

CFD Analysis on Marine Propeller with Various Geometrical Conditions

N. Shalom

Assistant Professor, Noorul Islam Centre for Higher Education, Kumaracoil, Kanyakumari,
Tamilnadu, India

E-mail: shalomnanthagopal@niuniv.com

Abstract

Computational fluid dynamics (CFD) modelling of a flow field surrounding marine propellers is difficult due to complex geometry and rotational effects. A propeller is a kind of fan that converts rotational motion to thrust to convey power. A difference in pressure is created among the front and back surfaces of an airfoil-shaped blade as well as the fluid accelerates back of the blades, producing two forces: one on the longitudinal direction of the ship, known as the thrust force, and the other, known as the tangential force, that produces the required torque. For the vast majority of parts, maritime propellers are made from aluminium or bronze alloys. In this study, a performance comparison is done between the original and modified blade version. SOLIDWORKS 2016 is used for propeller design, while ANSYS 2019 is used for structural analysis. The primary aim is to increase the rate of thrust force with a modified design and a constant input power. This study also implements cost estimation along with cost-cutting strategies. An effective cost-estimating framework can help you gain a competitive edge.

Keywords: Propeller, Thrust Force, Tangential Force, Aluminum or Bronze, High Tensile Strength, and Corrosion Resistance

1. Introduction

The ship has a marine propeller that is utilized for mobility. Marine propellers are composed of aluminium and stainless steel and have a fan-like rotor construction. Because they are designed to function in seawater, that causes corrosion, marine propellers are composed of corrosion-resistant materials. Sculling is the principle behind the use of a screw propeller.

Sculling involves moving a single blade in an arc from side to side while maintaining the blade's effective angle in the water. A propeller is one of the most prevalent types of ship propulsion, imparting velocity to a fluid and causing forces to act upon a ship. Optimal efficiency of any propulsion is identical. According to Bernoulli's principle, propellers generate thrust by creating lift with their spinning blades. Propeller hydrodynamics constitutes a subset of the larger topic of lift surface theory, which encompasses applications as diverse as airplanes, ship rudders, hydrofoil boats and keels of sailboats. Fibre Reinforced Plastics are commonly used in the manufacture of different structures such as wingtips, flight controls, stabilizer tips, marine propellers, antenna covers and radars. The Hydrodynamic component in the construction of composite propellers seeks attention it is efficient in predicting deflections and execution of propeller blade.

In this study, B-series propeller of twin-screw ferry passenger with speed of 15.5 knots and power of delivery is 1137 HP that is 836kW containing 4 blades with 1.98 m diameter rotating at 300 rpm. It is essential in forecasting and executing the deflection of the propeller blade. FRP offers a good ratio of strength versus weight. It is mildew and rust resistant. The remaining sections of a marine propeller may be manufactured since they are simple to make. FRP comprises a sandwich material that consists of two outside facings and a centre layer. If the center layer is made of carbon, the material is known as Carbon Fibre Reinforced Plastic (CFRP). The propeller is a device that includes a revolving hub and a propeller blade. Propellers are primarily used to propel a boat and aircraft and some industrial machinery or to transport fluid via system ducts. Design of the blade are proposed in such as way that its circular motion in fluid produces a differential pressure between the sides of the blade, which exerts force on the fluid via Bernoulli's principle. The overwhelming majority of maritime propellers are built of screws having helical blades that operate roughly on a horizontal axis propeller shaft. The remainder of the study is organized as follows. Section II discusses the related works and the screw principles behind the propeller. Section III elaborates Modelling of the propeller design. Section IV presents the materials and methods used in the design of the propeller. Section V design and analyses followed by material study in Section VI. Section VII results and discussion of all four models. Section VII concludes the present work.

2. Related Works

Sculling is the principle behind the use of a screw propeller. Sculling involves moving a single blade in an arc from side to side while maintaining the blade's effective angle in the

water. The screw propeller's innovation was to extend the arc over 360° by connecting cutting edge and revolving shaft. In practice, more than one blade is used to balance the force. Sculling principle is employed for the use of screw propeller. Sculling involves moving one blade in arc to side and maintaining the blade closest to contact with water's surface at all times.[1-5]

The history of the propeller may be traced back to BC, where Archimedes used screw to lift water from the water sources for irrigation, in later it is referred as Archimedes screw. Archimedes' unique study of spiral motion in space was most likely to use hollowed segmental waterwheel for irrigation. In 320 AD, the bamboo-copter, a popular flying toy used the screw concept to power the helicopter.[10-15]

The flow field surrounding marine propellers is difficult to simulate using computational fluid dynamics (CFD) due to its complex geometry and rotational effects. The open-water propeller efficacy coefficients including thrust along with torque coefficients were quantitatively explored in this work. For the first time, an anisotropic mesh adaption approach is used in maritime propellers as well as the computation of two different domains[15-20]. The performance comparison of computational cost of several previously implemented CFD results are carried out [2].

3. Modelling

In the modern era of design, development, production, and so on which we have entered cannot be envisaged without the contribution of computers. Computers have become such a vital element in various areas due to their widespread use.

So, it is necessary for the developing companies to accept current methods rather than traditional methods to adopt to better techniques such as CAD / CAM / CAE, and so on. The use of computer Aided Engineering (CAE), Computer Aided Design (CAD), and Computer Aided Manufacturing (CAM) setup is a possible fundamental technique for companies to have high-quality at reasonable costs. The manufacturers have benefited from the penetration of method concerns. Below are a few advantages.

- Enhance productivity
- Reducing lead-time
- Keeping prototype costs to a minimum
- Enhancing Quality

- Creating higher quality products

Computer-aided manufacturing (CAM) are used to manage as well as to control manufacture processes by means of computer interaction with company's production[21,22].

4. Materials and Methods

The fundamental challenge in most optimization issues is to define the aim underlying all the restrictions, except the mathematics or methodologies involved. The improper sort of propeller solutions can have a significant detrimental influence on both the vessel and the environment, resulting in low efficiency, large consumption of fuel, limited thrust force, and reduced speed[23,24].

Explanation of Geometric Parameters:

- Pitch is defined as the distance travelled by the propeller in single rotation.
- Leading edge is the front edge of the blade to come in contact with water surface.
- Trailing edge is the edge at the end of the blade to be in contact with the water surface.
- Skew angle is the degree of the generator line with respect to the blade's shaft.
- Rake angle is the angle perpendicular to the propeller hub, it is denoted in degrees.
- EAR(Expanded Area Ratio)is the ratio of total blade area to the area of propeller disc.

The below figure shows the geometrical structure of the propellor.

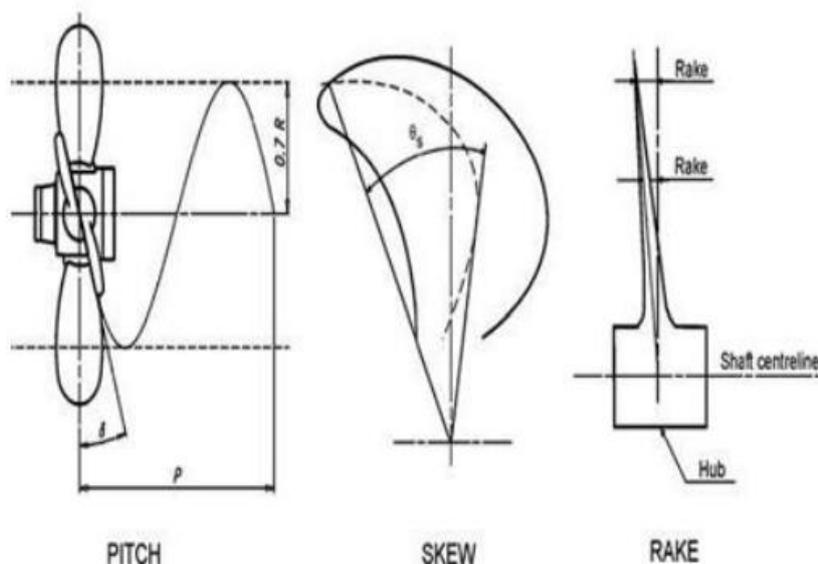


Figure 1. Geometrical Structure of the Propellor[2]

5. Design and Analysis

Solid Works Parametric is a software of feature-based parametric solids modelling design tool that makes use of the simple-to-learn windows graphical user interface. You may develop a completely associated 3-D solid design with or without restrictions, using automated or user-defined relations to represent design intent. The feature-based parametric modelling approach enables the designer to include the initial purpose of the design in the model's creation. The term parametric refers to the geometric specifications of the design, like dimensions, which can be changed at any point during the design process. The major characteristics of the design are identified and created using computer software in parametric modelling. The design factors indicated in the designs and features may be rapidly modified/updated.

Step 1: Determine the kind of the design's base feature, or the initial solid feature. The most frequent base features are revolve, extrude and sweep operations.

Step 2: Develop a rough two-dimensional drawing of the fundamental outline of the design's main feature.

Step 3: Apply or update the limits and dimensions on the two-dimensional sketching.

Step 4: Convert the two-dimensional parametric drawing into a three-dimensional feature.

Step 5: Complete the design by adding more parametric features by discovering feature relations.

Step 6: Create the desired 2D/3D drawings to document the design.

6. Material Study

Fibre Reinforced Plastics are frequently used in the production of various structures such as radomes, wingtips, antenna covers, marine propellers, and so on.

Table 1. Material Properties of Fibre Reinforced Plastics[3]

Property	Range
Density (gm/cm ³)	1.50–2.10
Tensile Strength (MPa)	600–3920
Young's Modulus (GPa)	37–784
Elongation (%)	0.5–1.8
Coefficient of Linear Expansion (10 ⁻⁶ /°C)	–9.0–0.0

Its mechanical properties include linear elastic with no obvious yielding stage, resulting in lower failure strain as well as elongation rates.

7. Results and Discussion

Solidworks parametric is a solid modeler; it creates designs as solids, allowing us to work in 3D. Solid models in Solidworks parametric contain volumes as well as surface areas. As a solid modeling tool, Solidworks parametric creates feature-based, associative, and parametric design models, which are then transformed into IGES or PARASOLID models for use in ANSYS. ANSYS Software cannot analyze designs. It includes mesh generation techniques to divide a problem into small components, as well as the usage of FEM-coded programs.

The below are the results with four different geometric conditions such as 5 blade, 5 blade thickness decreased by 30%, 5 blade thickness increased by 30%, 3 blade thickness increased by 50 %.

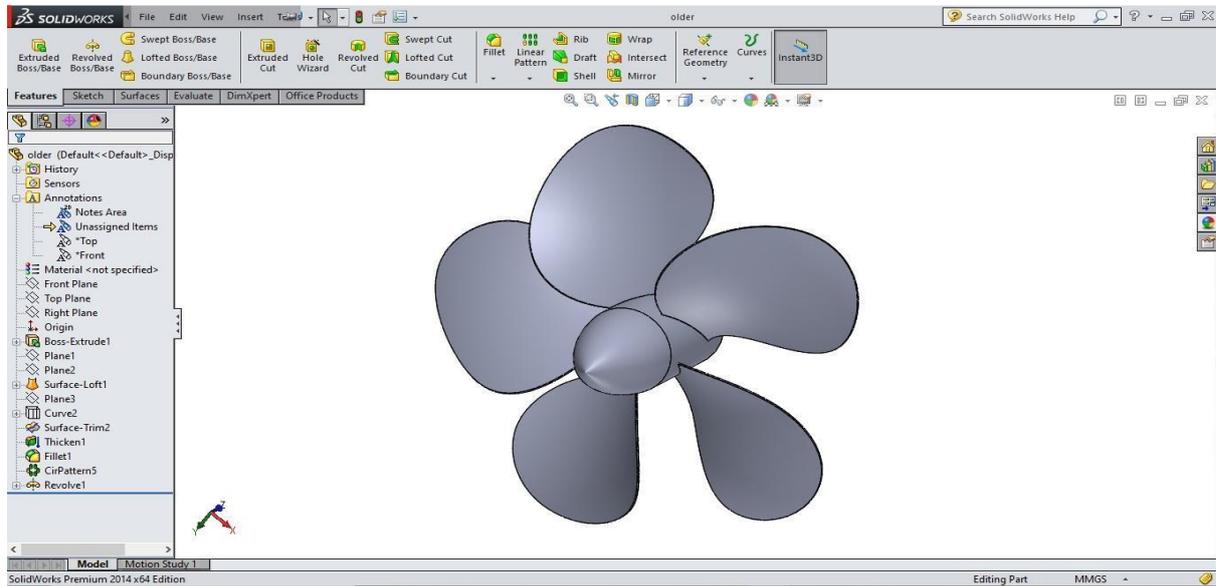


Figure 2. CAD Design of 5 Blade Propellers

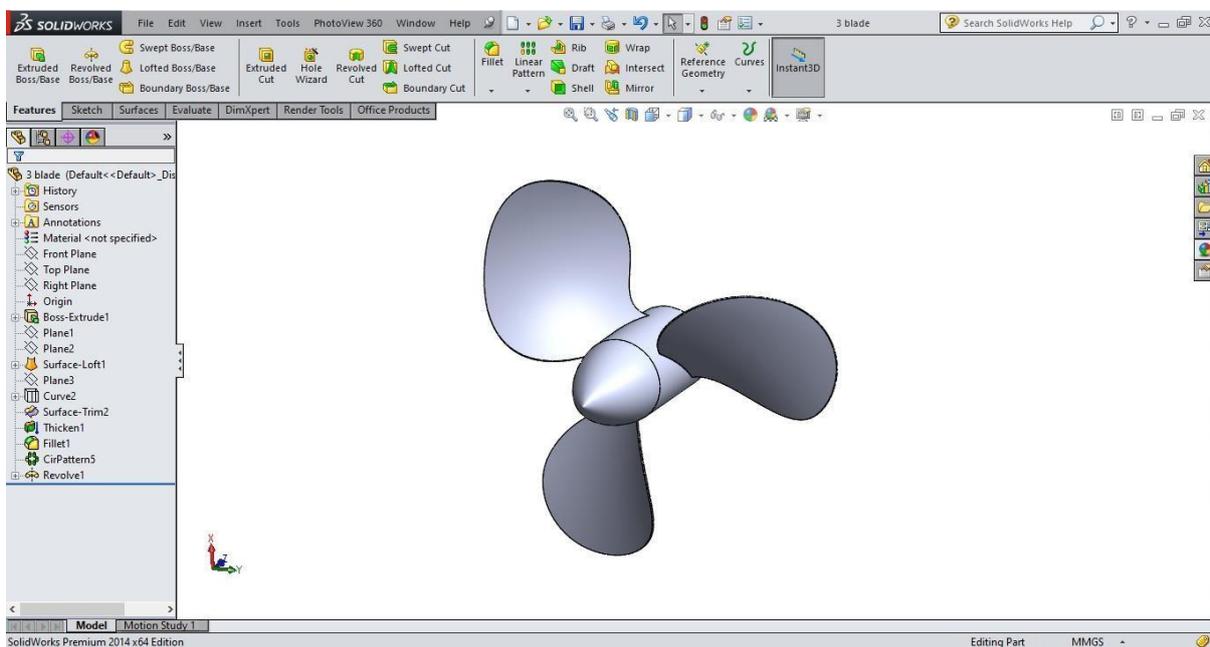


Figure 3. CAD Design of 3-Blade Propeller

A. Model 1 – 5 Blade Propeller

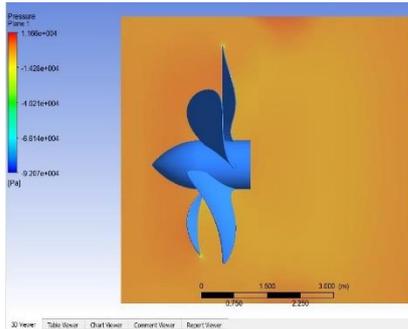


Figure 4. Pressure Distribution

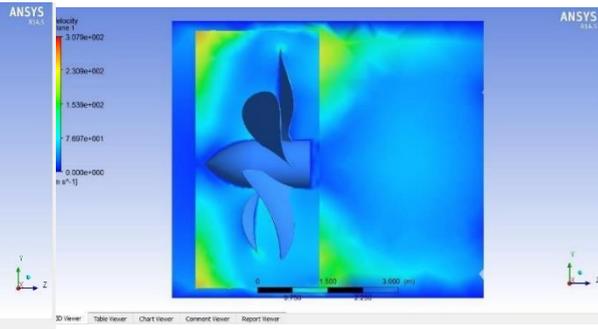


Figure 5. Max Velocity

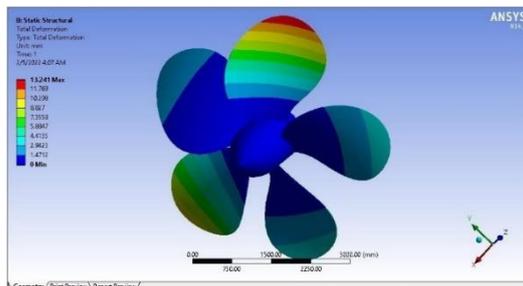


Figure 6. Deformation

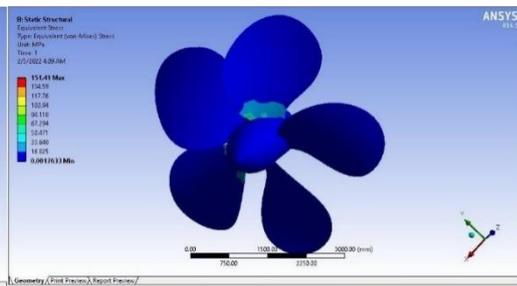


Figure 7. Stress

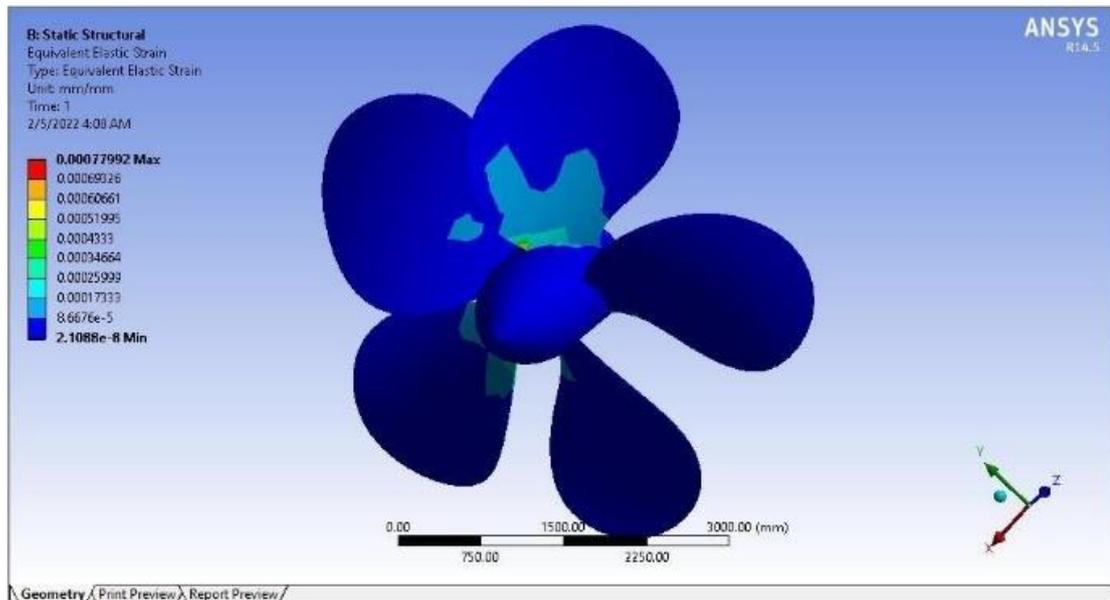


Figure 8. Equivalent Strain

B. Model 2 – 5 Blade Propeller (Thickness Decreased 30%)

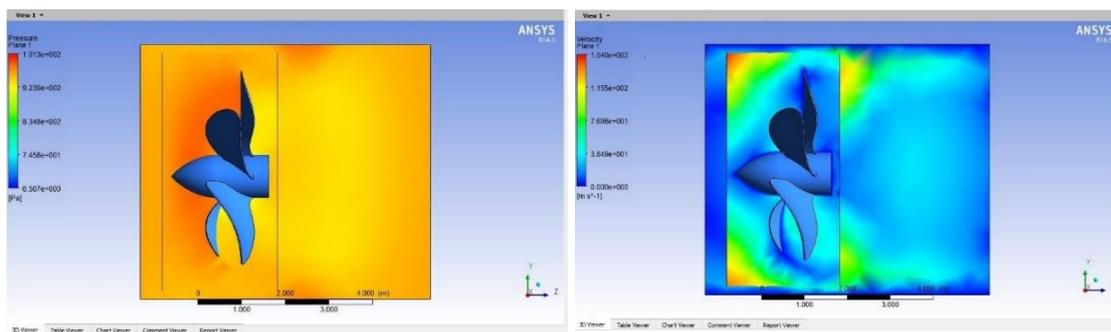


Figure 9. Pressure

Figure 10. Velocity

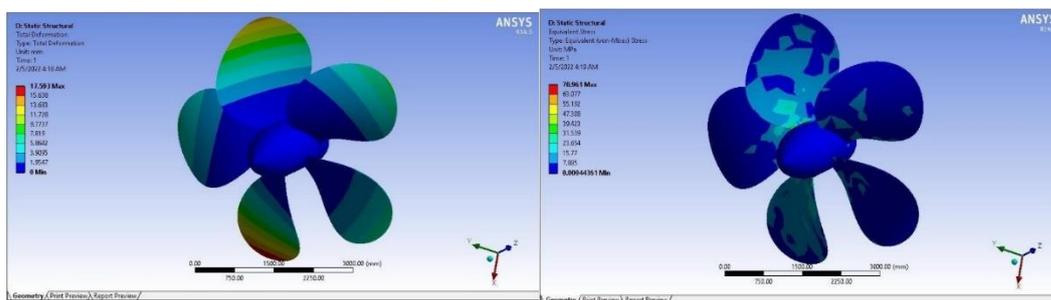


Figure 11. Deformation

Figure 12. Equivalent Stress

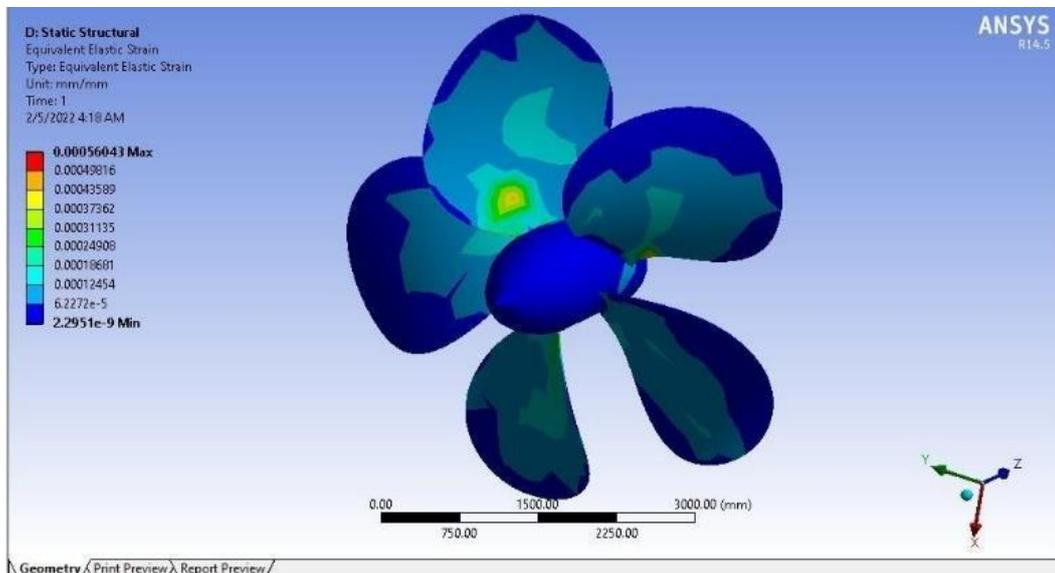


Figure 13. Equivalent Strain

C. Model 3 – 5 Blade Propeller (Thickness Increased 30%)

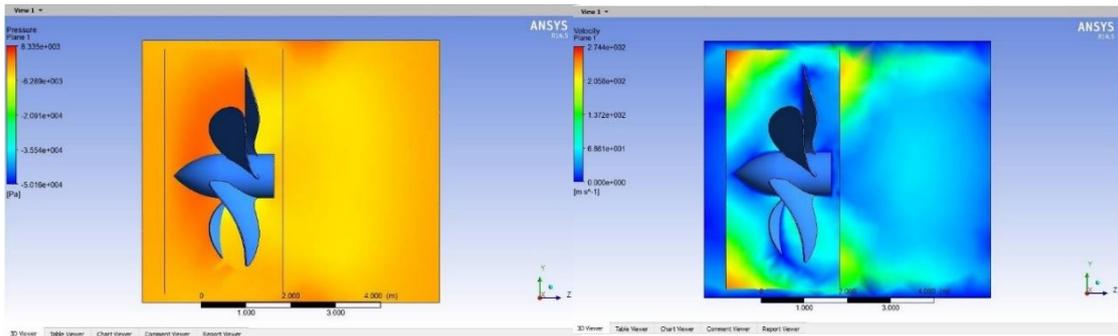


Figure 14. Distributed Pressure

Figure 15. Velocity

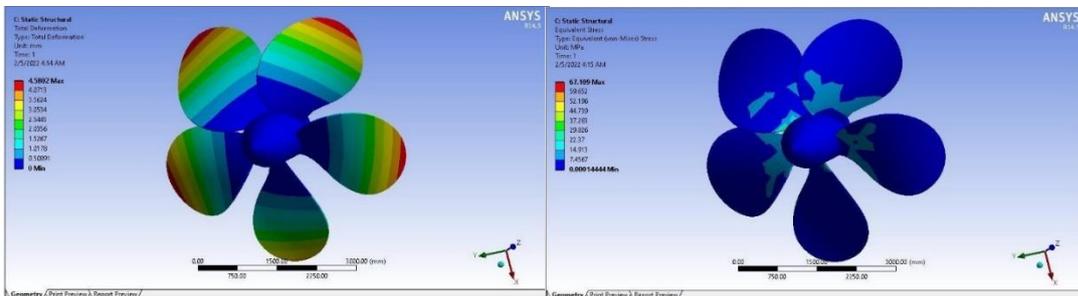


Figure 16. Deformation

Figure 17. Stress

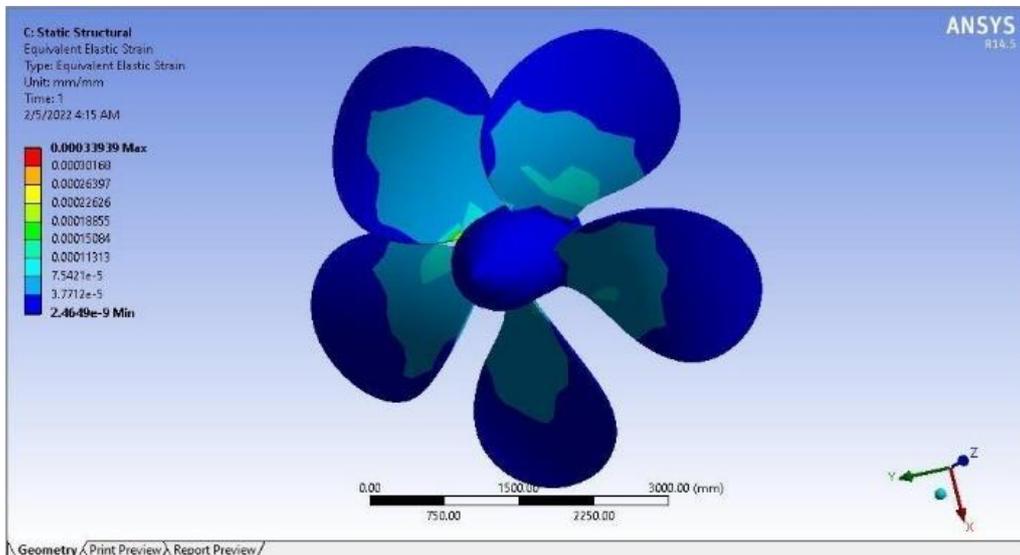


Figure 18. Equivalent Strain

D. Model 4 – 3 Blade Propeller (Thickness Increased 50%)

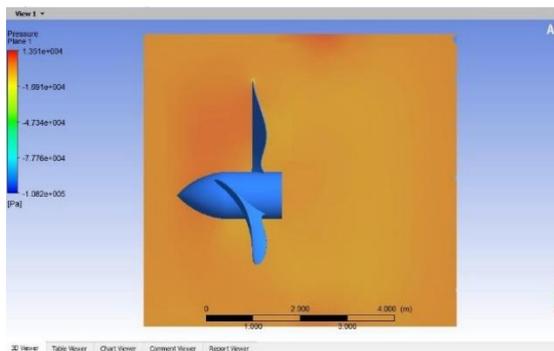


Figure 19. Pressure

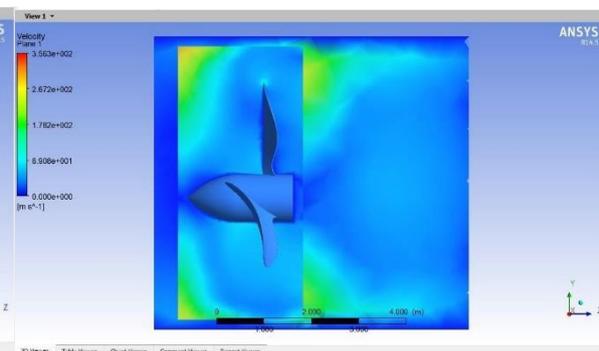


Figure 20. Velocity

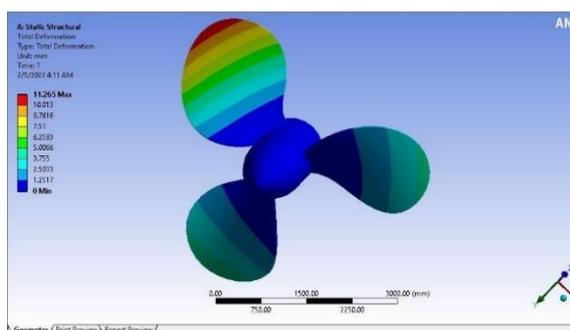


Figure 21. Deformation

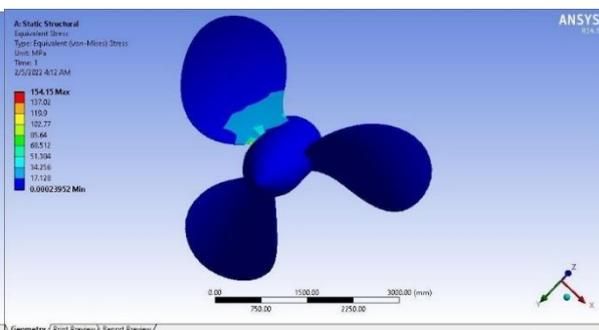


Figure 22. Stress

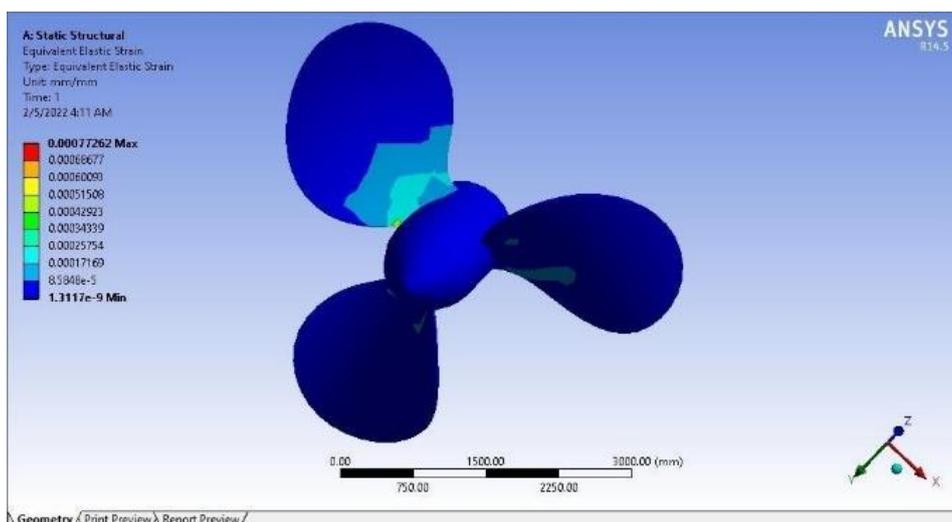


Figure 23. Equivalent Strain

Table 2. Comparison of Results

Model	Pressure (pa)	Velocity (ms-1)	Stress MPa	Total deformation (mm) (mm)	Strain
5 blade (model 1)	1.166e004	3.079e002	151.41	13.241	0.00077992
5 blade thickness decreased 30% (model 2)	1.013e002	1.540e002	70.961	17.593	0.00056043
5 blade thickness increased 30% (model 3)	8.335e003	2.744e002	67.109	4.5802	0.00033959
3 blade thickness increased 50 % (model 4)	1.351e004	3.563e002	154.15	11.265	0.00077262

From Table 2. Velocity and stress are observed high in 3 blade propeller with an increased thickness of 50%. High pressure of 8.335e003 is created by the 5-blade propeller with an increased thickness of 30% with very minimum stress and strain but model 4 produces slightly high stress and strain with little low pressure compared to model 3. On justifying all the parameters model 4 performs better.

8. Conclusion

The above-mentioned four models were analyzed by SOLIDWORKS 2016 and ANSYS WORKBENCH. The findings revealed that model four, a three-blade propeller, provides the highest velocity and the shortest trip time. It also has a larger stress value with respect to the higher-pressure value than the other model. Because the twin screw ferry

passenger ship requires a large load with low-speed requirements and a high velocity. As a consequence, this is the optimal design, according to the study.

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