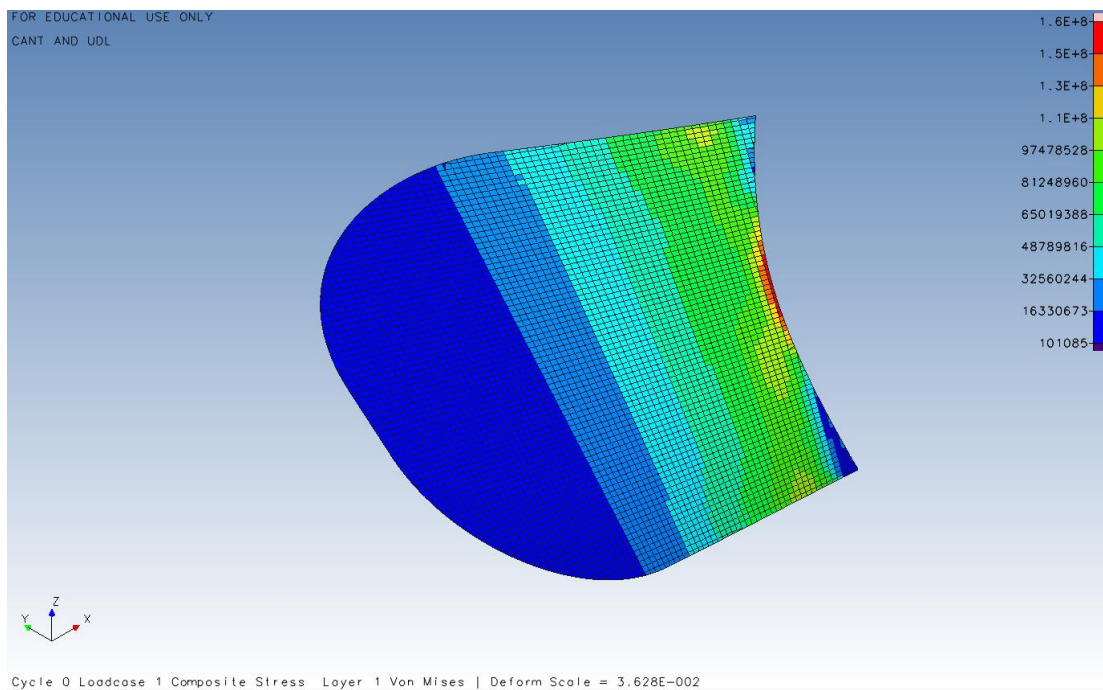
As can be seen in Figure 5, the largest amount of defection for both types of propellers is found at the very tip of the blades, where it measures 2.16 mm for the steel propeller and 55.80 for the carbon fiber propeller. A carbon composite propeller has around 26 times the tip deflection of a steel propeller. In comparison to steel propellers, composite propellers have a much larger defection because to their lower rigidity.

THE CURRENT MODEL RESULTS

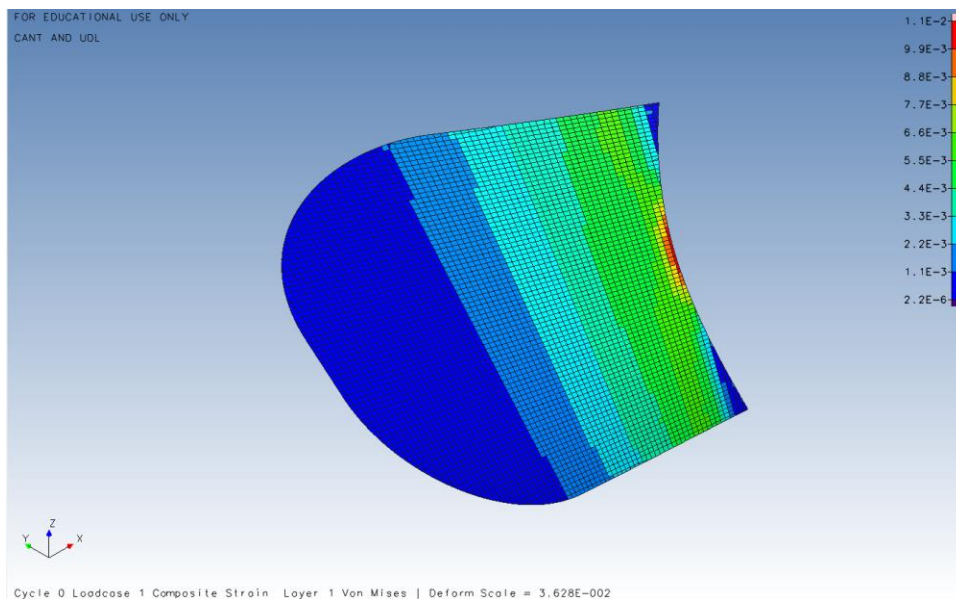
The following are the results of our design which is only on one blade, the displacement deformation are shown below.



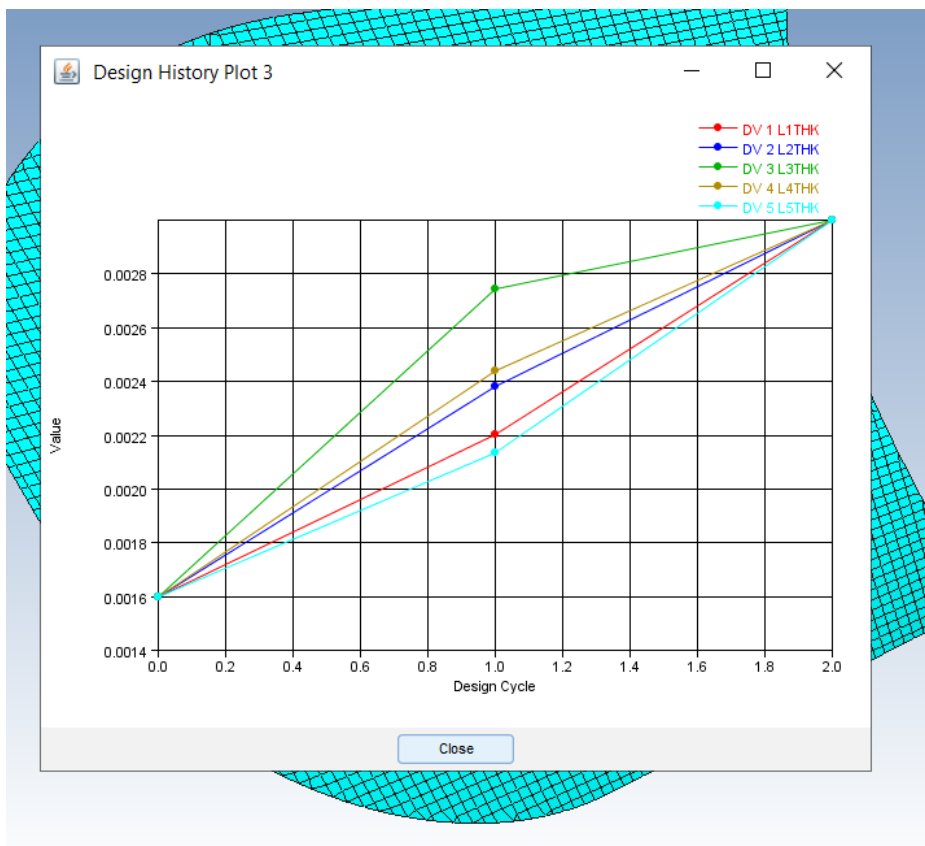
Now for the stress analysis is



Now for the strain analysis is shown below.



The history results of the propeller is shown below



CONCLUSION

After comparing the coupled analysis findings for open water, it was determined that the carbon composite propeller provides more hydrodynamic thrust than the traditional metal propeller.

Results from this research show that the hydro-elastic approach used to analyze the structural behavior and hydrodynamic performance of a composite propeller is accurate.

Due to the reduced rigidity of composite materials, the aforementioned strategy must be used to optimize the sections and geometry of the propeller blades. You may adjust the blade's profile to get the most thrust and efficiency out of it.

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