YILDIZ TECHNICAL UNIVERSITY
NAVAL ARCHITECTURE AND MARITIME FACULTY
DEPARTMENT OF NAVAL ARCHITECTURE AND
MARINE ENGINEERING

CFD RESEARCH FOR INSEAN E779A PROPELLER

190A1501
ONUR CAN MAZLUM

BSc. GRADUATE THESIS

ADVISER
DOÇ. DR. ÜMİT GÜNEŞ

ISTANBUL, 2024

FOREWORD

I would like to express my sincere thanks to Doç.Dr. Ümit Güneş who enables me to work on this topic. His guidance and motivation leads me to learn the present topic and finish the thesis on time. Lastly, encouragements and motivational supports of Büşra Zekioğlu Selen Cansın Çevik and Deniz Pekelgil are gratefully acknowledged.

May, 2024

Onur Can Mazlum

CONTENTS

MPa	Megapascal
Pa	Pascal
Q	Torque, N.m
T	Thrust, N
Z	Number of blades
K_T	Thrust coefficient
Kq	Torque coefficient
n	Rotational speed, rps
RPM	Revolutions Per Minute

ABBREVIATIONS LIST

Dp	Propeller Diameter
Dh	Hub Diameter
Lh	Hub Length
CFD	Computational Fluid Dynamics
CAD	Computer Aided Design

FIGURE LIST

Page

TABLE LIST

Page

CFD RESEARCH FOR INSEAN E779A PROPELLER

Onur Can Mazlum

Department of Naval Architecture and Marine Engineering

Advisor: Doç. Dr. Ümit Güneş

The present bachelor thesis is on the shipbuilding industry. It mainly aiming to measure the corrosion and pressure values of the Insean E779A propeller under different conditions and different blade numbers with CFD Research.

CHAPTER 1

INTRODUCTION

1.1 Aims of the thesis

INSEAN E779A propeller is a type of propeller commonly used in marine vessels. It is known for its high efficiency and low noise levels. In this study, calculations were made on the propeller geometry using CFD simulations to observe the performance of the propeller.

Keywords: CFD, Cavitation, Open Water Calculations, Blade Numbers, Corrosion

1.2 Literature Survey

During recent years Computational Fluid-Dynamics (CFD) models have demonstrated to rapidly become effective tools to analyse marine propeller single-phase flows. So, The INSEAN E779A is a four-bladed, fixed pitch, righthanded propeller, originally designed in 1959. The design of propeller has been optimized using experimental studies and CFD simulations. Blade skew and rake are small, and pitch ratio is almost constant along radius (P/D=1.1). A bronze model of diameter D_P=227.27 mm is used for experimental work.

Figure 1. Insean E779A Propeller with P/D=1.1

The E779A propeller has also previously been subject of calculations by the EU VIRTUE project. In the current work, the cavitation patterns, cavitation dynamics and associated pressure fluctuations are the major focus. In Figure 2. Figure 2 shows the propeller in the cavitation tunnel.

Figure 2. E779A propeller inside the cavitation tunnel

1.3 Design and Geometries

In this thesis, i used Ansys Fluent 2023 Student version for CFD experimentals. I used SolidWorks application for 3D drawing. During this Project, I used IGES and Parasolid formats. When drawing, I took the propeller diameter as 227 mm.

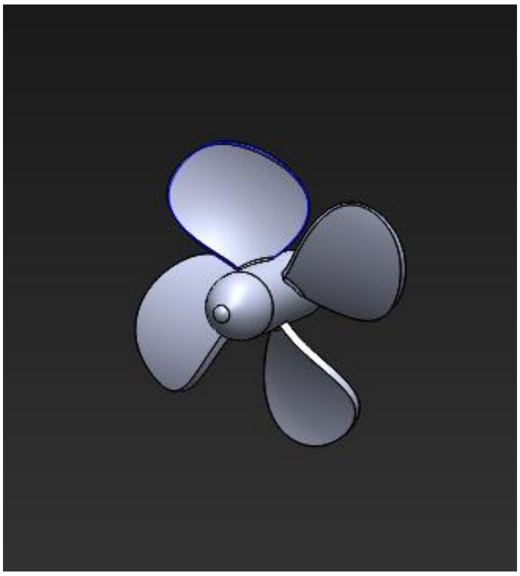


Figure 3. 3D propeller design made (CAD) in Solidworks software (IGES)

Table 1. Dimesions of the INSEAN E779a model propeller

Propeller Diameter	$D_p = 227.27$ mm
Number of blades	$Z = 4$
Hub diameter (at prop. Ref. line)	$D_{H} = 45.53$ mm
Hub length	$L_H = 68.30$ mm

Basic features of the propeller; Number of blades, blade diameter and Hub Length values are shown in Table 1.

Table 2. Blade characteristics of the INSEAN E779a model propeller

r/R_p	P/D_p	c/D_p	X_{LE}/D_p	T_{max}/D_p	x_{Tmax}/c	$rake/D_p$
0.2640	1.11179	0.27838	0.16044	0.044033	0.17633	+0.00601
0.3520	1.12039	0.30799	0.17083	0.03124	0.014066	-0.01072
0.4400	1.12021	0.33571	0.18019	0.02565	0.08674	-0.01437
0.5280	1.11671	0.36001	0.18718	0.02119	0.06993	-0.011794
0.6160	1.11467	0.37666	0.18966	0.01672	0.10353	-0.02158
0.7040	1.11728	0.37841	0.18489	0.01293	0.05860	-0.02501
0.7920	1.11738	0.36335	0.16954	0.00967	0.01661	-0.02876
0.880	1.11024	0.31704	0.13451	0.00626	-0.07573	-0.03267
0.9680	1.11089	0.19174	0.05974	0.00388	-.018842	-0.03644
0.9900	1.11012	0.11574	0.01621	0.00328	-0.45992	-0.03756
0.9988	1.11012	0.04906	-0.02073	0.00185	-0.97258	-0.03835

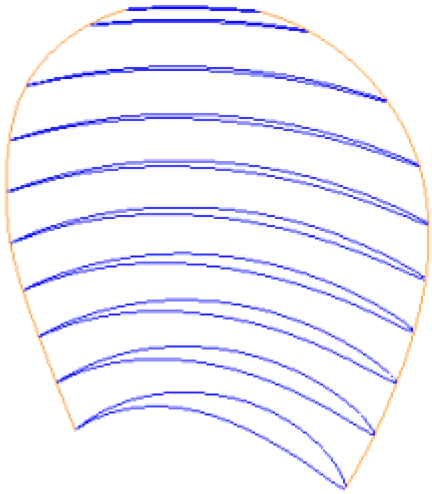


Figure 4. Wrapped sections for propeller

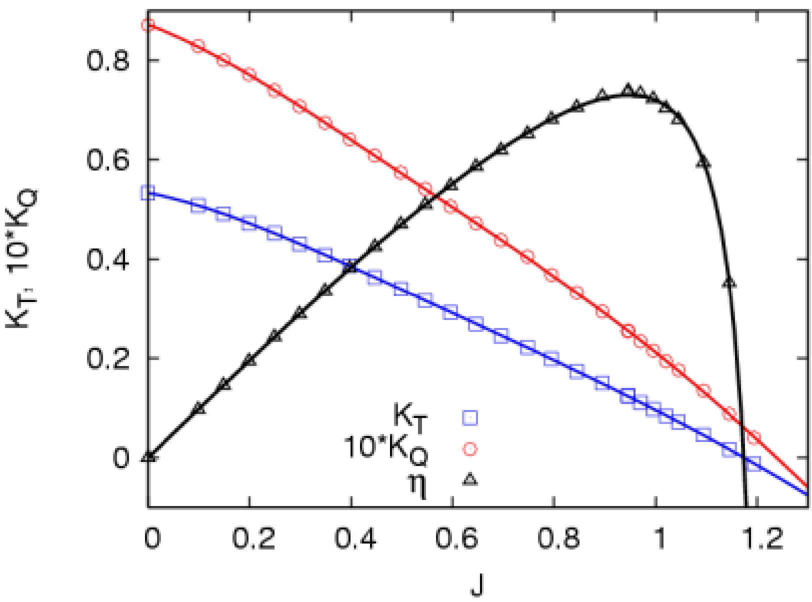


Figure 5. Open Water Characterictics of the INSEAN E779a [1]

Open Water Characteristics of the INSEAN E779A propeller are shown. It was observed that when J value increased, Kt and Kq values decreased.

CHAPTER 2

CALCULATIONS

So far, a lot of CFD calculations have been made for the INSEAN E779a propeller. In general, calculations were made at values between 11 and 50 rps. In my thesis, I worked with a value of 2000 rpm (33.3 rps). I chose sea water as the fluid and used the temperature of the water as 22 degrees. I used the IGES formatted file in the Ansys Fluent module. While making the calculations, I assigned a mesh with 900000 elements using the Finite Element Method and I made my calculations after assigning this mesh. I used the k-epsilon method, Realizable k-epsilon model as the viscous method.

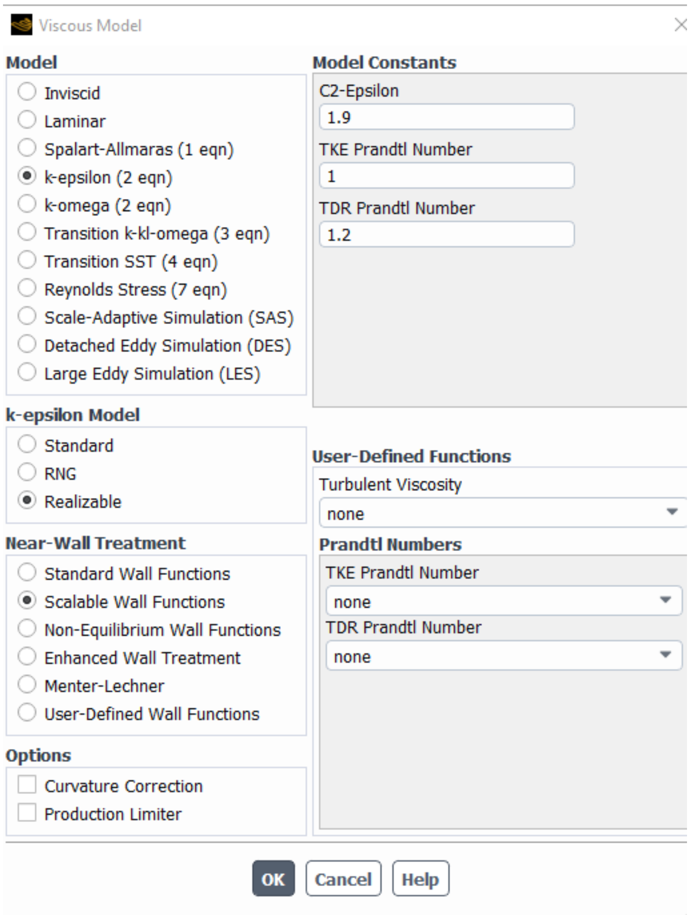


Figure 6. Viscous Model

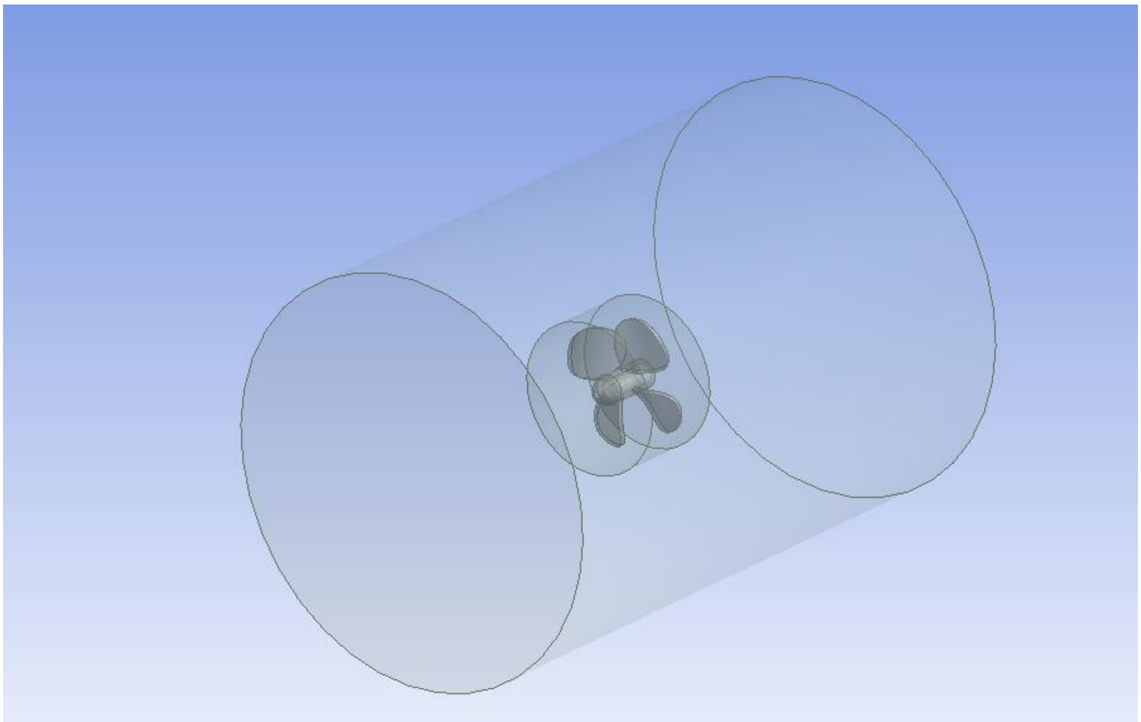


Figure 7. Enclosure part

To create an unreal flow field, I defined my propeller with the Enclosure command and sent it to the Mesh module to assign a Mesh to the propeller. After assigning two Enclosures, I named the Propeller separately.

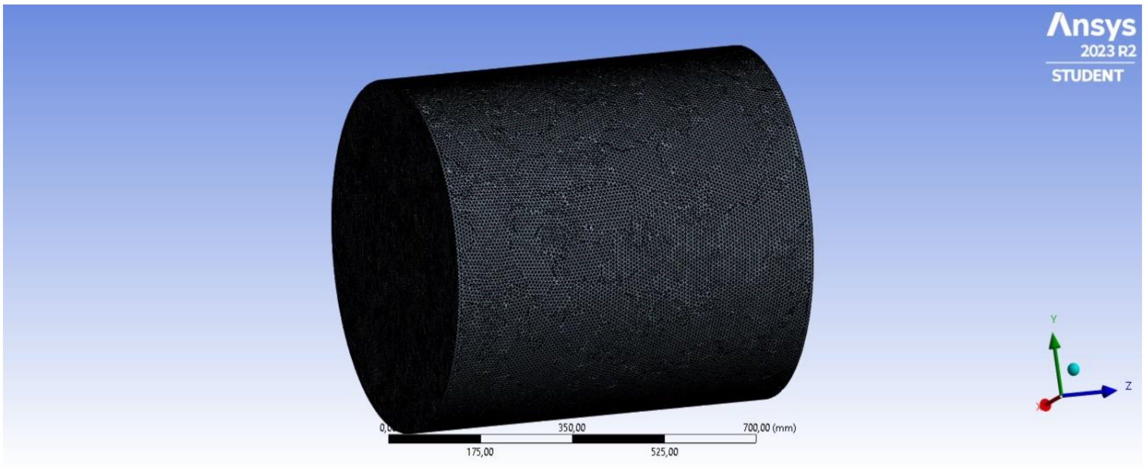


Figure 8. Mesh part

The mesh was assigned with the face sizing method and it was aimed to reduce the Average Skewness value. I chose cylinder type as the flow field, 10 mm as the element size, 1.2 mm as the Capture Proximity and 1.2 mm as the Growth rate.

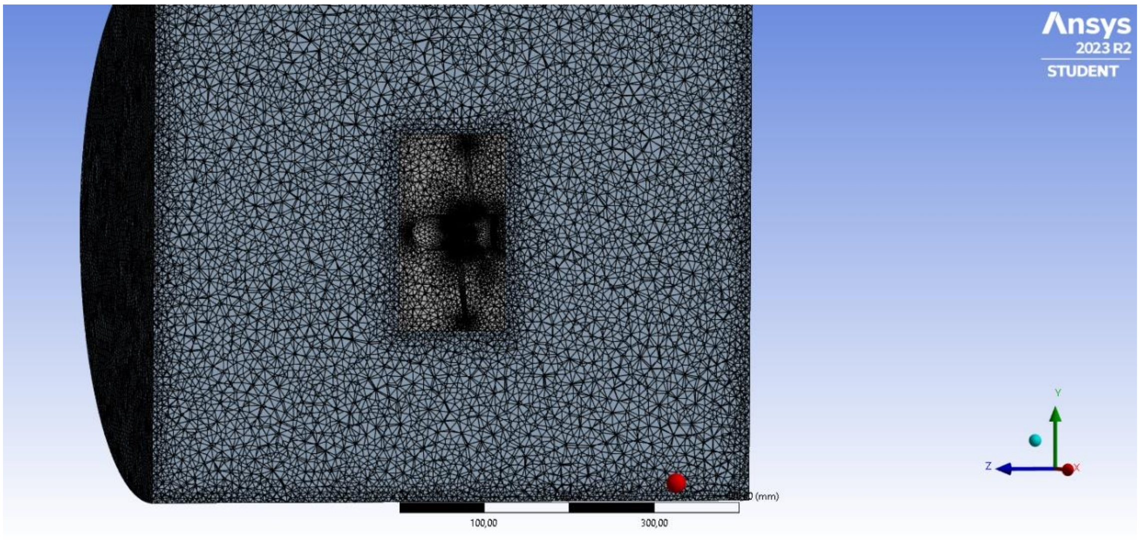


Figure 9. Mesh figure after Section Plane

I observed the errors in the Mesh using Section Plane. In this way, wherever there were faulty meshes, I re-meshed them. I aimed to keep the Skewness values low in the parts close to the propeller.

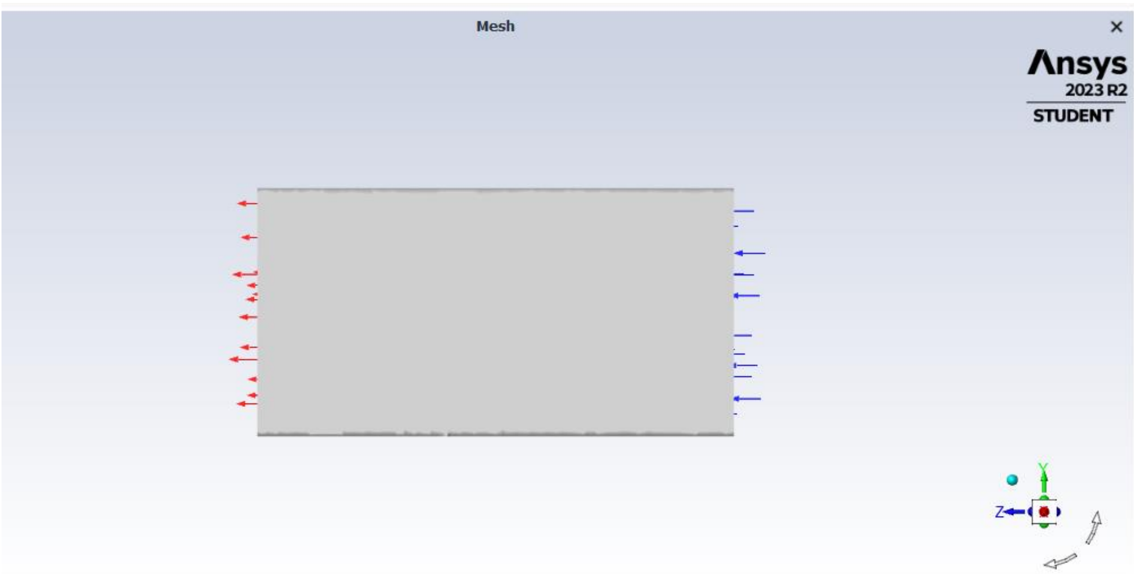


Figure 10. Inlet and Outlet Boundary Conditions

While doing my study, I determined inlet and outlet areas to determine the flow direction. Even though the propeller rotation speed was 2000 rpm, I aimed to get a

More realistic result by sending a speed of 0,5 m/s through the inlet section. (Blue arrows are inlet, red arrow are outlet section)

Quality Criterion	Warning Limit	Error (Failure) Limit	Worst
Max Aspect Ratio	Default (5)	Default (1000)	13,658
Min Element Quality	Default (0,05)	Default (5e-04)	0,176
Min Orthogonal Quality	Default (0,05)	Default (5e-03)	5,1e-03
Max Skewness	Default (0,9)	Default (0,999)	0,995

Figure 11. Mesh Quality Worksheet

All values are within their required ranges. The smaller the Skewness value, it means the more accurate the results. Average Skewness value was found to be 0.11 and average Orthogonal Quality value was calculated as 5.1e-03.

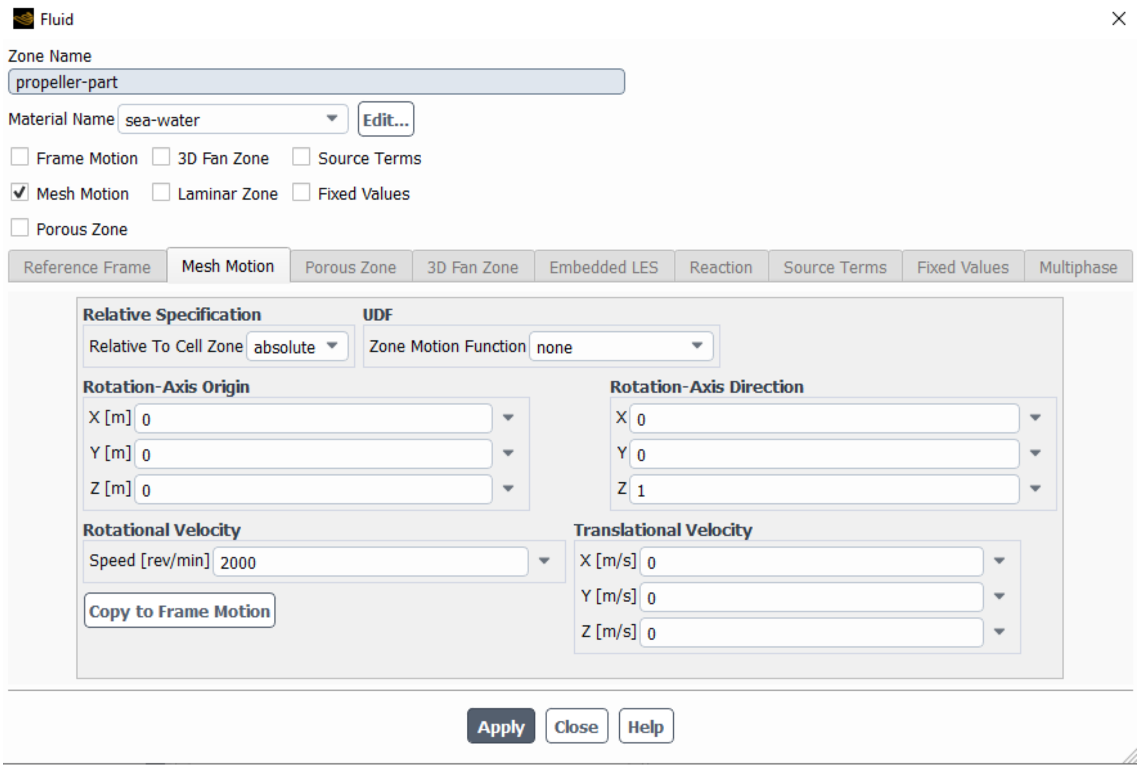


Figure 12. Cell Zone Conditions

I gave my propeller a speed of 2000 Rpm and assigned the Z value in the Rotation Axis Direction tab to 1 since it was on the Z axis. After entering all Cell Zone Conditions and Boundary Conditions values, I started my calculations. In my work, Sea Water was used as the fluid and Copper alloy was used as the propeller material.

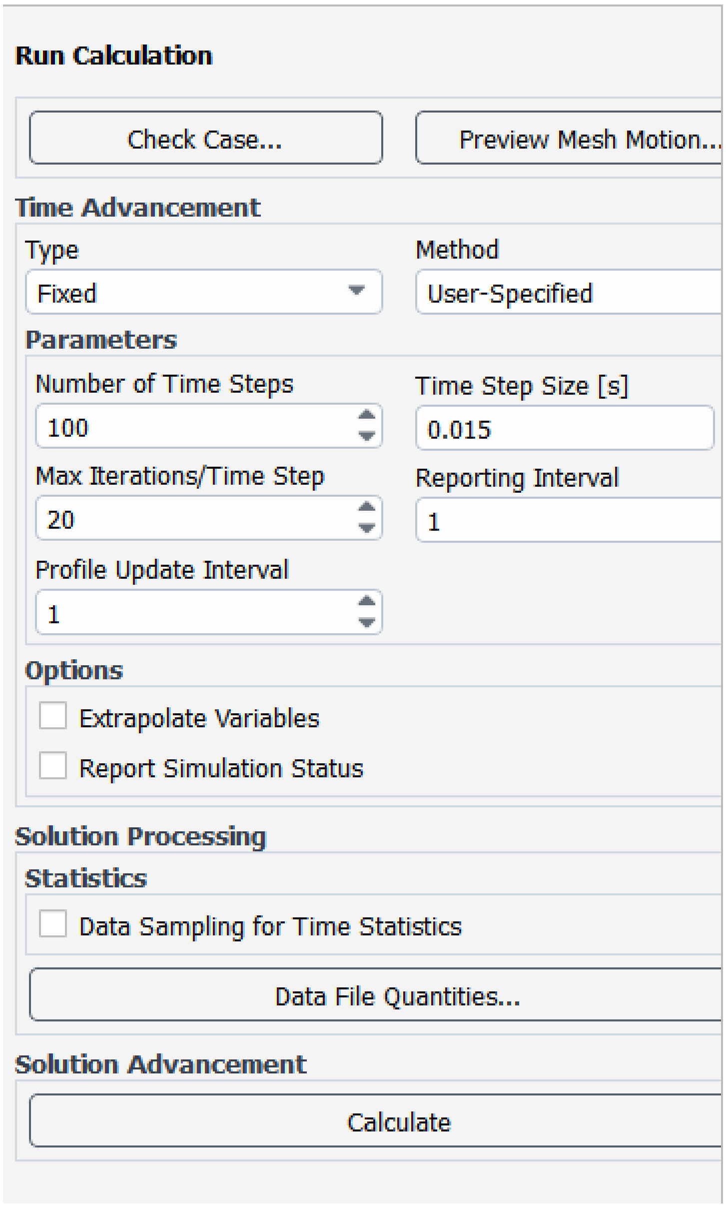


Figure 13.Calculation Task Page

As a Transient study, I started my study by assigning the values of 100 Number of steps, 0.015 s Time Step Size and Max 20 Iterations. Each of the calculations I made for 3 blades, 4 blades, 5 blades and 6 bladess took about 25 minutes. I did a long and detailed study to ensure that the calculations were correct. I used Aluminum in my CFD studies, Bronze Alloy and Copper Alloy in my Static Structural studies. Because Copper Alloy and Bronze Alloy materials are used more in the maritime industry. They have less electrical reaction and less corrosion values than structural steel and aluminum in the sea.

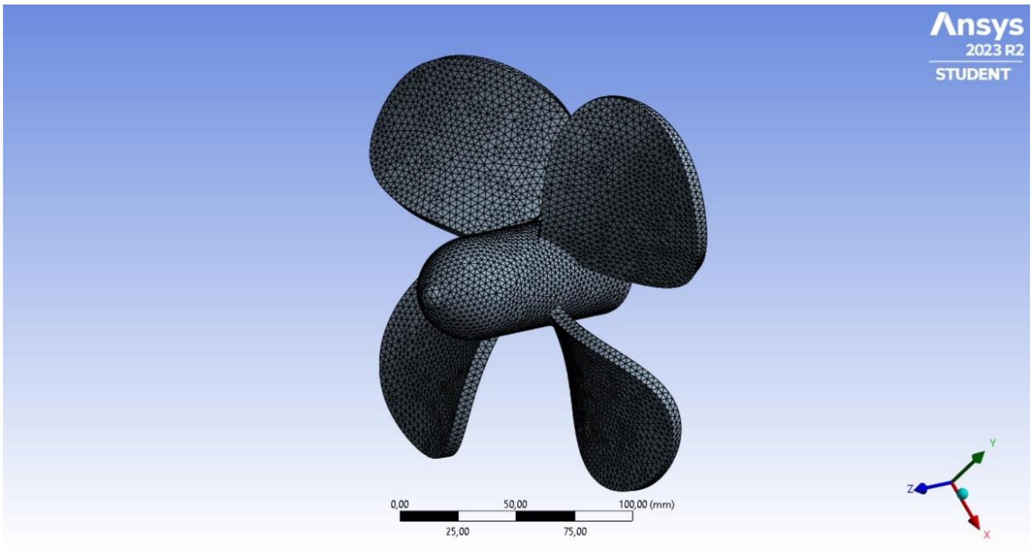


Figure 14. 4 wings Mesh figure

I aimed to keep the Skewness value of the propeller below 1. The Mesh image I assigned for this purpose is shown. This process was repeated on 3,5,6 blades and I aimed to get the most accurate mesh results.

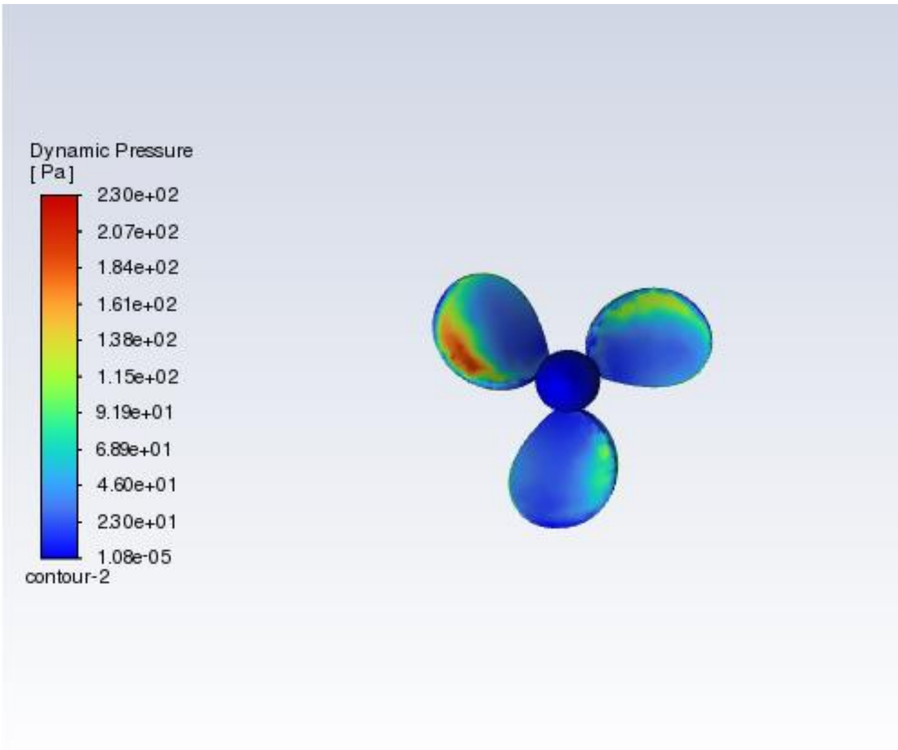


Figure 15. 3 blades Dynamic Pressure result

The purpose of my work is to observe corrosion and minimum and maximum pressure values on surfaces. It has been observed that when the number of blades increases, the pressure number increases, but the corrosion on the surfaces decreases.

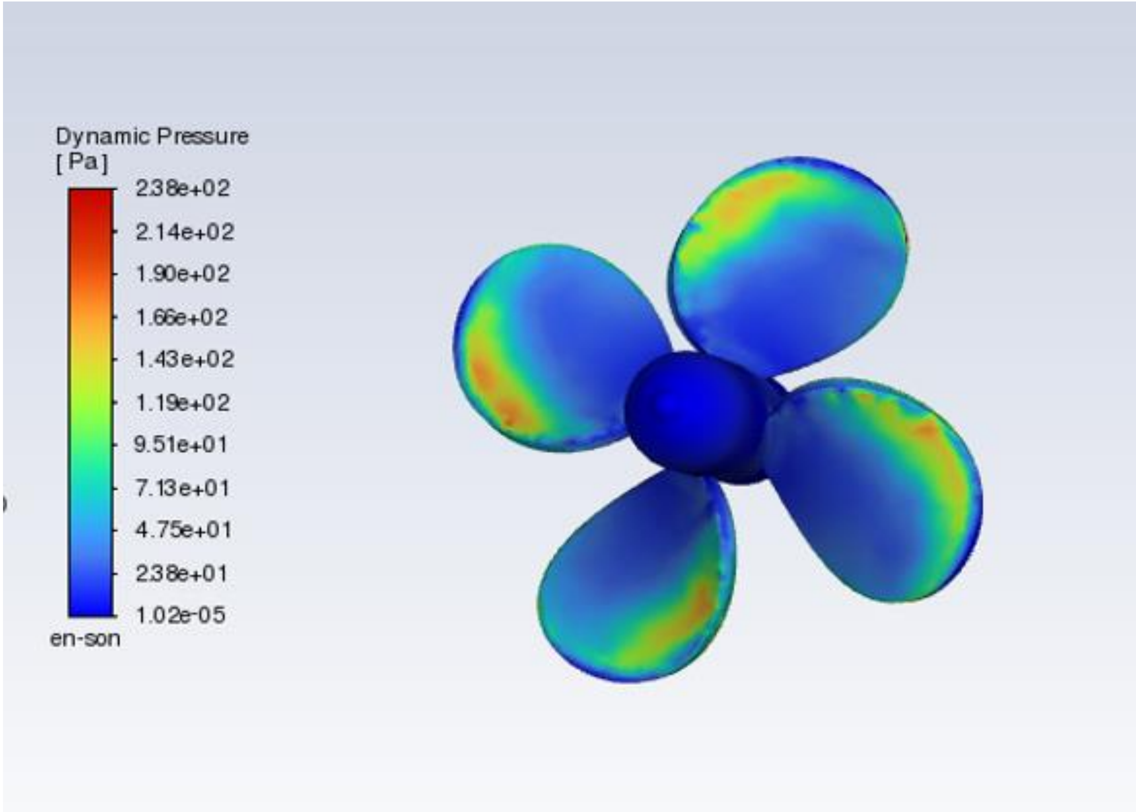


Figure 16. 4 blades Dynamic Pressure result

In the previous calculation, a 3-blade calculation was made. It was observed that the pressure values increased in the 4-blade calculation, which is the real version of the propeller. We see that when the number of wings increases, the pressure increases, but this pressure is distributed equally on the surfaces. As a result, when the number of wings increases, more lift force is created, thus the stress per wing and corrosion decreases.

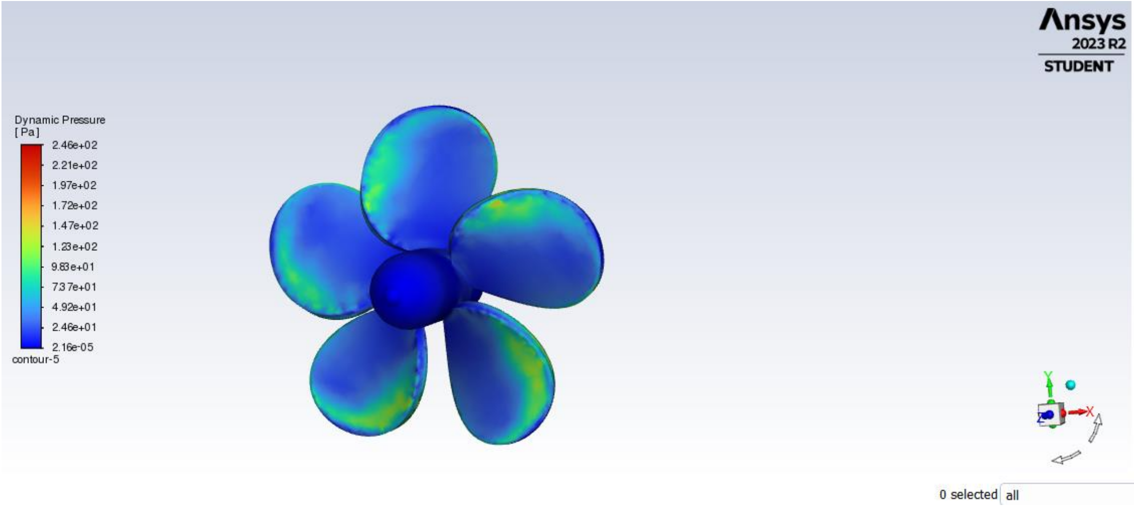


Figure 17.5 blades Dynamic Pressure result

When the number of wings increased to 5, our previous pressure value of 2.38e+02 Pa increased to 2.46e+02 Pa in case of 5 wings. As the pressure values increased, the corrosion per surface decreased.

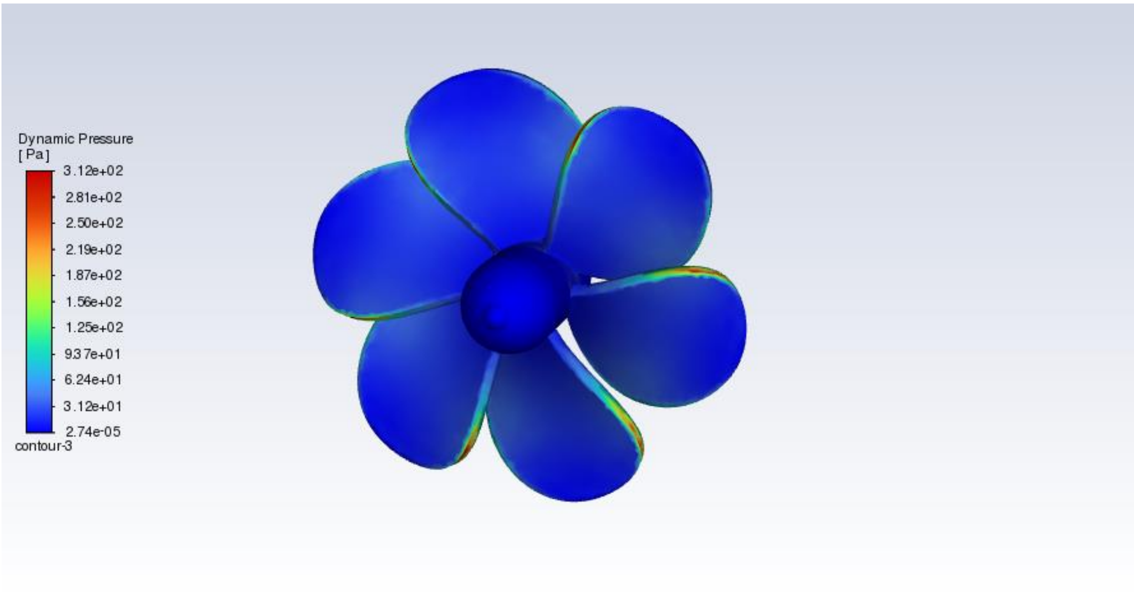


Figure 18. 6 blades Dynamic Pressure Result

I worked with 6 blades. With a number of blade of 6, the pressure value is highest, but corrosion and wear per surface is at the lowest level.

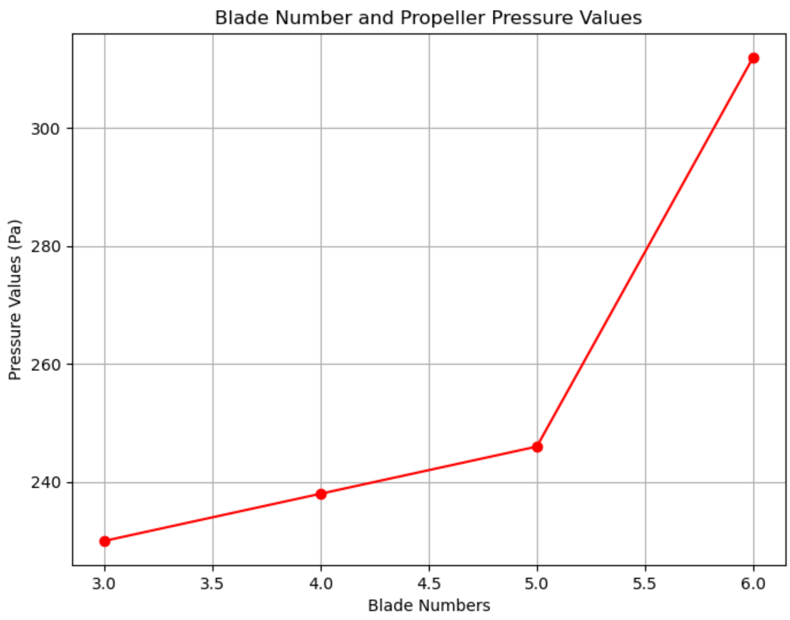


Figure 19. Pressure – Blade Number graph

I created a table of propeller blade number and pressure values using the matplotlib library in Python. As can be seen from the graph, when the number of wings increases, the pressure value decreases.

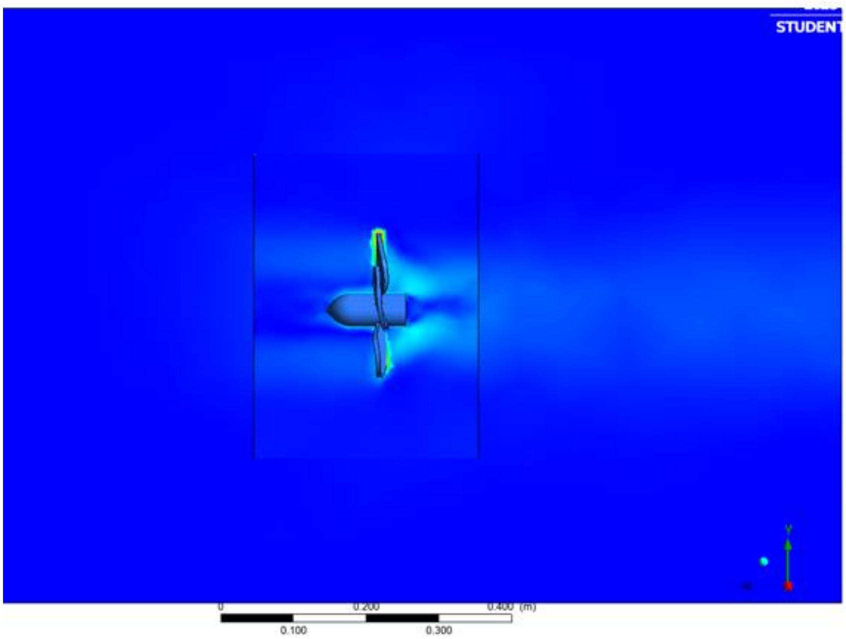


Figure 20. 5 blades CFD Post velocity figure

The velocity graph of the propeller moving at a speed of 0,5 m/s is shown.

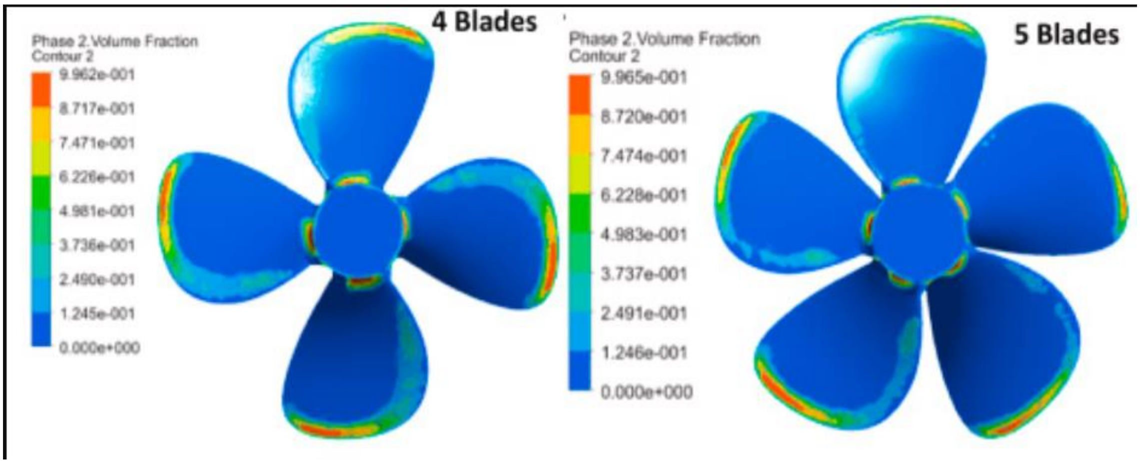


Figure 21. CFD Research for Mechanical Engineering Department, Faculty of Engineering, Diponegoro University [2]

In a study conducted at Diponegoro University, it was observed that the pressure increased as the number of wings increased. It has been observed that Volume Fraction values decrease when lower rpm and speed values are used.

2.1 Static Structural Calculations

In my studies above, I made Ansys Fluent CFD calculations. I calculated the deformation and Equivalent (Von-Mises) Stress values of the propeller according to the material difference. The materials I use in my work are Copper Alloy and Bronze Alloy. Deformation and Von -Mises values were compared when the number of blades increased.

Bronze, C51000 2

Bronze, CuSn4, C51000, hard (5% phosphor bronze), wrought

Data compiled by Ansys Granta, incorporating various sources including JAHM and MagWeb.
ANSYS, Inc. provides no warranty for this data.

Density	8,715e-06 kg/mm³
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	1,077e+05 MPa
Poisson's Ratio	0,34500
Bulk Modulus	1,1581e+05 MPa
Shear Modulus	40037 MPa
Isotropic Secant Coefficient of Thermal Expansion	1,675e-05 1/°C
Tensile Ultimate Strength	574,50 MPa
Tensile Yield Strength	505,00 MPa
Thermal	
Isotropic Thermal Conductivity	0,077350 W/mm·°C
Specific Heat Constant Pressure	3,845e+05 mJ/kg·°C
Electric	
Isotropic Resistivity	0,00011500 ohm·mm

Figure 22. Bronze Material View

The material properties of the Bronze material are shown in the Ansys Mechanical Engineering Data section. The Young Modulus value was calculated as 1.007e+05 MPa.

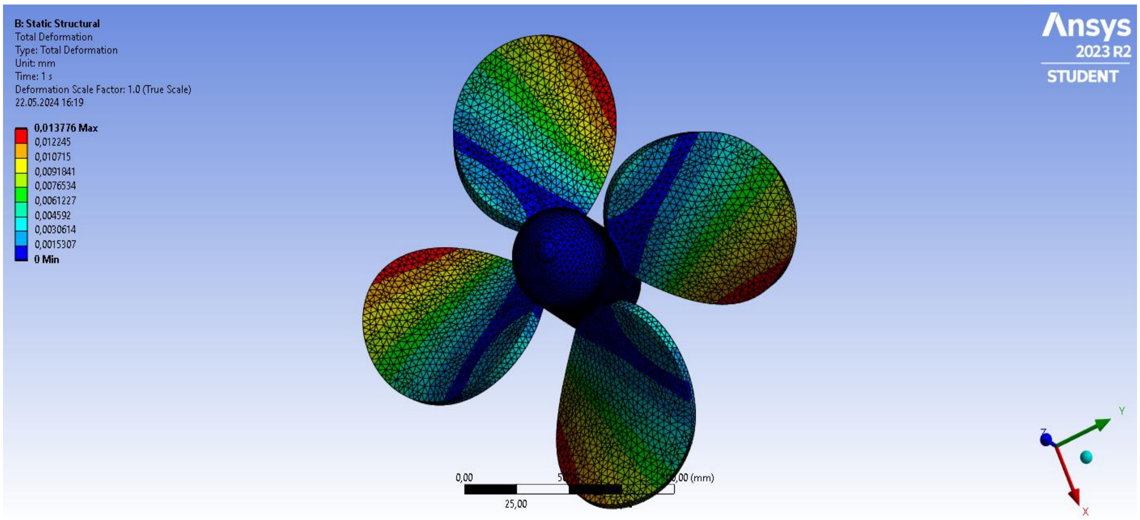


Figure 23. Bronze Deformation results

I gave Fixed Support to the propeller from the shaft connection point. Then, as I did in the CFD calculations, I rotated the propeller with a magnitude of 2000 RPM with the Rotational Velocity command (Z axis).

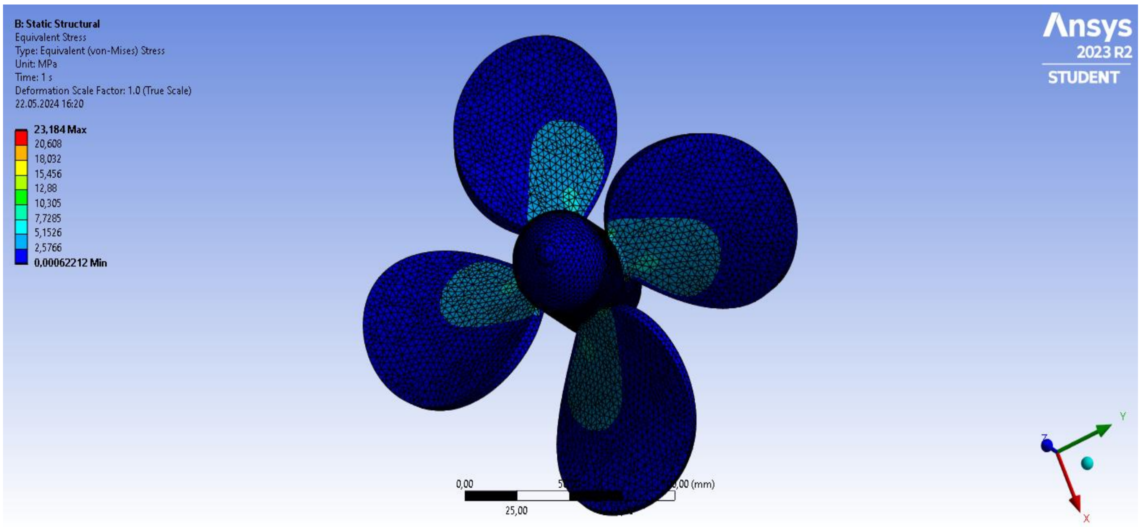


Figure 24. Bronze Equivalent Stress results

While calculating the stress, the maximum value was 23,184 Mpa and the minimum value was calculated as 0.00062212 Mpa.

Copper Alloy

Density	8,3e-06 kg/mm³

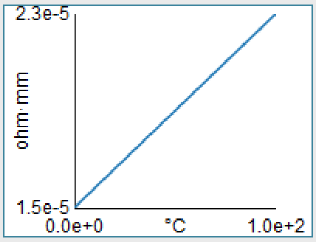
Structural

Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	1,1e+05 MPa
Poisson's Ratio	0,34000
Bulk Modulus	1,1458e+05 MPa
Shear Modulus	41045 MPa
Isotropic Secant Coefficient of Thermal Expansion	1,8e-05 1/°C
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	280,00 MPa
Tensile Ultimate Strength	430,00 MPa
Tensile Yield Strength	280,00 MPa

Thermal

Isotropic Thermal Conductivity	0,40100 W/mm·°C
Specific Heat Constant Pressure	3,85e+05 mJ/kg·°C

Electric

Isotropic Resistivity	

Magnetic

Isotropic Relative Permeability	1,0000

Figure 25. Copper Alloy Material View

The material properties of the Copper Alloy material are shown in the Ansys Mechanical Engineering Data section. The Young Modulus value was calculated as 1.1e+05 MPa.Poisson's ratio is 0.34000.

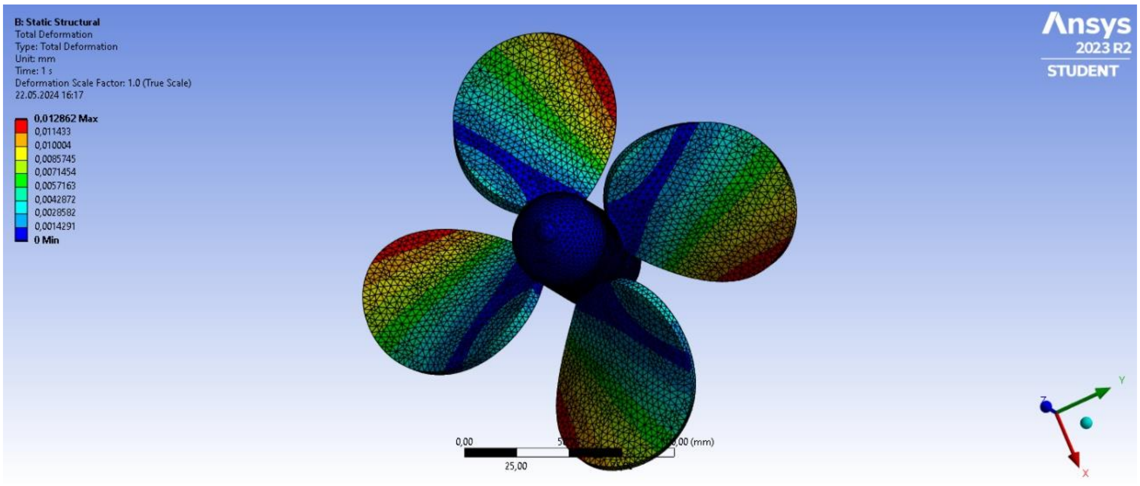


Figure 26. 4 blades Copper Alloy deformation results

The maximum deformation result of the Copper Alloy material is 0.012862. However, the maximum deformation value of the Bronze Alloy material was found to be 0.013376. As a result, we observed that the Copper Alloy material is less deformed.

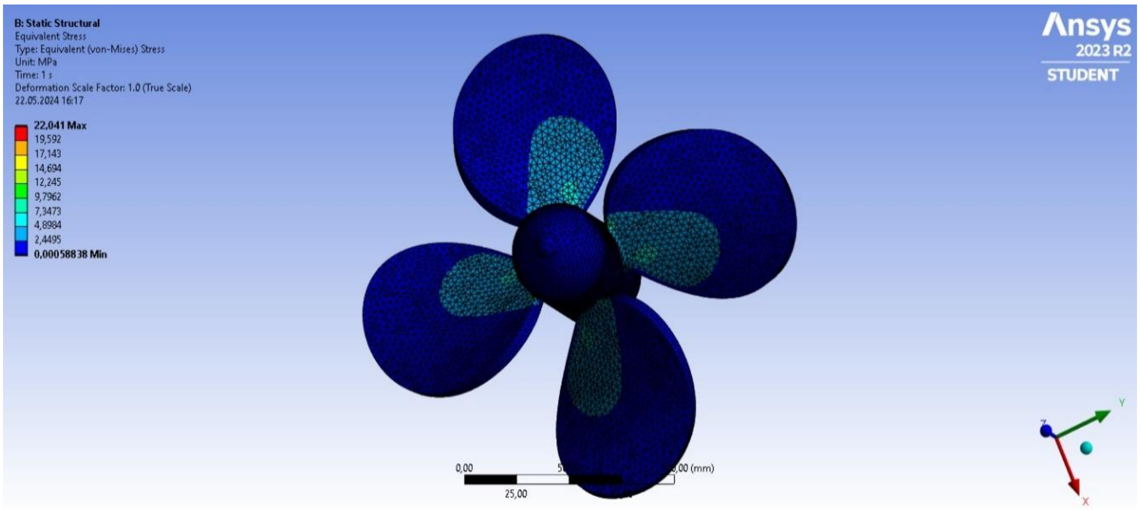


Figure 27. 4 blades Copper Alloy Equivalent Stress results

Maximum stress was found to be 22.041.Mininum stress was found 0.00058838.

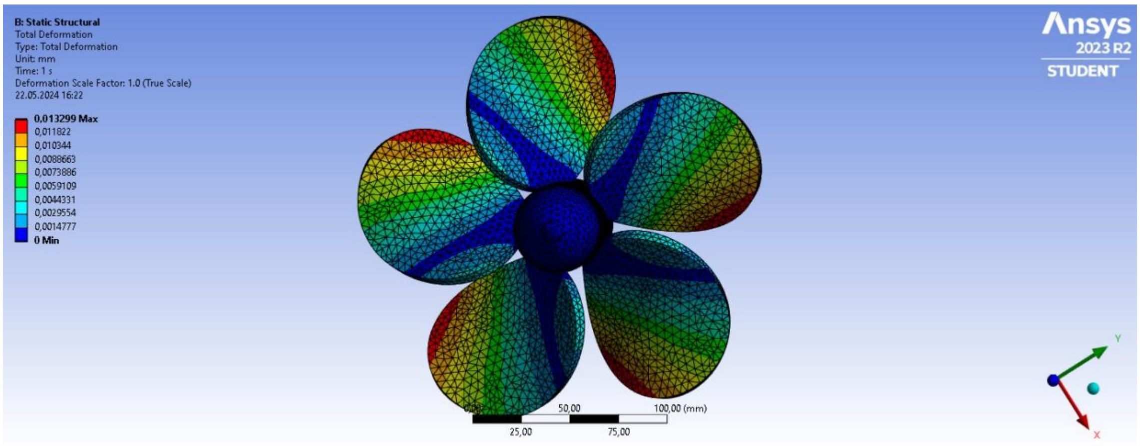


Figure 28. 5 blades Bronze Deformation results

As we see in CFD calculations, when the number of blades increases, the deformation rate per surface decreases because the deformation is distributed over all surfaces.

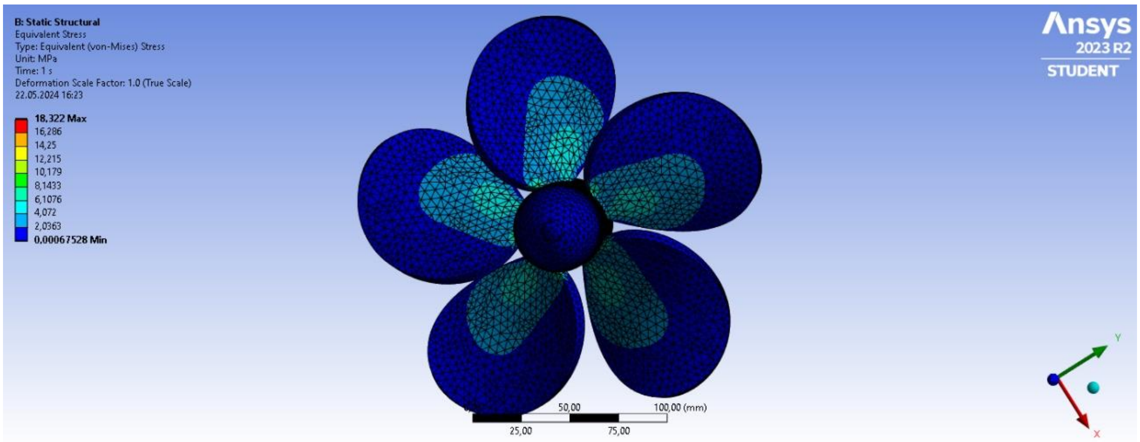


Figure 29. 5 blades Bronze material Equivalent (Von-Mises) Stress results

As the deformation value decreases, the Equivalent Stress value was found to be 23.184 when there were 4 blades and 18.322 when there were 5 blades.

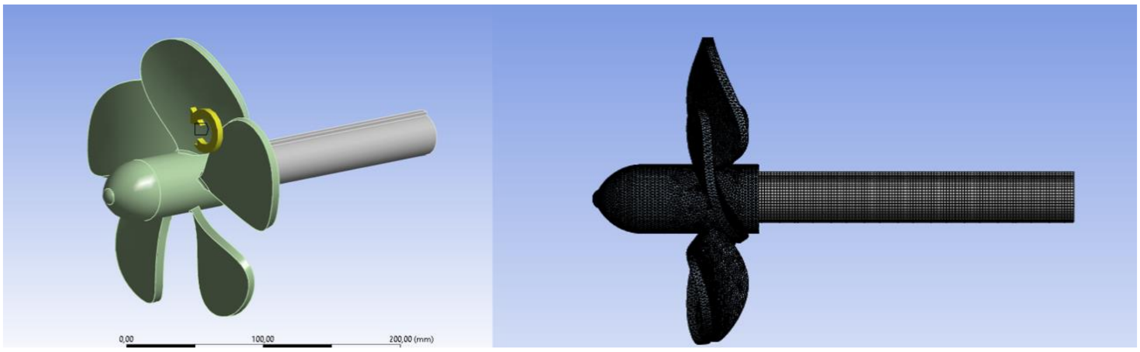


Figure 30. Shaft connected propeller figure

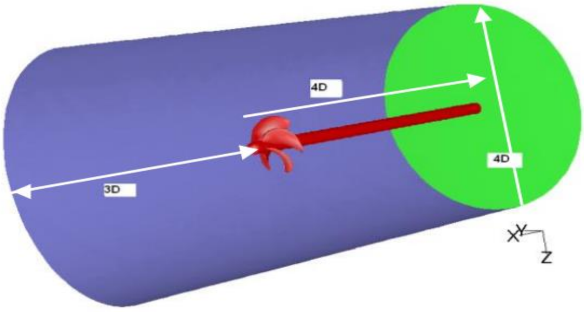


Figure 31. Mesh figure for shaft calculation

In the study conducted by S. Subhas [3], there was also a visual for the shaft, but there was no CFD or Static Structural analysis. I also performed the deformation analysis of the shaft after connecting it to the propeller in the Static module.

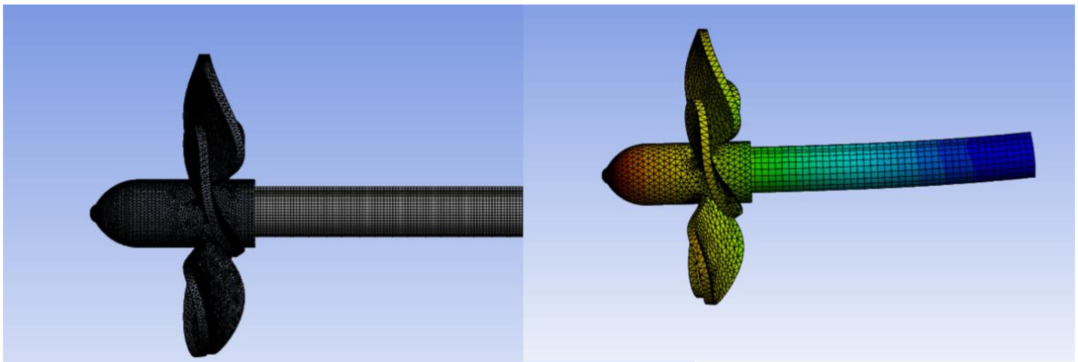
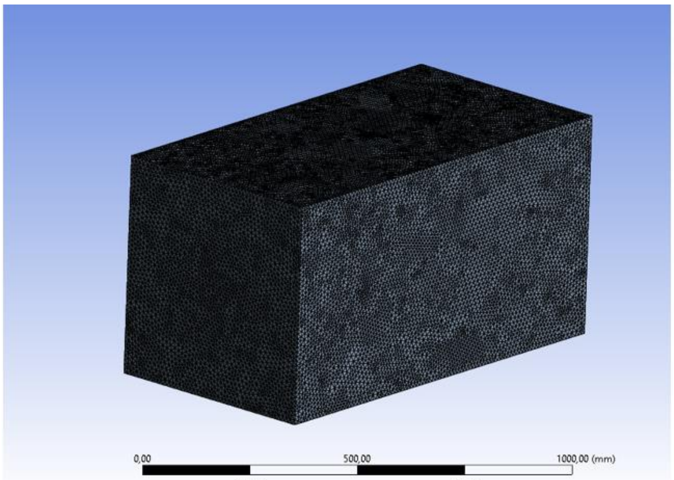
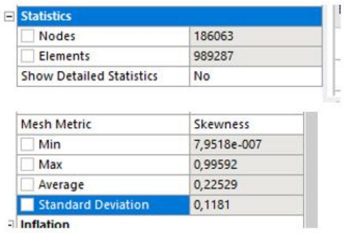


Figure 32. Shaft figure with meshed and deformation results

In the figure on the left, after connecting the shaft to the propeller, the Mesh is assigned. On the right, the deformation analysis of the wedge-mounted propeller can be seen. Deformation decreased It was observed that the direct tension decreased from the attachment point to the end of the shaft.





Statistics	
Nodes	186063
Elements	989287
Show Detailed Statistics	No

Mesh Metric	Skewness
Min	7,9518e-007
Max	0,99592
Average	0,22529
Standard Deviation	0,1181

Inflation

Figure 33. Box type mesh work with skewness values

In my studies, I also worked on making a Box type flow field. Cylinder results were similar to previous studies and more logically. In the study conducted with Box type Fluid Field with the same volume and the same number of elements, the values were higher.

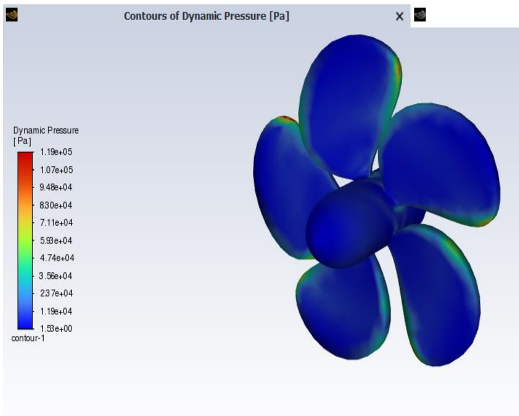


Figure 34. 5 blades pressure result with box type flow field

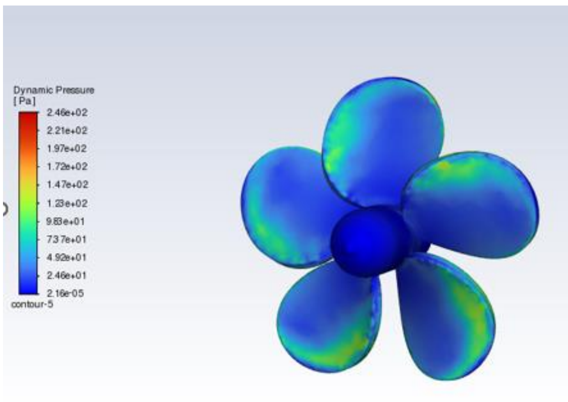


Figure 35. 5 blades pressure result with cylinder type flow field

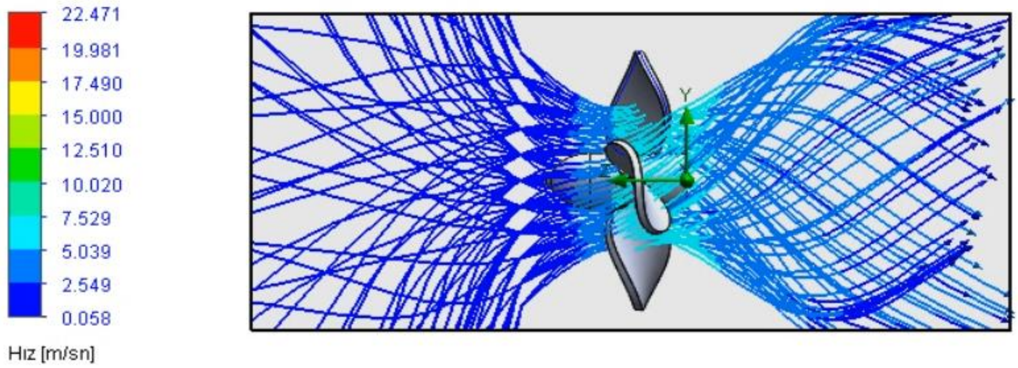


Figure 36. 4 blades Flow Simulation

The result when the propeller is rotated at 2000 rpm in the Solidworks Flow Simulation modüle. After creating a closed flow area, I determined the inlet part of the propeller and carried out my work.

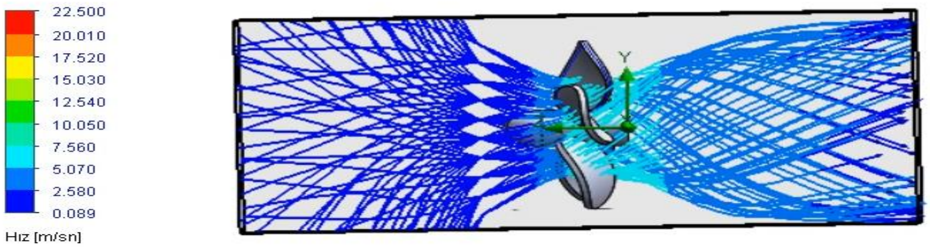


Figure 37. 5 blades Flow Simulation

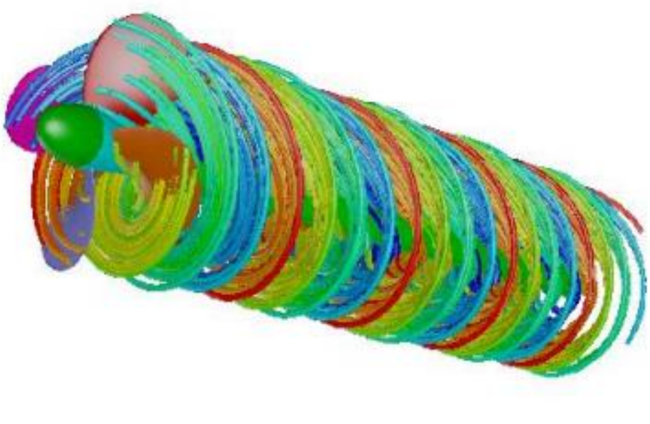


Figure 38. Propellers cavitation flow [4]

Table 3. J-KT-Kq values for INSEAN E779a for r/R=0.264

Condition	Advance coefficient (J)	Thrust Coefficient (K_T)	Torque Coefficient (K_Q)
Non Cavitating	0.846908	0.169183	0.0352437
Cavitating	0.846908	0.168778	0.0366621

Table 4. Uniform flow, J = 0.71. summary of predicted thrust and torque coefficients and experimental data [5]

Uniform Flow J = 0.71	$\mathbf{K_T}$ (Non-cavitating)	$10 \cdot \mathbf{K_Q}$ (Non-cavitating)	$\mathbf{K_T}$ (Cavitating)	$10 \cdot \mathbf{K_Q}$ (Cavitating)
Measured (tunnel)	0.256	0.464	0.255	0.460
Measured (O.W.)	0.238	0.429	-	-
FreSCo	0.237	0.438	-	-
Fine$^{\mathrm{TM}}$/Turbo	0.250	0.428	0.260	0.447
Fluent 6.3	0.240	0.426	-	-
FINFLO	0.234	0.418	0.249	0.459
M-UNCLE	0.276	0.498	0.256	0.476
Ch's OpenFOAM	0.256	0.453	0.252	0.450
PFC-BEM	0.244	0.419	0.247	0.449

The values of Kt and Kq in cavitating and non-cavitating states are shown using Fresco, Fine™/Turbo, Fluent 6.3, FINFLO, M-UNCLE, PFC-BEM software.

CHAPTER 3

CONCLUSION

I found multiple results. First of all, we observed that when the number of blades increases, the pressure increases, but the amount of corrosion per surface decreases.

Table 5. Blades – Pascal Results table

3 Blades	**4 Blades**	**5 Blades**	**6 Blades**
230 Pascal	238 Pascal	246 Pascal	312 Pascal

Table 6. Deformation – Equivalent (Von-Mises) Results table

<table>
<tr><th colspan="5">Deformation – Equivalent (Von-Mises) Results table</th></tr>
<tr><td colspan="3">Bronze Alloy</td><td colspan="2">Copper Alloy</td></tr>
<tr><td rowspan="2">4 blades</td><td>Deformation</td><td>Stress</td><td>Deformation</td><td>Stress</td></tr>
<tr><td>0.013776 mm</td><td>23.184 Mpa</td><td rowspan="2">0.012862 mm</td><td rowspan="2">22.041 MPa</td></tr>
<tr><td>5 blades</td><td>0.013299 mm</td><td>18.322 Mpa</td></tr>
</table>

As seen in the table, when the number of wings increased, Deformation and Equivalent Stress values decreased. Under the same conditions- in the case of 4 wings- Copper Alloy has less Deformation and Stress values than Bronze Alloy. So, Copper Alloy is a better option in propeller making.

[1] https://www.researchgate.net/figure/INSEAN-E779A-propeller-open-water-characteristics-Towing-tank-measurements-compared-to_fig5_259672073 https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=d743e60123484d1d72fae0ba39c1c685578453db

[2] https://www.sciencedirect.com/science/article/abs/pii/S0029801822013919.

[3] https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=d743e60123484d1d72fae0ba39c1c685578453db

[4] https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=d743e60123484d1d72fae0ba39c1c685578453db

[5] https://www.semanticscholar.org/paper/CFD-Analysis-of-a-Propeller-Flow-and-Cavitation-RamaKrishna-Ramakrishna/d743e60123484d1d72fae0ba39c1c685578453db

[6] https://www.semanticscholar.org/paper/Flow-Analysis-on-the-Effect-of-Rotational-Speed-on-Sun-Moon/3f3cac16d8f1615485f0dee01b52a10025753e17

CURRICULUM VITAE

PERSONAL INFORMATION

Name Surname	: Onur Can MAZLUM
Date of birth and place	:12.11.2000 - Sivas
Foreign language	: English
E-mail	: can.mazlum@std.yildiz.edu.tr