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Design and Simulation of Marine Propeller with Different Blade Geometry

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Abstract:- A propeller is a type of fan that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and rear surfaces of aerofoil shape blade and fluid is accelerated behind the blades which generates two force, one along the longitudinal direction of ship which is the axial force called thrust force and tangential force which produce the required torque. As propeller has great influence on the propulsive performance of ship, propeller design is important technology for energy saving in ship propulsion. A twin screw propeller consist of two propellers arranged side by side at the stern of the ship. Most ships are equipped with twin screws, and the propeller turn opposite ways either outward or inward. Large vessel often have twin screws to reduce heeling torque. Generally alloy of aluminium or bronze material are used for manufacturing of marine propeller. In our design we are using material for the blades which possess high tensile strength and propeller turn opposite ways either outward or inward. Large vessel often have twin screws to reduce heeling torque. Generally alloy of aluminium or bronze material are used for manufacturing of marine propeller. In our design we are using material for the blades which possess high tensile strength and corrosion resistance properties which enhance life of the propeller. Designing of propeller will be done using SOLIDWORKS 2016 and further structural analysis using ANSYS 2019. To compare the results between original and modified blade version. The main objective is to increase the thrust force using modified design using the same input power . Also, cost estimation will be done and suggestive measures will be undertaken to reduce the cost. An effective cost estimation framework can contribute to a competitive advantage.

I. INTRODUCTION

A propeller is the most common propulsor on ships , imparting momentum to a fluid which causes force to act on a ship. The ideal efficiency of any propulsor is that of actuator disc in ideal fluid . Propeller dynamics can be modeled by both Bernoulli's principle and Newton's third law.

Propeller produce thrust through the production of lift by their rotating blades . Propeller hydrodynamics is therefore part of the broader field of lifting surface theory , which includes such varied applications as aircraft , hydrofoil boats , ship rudders , and sail boat keels.

Fiber Reinforced Plastics are widely used in the manufacturing of different structures like radomes, wingtips, stabilizer tips, antenna covers, flight controls including the marine propellers. The hydrodynamic parts of the design of composite marine propellers have pulled inconsideration in light of fact that they are important in anticipating the deflections and execution of the propeller blade. Here we are selecting B-series type of propeller for twin screw ferry passenger which has a ship speed of 15.5 kts and delivered power 1137 HP (836kW) with number of blades 4 and diameter of propeller 1.98 m revolving at 300 rpm .Refer fig.1.

Basic Nomenclature:

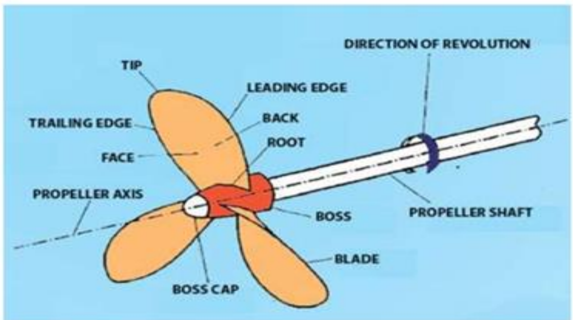

Fig1:- Propeller Layout

That they are important in anticipating the deflections and execution of the propeller blade. Fibre Reinforced Plastic has a high strength to weight ratio and is resistant to mildew and corrosion. As it is easy to fabricate, it is possible to manufacture the other parts of the marine propeller. FRP is a sandwich type material made up of two outer facing and a central layer. If the central layer which consists of a carbon then it is called Carbon Fiber Reinforced Plastic (CFRP).

II. LITERATURE REVIEW

Efficiency increases on increasing diameter of propeller but only upto certain limit .Worlds largest propeller was loaded onto ship at port of Hamburg measuring 10.3 meter , but its power consumption was 22.38 Mw which is very high.

Author John Carlton (2012) carried out the work of finding out balance between Power and Diameter in his book of Marine propeller and propulsion . Author Toshio Yamatogi, Hideaki Murayama (2011) carried out the work for finding out suitable material Carbon Fibre Reinforced

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Plastic (CFRP) by comparing the strength, degree of vibration, cavitation between commonly used material (Aluminium alloy) and CFRP in his journal paper of composite material marine propeller . H.N.Das, S.Kapuria (2013) carried out the experimental analysis to check the performance of marine propeller. In journal paper of smart composite propeller for marine applications .

John Carlton (2007) carried out detailed study of blade geometry in his book of marine propeller and propulsion . Author Frederikshavn (2015) carried out propulsion calculation and performance of ship parameters and concluded rules for increasing propeller diameter and number of blades in his journal paper of basic principle of ship propulsion . Also, found out analysis of high efficient fixed pitch propeller in 2012 in book of MAN Alpha. M.M.Bernitsas ,D.Ray (1982) carried out propeller model , test in open water in Netherlands and expressed optimal thrust , its coefficient and efficiency in terms of number of blades in paper optimal revolution B-series propellers .

➢ Properties of CFRP:
- High flexibility
- High tensile strength
- Low weight
- High resistance
- Low thermal expansion
- High strength-to-weight ratio

➢ Characteristics of CFRP:
- Specific gravity
- Tensile strength and modulus
- Compressive strength and modulus
- Damping
- Electrical and thermal conductivities
- High cost

III. PROBLEM DEFINITION

The main difficulty in most optimization problems does not lie in the mathematics or methods involved , it lies in formulating the objectives of all the constraints . The wrong type of propeller solution can have very negative impact on both the vessel and leads to low efficiency , high fuel consumption , low thrust force and low speed .

➢ Propeller Geometry :- (Refer Fig.3)
- Pitch : - Theoretical distance a propeller would move in one revolution .
- Leading edge :- forward edge of blade , first to encounter the water stream .
- Trailing edge :- last part of the blade to encounter the water stream .
- Skew angle :- It measures the degree of the generator line relative to the shaft of the blade section.
- Rake angle :- Rake is the amount of degrees the propeller blade angle perpendicular to the propeller hub.
- EAR(Expanded Area Ratio) :- Ratio of total blade area divided by the propeller disc area. Refer fig.2.

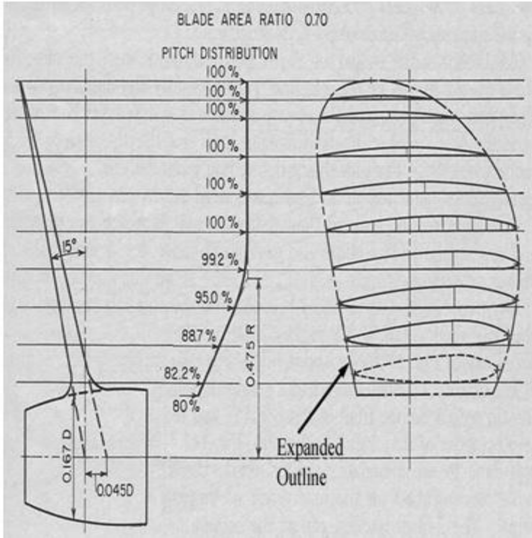

Fig 2

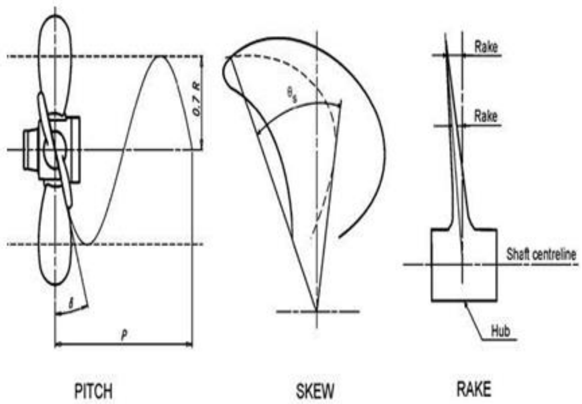

Fig 3:- Blade Geometry

➢ Advantages of flow simulation :
- Low cost
- Take less time
- Complete information
- Ability to stimulate realistic conditions
- Ability to stimulate ideal conditions
- Reduction of failure risks.

➢ Steps :- Modelling of marine propeller

- *Step 1 :-*

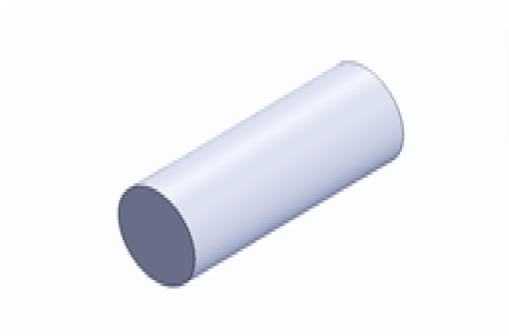

Fig 4:- Design of hub

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- *Step 2 :-*

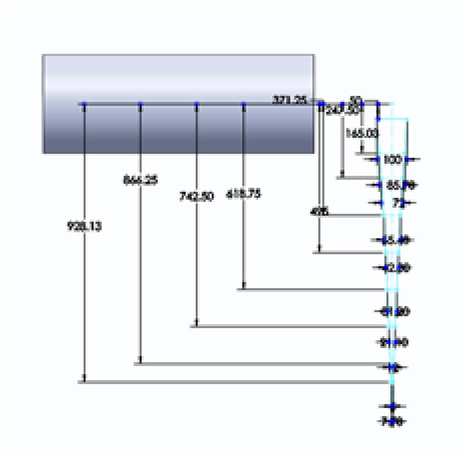

Fig 5:- Blade design

- *Step 3 :-*

Fig 6:- Swept blade geometry

- *Step 4 :-*

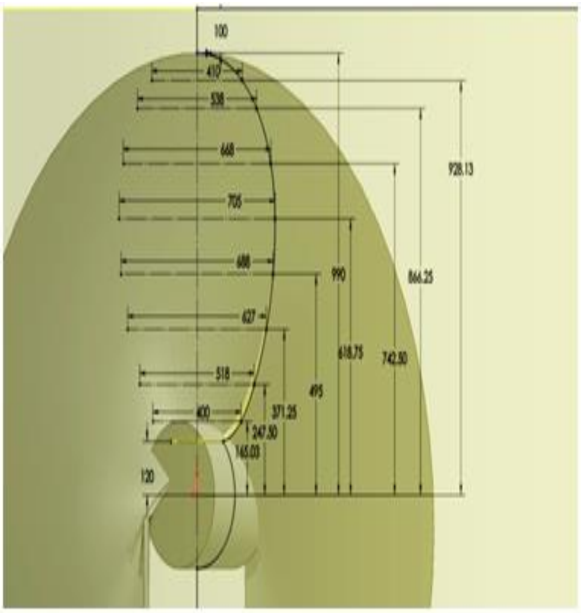

Fig 7:- Revolve cut

- *Step 5 :-*

Fig 8:- Result of revolve cut

- *Step 6 :-*

Fig 9:- Circular pattern of blade

- *Step 7 :-*

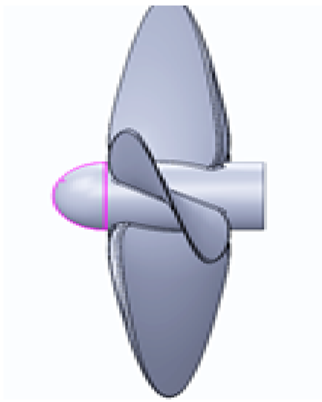

Fig 10:- Boss tip design

The thrust force of a marine propeller when working sufficiently far away from free surface may be expected to depend upon following parameters :
Diameter(D) , Speed of advance(Vs) , rotation speed(n) , density of fluid(ρ) , pitch(P) , Advance coefficient (J) , wake fraction (w)

➢ *Formula :-*

- $A = \pi(R)^2$
- $P = \tan(\alpha) * 2\pi * R$
- $m = A * Vs$

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- $T = \rho * m * (Vs - Vs*(1-w))$
- $J = Vs\,(n * D)$
- $Kt = T / (\rho * n^2 * D^4)$
- $Kq = Q / (\rho * n^2 * D^5)$
- $\eta = (J * Kt) / (2\pi * Kq)$

IV. MATERIAL STUDY

Fiber Reinforced Plastics are widely used in the manufacturing of different structures like radomes , wingtips , antenna covers , marine propellers , etc. Fiber Reinforced Plastic has high strength to weight ratio and is resistant to corrosion. Refer Table.1 & Table.2

Young's Modulus	115 GPa
Poisson Ratio	0.328
Density	2700 gm/cc

Table 1:- Nickel Aluminium Bronze mechanical properties

Young's Modulus	180 GPa
Poisson Ratio	0.28
Density	16 gm/cc

Table 2:- Mechanical Properties of CFRP

V. DETAILS OF ORIGINAL MODEL

Parameter	Values
Twist angle of blade	30°
Number of blades	4
Bending angle	10°
Diameter of propeller	1980 mm
Diameter of hub	330 mm
Area of blade	2.504 m^2

Table 3:- Considered Data

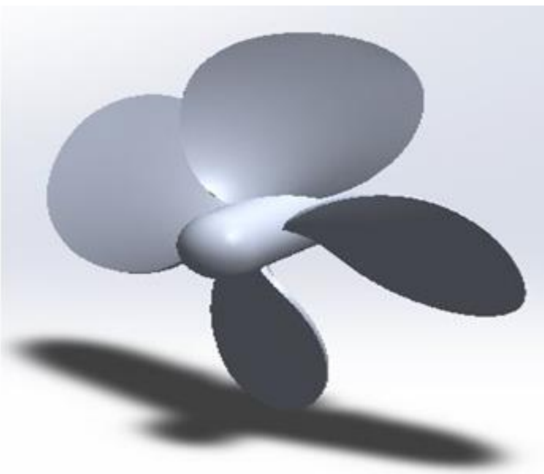

Fig 11:- original design

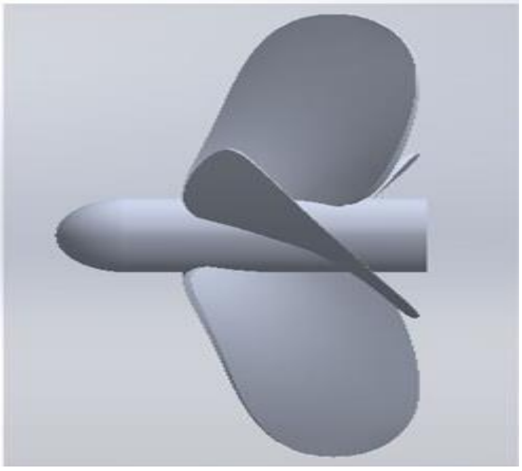

Fig 12:- side view

The next part is solidworks flow simulation 2016 of original model with this initial conditions :

- Analysis type as external and exclude cavities without flow conditions, internal space.
- Select rotation and reference axis as rotating axis (i.e Z-axis)
- Select fluid as water and flow type as laminar and turbulent.
- Take wall thermal conditions as adiabatic wall and roughness as 0 micrometer (consider smooth surface of propeller)
- Let the pressure be 101.325 kPa and temperature as 293.2 K
- Enter velocity of flow at inlet as 7.08m/s in direction of rotating axis.

Now find the value of outlet axial velocity and thrust force developed (i.e Force (Z)) for various rotating speed in rad/s . Refer fig.13

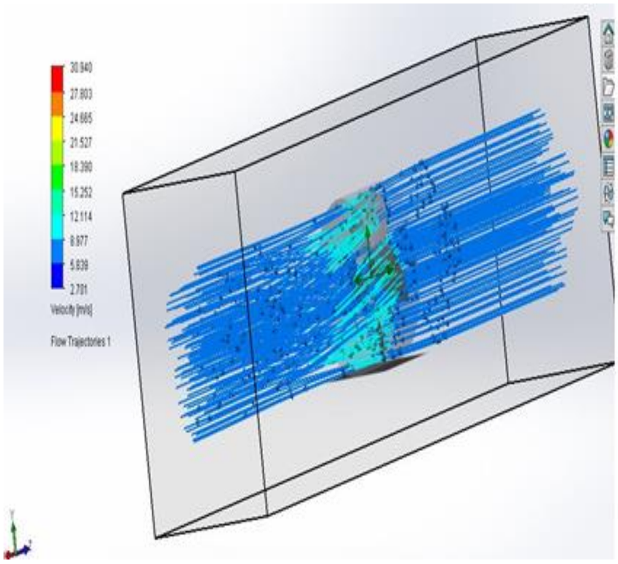

Fig 13:- Flow trajectories of original model

The thrust force obtained for 300rpm rotation of propeller is 52.028 kN with outlet axial velocity of 18.312 m/s. The mass of this propeller is 103.986 kg and total

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blade area of 2.504 m^2. The ansys structural analysis done concluded,

Deformation (mm)		Von-mises Equivalent Stess (MPa)	
NAB	CFRP	NAB	CFRP
11.56	7.68	65.722	67.739

Table 4:- Material Properties

VI. DETAILS OF MODIFIED TRIALS

- TRIAL 1 :
  Here the thickness of blade is increased by 30%.

- TRIAL 2 :
  Here the blade width is decreased by 30%.

- TRIAL 3 :
  Here the number of blades is decreased by 1 (i.e. total number of blades is 3) and blade width is increased by 50%.

- TRIAL 4 :
  Here the a new blade design is done based on requirements of results.

Model	Mass (kg)	% mass comparision
TRIAL 1	125.614	20.7 ↑
TRIAL 2	93.736	9.8 ↓
TRIAL 3	105.327	1.3 ↑
TRIAL 4	120.142	15.5 ↑

Table 5:- Mass comparision with original model

Model	Velocity (m/s)	% velocity comparision
TRIAL 1	18.3	0.0655 ↓
TRIAL 2	18.00	1.7 ↓
TRIAL 3	19.43	6.105 ↑
TRIAL 4	17.0637	6.82 ↓

Table 6:- Velocity comparision with original model

Model	Thrust force (kN)	% force comparision
TRIAL 1	69.311	33.79 ↑
TRIAL 2	79.488	52.78 ↑
TRIAL 3	73.542	41.35 ↑
TRIAL 4	84.139	61.71 ↑

Table 7:- Thrust force comparision with original model for same speed (consider 300rpm)

Model	Blade area (m^2)	%balde area comparision
TRIAL 1	2.53	1.038 ↑
TRIAL 2	1.747	30.23 ↓
TRIAL 3	2.8	11.82 ↑
TRIAL 4	1.897	24.24 ↓

Table 8:- Total blade area comparision with original model

VII. RESULTS

Ansys structural analysis is performed using ANSYS WORKBENCH 2016.

Deformation and Von-Misses Stress of original model with its forces acting in all directions (i.e. Fx=1.8579 N , Fy= 59.036 N , Fz = -52028 N). Refer Table.9

Model	Deformation (mm)		Von-misses Stress (MPa)	
	NAB	CFRP	NAB	CFRP
Original model	11.56	7.68	65.722	67.739

Table 9:- Deformation and Stress analysis

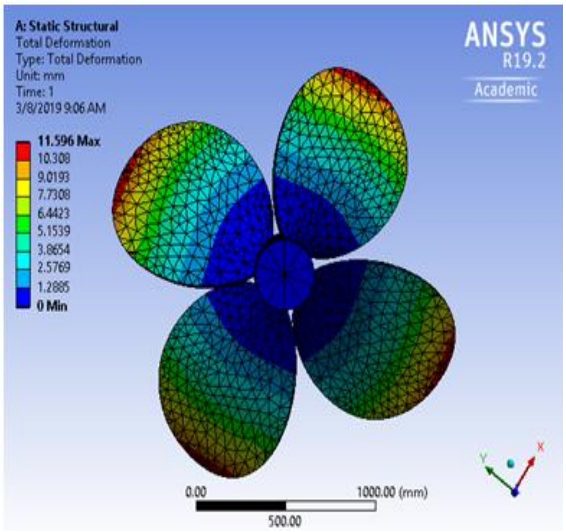

Fig 14:- Total Deformation

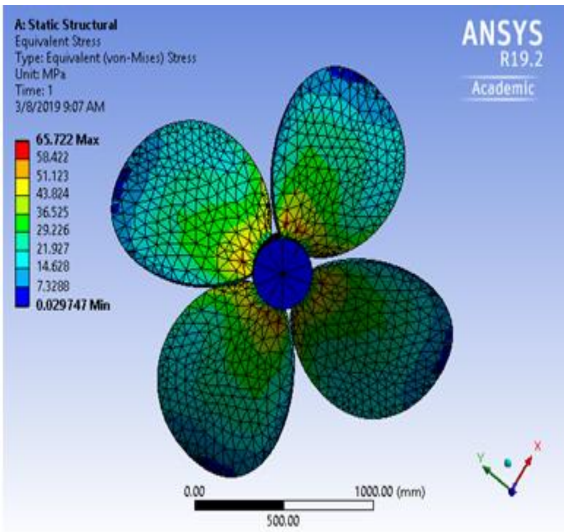

Fig 15:-Von-Misses Stress

Here the deformation for cfrp material is comparatively less so for further models analysis is compared with only CFRP material.

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➢ Results of other models :

- Trial 1

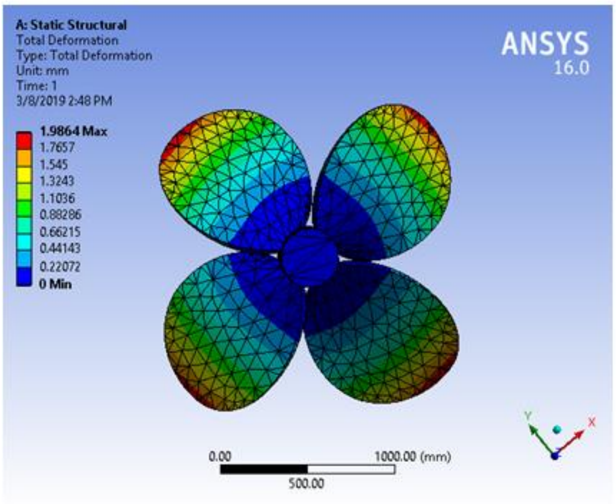

Fig 16:- Total Deformation

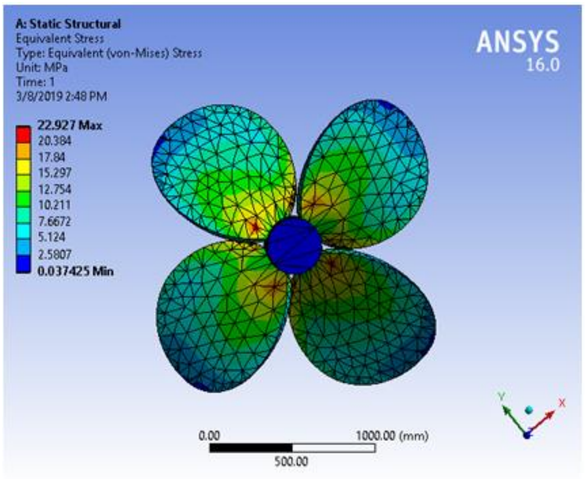

Fig 17:- Von-Misses Stress

- *Trial 2*

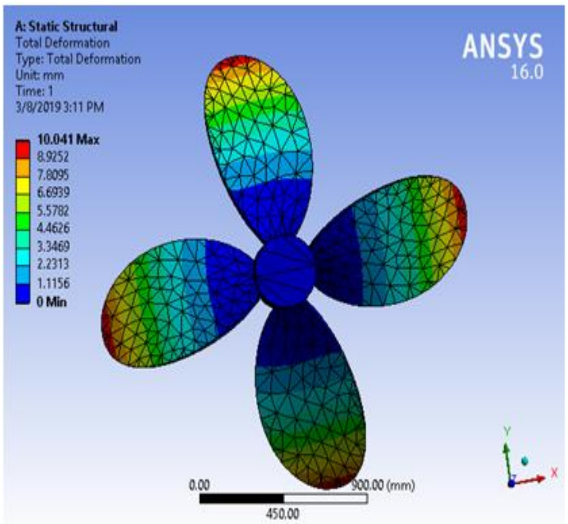

Fig 18:- Total Deformation

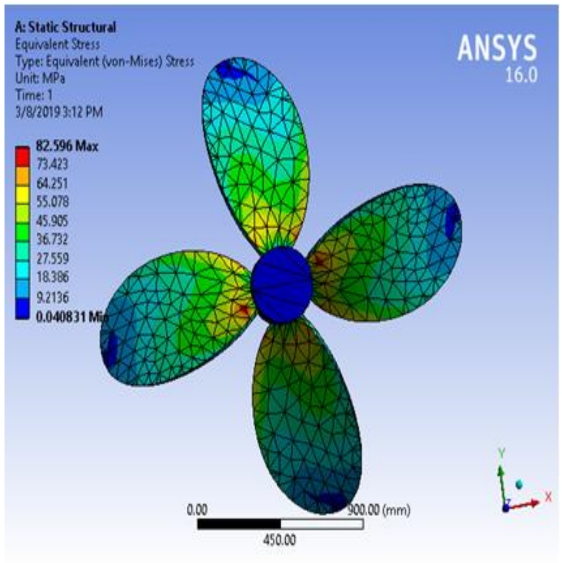

Fig 19:- Von-Misses Stress

- *Trial 3*

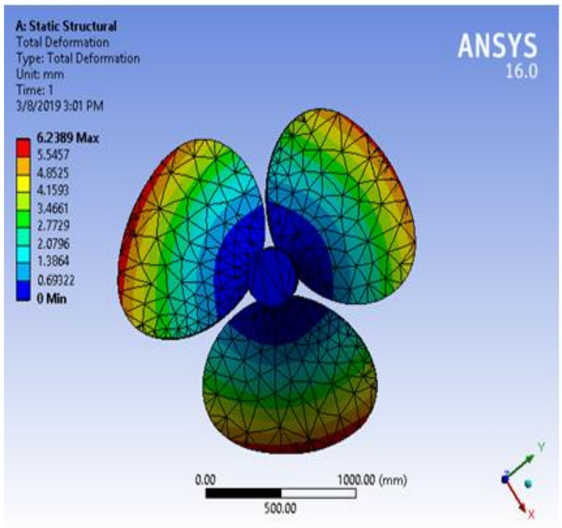

Fig 20:- Total Deformation

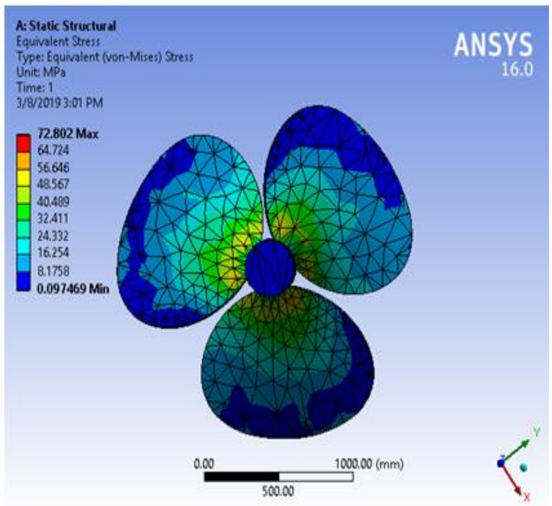

Fig 21:- Von-Misses Stress

- *Trial 4*

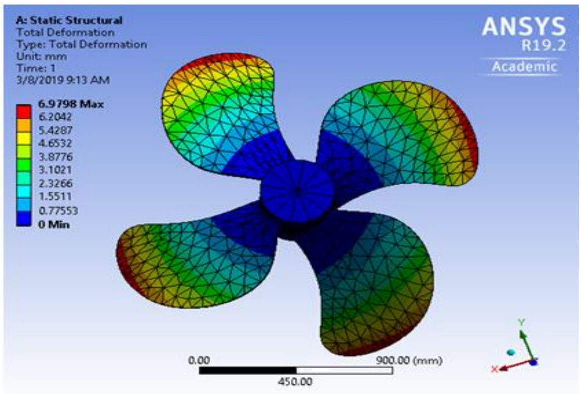

Fig 22:- Total Deformation

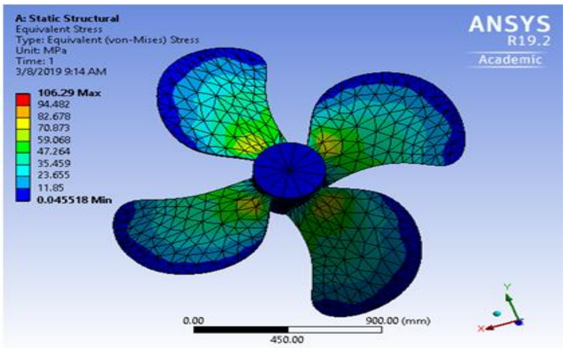

Fig 23:- Von-Misses Stress

Model	Total Deformation (mm)	% Difference
Trial 1	1.986	74 ↓
Trial 2	10.04	31 ↑
Trial 3	6.24	18.75 ↓
Trial 4	3.97	48.3 ↓

Table 10:- Deformation comparison with original model

Model	Von-Misses Equivalent Stress (MPa)	% Difference
Trial 1	22.92	66.16 ↓
Trial 2	82.6	22 ↑
Trial 3	72.8	7.4 ↑
Trial 4	60.13	11.23 ↓

Table 11:- Von-Misses Equivalent Stress comparison with original model

Comparison of calculated value and simulated value of thrust force at zero inlet flow velocity

Sr No	Calculated Thrust force (kN)	Simulated Thrust force (kN)
Trial 1	94.042	97
Trial 2	63.397	67.181
Trial 3	118.39	121.535
Trial 4	102.86	105.373

Table 12:- Thrust Force Analysis

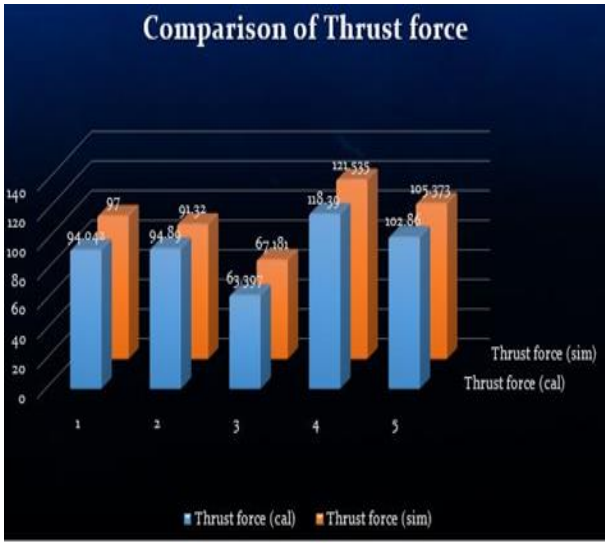

Fig 24:- Graph of Thrust Force

VIII. GRAPHICAL REPRESENTATION OF MODIFIED VERSION

The thrust force and outlet axial velocity of propeller is obtained from SolidWorks Flow Simulation 2016 with changing rotation speed of propeller in rpm between 300rpm to 1000rpm.

The reason behind selecting this speed range is that, the engine of twin screw ferry passenger is 836 kW which lies in the medium load condition. This condition generally operates between above speed range. Refer Table.13 & Table.14

Speed (rpm)	Thrust force (kN)				
	Original model	Trial 1	Trial 2	Trial 3	Trial 4
300	52.028	69.611	79.488	73.542	84.139
440	155.068	139.4	217.966	217.164	209.769
580	286.634	264.757	402.189	412.342	371.101
720	449.336	423.093	635.031	666.17	576.473
860	649.247	596.841	917.825	960.626	825.614
1000	884.012	822.454	1276	1327	1120

Table 13:- Graph of Thrust force vs Speed

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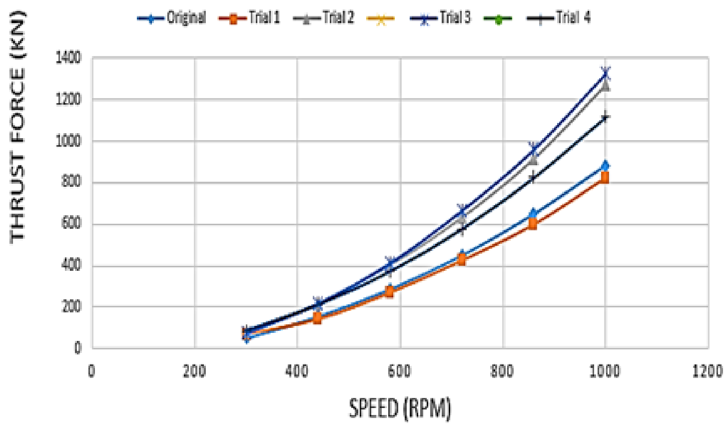

Fig 25:- Graph of thrust force vs speed

Speed (rpm)	Outlet Axial Velocity (m/s)				
	Original model	Trial 1	Trial 2	Trial 3	Trial 4
300	18.312	18.3	18.0	19.43	17.06
440	26.86	26.78	26.35	28.44	25.07
580	35.41	35.31	34.74	37.51	33.05
720	43.955	43.83	43.13	46.56	41.03
860	52.503	52.36	51.52	55.61	49.01
1000	61.0495	60.46	59.9	64.66	56.99

Table 14:- Graph of Velocity vs Speed

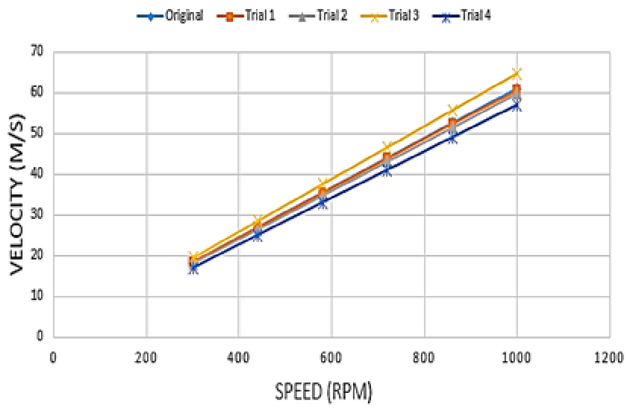

Fig 26:- Graph of velocity vs speed

IX. MATERIAL COST ESTIMATION

Generally material used for manufacturing of marine propeller is NAB (Nickel Aluminium Bronze). According to present market price cost of NAB per kg is Rs. 1400 while cost of per kg of CFRP is Rs. 1190.

Use of CFRP (Composite Fibre Reinforced Plastic) is very effective to reduce deformation on blade. Initially, when it was discovered it’s cost was way high but, as year passed by its cost has reduce. Before its implementation was not possible because of its high price but, now it is practical. Some material based cost analysis results are calculated,

Model	Material Cost (Rs.)		Saving (Rs.)
	NAB	CFRP	
Original	1,45,580	1,23,743	21,837
Trial 1	1,75,856	1,49,480	26,376
Trial 2	1,31,230	1,11,545	19,685
Trial 3	1,47,457	1,25,339	22,118
Trial 4	1,68,199	1,42,968	25,231

Table 15:- Cost estimation

X. DISCUSSION

As per the results obtained the thrust force is maximum for trial 4 but its mass is higher which increases the load on engine causing more fuel consumption also the velocity obtained is minimum of all model. The lowest mass is of trial 2 with significant amount of thrust force but as per ansys structural analysis deformation is greater with considerable high equivalent stress. The main drawback of this study is that no practical experimental proof is done to support the results obtained as the setup or manufacturing is costly at BE level. Moreover, not only material change would provide less deformation, reduce cavitation, increase life of blade and corrosion resistance but there is another newly developed method called melonite surface treatment of metal to tackle this objectives. Future research would include performing experimental results, advantage of melonite surface treatment technique over material changing, manufacturing and other financial cost analysis.

XI. CONCLUSION

From the analysis of the above 5 models using SOLIDWORKS FLOW SIMULATION 2016 and ANSYS WORKBENCH 2016 we conclude that trial 3 which is a 3 blade propeller provides maximum velocity which reduces transportation time. It also provides an increased thrust force of 73.542 kN and has comparatively less deformation then the original model. The requirement of the twin screw ferry passenger ship is heavy load and low speed so, a high thrust is required . Hence as per our analysis this is the suitable design. screw ferry passenger ship is heavy load and low speed so, a high thrust is required . Hence as per our analysis this is the suitable design.

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