

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
School of Mechanical, Chemical and Materials Engineering



Design and Analysis of Wind Turbine Integrated Propelled Boat

A thesis submitted in partial fulfillment of the requirements for the award of

Degree of

Masters of Science

In

Automotive Engineering

By

GARBE CHUKULU

Department Of Mechanical Systems and Vehicle Engineering

September, 2017

ADAMA, ETHIOPIA

CANDIDATE'S DECLARATION

I hereby declare that the thesis work which is being presented in the paper entitled “**Design and Analysis of Wind Turbine Integrated Propelled Boat**” in partial fulfillment of the requirements for the degree of masters of science in Automotive Engineering is an authentic record of my own work carried out from March 2017 to September 2017 under the supervision of Mr. Mekonnen Liben ,Assistant Professor, Department of Mechanical and Vehicle Engineering ,Adama Science and Technology University ,Adama, Ethiopia

The matter embodies in this paper has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this paper have been duly acknowledged.

Name

Signature

Date

Garbe Chukulu

Student

This is to certify that the above declaration made by candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

Name

Signature

Date

Mr. Mekonnen Liben (Assistant Professor)

(Advisor)

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical, Chemical and Materials Engineering

Department Of Mechanical and Vehicle Engineering



Design and Analysis of Wind Turbine Integrated propelled boat

By: - Garbe Chukulu

APPROVAL BY THE EXAMINING BOARD

_____	_____
Chairman, department graduate committee	Signature
_____	_____
Advisor	Signature
_____	_____
Internal examiner	Signature
_____	_____
External examiner	Signature

ACKNOWLEDGMENT

I would like to thank all the people who have helped the successful culmination of this study. First and foremost, I extremely grateful to my advisor, Mekonnen Liben (Asst. Prof.) without him the research would not have pushed through. I also would like to thank my sister from Computer science department who help me on some area of software writing like Java application programming, Miss Hagaya Shanchu. Also, I am thankful for my classmate students for their idea that supports me in the progress of making the thesis. I would also like to give thanks to my families and friends whom have helped me in the entire process of this thesis. Last but not the least; I would like to give my gratitude to God for guiding me during the entire process.

Table of Contents

Contents

Pages

ACKNOWLEDGMENT	iv
LIST OF TABLES	ix
LIST OF FIGURES	x
APPENDIX.....	xiii
ACRONYMS AND SYMBOLS.....	xiv
ABSTRACT.....	xv
CHAPTER ONE	
1 INTRODUCTION	1
1.1 Background.....	1
1.2 Statement of the problem	2
1.3 Objectives	3
1.3.1 General objective:.....	3
1.3.2 Specific objectives:.....	3
1.4 Significance of the project	3
1.5 Delimitation (scope)	3
1.6 Limitation of the Study	4
1.7 Organization of the study.....	4
CHAPTER TWO	
2 LITERATURE REVIEW	5
2.1 Introduction.....	5
2.2 The Electric Boat	5
2.2.1 Solar Voltage	5
2.2.2 Solar Panel Orientation.....	6
2.2.3 Power Comparison with Diesel	6
2.2.4 Estimating Power at Speed	6
2.2.5 Electric Boat Wiring.....	7
2.2.6 Electric boats charging energy sources.....	8
2.2.7 Electric Boats are more comfortable	8

2.2.8	Electric Boats are fun to sail	9
2.2.9	Electric Boats reduce pollution.....	9
2.2.10	Reliability of Electric Boats.....	9
2.2.11	Electric Boats are safer	9
2.2.12	DC Generators	10
2.2.13	Driveline (Electric Motors).....	10
2.3	Boat Designs	11
2.3.1	Propulsion and Steering.....	12
2.3.2	Propellers.....	12
2.4	Wind turbine as Electric Energy	14
2.4.1	Vertical Axis Wind Turbine	15
2.4.2	Horizontal Axis Wind Turbine	15
2.4.3	Main Parts of a Wind Turbine	16
2.5	Battery	17
2.5.1	Battery Chemistry.....	17
2.6	Horizontal Axis Wind turbines (HAWT) As Propulsion for ship.....	18
2.7	New Developed Idea.....	19
2.8	Boat Stability	20
2.8.1	How Stability Works	22
2.8.2	Wind and Waves - Wind on the Beam	23
2.8.3	Wind and Waves - Icing.....	23
2.9	ANSYS AQWA.....	25

CHAPTER THREE

3	MATERIALS AND METHODS.....	26
3.1	Materials	26
3.2	Methods	27
3.2.1	Develop Conceptual Design	28
3.2.2	Types and sources of data.....	28
3.2.3	Methods of data analysis	30
3.2.4	Java Programing Language.....	40

3.2.5 Stability Test Using ANSYS AQWA.....	41
3.2.6 Set AQUWA Boundary Condition	45
3.2.7 Set Boundary Conditions for ANSYS16 FLUENT CFD Simulation	47
3.2.8 CFD Fluent Solution Setup – Models.....	48
3.3 Java Code Output Results	48
3.3.1 Residual coefficient	50
3.4 Propeller size	52
3.5 Recommended size of wind Turbine	52
3.6 Generator Size	54
3.6.1 3D Model of Boat using Via Catia	54
3.6.2 Calculation of Mass Moment of Inertia and radius of gyrations.....	55

CHAPTER FOUR

4 RESULTS AND DISCUSSION.....	57
4.1 Simulation Result from ANSYS AQUA.....	57
4.1.1 Mesh generated:.....	57
4.2 Material Recommendation for Static Structural Analysis.....	71
4.3 Calculation for Static Structural analysis of Boat hull geometry	72
4.3.1 Materials Data	72
4.3.2 Wind Turbine Test for Determining Cd Value to get Load on the turbine	78
4.3.3 Calculations for Determining all load applied on Turbine.....	79
4.4 Static Structural analysis for turbine mounted frame	80
4.5 Turbine shaft analysis via ANSYS	84
4.5.1 Recommended Bearing Size.....	87
4.5.2 Transmission.....	87
4.6 Added mass of Upper structures and Furniture's or chairs	88
4.7 Human Ergonomics Design	89
4.8 Total Weight of Assembled part and Center of Gravity value	90
4.9 Prototype.....	90

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION.....	92
5.1 Summary.....	92

5.2 Conclusion	93
5.3 Recommendation	93
5.4 Future Scope	94
REFERENCES.....	134

LIST OF TABLES

Table 2-1: Electric propulsion power vs. speed-predicted vs. actual 30	7
Table 3-1: The materials to be used.....	26
Table 3-2: Equipment	26
Table 3-3: Interviewed data on Paddle driven and 10 h.p motor boat.....	29
Table 3-4: Scaled size of Interviewed data on Paddle driven and 10hp motor boat.....	30
Table 3-5: Estimated Results for Java input part I.....	49
Table 3-6: Residual resistance coefficient Parameters value.....	50
Table 3-7: Inpute Results For Part II Java	51
Table 3-8: Speed and produced power.....	53
Table 3-9: Basic Dimensional parameters of the boat	55
Table 4-1: Hydrostatic Results.....	58
Table 4-2: Hydrostatic Results.....	58
Table 4-3: Hydrostatic Result	59
Table 4-4: Hydrostatic Results.....	60
Table 4-5: Hydrostatic Results.....	60
Table 4-6: Boat Wind and Current Load coefficient	62
Table 4-7: Standard value and estimated value from model.....	63
Table 4-8: Hydrodynamic Graph Results	64
Table 4-9: Hydrostatic only	65
Table 4-10: Structure Position, Actual Response	68
Table 4-11: Structure Forces, All.....	69
Table 4-12: Structure Forces, Hydrostatic Only	70
Table 4-13: wind only force.....	70
Table 4-14: Aluminum Alloy Constants used for sailboat	72
Table 4-15: Aluminum Alloy Strength properties	72
Table 4-16: Model total mass of the structure	77
Table 4-17: Imported load	81
Table 4-18: When the load applied on y axis	83
Table 4-19: Turbine Mounted Frame Properties after Analysis	84
Table 4-20: Material definitions of Turbine Shaft.....	84
Table 4-21: Applied Loads on the shaft.....	86

LIST OF FIGURES

Figure 1-1: Definitions and system type.....	3
Figure 2-1: Wind sail Boat	5
Figure 2-2: Solar panel orientation on boat	6
Figure 2-3: Electric propulsion power vs. speed	7
Figure 2-4: Battery connected in series	8
Figure 2-5: Hp deference of motor and engine	11
Figure 2-6: Motor efficiency and Propeller diameter effect on thrust [46].....	13
Figure 2-7: Total assembled Simple electric motor propeller of boat.....	14
Figure 2-8: Darrieus wind turbines.....	15
Figure 2-9: Savonius wind turbines.....	15
Figure 2-10: Danish Wind Turbine.....	16
Figure 2-11: Diffuser Augmented	16
Figure 2-12: The Wind Turbine Model of Electric Car	17
Figure 2-13: Exploded View of Wind turbine	17
Figure 2-14: Actual capacity of battery	18
Figure 2-15: Illustration of a Vestas wind turbine onboard a tanker for power generation	19
Figure 2-16: New idea visual Drawing for the boat integrated with turbine	20
Figure 2-17: Stable fishing Vessel.....	20
Figure 2-18: Unstable fishing Vessel	21
Figure 2-19: Stable Vs. Unstable.....	21
Figure 2-20: Key Stability Terms.....	22
Figure 2-21: Negative Effect of Wind on The beam	23
Figure 2-22: Negative Effect of Icing.....	24
Figure 3-1: work Flow of the Project	27
Figure 3-2: Conceptual Boat Design	28
Figure 3-3: Hull dimensions (Source: ITTC57).....	31
Figure 3-4: Flow over Flat plate	33
Figure 3-5: Schematic drawing showing the drag forces exerted on two blade Savonius	37
Figure 3-6: The power coefficient C_p as a function of the tip speed ratio for different wind machines designs.	39

Figure 3-7: Torque formula	40
Figure 3-8: Angular velocity diagram	40
Figure 3-9: Detail of Geometry on water body	42
Figure 3-10: Incident sea description.	43
Figure 3-11: Minimum Consideration of dimensions for Analysis.	44
Figure 3-12: External forces with defined angles and relative direction in the boat (x_B, y_B)...	44
Figure 3-13 Performance for single blade	54
Figure 3-14: Boat Hull 3D Model	55
Figure 3-15: Mass moment of inertia.	56
Figure 4-1: complete geometry imported to the ANSYS Aqua.....	57
Figure 4-2: Mesh Generated on the Geometry	57
Figure 4-3: Pressure and Motion of Wave impact loading for different mass	61
Figure 4-4: Structure Forces in N, Wind Only	64
Figure 4-5: Graph of Rolling in X axis of Current Drag Only in N.m.....	65
Figure 4-6: Hydrostatic Only.....	66
Figure 4-7: Graph of Structure Position, Actual Response.....	66
Figure 4-8: Structure Forces Moment, All about X axis.....	67
Figure 4-9: Graph of Structure Forces, All about x axis.....	67
Figure 4-10: Structure Positions Graph for final Trial.....	68
Figure 4-11: Graph of Structure Forces moment about X axis, All.....	69
Figure 4-12: Graph of Response Amplitude Operator Rotation or angle	70
Figure 4-13: graph of wind only Force About y axis.....	71
Figure 4-14: Pressure and motion for selected Final trial	72
Figure 4-15: Stress analysis on first step	73
Figure 4-16: Safety Factor value of material and Total Deformation on first step	73
Figure 4-17: Stress analysis on second step.....	74
Figure 4-18: Safety Factor and Total Deformation of second step	74
Figure 4-19: Recommended internal frame of the boat	75
Figure 4-20: Catia 3D model of Boat Hull assembled with internal frame	75
Figure 4-21: 3D Model After it imported to ANSYS structural analysis	76
Figure 4-22: a. Stress Analysis on third step	76
Figure 4-23: Safety Factor and total Deformation of third steps	77
Figure 4-24: CFD Flow simulations Express of savonius rotor.....	78
Figure 4-25: Momentum Coefficient.....	78

Figure 4-26 : Drag coefficient convergence for rotor	79
Figure 4-27: Model of Turbine Mounted Frame	81
Figure 4-28: Mesh generated on Turbine Mounted Frame for analysis.....	81
Figure 4-29: Turbine Mounted frame Equivalent stress on structure	82
Figure 4-30: Total Deformations of Turbine Mounted frame.....	82
Figure 4-31: Turbine Mounted Frame Safety factor.....	83
Figure 4-32: Safety Factor of Turbine Mounted Frame for load applied along y axis	83
Figure 4-33: Model of turbine shaft imported to ANSYS	85
Figure 4-34: Mesh Generated on Turbine shaft.....	85
Figure 4-35: Turbine shaft Equivalent stress.....	86
Figure 4-36: Turbine shaft total deformations	86
Figure 4-37: Turbine Shaft safety factor.....	87
Figure 4-38: Hydrodynamic Keel.....	88
Figure 4-39: 3D model of Sitting Chair.....	89
Figure 4-40: Human Ergonomics Design and Center of Mass position	89
Figure 4-41: Hydrodynamic total weight and keel position	90
Figure 4-42: Materials Equipment's used To Develop the Prototype.....	91
Figure 4-43: Boat Hull developing Steps by folding aluminium.....	91
Figure 5-1: Boat air drag aerodynamic coefficients.....	116
Figure 5-2: Boat water or current drag coefficients.	117

APPENDIX

APPENDIX I: Java Code part I.....	95
APPENDIX II : Java Code Part II	98
APPENDIX III :Residual Coefficient Curve According to ITTC 57	102
APPENDIX IV : Generator Specification	111
APPENDIX V: Propellers specifications and Boat Motor Catalog.....	112
APPENDIX VI : Spur Gear Catalog	114
APPENDIX VII: Bearing Catalog.....	115
APPENDIX VIII : Wind and Current Force Coefficient for Standard River Boat.....	116
APPENDIX IX: Engineering Drawings	118
APPENDIX X: Component Assembly.....	127
APPENDIX XI: Total Assembly.....	131
APPENDIX XII : Wind Scale with related Sea Conditions	133

ACRONYMS AND SYMBOLS

HAWT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind Turbine
DC	Direct Current
AC	Alternate Current
Hp	Horse power
ρ_w	Water Density
C_{pm}	Marin Turbine Coefficient
C_p	Power Coefficient
AGM	Absorbed Glass Matt
TPPL	Thin Plate Pure Lead
C	Capacitor
MPPT	Maximum Power Point Tracking
ITTC	International Towing Tank Committee
FLA	Flooded Lead Acid
ICE	Internal Combustion Engine

ABSTRACT

During preliminary stages of boat design, decisions on boat properties are made only with little knowledge on boat hull geometry – a boat designer has only the basis dimensions at his disposal. Therefore on these initial stages of boat design, methods of calculation of boat properties (e.g. resistance) on the basis of basic design criteria are indispensable. The main objective of this thesis was designing a wind turbine integrated propelled boat. This means energy extracted from wind is converted into electrical energy that can be stored in the capacitor. This stored energy is used to drive the motor that is attached to the propeller of the boat or the shaft of water jet pump. The useful components of this boat are wind turbine, generator, Battery, Propeller. The method used for design was Catia V5 for modeling, mathematical investigations formula for propulsion power and ANSYS hydrodynamic software for stability testing. The study was limited to the hydrodynamic stability test and static structural analysis. All basic dimensions and propulsion power was determined by written java code. Then the recommended size of the boat that has overall length of 6m is taken and its propeller power was determined as 5h.p. The conceptual design of the boat 3D Model was created in the catia V5 and imported into the ANSYS Hydrodynamic diffraction and response analysis for Stability test. The test was recorded six times by adjusting the center of gravity and modifying boat mass. Hydrodynamic keel was also added as wind stability method. The test was done within the range of standard recommended metacentric height of boat. Then structural analysis for boat hull was done by importing the hydrodynamic pressure result of final step of the boat to ANSYS static structural analysis. From the trials results the final tested boat was accepted because the response of this final trial was very best when it compared with remained trials. The final trial center of gravity was taken as 0.5m and structural mass was 800kg. Therefore hydrodynamic pressure and motions result was determined from this final trial that gives 0.33MPa. This result of the final tested boat was used to determine the response of structure by applying ANSYS Static structural analysis. But for the other parts like turbine shaft and turbine mounted frame the ANSYS CFD program was used to determine drag coefficient on the turbine blade and calculating load transferred to each parts and the response of each part was determined by static structural analysis. After all components of the boat was analyzed and assembled in the Catia V5 the acceptable result of center of gravity was determined automatically from inertia mass tool bar. Then finally the determined result of vertical center of mass was 0.459m with total mass of 2500kg.

Keywords: *wind energy, Electrical energy, boat, Resistance of the boat, Propulsion power.*

CHAPTER ONE

1 INTRODUCTION

1.1 Background

This thesis can be implemented in and investigated on BOAT Traveling at sea. Travel at sea is the easiest compared with land transport and flying: a log floats and is carried with a body of water moving in a definite direction through a surrounding body of water; no hills to climb, no thick vegetation to be pushed aside. But, to go where we want, we need propulsion, and fluid propulsion is by far more difficult than land propulsion (in spite of the ease of fish locomotion by fins, as compared with terrestrial locomotion by legs). The reason of this difficulty is that, for us to advance, we need to push something backwards (Propulsion fundamentals), and it is far more efficient to push a massive object (the Earth) back by solid-friction forces at our feet (or by wheels), than to push a small amount of fluid back (the mass of water you can take in with your hands, or with oars, or even the mass of air surrounding the sail) [7]. Traditional boat is propelled by hand (paddle) which need human power. But now as is the case with general automobiles that are driven on land, the main type of engine used on ships is the internal combustion engine (motors such as diesel engines and gas turbines). It is a well-known fact that as a societal demand for reductions in carbon dioxide (CO₂) emissions has arisen, electric motor-driven systems have been introduced for use in automobile engines, thereby greatly improving fuel efficiency in hybrid or electric vehicles (which decrease CO₂ emissions by reducing the consumption of fossil fuels) [33]. So the renewable energy is considered as a new technology and an alternating energy source to be used instead of fossil fuel, its continuous rising cost of it and due to growing concern to reduce the effects of climate change, such as global warming, generated by extensive and deliberate use of fossil fuels, mainly in the electric power generating plants and transport. Global warming will continue unless dependence on fossil is reduced, thus the Wind power has a key role in reducing greenhouse gas emissions [18]. Today, the most commonly used wind turbine is the Horizontal Axis Wind Turbine (HAWT), where the axis of rotation is parallel to the ground. However, there exist other types of wind turbines, one of which will be the primary focus of this paper for propelling the boat, the Vertical Axis Wind Turbine (VAWT). These devices can operate in flows coming from any direction, and take up much less space than a traditional HAWT [32]. VAWTs has a number of advantages over HAWTs, such as,

1. Extremely (low cost), simplicity reduces cost of construction, and aids installation.
2. They can accept wind from any direction, thus eliminating the need for re-orienting towards the wind [32].

3. Ability to operate under complex turbulent flows [29].
4. Low rotation speed and noise emission [30].
5. High starting torque, good starting performance [31].
6. VAWTs work well in places with relatively low wind strength, and constant winds, VAWTs include both a drag type configuration, such as the savonius rotor, and a lift-type configuration, such as the Darrieus rotor [32].

Increasing focus on reduction of CO₂ emissions and the possibility of future severe shortage of oil have spurred renewed interest in wind as supplementary propulsion of merchant ships. Several alternative solutions have been considered, like kites, conventional soft sails, rigid sails, Flatter rotors, and wind turbines. A tempting aspect of Wind turbine propulsion is that it can provide propulsive force when sailing directly upwind, something that is impossible with the other mentioned forms of wind-assisted propulsion [26]. In Ethiopia there are many lakes present which are attracting tourists some of those are, Koka Reservoir, Lake Abay Lake Abbe, Lake Abijatta, Lake Afambo, Lake Afrera, Lake Haramaya, Lake Ashenge, Lake Hawasa, Lake Bario, Lake Basaka, Lake Chamo, Lake chelelektu, Lake Chew Bahir, Lake Gargori, Lake Gummare, Lake Hayq, Lake Kadabassa, Lake Karum, Lake Laitali, Lake Langano, Lake Shala, Lake Tana, Lake Turkana, Lake Zway, and Zengena Lake. Recreational boating is the major attraction of these lakes. So designing a propulsion system powered by non-polluting and renewable energy sources is necessary.

1.2 Statement of the problem

The existing IC Engine propelled boats are polluting the lakes in Ethiopia. So there is a need to develop wind turbine propelled boats to avoid water pollution and pollution of surroundings in recreational boating zones. On addition to this there are many recreational manual or hand driven boats that need human power the design of which is also considered for changing from manual to automatic.

Therefore the Design or the study will focus on problems like:-

- How wind energy can propel the boat floating on water body indirectly?
- How much power is needed from the wind turbine to propel the boat?
- Which type of battery must be used to charge electric energy?
- How to make the boat stable?
- How does the shape of the boat system look like?

The above mentioned problems can be solved by applying the necessary design procedure. The figure 1-1 below shows overview of the system.

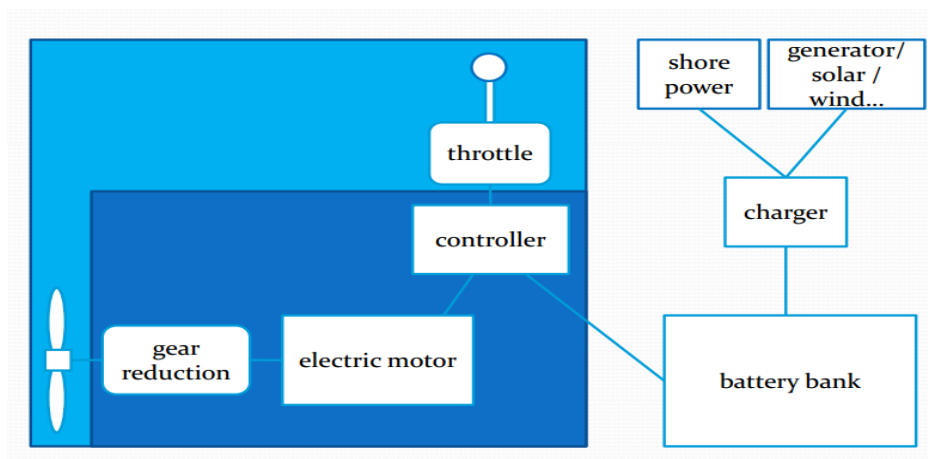


Figure 1-1: Definitions and system type

1.3 Objectives

1.3.1 General objective:

The general objective of this project is to develop wind turbine integrated boat.

1.3.2 Specific objectives:

- To collect the data related to recreational boats used in Ethiopia
- To design wind turbine propulsion mechanism for boats
- To model and simulate the mechanism
- To prepare the Prototype for demonstration purpose.

1.4 Significance of the project

The significances of the proposed project are as follows:

- Reducing the pollution of the environment
- Minimizing the cost required from recreational persons during tour.
- Reducing human effort for propulsion systems
- For fishing, for study of water body etc.

1.5 Delimitation (scope)

The scope of this project is to deal with the design of the boat that can be propelled by wind energy.

- The study will focus on the Aluminum multipurpose boat which will be operated with Savonius type of wind turbine.
- Applying static structural analysis of all basic components.
- Consideration of Static and Hydrodynamic stability Test.

1.6 Limitation of the Study

Due to time limitations only a restricted number of components are analyzed by ANSYS static structural analysis. The number of components that did not analyzed was Gear, Bearing, and Turbine Blade.

1.7 Organization of the study

Chapter one describes a general introduction of the Thesis and the project. Chapter two presents' literatures review about the existing Electric boat and existing Wind turbine propelled ship system in the world. Chapter Three Materials and methods of data collection, analysis of the critical components of the machine. Chapter four covers results and discussion. Finally chapter five give a short recommendation and conclusions.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction

The origin of this study at its simplest depends on boat propelled by hand and wind sailed boat originated from literally means, historical it is a long tube or funnel of sailcloth conveying air to the lower parts of the ships. Because the first vessels might surely have been propelled by hand work, but it was obvious that wind has an important entrainment effect and the larger the frontal area the larger the push, what originated the sail? There is evidence of sailing boats and wooden oars in the Middle East dating from 5000 BCE, and, in ancient Egypt by 3000 BCE, the Nile was the main transport route, taking advantage of the water current to go downstream, and of the prevailing Northern winds to go upstream. The following figure 2.1 shows wind sail boat [6].



Figure 2-1: Wind sail Boat

2.2 The Electric Boat

The Electric Drive industry is experiencing a renaissance after 120 years of quiet operation in pleasure launches, trolling boats, and submarines. Battery technology is now available to make all-electric boats applicable for day sailors and hybrid boats for cruisers. Solar Electric Boats are capable of sustained, continuous operation and have circled the world on solar power alone [1].

2.2.1 Solar Voltage

Panel voltage must be higher than battery voltage unless a boosting charge controller is employed. Panel Voltage should be between 20 and 30 percent higher than battery voltage, depending on the type of charge controller used. Check the panel for maximum power voltage. This voltage should be higher than the batteries absorption voltage (lead acid) or the maximum voltage of a Lithium Battery. When using MPPT charge controller, the Maximum Power voltage

should be 10 to 20 percent higher than the battery absorption voltage (lead acid) or maximum voltage of a Lithium Battery to give the MPPT circuitry room to function [1].

2.2.2 Solar Panel Orientation

The solar panel installed on Kapowai can change angle and bearing to focus on the sun to increase output. This is most noticeable at dawn and dusk where output can increase tenfold. One evening when the panel was horizontal the output noticed down to 20 watts. This increased to 200 watts when focused on the sun [1]. Figure 2.2 shows panel orientations.



Figure 2-2: Solar panel orientation on boat

The solar panel has to revolve around two axes to be able to focus on the sun. One axis of operation, a hinge, is still a big benefit to the overall output of the panel [1].

2.2.3 Power Comparison with Diesel

We have found that 1kW per ton moves the average electric boat at 90% of hull speed in calm conditions with no wind and no waves. With diesel boats we find that 3+kW per ton moves a boat at close to hull speed in calm conditions with no wind and no waves. Why such a discrepancy between power levels? The Electric motor can run a big propeller due to the flat torque curve. A diesel motor is limited to running a small, fast turning propeller due to the limited torque available to a diesel at idle [1].

2.2.4 Estimating Power at Speed

The basic physics of a boat reveals that for each knot you increase in boat speed there is roughly a doubling of the power requirement. As you can see in the following graph, at low boat speeds it takes very little power to push the boat. It is at these speeds that electric propulsion really shines. Small amounts of power make huge differences while motor sailing. Small amounts of power can make the difference of whether the sails are luffing or not and whether the boat has directional stability or not. For more detail the following figure 2.3 showed as graph of power at boat speed and table 2-1 power vs. predicted speed [1].



Figure 2-3: Electric propulsion power vs. speed

Table 2-1: Electric propulsion power vs. speed-predicted vs. actual 30

SPEED	POWER	Catalina 30	Predicted	Actual
HULL SPEED	2 KW PER TON	6.7 knots	12 KW	
90 % of Hull Speed	1 KW PER TON	6 knots	6 KW	6 KW
90 % of Hull Speed less 1 knot	500 watts per ton	5 knots	3 KW	3.2 KW
90% off Hull Speed less 2 knots	250 watts per ton	4 knots	1.5 KW	1.48 KW
90% of Hull Speed less 3 knots	125 watts per ton	3 knots	750 watts	663 watts
90 % of Hull Speed less 4 knots	62 watts per ton	2 knots	375 watts	262 watts

2.2.5 Electric Boat Wiring

Wiring on an electric boat should be done to a higher standard than traditional diesel wiring. The systems are more complex with a greater number of circuits operating at higher voltages and currents. Electric boat systems need to work flawlessly over time so there is no room for error on the installation. The most noticeable feature of an electric boat is the large, higher voltage battery. The large battery serves both the house and propulsion loads of the boat. Having a high energy house battery has many advantages, the most notable being the extended duty cycle at anchorage. All batteries, regardless if they are paralleled or in series, should be monitored for temperature and voltage and, if possible, equipped with audible and visual alarms. Dissimilar voltages in a string should be corrected. As showing on figure 2.4 (A String of Batteries means several batteries connected in Series) A string of batteries is only as good as its weakest cell [1].

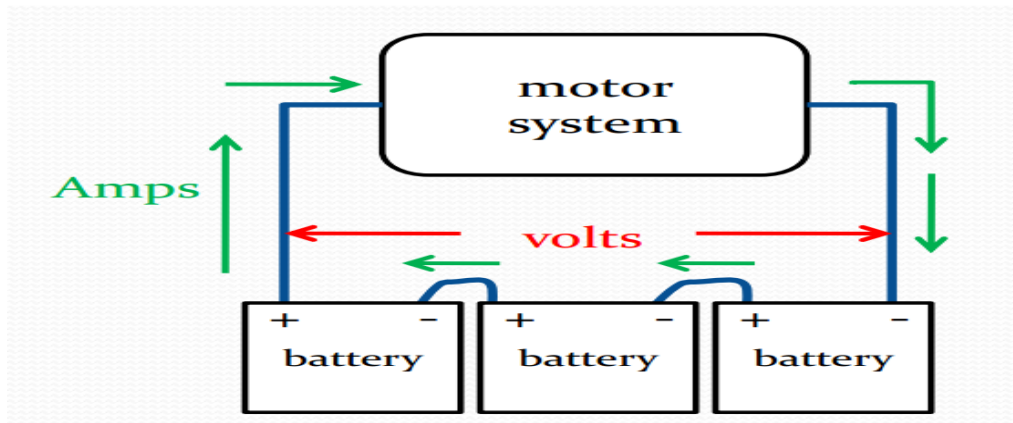


Figure 2-4: Battery connected in series

Charging at the cell level is best, followed next by charging at the battery level. No batteries should be left unattended in parallel without automatic disconnect in the event of a battery failure. This is to prevent the good battery driving a short in the bad battery which can lead to a thermal and possible fire. Lead acid batteries at the end of their life are particularly susceptible to this fault condition. It is vitally important for an owner of an electric boat to know his batteries and how they Work in both the charging and discharging cycles [1].

2.2.6 Electric boats charging energy sources

- 1) Solar power is a replenishing resource on a boat, while diesel is a depleting resource. Even though a battery stores a fraction of the amount of energy as diesel, it can store it over 2,000 times.
- 2) Electric boats can be recharged with solar power.
- 3) Electric boats can be recharged with wind power.
- 4) Electric boats can be recharged from the propeller spinning (regeneration).
- 5) Electric boats can be recharged from shore power.
- 6) Electric boats can be recharged with a portable gasoline generator.
- 7) Electric boats can be recharged with a diesel generator.
- 8) Electric boats have redundancy in their energy supply. You may have to wait for solar to recharge your batteries, but you never completely run out of energy [1].

2.2.7 Electric Boats are more comfortable

- 1) Solar Electric boats have no smell of fuel or exhaust.
- 2) There is less incidence of sea sickness on an electric boat. Diesel fumes and exhaust contribute to seasickness on diesel powered boats. Hybrid boats can choose when to run the diesel to minimize exposure to exhaust fumes.
- 3) Batteries can be used for large house loads for extended periods of time before recharging.

2.2.8 Electric Boats are fun to sail

- 1) Keeping an eye on your energy, how it is regenerating or depleting, what your electric only range is, focusing your solar panels at the sun, monitoring power consumption and its effect on motor-sailing - all great fun and intellectually stimulating.
- 2) Owning an electric boat is a cultural shift in sailing. It is dramatically different and a far nicer experience on the water.
- 3) An electric boat is more in line with the spirit of sailing using natural energy to propel your boat.
- 4) Small amounts of electric power can act like a mizzen sail. The sail-like qualities enhance the boats sailing attributes by creating apparent wind.
- 5) Because an electric boat can generate apparent wind, it is rarely, if ever, becalmed.

2.2.9 Electric Boats reduce pollution

- 1) Electric boats pollute less and reduce global warming.
- 2) There is little to no pollution in your local environment.
- 3) There is no smell of diesel fuel, or of diesel exhaust, on an all-electric boat.
- 4) There is no Grundy, smelly stuff under the motor of an electric boat.
- 5) There is no oil in the bilge water.
- 6) An electric boat smells pure and clean.
- 7) Electric boats don't vibrate.
- 8) Electric boats are very quiet with far less noise pollution.

2.2.10 Reliability of Electric Boats

- 1) The simplicity of an electric drive results in higher reliability. Simply turn the electric motor on and it goes.
- 2) An electric motor has fewer things to go wrong with it than a diesel motor does.
- 3) Temperature sensors in the motor and controller communicate with the controller preventing overheating caused by high ambient temperatures or obstruction of the propeller.

2.2.11 Electric Boats are safer

- 1) Higher reliability increases safety.
- 2) Better boat handling increases safety.
- 3) Higher Acceleration and Deceleration increases safety.
- 4) Reduction or complete elimination of fossil fuels increases safety.
- 5) Elimination of sticky shifter and throttle cables increases safety.
- 6) Electric boats equipped with solar panels never completely run out of energy.

7) Electric boats using Lithium Battery Management Systems monitor battery voltage and temperature on every cell which reduces the possibility of a battery failure.

2.2.12 DC Generators

Hybrid Electric Boats Employ DC Generators Which are far more efficient than their counterparts or diesel driven alternators.

DC generators with a Battery Pack run a fraction of the time of an AC generator when used for house loads. The DC generator runs only long enough to recharge the batteries, and then shuts down, while many AC generators run 24 hours a day. AC Generators are sized for the maximum starting current on the boat. Typically a starting current of a motor can be twice the operating current. Most AC generators run unloaded most of the time. DC Generators require less maintenance than AC generators because they are simpler and run at optimum load all the time which is easier on the diesel. DC generators with inverters are far superior than AC generators for providing clean and reliable power because the power comes from an inverter from a stable DC power source. There are no spikes or brown outs when starting or stopping. A hybrid's DC generator runs a fraction of the time of a traditional diesel which utilizes the diesel's alternator for house loads. A 30 h.p. diesel will commonly employ a 100 amp alternator, which utilizes about 5 h.p or 16% of the engines power while charging at anchorage. An alternator's efficiency is about 50%. Total system efficiency of an alternator is thus only 8% while recharging batteries at anchor. In comparison, a DC generator set has up to 40% efficiency [1].

2.2.13 Driveline (Electric Motors)

Electric motors convert electrical energy into rotational energy plus heat. The heat is created by the inefficiency of the motor. Consider our 92 % efficient, 10 kW Electro prop. 8 percent of the power consumed by that motor will be given off as heat- 800 watts at full power. It is a motor's ability to dissipate heat that partially determines the maximum power capability of the motor. Water cooling is the best way of dissipating heat. And the world's largest heat sink is only a foot away! Heat created is closely related to motor current. Both should be monitored. Battery current to the controller is different from controller current to the motor. The gear ratio of the speed reducer changes the ratio between the battery current and the motor currents. Increasing the ratio of the speed reducer reduces the motor current for any particular motor rpm [1].

Magnets in the stator (stationary winding) move magnets in the rotor (the part of the motor which rotates). The magnetic fields alternate at a frequency proportional to the rpm of the motor and the number of poles of the motor. Induction motors create the magnetic field in the rotor through passing a current by induction to the rotor. Permanent magnet motors rely on rare earth permanent magnets in the rotor. Permanent magnet motors are more efficient and smaller than induc-

tion motors because they don't have to create and maintain the second electromagnet. Torque is proportional to current and speed is proportional to voltage on a Permanent Magnet AC motor. Permanent magnet motors are directly proportional and have a current to torque coefficient and a voltage to rpm coefficient. Induction motors have some slip in the magnetic fields so the torque / current and speed / voltage ratios change. A motor that has no slip is said to be synchronous. Permanent Magnet Alternating Current and Brushless Direct Current motors are synchronous. Stators can be positioned next to the rotor axially or radially. Axially arranged stators create an axial force on the rotor. Mounting a stator on either side of the rotor cancel out these axial forces for higher efficiency. Most high power permanent magnet motors have twin stators for this reason. New motor technology is seeing efficiency claims as high as 98%. Most common AC permanent magnet motors have efficiencies between 88 and 94 %. Efficiency changes with load and rpm so an efficiency map is necessary for a complete understanding of any particular motor. Motors need to be rated for their continuous output.

At similar peak HP ratings on figure 2.5, Electric has much more torque at slower speeds. ICE is better for higher continuous speeds.

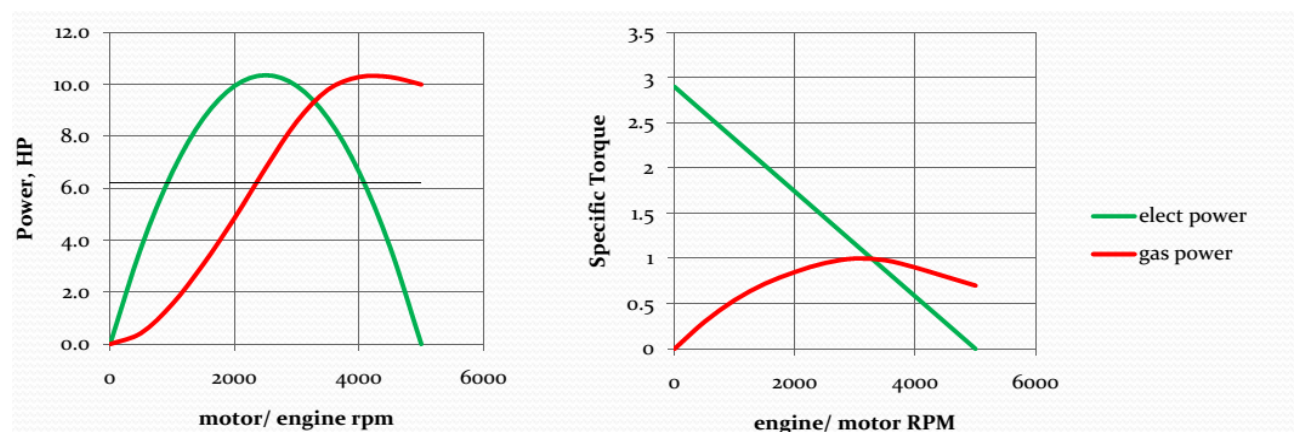


Figure 2-5: Hp deference of motor and engine

2.3 Boat Designs

Most hulls used in the Pacific Basin are locally built, since those boats produced in the U.S. generally produced wooden boats. Furthermore, by are work boat standards, most small pleasure boats equipped with extraneous, unusable features. In addition, freight costs can add as much as the original cost of the boat when delivered from a foreign source. The technical skills to produce “low cost “fiberglass boats quickly [6].

A wide range of opinion exists on the subject of boat design. Several observations are presented: A deep V planning hull rides much better in rough water but is expensive to operate, since high horsepower propulsion is needed to plane. With insufficient horse Power a deep V is relegated to the displacement hull (none planning) category. A flat bottom skiff bearing even heavy loads can reach planning speeds with only a minimum of horse power. Also, the shallow draft characteris-

tics of a flat bottom offer more versatility of operation in shallow, protected lagoon waters. A flat bottom skiff is also quite stable. Characteristics, however, of flat bottom skiffs, make these boats inappropriate for use in rough open seas. The answer rests in a compromise with shallow and rough water V favoring a flat bottom design. (Banana Form Hull) ride would be less comfortable than that offered by the deep-V in rough open seas, but operational costs would outweigh crew discomfort. Other design factors to be considered in the design are minimum weight with maximum strength and simplicity of construction [6].

2.3.1 Propulsion and Steering

Propulsion and steering are considered together here for two reasons. Applying thrust has no use if you can't control the vessel's direction, and often the device providing the propulsion also provides the steering. There are three common methods of transferring power and providing directional control:

- Rotating shaft and propeller with separate rudder
- A movable (steerable) combination, such as an outboard motor or stern drive
- An engine-driven pump mechanism with directional control, called a water jet

All three arrangements have their advantages and disadvantages from the standpoint of mechanical efficiency, ease of maintenance and vessel control. Using one type of propulsion instead of another is often a matter of vessel design and use parameters, operating area limitations, life cycle cost and frequently, personal preference. There is no single "best choice" for all applications. Regardless of which type you use, become familiar with how each operates and how the differences in operation affect vessel movement [7].

The following assumptions will apply to our discussion of propulsion:

- If a vessel has a single-shaft motor or drive unit, it is mounted on the vessel's centerline
- When applying thrust to go forward; most propellers turn clockwise (the top to the right or a "right-handed" propeller), viewed from astern. When going astern it turns counter clockwise viewed from astern when making thrust to go astern.
- If twin propulsion is used, most vessels have counter rotating drives in the following configuration: starboard propeller when going ahead, operates as above (right-hand turning) while the port unit turns counter clockwise (left-hand turning) [7].

2.3.2 Propellers

A boat is only as good or bad as its prop. With the right prop, your boat is a joy. Fast, smooth, comfortable, fuel-efficient and just plain fun. With the wrong prop, your boat will feel rough, or

slow, or sluggish or lacking in top end. The wrong prop can even damage your engine through lugging or over revving. Even the right prop, when damaged, can drastically reduce performance and fuel efficiency. Just running a prop through silt or sand can damage it enough to affect how your boat runs. In one test, a damaged prop dropped top speed more than 13%, acceleration 37%, and optimum fuel miles were reduced 21%. So you can see why you should check your prop often and have a damaged prop checked and repaired by an authorized dealer or repair station [7].

2.3.2.1 Propeller Selection Data

Propeller pitch and gearing should target peak motor efficiency at cruise speed. Propellers should be chosen carefully; Maximize diameter, minimize blade area. Figure 2.6 shows effect of motor efficiency and propeller diameter and figure 2.7 shows Total assembled Simple electric motor propeller of boat [35].

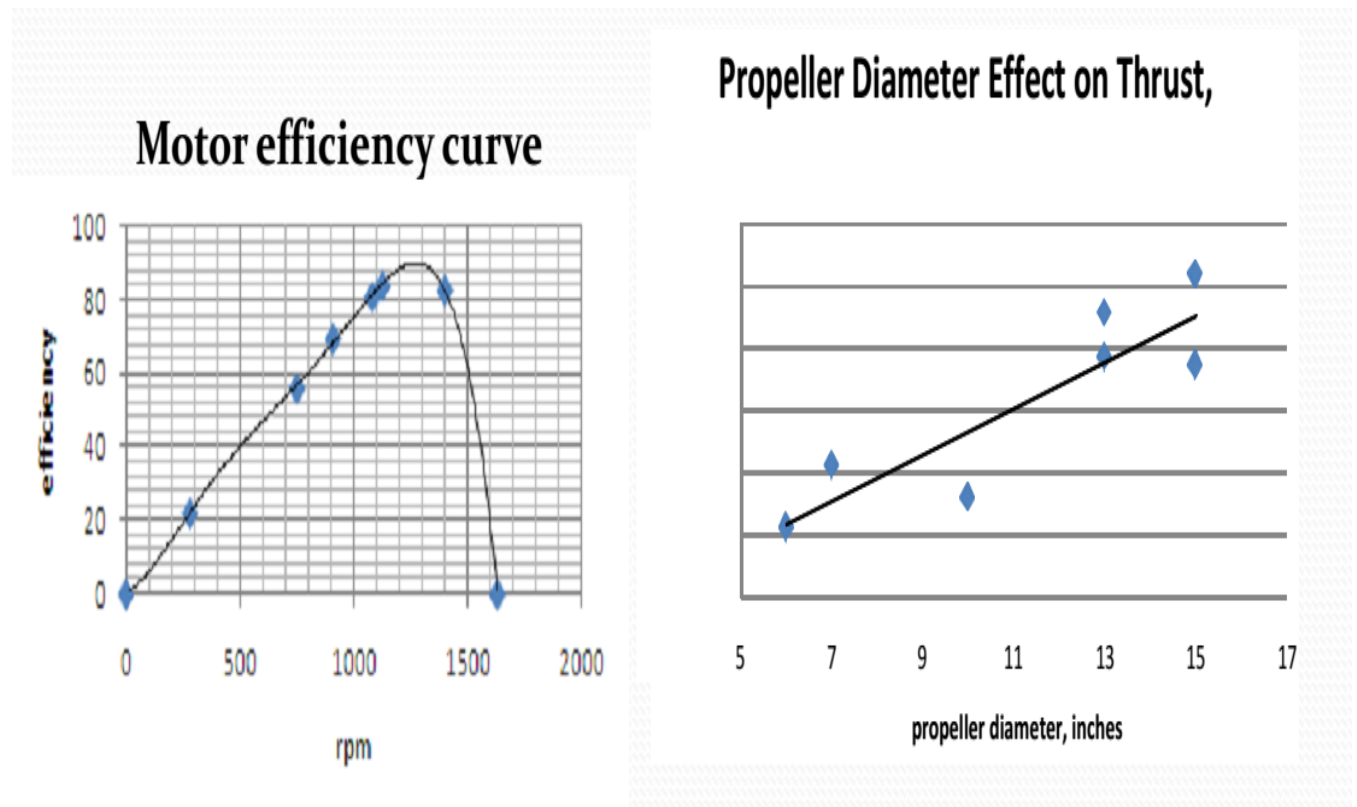


Figure 2-6: Motor efficiency and Propeller diameter effect on thrust [46]

Cruise 2.0 R/T

Also available with tiller

5^{HP}
equivalent*

Cruise 4.0 R/T

Also available with remote throttle

8^{HP}
equivalent*

Cruise outboards - high-tech drive system with maximum efficiency:

The optimum torque characteristics of Torqeedo drive systems ensure maximum efficiency at any speed - greater performance and greater range than all other electric motors in this class with the same battery capacity. Equipped with all of the convenience of a genuine Torqeedo:



- + All models have a **GPS on-board computer and display** in the tiller or the remote throttle with real-time display of speed and input power - and the exact battery status and remaining range when used in combination with the Power 26-104 lithium battery
- + **Waterproof housing and plug connections (IP67)**, when connected or unconnected
- + **Extra robust design**, with lubricant-free polymer plain bearing. Protect against damage from debris - wear-resistant and maintenance-free
- + **Stable pylon** made from **highest-grade seawater-proof aluminum** and with an extra-reinforced fin, suitable for the toughest conditions
- + **Simple motor start** at the press of a button

Performance: speed and range**

Cruise 2.0 with 2 lead batteries (2 x 12 V / 200 Ah, battery weight approx. 265 lbs)

Dinghies and sailboats up to 3 tons	Speed in mph	Range in miles	Runtime in hh:mm
● ● ● Slow	approx. 3.1	approx. 31	10:00
● ● ● Full throttle	approx. 6.9	approx. 14	02:00

Cruise 4.0 with 2 x Power 26-104 (26 V / 104 Ah, battery weight 106 lbs)

Motorboats and sailboats up to 4 tons	Speed in mph	Range in miles	Runtime in hh:mm
● ● ● Slow	approx. 3.1	approx. 33.4	10:45
● ● ● Full throttle	approx. 8.1***	approx. 9.2	01:10

Figure 2-7: Total assembled Simple electric motor propeller of boat

2.4 Wind turbine as Electric Energy

A wind turbine is a device that converts kinetic energy from the wind into mechanical energy. If the mechanical energy is used to produce electricity, the device is called a wind generator. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump. The smallest turbines are used for applications such as battery charging or auxiliary power on sailing boats, while large grid-connected turbines are becoming large sources of commercial electric power. Wind turbines can be put into two basic categories: namely, vertical axis and horizontal axis wind turbines.

2.4.1 Vertical Axis Wind Turbine

The vertical axis wind turbine has its blades rotating on an axis perpendicular to the ground. The major advantage of a vertical axis rotor (resulting in a 'vertical axis wind turbine' or VAWT) is that there is no need for a yaw system. That is, the rotor can accept wind from any direction. Another advantage is that in most vertical axis wind turbines, the blades can have a constant chord and no twist. These characteristics should enable the blades to be Manufactured relatively simply (e.g. by aluminum pultrusion) and thus cheaply. A third advantage is that much of the drive train (gearbox, generator, and brake) can be located on a stationary tower, relatively close to the ground [3]. Examples of this type of turbine are the Darrieus (Fig 2.8.) and the Savonius wind turbines (Fig 2.9.)



Figure 2-8: Darrieus wind turbines



Figure 2-9: Savonius wind turbines

2.4.2 Horizontal Axis Wind Turbine

The most fundamental decision in the design of a wind turbine is probably the orientation of the rotor axis. In most modern wind turbines the rotor axis is horizontal (parallel to the ground), or nearly so. The turbine is then referred to as a 'horizontal axis wind turbine' (HAWT). There are a number of reasons for that trend; some are more obvious than others. Two of the main advantages of horizontal axis rotors are the following:

- 1) The rotor solidity of a HAWT (and hence total blade mass relative to swept area) is lower when the rotor axis is horizontal (at a given design tip speed ratio). This tends to keep costs lower on a per KW basis.
- 2) The average height of the rotor swept area can be higher above the ground. This tends to increase productivity on a per kW basis. This type of turbine has the main rotor shaft and electrical generator at the top of a tower and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor cou-

pled with a servo motor. Figure 2.10 and 2.11 shows two different configuration of horizontal axis wind turbine.



Figure 2-10: Danish Wind Turbine



Figure 2-11: Diffuser Augmented
Wind Turbine

But also Marine turbines are designed using the same principles as wind turbines. However, they are used in the different conditions and the variables used in the power equation given in equation are also slightly different.

2.4.3 Main Parts of a Wind Turbine

There are three major components that made up a wind turbine. These include the rotor, the generator and the tower.

i.Rotor

The portion of the wind turbine that collects energy from the wind is called the rotor. The rotor usually consists of two or more wooden, fiberglass or metal blades which rotate about an axis (horizontal or vertical) at a rate determined by the wind speed and the shape of the blades. The blades are attached to the hub, which in turn is attached to the main shaft [26].

ii.Generator

This part is what converts the turning motion of a wind turbine's blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity. Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The generator's rating, or size, is dependent on the length of the wind turbine's blades because more energy is captured by longer blades [26]. Figure 2-12 and 2-13 respectively shows wind turbine model of electric car and exploded view of wind turbine [26].

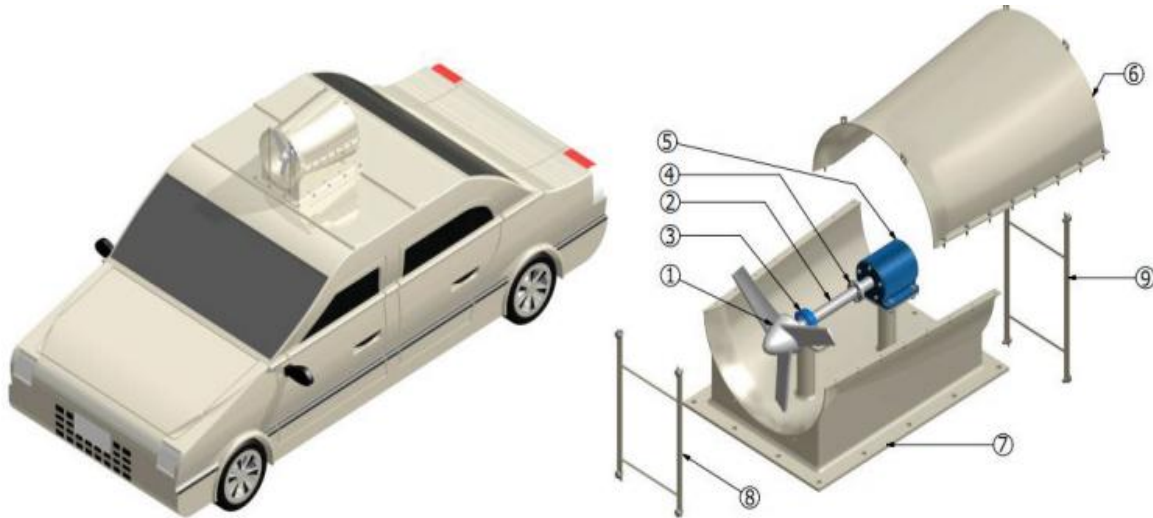


Figure 2-12: The Wind Turbine Model of Electric Car

Figure 2-13: Exploded View of Wind turbine

The main components of the proposed design are the rotor, main shaft, main bearing coupling, generator, top shroud, base shroud, inlet safety guard, exhaust safety guard. The rotor (1) is coupled to the main shaft (2) by a set of four hexagonal head bolts. The main shaft (3) and the generator (5) are fastened to the supports on the base shroud (6) by a set of hexagonal head bolts [26]. But also as the marine turbine works in water rather than air, we will use density of water instead of air: Density of water, $\rho_w = 1000 \text{ kg/m}^3$ the average power coefficient, C_p , for marine turbines is also different than that of wind turbines. Currently, the technology for marine turbines is not that much developed to reach the same levels of results as wind turbines. However, the theoretical maximum for marine turbines is still defined by Betz Law with a limit of 0.59 and we will use the following value of this coefficient [2].

2.5 Battery

2.5.1 Battery Chemistry

The five different types of battery chemistry being commonly used on boats today are flooded lead acid, Gel, Absorbed Glass Matt (AGM), Advanced AGM (TPPL) and Lithium Iron Phosphate.

2.5.1.1 Lead acid

AGM, GEL, and FLOODED batteries all use the same basic Lead Acid Chemistry - Lead plates with a Hydrogen Sulphate Electrolyte. The major differences between these chemistries are the viscosity of the electrolyte and the thickness of the plates. All Lead Acid Batteries can off-gas and all Lead Acid Batteries should be ventilated to prevent the buildup of explosive hydrogen gas. Off gassing increases throughout a batteries life. A sealed battery has a vent that release gases at a certain pressure; otherwise they are recombined into the electrolyte. Sealed Batteries are

more likely to vent at the very end of their life, where they should be monitored most closely for this condition [1].

2.5.1.2 Flooded Lead Acid

Due to the high currents involved, Flooded Lead Acid batteries are not recommended. They have to be derated to 47 percent at a 1 C load which is borderline damaging to the battery. FLA batteries emit hydrogen gas while charging and discharging. The slightest spark from a loose connection can cause these batteries to explode [1]. Avoid the use of flooded lead acid batteries on an electric boat and be very wary of them on any other boat.

2.5.1.3 Harbor

This is a very real danger and on electric boats even more so because of the loads involved. Gassing off increases as the battery ages and at end of a battery's life, gassing off can be constant while charging. Flooded lead acid battery terminals build up acidic corrosion from the vaporized electrolyte depositing on the terminals. This leads to a bad connection with possible thermal condition. Flooded lead acid batteries can dry out and if charged in that state will create a thermal condition. Avoid the use of flooded lead acid batteries on an electric boat and be very wary of them on any other boat [1]. From the figure 2.14 we can understand the actual capacity of the each battery that may use.

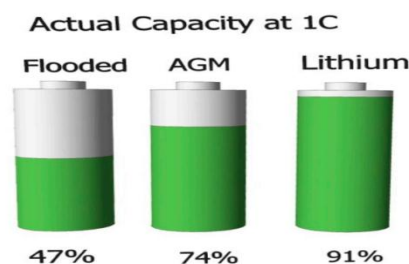


Figure 2-14: Actual capacity of battery

2.6 Horizontal Axis Wind turbines (HAWT) As Propulsion for ship

Wind turbines have been mooted over many years for ship propulsion. However, to date there are no successful prototypes of their application. This reflects systemic issues with their ultimate stability and vibration and the inherent inefficiency in energy conversion relative to other technologies. The advantage of the turbine is that it can continue to harness power even when the craft is sailing directly into the wind. There is a case to be made for wind turbines as a producer of ancillary power for ships and as a replacement for shore-side electricity generated from non-renewable sources. Given the enormous advances made in wind turbine technology for electricity generation, it is highly likely there are important lessons to be transferred now to the shipping sector [20]. Increasing focus on reduction of CO₂ emissions and the possibility of future severe

shortage of oil have spurred renewed interest in wind as supplementary propulsion of merchant ships. Several alternative solutions have been considered, like kites, conventional soft sails, rigid sails, Flatteners rotors, and wind turbines. A tempting aspect of wind turbine propulsion is that it can provide propulsive force when sailing directly upwind, something that is impossible with the other mentioned forms of wind-assisted propulsion. In the last decades, vertically oriented airfoils, known as wing sails, have at an increasing rate replaced soft sails as they are aerodynamically more efficient when a high lift to-drag ratio is important [25]. Look the following figure 2.15 wind turbine onboard for power generation.



Figure 2-15: Illustration of a Vestas wind turbine onboard a tanker for power generation

2.7 New Developed Idea

The new thing that going to be done is to redesigning and developing the above mechanisms in figure for Boat or model ship using savonius type of wind turbine.

- On the above figure due to the rigidity of ship or largeness of ship the horizontal axis wind turbine was done. Which means it's possible to stabilize the ship movement as much as possible. But for small boat especially for recreational boat using horizontal axis wind turbine propulsion has great challenges to stabilize the movement of the boat and also the shape of the boat is no more attractive. So the study will focus on compatible design with savonius type of wind turbine. The following figure 2-16 shows the system development of this study or visual drawing.
- We know that the vertical axis wind turbine needs initial starting torque mechanism. From this type of wind turbine integrated boat the best idea that used to assume is simply at the first starting movement of the boat or forward movement of the boat there is developed collision between the stationary air or moving air and the turbine blade that have linearly movement with the boat. This starting system makes the turbine try to rotate.

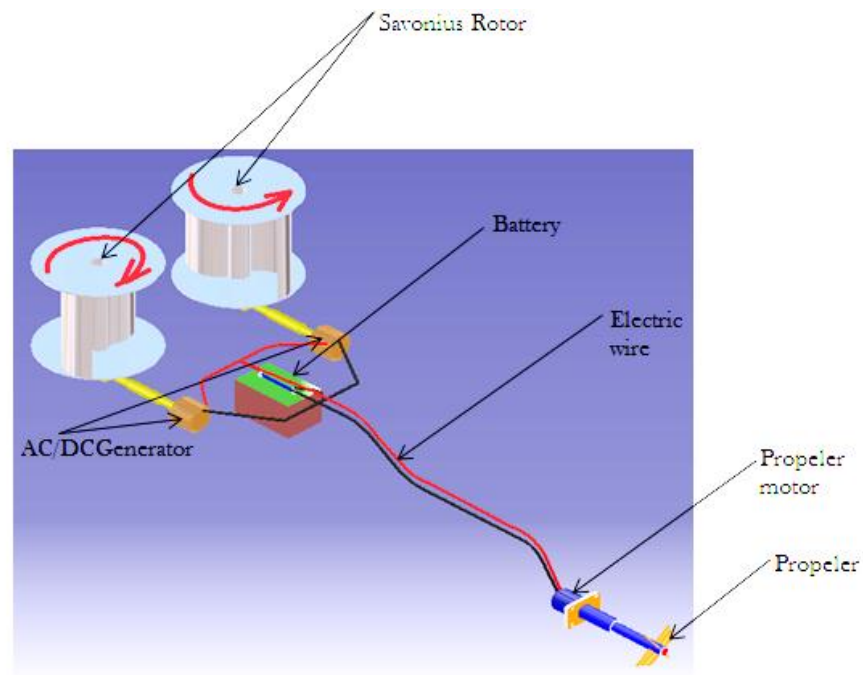


Figure 2-16: New idea visual Drawing for the boat integrated with turbine

2.8 Boat Stability

Stability is the ability of a floating object to return to its initial upright position of stable equilibrium after being disturbed by an outside force. In fishing vessels, stability is the ability of the vessel to return to its upright position after being heeled over by any combination of wind, waves, or forces from fishing operations. A fishing vessel is called **stable** when it has enough positive stability to counter the external forces generated by current weather and fishing conditions and will return to its upright position. To easily understanding figure 4-17 shows the fishing stability of vessel [34].

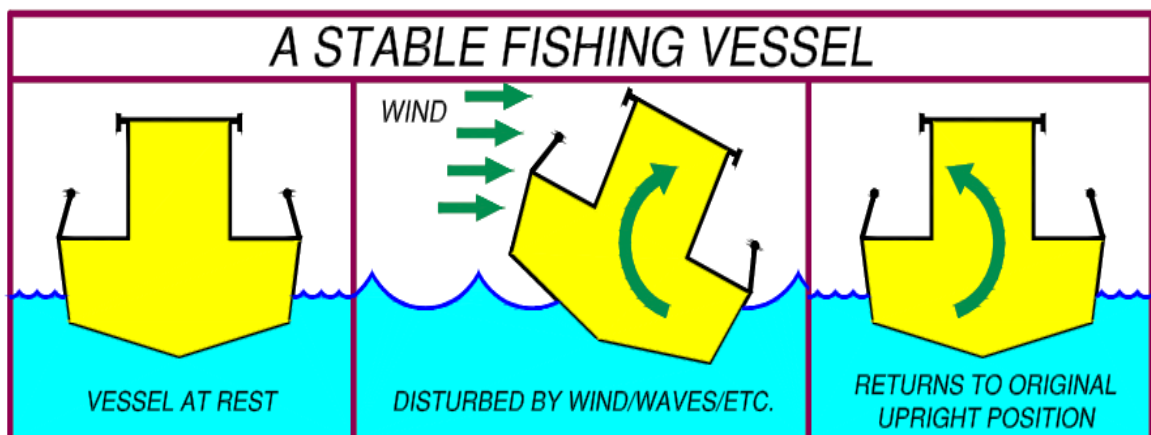


Figure 2-17: Stable fishing Vessel

A fishing vessel is called **unstable** when it does not have enough positive stability to counter the external forces generated by current weather and fishing conditions and capsizes. Look the following figure 2.18 bellow.

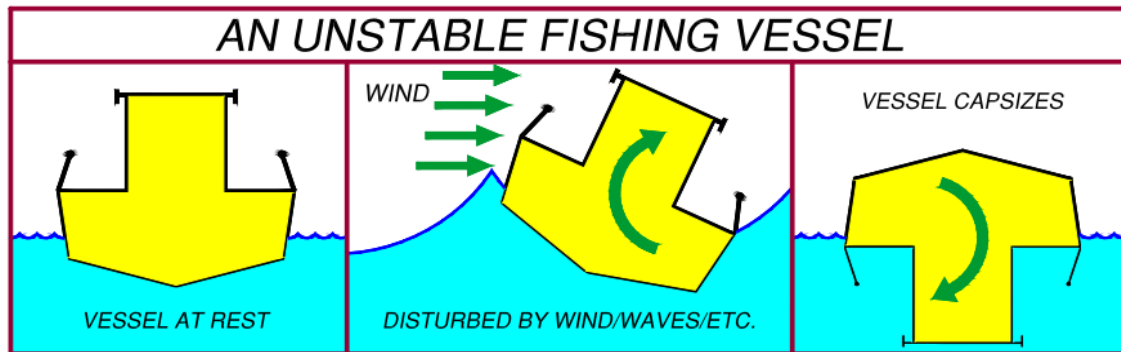


Figure 2-18: Unstable fishing Vessel

Important Lesson- Since a fishing vessel's stability is constantly changing during its voyage due to changes in the weather, the vessel's loading or fishing operations, an originally stable fishing vessel may become unstable.

When is a Vessel Stable or Unstable?

Whether a fishing vessel is stable or unstable depends on two key factors:

- 1) The moments acting to right the vessel (vessel's hull shape and loading).
- 2) The moments acting to capsize the vessel (weather, sea conditions, fishing operations, etc.).

In the figure below 2-19, the upper green line represents the total righting moments available and the lower red line is the total capsizing moments acting on the vessel during a voyage. As long as the moments available to right the vessel (the green line) are greater than the moments acting to capsize the vessel (the red line), the vessel will remain upright and is considered stable. The instant the moments acting to capsize the vessel (the red line) are greater than the moments available to right the vessel (the green line), the vessel becomes unstable and will capsize. Important Lesson- The key to having a stable vessel is making sure there is sufficient stability to counter the capsizing moments from the current weather, waves, and fishing conditions during the entire voyage. Figure 2-19 shows stable versus unstable [34].

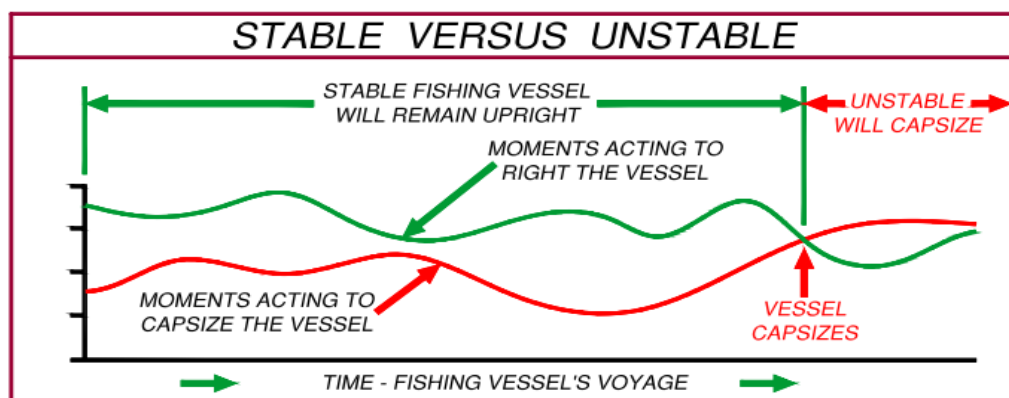


Figure 2-19: Stable Vs. Unstable

Note: Both of these moments are constantly changing during a fishing vessel voyage. The figure 2-20 bellow shows the key stability terms of the vessel.

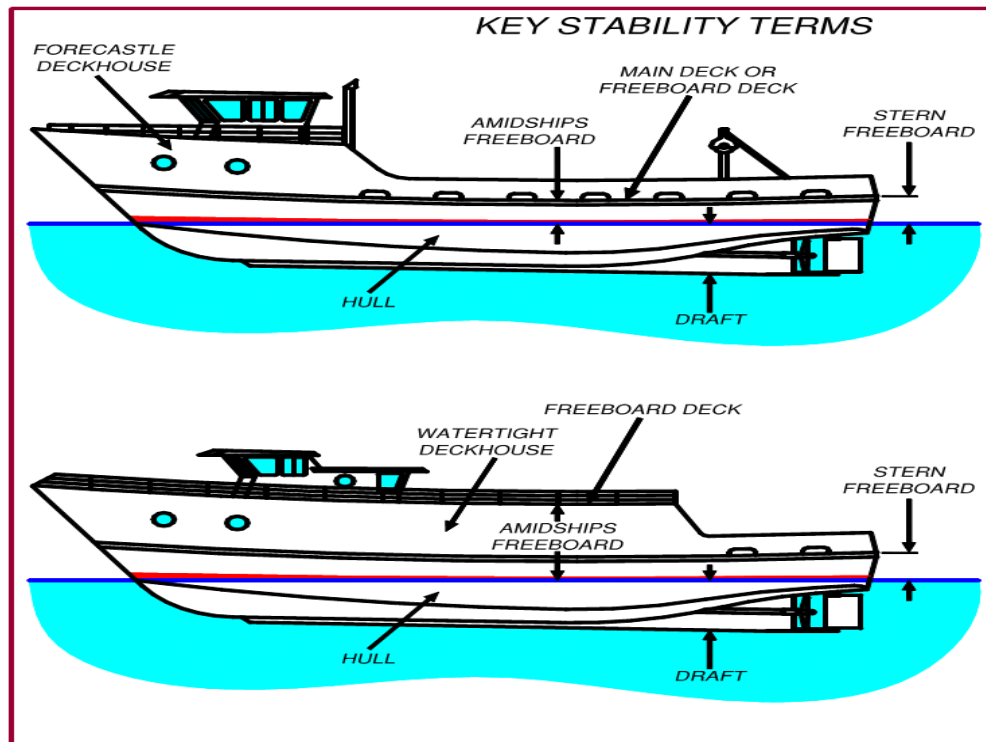


Figure 2-20: Key Stability Terms

Hull: -The enclosed portions of the vessel below the highest watertight deck that runs continuously from the bow to the stern. In most fishing vessels, the main deck is the highest watertight deck.

Superstructure or Deckhouse: -The enclosed portions of the vessel above highest watertight deck.

Waterline: -The position of the water surface along the hull.

Freeboard: -The vertical distance between the waterline and the highest watertight deck.

Draft: -The vertical distance between the waterline and the bottom of the keel.

Watertight Envelope: -The hull and watertight portions of the superstructure or deckhouses. The entire watertight envelope must remain watertight to ensure the vessel's stability [34].

2.8.1 How Stability Works

1) There are two primary forces, gravity and buoyancy, that provide a vessel's stability.

A. The center of buoyancy "B" is a mathematical calculation of the geometric center of the submerged watertight volume of the vessel.

B. The outboard shift of the center of buoyancy "B" reduces when the freeboard deck edge becomes submerged and eventually reverses direction as the vessel heels further.

C. The center of gravity "G" is a mathematical calculation of the individual weight's center of gravities [35].

- 2) An inclining experiment (also called a stability test) is carried out to determine a fishing vessel's lightship characteristics that are used in all stability calculations.
- 3) A fishing vessel stays upright when the center of buoyancy "B" shifts faster outboard than the center of gravity "G" as the fishing vessel heels over.
- 4) The center of buoyancy "B" shifts when the shape of the submerged portion of the fishing vessel's hull changes as the vessel heels over.

A. Positive stability occurs when the center of buoyancy "B" has shifted farther outboard than the center of gravity "G".

B. Negative stability occurs when the center of gravity "G" has shifted farther outboard than the center of buoyancy "B".

2.8.2 Wind and Waves - Wind on the Beam

A strong wind on the fishing vessel's beam can significantly reduce its overall stability without the crew being aware of the danger they are facing. The overall stability is reduced because the righting energy used to resist the beam wind (the red shaded area under the wind heeling arm curve) is no longer available for other forces acting on the fishing vessel such as the waves or the loads from fishing gear. The following figure 2-21 describes the negative effect of the wind on the beam.

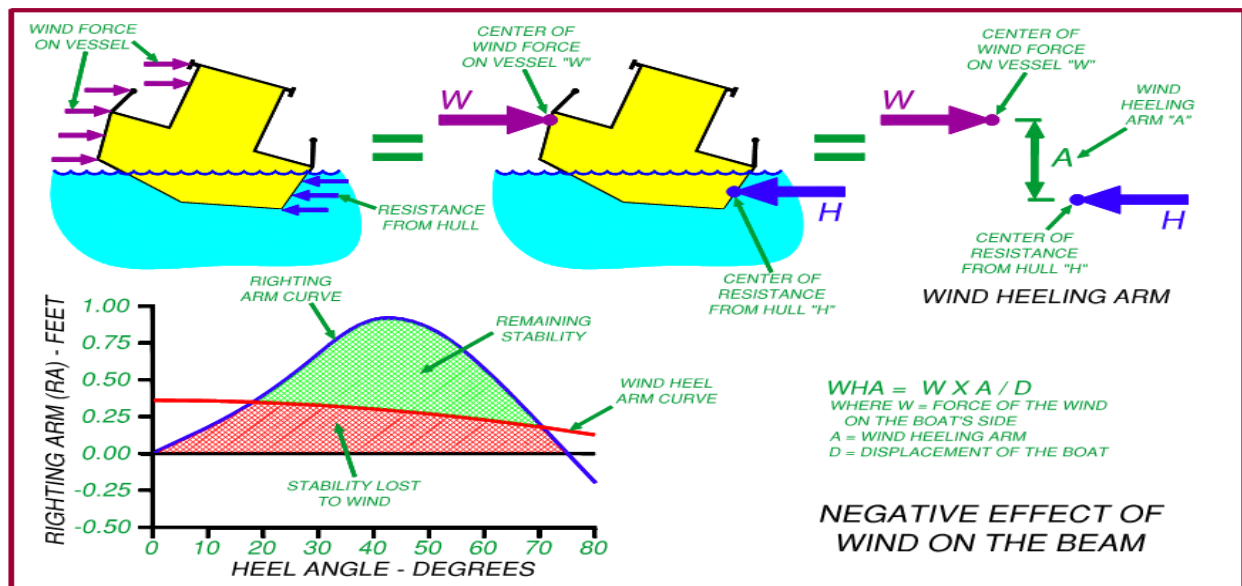


Figure 2-21: Negative Effect of Wind on The beam

Recommendations: When in strong winds, head into the seas to reduce the heeling moments from the wind [34].

2.8.3 Wind and Waves - Icing

Operating in icing conditions significantly reduces a fishing vessel's stability from the weight of the accumulating ice because: The center of gravity "G" rises rapidly from the added weight high

on the vessel. The freeboard is reduced because of the added weight, which causes the deck edge to submerge at smaller heel angles. These are the same effects that occur when the vessel is overloaded. Figure 2-22 shows negative effect of icing on the beam .Initial vs. Overall Stability – Over loading for details. Recommendations: When icing conditions are encountered immediately take appropriate corrective action in any of the following procedures:

- If possible, alter course to return to warmer or protected waters.
- Steaming downwind reduces the speed of the ice formation, but use caution if the seas are very strong because stern seas increase the chance of broaching, boarding seas, or burying the bow.
- Secure all fishing gear below deck to minimize surfaces that ice can form on.
- Keep freeing ports clear of ice to allow rapid draining of water off the decks.
- Remove as much ice accumulation as is safe for the current weather conditions.
- Maintain radio communication with other vessels and shore side on a regular schedule.
- All lifesaving equipment should be broken out and ready for use.

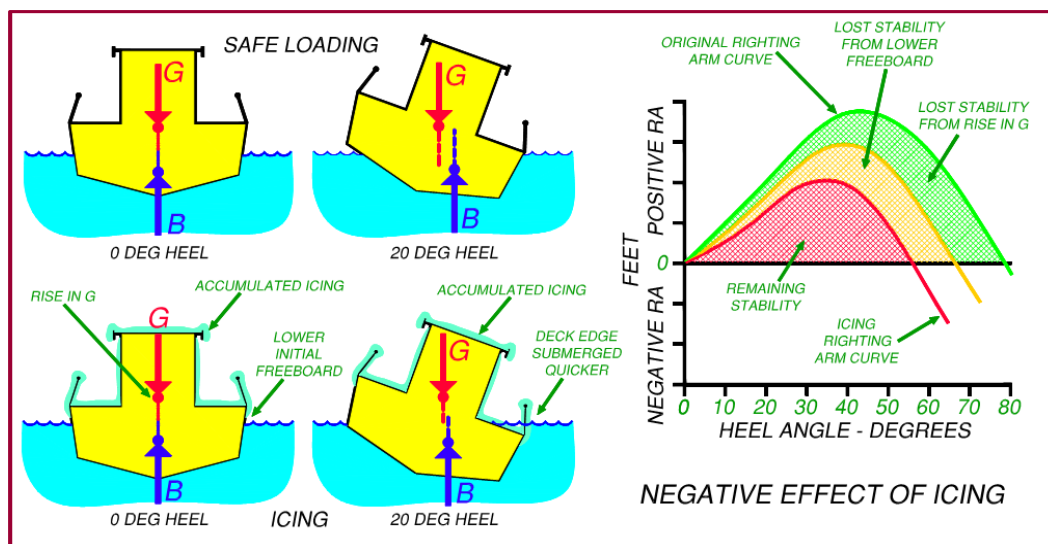


Figure 2-22: Negative Effect of Icing

Recommendations: When icing conditions are encountered immediately takes appropriate Corrective action in any of the following procedures:

- If possible, alter course to return to warmer or protected waters.
- Steaming downwind reduces the speed of the ice formation, but use caution if the seas are very strong because stern seas increase the chance of broaching, boarding seas, or burying the bow.
- Secure all fishing gear below deck to minimize surfaces that ice can form on.
- Keep freeing ports clear of ice to allow rapid draining of water off the decks.
- Remove as much ice accumulation as is safe for the current weather conditions.

- Maintain radio communication with other vessels and shore side on a regular schedule.
- All lifesaving equipment should be broken out and ready for use [34].

2.9 ANSYS AQWA

ANSYS Aqwa provides an engineering toolset for the investigation of the effects of wave, wind and current on floating and fixed offshore and marine structures, including: spars; floating production, storage, and offloading (FPSO) systems; semi-submersibles; tension leg platforms (TLPs); ships; renewable energy systems; and breakwater design.

- Aqwa Hydrodynamic Diffraction provides an integrated environment for developing the primary hydrodynamic parameters required for undertaking complex motions and response analyses. Three-dimensional linear radiation and diffraction analysis may be undertaken with multiple bodies, taking full account of hydrodynamic interaction effects that occur between bodies. While primarily designed for floating structures, fixed bodies such as breakwaters or gravity-based structures may be included in the models.
- Computation of the second-order wave forces via the full quadratic transfer function matrices permits use over a wide range of water depths.
- Aqwa Hydrodynamic Diffraction can also generate pressure and inertial loading for use in a structural analysis as part of the vessel hull design process. The results from a diffraction analysis can be mapped onto an ANSYS Mechanical finite element model for further structural assessment and detailed design. Since the mapping function automatically accounts for mesh differences between the hydrodynamic and finite element models they do not have to be topologically identical.
- Aqwa Hydrodynamic Time Response provides dynamic analysis capabilities for undertaking global performance assessment of floating structures in the time domain. A wide range of physical connections, such as mooring lines, fenders, and articulations, are provided to model the restraining conditions on the vessels. In addition, sea-keeping simulation may be undertaken with the inclusion of forward speed effects. Slow-drift effects and extreme-wave conditions may be investigated, and damage conditions, such as line breakage, may be included to study any transient effects that may occur.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Materials

The table 3-1 below shows the material used for prototype.

Table 3-1: The materials to be used

<u>NO</u>	Item	Specification	Quantity
1	Aluminum sheet	6000 x 6000 x 5 [mm]	1
2	Internal Frame	3000x250x25 [mm]	20
2	Generator	DC115	2
3	Lead acid Battery	12V/200AH	2
4	Structural steel Spur Gear	GR72	2
5	Structural steel Pinion Gear	GR18	2

Table 3-2: Equipment

<u>NO</u>	Equipment
1	volt meter
2	Measure Tape

3.2 Methods

This section describes the methods used to complete the objectives of this thesis.

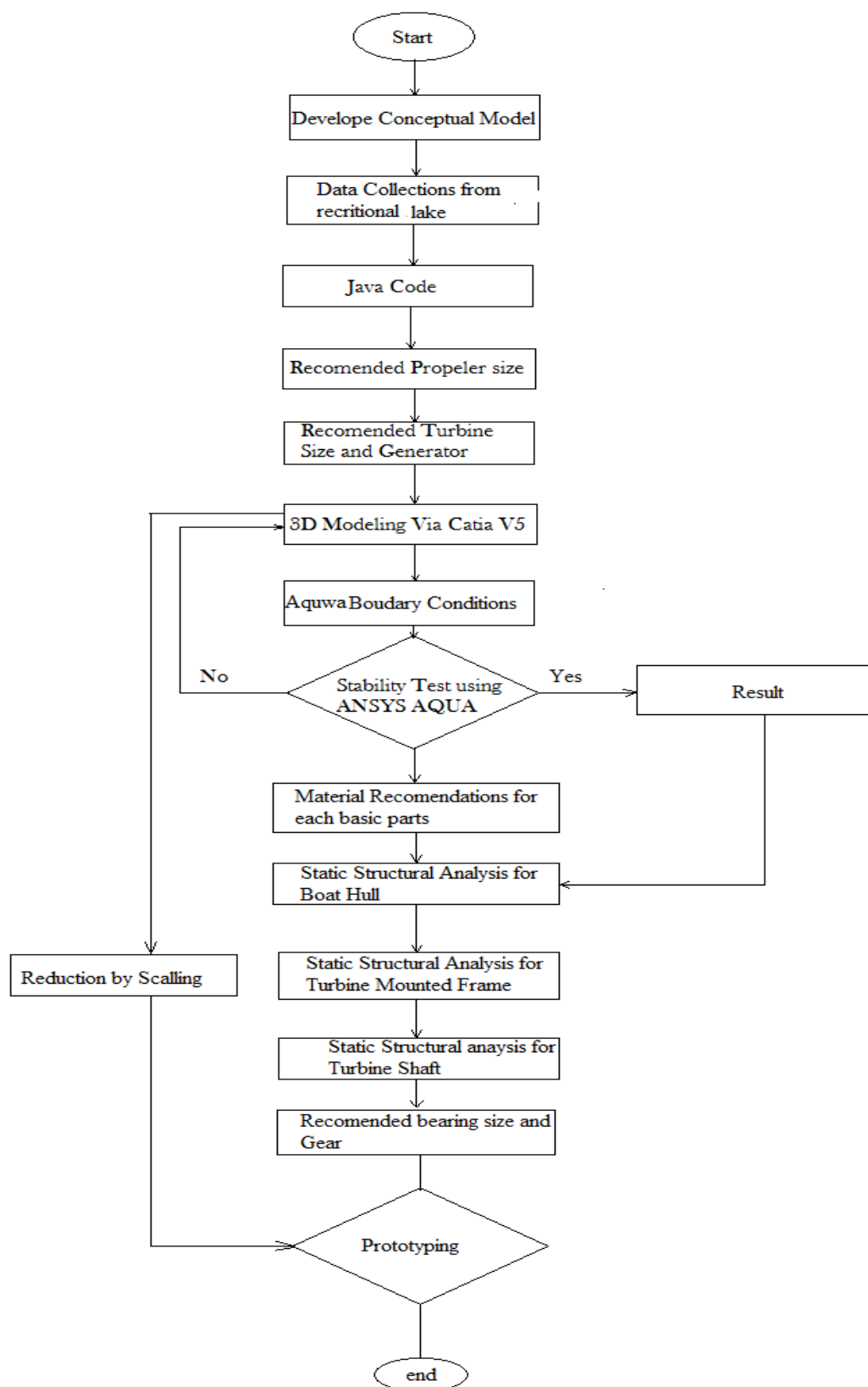


Figure 3-1: Work Flow of the Project

3.2.1 Develop Conceptual Design

The concept for the Turbine mounted boat design was developed to allow the conversion of wind energy into the electrical energy for propulsions of boat. It is initially created from a sheet metal body which is compact assemble. The main design difference between the concept and the pre-existing boat is that the conceptual turbine boat can work under low wind velocity, Turbines no need the yawing system, Two turbine rotates on opposite directions to make zero total moment that created by the each blade. In theory, this should improve the Stability performance of the boat in comparison with the rigid ship that mounted with conventional type of wind turbine. The following figure 3-2 represents the conceptual design of turbine mounted boat.

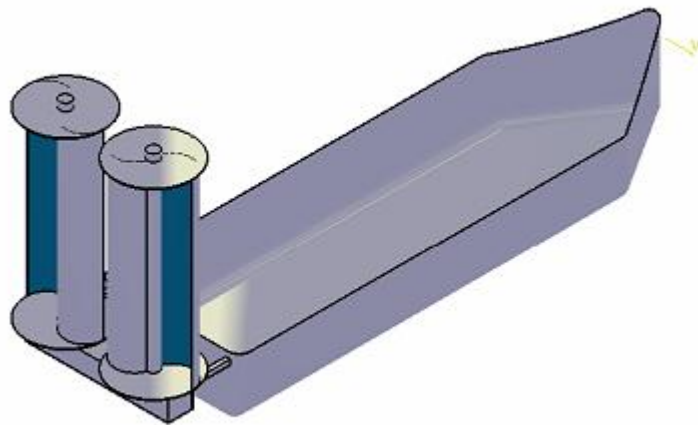


Figure 3-2: Conceptual Boat Design

3.2.2 Types and sources of data

For the purpose of this study the type of data that was used is both primary and secondary data. The primary data was collected from selected categories of recreational person's boats at the lakes in Ethiopia. Therefore, for this design of the boat and for more safe work it is better to check recreational boat and its specifications, which found in the country Ethiopia; Bushoftu (Babogaya lake), Langano, Bahidar. etc. The sample size that was selected for interviewee is shown on the table 3-3.

3.2.2.1 Study Area

Before interviewing and gathering the information's to get through the fence of the lake there was recommended tax that must paid. Then the researcher made a tour around the lakes to check how it looks likes of the lake surfaces, the quality of water, wave height at calm water conditions, looking working boat and non-working boat at the lake. Area contains, recreational

hotels, maritime training institute company. Then the decision was made to tour on the lake by paddle driven boat of one owner to ask the information's.

3.2.2.2 Questionnaire

A set of interviewed questions, devised for a survey or statistical study described as follow.

- What about the size of this lake?
- What is the depth of the lake?
- At what time and the day person wants to recreate?
- What about the service allowance of the boat per day?
- What about the price for recreational on one boat?
- Many time which type of the hull works on these lakes; flat bottom skiff or V planning hull or U shape?
- Finally the dimensions of the boat were measured.

3.2.2.3 Collected Data and Gathered Information

- The maximum depth of the lake 48m according to the interviewed
- According to the information gathered from boat owner the service of the boat on Babogaya lake many time from 12:0-6:15 PM. Because many time person recreat afternoon on this lake. This was used to Estimate the service allowance for the boat. The Estimation is depend on perday service. One can work 6-8:15 hours; this is approxime determined as.

$$\text{Service allowance} = \frac{\text{Time(hours)}}{\text{Unit day(hour)}} = \frac{8.25}{24} \times 100\% \approx 35\%$$

- The recreating price of the boat on this lake simple depend on the time taken of recreating person.
- The hull shape of many boat used on this lake was V flatt bottom.
- On the lake there were many boat that have different sizes. But as a sample the mesured size of boat shown on table 3-3 below.

Table 3-3: Interviewed data on Paddle driven and 10 h.p motor boat

Parameters	Value
Breadth	1.5m
L _{wl} (Water line length of the boat)	3m
Draught(the depth of water needed to float a boat)	0.25m
Displacement for eight person + boat weight	0.8 ton
Bottom corner fillet radius	0.15m

Material of this boat was Fiber

From above Table of 3-3, as the information from the boat owner said; The over all mass was 800kg. But the size of the boat seams very small when it compared with recommended total weight of the boat. Therefore the decided idea of this boat was to increase its size to that shown on Table 3-4.

Table 3-4: Scaled size of Interviewed data on Paddle driven and 10hp motor boat
New Idea of the boat from 3D model of boat hull On CATIA V5 and its dimensions Assumptions are followed as;

Parameters	Value
L_{wl} (overall length of the boat)	6m
Draught(the depth of water needed to float a boat)	0.365m
Displacement (∇)	2.5 ton
Bottom corner fillet radius	0.15m

the assumed Material of the boat was Alluminium Alloy instead of fiber.

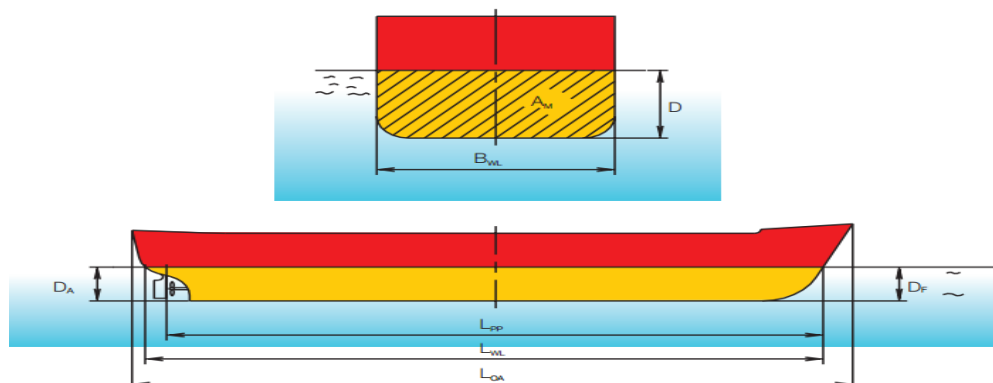
The secondary data was obtained from internet and reference book. For the detail calculation the design data books are used. Especial on this design of boat the ITTC recommended many formulas are used to determine propulsion power.

3.2.3 Methods of data analysis

In order to achieve the required objective this study will try to use design data book. Then the data was analyzed by the necessary design of some empirical relation formulas and also used ANSYS Hydrodynamics software for simulation and ANSYS Static structural analysis for basic structural component parts. The software's used on this thesis were, ANSYS 16, CATIA, and SOLID WORK.

3.2.3.1 Resistance and Propulsion power

Resistance is the total force that resists the boat during the propulsion period. The opposite is the propeller force that used to overcome total resistance of the boat. Figure 3-3 shows the basic dimensional parameters of the hull geometry.



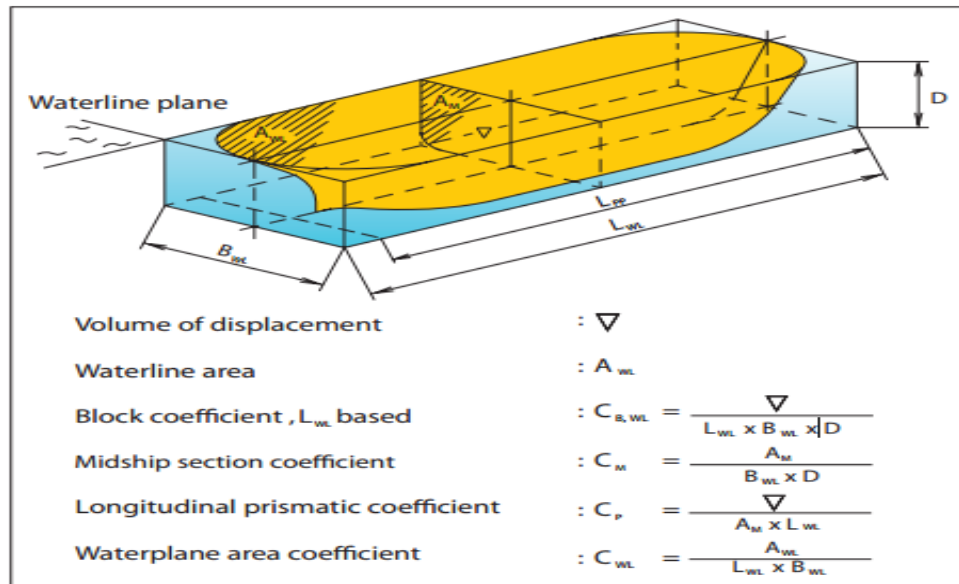


Figure 3-3: Hull dimensions (Source: ITTC57)

Shipbuilders often use block coefficient $C_{B,PP}$ based on the length between perpendiculars, L_{PP} , in which case the block coefficient will, as a rule, be slightly larger because, as previously mentioned on figure 3-3, L_{PP} is normally slightly less than L_{WL} .

To calculate the propulsion power for a ship, the resistance and the total propulsive efficiency have to be determined with the highest possible accuracy. As empirical methods are normally used for these calculations, it is worthwhile at least to know the accuracy of the different elements in the calculation procedures such that the propulsive power can be predicted in combination with an estimate of the uncertainty of the result. In the following the calculation procedures used for the present project will be described in detail [47].

3.2.3.1.1 Fixed values

According to the report written for design of any vessels on international towing tank conference fixed value is described into three categories.

a.Design values: L_{OA} , B , T , ∇ , V

where L_{OA} : Length overall

T = The draught at a midships

B =Breadth

∇ =Displacement or Volume of water displaced

V = Speed of vessel

b.Calculated values (using design values): C_B , C_P , M , F_n , R_n

F_n : Froude number: a dimensionless number used in hydrodynamics to indicate how well a particular model works in relation to a real system. Named after the Engl. civil engineer William Froude

(1810–79).

C_B : Block coefficient

M : Length displacement ratio or slenderness ratio

C_p : Prismatic coefficient

c. Calculated values using approximations: S (wetted surface area)

d. Environmental constants: Water density, temperature, kinematic viscosity

3.2.3.1.2 Variables

the variable used to determine effective power of the vessels described as ITTC1957

- Speed
- Vessel type
- Sailing condition: Displacement, draft and trim
- Total Resistance Coefficient
- The total resistance coefficient, C_T , of a ship can be defined by:

$$C_T = C_F + C_A + C_{AA} + C_R = \frac{R_T}{\frac{1}{2} \rho_w \cdot V_m^2 \cdot S} \dots\dots\dots \text{Equation 3-1}$$

Where: C_F is Skin friction Coefficient

C_A is correlational allowance coefficient or increamental resistance Coefficient

C_{AA} is Air resistance coefficient

C_R is Residual resistance coefficients

R_T Total resistance Coefficients

ρ_w water density

V_m model speed

This is the originally ITTC1957 method from the International Towing Tank Committee (ITTC).

All parameters in the above equation will be described in the present section.

i. Wetted Surface (S)

The wetted surface is normally calculated by hydrostatic programs. However for a quick and fairly accurate estimation of the wetted surface many different methods and formulas exist based on only few ship main dimensions, as example Mumford's formula below:

$$S = 1.025 \cdot L_{pp} \cdot (C_B \cdot B + 1.7 \cdot T) = 1.025 \cdot \left(\frac{\nabla}{T} + 1.7 \cdot L_{pp} \cdot T \right) \quad [47] \dots\dots\dots \text{Equation 3-2}$$

ii. Frictional Resistance Coefficient (C_F)

The frictional resistance coefficient, C_F , in accordance with the ITTC-57 formula is defined by:

$$c_F = \frac{0.075}{(\log_{10} R_n - 2)^2} = \frac{R_F}{\frac{\rho_w}{2} \cdot V^2 \cdot S} \quad [47] \dots\dots\dots \text{Equation 3-3}$$

where the frictional resistance, R_F , is sum of tangential stresses along the wetted surface in the direction of the motion and R_n is the Reynolds number:

$$R_n = \frac{V \cdot L_{pp}}{\nu} \quad [47] \dots\dots\dots \text{Equation 3-4}$$

Where L_{pp} -length between perpendicular

$$\nu = ((43.4233 - 31.38 \times \rho) \times (t + 20))^{1.72 \times \rho - 2.202} + 4.7478 - 5.779 \times \rho \times 10^{-6} \quad [47] \dots\dots \text{Equation 3-5}$$

where ν is the kinematic viscosity of water:

t is water temperature in degrees Celcius. How to take into account the too small Reynolds number? Figure 3.4 shows the condition of flow over flat plate.

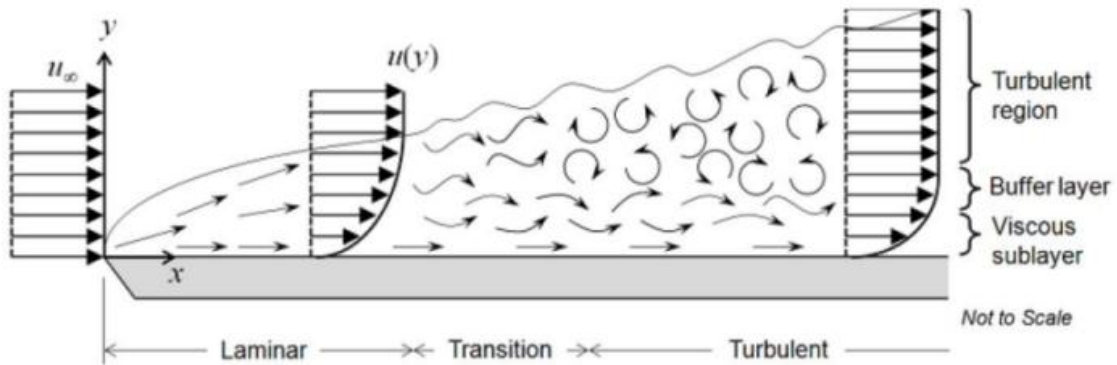


Figure 3-4: Flow over Flat plate

As in the original resistance calculation method by Harvard (called “Ship Resistance”), it is here decided to leave out a form factor in the C_F part, but include a correction for special hull forms having U or V shape in the fore or after body, as suggested by Harvald. The influence of a bulbous bow on the resistance is included in a bulb correction.

iii.Incremental Resistance Coefficient

The frictional resistance coefficient is related to the surface roughness of the hull. However the surface roughness of the model will be different from the roughness of the ship hull. Therefore, when extrapolating to ship size, an incremental resistance coefficient C_A is added in order to include the effect of the roughness of the surface of the ship. This incremental resistance coefficient for model-ship has very often been fixed at $C_A = 0.0004$. Shown that C_A decreases with increasing ship size and following roughness correction coefficient is proposed according to Harvald.

iv. Air Resistance Coefficient

ITCC-78 descriptions of air resistance coefficients, C_{AA} .

$$C_{AA} = \frac{A_{VT}}{1025 \times S} \quad [47] \dots\dots\dots \text{Equation 3-6}$$

Where: A_{VT} -average frontal area of the vessels above water plane

S -wetted surface area

v. Residual Resistance Coefficient

The residual resistance coefficient, C_R , is defined as the total model resistance coefficient minus the model friction resistance coefficient, Harvald -1983 describes this idea also by considering hull form.

$$C_R = C_T - C_F \quad [47] \dots\dots\dots \text{Equation 3-7}$$

- Hull form A hull shape correction to C_R is applied if the aft or fore body is either extremely U or V shaped

Fore body Extreme U: -0.1×10^{-3} Extreme V: $+0.1 \times 10^{-3}$

After body Extreme U: $+0.1 \times 10^{-3}$ Extreme V: -0.1×10^{-3}

As described earlier the curves for C_R are given as function of the three parameters Shown on APPENDIX III: The length displacement ratio (M), the prismatic coefficient (C_P) and finally the Froude number (F_n). From the Appendix the value of C_R can be determined according to the [ITTC57] (according to the international towing tank committee on maritime institute).

$$M = \frac{L_{WL}}{\nabla^{1/3}} \quad [47] \dots\dots\dots \text{Equation 3-8}$$

$$C_P = \frac{C_B}{C_M} \quad [47] \dots\dots\dots \text{Equation 3-9}$$

$$F_n = \frac{V}{\sqrt{gL_{WL}}} \quad [47] \dots\dots\dots \text{Equation 3-10}$$

Where: L_{WL} -water line length

C_B -Block coefficient

V -vessel speed

C_M -mid section area coefficient

g - gravitational acceleration

vi.Total Ship Resistance, R_T

The total ship resistance represents the total force exerted during propulsion system. It is given by the following equation 3.12.

$$R_T = \frac{1}{2} C_T \times \rho \times S \times V^2 \quad [47] \dots \dots \dots \text{Equation 3-11}$$

vii.Effective Power

Effective power is the power needed to overcome total resistance force

$$P_E = R_T \times V \quad \dots \dots \dots \text{Equation 3-12}$$

viii.Service allowance

The service allowance is used for determination of the installed main engine power, which means that it shall be determined based on the expected service area the size of the Boat shall be taken into account, as the service allowance will be relatively higher for small Boat compared to large Boat. Furthermore the hull form will also have an influence on the necessary service allowance. The more slender hull form, the less service allowance is needed. According to the harvald for different area it is 15-40 %.

$$P_E = R_T \times V \frac{(1 + \text{service_allowance} \%) }{100} \quad \dots \dots \dots \text{Equation 3-13}$$

Where: V-speed of the vessel

3.2.3.2 Propulsive Efficiencies

Total efficiency:

$$\eta_T = \eta_H \times \eta_O \times \eta_R \times \eta_S \quad \dots \dots \dots \text{Equation 3-14}$$

Where:

η_H -Hull efficiency

η_O -Propeller in open water condition

η_R -Relative efficiency

η_S -Transmission efficiency (shaft line and gearbox)

a. Hull efficiency

The hull efficiency is a function of the wake fraction, w, and the thrust deduction fraction, t, [Harvald 1983]

$$\eta_H = \frac{1-t}{1-w} \quad [47] \quad \dots \dots \dots \text{Equation 3-15}$$

The form in the aft body (Fa) can be described by factors: [-2, 0, +2], negative values for U-shape, positive for V-shape and zero for N-shaped hull form. Wake fraction determined as ITTC57 and thrust deduction.

$$w = \frac{0.1 \times B}{L_{WL}} + 0.149 + \frac{\frac{0.05 \times B}{L_{WL}} + 0.449}{585 - \frac{5027 \times B}{L_{WL}} + 11700 \times \left(\frac{B}{L_{WL}}\right)^2 \times (0.98 - C_B)^3 + 1} + \frac{0.025 \times F_a}{100 \times (C_B - 0.7)^2 + 1} - 0.18 + \frac{0.00756 \times F_a}{\left(\frac{D_{prop}}{L_{WL}} + 0.002\right)^2 + 1}$$

[47].....Equation 3-16

$$t = \frac{0.625 \times B}{L_{WL}} + 0.08 + \frac{0.165 - \frac{0.25 \times B}{L_{WL}}}{525 - \frac{8060 \times B}{L_{WL}} + 20300 \times \left(\frac{B}{L_{WL}}\right)^2 \times (0.98 - C_B)^3 + 1} - 0.01 \times F_a + 2 \times \left(\frac{D_{prop}}{L_{WL}} - 0.04\right)$$

[47].....Equation 3-17

Where: C_B -block Coefficient

w -wake fraction

D_{prop} -propeller diameter

L_{WL} -Water line length

t - Thrust deduction fraction

b. Propeller efficiency

Basic factors for the boat

- L_{WL} should be = $L_{OA} \times 0.87$
- The relationship $L_{OA}/\text{Width} = 2.8\text{--}3.2$
- The maximum hull angle at the transom shield = $15^\circ\text{--}17^\circ$
- The displacement should include load and passengers
- The total output at the propeller = flywheel output $\times 0.93$
- Hull form = U-bottom with round or flat [34].

$$D_{prop} = 0.713 \times \text{max_draught} - 0.08 \quad [\text{ITTC57}].....\text{Equation 3-18}$$

$$R = (1 - t) \times T \quad \text{Equation 3-19}$$

$$V_A = (1 - w) \times V \quad \text{Equation 3-20}$$

Where: V - Vessels speed

V_A -Propeller speed

R -total resistance force

- c. **Relative rotated efficiency and shaft efficiency:** According ITTC, behind propeller efficiency as the relative rotated efficiency in average is close to one (it normally varies between 0.95 and 1.05) the size of this value depends of propeller shaft length, number of bearings and the gearbox. For a shaft line with directly mounted propeller is approximately 0.98, while it is 0.96 – 0.97 for a shaft system including a gearbox solution.

3.2.3.3 Propulsion Power, P_p

Propulsion power is the total power needed for propulsion or over all power

$$P_p = \frac{P_E}{\eta_T} \quad [47] \dots \dots \dots \text{Equation 3-21}$$

Where: η_T -Total efficiency

P_p -Propeller power

P_E -Effective Power

3.2.3.4 Principles of savonius rotor wind turbine

Savonius turbines are one of the simplest turbines. Aerodynamically, they are drag-type devices, consisting of two or three blades (vertical – half cylinders). A two blades savonius wind turbine would look like an "S" letter shape in cross section; Figure 3-5 shows the cross section of savonius rotor. The savonius wind turbine works due to the difference in forces exert on each blade. The lower blade (the concave half to the wind direction) caught the air wind and forces the blade to rotate around its central vertical shaft. Whereas, the upper blade (the convex half to wind direction) hits the blade and causes the air wind to be deflected sideways around it [17].

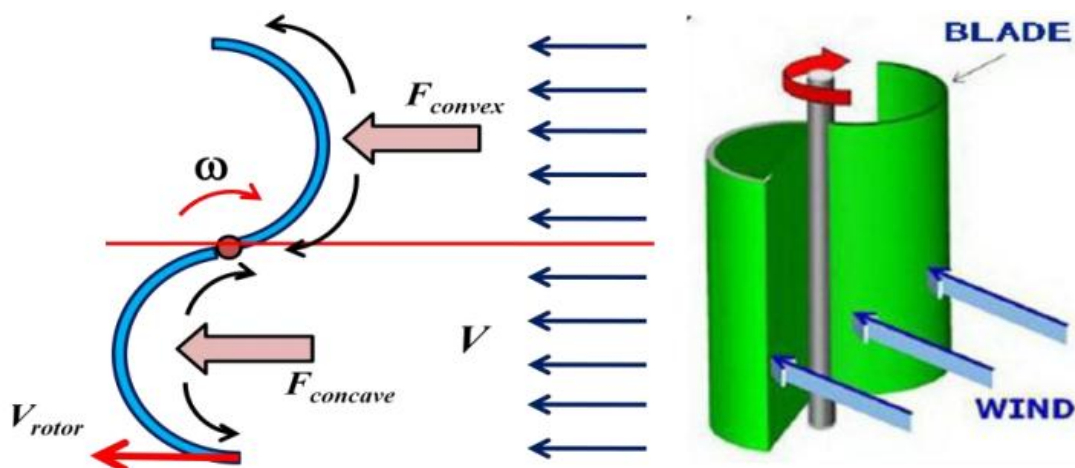


Figure 3-5: Schematic drawing showing the drag forces exerted on two blade Savonius

Because of the blades curvature, the blades experience less drag force (F_{convex}) when moving against the wind than the blades when moving with the wind (F_{concave}). Hence, the half cylinder with concave side facing the wind will experience more drag force than the other cylinder, thus forcing the rotor to rotate. The differential drag causes the Savonius turbine to spin. For this reason, Savonius turbines extract much less of the wind's power than other similarly sized lift type turbines because much of the power [18]. That might be captured has used up pushing the convex half, so savonius wind turbine has a lower efficiency.

i.Swept Area

The swept area is the enclosed area when the turbine is in motion; the shape depends on the turbine orientation. The swept area of an HAWT is circular shaped while the VAWT has a rectangular shape and is calculated using:

$$A_s = H \times D \quad [17] \dots\dots\dots \text{Equation 3-22}$$

Where: A_s - swept area [m^2],
 D -the rotor diameter [m], and
 H - Blade length [m].

The volume of air is limited by the swept area of the turbine. The rotor converts the energy from the wind in rotational movement so a larger area will give a larger power output from the same wind conditions.

ii.Power and Power Coefficient

The power that the rotor extracts from the wind is mechanical power given by

$$P_m = T \times \omega \quad [17] \dots\dots\dots \text{Equation 3-23}$$

Where: T - Generated torque on the turbine rotor [N.m]
 ω -Angular velocity of the rotor [rad/sec]

The Wind Power can be computed from the formula:

$$P_w = \frac{1}{2} \rho \times A_s \times V^3 \quad [17] \dots\dots\dots \text{Equation 3-24}$$

Where: V - the velocity of the wind [m/s] and
 ρ - The air density [kg/m^3],

The reference density used its standard sea level value ($1.225 \text{ kg}/\text{m}^3$). A_s is the rotor swept area, [m^2]. The available power is dependent on the cube of the air speed.

Note that the efficiency curves of the Savonius and the American multi blade designs were inadvertently switched. In some past publications, they discouraged the study of the Savonius design. The following figure 3-6 shows the power coefficient as a function of tip speed ratio for different type of wind machines.

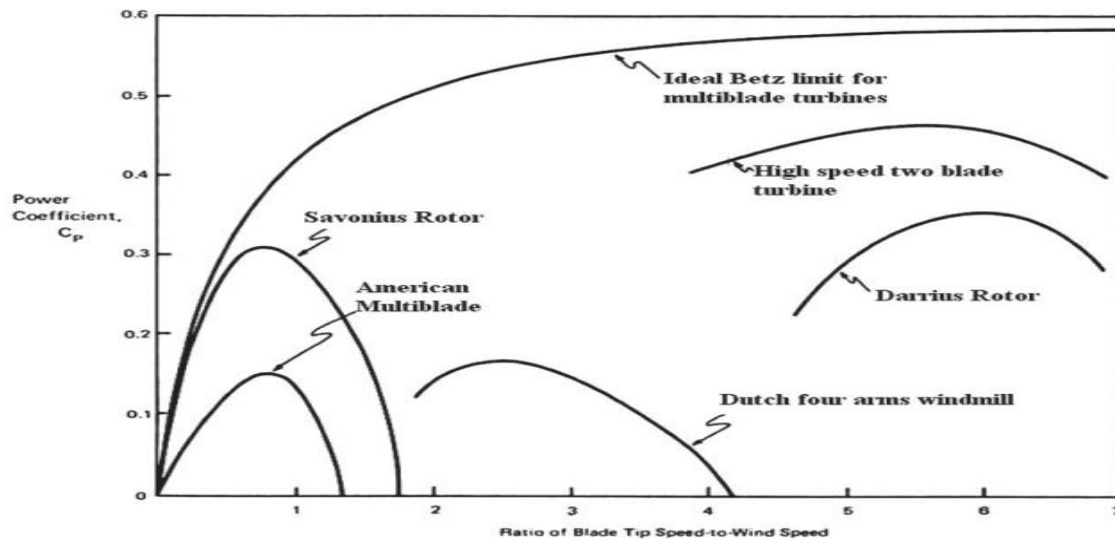


Figure 3-6: The power coefficient C_p as a function of the tip speed ratio for different wind machines designs.

$$C_p = \frac{\text{the extracted power from the wind}}{\text{the available power of the wind}} = \frac{P_m}{P_w} \quad [17] \dots \dots \dots \text{Equation 3-25}$$

C_p represents the part of the total available power that is actually taken from wind, which can be understood as its efficiency. There is a theoretical limit in the efficiency of a wind turbine determined by the deceleration the wind suffers when going across the turbine. For the HAWT, the limit is 19/27 (59.3%) and is called Lanchester-Betz limit. For VAWT, the limit is 16/25 (64%). These limits come from the actuator disk momentum theory which assumes one-dimensional steady, in viscous and without swirl flow. The power coefficient only considers the mechanical energy converted directly from wind energy; it does not consider the mechanical-into-electrical energy conversion, which involves other parameters like the generator efficiency [17].

iii. Lift or Drag Type

There are two ways of getting the energy from the wind depending on the main Aerodynamic forces used:

- The drag type requires less energy from the wind but gets higher torque and is used for mechanical applications as pumping water. A common representative model of drag-type VAWTs is the Savonius [17].

- The lift type uses an aerodynamic airfoil which creates a lift force, and the airfoil can move faster than the wind flow. This type of turbines is used for the generation of electricity. The most representative model of a lift-type VAWT is the Darrieus turbine; its blades have troposkein shape which is appropriate for withstanding high centrifugal forces [17].

iv.Torque

Figure 3-7 shows how the torque can be created.

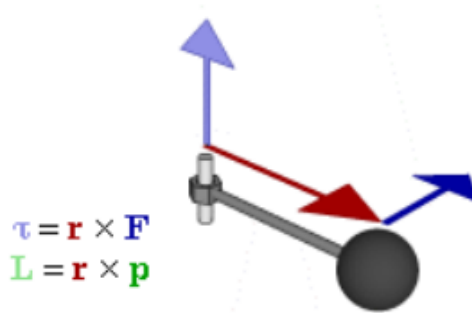


Figure 3-7: Torque formula

The torque is a measurement of the turning force of an object which is presented in the Mathematical equation, where F is the force and r is the moment arm about the axis of rotation.

$$T = F \cdot r$$

v.Angular Velocity

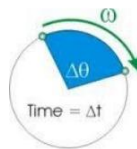


Figure 3-8: Angular velocity diagram

The angular velocity is known as the rate that the angular displacement changes and can be represented by the equation:

$$\omega = \theta / t$$

Where: ω -the angular speed [rad/s],

θ -the angle measured in radians and t - The time [s].

3.2.4 Java Programing Language

The java code was used on this project to determine all necessary dimensions and the propulsion power of the boat. All formula of hull geometry was written on this program

- To minimize manual calculation.

- To get any size of the boat propulsion power instead of trying many time by hand
- To do the small size of prototype the power and dimensions can be easily determined.

From appendix I of java code part I we can determine the basic dimensions and other parameters like Froude number that represent speed per squawroots of gravitational acceleration times over water line length of the boat hull, Slenderness ratio, Prismatic coefficients, and Wetted surface area of the boat at maximum design draught. Java code part II is used to determine the propulsion power.

3.2.5 Stability Test Using ANSYS AQWA

ANSYS Aqua that used on this analysis was to provide the effects of wave, wind and current on floating systems.

- Aqua Hydrodynamic Diffraction can generate pressure and inertial loading for use in a structural analysis as part of the vessel hull design process.
- The result from a diffraction analysis was mapped onto an ANSYS Mechanical finite element model for further structural assessment and detailed design of boat hull.

3.2.5.1 Principles of static stability

The principals involved in the stability of a vessel are well known and understood, although they are complex to calculate analytically, as they rely mainly on the geometric shape of the vessel under study. The intricate curves found on ships require numerical integration, usually using Simpson's rule, to evaluate sectional areas and volumes – as these areas change with draught, trim, heel etc., it would be too large a task to perform a full stability assessment by hand. Therefore, the Hydrostatics software ANSYS Hydrodynamics published.

3.2.5.2 Stability Theory

Stability is according to Aqua Theory Manual divided into two different types of stability, hydrostatic stability and hydrodynamic stability. Hydrostatic stability refers to a body being affected by nothing more but the buoyancy force and the gravitational force in still water. Hydrodynamic stability gives a more detailed look of the stability; it considers the waves that interact with the body, the forces acting on the body while the body is in motion and similar dynamic effects. Stability is determined by the relationship between three things, center of gravity (CG), center of buoyancy (CB), and something called meta centric height (GM). Also we need to know the difference between initial stability and reserve buoyancy.

Initial stability: A measure of the boat's ability to right itself at low angles of heel. A boat that lists to one side or the other when sitting at the dock and feels “tippy” to the owner, has low initial stability. But this boat once heeled may have high reserve buoyancy.

Reserve buoyancy: A measure of the increase in buoyancy and stability as the boat heels over. A boat with large reserve buoyancy tends to right it, easily and quickly, while a boat that has low reserve buoyancy tends to come upright very slowly or not at all. Normally, under static conditions, if you draw a vertical line upward from the center of buoyancy it will pass through the center of gravity. At rest with no heel, the center of gravity should be directly in line vertically with the center of buoyancy.

First a few definitions

Center of gravity is the point in the boat where all of the forces of gravity (down) are equal. In other words if you could balance the boat on a point, this would be the point where it balances.

Center of buoyancy is the point where all the forces upward from the water are acting. It is essentially the center of the underwater volume of the boat.

A Meta center is an imaginary point at some height above the CB and CG of the boat [40].

Figure 3.9 bellow shows the details of points.

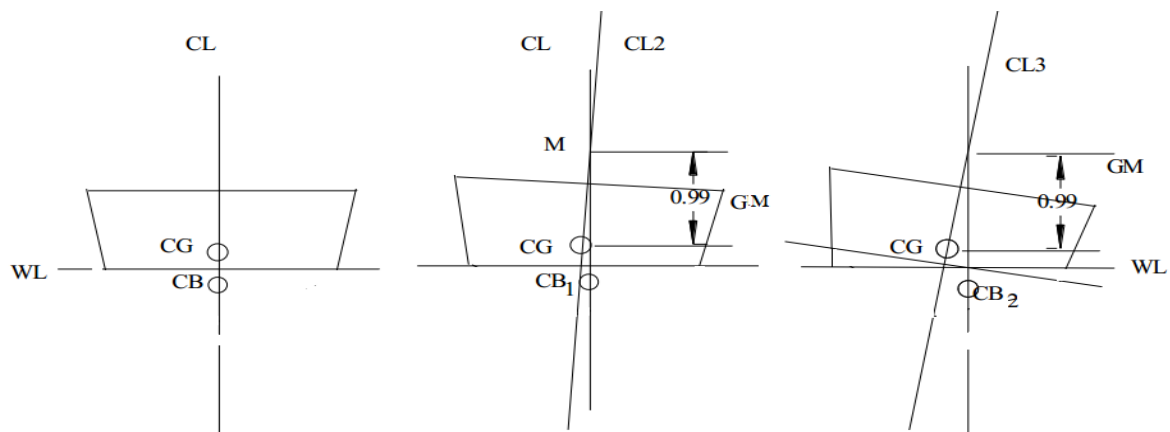


Figure 3-9: Detail of Geometry on water body

For different types of vessels, different meta centric heights are desired. For fully loaded “General cargo ships”, the typical meta centric height is 0.3 - 0.5 meters, for “Container ships” the value is 1.5 - 2 meters and for “Double-hull supertankers”, the meta centric height is 2 - 5 meters. The Meta centric height should never be less than 0.15 meters for any type of vessel [43].

Vessels Less Than 16 Meters Measured Length

The stability of a vessel less than 16 meters in measured length may be considered satisfactory if the meta centric height (GM) in the worst anticipated condition of loading is not less than 0.75 m, and the angle of deck edge immersion at the point of lowest freeboard is not less than 14° [45].

3.2.5.3 Wave Loading Impact

Motion of a ship defined with a right handed coordinate system with forward motion as the positive x- Direction and positive heave upwards. Waves incident on the structure or ship can be described as head seas, following seas, beam seas, or quartering seas depending on the incident direction. Figure illustrates the first three cases and quartering seas are defined as those that approach the ship from the either the port (left) or starboard (right) stern quarter of the ship (between 90° and 180° or 180° and 270°). Figure at left shows head, beam and following seas. The incident angle, μ , is measured from the bow (x-axis is $\mu = 0^\circ$) counterclockwise [46].

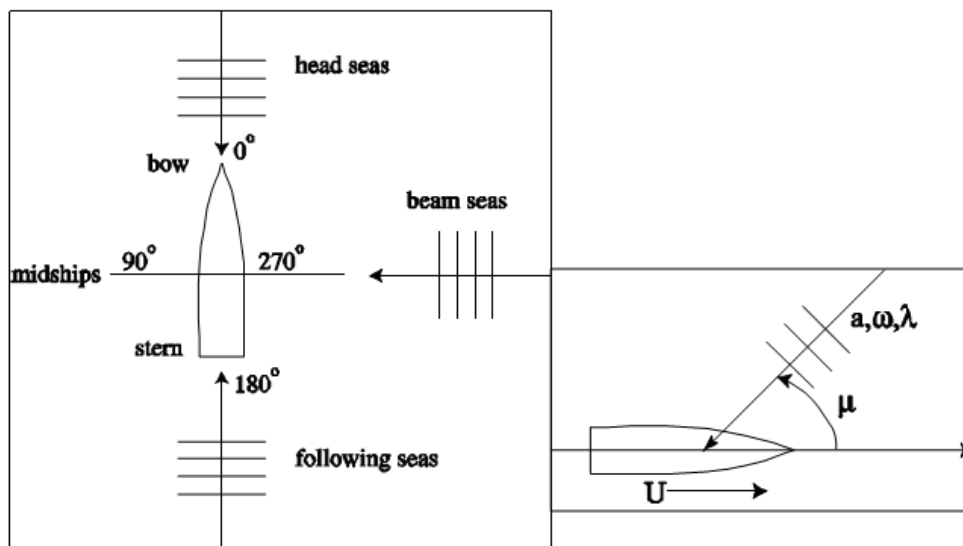


Figure 3-10: Incident sea description.

3.2.5.4 Computational domain definition

A large domain was created in order to avoid effects from the domain boundaries to affect the flow near the hull. Since only the dynamic sink age and trim angle were studied, a symmetry plane was defined along the longitudinal axis of the hull and only half the hull was included in the domain. In Figure 3-11, the computational domain is illustrated and its dimensions are expressed in terms of the overall hull length, LOA these dimensions agree well with the minimum recommendations of ITTC [44].

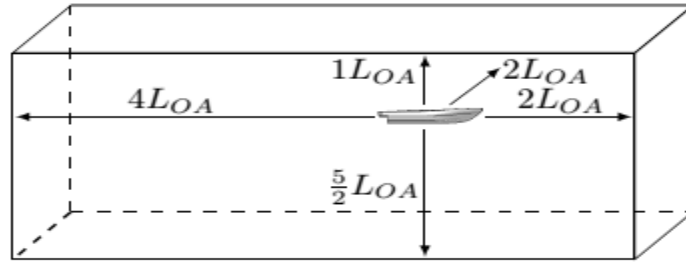


Figure 3-11: Minimum Consideration of dimensions for Analysis.

Therefore the minimum depth of the water should be $2.5 \times L_{OA}$ according to ITTC

$$\text{Depth} = 2.5 \times 7 = 17.5 \text{m.}$$

This is the minimum depth according to the design model the shallow water depth is up to 60m

Frequency of wave for shallow water is below 0.05 Hz [41].

3.2.5.5 Mathematical model for riverboat dynamics

The mathematical model of boat motion makes a few assumptions: (a) the boat is rigid body and oscillations are ignored, (b) the boat is symmetrical with respect to its x_B axis on Figure 3-12, (c) boat motion is restricted to two-dimensional motion only, and roll and pitch oscillations are ignored. Restrictions are possible because of the specific boat geometry, as they are much wider than conventional boats. As mentioned in the introduction, the foundation of the model is the square drag law [39].

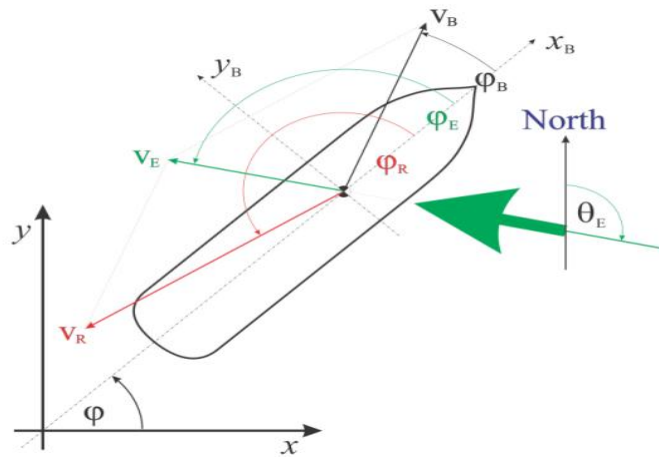


Figure 3-12: External forces with defined angles and relative direction in the boat (x_B, y_B).

3.2.5.6 Sailboat keels

The keel was also considered on this designed boat. In sailboats, keels use the forward motion of the boat to generate lift to counteract the leeward force of the wind. The rudimentary purpose of the keel is to convert the sideways motion of the wind when it is abeam into forward motion. A secondary purpose of the keel is to provide ballast. Keels are different from centerboards and other types of foils in that keels are made of heavy materials to provide ballast to stabilize the

boat. Keels may be fixed, or non-movable or they may retract to allow sailing in shallower waters. Retracting keels may pivot (a swing keel) or slide upwards to retract, and are usually retracted with a winch due to the weight of the ballast. Since the keel provides far more stability when lowered than when retracted (due to the greater moment arm involved), the amount of sail carried is generally reduced when sailing with the keel retracted [42].

Types of non-fixed keels include swing keels and canting keels. They provide considerably more righting moment as the keel moves out to the windward-side of the boat while using less weight. The horizontal distance from the weight to the pivot is increased, which generates a larger righting moment [42].

3.2.6 Set AQUWA Boundary Condition

1. Geometry was inserted from Catia V5 to ANSYS 16 Hydrodynamics. Then water plane line is set under this geometry options. The draught or height from surface to the underside of boat was labeled by using cut water plane area.
2. The model is transferred from geometric chamber to the model analysis chamber. On this,
 - The depth of water was set to according to the global co-ordinate systems. Depth of the water was estimated as 250m depth, this assumption is deep water.
 - On these processes of step the imported mass of structure was by using manual system, the radius of gyration must or Inertia value was used during importing the point mass.
 - wind and current coefficient data was set according to data read from Appendix II

Note: *wind and current force coefficient works under hydrodynamic response only.*

 - Mesh generation tools. The mesh used on this hull shape was Global Basic mesh type. The size which program controllable and the maximum element size was set to be 1m.

Diffeaturing: - If Global Controls set to Basic, a limited number of meshing options are available in the Details panel. The mesh is automatically generated on the bodies in the model; its density is based on the Diffearing tolerance and maximum element size parameters. The Diffearing Tolerance controls how small details are treated by the mesh. If the detail is smaller than this tolerance then a single element may span over it, otherwise the mesh size will be reduced in this area to ensure that the feature is meshed. The defeaturing tolerance cannot be greater than $0.6 \times \text{max element size}$. So diffeaturing tolerance was set to 0.5m.

Added Sizing mesh: - Adding a Mesh Sizing object enables the refinement of a mesh on a given part of the body by enabling a smaller element size to be associated to the geometry. It was set to 0.15m.

3. Wave Directions: - The Wave Directions tree object enables the definition of a range or single wave direction to use in the analysis. If Types set to Single Direction, Forward Speed, you can enter a structure Forward Speed and a Wave Direction. In this case, only a single wave direction can be analyzed. If Types set to Range of Directions, No Forward Speed, waves are automatically created in -180 and +180 directions, and either the Interval or the number of intermediate directions (No of Intermediate Directions) can be specified. If a direction range is of particular interest, additional ranges or specific directions can be added. On this analysis the range of direction was set to no forward speed.

- Number of intermediate frequency's set to 20.
- Number of intermediate Direction's set to 7.
- wave direction interval is set to standard 45^0
- wave grid size was set to 10

4. Hydrodynamic Pressures and Motions Results

The Pressures and Motions results object enables the visualization and display of a number of results generated from Aqua once a hydrodynamic solve has been performed. The Incident Wave Amplitude can be modified to provide results that are factored from the unit 1m wave that is the default; extreme modification may extend results beyond the capabilities of a linear analysis. And the response amplitude operator (RAO) also determine from simulations.

Simulations Trials:

The simulations trials were based on vertical center of gravity (CG) in [m] and Mass in [kg].

From first trial to final fifth trial, the mass was estimated as only structural mass except under fifth trial 2500kg mass was assumed as full load conditions.

Trial 1: m = 850kg, CG=1m

Trial 2: m = 850kg, CG=0.75m

Trial 3: m = 578kg, CG=1m

Trial 4: m = 578kg, CG=0.75m

Trial 5: m = 800kg, CG=0.5m

- This trial was the final trial test for analysis of boat hull
- Under this condition, full load is encountered at the same CG value which is estimated as.

Trail 6: m = 2500kg, CG=0.5m

Simulation in Shallow water was done; this simulation was done on from 17.5m to 100m in shallow water for visualization. This step is the final test of boat

5. Hydrodynamics time response was mapped to the system of hydrodynamic diffractions.

- wind speed was set according to the ITTC of Beaufort maximum 35m/s at wave height 15m

The direction of the wind was set to 45⁰

- Current speed also set ,from 0.5-3m/s at 45⁰
- One Irregular wave was inserted. It must be.

Finally all total response, animations, wind force, current force, even total force convergence in any direction also can be determined.

3.2.7 Set Boundary Conditions for ANSYS16 FLUENT CFD Simulation

The boundary conditions such as the type of solver, time, space, model of calculation, solution methods, number of iterations, and Other situational conditions such as the wind velocity, density, etc., based from according to the other related researches.

The models were used to simulate based on the wind speed of 35 m/s is expected to be the maximum reasonable wind speed for lake in the Ethiopia and other area of the world.

3.2.7.1 CFD Fluent Solver Type

There are two types of solvers Pressure-Based and Density-Based. Both solvers may be used for different types of flows but each can produce better results than the other. The solvers differ with how the continuity, momentum and energy equations are solved.

- Pressure-Based solver is mostly used for incompressible and mildly compressible flows.
- The Density-Based solver is designed for high-speed compressible flows. Both are now applicable to both incompressible and highly compressible flows.

The Density Based solver was chosen in the simulation since it has a feature which makes it more compatible for models with real gas.

- Mesh Used was relevance fine mesh and the others setting of meshes was default set.

a.Velocity Formulation

Velocity Formulation also has two types – Absolute and Relative. The Relative Velocity Formulation was chosen as it was for Density-Based solver. It is also preferred in applications where the flow in most of the space is moving or there are relative motions between two particles [36].

b.Time

For Time, the researcher used Steady state for the model to be tested was not time dependent.

c.3D Space

My simulation is based on three-dimensional space.

d.Gravity

Gravity was not considered in the simulation since its effects were seen to be negligible.

e.Units

The simulation used the metric system of measurement.

3.2.8 CFD Fluent Solution Setup – Models

In the model settings, only the Energy setting was turned on and the viscous model was set to be Standard k-epsilon. The Energy setting must be able to calculate the transformation of energy from air to the rotor. Meanwhile, Standard k-epsilon was chosen because of its practical precision for the wide range of turbulent flows which made it popular for industrial flow and heat transfer simulations [36].

3.2.8.1 Solution Setup – Materials

The materials chosen for the fluid were air as chosen from the Fluent Fluid Materials. The Air density property was set to be ideal gas. Whereas the material chosen from the Fluent Solid Material was, the solid rotor was set to be aluminum [36].

3.2.8.2 Solution Methods

Implicit formulation was used because the converged steady-state solution can be obtained much faster compared to the explicit formulation. However, the implicit formulation needs more memory than the explicit formulation. The remaining settings were left to be default [36].

3.3 Java Code Output Results

The table 3-5 below shows the collected data and some standard parameters value that was used to calculate the propulsion power.

Table 3-5: Estimated Results for Java input part I

Parametrs	Values
L_{OA} (over all length of the hul)	6m
<i>Draught</i>	0.365
V (speed of boat)	1
<i>Displacement</i> (∇)	2.5ton
Bottom corner fillet radius of the boat (assume)	0.15m
Length width ratio	3
Roof considering Height	2m
Standard temperature of the water at Babogaya lake	25°C
ITTC correction coefficient for U form aft body planning Hull	0.0001
Gravitational Accelerations	9.81m/s ²
Density of the water (sea water condition)	1025kg/m ³

Part I

*****INPUT RESULTS*****

enter over all length of the boat L_{OA} in m=6

enter overall length to width ratio of the boat from Standard of boat- 2.8-3.2 $L_{OA}W=3$

enter Draught of a midship in m=0.365

enter the maximum speed of the boat in m/s=1

enter the density of the water in kg/m³=1025

enter the temperature of the water in oC=25

enter the gravitational acceleration in m/s²=9.81

enter the Displacements in ton=2.5

enter the fillet radius of the hull on the waterline edge in m =0.15

enter frontal average area of the boat above water line in m²=6

enter the incrimental resistance coefficient for model=0.0004

enter the correction coefficient for boat hull geometry for U or V shape according to ITTC fro to
=-0.0001

*****OUTPUT RESULTS*****

Prismatic coefficient=0.8635994051147313

Slenderness ratio=5.1

Block coefficient=0.8144347814472409

Froud number=0.14137753599223746

partial Resistance coefficient=0.06130141069623286

*****Basic Dimensions of the hull*****

LoA=6.0

Lwl=5.1

Lpp=4.946999999999999

Width=2.0

Bwl=1.7

r=0.15

D=0.365

S=10.166901782705477

3.3.1 Residual coefficient

Read From appendix I; residual coefficient was determined according to the (ITTC 57) by depending on below table 3-6, three values calculated from java programming language of part I.

Table 3-6: Residual resistance coefficient Parameters value

$Fn = V / (gL_{wl})^{0.5} = 0.141$
$L/\nabla^{1/3} = 6/1.5^{1/3} = 5.1$
$C_p = 0.814$
$C_R = 0.001$

Part II Java Code Input

Propulsion Power: it is the power needed from the propeller motor to propel the boat. Inserting some result calculated in part I java code into Part II

Table 3-7: Input Results For Part II Java

Parameters	Values
Block coefficient	0.81
Water line length	5.1m
Waterline breadth	1.7m
Design Draught	0.365m
Form Factor for U Planning Hull (ITTC recommended)	-2
Propeller diameter (from the appendix of propeller selections range is 6-14inches for small boat)	0.35m
Residual resistance coefficient	0.001
Partial resistance coefficient	0.061
Wetted Surface Area	10.16m ²
Service Allowance on water	35%
Relative rotating efficiency for propeller (no gear box) (assumption)	1
Shaft efficiency from 0.96-0.97 (including gearbox) (assumption)	0.96

enter the Block coefficients=0.81

enter the water line length in m=5.1

enter the waterline breadth in m=1.7

enter the maximum draught in m=0.365

enter the the value of form factor Fa from [-2,2]=-2

enter the disk diameter=0.35

enter the Maximum speed of the boat=1

enter the partial resistance coefficient=0.0614

enter the Residual resistance coefficient=0.001

enter the wetted surfaces Area=10.166

```

enter the density of water=1025

enter the service Allowance water in %=35

enter the relative rotating efficiency from 0.95-1.05 =0.97

enter the shaft efficiency from 0.96-0.97 including gearbox=0.96

*****OUTPUT RESULT*****

E=0.12224632954713958

Propeler power=3590.2649971241585

VA=0.6836833638217815

CTh=24.394793124957577

Eh=0.8461878267290259

BUILD SUCCESSFUL (total time: 1 minute 54 seconds)

```

From the results of above java code part II programs the calculated propulsion power is 3.6kw, Hull Efficiency 84%, Overall Efficiency 12%, Thrust load Coefficients 24, Propeller speed 0.68m/s. So for the selection of propeller size the power needed from propeller must be not less than 3.59kw.

3.4 Propeller size

Compact form of propeller is selected. The propulsion power is according to the calculation of java programming code which it gives 4kw or 5Hp it read from Appendix II. The two 12v Lead Battery is also considered with this type of propeller.

3.5 Recommended size of wind Turbine

How to calculate necessary power for the expected wind turbine wind

Assumption

$$h=2.4m$$

$$D=1.2m$$

Basic equations: -The maximum power of the rotor is estimated according to Betz's law

$$\frac{1}{2} \rho \times A \times V^3 \times C_p \quad [17] \quad \dots\dots\dots \text{Equation 3-26}$$

$$A=h \cdot D \quad [17] \dots\dots\dots \text{Equation 3-27}$$

$$\rho = 1.225 \text{ kg/m}^3$$

Where: V is the speed of the wind

ρ is the air density, A is the sweep area of the rotor blade is the height of the blade, D is blade diameter and $C_p=0.64$ the Betz coefficient. However, there are aerodynamic and mechanical losses in the order of 50% means $C_p=0.3$. Then our rotor shaft power equation becomes [17].

$$P_s = 0.18 \times h \times D \times V^3 [\text{W}] \quad [17] \dots \dots \dots \text{Equation 3-28}$$

Shaft power of the rotor for the design the value of speed is taken as bellow table 4-2:

Table 3-8: Speed and produced power

V(m/s)	Ps(W)	Turbine Quantity (2)(w)
6	111.9744	223.9488
8	265.4208	530.8416
10	518.4	1036.8
12	895.7952	1791.5904
14	1422.4896	2844.9792
16	2123.3664	4246.7328
18	3023.3088	6046.6176
20	4147.2	8294.4
22	5519.9232	11039.8464
24	7166.3616	14332.7232
26	9111.3984	18222.7968
28	11379.9168	22759.8336
30	13996.8	27993.6

From above table of 3-8 speed vs. power is tabulated for single and two turbines. As the speed of the wind increases the rotor produced power also increases. By depending on the tabulated data figure 3-13 shows the performance curve of the turbine.

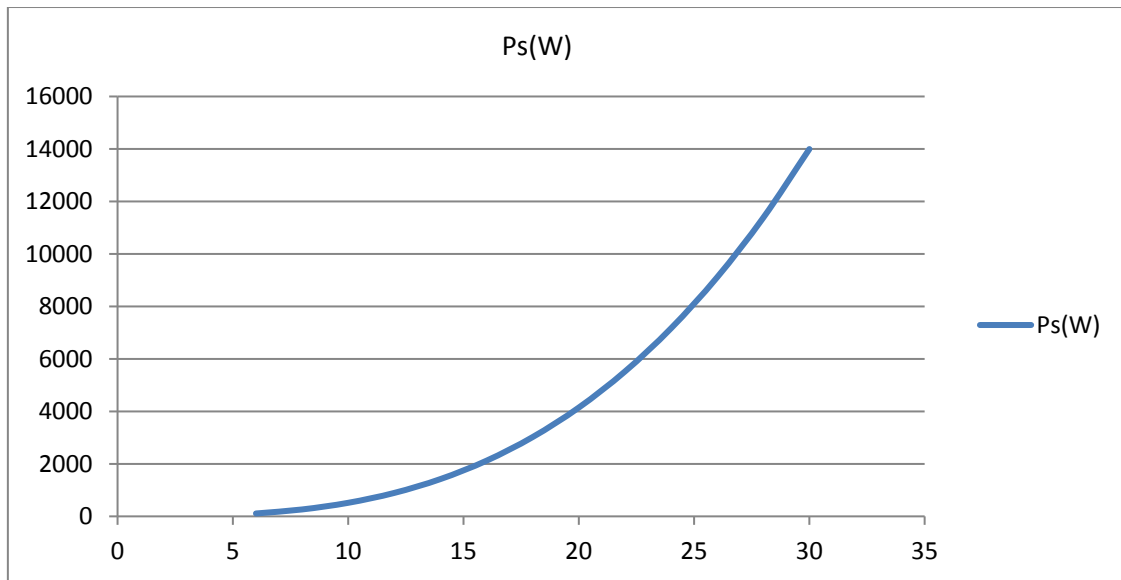


Figure 3-13: Performance for single Turbine

Above Figure 3-13 describes the curve of speed vs. power produced by the rotor. As speed increase arithmetic progression but rotor power increases geometrical progressions form, means the power immediately increase with small change of speed value.

3.6 Generator Size

The generator size was based from the Mechanical power produced by the rotor. Since the P_{mech} of the selected configuration was about up to 10714W at wind speed of 18m/s considering mechanical efficiency of the gear and bearing 96% the recommended generator size was a DC115, 3000W at $C_p=0.28$ generator with a rated rpm of 300 rpm. For two turbines two generators were used.

3.6.1 3D Model of Boat using Via Catia

Models were created in the program, Catia 3D model. A total of 3 models were created by combining the following parameters in the configuration of the boat;

Two wind Turbines, roof, side considering plate for determine total wind effect on the all structures, Keel to increase the stability of the boat. The hull was created according to the dimension given on the table 3-9.

When we do hydrodynamic diffraction system on ANSYS 16, firstly when the geometry is inserted to the mesh chamber the set up needs Inertia or radius of gyration values. Therefore it is better to determine at least one result from two cases. On this research the decided or recommended value of I and k is simply determined from CATIA 3D modeling this is after the boat modeling is finished. The figure 3-14: shows how to determine the inertia value of the first model. Simply by selecting the geometry and clicking on inertia mass tool.

Table 3-9: Basic Dimensional parameters of the boat

Dimensional parameter of the boat	Unit in (m)
Overall Length(L_{OA})(Assumption)	6
Water line length(L_{WL})	5.1
Breadth(B)	2
Breadth on water line(B_{WL})	1.7
Maximum draught(D_{Max})(Assumption)	0.365

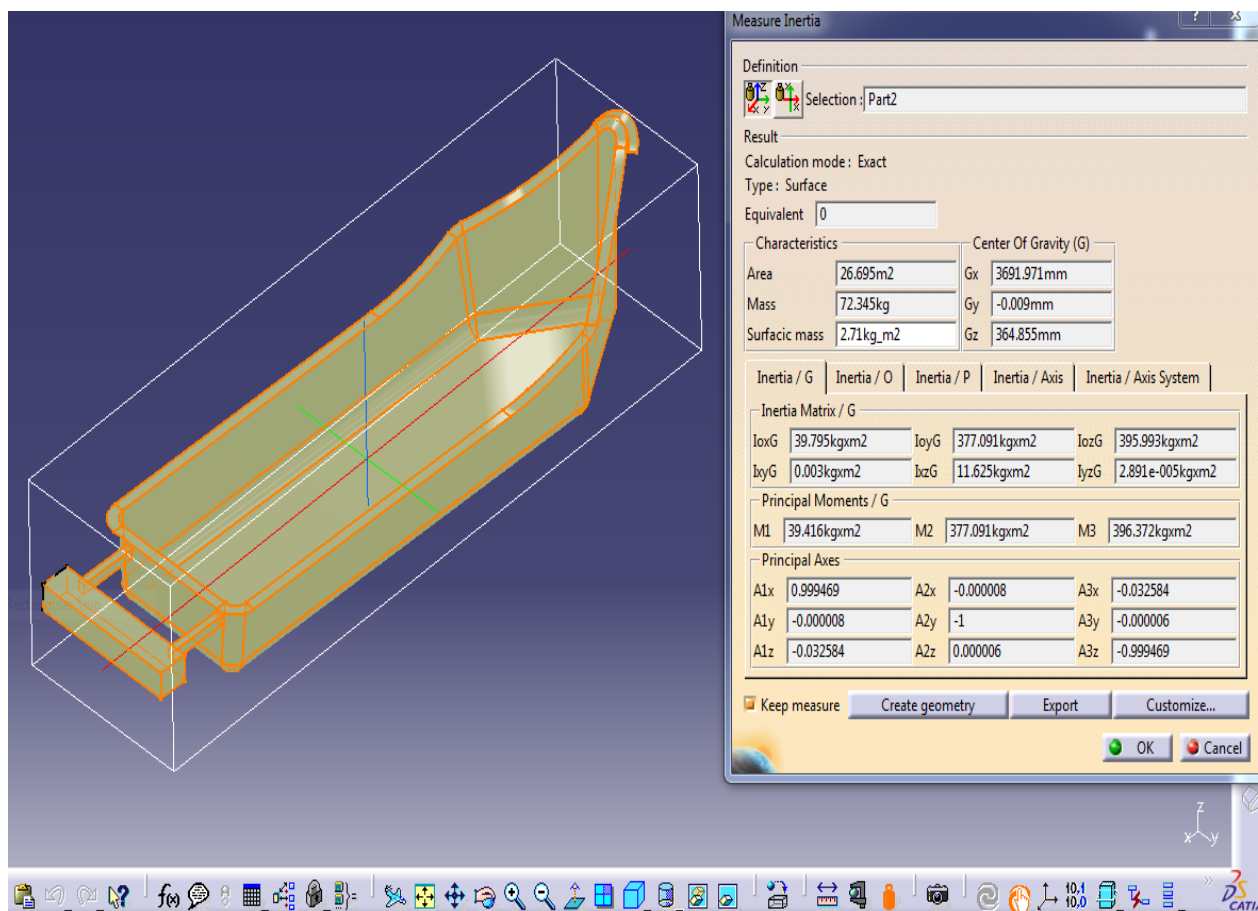


Figure 3-14: Boat Hull 3D Model

3.6.2 Calculation of Mass Moment of Inertia and radius of gyrations

It has been established since long that a rigid body is composed of small particles. If the mass of every particle of a body is multiplied by the square of its perpendicular distance from a fixed line, then the sum of these quantities (for the whole body) is known as mass moment of inertia of the body. It is denoted by I . Consider a body of total mass m . Let it be composed of small particles of

masses m_1, m_2, m_3, m_4 , etc. If k_1, k_2, k_3, k_4 , etc., are the distances from a fixed line, as shown in Figure 3-15, then the mass moment of inertia of the whole body is given by [39]

$$I = m_1 (k_1)^2 + m_2 (k_2)^2 + m_3 (k_3)^2 + m_4 (k_4)^2$$

If the total mass of a body may be assumed to concentrate at one point (known as center of mass or center of gravity), at a distance k from the given axis, such that

$$mk^2 = m_1(k_1)^2 + m_2(k_2)^2 + m_3(k_3)^2 + m_4(k_4)^2 \quad [37] \dots \dots \dots \text{Equation 3-29}$$

then $I = m k^2$

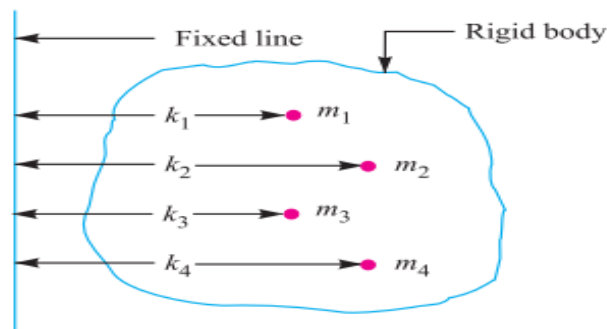


Figure 3-15: Mass moment of inertia.

$$k_{xx} = \sqrt{\frac{I_{xx}}{m}} = \sqrt{\frac{39.795}{72.345}} = 0.74m$$

$$k_{zz} = \sqrt{\frac{I_{zz}}{m}} = \sqrt{\frac{395.993}{72.345}} = 2.074m$$

$$k_{yy} = \sqrt{\frac{I_{yy}}{m}} = \sqrt{\frac{377.091}{72.345}} = 2.283m$$

Where: k -called the radius of gyration

I_{xx} - the mass moment of inertia about x axis.

I_{yy} - mass moment of inertia about y axis,

CHAPTER FOUR

4 RESULTS AND DISCUSSION

This Portion describes the discussions of results that determined from the software.

4.1 Simulation Result from ANSYS AQUA

➤ Imported geometry

Figure 4-1 below shows the imported drawing to the ANSYS hydrodynamics

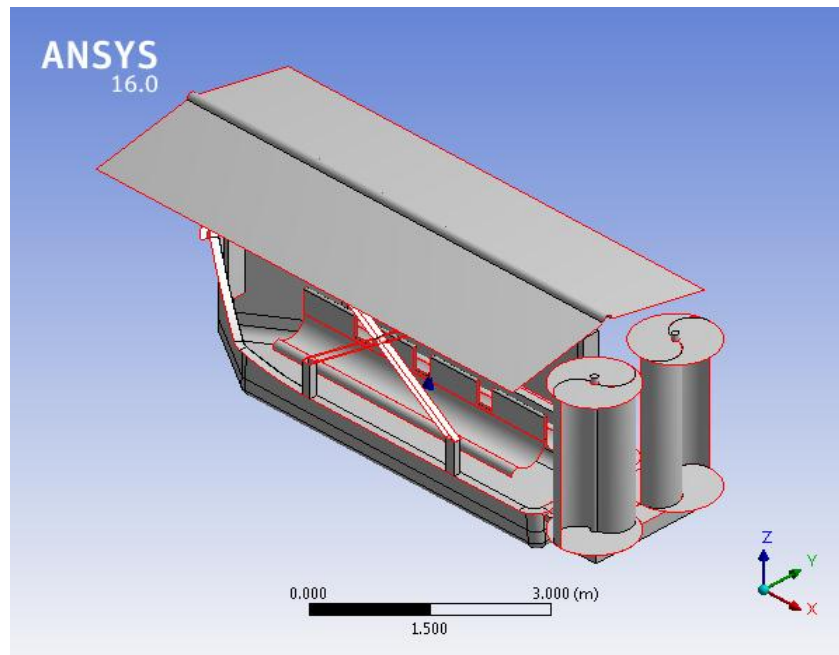


Figure 4-1: complete geometry imported to the ANSYS Aqua

4.1.1 Mesh generated:

The mesh Generated on this model is Basic geometric mesh from hydrodynamics tool bars.

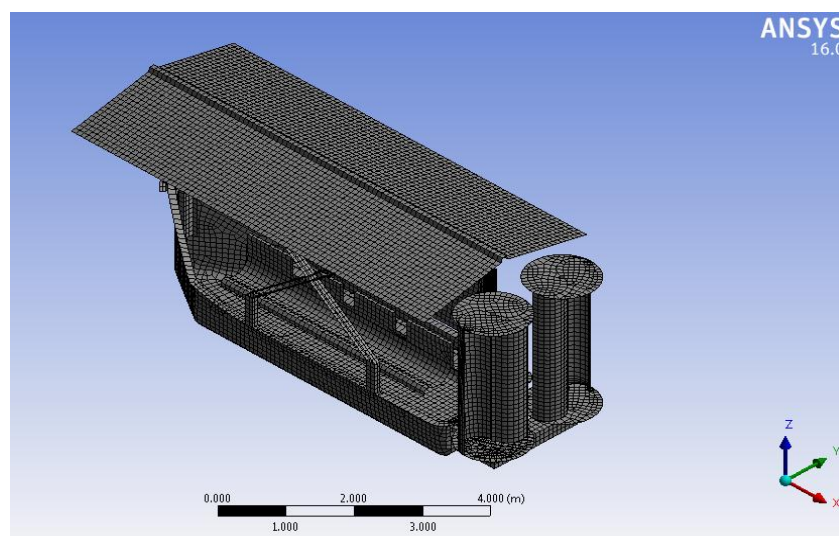


Figure 4-2: Mesh Generated on the Geometry

4.1.1.1 Simulations for Different Trials

Trial 1

$m_{st} = 850\text{kg}$, $CG = 1\text{m}$, where m_{st} is structural mass, CG is vertical center of gravity.

Table 4-1: Hydrostatic Results

Structure		BOAT			
Hydrostatic Displacement Properties					
Actual Volumetric Displacement:		-3.34062m³			
Equivalent Volumetric Displacement:		0.82926m³			
Centre of Buoyancy (CoB) Position:	X:	3.57380m	Y:	-6.97e-5 m	Z: -0.169454m
Cut Water Plane Area:		-9.99833 m²			
Centre of Floatation:	X:	3.57781m	Y:	5.86e-6 m	
CoG to CoB (BG):		1.16945m			
Metacentric Heights (GMX/GMY):		7.44316 m		-0.472748m	
CoB to Metacentric (BMX/BMY):		8.612620m		0.69670 m	

Trial 2

$m_{st} = 850\text{kg}$, $CG = 0.75\text{m}$

Table 4-2: Hydrostatic Results

Structure		BOAT			
Hydrostatic Displacement Properties					
Actual Volumetric Displacement:		-3.362 m³			
Equivalent Volumetric Displacement:		0.8296 m³			
Centre of Buoyancy (CoB) Position:	X:	3.5734 m	Y:	-6.9779e-5 m	Z: -0.1694 m

Cut Water Plane Area:		-9.9989 m ²				
CoG to CoB (BG):		0.919 m				
Metacentric Heights (GMX/GMY):		7.6933 m		-0.222 m		
CoB to Metacenter (BMX/BMY):		8.6124 m		0.696 m		

Trial 3

$m_{st} = 578\text{kg}$, $CG = 1\text{ m}$, where m_{st} is structural mass

Table 4-3: Hydrostatic Result

Structure		BOAT				
Actual Volumetric Displacement:		-3.3406 m ³				
Equivalent Volumetric Displacement:		0.5634 m ³				
Centre of Buoyancy (CoB) Position:	X:	3.5734 m	Y:	-6.97e-5 m	Z:	-0.1694 m
Cut Water Plane Area:		-9.9 m ²				
Centre of Floata-tion:	X:	3.57781m	Y:	5.8e-6 m		
Angle Principal Axis makes with X(FRA):		89.999°				
CoG to CoB (BG):		1.16945m				
Metacentric Heights (GMX/GMY):		7.44316m		-0.4727 m		
CoB to Metacen-tric (BMX/BMY):		8.6104 m		0.699 m		

Trial 4

$m_{st} = 578\text{kg}$, $CG = 0.75\text{m}$

Table 4-4: Hydrostatic Results

Hydrostatic Displacement Properties						
Actual Volumetric Displacement:		-3.3406m³				
Equivalent Volumetric Displacement:		0.56390m³				
Centre of Buoyancy (CoB) Position:	X:	3.5738 m	Y:	-6.977e-5 m	Z:	-0.1691 m
Water Plane Area:		-9.99833m²				
Distance to CoB (BG):		0.9194561m				
Metacentric Heights (GMX/GMY):		7.6931643m		-0.222m		
Distance to Metacentre (BMX/BMY):		8.61204m		0.696m		

Trial 5

m = 800kg CG = 0.5m

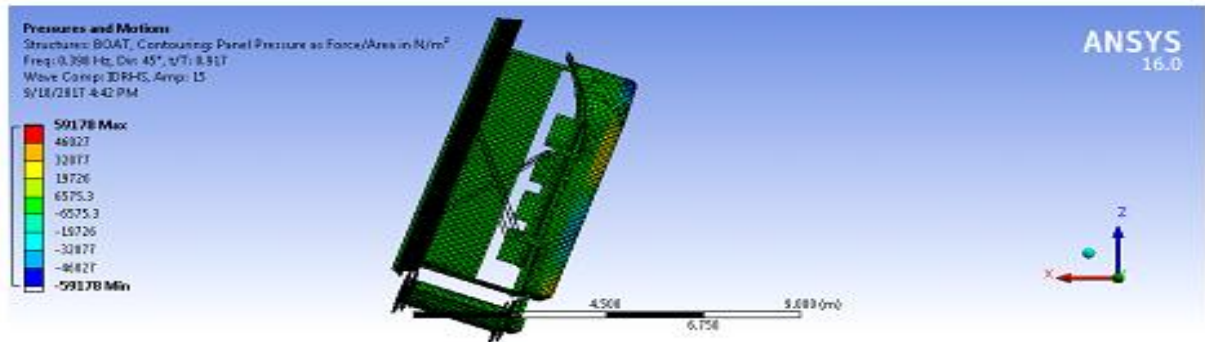
Table 4-5: Hydrostatic Results

Structure		BOAT				
Actual Volumetric Displacement:		-3.34063m³				
Equivalent Volumetric Displacement:		0.78048 m³				
Centre of Buoyancy (CoB) Position:	X:	3.573803m	Y:	-6.97e-5 m	Z:	-0.1694 m
Cut Water Plane Area:		-9.99833 m²				
CoG to CoB (BG):		0.66945 m				
Metacentric Heights (GMX/GMY):		7.948 m		2.71e-2 m		
CoB to Metacentre (BMX/BMY):		8.61204 m		0.6967 m		

As a standard of the boat below 16m length, metacentric height must greater than 0.75m. From above all five tables the result of metacentric height was very satisfied when it compared with minimum consideration of metacentric height. But it needs to know the wave loading impact on different mass of the boat.

From above Five tables of hydrostatic results the metacentric height is no more depended on the weight. This means it depends on the center of gravity position; as center of gravity moved down the metacentric height of the system increased. But for hydrodynamic wave impact loading there is the great disturbance for small mass as compared with large mass at the same center of gravity. The figure 4-3 bellow shows the detail.

At $m=850\text{kg}$, $\text{CG}=1\text{m}$



At $m=578\text{kg}$, $\text{CG}=1\text{m}$

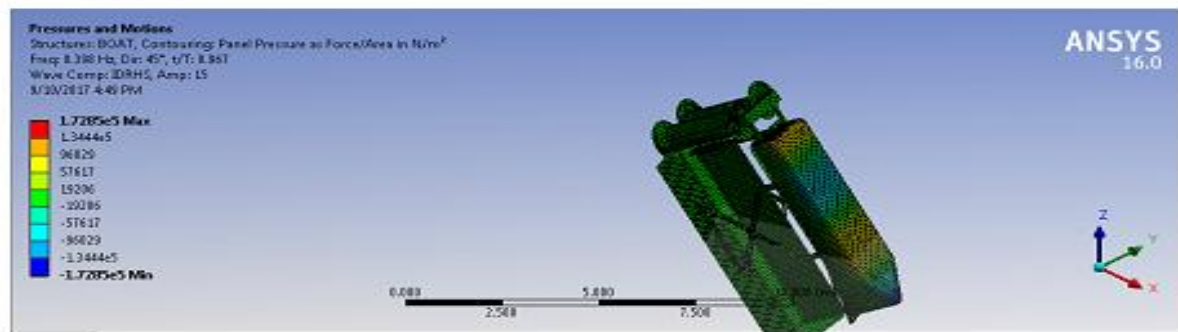


Figure 4-3: Pressure and Motion of Wave impact loading for different mass

Discussion: For 0.5m CG it was difficult to move down all structural mass. Because the design also considered upper structural mass and mass of the hull it also considered to overcome the wave load and wind. Also as much as possible to match CG Value for Simulation 0.5m with the catia model the keel mass is added. Keel also has a great advantage to move down CG value in addition to the other advantages.

Hydrodynamic response Analysis

Dynamic Stability Test

When we apply Dynamic Stability test wind and current force coefficient must be considered to the system in addition to wave loading.

Table 4-6: Boat Wind and Current Load coefficient

The data is read from appendix V

At 0°

Coefficients	Moment(yaw)Coefficient	C _D	C _S
Wind	0	0.25	0
Current	0	0.15	0

At 75°

Coefficients	Moment(yaw)Coefficient	C _D	C _S
Wind	0.25	1.75	1.6
Current	0.35	1.65	2.5

At 100°

Coefficients	Moment(yaw)Coefficient	C _D	C _S
Wind	-0.18	-0.25	0.85
Current	-0.18	-1	2.6

At 180°

Coefficients	Moment(yaw)Coefficient	C _D	C _S
Wind	0.01	-0.2	0.2
Current	-0.25	0.01	-2.6

This result can be imported in to the ANSYS for Hydrodynamic response Analysis and Stability. The result will be inserted as Newton per (meter/sec)². Therefore rearranged formula was written as,

$$\frac{F}{V^2} = C \frac{1}{2} \rho A \quad [41] \quad \dots\dots\dots \text{Equation 4-1}$$

Where:

A -Average Projected area from which the wind applied or current applied.

C -current or wind coefficient in dimensionless from above table.

ρ - Density of water or wind.

Table 4-7: Standard value and estimated value from model

Standard values of density	
Density of air	1.225kg/m ³
Density of water	1025kg/m ³
Estimated Area Value From Model	
Frontal Area above water surface	6m ²
Side Area above water surface	18m ²
Frontal Area bellow water surface	0.6m ²
Side Area below water surface	2.1m ²

The result become

at 0°

Coefficients	Moment(yaw)Coefficient	C _D	C _S
Wind	0	0.918	0
Current	0	45	0

at 75°

Coefficients	Moment(yaw)Coefficient	C _D	C _S
Wind	2.758	6.43	17.64
Current	367	495	750

at 100°

Coefficients	Moment(yaw)Coefficient	C _D	C _S
Wind	-1.989	-0.915	9.37
Current	-189	-300	2730

at 180°

Coefficients	Moment(yaw)Coefficient	C _D	C _S
Wind	0.11	-0.735	2.205
Current	-2250	3	-23400

m = 850kg, CG=0.75m

Table 4-8: Hydrodynamic Graph Results

Structure	BOAT
Type	Structure Forces
Subtype	Wind Only
Component	Global Y
Position of Min in X	263
Position of Max in X	2126
Minimum Value	798.152N
Maximum Value	15220.802N

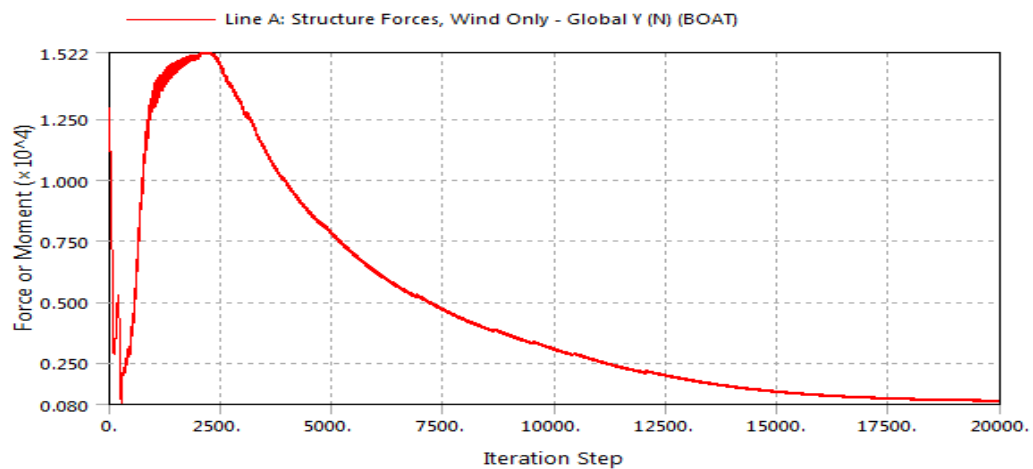


Figure 4-4: Structure Forces in N, Wind Only

From the above figure 4-4, graph of wind only force during simulations then maximum value of the wind force applied on the side of the boat is 15220.8N at the iterations number of 2126 and the position of minimum value 789N is 263. But the convergence above 2000atetration is going to be the force.

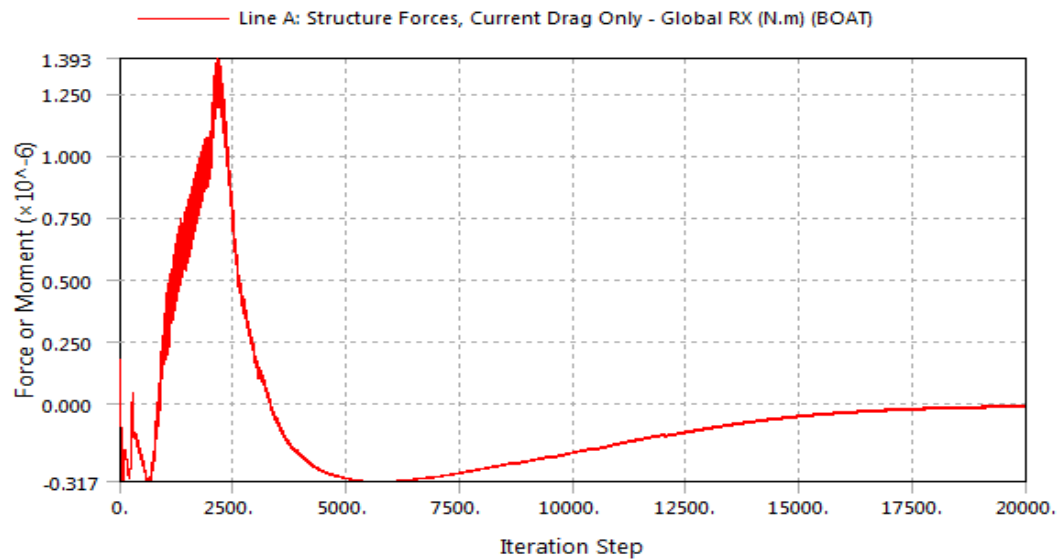


Figure 4-5: Graph of Rolling in X axis of Current Drag Only in N.m

The above figure 4-5 shows rolling momentum about x axis of Current Drag only the characteristics of the graph is the same as the above figure of 4-4. The rolling effect created by current is almost negligible as described on the above graph of current load only.

Table 4-9: Hydrostatic only

Type	Structure Forces
Subtype	Hydrostatic Only
Component	Global X
Position of Min in X	3443
Position of Max in X	286
Minimum Value	-6579.478
Maximum Value	4676.807

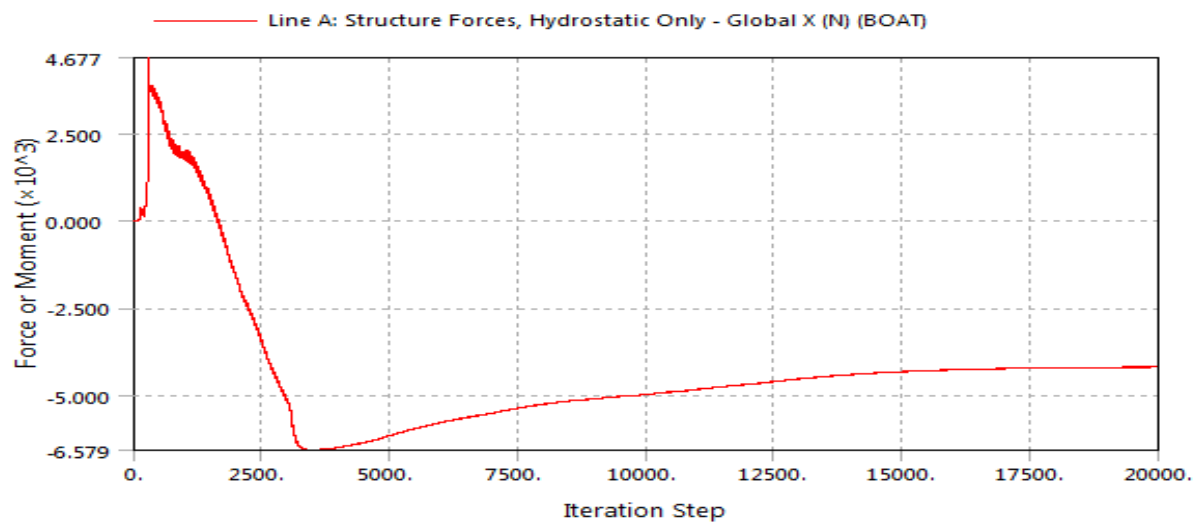


Figure 4-6: Hydrostatic Only

On the above figure 4-6 we can understand that the total hydrostatic only force described. The maximum force applied 4676N at 3443 iteration's in global x axis at. This value simply can be assumed as the maximum resistance force of water applied on the boat. But it converged to the minimum value -6975N at 20000 iteration.

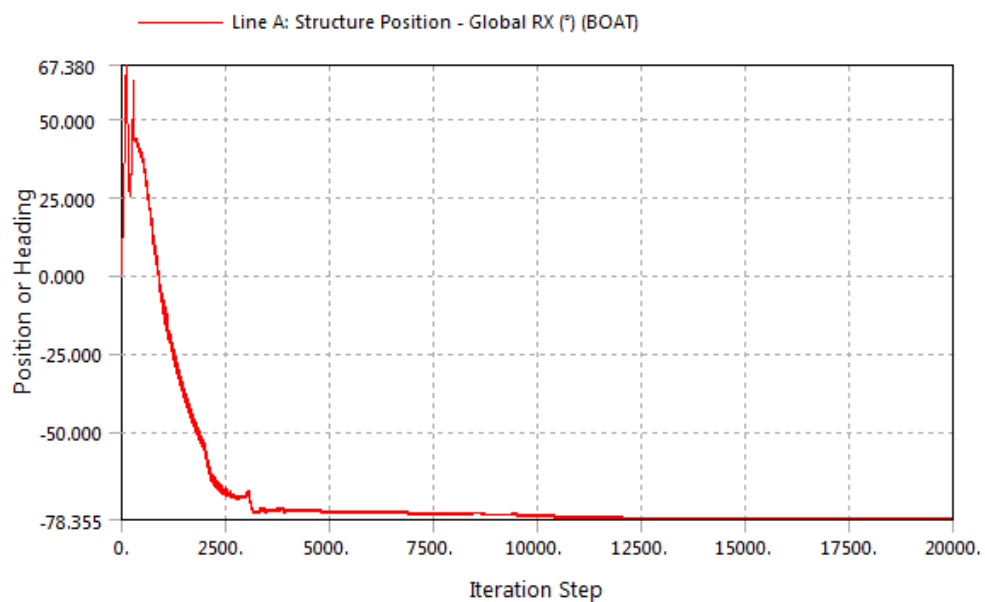


Figure 4-7: Graph of Structure Position, Actual Response

On the above graph of the hydrodynamic response the maximum heeling angle about x axis is 67.38° this angle is very large means the boat roll about x axis more and more so it is not comfortable during recreational . Therefore the boat needs modification of mass and CG value.

Total Structural Force

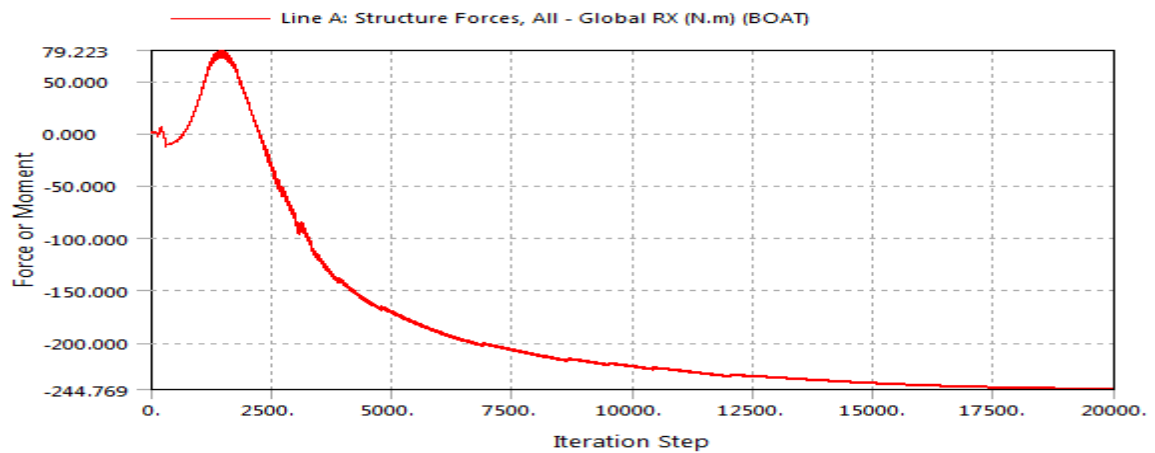


Figure 4-8: Structure Forces Moment, All about X axis

As On the Figure 4-8 shows the total rolling moment about global x axis was described. The rolling effect is almost converged in to zero. But the maximum rolling moment as shown on the above graph is 79.22N.m

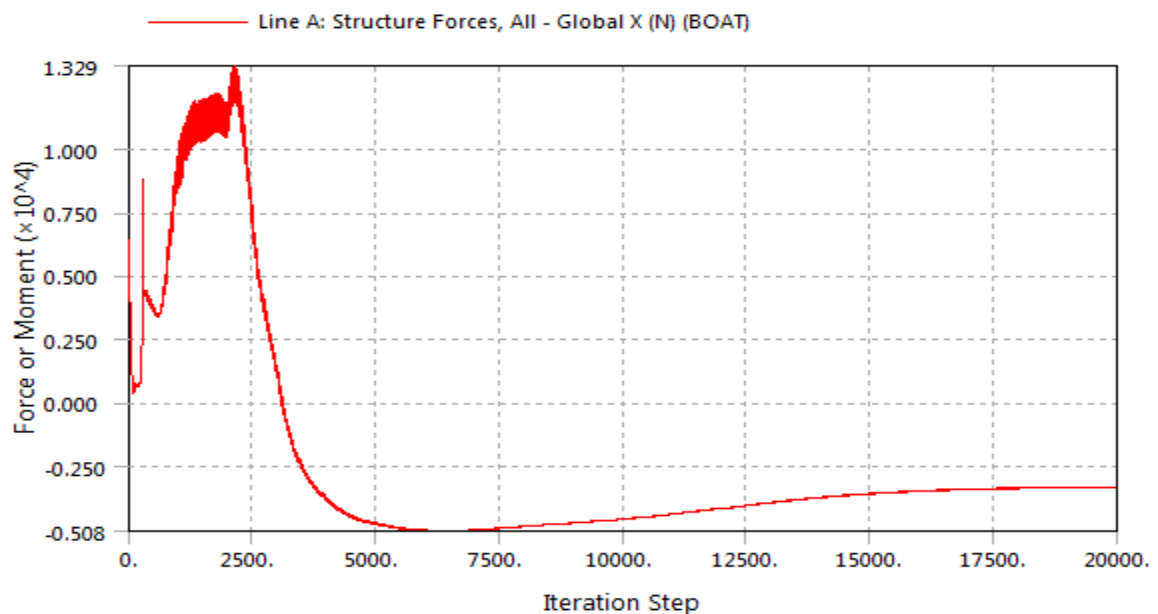


Figure 4-9: Graph of Structure Forces, All about x axis

Above Figure 4-9 shows all force on the structure that the maximum value is about 13290N. The converged value is estimated as -3125N. This value is determined from the above graph.

at $m = 800\text{kg}$, $CG=0.5\text{m}$

The final Stability of the boat give the following response after the wind load and current load applied in addition to wave loading.

Table 4-10: Structure Position, Actual Response

Subtype	Actual Response
Component	Global RX($^{\circ}$)
Position of Min in X	366
Position of Max in X	6570
Minimum Value	-8.989
Maximum Value	0.971

This result of heeling angle is very small as it compared with the previous of graph of value 67° , this reduction make the boat more comfortable for recreational persons due to no more disturbance.

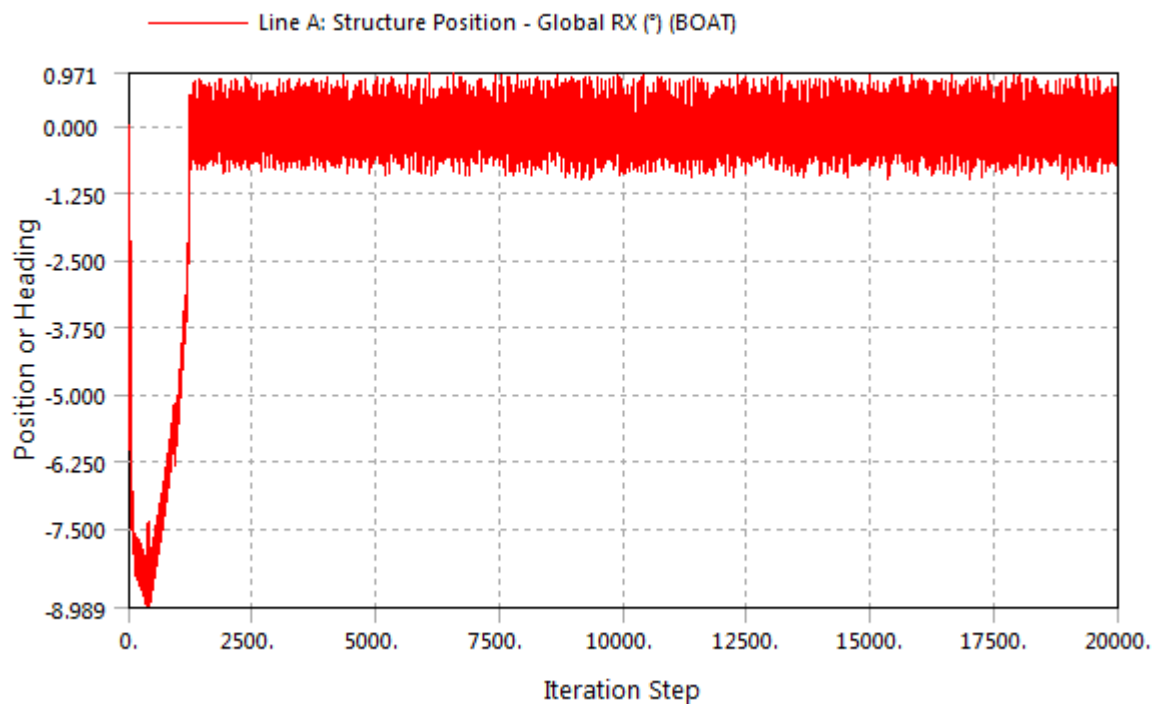


Figure 4-10: Structure Positions Graph for final Trial

Table 4-11: Structure Forces, All

Subtype	All
Component	Global RX
Position of Min in X	13
Position of Max in X	19566
Minimum Value	-0.658
Maximum Value	27.365

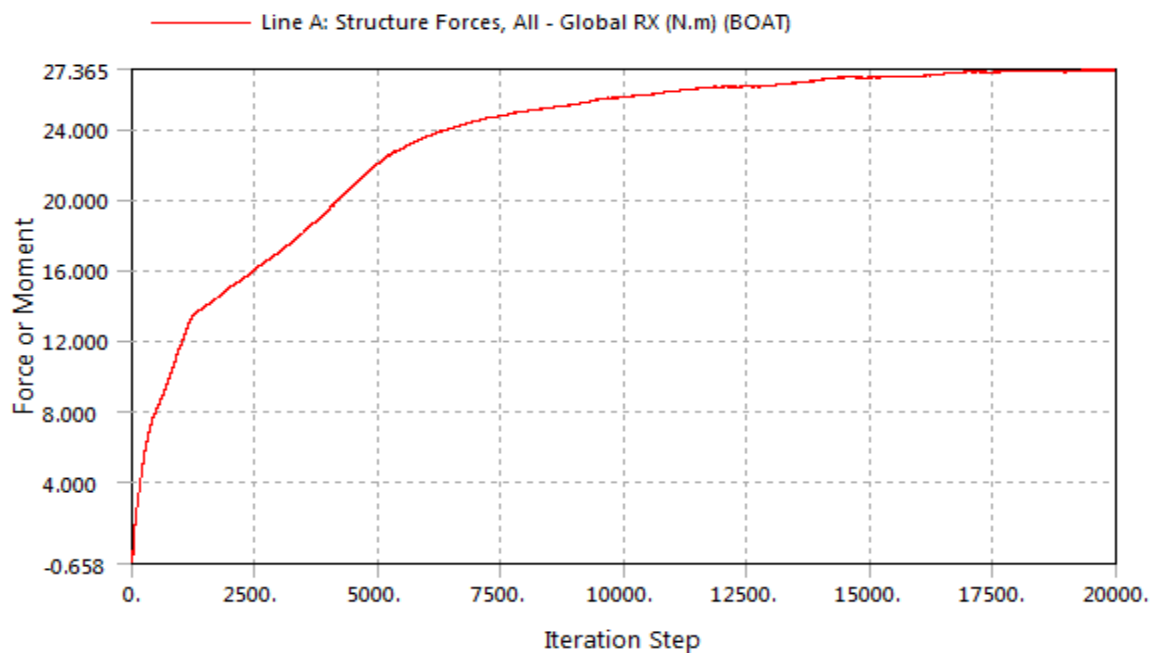


Figure 4-11: Graph of Structure Forces moment about X axis, All

Comparing the result with the previous 850kg, CG=0.75m of moment 79.2Nm, the above result of moment 27.3 is small when it is compared with that of CG=0.75m. From all trials this best trial of test.

Therefore the response of final tested boat is realizable when compared with previous results. Even if the result from the test was very satisfied I have also tried to reduce upper structural height to overcome the load applied by wind from the side of the boat.

From this table below we can understand that the value of total hydrostatic moment of force is almost the same as total moment from figure 4-11. This means the rolling moment created by current and wind are negligible.

Table 4-12: Structure Forces, Hydrostatic Only

Type	Structure Forces
Subtype	Hydrostatic Only
Component	Global RX
Position of Min in X	13
Position of Max in X	19566
Minimum Value	-0.658
Maximum Value	27.365

4.1.1.2 Simulations for Full Load Conditions Boat Hydrodynamics

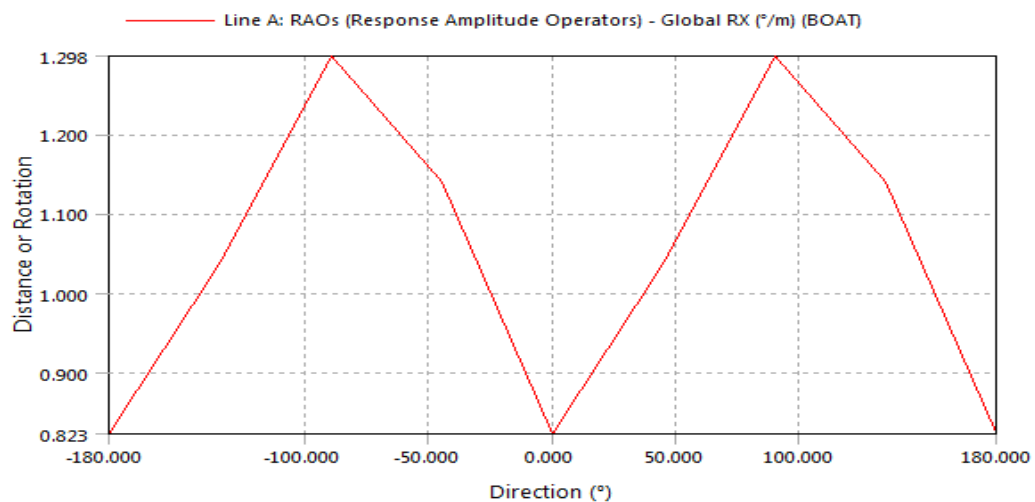


Figure 4-12: Graph of Response Amplitude Operator Rotation or angle

We know that the heel angle due to hydrodynamic diffraction and wave was 1.839^0 on the previous of mass 800kg,CG=0.5,but at the full load of 2500kg no more heel angle or 1.298^0 due to hydrodynamic diffractions.

4.1.1.2.1 Hydrodynamic response After Wind and Current Applied on the Structure at Full load

Table 4-13: wind only force

Subtype	Wind Only
Component	Global Y
Position of Min in X	19915

Position of Max in X	0.0
Minimum Value	4337.572
Maximum Value	12965.403

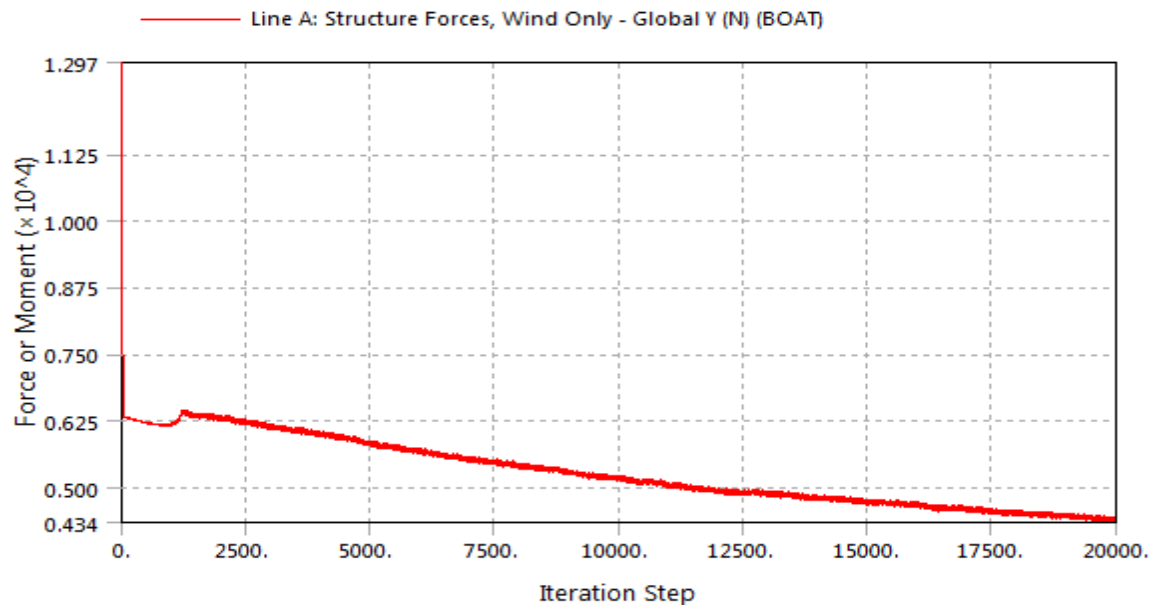


Figure 4-13: The wind Force About y axis

On the above figure of wind only force on global y axis maximum is 12965N when it compared with the previous of 15220N. The wind force applied on the structure was reduced by 2255N. This was due to the draught increase when mass increased. Therefore the wind load applied on the structure is reduced.

4.2 Material Recommendation for Static Structural Analysis

Aluminum was selected as the blade and Boat hull material versus steel because of weight issues. As the surface area of the rotor was computed, the mass of the rotor was calculated. It was noted that the mass of the rotor if it would be made out of steel was almost 2 times if it were made of aluminum. Thus, it was decided that for the purpose of this research, it would be more beneficial to use and recommend Aluminum as the blade and Boat hull material. AISI 1045 Steel was selected as the shaft material as based from research, it is commonly used for shafting. Aluminum was considered because of weight reasons, but was not selected due to its lower yield strength which would require a bigger diameter of the shaft. Thus, AISI 1045 Steel was recommended as the shaft material.

4.3 Calculation for Static Structural analysis of Boat hull geometry

4.3.1 Materials Data

Aluminum Alloy

Aluminum alloys used by the marine industry have high mechanical properties and a good resistance to corrosion. They are produced in a wide variety of sheets and plates of different thickness, and extrusions of various shapes. After 100 years in existence, the possibilities in aluminum boat building guarantee new developments in the years to come.

The 6061T6 alloy, widely used for extruded shapes such as sailboat masts.

Table 4-14: Aluminum Alloy Constants used for sailboat

Density	2770 kg m ⁻³
Coefficient of Thermal Expansion	2.3e-005 C ⁻¹
Specific Heat	875 J kg ⁻¹ C ⁻¹

Table 4-15: Aluminum Alloy Strength properties

Compressive Yield Strength Pa	Tensile Yield Strength Pa	Tensile Ultimate Strength Pa
2.8e+008	2.8e+008	3.1e+008

For the simulations of static structural analysis the load used to analyse the structure is simple from hydrodynamic pressure and motion results as shown on figure 4-14 .The simulation was taken from the final trials of M=800kg;CG=0.5m.

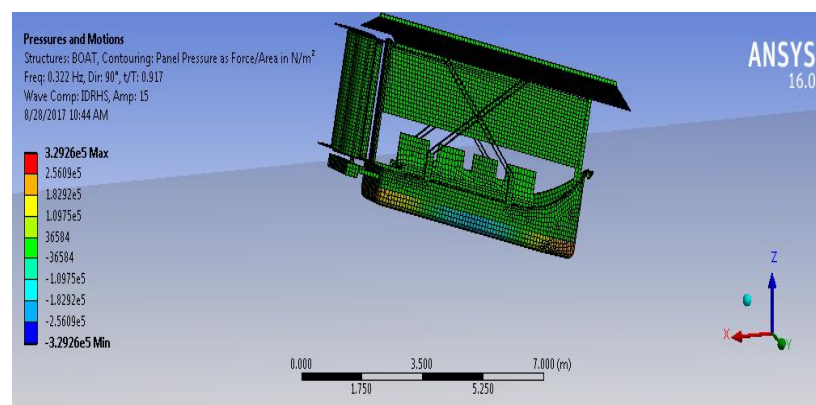


Figure 4-14: Pressure and motion for selected Final trial

The selected body is only the hull geometry for the static structural analysis. Maximum pressure is imported to the static structural analysis module from hydrodynamic diffraction as the simulated on above figure.

- i. On this the first simulations of static structural analysis, assumption of boat hull thickness was set to 3mm and the mesh considered for hull geometry is fine and the calculated results on figure 4-15 shows the equivalent (von miss stress) and maximum principal stress.

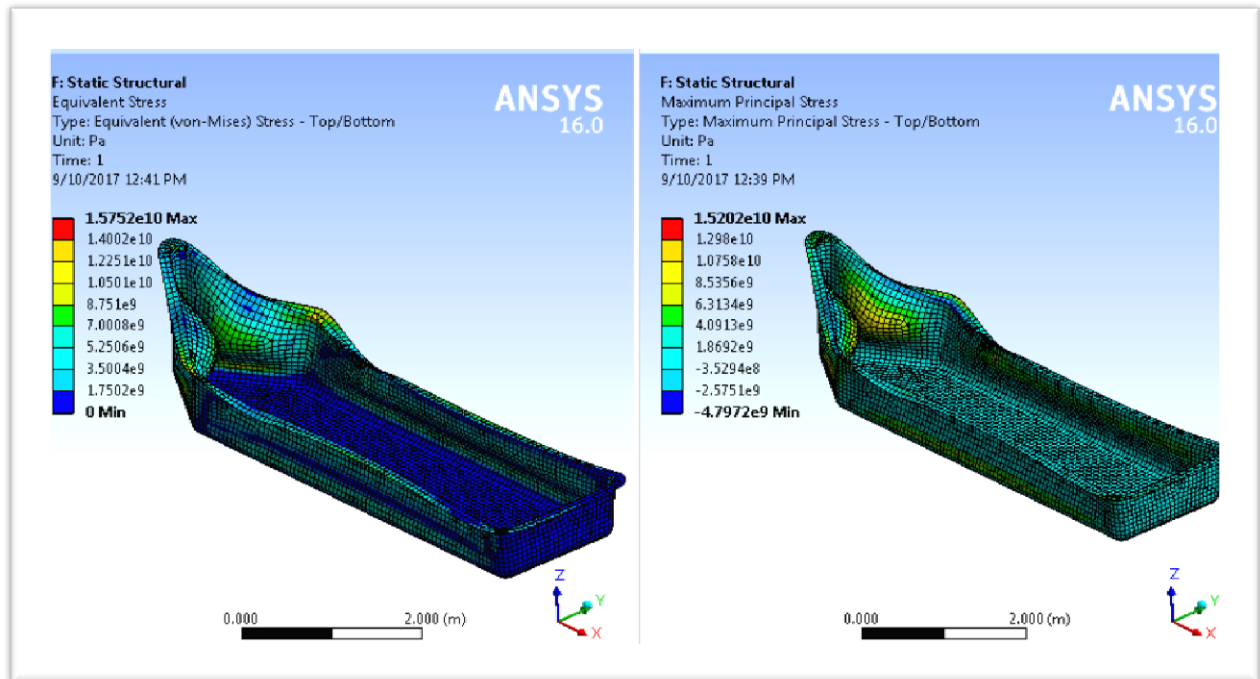


Figure 4-15: Stress analysis on first step

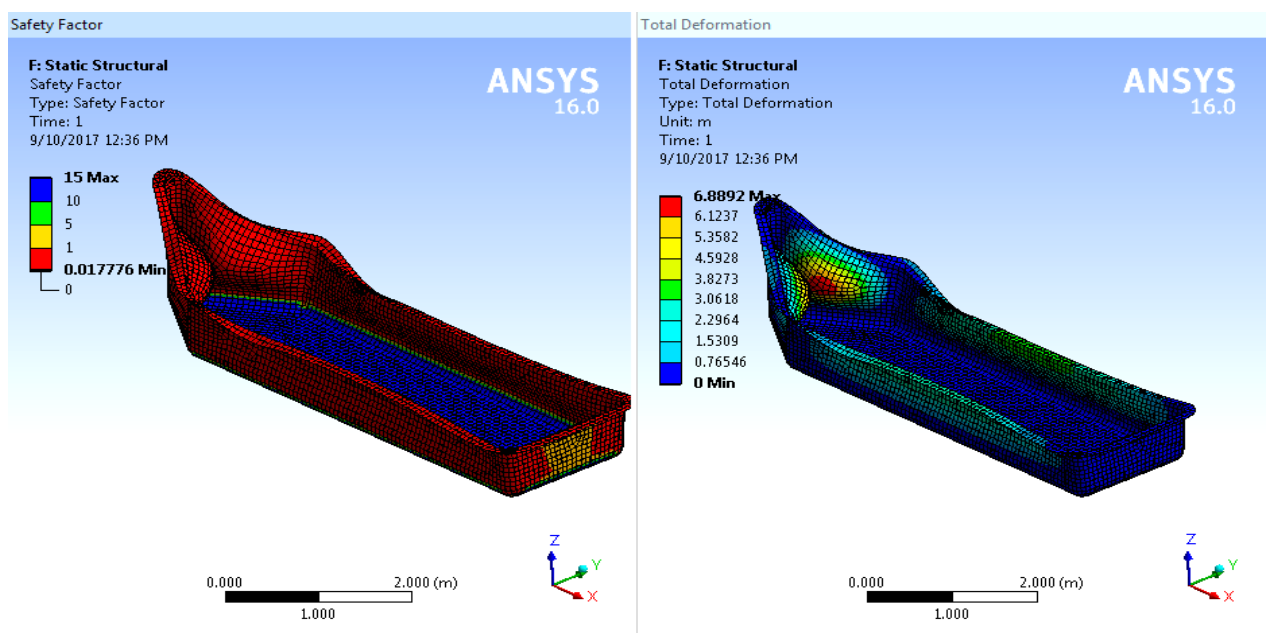


Figure 4-16: Safety Factor value of material and Total Deformation on first step

ii. The deformation of first simulation was very large. So Increasing the thickness to $t = 5\text{mm}$ is considered and the results followed as the following figures.

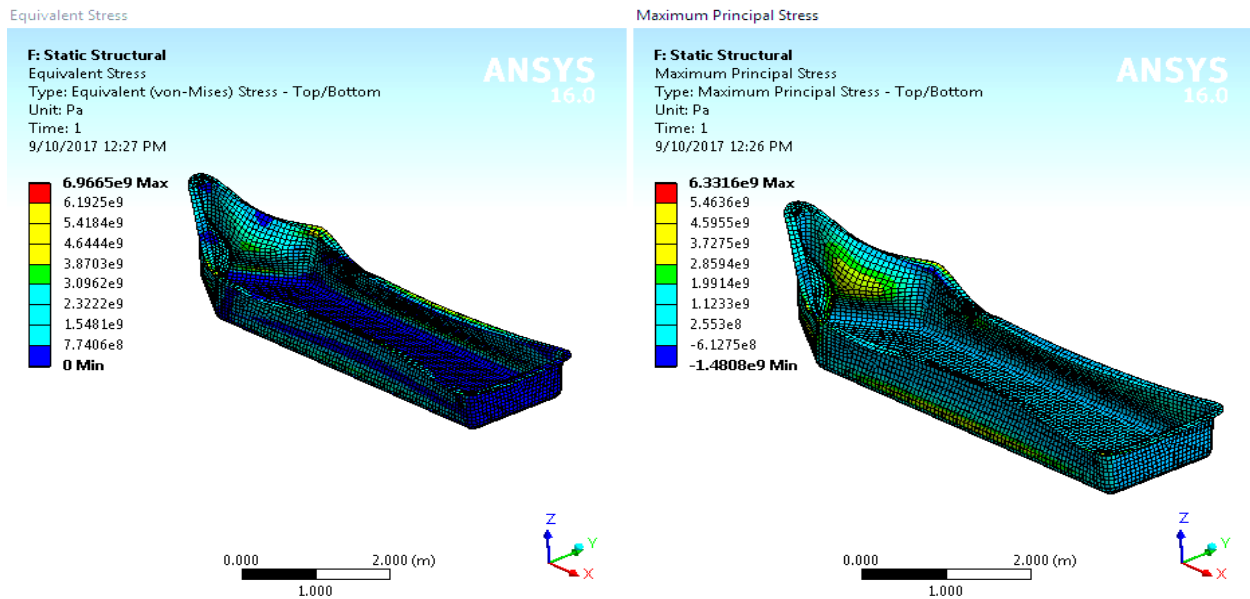


Figure 4-17: Stress analysis on second step

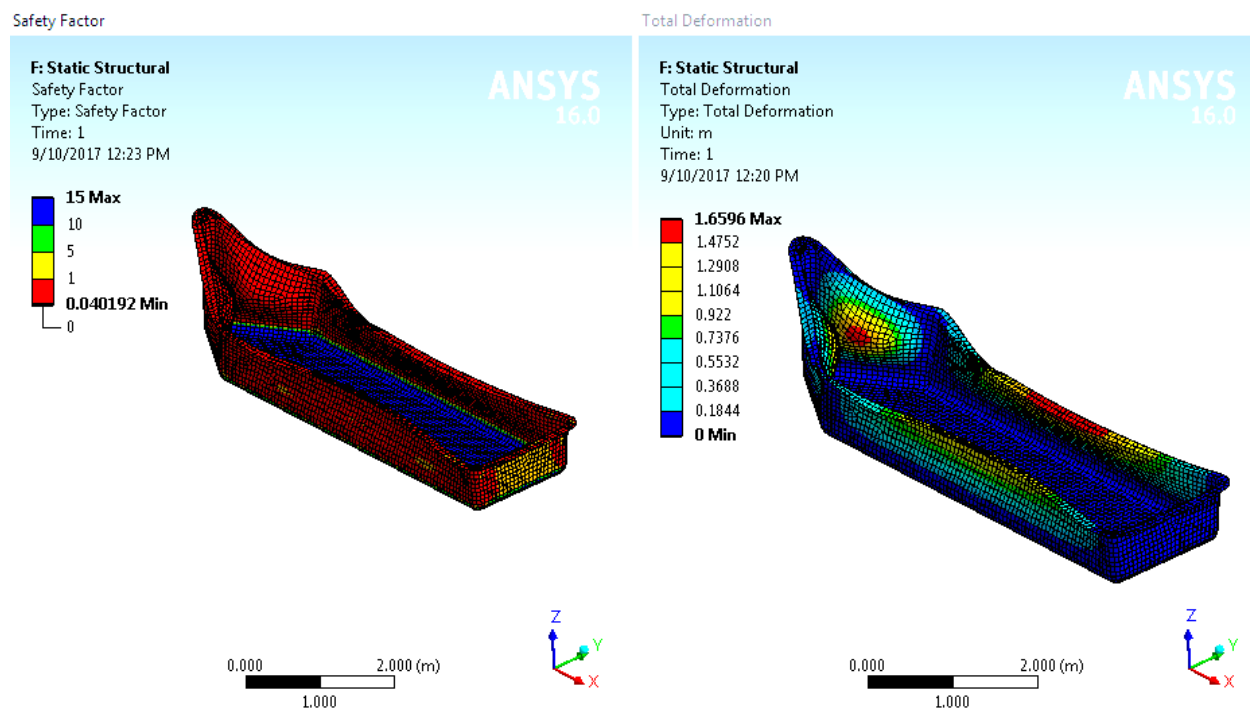


Figure 4-18: Safety Factor and Total Deformation of second step

From Simulated results of unmodified thickness and modified one on above boat hull the result are no more satisfied safety factor. So it needs to more modification to safe material from high loading conditions.

iv. To increase the safety factor or to reduce the total deformation of hull material. The decided internal frame that has the size given as;

Number of Frames=20

Frame thickness = 2.5mm

Hull thickness = 5mm

Figure 4-19 shows the 3D model of frame geometry

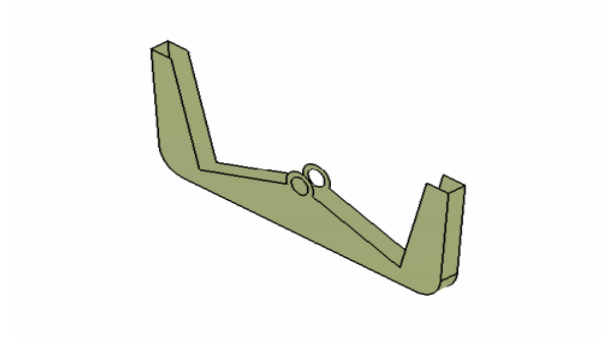


Figure 4-19: Recommended internal frame of the boat

Both frame and hull is assumed as the same materials and assembled together. Figure 4-20 shows the assembled frame with hull geometry.

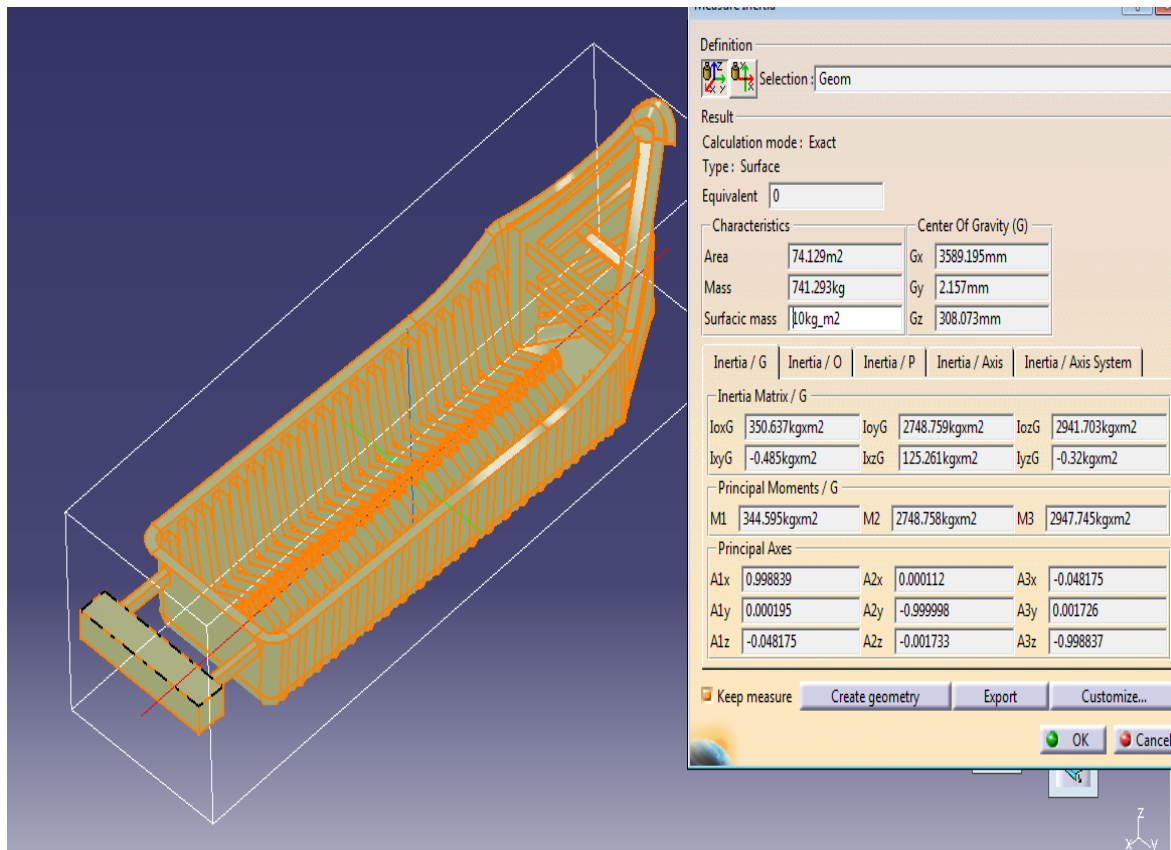


Figure 4-20: Catia 3D model of Boat Hull assembled with internal frame

Imported Drawing to the ANSYS

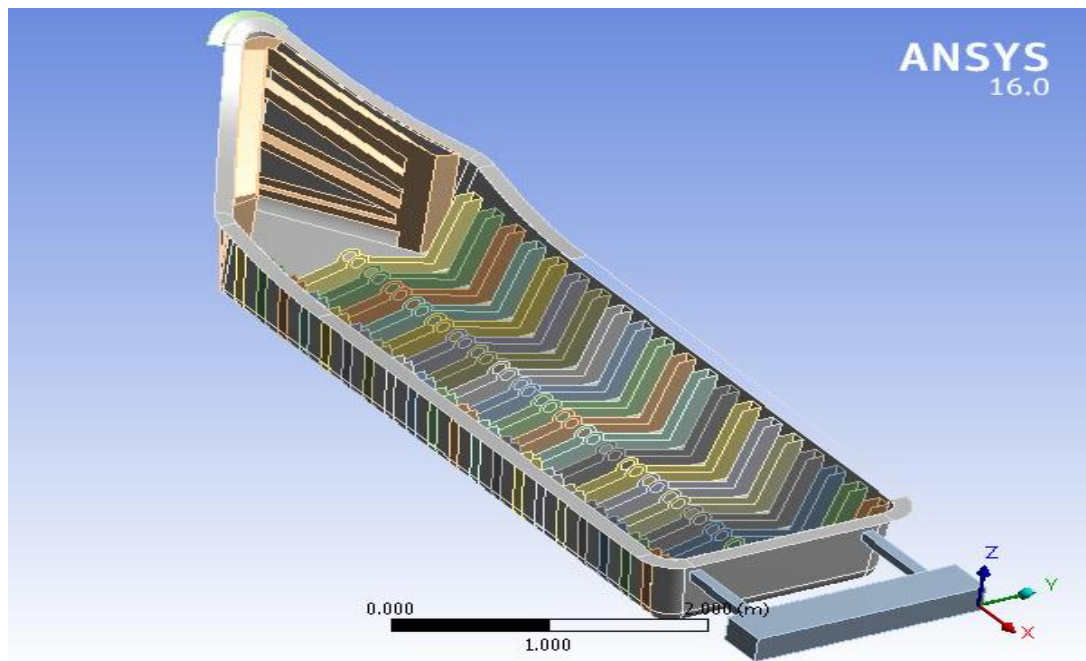


Figure 4-21: 3D Model After it imported to ANSYS structural analysis

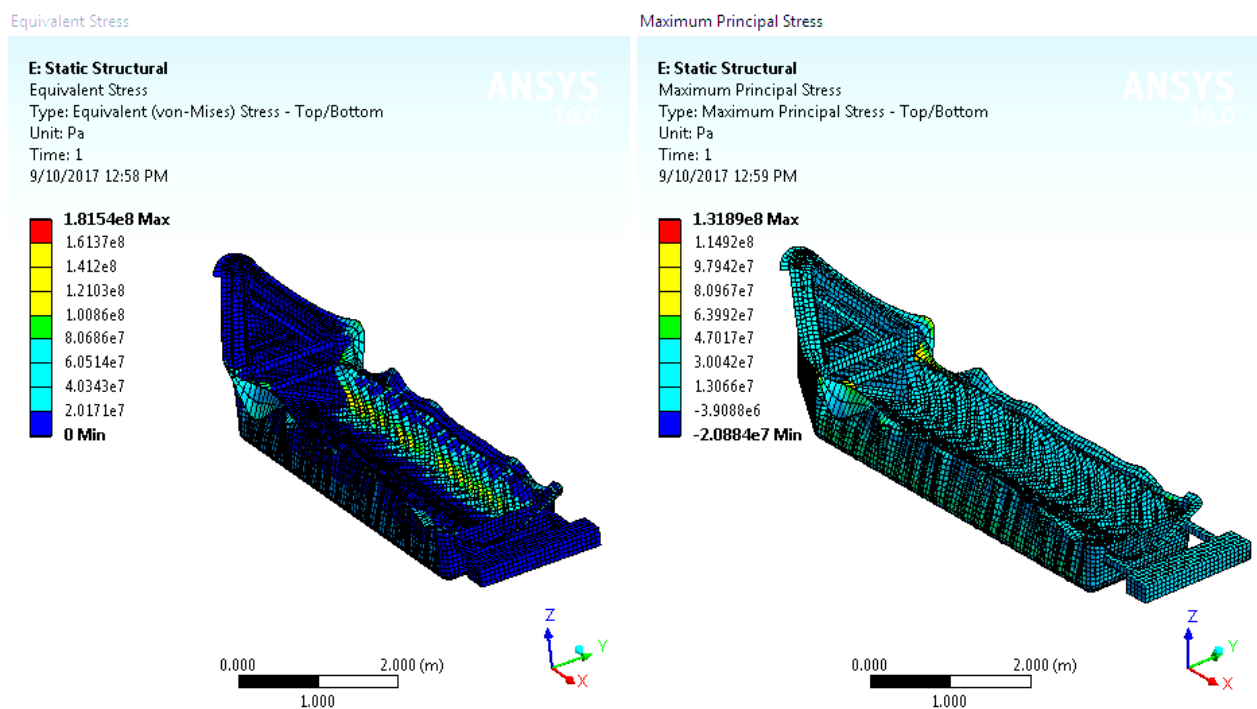


Figure 4-22: a. Stress Analysis on third step

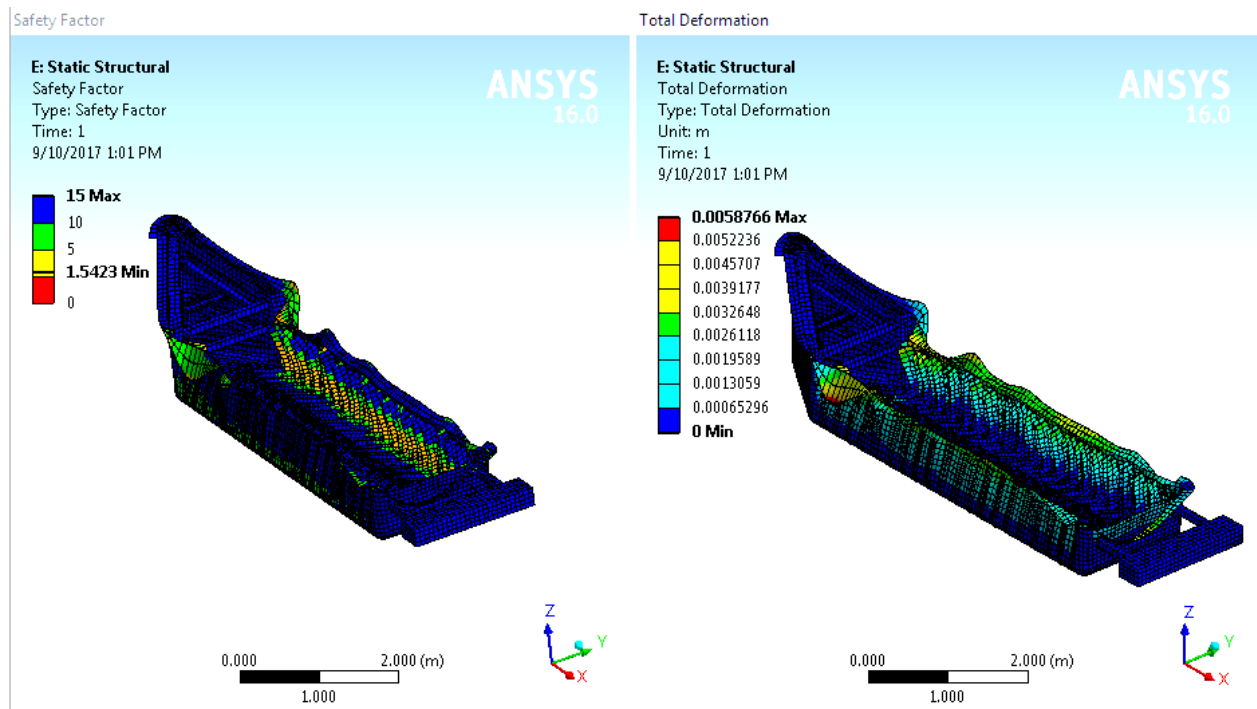


Figure 4-23: Safety Factor and total Deformation of third steps

From first hull shape and second one of increased in thickness we can understand that the deformation is very large. Which means the material ability to withstand the load is very low. So I decided to add multiple frames at the inner side of the hull shape. Then the response of structure now it is, very good due to minimum safety factor is 1.5415 when it compared with the previous one of 0.0157 and 0.047. But from ANSYS Model the mass of total structure is calculated on table 4-16 below.

Table 4-16: Model total mass of the structure

Object Name	<i>Geometry</i>
State	Fully Defined
Definition	
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	7.6354 m
Length Y	2.0616 m
Length Z	1.8395 m
Properties	
Volume	0.2501 m ³

Mass	692.78 kg
Surface Area(approx.)	74.129 m ²

4.3.2 Wind Turbine Test for Determining Cd Value to get Load on the turbine

For the structural analysis of the blade, turbine shaft and turbine mounted frame the total load is determined according to the CFD program. On this the idea is to determine the Turbine drag coefficient. Figure 4-24 shows flow simulation on the blade.

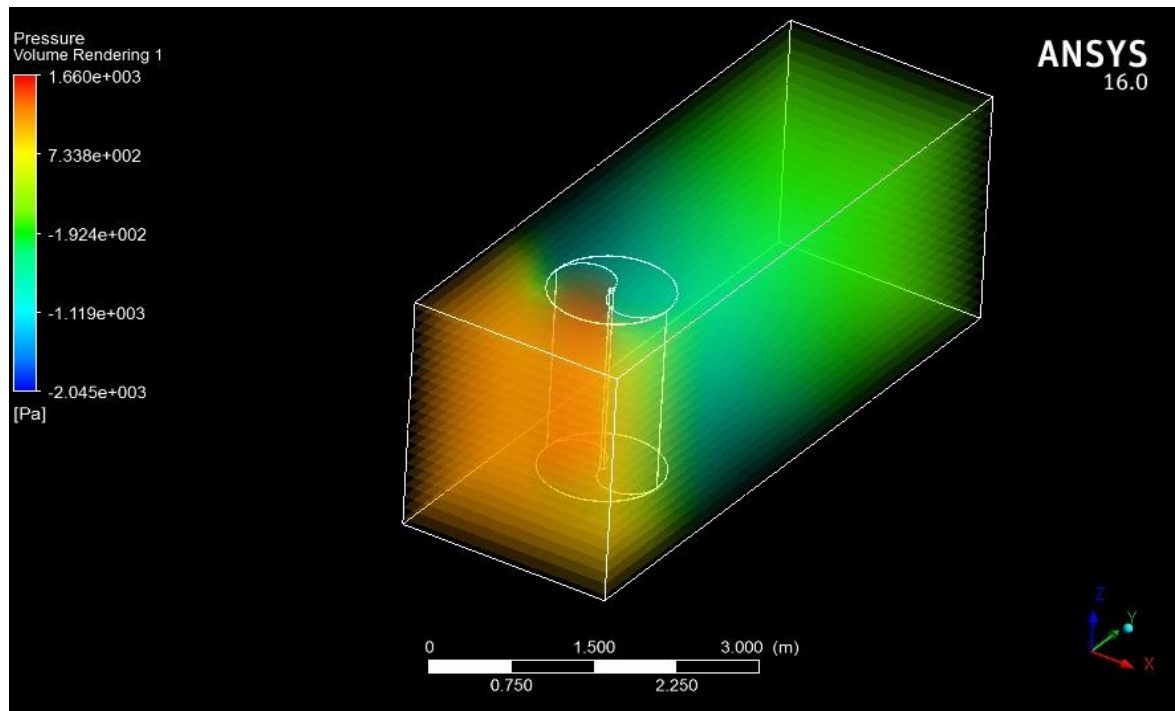


Figure 4-24: CFD Flow simulations Express of savonius rotor

CONVERGENCY HISTORY OF MOMENTUM COEFFICIENT

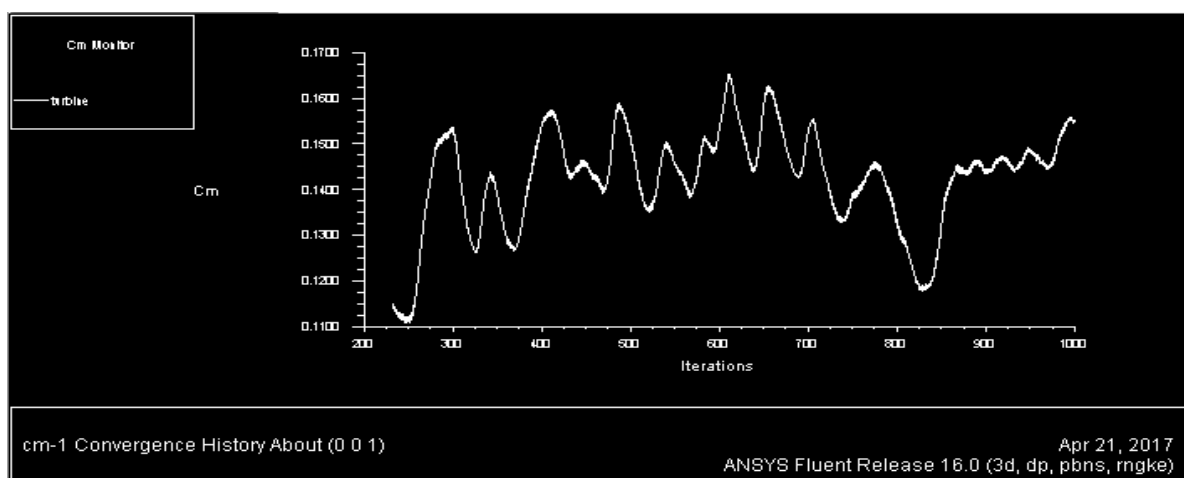


Figure 4-25: Momentum Coefficient

CONVERGENCY HISTORY OF DRAG COEFFICIENT

The drag coefficient of this wind turbine is converged to average Cd=2. But for flat plate the Cd value is 1.98 according to experimental data. Many researchers used the flat plate Cd value to analyse the savonius rotor. Almost the value of both turbine blade and flat plate are approximately the same. Figure 4-26 shows the convergence of drag coefficient at 1000 iteration.

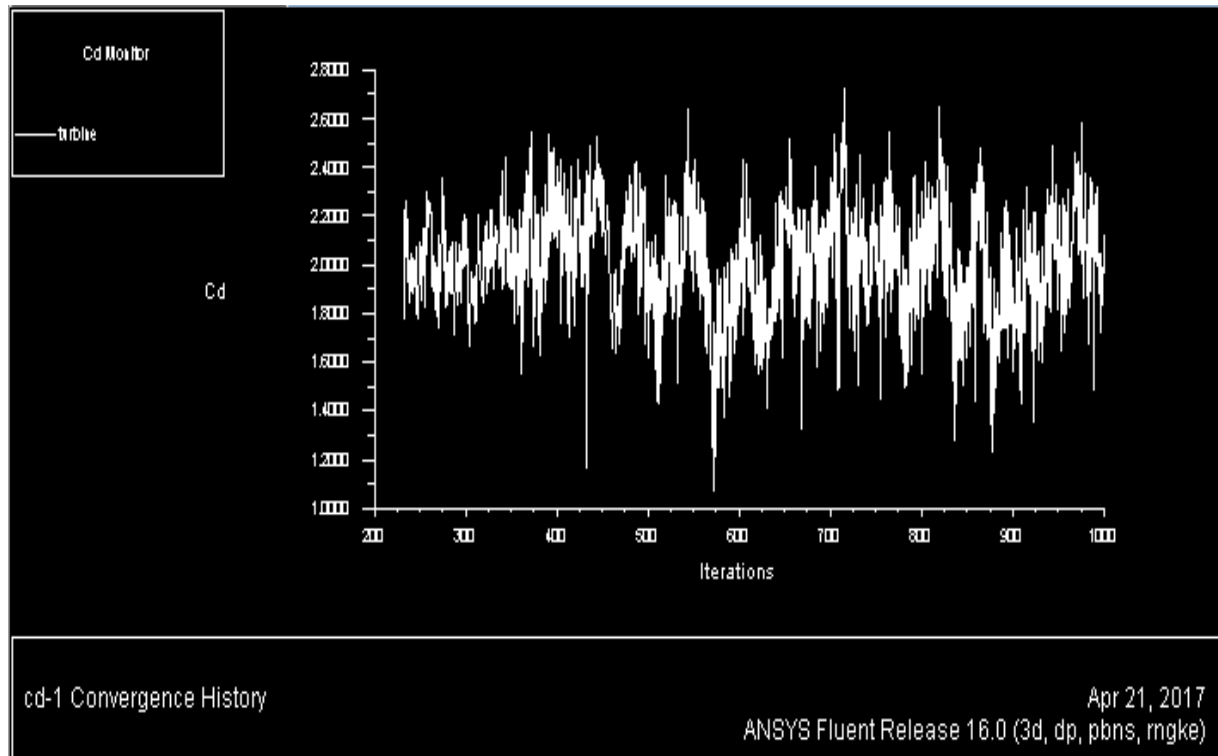


Figure 4-26 : Drag coefficient convergence for rotor

4.3.3 Calculations for Determining all load applied on Turbine

$$F_{drag} = \frac{1}{2} C_d \rho A V^2 \quad [36] \dots\dots\dots \text{Equation 4-2}$$

where: Drag Coefficient, $C_d = 2$ from CFD program of previous simulation but 1.98 (for flatplate)

$$\text{air, } \rho = 1.2041 \frac{\text{kg}}{\text{m}^3} \text{ Cross sectional, } A = 2.88 \text{m}^2$$

upper limit wind velocity, $v = 35 \text{m/s}$ for extremely blown area

$$F_{drag} = \frac{1}{2} 2 \times 1.2041 \times 2.88 \times 35^2 = 4248.06 \text{N}$$

$F_{drag} = 4248.06 \text{N}$ (Bending load) because the upper and lower portion of the shaft is cylindrical jointed with the body of the boat structures.

$$M = F_d R = 1387.12 \times 1.2 = 5097.672 \text{ Nm}$$

$$\text{Lever arm, } R = 1.2 \text{ m}$$

$$\text{Drag Force, } F_{drag} = 4248.06 \text{ N}$$

$$\text{Bending Moment, } M = 5097.672 \text{ Nm}$$

F = Weight of rotor

$$F = W_{blades} + W_{endplates} = \pi \times \frac{D}{2} \times H \times t \times \rho \times g + 2 \times \frac{\pi D^2}{4} \times t \times \rho \times g \quad [36] \quad \text{.....Equation 4-3}$$

$$F = W_{blades} + W_{endplates} = \pi \times \frac{1.2}{2} \times 2.4 \times 0.003 \times 2710 \times 9.81 + 2 \times \frac{\pi \times 1.2^2}{4} \times 0.003 \times 2710 \times 9.81$$

$$F = 541 \text{ N (Axial Load)}$$

Torsional load on Blade

$$F_t = \frac{1}{2} \rho A V^2 \quad [36] \quad \text{.....Equation 4-4}$$

Where: A -swept area of the rotor

ρ -Density of air

V-speed of air

$$F_t = \frac{1}{2} \rho A V^2 = \frac{1}{2} \times 1.205 \times 2.88 \times 35^2 = 2125.375 \text{ N}$$

Torque

$$T = \frac{1}{2} \times F_t \times D \quad [36] \quad \text{.....Equation 4-5}$$

Where: F_t -tangential force on the rotor blade

D-Diameter of the rotor in m

$$T = \frac{1}{2} \times F_t \times D = \frac{1}{2} \times 2125.375 \times 0.6 = 637.6125 \text{ N-m}$$

4.4 Static Structural analysis for turbine mounted frame

All thickness is set to 3mm

➤ Drawing imported to the ANSYS 16

The 3D model of turbine mounted frame was constructed into the Catia V5 and for simulation of static structural analysis it is imported to the ANSYS 16. Figure 4-27 shows turbine mounted frame imported to ANSYS for analysis.

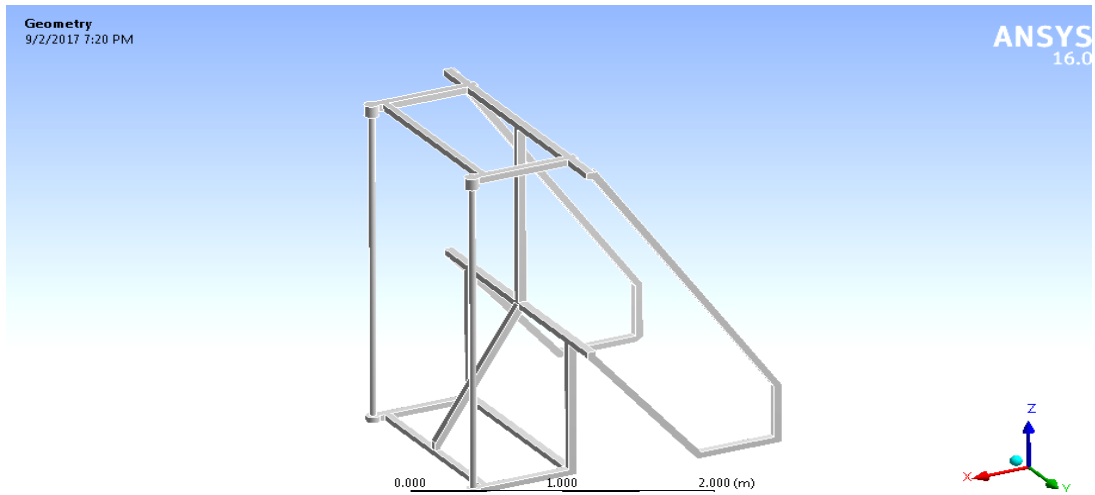


Figure 4-27: Model of Turbine Mounted Frame

Meshed body

On this frame structure mesh sizing set to relevance fine to get more accurate results.

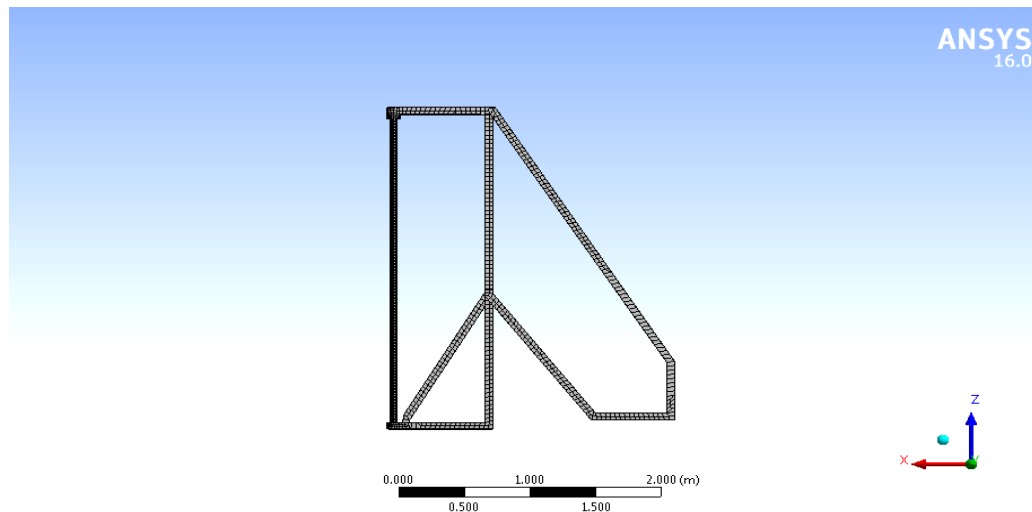


Figure 4-28: Mesh generated on Turbine Mounted Frame for analysis

Imported Load

Total load applied at the center of turbine shaft along x axis is 4248N. Simply it is drag force. But for two ended shaft the force would be -2124N. Table 4-17 shows imported load for analysis.

Table 4-17: Imported load

Define By	Components	
Coordinate System	Global Coordinate System	
X Component	-2124. N (ramped)	0. N·m (ramped)
Y Component	0. N (ramped)	0. N·m (ramped)
Z Component	0. N (ramped)	637. N·m (ramped)
Behavior	Deformable	

Results

i.Equivalent Stress

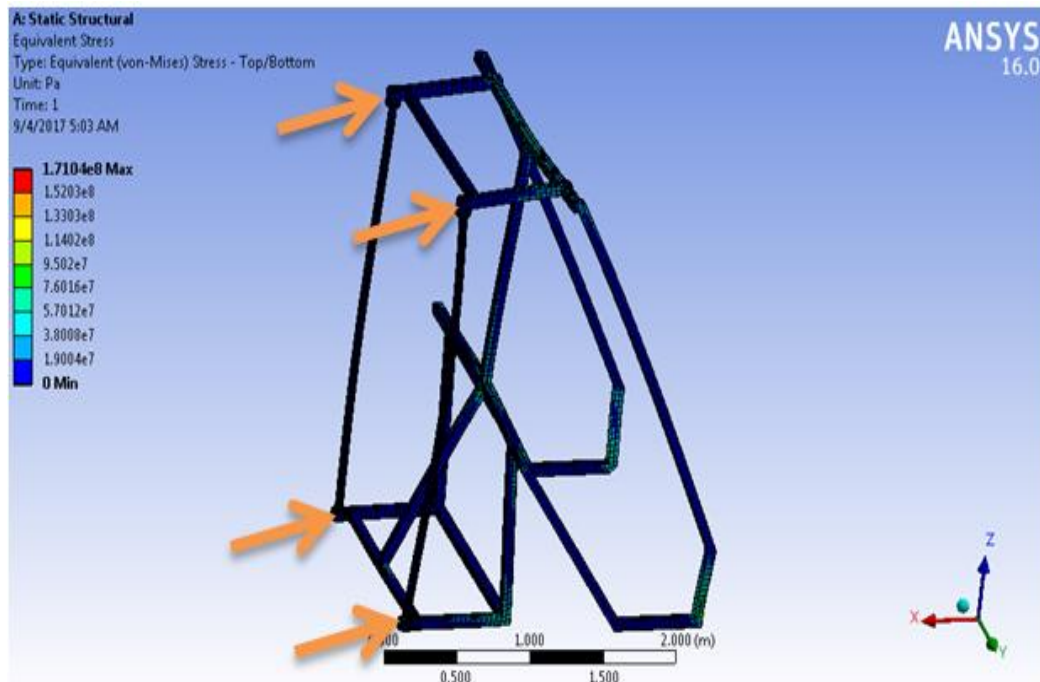


Figure 4-29: Turbine Mounted frame Equivalent stress on structure

ii.Total Deformation

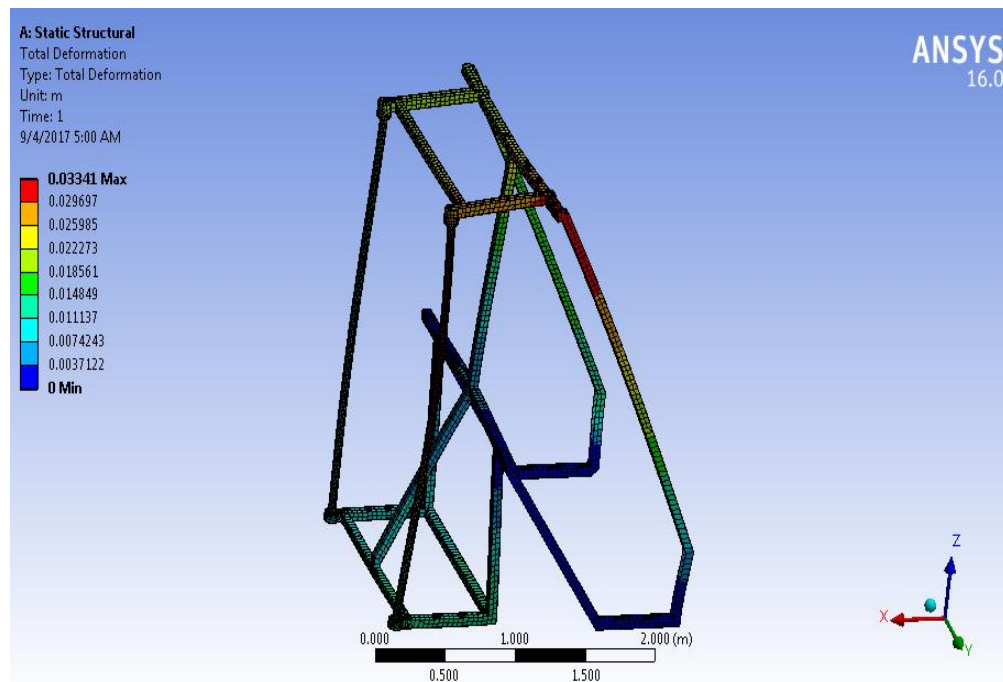


Figure 4-30: Total Deformations of Turbine Mounted frame

iii.Safety Factor

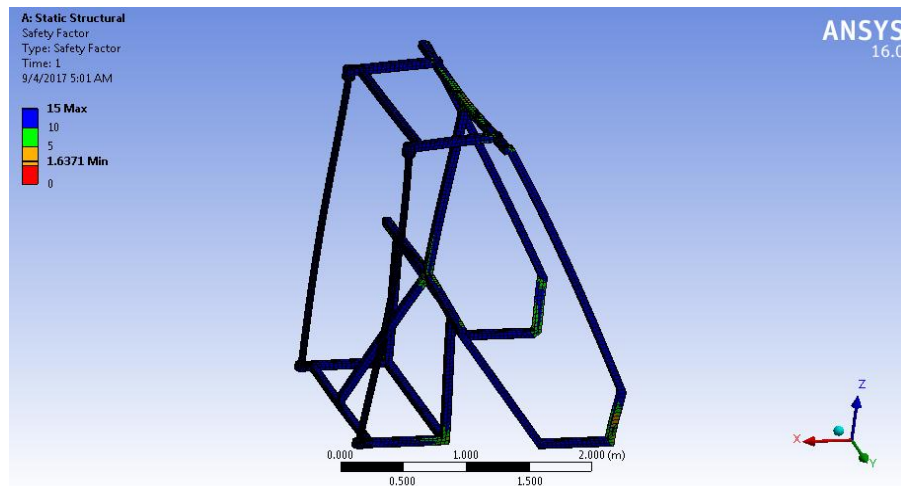


Figure 4-31: Turbine Mounted Frame Safety factor

Table 4-18: When the load applied on y axis

Define By	Components	
Coordinate System	Global Coordinate System	
X Component	0	0. N·m
Y Component	-2124. N	0. N·m
Z Component	0. N	637. N·m

When the load applied along y axis the figure 4-32 below shows the determined safety factor.

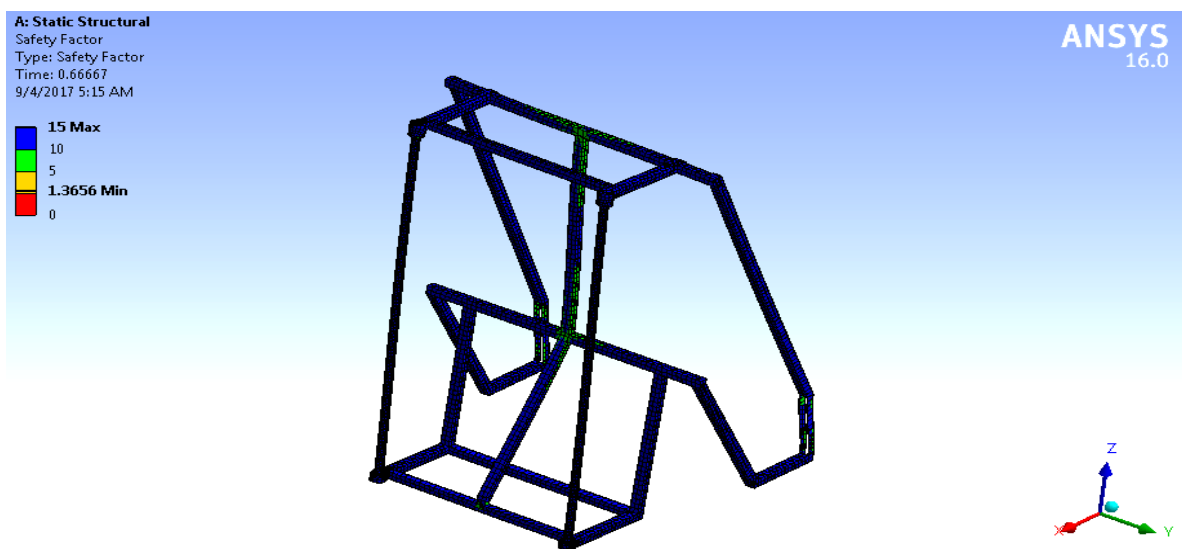


Figure 4-32: Safety Factor of Turbine Mounted Frame for load applied along y axis

From above the simulation results both safety factor of material is realizable for the case of two load position. From the result of turbine mounted frames stress analysis, the properties of frame after simulation are described in the table 4-19.

Table 4-19: Turbine Mounted Frame Properties after Analysis

Volume	2.0695e-002 m ³
Mass	57.325 kg
Centroid X	6.6261 m
Centroid Y	7.7587e-004 m
Centroid Z	1.9533 m
Moment of Inertia Ip1	89.836 kg·m ²
Moment of Inertia Ip2	77.355 kg·m ²
Moment of Inertia Ip3	49.206 kg·m ²
Surface Area(approx.)	6.8983 m ²
Statistics	
Nodes	10810
Elements	10799

4.5 Turbine shaft analysis via ANSYS

Before analysis the materials definitions of shaft must be explained. Therefore the best material for the shaft was described in below table 4-20.

Table 4-20: Material definitions of Turbine Shaft

Parameter Value	Value
Material	Steel, AISI 1045
Shaft Diameter (assumption)	50mm
Shaft Length with bearing on the mounting with upper and lower portion of frames	2.4 m
Yield Strength	505 MPa
Ultimate Stress	585 MPa

Modulus of Elasticity	200 GPa
Poisson's Ratio	0.28

Turbine Shaft imported To ANSYS Static structural analysis

The shaft recommended for this turbine boat is hollow shaft for reducing the vibration, bending, and weight reduction. Figure shows hollow shaft outer diameter is 50mm and inner diameter 40mm. the key on the shaft is used to rigid connection with turbine plate upper and bottom mounted.

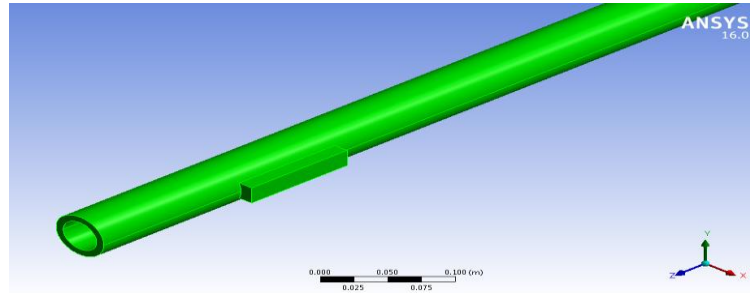


Figure 4-33: Model of turbine shaft imported to ANSYS

Mesh generated

The mesh used on this shaft is fine mesh to get accurate results.

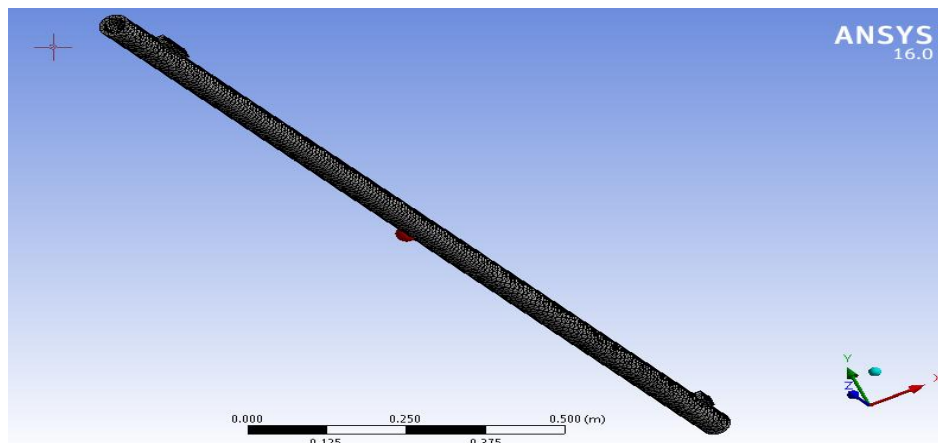


Figure 4-34: Mesh Generated on Turbine shaft

Imported load for shaft analysis

To determine the response of this hollow shaft there are load that need to apply .By converting drag force into the bending moment the value of bending moment was determined as 5097N.m from previous calculations of CFD program and the torsional moment was 637N.m. table 4-21 shows load applied on the shaft.

Table 4-21: Applied Loads on the shaft

Type	Moment	Force
X Component	5097.7 N·m	0. N
Y Component	0. N·m	0. N
Z Component	637. N·m	-541. N

Results

a.Von mises Stress

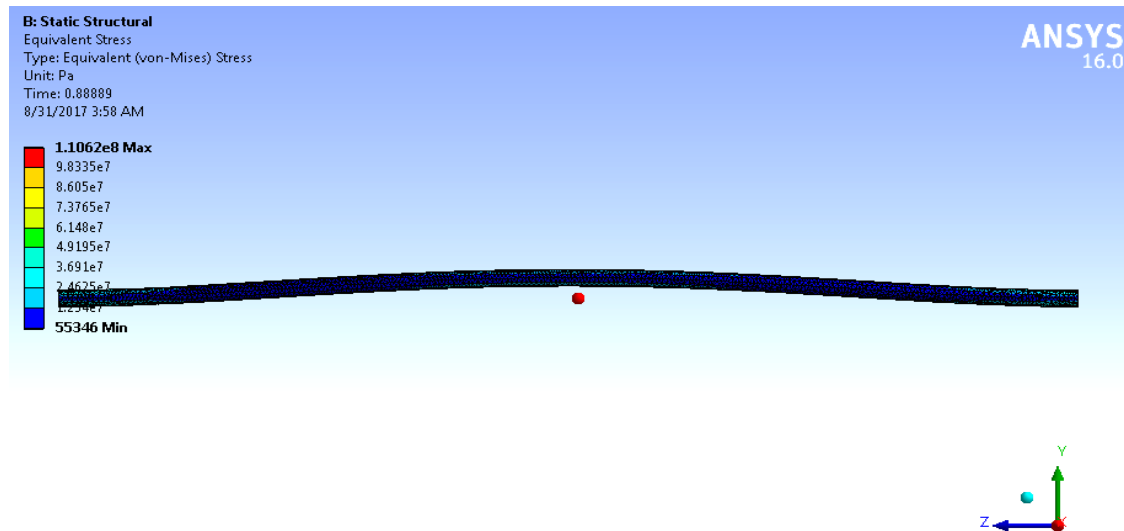


Figure 4-35: Turbine shaft Equivalent stress.

b.Total Deformation

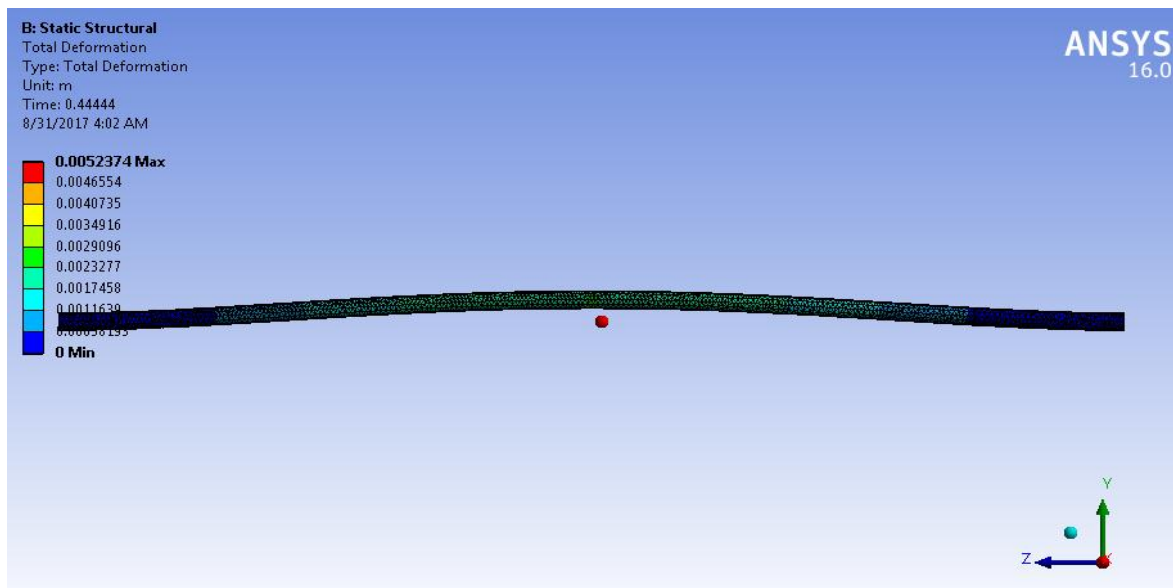


Figure 4-36: Turbine shaft total deformations

c. Safety factor of shaft material

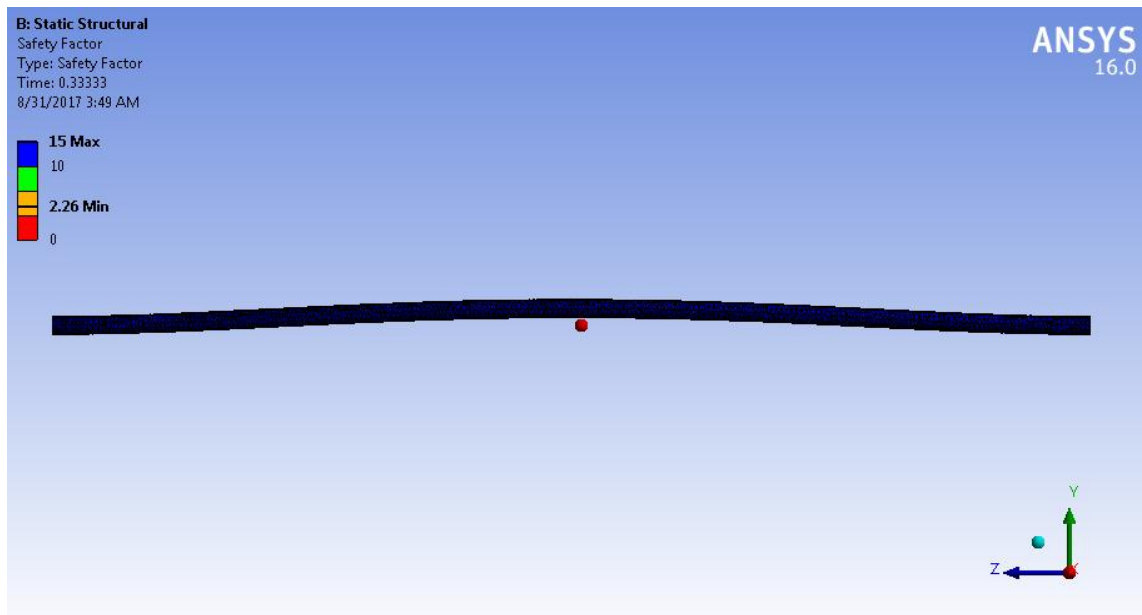


Figure 4-37: Turbine Shaft safety factor

From above the figure 4-37 the safety factor of recommended shaft size is very realizable.

4.5.1 Recommended Bearing Size

The bearings to be used in the design were also selected from the manufacturer's catalog obtained from the web. The recommended bearing sizes were based from the analyzed results of small outer diameter of shaft which is 50mm or 1.9 inch at static load applied on turbine bearing shaft 4248N.

4.5.2 Transmission

Gear drive, chain drive and belt drives were considered in the recommended type of transmission to be used. Upon research, the chain drive system was found to be an inferior candidate in VAWT application. It was found that the weight of the chain generates bending load on the sprocket teeth which lessens the lifespan of the said part. Meanwhile, belt drives exhibits slippage in some cases and can prove to be ineffective if exposed to the elements. Finally, the gear drive was selected as the recommended type of transmission as it has virtually no slippage and high resistance to the elements. The gear ratio was calculated to be around 1:4 since the angular rotation shaft is around 50 rpm while rpm rating of the generator is 300. The driver gear connected to the shaft is recommended to have a bore of 30mm and with 80 teeth while the driven gear a bore of and 18 teeth. The specification is read from gear catalog of Appendix IV G77-80.

4.6 Added mass of Upper structures and Furniture's or chairs

From calculations of estimated turbine blade design the mass of turbine is 54kg for one turbine only and the turbine mounted frame mass is 57kg as shown on the properties table 4-19. Two electric motor generators and propeller from appendix V is estimated as 20kg and 30kg; total 50kg.

On this design of project I decided to add plastic or fibre chair that mounted on the ground of hull internal rectangular frame of the boat. So the estimated total mass of the eight fibre chair is 50kg. Let assume mass of roof and light steel bar for holding roof is 14kg. Therefore total structural mass is calculated as:-

$$m_t = 692 + 2 \times (54) + 57 + 50 + 14 + 50 = 971 \text{ kg}$$

Where: m_t –over all total structural mass [kg]

Added Hydrodynamic Keel

In sailboats, keels use the forward motion of the boat to generate lift to counteract the leeward force of the wind. The rudimentary purpose of the keel is to convert the sideways motion of the wind when it is abeam into forward motion. A secondary purpose of the keel is to provide ballast. Keels are different from centerboards and other types of foils in that keels are made of heavy materials to provide ballast to stabilize the boat. Keels may be fixed, or non-movable or they may retract to allow sailing in shallower waters.

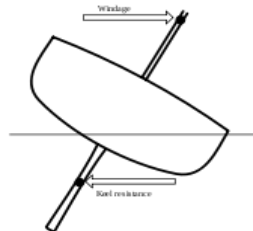


Figure 4-38: Hydrodynamic Keel

The keel center of mass distance from center of gravity of whole body was determined from 3D model of Catia v5 by selecting the central axis of the keel.

Previously On the stability test all roof, turbine, vertical plate to know the response of the wind how much it have the effect as it blown from the side were considered. From this point of view we understood that as mass of the hull increased the wind ability to push to the side decrease. Finally I tried to minimize the average area of the boat to reduce wind transversal load effect on the boat. After that the decided idea was to test the boat on both 250m depth and also very shallow water depth about 17.5 m at both unloaded hull 971kg and full loaded 2500kg. The simulation of this step was only for visualization.

4.7 Human Ergonomics Design

The Product of human body was investigated from catia V5 and the sitting chair was modeled according to the human structural body in the catia. The percentile of weight was taken as 95%, this is standard and the people selection standard was taken as American People from Catia products of Human Ergonomics Design that gave 100kg. Firstly the model of chair was created and checked to scale with human body structures. The figure 4.39 and 4.40 shows sitting chair and human Ergonomics Design with position of vertical center of mass.

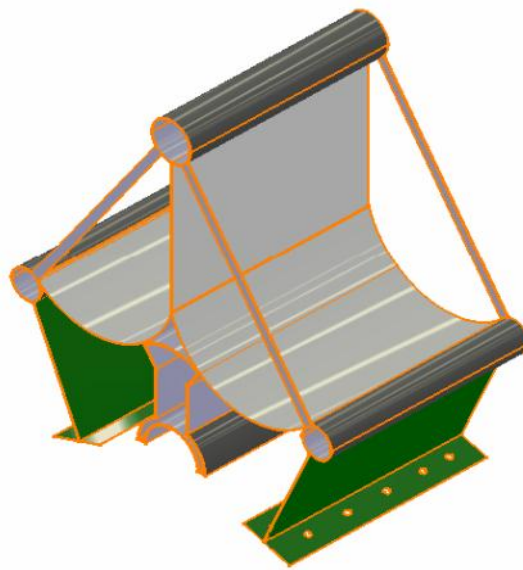


Figure 4-39:3D model of Sitting Chair

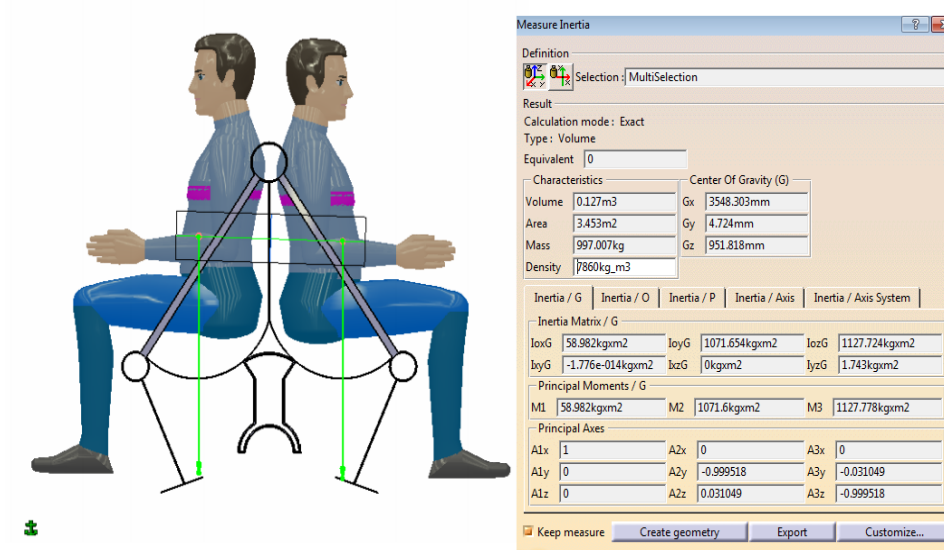


Figure 4-40: Human Ergonomics Design and Center of Mass position

As shown on the figure 4-40 human ergonomics design center of mass or vertical center of gravity value was determined as 0.951m from the principal axis. The total mass of humans also 997kg.

4.8 Total Weight of Assembled part and Center of Gravity value

After all components are assembled and ten peoples are also encountered, the product moment of inertia and center of mass will be determined as figure 4.41. On the figure we understand the Vertical center of gravity Value was determined as 0.459m. This value is very realizable because our main objective on this model is try to move down vertical center of gravity value to that of 0.5m from ANSYS hydrodynamic final results trialed.

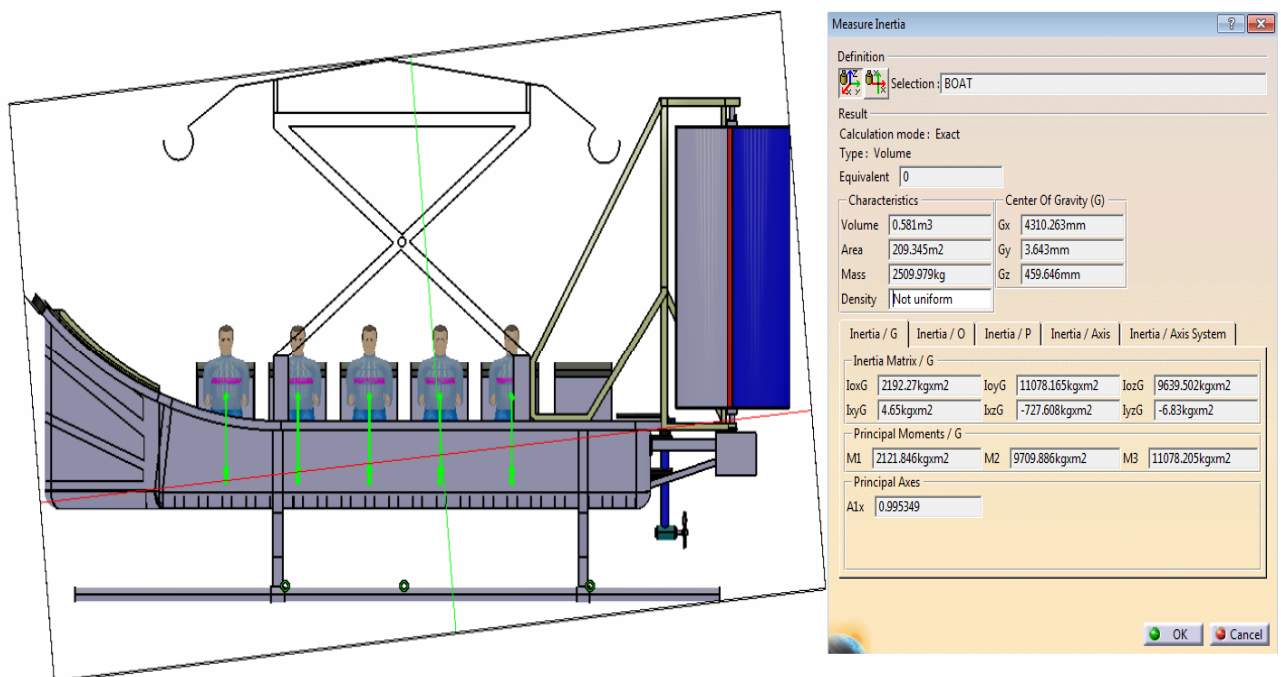


Figure 4-41: Hydrodynamic total weight and keel position

From the above figure 4-41 of Catia 3D model the calculated Total mass of the model was 2505kg and vertical axis CG is 0.459m. The mass is almost matched with designed Weight of 2500kg. So the designed models are acceptable. From above figure of 4-41, the keel mass was determined as 601 kg. But the keel mass can be varied according to the positions it moved up or down at fixed vertical centre of gravity.

4.9 Prototype

For demonstration purposes I tried to do the typical example of small sized boat. The materials prepared for this prototype are like, three small sizes 6Volt DC Motors, Small size of rechargeable battery, Aluminium sheet, Ruler. The prototype size was reduced from previous of boat 3D

model. The scale used was 1:12 to minimize the all component together. Figure 4-42 shows the materials and equipment's used.



a. DC motor



b. Battery



C. Equipment's

Figure 4-42: Materials Equipment's used To Develop the Prototype

During developing small size of the boat hull from aluminium sheet of 0.4mm. I developed by folding not welding. Because due to this aluminium thickens is very low the welding may create orifice that the water may splashes through it. The figure 4-43 below shows the folded aluminium sheet.

Step 1



Step2



Step 3



Figure 4-43: Boat Hull developing Steps by folding aluminium

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

5.1 Summary

As explained on introduction the designing powered by renewable energy source is very necessary for modern technology. So the wind turbine integrated boat propulsion system was developed to reduce the pollution of the environment as its renewable energy. The system was developed by using the collecting data related to recreational boat Lake of Babogaya and the method used was design data books and some basic software like ANSYS 16, Catia V5. Before any stability test the recommended size of the boat was taken with total displacement of 2.5ton as its overall length of the boat was 6m and breadth was 2m. The java programing used to determine the propulsion power of this size of boat. The recommended size of 5hp propeller, two vertical axis turbine DC Generators each of them produce 4KW power, Gear was selected and also Turbine size was recommended as 2.4m height and 1.2m Diameters.

- The ANSYS Hydrodynamic Test was encountered to stabilize the boat as much as possible. The test was trialled six times by changing the vertical centre of gravity and structural total mass. From the simulations trails changing the structural mass have no effect on metacentric height but it has effect on external load applied. When the structural mass increased the boats ability to overcome or rigidity under load is high. But the great advantage of metacentric height is to increase the righting moment of the boat. From the simulations trails the 800kg mass at centre of gravity 0.5m was the best result.
- The statics structural analysis of boat hull used the result of final simulation that has the pressure and motion results of 0.33MPa.
- The analysis of Turbine mounted frame and Turbine shaft are depended on the wind load applied on the blade at 35m/s.
- Finally the weight of each basic part like, turbine, turbine mounted frame and turbine shaft was determined during static structural analysis at final stage of simulations results. The weight for model of DC generator and out board propellers was estimated as the selected category of standard size of motor and propeller from Appendix V.

5.2 Conclusion

From the general contents of this thesis results the following point was drawn.

- The maximum pressure value that determined from hydrodynamic wave loading impact of final trial simulations was 0.33MPa. This value was used for hull static structural analysis.
- The result from CFD program determined as drag coefficient of 2. This was used to determine the load applied on the turbine mounted frame and turbine shaft.
- The safety factor for first hull thickness was 0.017 and the deformation of hull material was 6.88m. This makes the materials thickness modified and the internal frames were added.

The result that determined from modified material thickness was very satisfied that have a minimum safety factory is 1.54 and the deformation was 0.0058m.

The safety factor and deformations of turbine mounted frame was determined. The acceptable safety factor value determined from software simulation was 1.63 when load positioned in x axis and 1.36 in y axis and the deformations of turbine was 0.033m.

The deformation for turbine shaft was 0.0052m and the safety factor was 2.26. Therefore the designed hollow shaft is acceptable.

- Finally by comparing the trialed mass of 2500kg at CG 0.5m with the catia 3model the result of vertical center of gravity that determine after all component assembled was CG 0.45m. This result was acceptable because the designs or trial vertical center of gravity value was not lower than the assembled model at full load conditions.

5.3 Recommendation

It is recommended that another research should be conducted to find out the extent to which the power generated by the turbine can increase the driving range of the electric Boat. It is also recommended that more research should be done in order to incorporate the turbine design into the body of the electric Boats.

- For more guidance if the boats have a problems of stability, don't add weights to correct a list. This is not a good solution. Move things around. Move the batteries to the opposite side. If the boat has a side cabinet, try moving the cabinet to the center, or to the opposite side. Adding hollow lifting strakes along the chine might add more buoyancy by widening the boat at the waterline.
- Think about the problem and try to find solutions that do not add weight, but that shift the CG downward without raising the Center of Buoyancy. On larger boats with cabins there are many ways that the weight can be reduced up high or things that can be moved to shift weight to a lower position.

- When installing two sovonius rotor you must reverse one blade from the other one. Because when the blades rotate in the same directions two moments of the blade added together and increase the amount of force tending to the side on the boat. The total vertical moment that created by the turbine rotation try to make the boat yawing about vertical axis. But when the blade rotates in opposite direction the total momentum created by the turbine becomes zero and no yawing moment about vertical axis.
- On this design of boat the balancing case of longitudinal center of mass can be adjusted by keel mass translating, the owner can use translating keel mass along the longitudinal axis as the keel shaft axis is parallel with longitudinal axis of the boat. This translation also used to lift up the bow portion of the boat. As a standard of boat the maximum hull angle at the transom shield is from 15° to 17° . Try to translate to get the range of this angle.

5.4 Future Scope

- Although this project is complete, wind does not blow constantly at all, special some areas are non-breath wind conditions. Therefore to make the propulsion power enough for boat it's better to consider solar energy to recharge the battery. Means to say totally electric boat in addition turbine produced power.
- It's better to use gyroscopic stabilizer additionally on design for more safety.
- Trying to designs the wind propulsion system directed propel the boat. This means it is not electrical but transferring the rotations of turbine by making as it's better to push the water.
- For more accuracy it's better to use the CFD program to get wind and current force coefficients instead of using mathematical modeling of river boat dynamics data.

APPENDIX I: Java Code part I

```
package dimensional Analysis;

/**
 *
 * @author Garbe
 */

import java.util.Scanner;

public class area {

    public static void main(String args[]){

        double
            Lwl,Lpp,LoA,Am,Bwl,D,C,Df,DA,y,S,V,Fn,Rn,CB,r,CM,Cp,M,d,t,v,Cedd,CT,CF,CA,CA
            A,LoAW,Width,g,Aav,Cpartial;

        Scanner s=new Scanner(System.in);

        System.out.println("*****INPUT RESULTS*****");

        System.out.print("enter over all length of the boat LoA in m=");

        LoA=s.nextDouble();

        System.out.print("enter overall length to width ratio of the boat from Standarad 2.8-3.2
            LoAW=");

        LoAW=s.nextDouble();

        Width=LoA/LoAW;

        Lwl=0.85*LoA;

        Bwl=Lwl/LoAW;

        Lpp=0.97*Lwl;
```

```

System.out.print("enter Draught of a midship in m=");

D=s.nextDouble();

System.out.print("enter the maximum speed of the boat in m/s=");

V=s.nextDouble();

System.out.print("enter the density of the water in kg/m3=");

d=s.nextDouble();

System.out.print("enter the temprature of the water in oC=");

t=s.nextDouble();

System.out.print("enter the gravitational acceleration in m/s2=");

g=s.nextDouble();

System.out.print("enter the Displacement in ton=");

y=s.nextDouble();

System.out.print("enter the fillet radius of the hull on the waterline edge in m =");

r=s.nextDouble();

Am=D*Bwl-3.14*r*r*0.5;

v=((43.4233-31.38*d)*Math.pow(t+20,1.72*d-2.202)+4.7478-5.779*d)*Math.pow(10,-6);

Rn=(V*Lwl)/v;

CF=0.075/Math.pow(Math.log10(Rn)-2,2);

Fn=V/Math.pow(g*Lwl,0.5);

M=Lwl/Math.pow(y,1/3);

CB=y/(Lpp*Bwl*D);

CM=Am/(Bwl*D);

Cp=CB/CM;

System.out.print("enter frontal average area of the boat above water line in m2=");

```

```

Aav=s.nextDouble();

S=1.025*Lpp*(CB*Bwl+1.7*D);

CAA=Aav/1000*S;

System.out.print("enter the incremental resistance coefficient for model=");

CA=s.nextDouble();

System.out.print("enter the correction coefficient for boat hull geometry for U or V shape ac-
    cording to ITTC fro to =");

C=s.nextDouble();

Cpartial=CF+CAA+CA+C;

System.out.println("*****OUTPUT RESULTS*****");

System.out.println("Prismatic coefficient="+Cp);

System.out.println("Slenderness ratio="+M);

System.out.println("Block coefficient="+CB);

System.out.println("Froud number="+Fn);

System.out.println("partial Resistance coefficient="+Cpartial);

System.out.println("*****Basic Dimensions of the hull*****");

System.out.println("LoA="+LoA);

System.out.println("Lwl="+Lwl);

System.out.println("Lpp="+Lpp);

System.out.println("Width="+Width);

System.out.println("Bwl="+Bwl);

System.out.println("r="+r);

System.out.println("D="+D);

System.out.println("S="+S);

```

```
}}
```

APPENDIX II : Java Code Part II

```
*/  
  
package javaapplicationProgramPropulsionPower;  
  
/**  
 *  
 * @author Garbe  
 */  
  
import java.util.Scanner;  
  
public class JavaApplication18 {  
  
    public static void main(String[] args) {  
  
        double  
            Eh,t,w,w1,w2,w3,a,b,c,t1,t2,t3,d,e,Dpro,f,Fa,draught,CR,AL,T,R,CTh,E,Er,dw,Es,CB,Bwl,  
            Lwl,V,VA,Adisk,Cpartial,Eprop1,Eprop2,PE,Pp,S,CT;  
  
        Scanner s=new Scanner(System.in);  
  
        System.out.print("enter the Block coeficient=");  
  
        CB=s.nextDouble();  
  
        System.out.print("enter the water line length in m=");
```

```

Lwl=s.nextDouble();

System.out.print("enter the waterline breadth in m=");

Bwl=s.nextDouble();

System.out.print("enter the maximum draught in m=");

draught=s.nextDouble();

a=(0.1*Bwl/Lwl)+0.149;

b=(0.05*Bwl/Lwl)+0.449;

d=(0.625*Bwl/Lwl)+0.08;

e=0.165-(0.25*Bwl/Lwl);

f=525-(8060*Bwl/Lwl)+20300*Math.pow((Bwl/Lwl),2);

c=585-(5027*Bwl/Lwl)+11700*Math.pow((Bwl/Lwl),2);

w1=a+(b/(c*Math.pow((0.98-CB),3)+1));

System.out.print("enter the the value of form factor Fa from [-2,2]=");

Fa=s.nextDouble();

w2=(0.025*Fa)/(100*Math.pow(CB-0.7,2)+1);

System.out.print("enter the disk diametr=");

Dpro=s.nextDouble();

w3=-0.18+0.00756/((Dpro/Lwl)+0.002);

w=w1+w2+w3;

System.out.print("enter the Maximum speed of the boat=");

V=s.nextDouble();

System.out.print("enter the Partial resistance coefficient=");

Cpartial=s.nextDouble();

System.out.print("enter the Residual resistance coefficient=");

```

```

CR=s.nextDouble();

System.out.print("enter the wetted surfaces coefficient=");

S=s.nextDouble();

CT=Cpartial+CR;

System.out.print("enter the density of water=");

dw=s.nextDouble();

R=CT*0.5*dw*S*V*V;

System.out.print("enter the service Allowance water in %=");

AL=s.nextDouble();

PE=R*V*(1+AL/100);

t1=d+e/(f*Math.pow(0.98-CB,3)+1);

t2=-0.01*Fa;

t3=2*((Dpro/Lw1)-0.04);

t=t1+t2+t3;

Eh=(1-t)/(1-w);

T=R/(1-t);

VA=(1-w)*V;

Adisk=3.14*Dpro*Dpro/4;

CTh=T/(0.5*(dw*Adisk*VA*VA));

Eprop1=(2/(1+Math.pow(CTh+1,0.5)))*0.65;

Eprop2=(2/(1+Math.pow(CTh+1,0.5)))*(0.81-0.014*CTh);

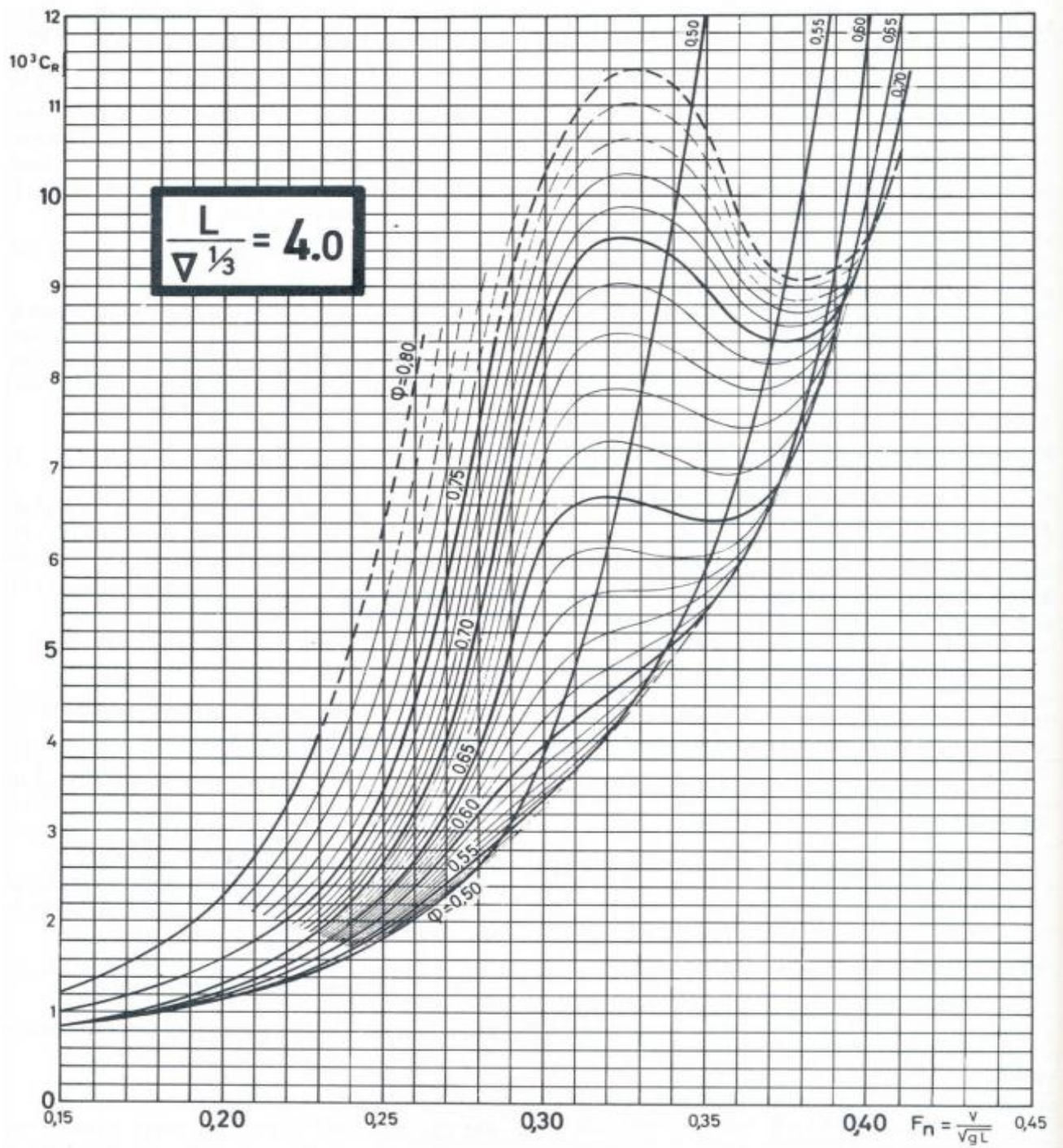
System.out.print("enter the relative rotating efficiency from 0.95-1.05 =");

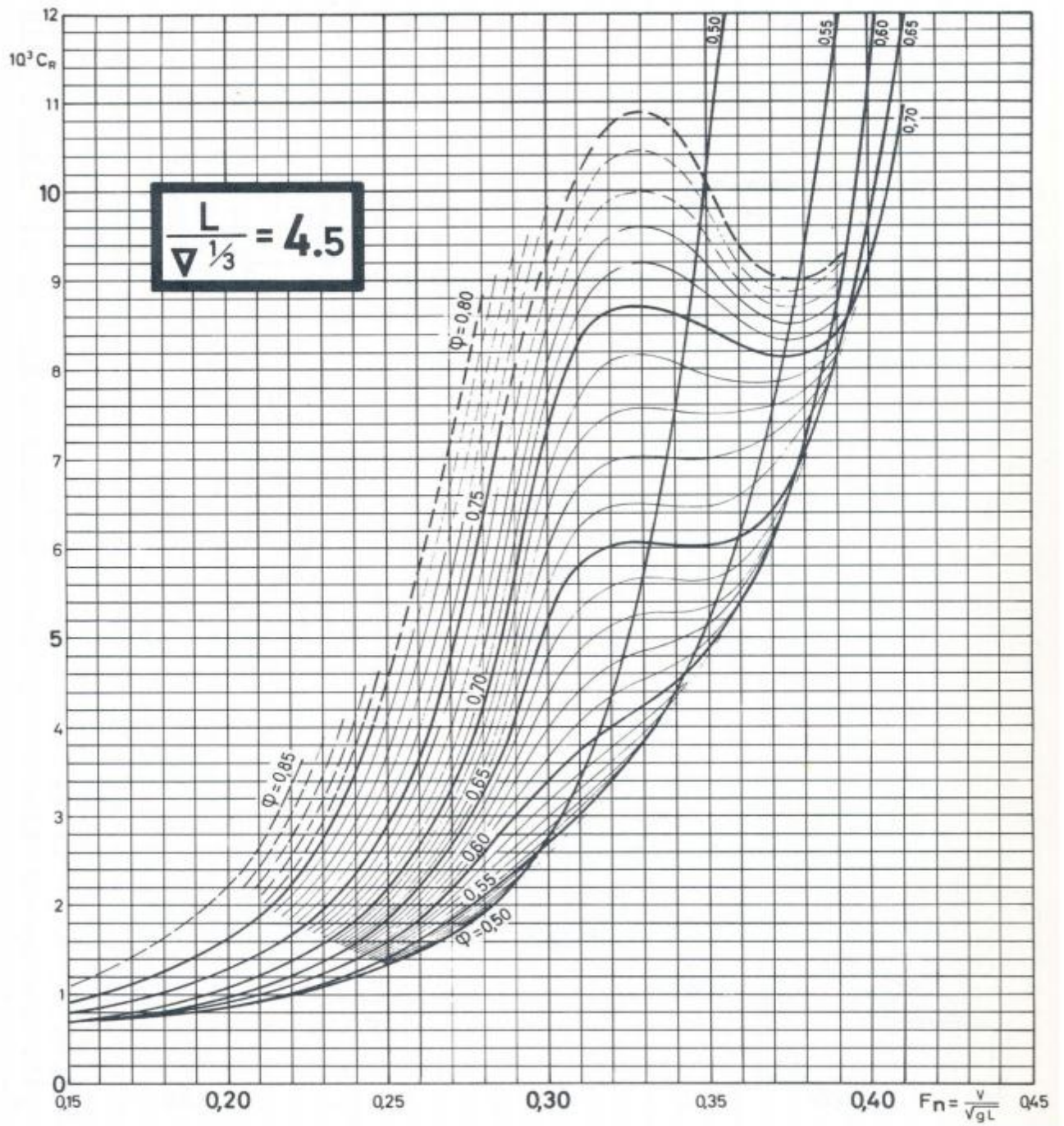
Er=s.nextDouble();

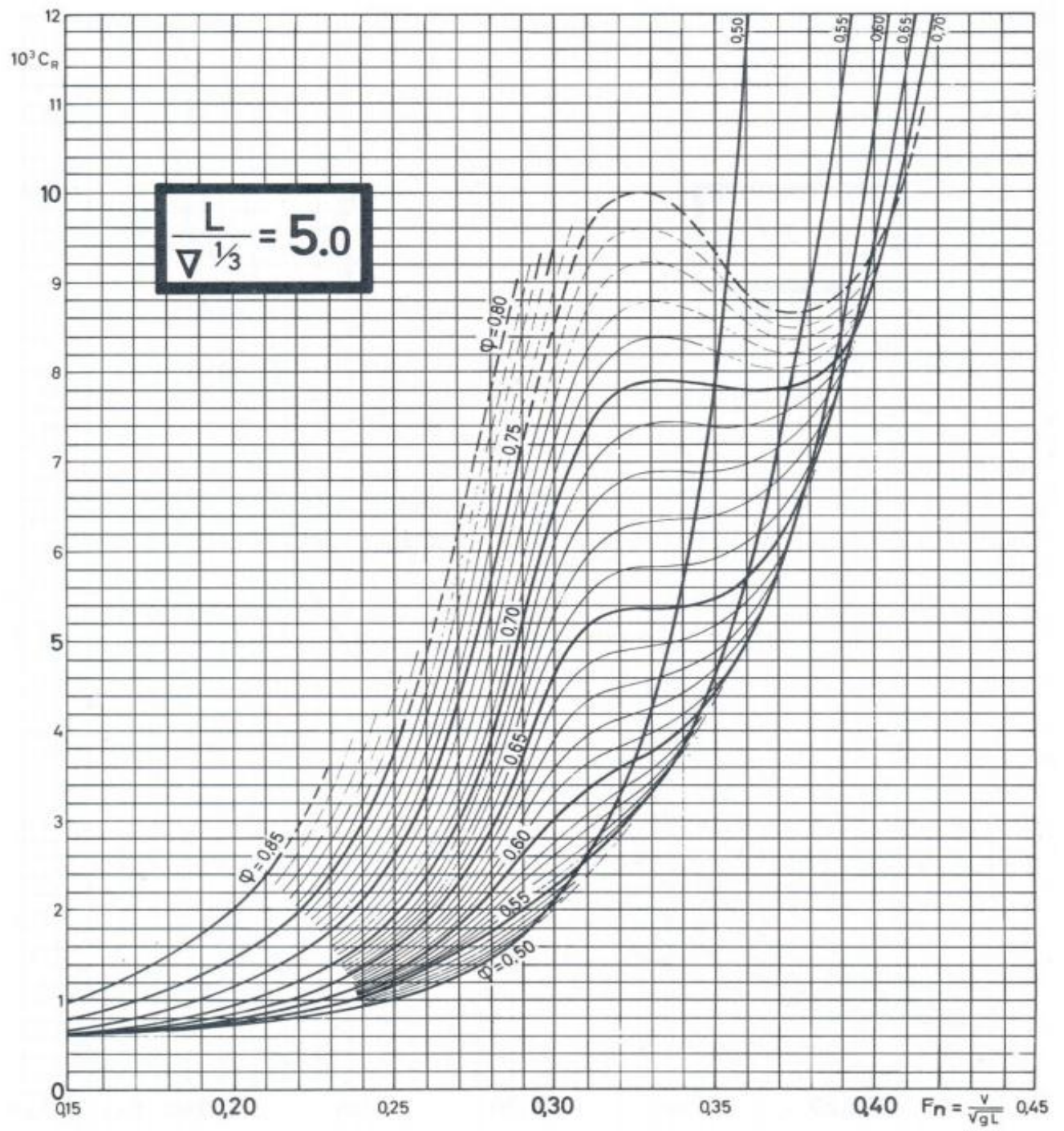
```

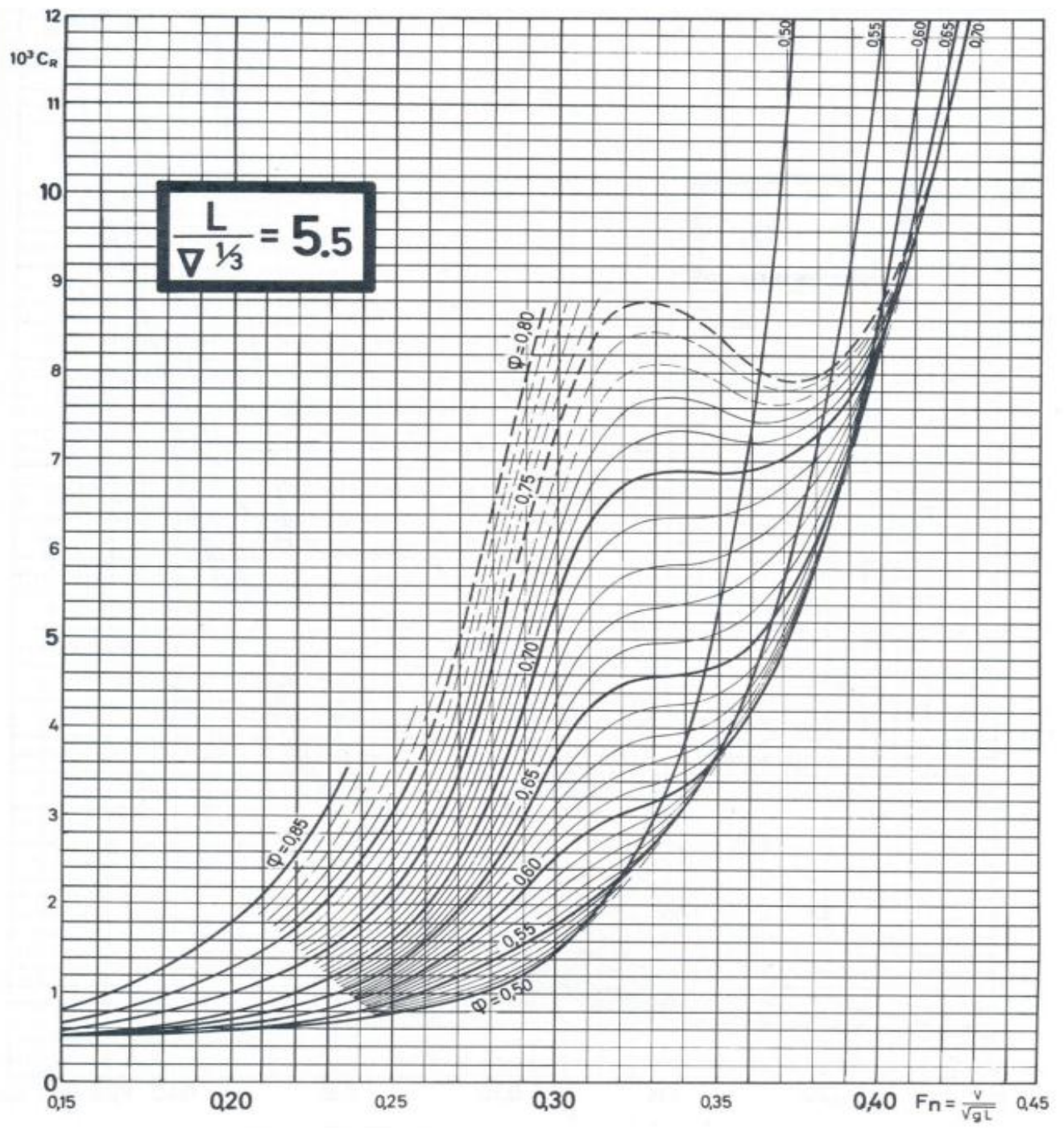
```
System.out.print("enter the shaft efficiency from 0.96-0.97 including gearbox=");  
  
Es=s.nextDouble();  
  
E=Eh*Eprop2*Er*Es;  
  
Pp=PE/E;  
  
System.out.print("*****OUTPUT RESULT*****");  
  
System.out.println("E="+E);  
  
System.out.println("Propeler power="+Pp);  
  
System.out.println("VA="+VA);  
  
System.out.println("CTh="+CTh);  
  
System.out.println("Eh="+Eh);  
  
    }}
```

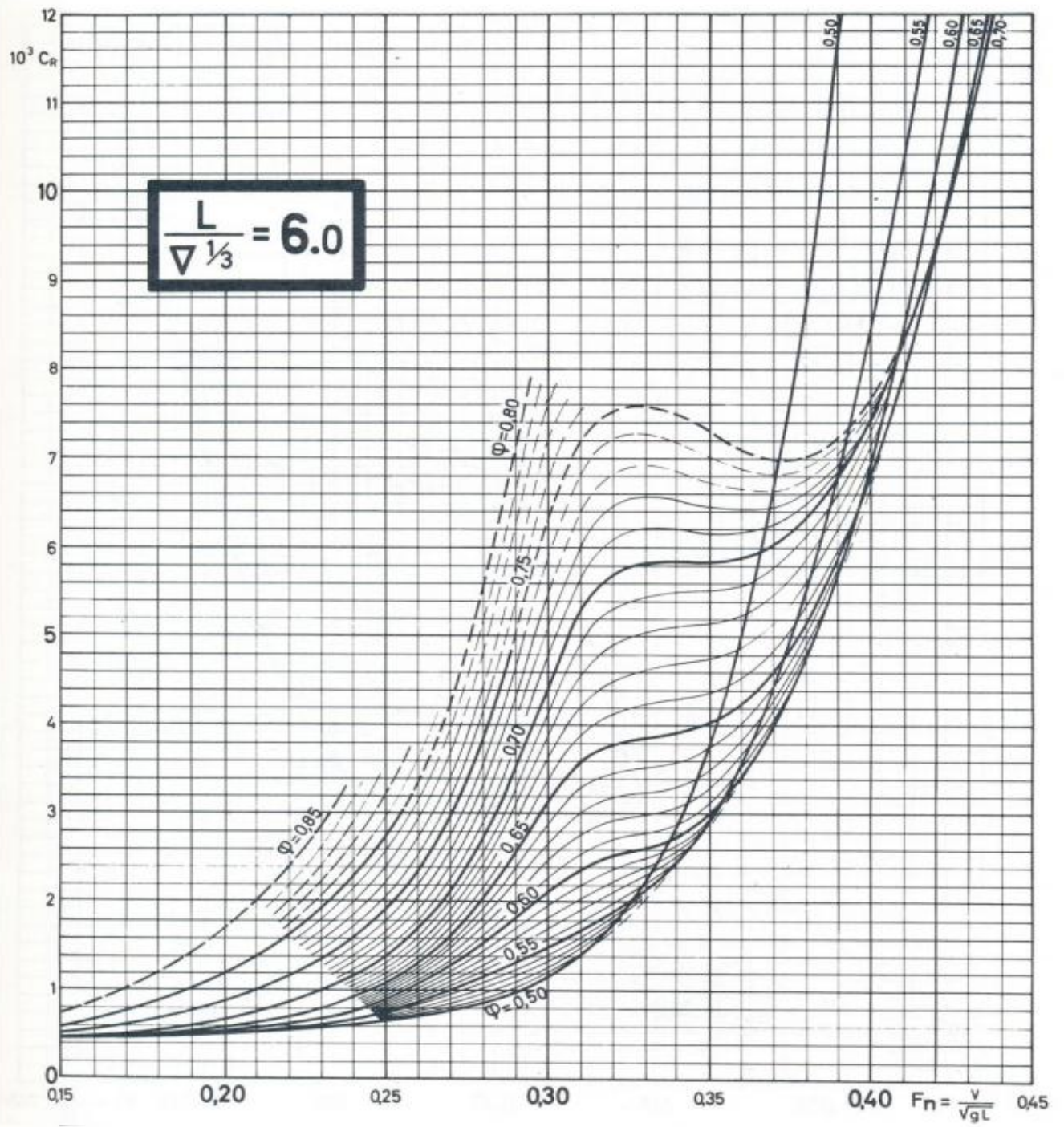
APPENDIX III Residual Coefficient Curve According to ITTC 57

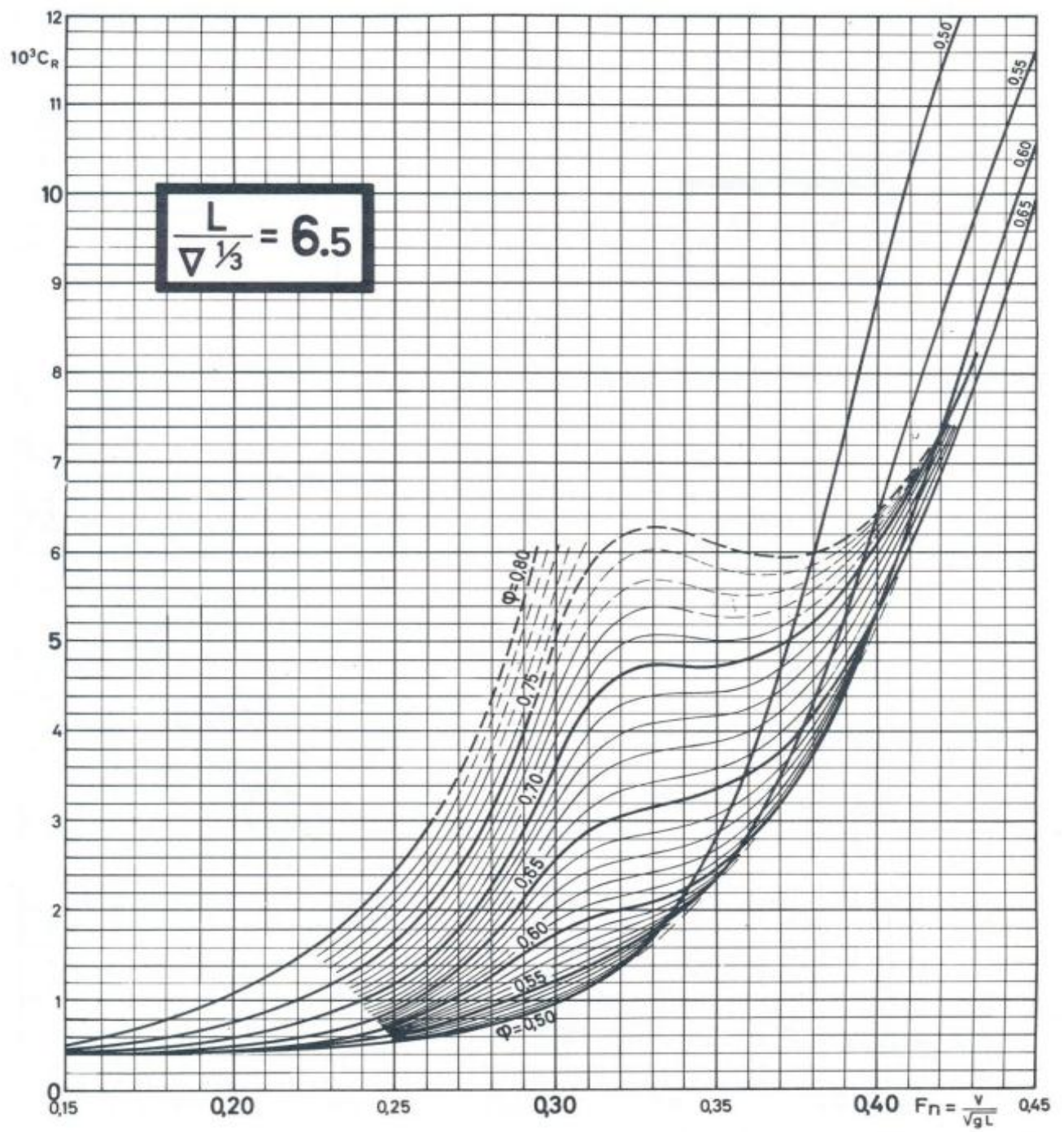


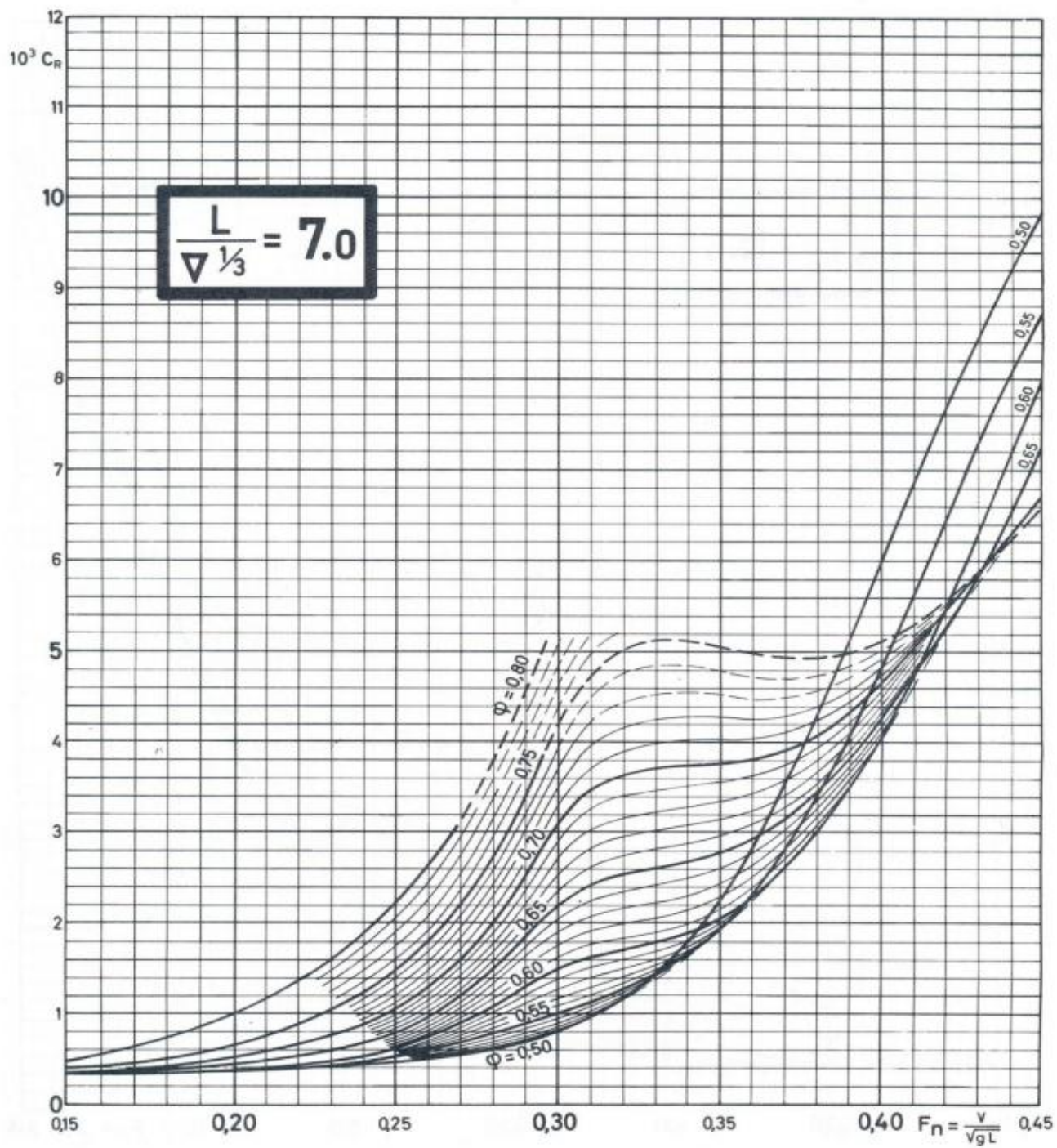


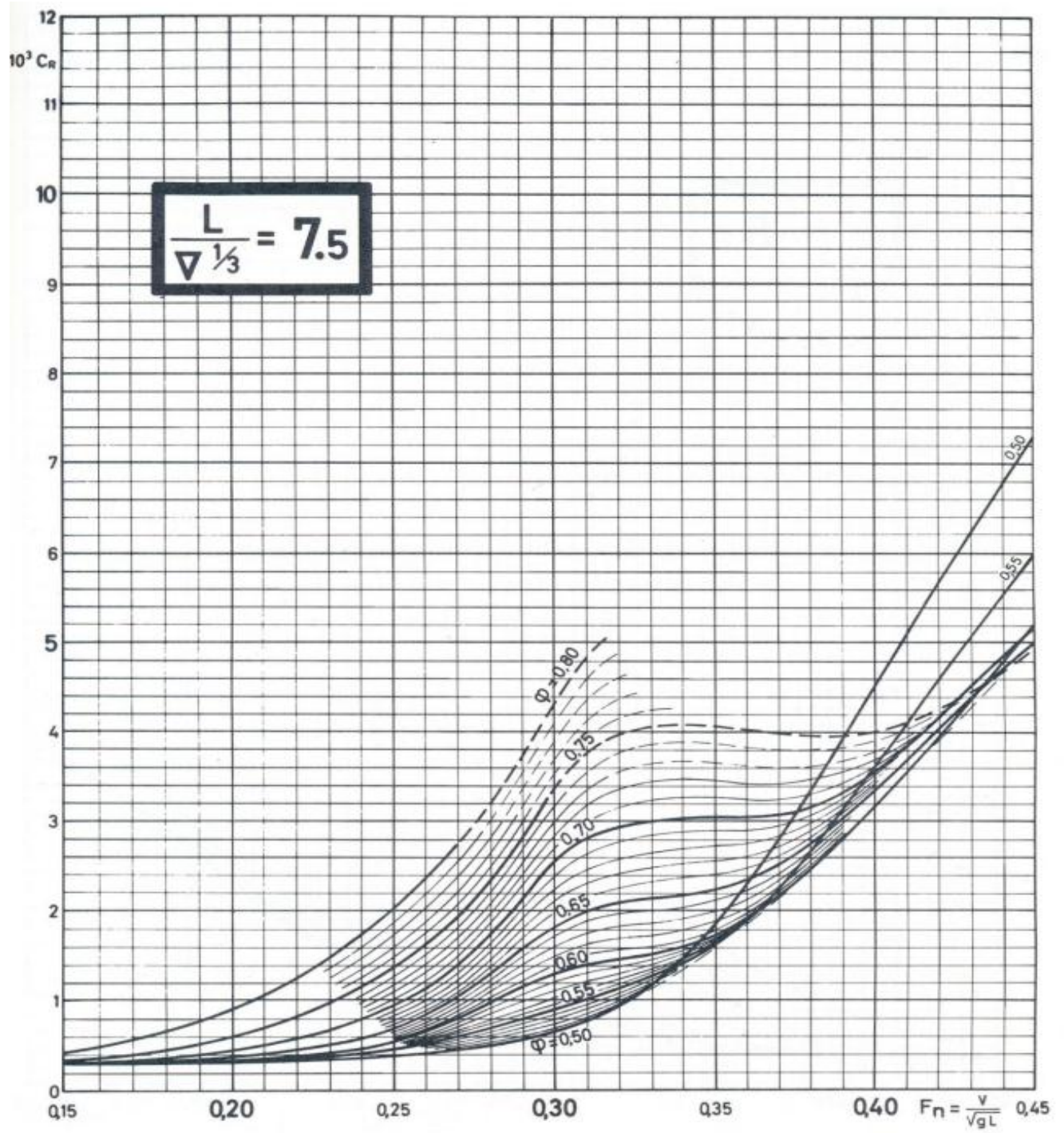


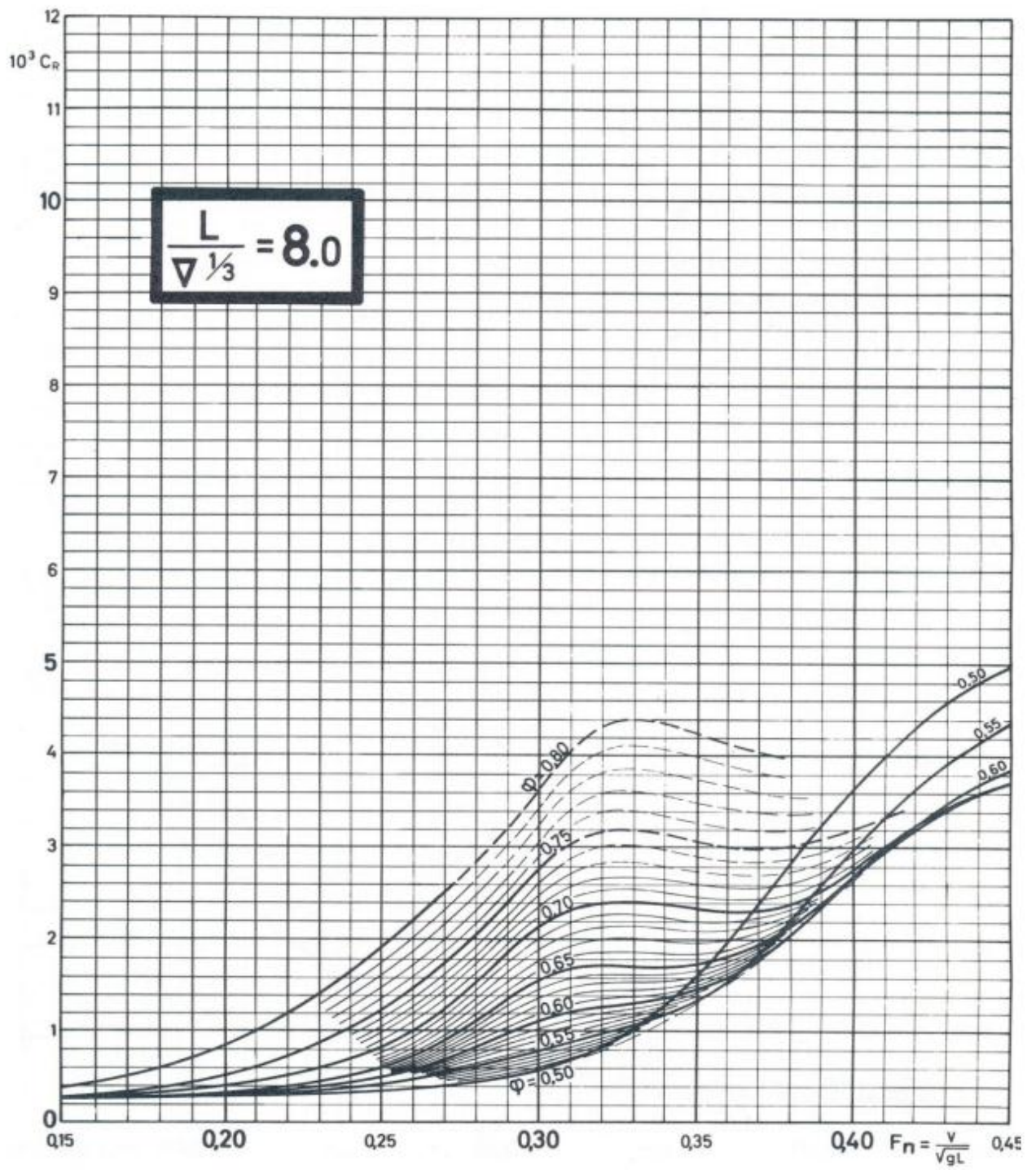












APPENDIX IV : Generator Specification

200w Vertical permanent magnet motor generator low rpm pmg



Quick Details

Place of Origin: China (Mainland)
Voltage: 230v 440v 380v 110v (custo...
Shaft Material: Nickel plated 40Cr Steel with q...
Winding Temperature Class: 150 °C

Type: wind or hydro turbine generator Material: Ndfab
Insulation Class: F Mounting: vertical or horizontal
Bearing: SKF bearing Shell Material: steel
Permanent Magnet Material: NdFeB N40SH Protection Grade: IP54

Specifications

Permanent magnet generator, We offer various kinds of permanent magnetic generator from 0.1KW-1500KW(vertical and horizontal

Product Description

We offer various kinds of permanent magnetic generator from 0.1KW-1500KW(vertical and horizontal), please contact us for more detail informations.

Features of permanent magnet generator

*Low start up speed, Gearless, low RPM generator

*High standard components for use in hard and extreme

Environments for wind turbine

*High efficiency low mechanical resistance energy loss

*Design for reliable long operational lifetime

Model	Rated power (W)	Rated voltage (V)	Rated rotated speed (rpm)	Startup torque (N*M)	Efficiency
LSL-50W	50	DC14	200	0.25	70%
LSL-100W	100	DC14	200	0.35	75%
LSL-200W	200	DC28	200	0.65	78%
LSL-300W	300	DC28	200	0.7	78%
LSL-500W	500	DC28	200	1.2	78%
LSL-1000W	1K	DC56	200	2	88%
LSL-2000W	2K	DC115	200	2.5	85%
LSL-3000W	3K	DC115	300	2.5	85%
LSL-5000W	5K	AC230	200	4	88%
LSL-10KW	10K	AC230	200	6.5	90%
LSL-20KW	20K	AC400	150	15	90%
LSL-50KW	50K	AC690	150	40	90%
LSL-100KW	100K	AC690	140	85	90%
LSL-300KW	300K	AC690	350	185	90%

APPENDIX V: Propellers specifications and Boat Motor Catalog

Cruise 2.0 R/T

Also available with tiller

5^{HP}
equivalent*

Cruise 4.0 R/T

Also available with remote throttle

8^{HP}
equivalent*



Cruise outboards - high-tech drive system with maximum efficiency:

The optimum torque characteristics of Torqeedo drive systems ensure maximum efficiency at any speed - greater performance and greater range than all other electric motors in this class with the same battery capacity. Equipped with all of the convenience of a genuine Torqeedo:

- + All models have a **GPS on-board computer and display** in the tiller or the remote throttle with real-time display of speed and input power - and the exact battery status and remaining range when used in combination with the Power 26-104 lithium battery
- + **Waterproof housing and plug connections (IP67)**, when connected or unconnected
- + **Extra robust design**, with lubricant-free polymer plain bearing. Protect against damage from debris - wear-resistant and maintenance-free
- + **Stable pylon** made from **highest-grade seawater-proof aluminum** and with an extra-reinforced fin, suitable for the toughest conditions
- + **Simple motor start** at the press of a button

Performance: speed and range**

Cruise 2.0 with 2 lead batteries (2 x 12 V / 200 Ah, battery weight approx. 265 lbs)

Dinghies and sailboats up to 3 tons	Speed in mph	Range in miles	Runtime in hh:mm
● ● ● Slow	approx. 3.1	approx. 31	10:00
● ● ● Full throttle	approx. 6.9	approx. 14	02:00

Cruise 4.0 with 2 x Power 26-104 (26 V / 104 Ah, battery weight 106 lbs)

Motorboats and sailboats up to 4 tons	Speed in mph	Range in miles	Runtime in hh:mm
● ● ● Slow	approx. 3.1	approx. 33.4	10:45
● ● ● Full throttle	approx. 8.1***	approx. 9.2	01:10

Aluminum 4 Deluxe-8 HP Pin Drive, 2-Stroke

- 4 & 4.5 HP, 1980 - 1986
- 6 / 7.5 / 8 HP, 1980 - 2005
- 7 HP Commercial, 1991 - 2000



RH P/N	LH P/N	Description	Blades	Dia.	Pitch
778796		Aluminum	3	8"	7"

Aluminum 6 HP Pin Drive, 2-Stroke

- 1966 - 1979



RH P/N	LH P/N	Description	Blades	Dia.	Pitch
763745		Aluminum	2	8"	7 1/4"
763588		Aluminum	3	8 1/4"	8"
763586		Aluminum	3	8 1/4"	9"

Boat motor catalog

version V01.06

Article no.	Type	Continuous power		Voltage	Current	Total efficiency	Weight	up to boat weight	
		Consumption	Output					Sailing boat	Powerboat
102817	GPRV 0,5	0,5 kW	0,4 kW	24 V	21 A	85 %	15 kg	0,4 t	0,2 t
141303	GPRV 0,8	0,8 kW	0,7 kW	24 V	34 A	85 %	16 kg	0,7 t	0,3 t
102181	GPRV 1,6	1,6 kW	1,4 kW	24 V	67 A	85 %	21 kg	1,4 t	0,6 t
102182	GPRV 2,2	2,2 kW	1,9 kW	36 V	61 A	85 %	21 kg	1,9 t	0,8 t
138932	ACR 1,8	2,4 kW	1,8 kW	24 V	100 A	75 %	22 kg	1,8 t	0,7 t
	ACR 2,0	2,6 kW	2,0 kW	24 V	107 A	78 %	30 kg	2,0 t	0,8 t
139425	ACR 4,0	5,0 kW	4,0 kW	48 V	104 A	80 %	30 kg	4,0 t	1,6 t
140404	ACR 8,0	9,7 kW	8,0 kW	48 V	202 A	82 %	44 kg	8,0 t	3,2 t
141646	ACRS 10,0	12,0 kW	10,0 kW	48 V	250 A	83 %	54 kg	10,0 t	4,0 t
possible option									
	GPRV 0,5 and GPRV 0,8 with two-stage switch for speed control								
104817	Rudder for GPRV								
138910	Rudder for ACR 1,8 und ACR 4,0								
105297	Special shaft length up to 1m to 5kW motor power								
140888	Special shaft length up to 1m for ACR 8,0								
101358	Rudder gland for GPRV, ACR 1,8 and ACR 4,0 - Ø30mm, length 175mm								
104066	Rudder gland for GPRV, ACR 1,8 and ACR 4,0 - Ø30mm, length 275mm								
140077	Rudder gland for ACR 8,0 and ACRS 10,0 - Ø40mm, length 205mm								
138905	Rudder gland for ACR 8,0 and ACRS 10,0 - Ø40mm, length 305mm								

Length of standard shaft 450mm

Attention: The GPRV motor is only for short term use in seawater.

APPENDIX VI : Spur Gear Catalog

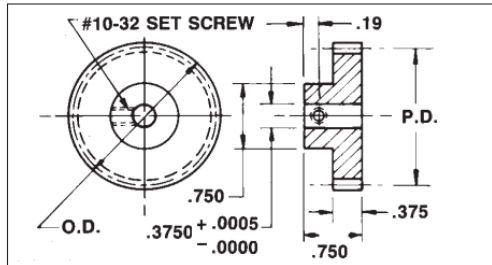
www.pic-design.com
Interactive catalog ■ CAD ■ e-commerce



Phone: 800-243-6125 ■ FAX: 203-758-8271
E-Mail: sales@pic-design.com

SPUR GEAR-20 PITCH — $\frac{3}{8}$ " Face Width ■ 20° Pressure Angle

Pin Hub — $\frac{3}{8}$ " Bore



For gears with a number of teeth not shown within the range listed above, substitute the required number of teeth for the digits at the end of the Part Number.

Pricing can be determined by using our online E-Commerce price list for the next higher published part number in the listing.

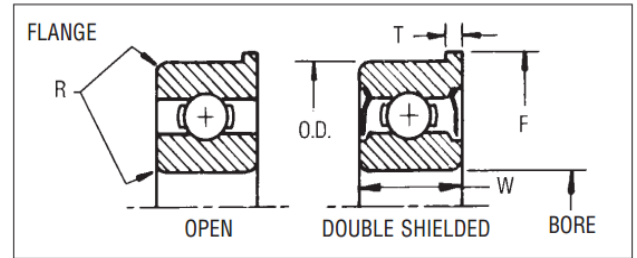
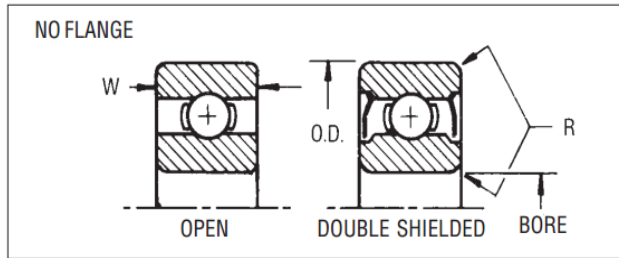
AGMA Quality Number 10-C	Tooth-to-Tooth Composite	Total Composite
Up to 20 Teeth Inclusive	.0007	.0010
Over 20 Teeth—up to 1.999" P.D.	.0005	.0010
Over 20 Teeth—2" to 2.999" P.D.	.0005	.0012
Over 20 Teeth—4" P.D. and over	.0005	.0014

"C"—BACKLASH DESIGNATION.

Provides .0005 to .001 tooth thinning at pitch line. Allows operation on theoretical centers.

Gear Data			#303 STAINLESS STEEL	BRONZE Alloy 464
No. Teeth	P.D.	O.D.	Part No.	Part No.
18	.9000	1.000	G77-18	G78-18
20	1.0000	1.100	G77-20	G78-20
24	1.2000	1.300	G77-24	G78-24
28	1.4000	1.500	G77-28	G78-28
30	1.5000	1.600	G77-30	G78-30
36	1.8000	1.900	G77-36	G78-36
40	2.0000	2.100	G77-40	G78-40
48	2.4000	2.500	G77-48	G78-48
56	2.8000	2.900	G77-56	G78-56
60	3.0000	3.100	G77-60	G78-60
72	3.6000	3.700	G77-72	G78-72
80	4.0000	4.100	G77-80	G78-80
84	4.2000	4.300	G77-84	G78-84
96	4.8000	4.900	G77-96	G78-96
100	5.0000	5.100	G77-100	G78-100

APPENDIX VII: Bearing Catalog



Material: ABEC 3 & 7 440 Stainless Steel
ABEC 1 - 52100 Steel

Lubrication: Open - Oil per MIL-L-6085
Double Shielded & Sealed: Grease per MIL-G-23827

PRECISION BALL BEARINGS

Continued from page 6-4

ABEC 1, 3, and 7 Tolerances

Bore	O.D.	W	F	T	R Radius	Shield Data	Radial Load Rating (lbs.)		No Flange			Flanged		
									ABEC 1 Part No.	ABEC 3 Part No.	ABEC 7 Part No.	ABEC 1 Part No.	ABEC 3 Part No.	ABEC 7 Part No.
							Dynamic	Static						
.6250	1.375	.2812 .3438			.031	Open Dbl. Shield	1072	582	E9-01 E9-S1	E9-03 E9-S3				
.7500	1.625	.3125 .4375			.031	Open Dbl. Shield	1688	1048	E10-01 E10-S1	E10-03 E10-S3				
.8750	1.875	.3750 .5000			.031	Open Dbl. Shield	1816	1048	E11-01 E11-S1	E11-03 E11-S3				
1.000	2.000	.3750 .5000			.031	Open Dbl. Shield	1816	1048	E12-01 E12-S1	E12-03 E12-S3				
*1.1250	2.1250	.5000			.031	Open Dbl. Shield	2384	1488	E17-01 E17-S1	E17-03 E17-S3				
*1.2500	2.250	.3750 .5000			.031	Open Dbl. Shield	2384	1488	E18-01 E18-S1	E18-03 E18-S3				
*1.5000	2.625	.4375 .5625			.031	Open Dbl. Shield	3016	2072	E19-01 E19-S1	E19-03 E19-S3				

APPENDIX VIII : Wind and Current Force Coefficient for Standard River Boat

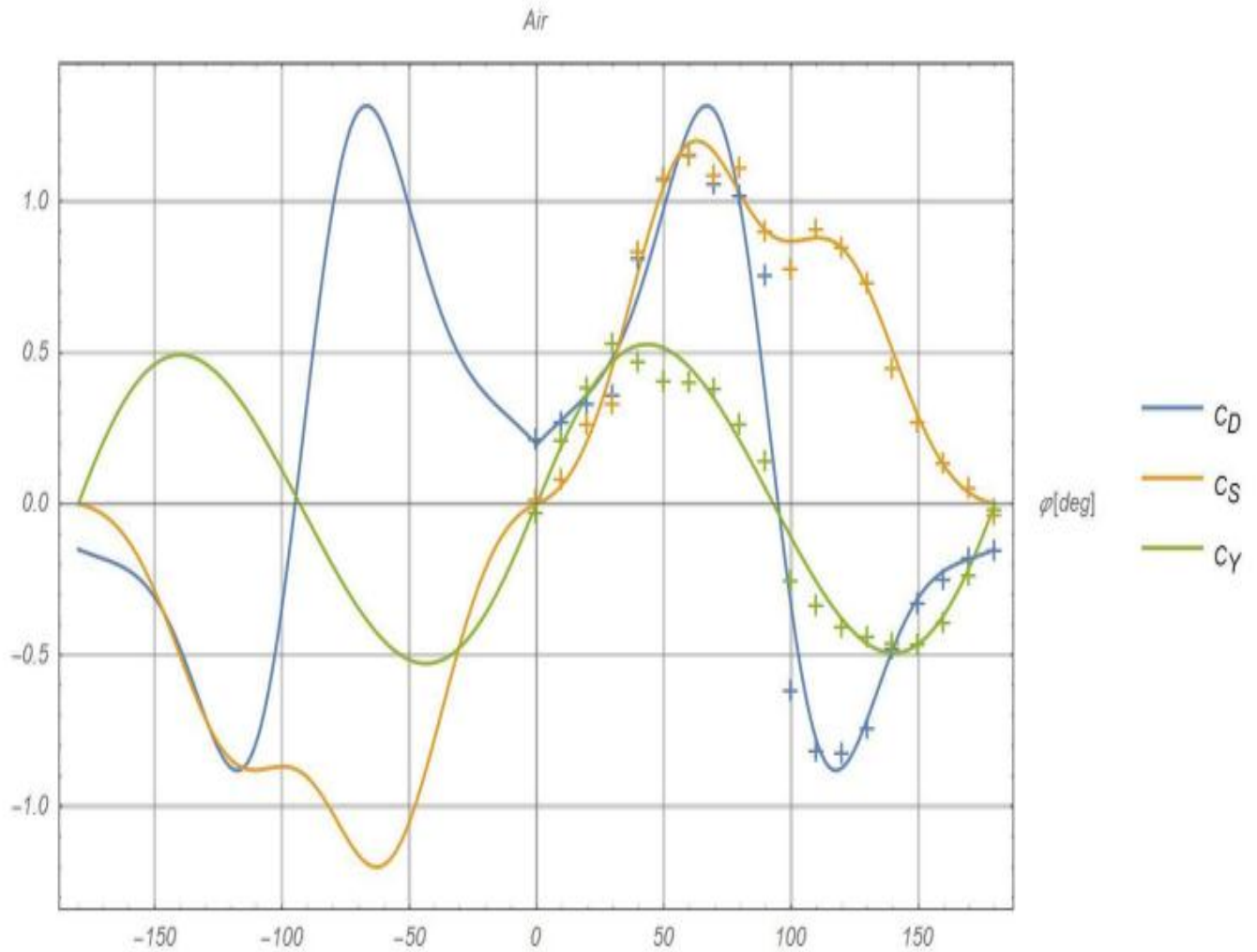


Figure 5-1: Boat air drags aerodynamic coefficients.

C_D , C_S , and C_Y are drag, side force coefficient, and yaw moment coefficient. ϕ is the apparent wind direction. Cross markers show data obtained from CFD simulations and curves show plots of basic mathematical Equation (Source: Mathematical modeling of River Boat).

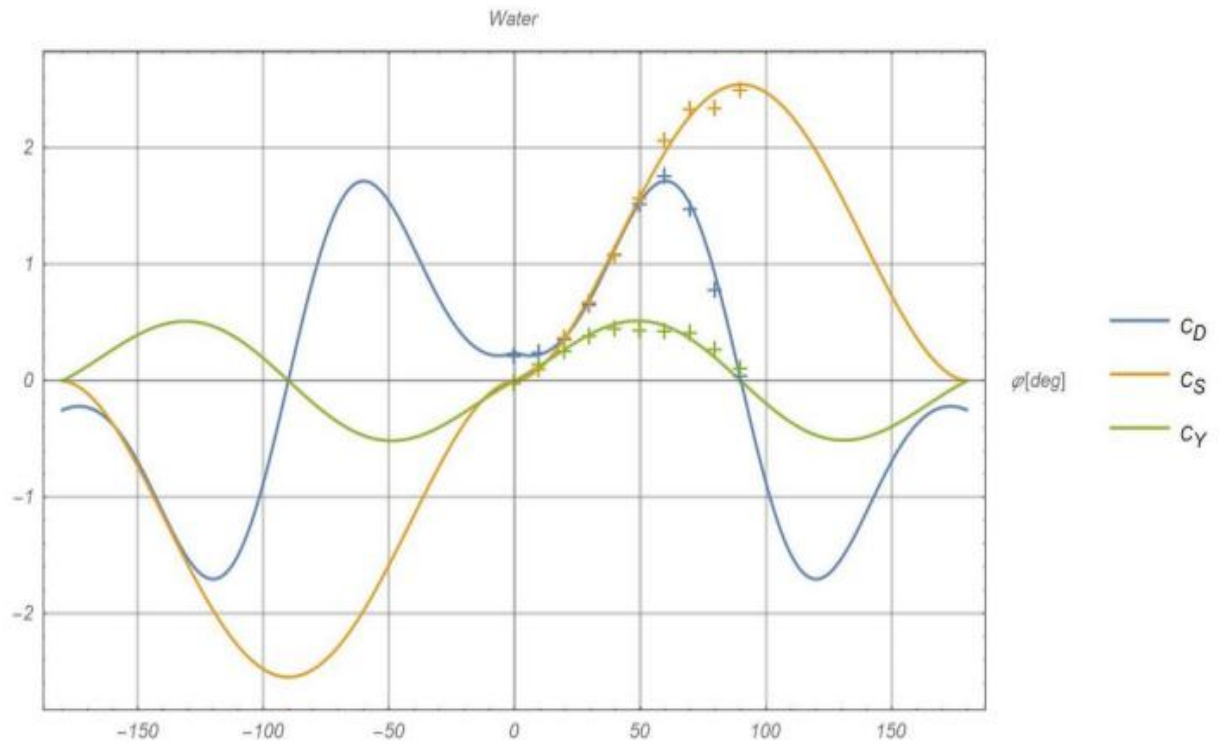
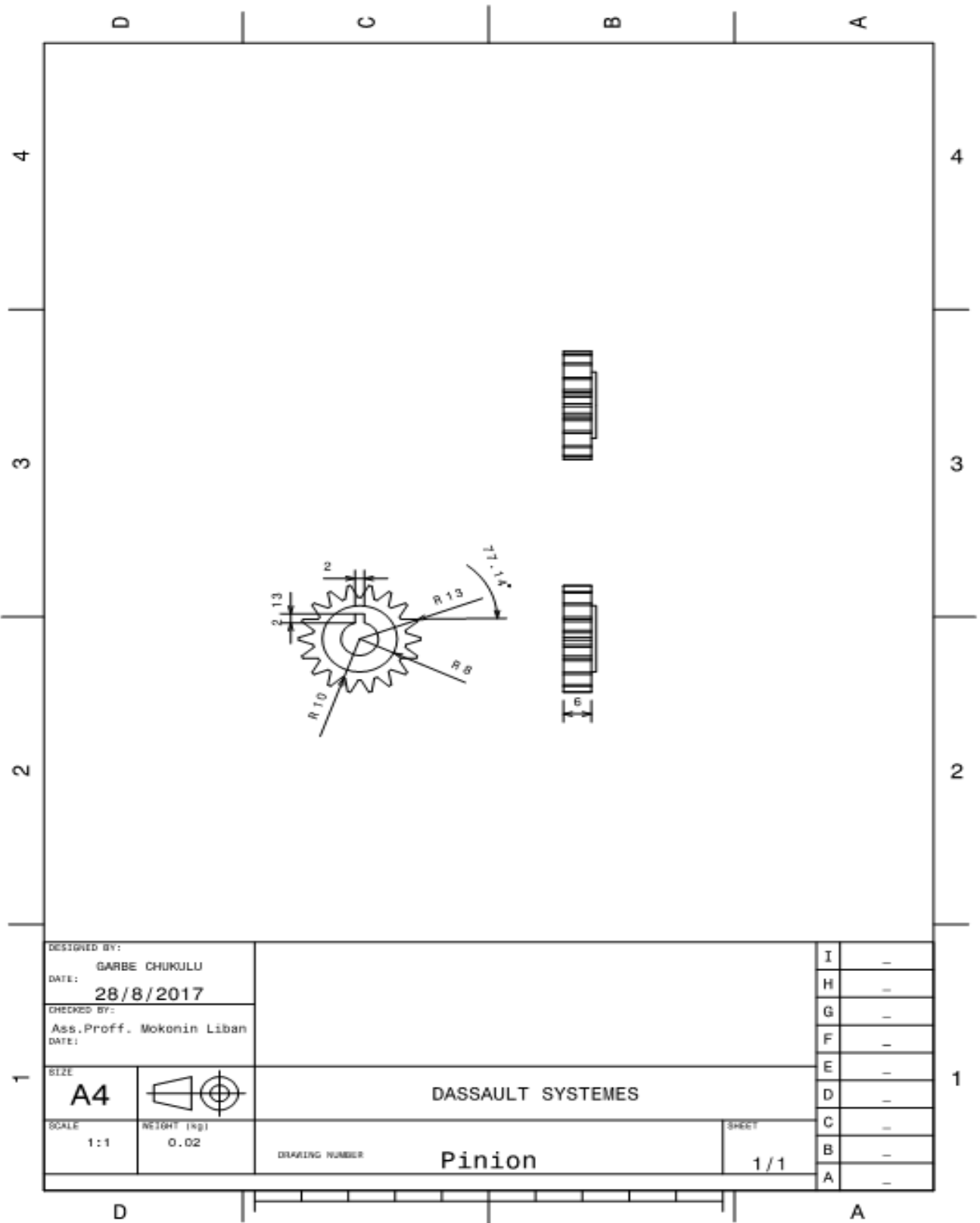
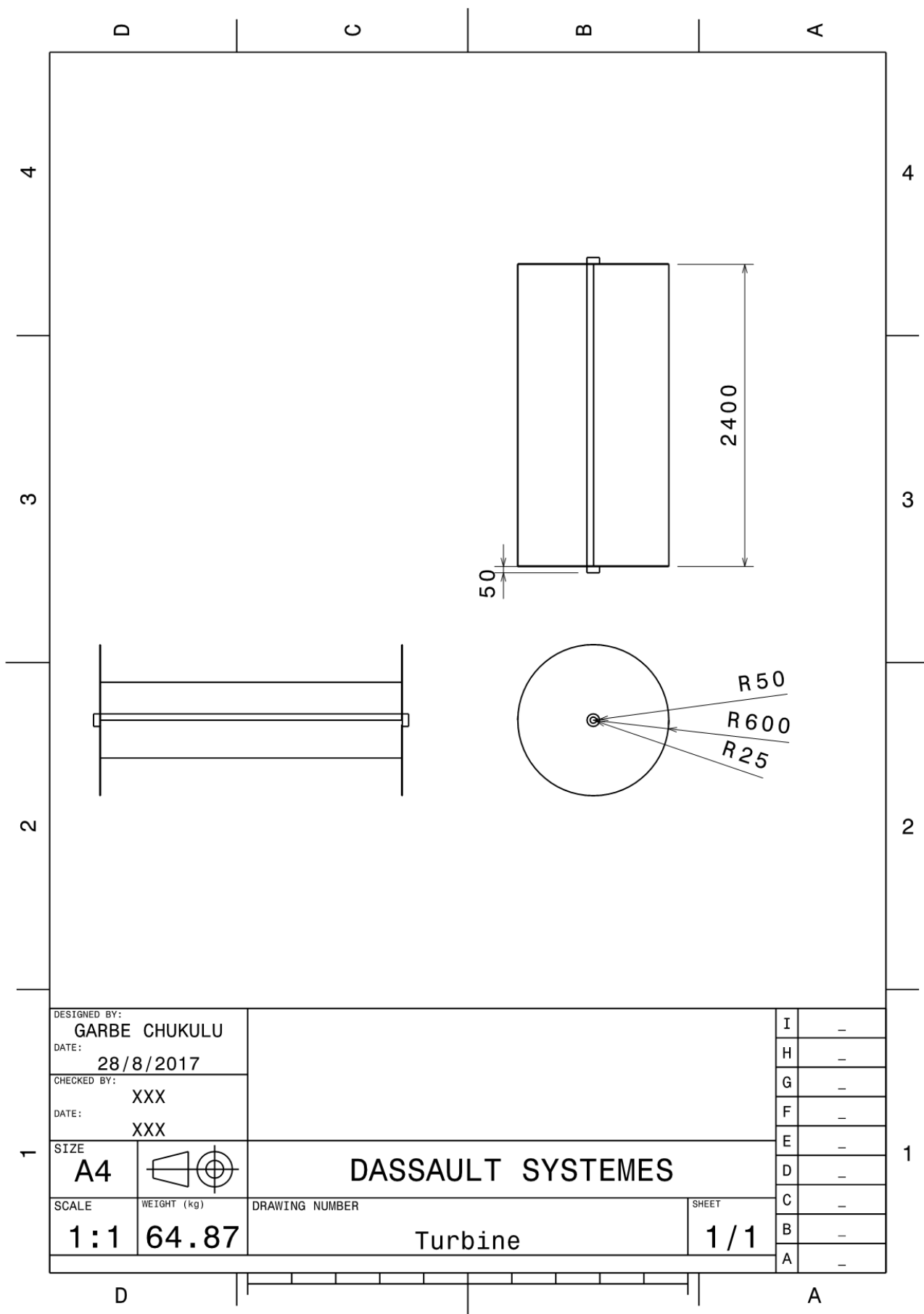


Figure 5-2: Boat water or current drags coefficients.

C_D , C_S , and C_Y are drag, side force coefficient, and yaw moment coefficient. φ is the apparent current direction. Cross markers show data obtained from CFD simulations and curves show plots of equation (Source: Mathematical modeling for river boat).

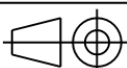
APPENDIX IX: Engineering Drawings





DESIGNED BY:
GARBE CHUKULU
DATE:
28/8/2017
CHECKED BY:
XXX
DATE:
XXX

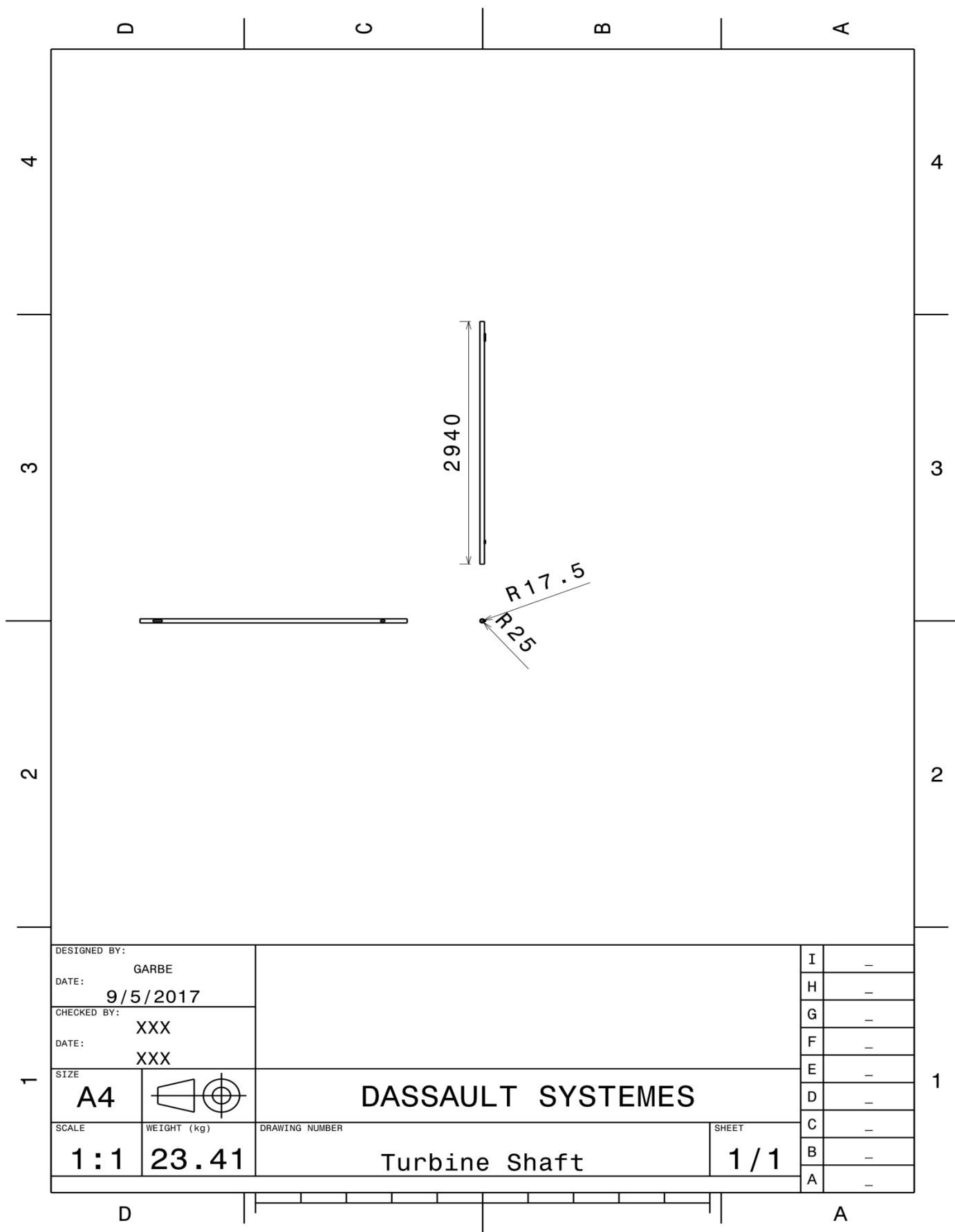
SIZE
A4

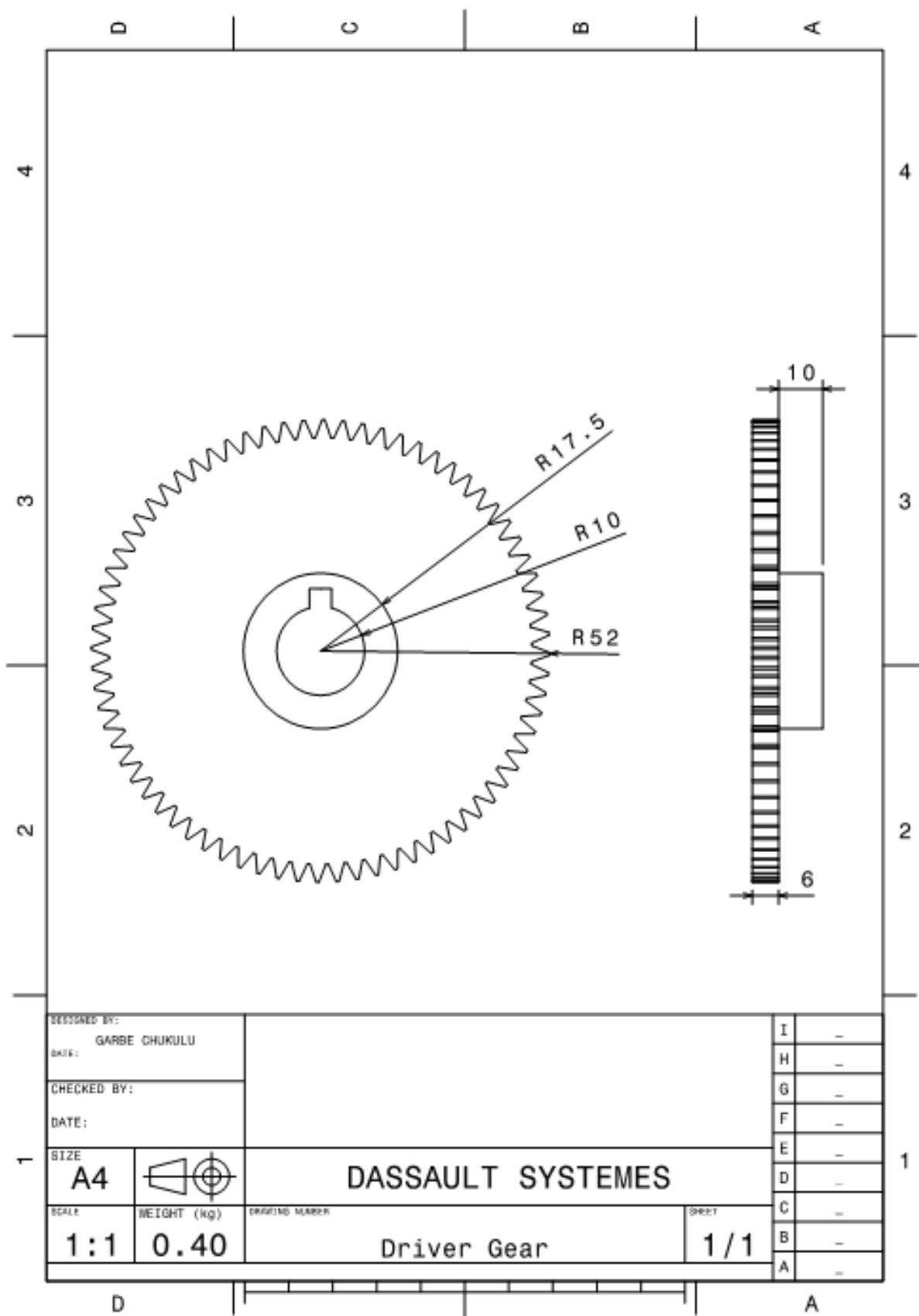


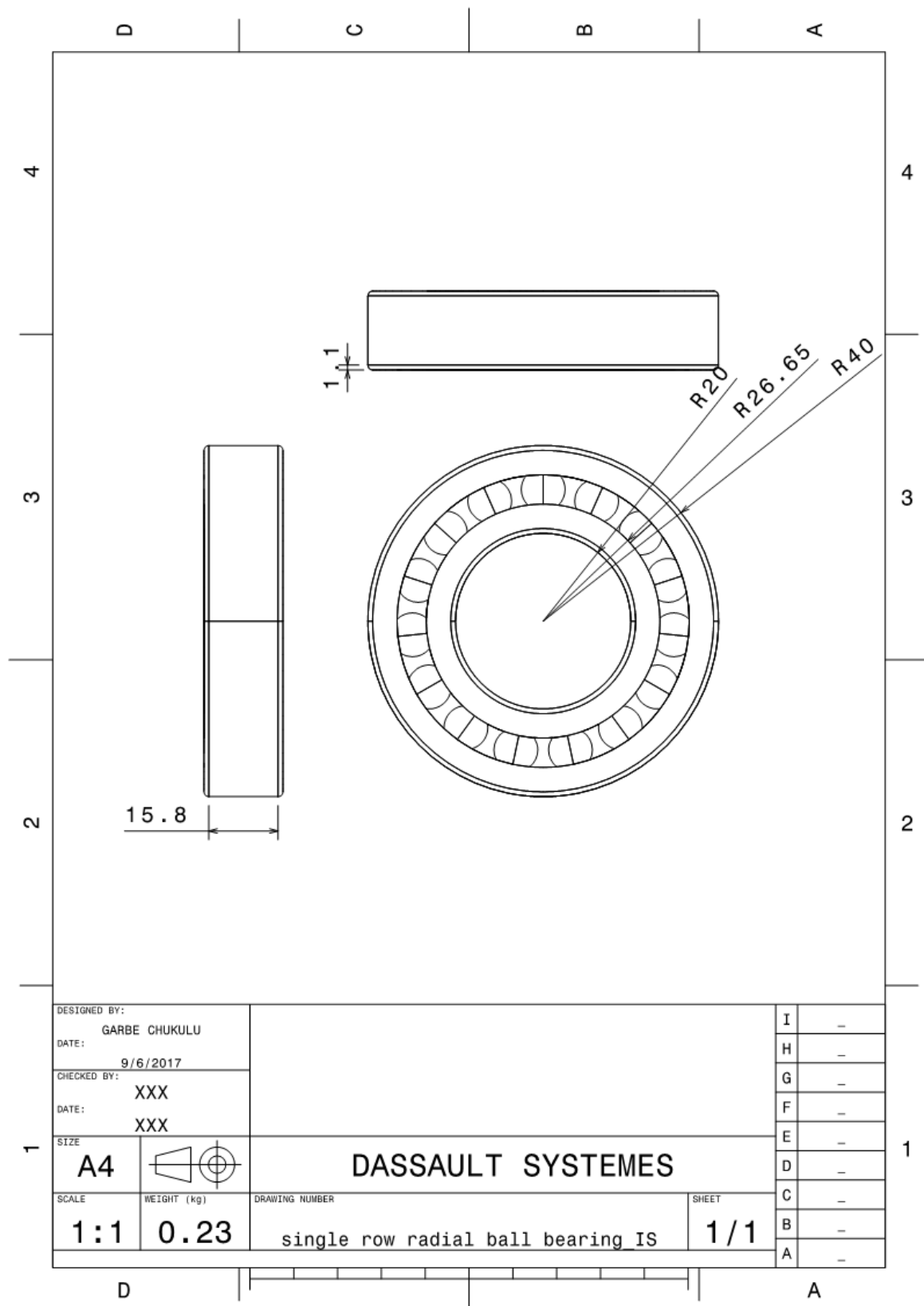
SCALE
1:1
WEIGHT (kg)
64.87

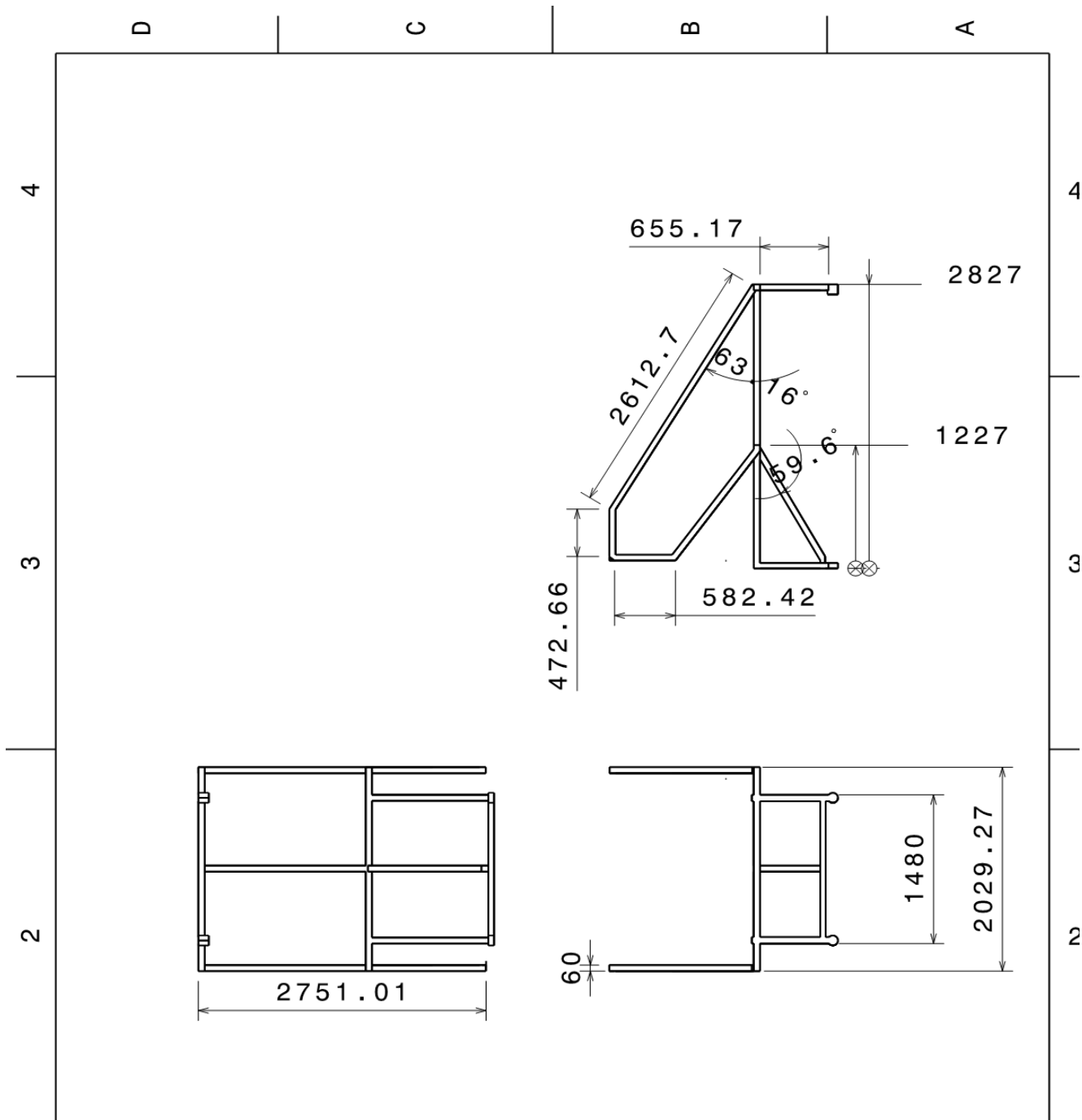
DASSAULT SYSTEMES
Turbine
DRAWING NUMBER
SHEET
1/1

I	-
H	-
G	-
F	-
E	-
D	-
C	-
B	-
A	-

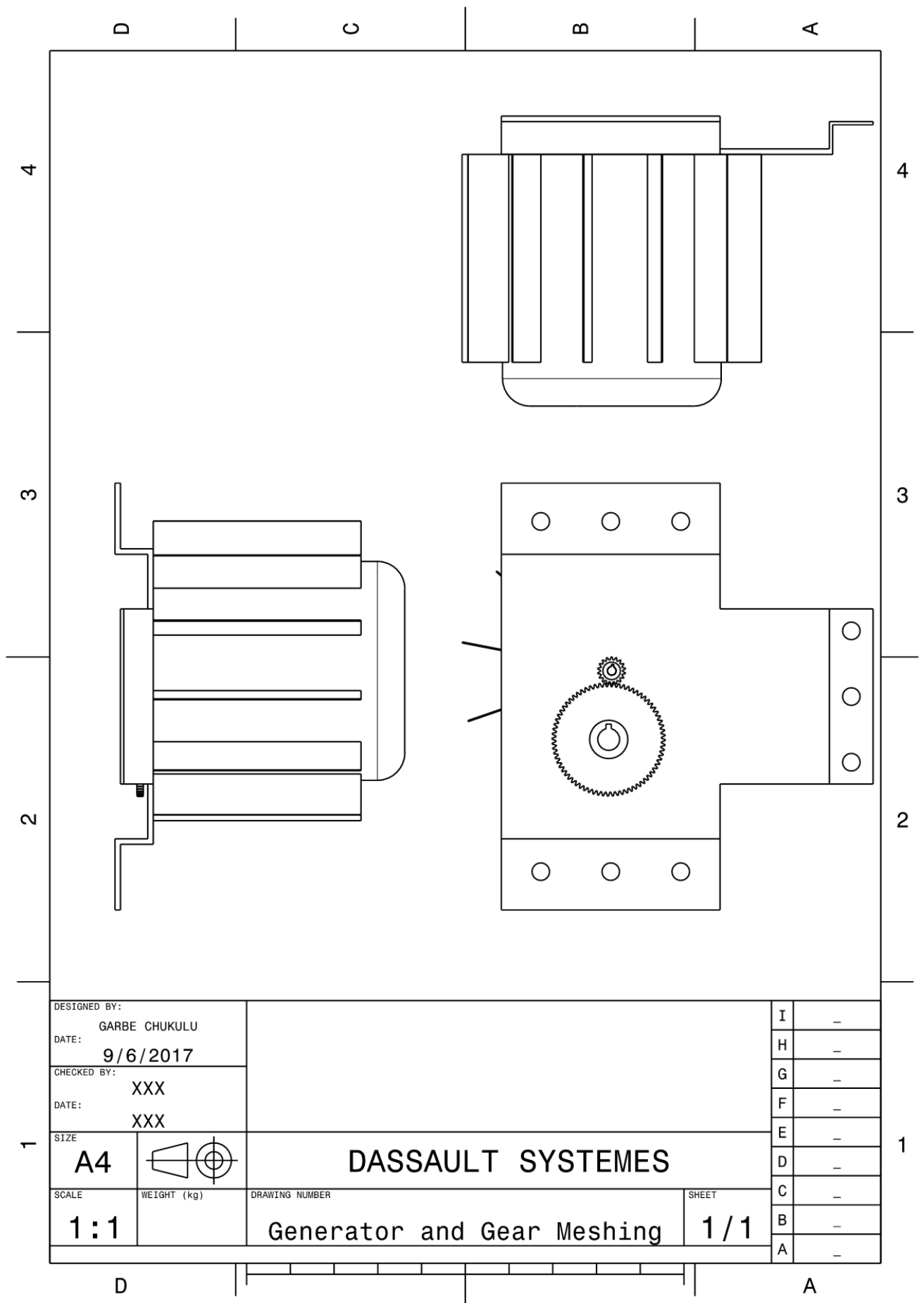


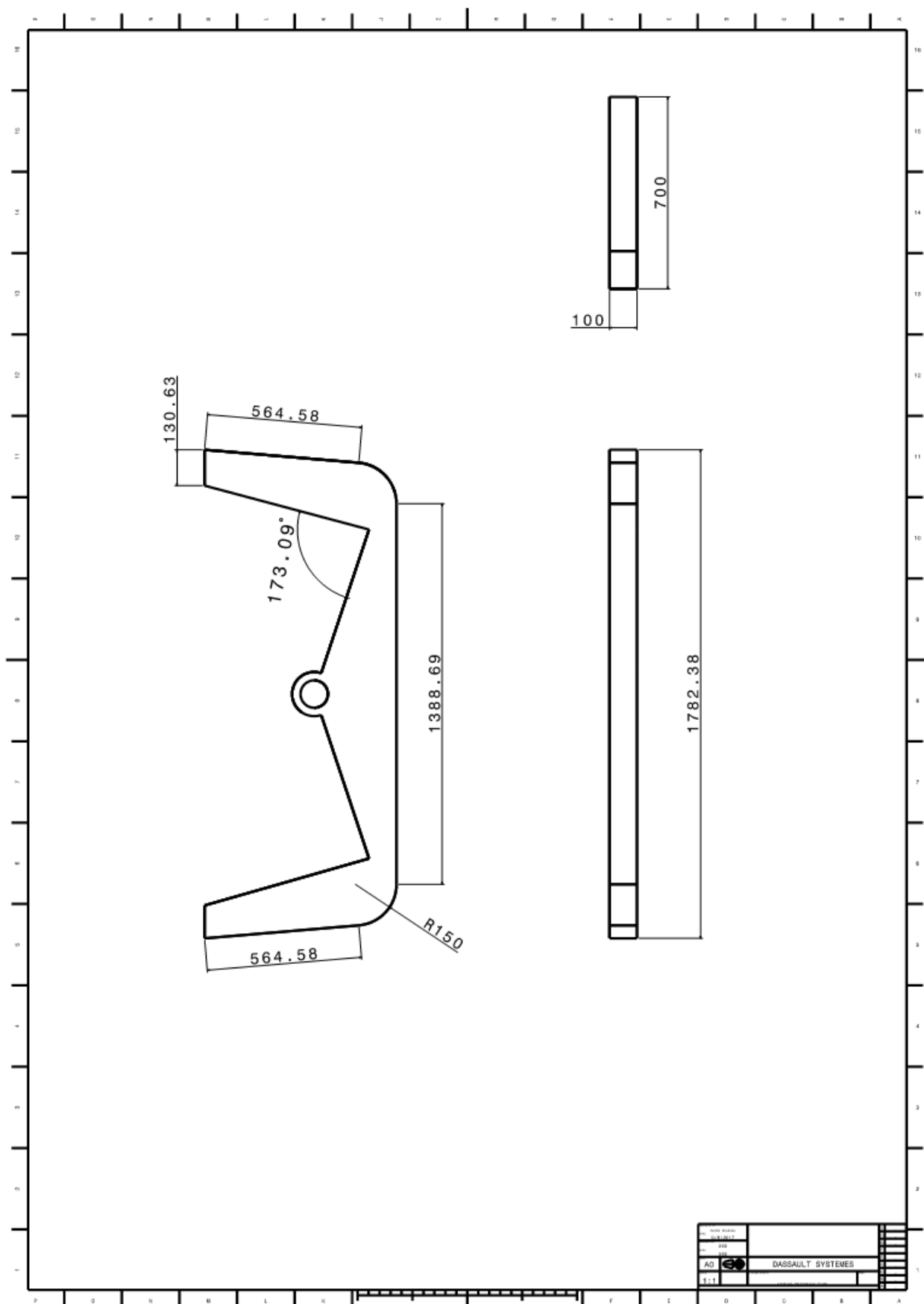


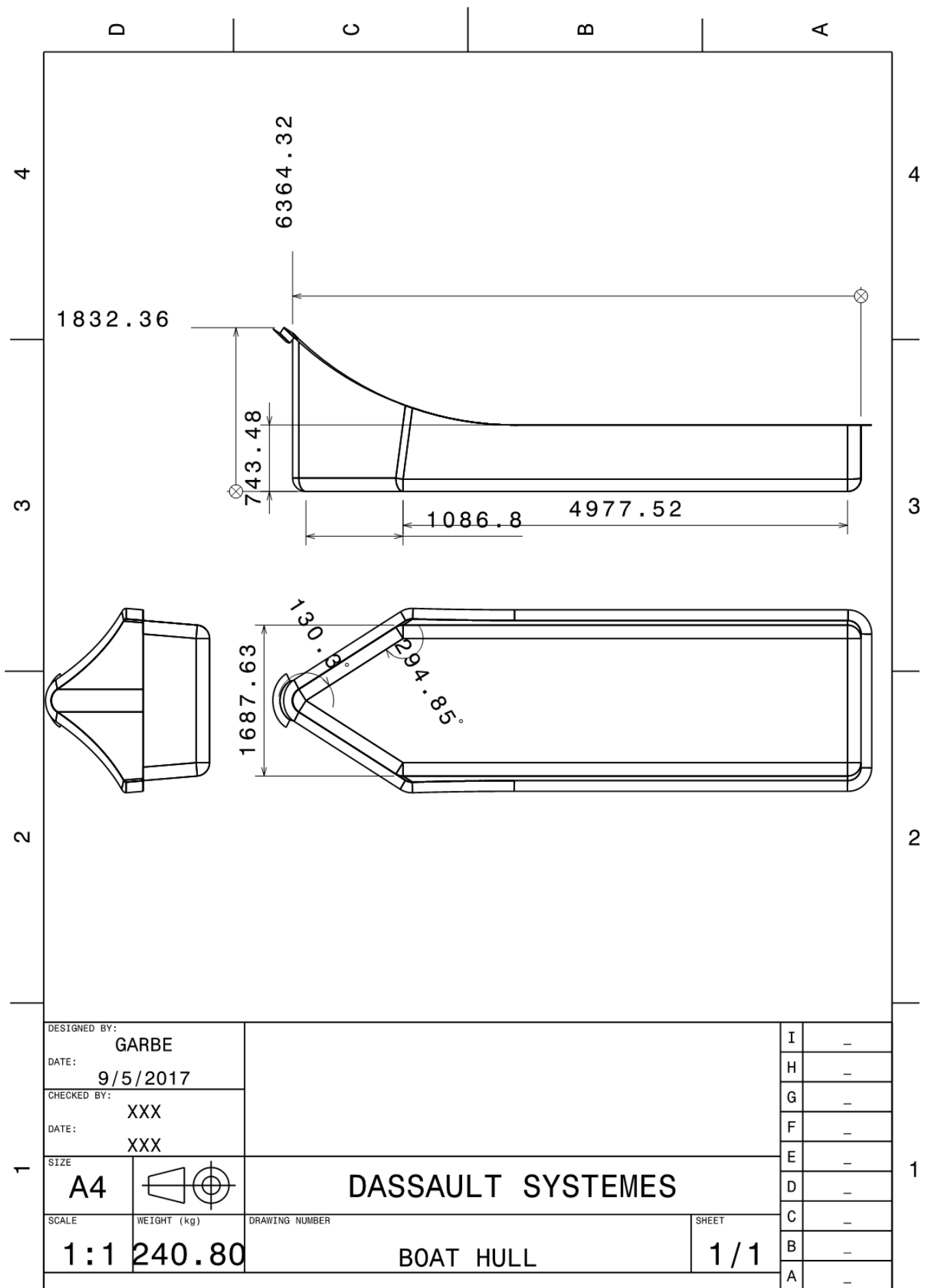




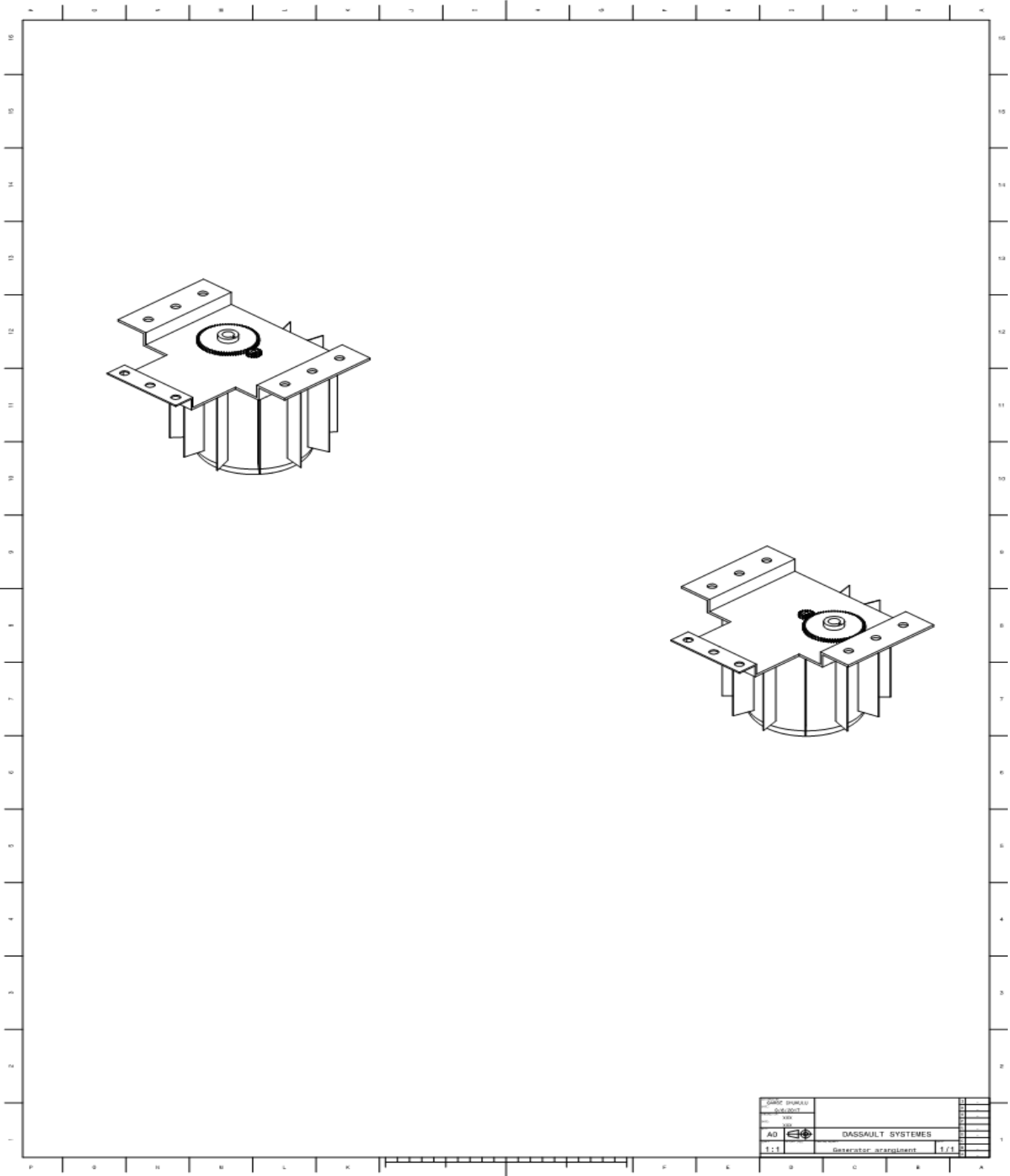
DESIGNED BY: GARBE CHUKULU				I	—	
DATE: 28/8/2017				H	—	
CHECKED BY: XXX				G	—	
DATE: XXX				F	—	
SIZE A4				E	—	
				D	—	
SCALE 1 : 1	WEIGHT (kg) 61.79	DRAWING NUMBER TURBINE MOUNTING FRAME		SHEET 1 / 1	C	—
					B	—
					A	—

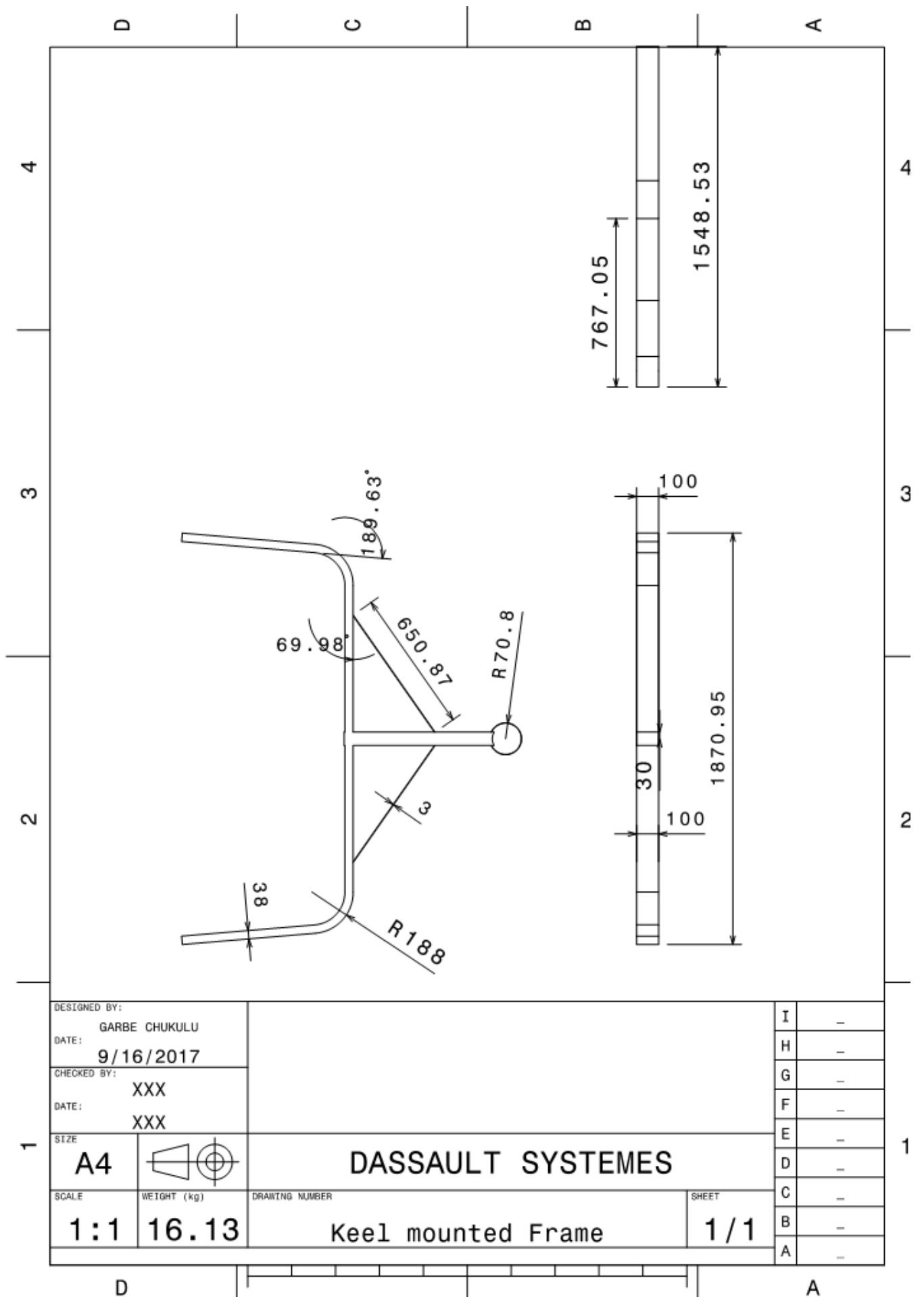


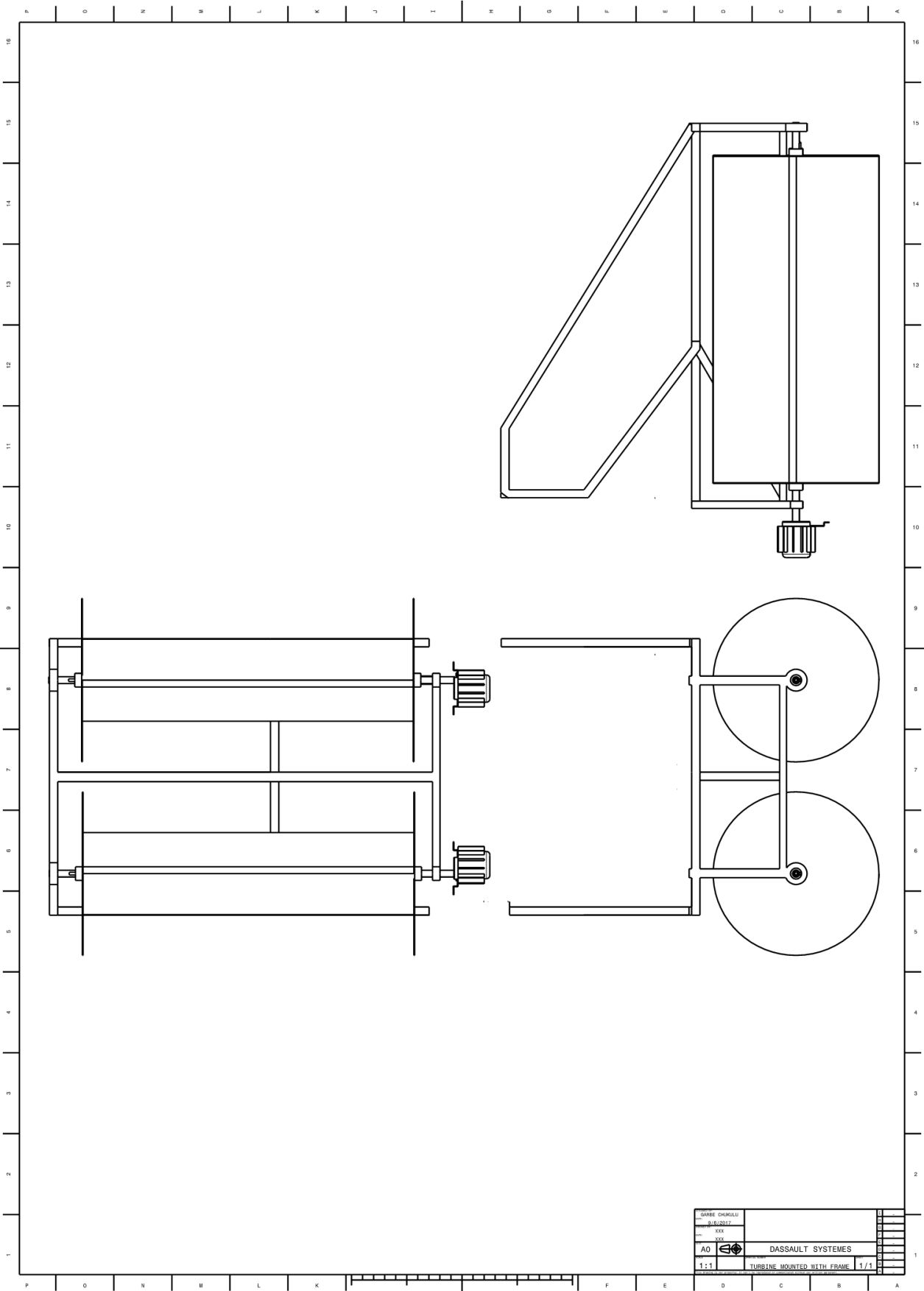




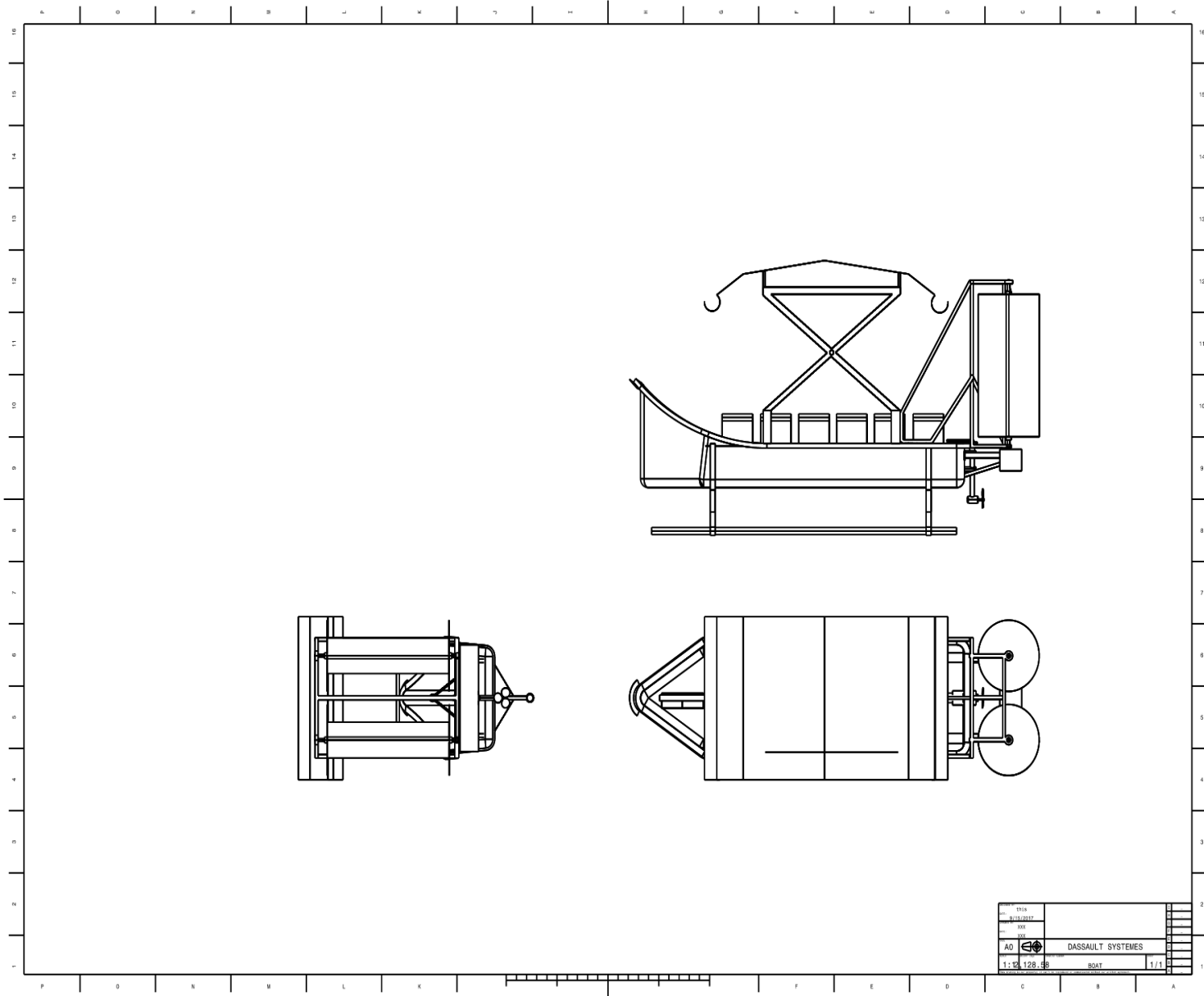
APPENDIX X: Component Assembly

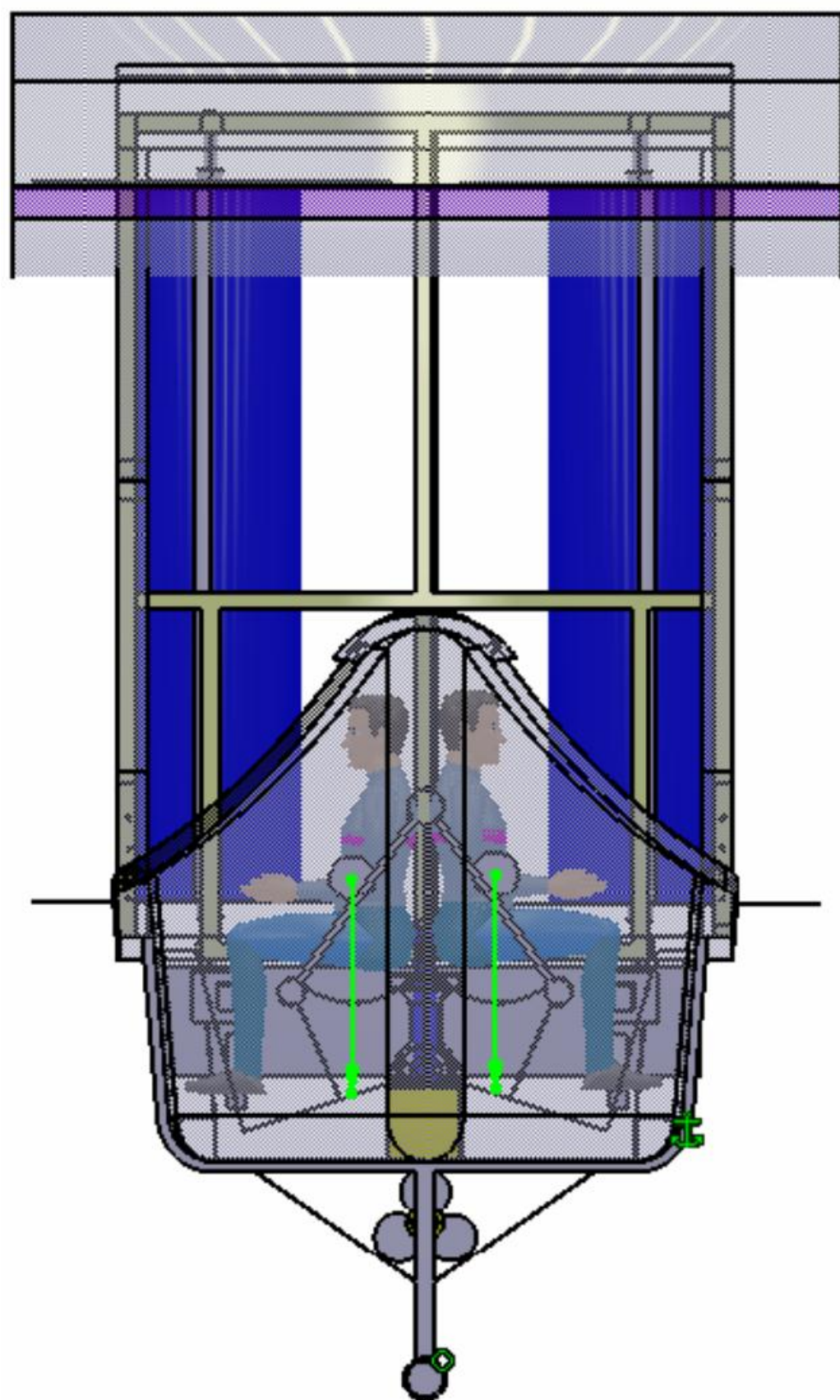






APPENDIX XI: Total Assembly





APPENDIX XII : Wind Scale with related Sea Conditions

Beaufort wind scale with related sea conditions

Beaufort	Sea state	Description term Wind	Wave	Wind sp. [knots]		Wave height [m]	
				min	max	Probable	Max
0	0	Calm	Calm	0	1	0	0
1	0	Light air	Ripples	1	3	0.1	0.1
2	1	Light breeze	Small wavelets	3	6	0.2	0.3
3	2	Gentle breeze	Large wavelets	6	10	0.6	1
4	3	Moderate breeze	Small waves	10	16	1	1.5
5	4	Fresh breeze	Moderate waves	16	21	2	2.5
6	5	Strong breeze	Large waves	21	27	3	4
7	6	Near gale	Large waves	27	33	4	5.5
8	7	Gale	Moderately high waves	33	40	6	7.5
9	8	Strong gale	High waves	40	47	7	10
10	9	Storm	Very high waves	47	55	9	12.5
11	9	Violent storm	Exceptionally high waves	55	63	11.5	16
12	9	Hurricane	Exceptionally high waves	63	71	14	16
13	9	Hurricane	Exceptionally high waves	71	80	>14	>16
14	9	Hurricane	Exceptionally high waves	80	89	>14	>16
15	9	Hurricane	Exceptionally high waves	89	99	>14	>16

REFERENCES

- [1] James Lamb den, Santa Barbara, CA Practical. Hands on manual for designing, building and owning an electric boat.
- [2] The IEEE IAS Myron Zucker ,Report prepared for Undergraduate Student Design May 2015
- [3] J.F. Man well, J.G. McGowan and A.L. Rogers ,Wind Energy Explained – Theory, Design and Application.
- [4] Professor Tilak Chandratilleke Department of Mechanical Engineering , CFD Analysis of Container Ship, Curtin University
- [5] Hubert F. Ohmayer: Propulsion System Choices for modern Naval Vessels. Washington, November8, 2012.
- [6] J. M. RE [NHAR] ;Small Boat Design Proceedings of the ICLARM Conference On Small Boat Design “Noumea, New Caledonia, October 27-28, 1975
- [7] MAN Diesel & Turbo; Basic Principles of Ship Propulsion, Tegllholmsgade 41 2450 Copenhagen SV, Denmark Phone +4533851100, Fax +4533851030; .E-mail info@cph@mandieselturbo.com , www.mandieselturbo.com .
- [8] Isadora Martinez; MARINE PROPULSION, 1995
- [9] John Mc CoskerRensselaer ,Design and Optimization of a Small Wind Turbine Polytechnic Institute Hartford, Connecticut December 2012.
- [10] Alex Kalmikov and Katherine DykesWind; Power Fundamentals; IT Wind Energy Group Renewable Energy Projects in Action, Email: wind@mit.edu.
- [11] Professor P.N. Mpotsaris, Design of a Savonius Wind Turbine.
- [12] Dave Mussels, Design of Savonius Wind Turbine.
- [13] F. Sigernes, Savonius wind rotor basics, University Centre in Svalbard (UNIS), Norway.
- [14] A. Al-Faruk and A. S. Sharifian; Effects of flow parameters on the performance of vertical axis swirling type Savonius wind turbine, International Journal of Automotive and Mechanical Engineering (IJAME) ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online) ,Volume 12, pp. 2929-2943, July-December 2015,©Universiti Malaysia Pahang;DOI:<http://dx.doi.org/10.15282/ijame.12.2015.10.0245>.
- [15] B. Loganathan, I. Mustary, H. Chowdhury and F. Alam, Aerodynamic Behaviour of Small Savonius Turbine with 3 Different Configurations.

- [16] SARGOLZAEI J. ,Prediction of the power ratio and torque in wind turbine Savonius rotors using artificial neural networks; Department of chemical engineering, Ferdowsi university of Mashhad,P.O. Box:9177948944, Mashhad, IRAN
- [17] Mohammed Hadi Ali, Lecturer University of Mustansiriya, Experimental Comparison Study for Savonius Wind Turbine of Two & Three Blades at Low Wind Speed; International Journal of Modern Engineering Research (IJMER),www.ijmer.com Vol. 3, Issue. 5, Sep - Oct. 2013 pp-2978-2986 ISSN: 2249-6645.
- [18] Magdi Ragheb and Adam M. Ragheb, Wind Turbines Theory - The Betz Equation and Optimal Rotor Tip Speed Ratio ,Department of Nuclear, Plasma and Radiological Engineering ,Department of Aerospace Engineering University of Illinois at Urbana-Champaign, 216 Talbot Laboratories.
- [19] Jess, Graduate Engineer, npower renewables, Wind Turbine Power Calculations RWE npower renewables Mechanical and Electrical Engineering Power Industry.
- [20] Rehan Jamil, Zahid Hussain, Vertical axis wind turbine – A review of various configurations and design techniques, Renewable and Sustainable Energy Reviews, Volume 16, May 2012, (<http://www.sciencedirect.com/science/article/pii/S136403211100596X>)
- [21] Saha,U.K,S. Thotla, and D.Maity. "Optimum design configuration of Savonius rotor through wind tunnel experiments." Journal of Wind Engineering and Industrial Aerodynamics 96.8 (2008) 1359-1375.
- [22] Paint supplier “International Coatings Ltd.”, 2003.
- [23] MAN Alpha High-efficient Fixed Pitch Propellers, MAN Diesel & Turbo, Frederikshavn, Denmark, January 2012.
- [24] Sv. Aa. Harvald & J.M. Hee, Propulsion of Single-Screw Ships, 1981.31180755
- [25] Khandakar Niaz Morshed , Experimental and Numerical Investigations on Aerodynamic Characteristics of Savonius Wind Turbine With Various Overlap Ratios, in 2010” ,
- [26] http://dspaceprod.georgiasouthern.edu:8080/jspui/bitstream/10518/3541/1/morshed_khandakar_n_201001_ms.df
- [27] Robert E. Wilson, Peter B. S. Lissaman, "Applied Aerodynamics of Wind Power Machine", National Science Foundation, 1974.
- [28] Pope, K.; Dincer, I.; Naterer, G. Energy and energy efficiency comparison of horizontal and vertical axis wind turbines. Renew. Energy 2010, 35, 2102–2113.
- [29] Shigetomi, A.; Murai, Y.; Tasaka, Y.; Tasaka, Y. Interactive flow field around two Savonius turbines. Renew. Energy 2011, 36, 536–545.
- [30] Sivasegaram, S. Design parameters affecting the performance of resistance-type, vertical-axis wind rotors_An experimental investigation. Wind Energy 1977, 1, 207–217.

- [31] R. Gupta, R. Das & K.K. Sharma, " Experimental Study of a Savonius- Darrieus Wind Machine", Proceedings of the International Conference on Renewable Energy for Developing Countries-2006.
- [32] Hitachi Review Vol. 62 (2013), No. 3 .Electric Propulsion Systems for Ships topics Yoshifumi Ajioka Kiyoshi Ohno
- [33] SE-405 08 Goteborg Sweden Inboard propellers and speed calculation Marine Engines 2.1L–16L; 7739174-6 English 09-1998.
- [34] REAR ADMIRAL T. H. GILMOUR ;United States Coast Guard (USCG) Headquarters Commercial Fishing Vessel Safety (CFVS) Coordinator 2100 Second Street, SW, Room 1308 Washington,DC 20593 Phone: 1-202-267-2988 1-800-368-5647 www.uscg.mil/hq/g-m/cfvs/index.shtm
- [35] Christoph Ballin, Tess Small bridge Electric Boating, 2016
- [36] Almazan, Kaye L.et al, Design and Analysis of the Aerodynamic Performance of a Conceptual Multi-Bladed Vertical-Axis Wind Turbine, December 2014.
- [37] R.S. KHURMI J.K. GUPTA ,A Textbook for the Students of B.E. / B.Tech. U.P.S.C. (Engg. Seviess); Section ‘B’ of A.M.I.E. (I)
- [38] Alexander Grm; MATHEMATICAL MODEL FOR RIVERBOAT DYNAMICS;Volume68 Number3, 2017 <http://dx.doi.org/10.21278/brod68302>
- [39] Copyright newboatbuilders.com 2007 All rights reserved. NEW BOATBUILDERSHOME PAGE
- [40] Seidman, David, *The Complete Sailor*, International Marine, 1995
- [41] Aqwa Theory Manual, Ansys Inc., November, 2013.[Online] Available on: <http://148.204.81.206/Ansys/150/Aqwa%20Theory%20Manual.pdf> [Last accessed 12th December 2015].
- [42] Derrett, D.R. & Barrass, C.B., Ship stability for masters and mates, 2006;2011,7th /revis by 6; edn,
- [43] 26th ITTC Specialist Committee on CFD in Marine Hydrodynamics. Practical Guidelines for Ship CFD Simulations. Technical report 7.5-03-02-03. Revision 01. International Towing Tank Conference (ITTC), 2011.
- [44] PAUL BARCROFT ECCLES, MARITIME OPERATIONS DIVISION FOR COMMONWEALTH OF AUSTRALIA ORDER UNDER SECTION 427 OF NAVIGATION ACT 1912
- [45] Prof. A.H. Techet, Design Principles for Ocean Vehicles, Spring 2005.
- [46] (Source: Joe Grez President of Prop Ele Electric Boat Motors Inc. Sept, 2011)
- [47] ITTC method from the International Towing Tank Committee, 1957