Sultan Qaboos University

Department of Mechanical and Industrial Engineering

DESIGN AND CONSTRUCTION OF HUMAN POWERED SUBMARINE SULTANAH III

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ABSTRACT

Two generation of submarine designed by SQU team of mechanical engineering graduates had competed in International Submarine Race (ISR) in 2011 and 2013. The success of their designs is confirmed in 3^{rd} generation and the aim is to farther improve the design and performance of SQU submarine to bring it to the winning podium an opportunity to design and construct a submarine as well as enhancing the creativity and innovation in solving engineering problems. The submarine must be operated manually using human power. The submarine consists of hull, propulsion system, steering system, control system and safety system. The design constrains and specifications were set in consultation with project supervisor and abiding by the roles by ISR. The short coming from the previous design were identified and handled in 3^{rd} generation. The objective of this project is to redesign propulsion system to increase the speed of the submarine. Mechanical variable pitch gear, propeller, gearbox, fins and control system are to be modified to improve the performance. Propeller manufacturing strategy is developed and introduced for the first time to overcome the limitation of CNC machine and materials availability. Fins were designed using GAMBIT and Fluent softwares to enhance the control and stability of submarine.

The process has started by studying all alternatives concepts for parts needed to be improved. Next, calculations and drawings of all modified systems were prepared and parametric design. Finally, the configuration design of each part or system was set to verify their installation and operation.

In addition to this, a variable pitch mechanism was designed and fabricated and are ready to be installed. Moreover a cover for this mechanism, also called hub cap, was designed and fabricated due to the improper design of hub cap in second generation.

ACRONYMS AND ABBREVIATIONS

Terminology	***Description***
AOA	*Angel Of Attack*
CAD	*Computer Aided Design*
CNC	*Computer Numerically Controlled*
CVP	*Continues Variable Planetary*
CVT	*Continues Variable Transition*
AGMA	*American Gear Manufacturers Association*
FLUENT	*Software can perform physical modeling*
GAMPLIT	*Software used to simulate nose and mesh*
HSR	*Human Submarine Race*
ISR	*International Submarine Race*
NACA	*The National Advisory Committee for Aeronautics*
OMER	*Submarine teams hold the human-powered submarine world speed records for one-seater, two-seater, and non-propeller categories.*
RPM	*Revolution Per Minute*
US	*United States*

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

A submarine is a watercraft which has the ability to operate beneath water surface independently. The term submarine is mostly common to be used to refer to large, crewed vessel. As a noun, it is a shortened form of submarine boat. A sub is also a further shortened form of submarine. During the nineteenth century, submarine design evolved and continued developing. The World War I, submarines were widely used for military purposes.

Submarines are widely used for a variety of purposes. Mainly, they are used for military purposes. They are used for attacking enemy, protecting other watercrafts, launching ballistic missiles and other objectives. It is also used for civilian purposes. Such uses include exploration, inspection, marine science, maintenance and some are used for tourism.

Large submarines are mainly cylindrical in shape with hemispherical or conical ends. It usually contains vertical structures too. These structures, which are called sails or fins, contain communication devices and periscopes.

1.2 PROBLEM STATEMENT

During the last ISR race, sultana II speed was not high or at least not as anticipated. Our team is requested to work on identifying the problems that have led to this. Gearbox, propeller, steering and fins were the focuses of the analysis. To improve the moving and stability of the submarine the team decided to analysis the steering system for improvement. In additionally an end cone will be design and attached to the end of the hull.

1.3 PROJECT OBJECTIVES

The project aim is to modify the human powered submarine to participate in the ISR in June, 2015. This submarine will be modified to perform well in the race. The problems faced in Sultana I and Sultana II, were considered in designing Sultana III.

The detail objectives of this project are:

- To design variable pitch propeller
- To design variable pitch control mechanism

- To modify and construct steering system
- To design and select gear box
- To improve performance and increase reliability of the submarine

1.4 DESIGN SPECIFICATIONS AND CONSTRAINTS

Design Specifications:

- Human powered
- Submarine filled with water
- All components should be fitted within the diameter of the submarine
- Hazards and soluble material are not allowed to prevent pollution

Design Constrains:

- Average power delivered by an average person in GCC is about 280 watt.
- Electric device not allowed to be used in the internal system of the submarine.
- Maximum and minimum diameter of the submarine is 67cm and 6cm respectively.
- Total length of the submarine is 2.7m.

1.5 IMPACTS

The team will represent Oman in the ISR competition in the USA which will increase the reputation and the awareness of people about our country. Also, this project can be implemented in the underwater tourism field.

- Environmental considerations
    - Using environmental friendly materials.
    - Use non-toxic materials
    - Consider minimal waste of resources
- Economic aspects

- Considering design within available budget.

- legal and ethical issues
  - Design using original idea and refer to others' intellectual properties where appropriate.
  - Regarding the legal issues or ethical issues there will be no problems.

- Safety aspects
  - All safety issues must be taken in consideration such as submarine coloration, crew visibility, stripe marking light and emergency pop-buoy.

1.6 ISR INTRODUCTION

The International Submarine Races were conceived as an engineering competition to foster engagement in the ocean engineering and science disciplines by young students. This was to address the developing shortfall in maritime engineering and sciences necessary for the economic success of participating nations. An engineering competition was chosen as the method to attract these students into these career fields.
Each team must develop a one or two-person "wet" submarine. Crew members breathe SCUBA from the air supply carried aboard. Each sub is unique, designed from "scratch," and relies upon novel techniques for propulsion and guidance.

The International Submarine Race's ™ specific goals are:

- To inspire students of the various engineering disciplines to delve into broad areas of underwater technology advancement and to provide them an educational experience that translates their theoretical knowledge into reality.
- To foster advances in subsea vehicle hydrodynamic, propulsion and life support systems.
- To increase public awareness of the challenges people face in working in and exploring the ocean depths.

International Submarine Races has had over 2500 contestants in 297 teams building 231 submarines (including modifications) to date. These teams are comprised of contestants from 9 countries. The first human-powered International Submarine Race TM (ISR) was held in 1989 at Singer Island off Riviera Beach, Florida and drew 17 boats. ISR 2 grew to 35 sub team entries in 1991. ISR 3 in 1993 off Ft. Lauderdale drew 44 submarine teams. The 1995 design competition, ISR 4, was the first in a controlled environment and was held at the NAVAL Surface Warfare Center (NSWC) - Carderock Division. NSWC Carderock has graciously hosted the races every other year since, and it has growth to 19 teams competing in 2013 with 21 boats entered.

Contestants include universities, high schools, individuals and research labs. Various awards are given out at each ISR, including ones for best overall performance, innovation, and speed by category, best use of composite materials and spirit of the race.

1.7 PROJECT PLAN

This project is expected to go through two phases. The tasks to be performed in phase one are as follows:

- Design variable pitch propeller
- Design variable pitch control mechanism
- Design new steering system
- Design and select gear box

The second phase will focus on the fabrication of the submarine as well as testing. Figure 1 below shows the detailed plan of the project in Gantt chart.

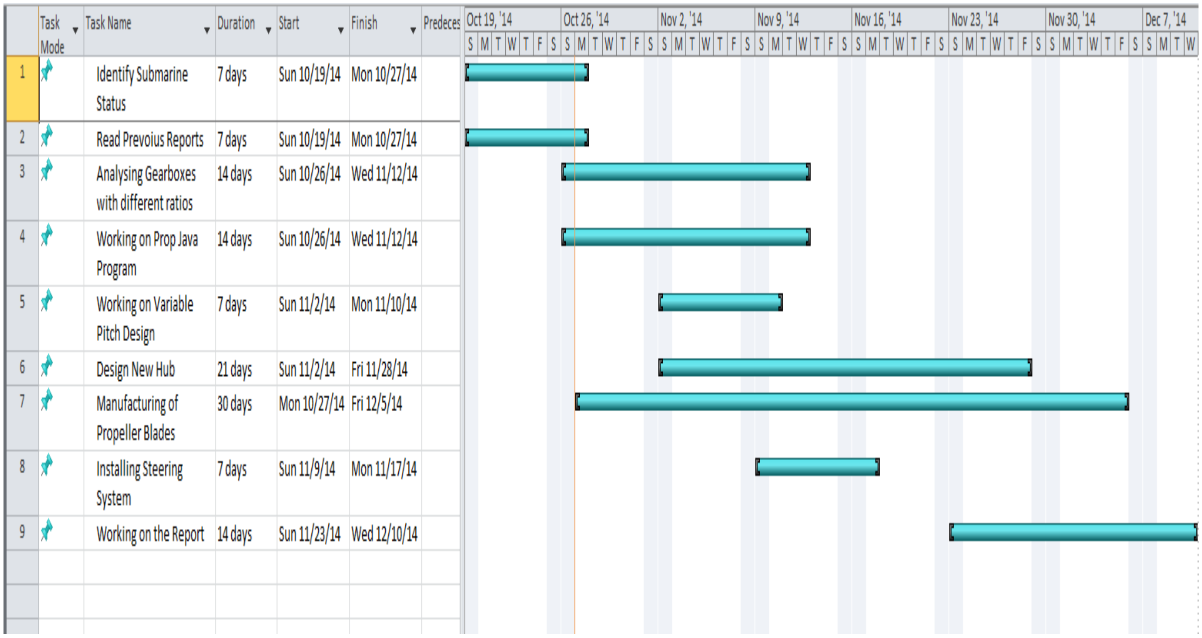


Figure 1 Gant Chart

1.8 Summary

A human powered submarine (Sultanah II) is to be modified to participate in ISR 13 in June 2015. Design of a variable pitch propeller is considered as a main objective in the project as well as increased ratio gearbox. In addition, a new steering system has to be designed to improve the performance of the submarines movement. Environmental, Economic, legal and ethical, and safety aspects will be considered in the design of the submarine.

Chapter 2: LITERATURE REVIEW

2.1 Introduction

The submarine is a watercraft that has the ability of doing a certain operations below the surface of the water. At the beginning, people started to build some concepts of the primitive submarine. There are a lot of very old pictures that show some devices that have the same concept of a submarine. For example figure 2 shows the 16^{th} century Islamic painting shows a submersible glass with a man inside. However, the first successful submarine was built in 1620 by Cornelius Jacobszoon Drebbel as shown in figure 3.

Figure 3: A 16th-century islamic painting

Figure 2: The Drebbel, the first navigable submarine depicting a man being lowered in

The International Submarine Races (ISR) were conceived as an engineering competition to enable students showing their skills and knowledge in this field. The first ISR was held in 1989 at Singer Island off Riviera Beach, Florida with 17 teams. Sultan Qaboos University (SQU) presented by the Department of Mechanical and Industrial engineering participated in 11^{th} ISR with Sultanah I (figure 4) in 2012. Then, they designed the second generation of sultana (Sultanah II) with a lot of modification and participated in 2013 of the 13^{th} ISR. Sultanah II (figure 5) were able to reach 2.55 knots. The target of Sultanah III team is to do some modifications to avoid the problems faced by the previous teams, get better performance and reach a higher speed.

Figure 4: Sultana I Submarine (SQU, 2012)

Figure 5: Sultana II Submarine (SQU, 2013)

2.2 LITERATURE REVIEW

2.2.1 Hull

The design of the sultanah' hull was based on the National Advisory Committee for Aeronautics (NACA) standards. NACA found to be one of the most reliable resources and widely used data base. The NACA airfoils shape is described by different groups, each one is called series. The numerical codes in the series digits can be used to generate the cross-section of the airfoil and calculate its properties by entering them into certain equations.

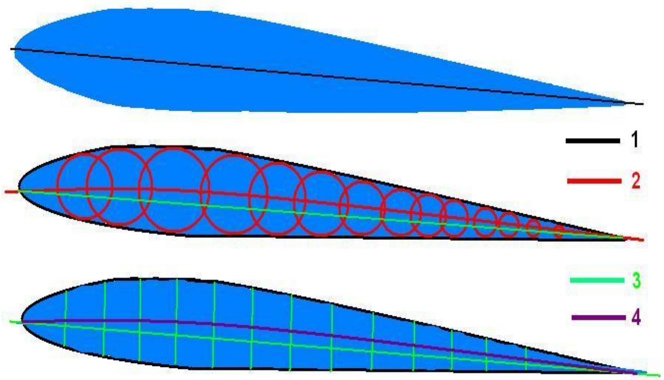


Figure 6: Profile lines – 1: Chord, 2: Camber, 3: Length, 4: Midline

The most appropriate series to provide an improvement over 1-series airfoils with emphasis on maximizing laminar flow is 6-series which it was used for our situation.

The airfoil is described using five digits in the following sequence:

The number "6" indicating the series.
One digit describing the distance of the minimum pressure area (maximum diameter) in tens of percent of chord.
One digit describing the design lift coefficient in tenths.
Two digits describing the maximum thickness in tens of percent of chord.

For example, the NACA 67-325 airfoil is 6-series type which has minimum pressure 70% of the chord back with a lift coefficient of 0.3 and maximum thickness of 25% of the chord.

2.2.2 Propeller

A propeller is a mechanical device consisting of a revolving hub with two or more twisted (angled) blades to produce required thrust. It is illustrated in figure 7 below. Another definition states that a propeller is a series of rotating airfoils or blades for the purpose of producing thrust. The shape of a propellers blade is very similar to the wing of an airplane. The main difference is that the wing is specifically designed to give the lifting force, while in the blade, it is designed to produce the reaction from the air to drive the airplane forward. A propeller is considered as a wing which is reduced in dimensions. The shape of the propeller segment is as a wing segment. A segment of a blades profile is called an airfoil or an aero-foil. It is a cross-section of the blade at any location from the hub to the tip. Attaching such a reduced wing onto a shaft makes it be considered as a propeller blade.

Figure 7: Propeller, Blade and Hub Assembly.

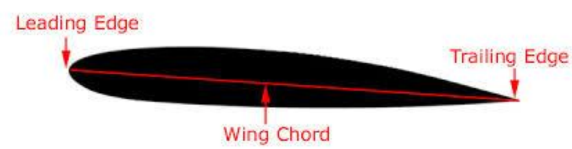


Figure 8: Airfoil Segment

Airfoils are very significant in the design of propeller blades. Their geometry and profile effects the characteristics of the blade and hence, the propeller. As shown in figure 8 above, an airfoil has a leading and trailing edges. The wind chord connects the two edges. This terminology is important for the study of airfoils. Turbulence, separation point, shockwaves initiated, pressure coefficient and the pressure difference are directly affected by the design of the blades airfoil. Published and standardized airfoil designs was a result of long period studies and experiments. Such standardized designs are published by The National Advisory Committee for Aeronautics (NACA). This committee published different kinds of designs with different specifications and shapes. Other examples of such committees are MH114, ARA D, Clark Y and E193. Some applications need special kinds of airfoil designs which requires further studies and designing.

The flow of fluid around a rotating blade creates a force that is similar to the force created by the fluid flowing around a wing. Figure 9 shows airfoil upper and lower surfaces. The difference of both forces is the direction. The force around the wing lifts it upward as in figure 10, while the force acting around a rotating blade pulls it forward. When a fluid moves against the profile of a propeller, a pressure difference initiates. This is due to the velocity difference between the front and rear surfaces of the propellers blade profile. The velocity difference is caused by the fact that the rear surface is larger than the front which creates higher pressure on the rear surface which provides the required pulling force, or thrust. Bernoulli's principle in fluid dynamics states that for an inviscid flow of a fluid, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or in the fluids potential energy. According to the principle, the difference in pressure between the front and rear surfaces of the blade will result in thrust force.

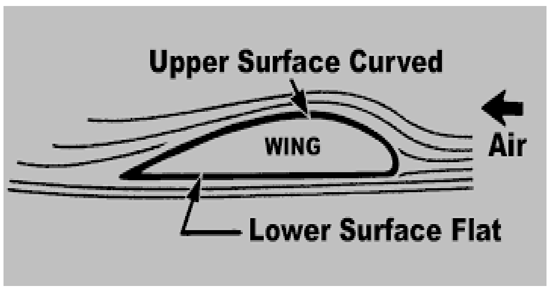


Figure 9: Airfoil Surfaces

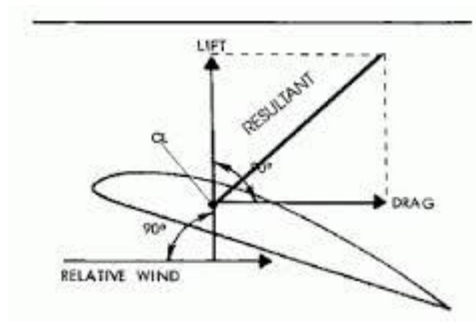


Figure 10: Lift and Drag Forces.

To obtain the required thrust force, the rotating blade must be installed into the right angle. This angle is called the "blade angle" or "angle of the blade". The "blade angle" itself varies along the length of the blade which produces the maximum operational efficiency. This blade profile is very crucial to obtain the thrust since the blade is acting as a screw that screws into the fluid in a spiral path to advance forward as in figure 11. This spiral path increases in amplitude as the point of interest along the blade reaches the tip. Tracing the most effective angle of the blade requires tracing various elements and sections of the blade. The blades are designed with greater angles toward the shank and gradually decreases toward the tip.

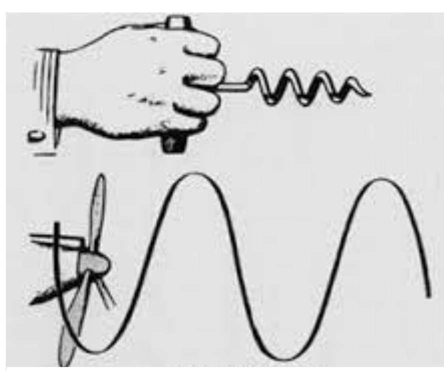


Figure 11: Screw Path of the Propeller

There are many forces that act on a spinning blade. Thrust, drag and centrifugal forces act on a spinning blade. Thrust is the forces pulling forward, drag is the force pulling backwards and centrifugal force acts radially as shown in figure 13. As the blades rotate around the hub, they tend to escape from hub due to the centrifugal force. This force is an important design factor. In addition, the centrifugal force makes the blades tend to rotate toward the low blade angle. Moreover, rotating blades produce thrust which tends to bend the blades forward. However, the tremendous centrifugal force holds the blades straight.

Figure 13: Centrifugal Force Acting on the Blades

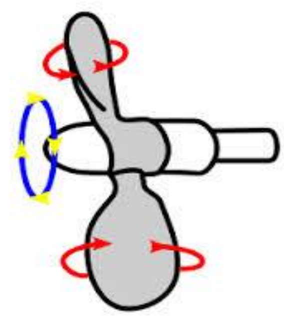


Figure 12: Controllable Pitch Propeller

Controllable pitch propeller is an idea full of potential. The blades angle can be adjusted or rotated normal to the driving shaft with the aid of linkages or hydraulic system as in figure 12. This idea is capable of giving the right angle of attack to give the required thrust at any speed. It is also capable of reversing the direction of movement which makes the reversing gear unnecessary.

The idea is to change the direction of the relative fluid flow. Consider a standing still submarine or boat, the propeller rotates with the relative fluid flow being perpendicular to the rotating shaft and the blade angle is low. When gaining speed, the forward movement of the submarine increases the angle of the relative flow. The adjustments made to the blade angle to change the angle of relative flow are very small but are sufficient of giving the optimal angle of attack. This is illustrated in figure 14.

The thrust and drag are affected by increasing and decreasing the angle of the blade. To operate the propeller at the maximum efficiency, the optimal angle must be sought. To obtain this optimal angle, the thrust must be the greatest to the drag acting on the blade. This means that the angle of the blade is adjusted to meet the varying conditions which maintains a blade angle with maximum thrust and minimum drag forces.

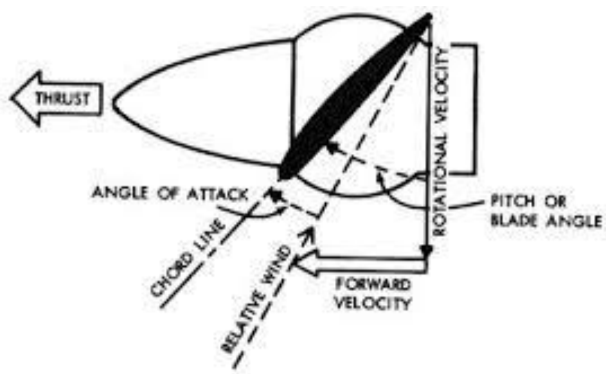


Figure 14: Changing Blade Angle

The changing sailing conditions are actually the changes in the direction of the relative fluid. To further explain this statement, consider a standing still submarine. The relative flow of the fluid is acting on a perpendicular plane to the shaft of the rotating propeller with low blade angle. However, while speeding, the angle of the relative flow increases due to the movement of the submarine. Consequently, the angle of the blade is to be slightly increased to get better efficiency. At an increased fluid speed, the speed of rotation is decreased. Because the relative flow strikes the blade at a higher angle, the blades are further adjusted to an increased angle. Due to the continuous change of the flight conditions, changes are required to the propeller blades so that it performs at the best efficiency.

A team previously participated in the International Human Powered Submarine Race used counter rotating propellers. Although counter rotating propellers are more efficient and faster than single propellers, it was found that they were not as efficient at low speeds. The team which worked on Sultanah II compared single, dual and contra dual bladed propellers based on thrust, drag, power loss and manufacturability criteria and they discovered that single bladed propellers are optimal for low speed purposes. With boundary conditions being considered, they designed a blade using Java Prop software. The diameter of their blade design was 0.55m, less than the maximum diameter of the hull to prevent turbulence and issues regarding the flowing fluid.

2.2.3 Hub Cap (cone)

To increase the stability of the submarine, a hub cap is designed carefully to eliminate turbulence at the rear of the submarine. The hub cap ensures smoother movement of fluid along the rear end of the submarine. The hub caps are manufactured of light materials so that the rear end would not be lower than the equilibrium level.

2.2.4 Gearbox

2.2.4.1 Sultanah I Gearbox

Sultanah I team members used right angle bevel gear with one input and one output located at the back to transmit the power by 90 degree to the propeller. Gear-chain system was used with a gear ratio of 1:4.5. A gear is attached to the output gear's shaft and is in mesh with it. The bevel gear is connected with the propeller through a shaft. This system had many drawbacks such as unstable pedals and loose chain. Another drawback was water resistance to the moving chain and gear. Moreover, lubrication of the chain and gears was lost due to water contact. Eventually, it was difficult for the pilot to pedal with all of these drawbacks combined.

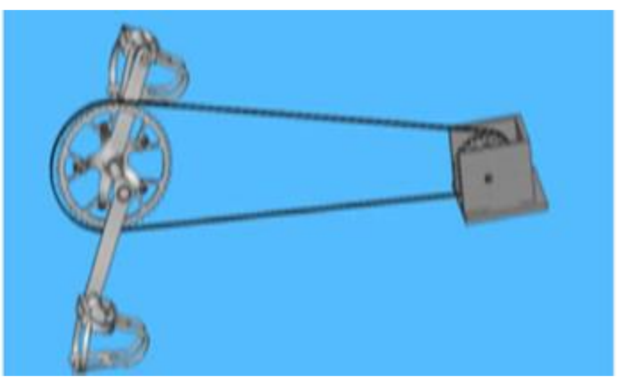


Figure 16: Chain-gear Combination

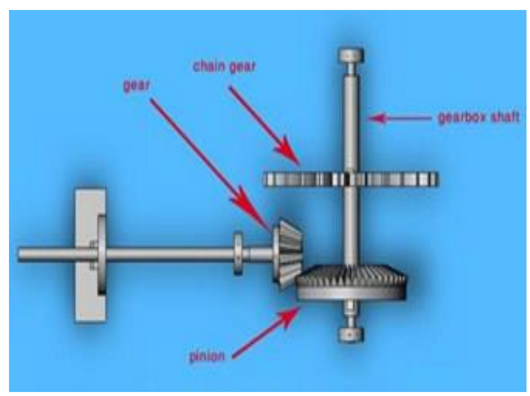


Figure 15: Bevel Gearbox

2.2.4.2 Sultanah II Gearbox

The team of Sultanah II worked on modifying Sultanah I gear box .They used a bevel gear but with two inputs which are peddles itself and one output. The output of the bevel gear was a direct shaft connecting the propeller at the back of the submarine to the

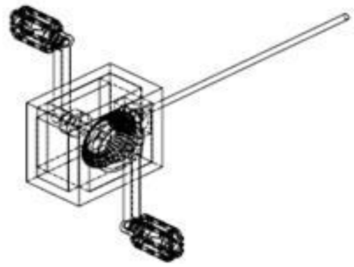


Figure 17: Configuration of Sultanah II Gearbox

bevel gear with a ratio of 1:3 is used. The idea of the shaft comes from one of the alternatives to solve the chain problem. Figure 17 above describes the configuration of the gearbox. Like the previous team, the problem off accelerating and take of still there to be modified and repaired.

2.2.5 Steering System

The steering system gives the pilot the ability to control the direction of motion for the submarine. While in water, it is necessary to adjust the path of the submarine regularly. A steering system would provide the needed adjustments. The steering system should be designed and built to provide an effective control system to direct the submarine in two directions: up/down and right/left .Some constrains should be considered while designing it like weight, friction and operation.

Steering systems would be either fully mechanical or electromechanical system with small motors. To design such system different types of steering systems should be studied and then the most suitable solution for the submarine should be selected. The fully mechanical system consists of four fins. Each two parallel fins are fixed to each other to

Figure 18: Sultanah II Steering System

allow movement in the same direction. The fins are moved with a pair of push-pull cables which are attached to two handles, figure 18 illustrates the mechanism further. Sultanah I and Sultanah II used a fully mechanical steering system.

Regarding the electromechanical system, a joystick is connected to a micro controller. The micro controller was prepared with an algorithm to control the motors attached to the fins. A steering system with one mechanical joystick would provide instant reaction. This idea is to be studied further and more is to be added to make it successful. The fins of the steering system are to be studied under fluid mechanics theories. In order to get the optimal profile and shape of the fins without causing any turbulence or drag force.

2.2.6 Summary

The submarine is a watercraft that has the ability of doing a certain operations below the surface of the water. A submarine can be powered by engines or motors. Sultanah is a human powered submarine that meets the recruitments of ISR (International Submarine Races). Propulsion system including the propeller and power transmission system play a major role in increasing the thrust of the submarine. This chapter aims to understand the submarine in terms of components, physical design and previous teams' problems.

A propeller is considered as a wing which is reduced in dimensions. Airfoils geometry and profile effects the characteristics of the blade and hence, the propeller. The pressure difference between the front and rear surfaces of the propellers blade profile results in an increase in the velocity and provides thrust force. This blade profile is very important to obtain the required thrust since the blade is acting as a screw that screws into the fluid in a spiral path.

A gearbox design of chain-gear combination was used in Sultana I. For Sultana II, a bevel gearbox was used.

The submarines path in water requires continuous adjustments. A steering system would provide the needed adjustments. A fully mechanical system with four fins was considered previously in the submarine.

Chapter 3: HULL DESIGN

3.1 HULL DESIGN

After the ISR race Sultanah I achieved a low top speed, the hull was redesigned. The hull of Sultana 2 was designed to have the smallest cross-sectional area, while still being large enough to accommodate the leg motion required of the Driver. This shape (as shown in figure 19) reduced drag, allowing more of the thrust to be translated into velocity. While minimizing cross sectional area it’s important to maintain the smallest overall volume is also important. The design of Sultana II was improved by reducing the size and choosing another type of material to reduce the weight. The primary competitive objective is to achieve the maximum possible velocity.

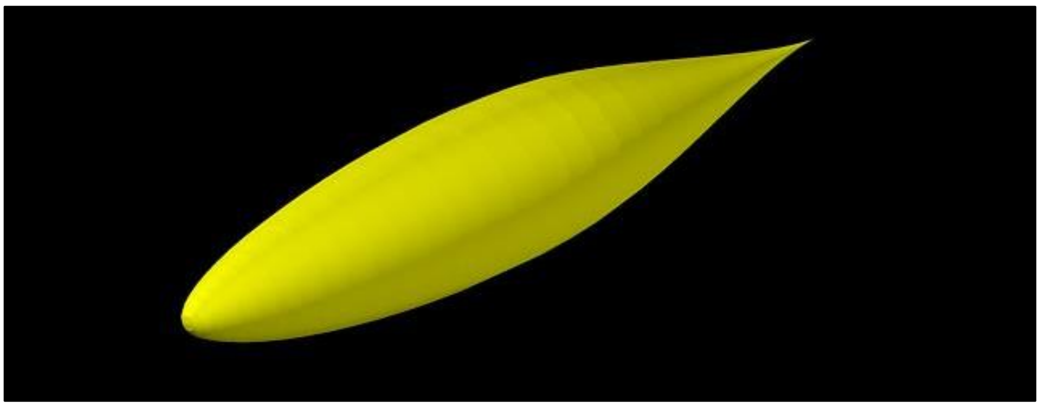


Figure 19 Hull Shape

3.1.1 Hull Shape Design

The hull is designed for one-person propeller driven category. In the initial design of the hull, a driver height limit was determined. With these limits known, a study on hull shape design was completed to determine the proper length to diameter ratio to produce a hull with the lowest possible drag coefficient. (as shown in figure 20).

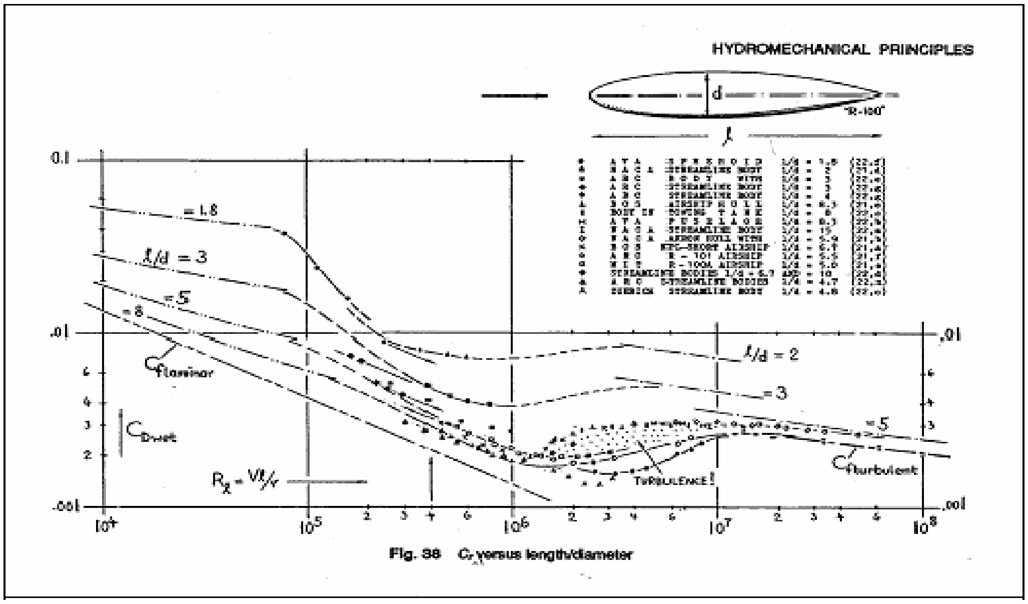
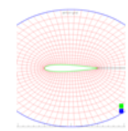


Figure 20 Drag Force Coefficients (mh-aerotools, 2011)

Early in the project, the design team established the basic dimensions of a hull that would accommodate the largest individual among the students who had expressed interest in Diving. We also considered the general lines used by many of the previous ISR entries.

In order to reduce drag on the hull, this profile was redesign in an elliptical shape (due to the evaluation done in the table 1). Fluid dynamics simulations on computers showed that global drag was reduced even though the hull gains a little in volume. To compensate this increase and ease water flow all around the hull, the total length was also increased to the exact dimensions given by the NACA profile.

Table 1 Evaluation of each Concept Design

Feature	importance (1-5)	relative importance	Concept(1)		Concept(2)		Concept(3)	
			Cube-Shell 		cylinder-Shell 		NACA6-profile 	
			Weight	Relative Weight	Weight	Relative Weight	Weight	Relative Weight
Easy to manufacture	4	0.19	5	0.95	5	0.95	3	0.57
Easy to turn	3	0.14	3	0.42	3	0.42	5	0.7
material use	4	0.19	3	0.57	3	0.57	4	0.76
Less drag force	5	0.24	1	0.24	1	0.24	5	1.2
More Speed	5	0.24	1	0.24	1	0.24	5	1.2
Total	21	1		2.42		2.42		4.43

NACAs are a group of profiles with standardized dimensions in which the maximum height corresponds to a certain percentage of its total length.

Chord length needed: L = 3.0 m,

Maximum first diameter needed: D = 0.67 m.

First Length-diameter ratio: r = L/D = 0.24.

Therefore, the last two digits and our first shape is NACA 67-024. This profile is the one which match best with the physiognomy of the Driver while pedaling. Once this profile is chosen and the hydrodynamics analysis is completed, the hull can be meld by linking the NACA profile from both sides. The next step was to generate a sketch of the desired shape. "Design FOIL" software was used to accomplish this task. Values were entered and the shape appeared in the screen. The result was exported in DXF file. The 3D model of the hull shape was generated using the DXF file generated from Design FOIL.

3.1.2 Driver

The Driver is lying in the longitudinal position with stomach downward and with the head toward the nose of the submarine. The air tank is mounted to a solid harness underneath the Driver's torso. In order to insure an optimum position for leverage on the drive system (as shown in figure 21), a new top-mounted shoulder harness was designed for the Driver to lie against. The harness includes a waist belt to secure the driver's torso. Bicycle toe clips are used to ensure that the Driver's feet do not slip while pedaling.

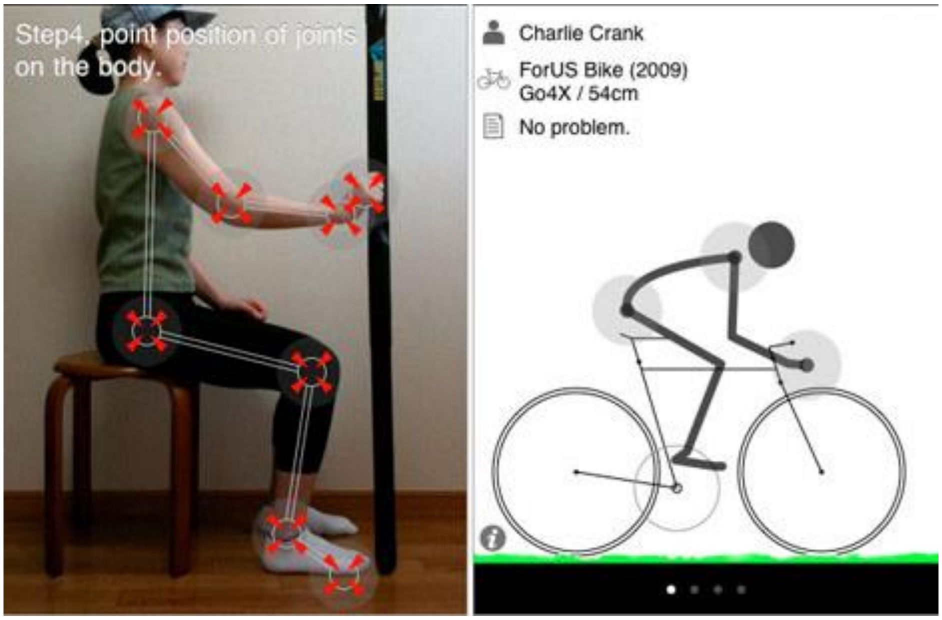


Figure 21 Driver Shape (core77, 2011)

The Driver will use shoulder restraints to push against when pedaling. The restraints are built from a standard aluminum plate fixed on a path that will be adjustable to accommodate Drivers of different heights.

A standard SCUBA tank will be used. We plan to position it just below the Driver's torso, but the exact location will be determined after the hull is completed and the drive mechanism has been installed.

3.1.3 Safety Issues

Another essential point is to ensure the Driver's safety, which is done by different systems as required by the competition's rulebook. The most important one is the evacuation of the Driver. A door is positioned on the side of the submarine. This door can be opened by the Driver and by the teammates in the water. With this mechanism, the driver can be rescued in an emergency at any time. Another door is disposed at the back of the submarine to let the team work easily on the propulsion system. At the front of the submarine, a porthole allows the Driver to see clearly under and in front of him while pedaling. This porthole is also a safety item because the teammates are able to see the face of the Driver at any time during the tests or the competition.

3.1.4 Material

Various materials, such as carbon fiber (figure 22), E-glass, and S-glass were considered while brainstorming the design of the hull (table 3.2). Carbon fiber would have been a great material due to its strength and flexible.

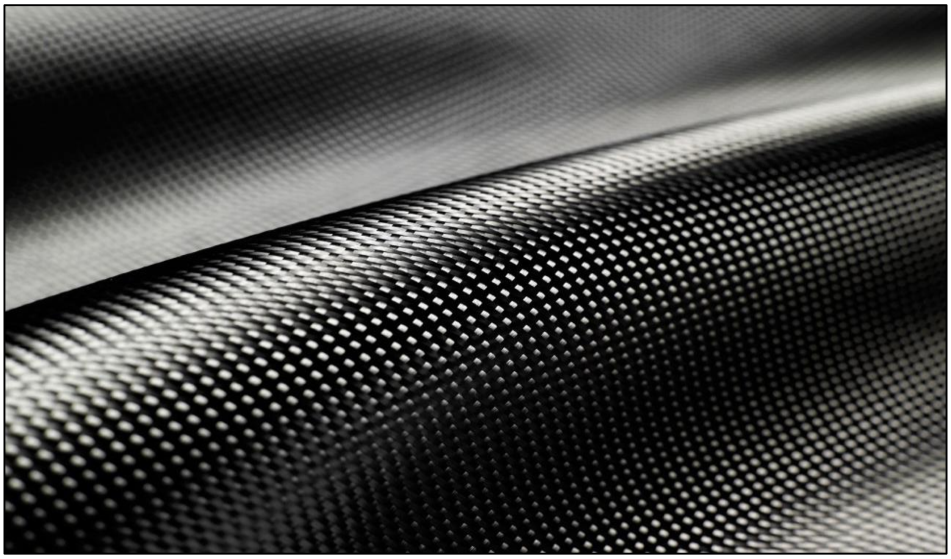


Figure 22 Carbon Fiber (Speedcraftcomposites, 2011)

Sultana II is made of a sandwich composite hull. This means that a lightweight material was used in the center of the hull to separates the inside fiberglass layers from the outside fiberglass layers. This was intended to add buoyancy to the submarine, to increase its strength perpendicular to the surface of the hull and to add resistance to bending stress.

Table 2 Material Alternatives Evaluation

Feature	importance (1-5)	relative importance	Concept(1) Fiber glass		Concept(2) Fiber Carbon		Concept(3) Eglass	
			Weight	Relative Weight	Weight	Relative Weight	Weight	Relative Weight
strenght	5	0.28	4	1.12	5	1.4	3	0.84
Less density	5	0.28	2	0.56	5	1.4	2	0.56
Less Cost	4	0.22	4	0.88	2	0.44	5	1.1
Easy to use	4	0.22	4	0.88	4	0.88	4	0.88
Total	18	1		3.44		4.12		3.38

So the hull material was selected to be a Carbon fiber. It was selected depending on its suitability of the following criteria:

1. The mold ability to almost any boat design.

2. Seamless construction.

2. High strength and great durability.

3. Minimum maintenance.

4. Freedom from corrosion and rust.

3.2 Hull Shape Analysis

Since the type of composite layers in sandwich used for the fabrication of the hull is not a standard material in the software of finite element analysis, its properties had to be determined for each material.

3.2.1 Finite Element Analysis

Computational fluid dynamics (CFD) is a branch of fluid dynamics where the flow is analyzed using numerical methods and algorithms. The fluid and other solid domains are divided into small finite elements in a process called meshing. Then properties and boundary conditions are specified and the calculation is left to computer software (figure 23 and figure 24).

Figure 24 ANSYS Software

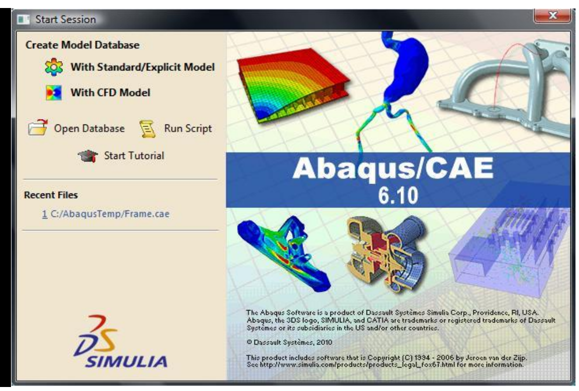


Figure 23 ABAQUS Software

There are many different software packages that use CFD to analyze fluid flow. In this project, ANSYS Fluent v12 has been used in analyzing the fluid flow problem. However, we have kept in minds that Fluent gives qualitative results. The most important output from Fluent is the water pressure in the outer surface of the hull as the submarine moves at a target velocity of 8knots. Pressure results will be exported to mechanical analysis in ANSYS. In ANSYS Fluent, the analysis procedure consists of five steps: geometry, mesh Generation, setup, solution and results.

3.2.2 Geometry (Dynamic)

Autodesk Inventor was used to create the geometry. A water domain was modeled as a box with (9m×12.0m). Then the submarine geometry was subtracted from the water domain.

3.2.3 Mesh Generation (Dynamic)

The next step was to generate the mesh. The mesh is Generated using ABAQUS (figure 25 and figure 26) software since it is superior in this field. Surface meshing was generated. All elements generated are tetrahedral in shape. Small mesh size has been used for critical areas like fins and tip of the submarine.

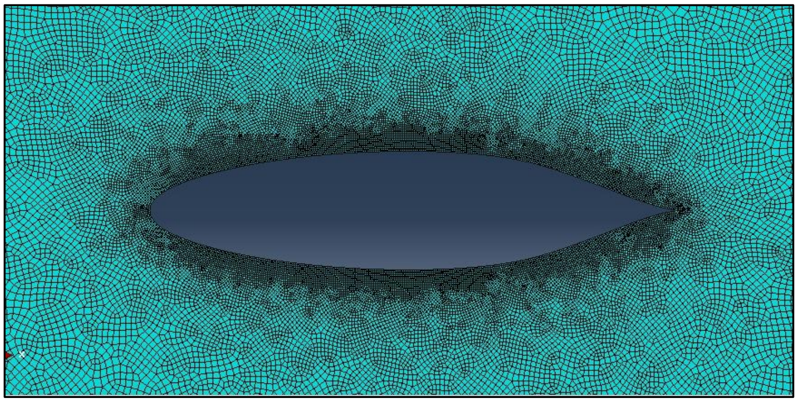


Figure 25 Mesh1

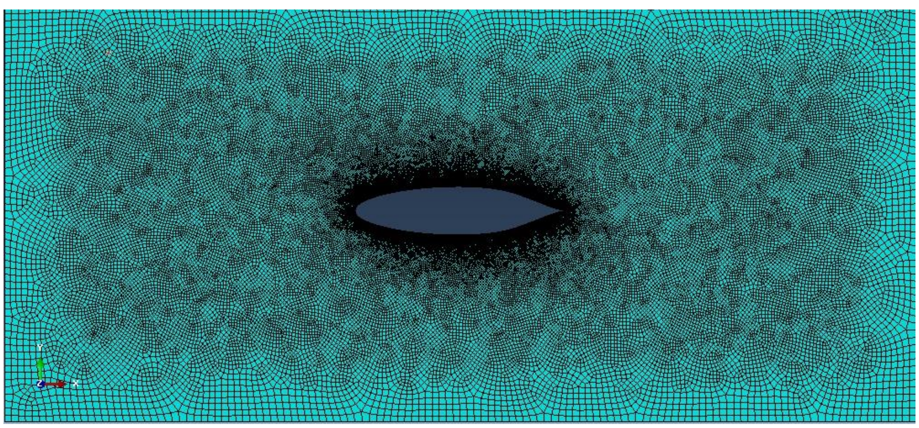


Figure 26 Mesh 2

3.2.4 Boundary Conditions (Dynamic)

This stage considers the properties of the fluid and boundary conditions (table 3). The fluid was chosen to be water at 17C. In reality the submarine moves against water. However, analyzing flow patterns past a moving body with stationary fluid is dynamically equivalent to analyzing the flow patterns around a stationary body as the flow moves. The left side is set to be the inlet with a normal velocity of 8 knots and the right as an outlet with the same boundary condition of 8 knots. The front side is used as a symmetry plane. The other sides were considered as frictionless walls. The table below summarizes the boundary condition used in each surface.

Table 3 Summary of the boundary condition used in each surface

Surface	BC type	BC value
Left side	Inlet, velocity	8 knots
Right side	Outlet, velocity	8 knots
Front side	Symmetry plane	
Other sides	Wall, No friction	
Submarine	Wall, No friction	

3.2.5 Results (Dynamic)

The software carries out the calculations needed and uses an iterative process. When it reaches an error below the specified value of (1.0e-4), it stops the solution process.

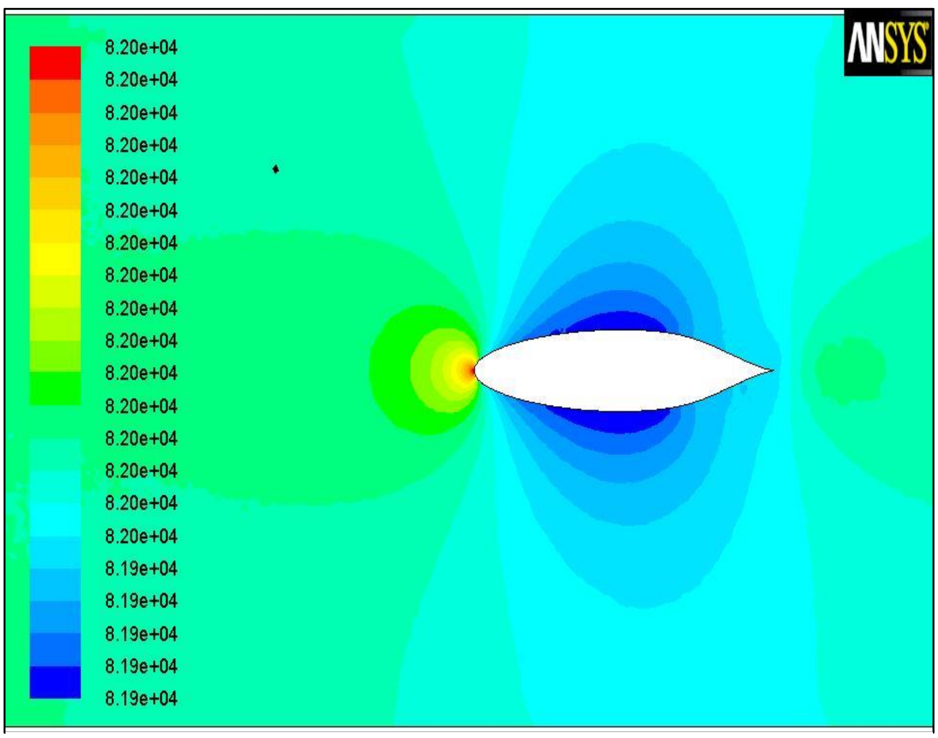


Figure 27 Static Pressure Analysis using Ansys Program

Pressure (figure 27), velocity (figure 28), viscosity and other results can be viewed in this stage. The value of maximum pressure is 8.20kPa at the nose of the submarine. This value is considered very logical since this region has the least area and it is perpendicular to the flow direction. This value agrees with our calculation in the parametric design section. The minimum pressure was at the region with the bigger cross section area which is located at 70% from the nose. These pressure results will be transferred to mechanical analysis.

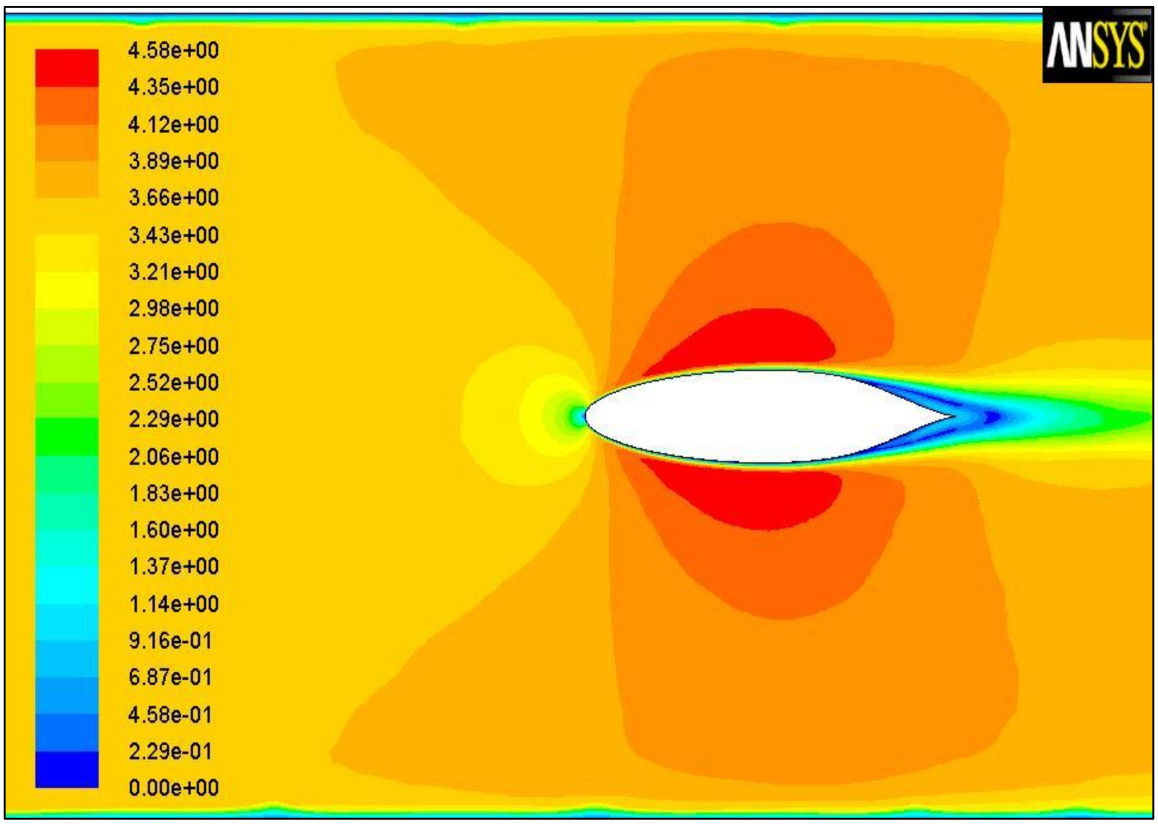


Figure 28 Velocity Analysis using Ansys Program

From the velocity results shown below, the maximum velocity is at the inlet and the outlet. It decreases near the surface of the submarine as a result of the drag force. Mechanical Analysis

After Fluent analysis, the next step is to perform mechanical analysis were the pressure results will be imported to ABAQUS static structural analysis where the total deformation will be calculated.

3.2.5.1 Geometry (Static)

Half of the hull was created using Autodesk inventor (figure 29). The thickness of the hull was set to be 4mm.

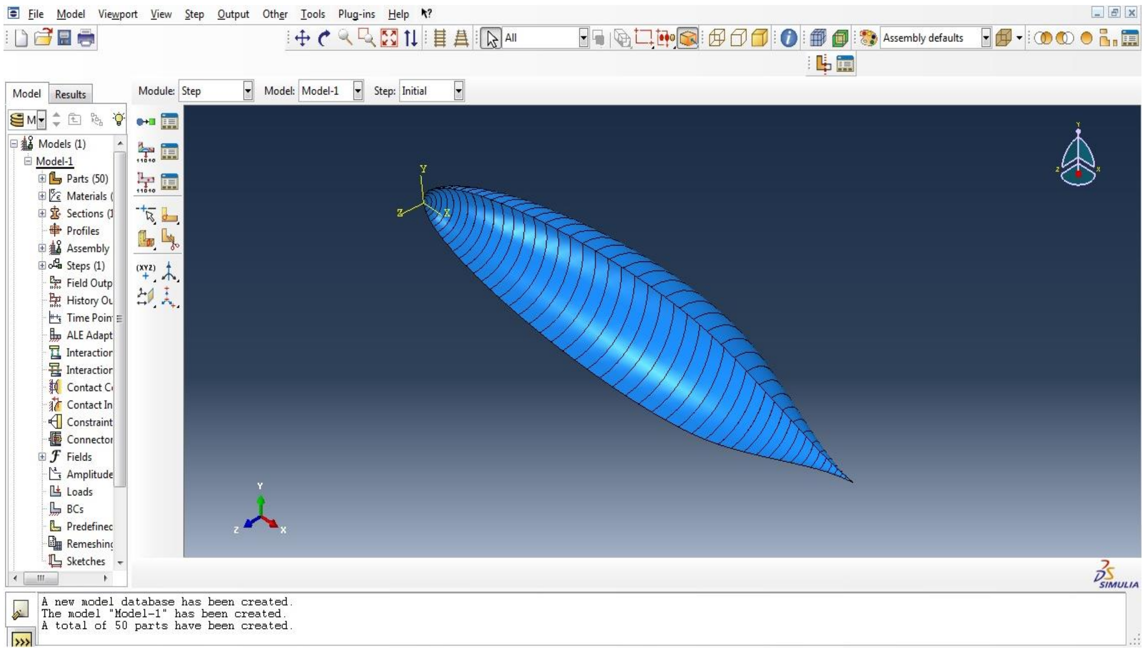


Figure 29 Shell Geometry

3.2.5.2 Material model (Static)

The finite element model requires the material properties of the hull. Since the system under goes static analysis and in the linear elastic region modulus of elasticity and Poisson ratio of the hull material will be provided only. A carbon fiber material was used for the hull of the submarine.

3.2.5.3 Mesh Generation (Static)

The same procedure done in ABAQUS meshing (figure 30) was repeated to generate the hull mesh. Surface mesh size is different in each face of the hull. Finer surface mesh is used in the critical edges.

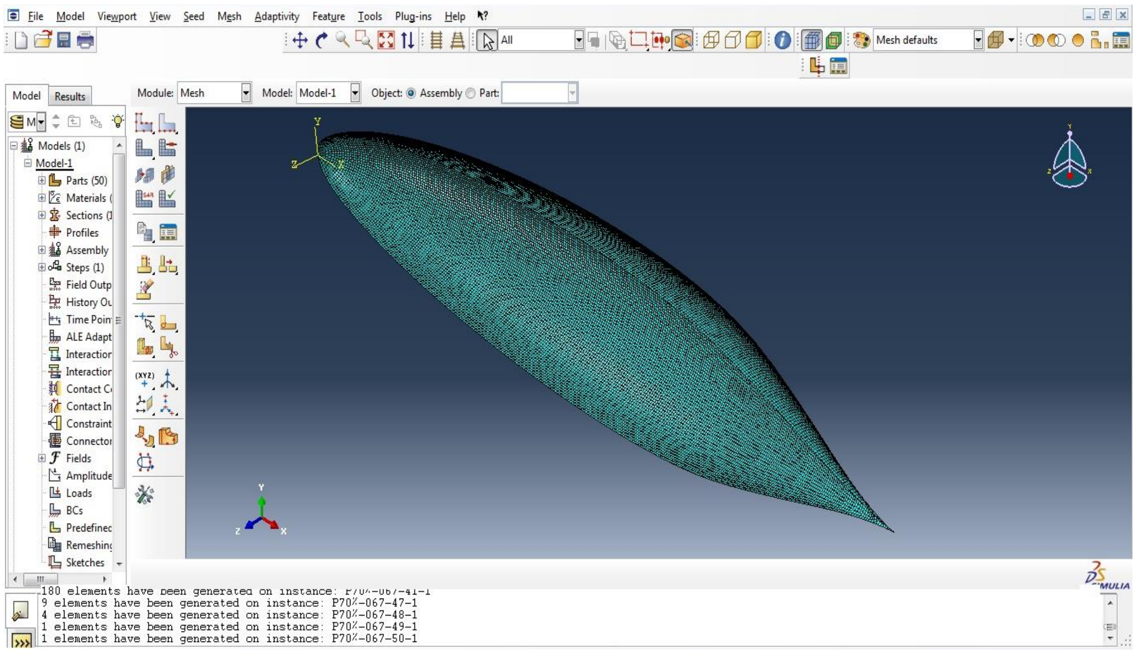


Figure 30 Mesh 3

3.2.5.4 Boundary Conditions (Static)

There are three different loads in the hull of the submarine. There are two hydraulic pressures resulted from the weight of water column. One of them is in the outer surface of the hull, while the other one is on the inner surface. However, those two pressures are approximately the same but in opposite directions. Therefore, they will cancel each other. The third pressure is the pressure of water in the outer surface of the hull that is resulted from the movement of the submarine through water. This data will be imported from the fluent analysis done before.

3.2.5.5 Results (Static)

Results from the static structural analysis in ABAQUS were generated. We can see that the maximum defection is about 0.56mm. It is in the middle of the hull. Stress results in the hull are shown in figure 22. The maximum stress is about 225MPa.

3.3 Manufacturing of the hull

The hull manufacturing started on 23rd of April, 2012. After the dimensions of the hull was proved and provided to the workshop. They conduct the following:

1- To make the mold they make a mixture of foam and gypsum as a half cylinder shape as shown in (figure 31). They will make two pieces of it one for the upper half part and the second is for the lower half of the hull. Even though the hull is a symmetrical shape they did like this in order to finish the job as fast as possible also in the upper half there is doors so to make the cutting from the beginning.

Figure 31 First half of the mold before cutting

2- Then they starts cutting the extra material of it in order to reach the desired shape as shown in (figure 32 & 33)

Figure 32 The mold after cutting started

Figure 33 The mold after cutting started in second half

3- After they finish the cutting (still they didn't finish) they will join two half's in order to make sure that the hull is symmetrical as shown in (figure 34 & 35)

Figure 34 Joining the Halves

Figure 35 Cutting in the back of the Submarine

4- The cutting of the front window will be done later.

5- Finally they will put the three layers of carbon fibre, plastic fibre and the roofing. Also the resin will be added to strengthen these layers and make them compact. This will be done in the following weeks.

3.4 Positioning

3.4.1 Introduction:

A step of completing the submarine is to determine the position of parts inside the body. This step is important to determine some parameters as the next discussion explain. Also, positioning will determine the final submarine configuration form inside.

The hull of the submarine is 3 m long with a curvature shape and maximum diameter of 0.67 m. the diameter is changing through the hull shape and this variation creates non-balanced dimension for positioning.

The next sections will discuss the position of parts inside the submarine.

3.4.2 General positioning analysis:

The first step in positioning part is to determine the parameters that will control the position of parts. These parameters are:

1- Total length of the submarine = 3 m

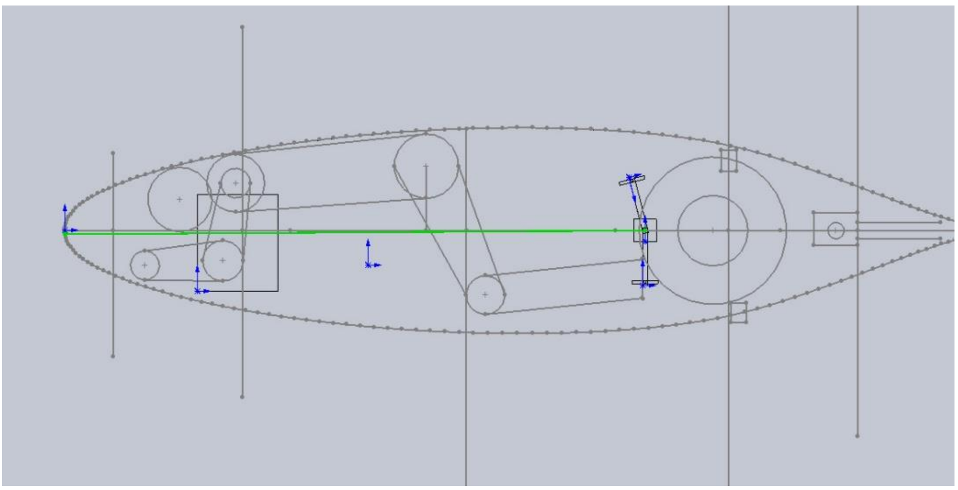
2- Maximum diameter= 0.67m

3- Average length of the crew

4- Shape of the hull

The length of the hull is divided into two parts: 0.55 m window and 2.45 m carbon fiber. The carbon fiber area is the place where the crew can place parts. The hull was designed to have circular cross section at any length with a constant radius. Those, a cut at any length would give a regular circle. The diameter of this circle will differ from length to another. This shape was designed using solidworks by inserting certain points generated by NACA and series number 6.

The positioning depends on the rider length as it will be proper for the whole team to use. So, I measure the lengths of the crew and took the average as the standard length of the rider with an error margin to fit for all team members. The average length of the team is 172 cm.



3.4.3 Design of position:

There are two plans for designing position and configuration inside the submarine. Those plans depend on the available material in the market. They are explained below.

Plan A:

This plan depends on a one output and two input gearbox. This is the main plan for SULTANA II. The design is to place the gearbox and directly connect it to the shaft and the paddles. The rest is configuration of chair and steering system in the submarine. It is shown in the duplication plate below. The plate is 3 m long and simulation of the part position was up to the dimension.

Figure 36 Configuration A

An advantage of this plan is that it takes small area inside the submarine with a maximum use of human power without losses in energy transfer. On the hand, the position of the gear box creates large area beneath it witch require long shaft that can bend during rotation.

Plan B:

This plan is developed in the case of the required gearbox absences. It is to design for separate gear box and pedals with a transmission chain system inside the submarine. The main challenge in this design is to choose proper dimension for the chain, paddle and gearbox supports to be proper for the rider. The gearbox center should be at the centerline of the submarine to connect with the shaft.

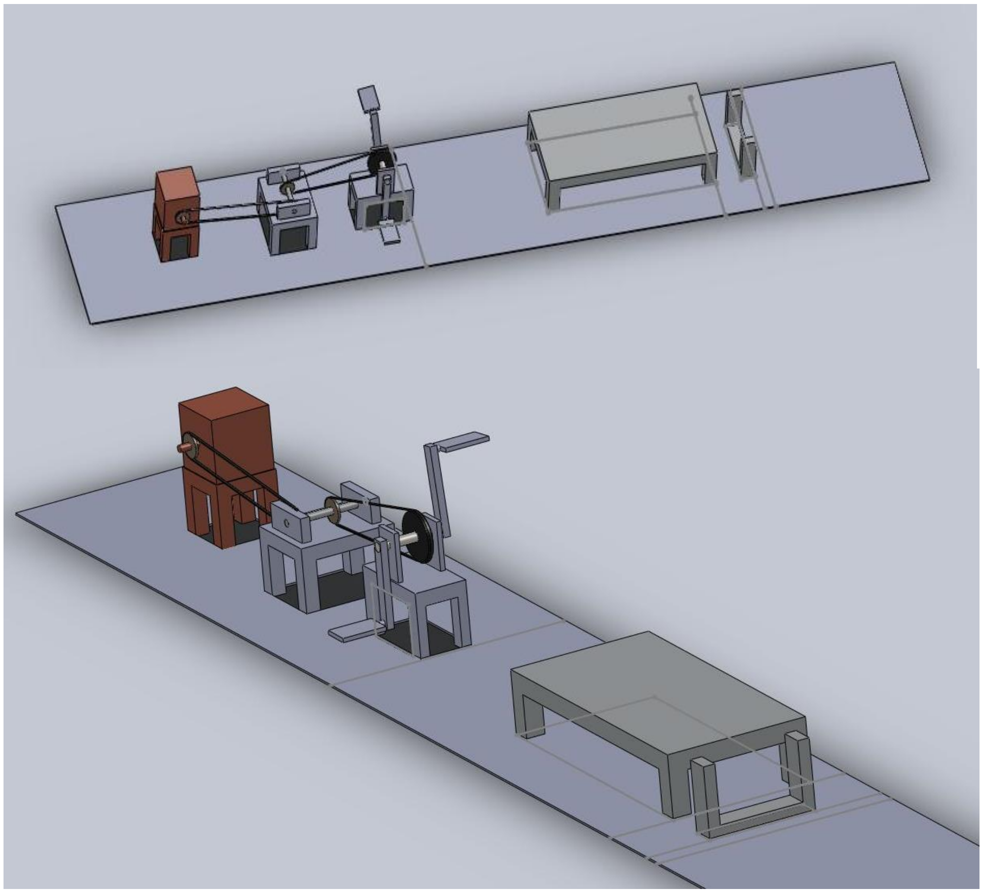


Figure 37 Configuration B

The configuration of the second option is shown above using solidworks. This idea of having chain inside the submarine takes more space. The dimensions of the parts position generated due to the paddle position. The paddle base is placed at 1.8 m long from the front section of the submarine. The steering placed at 4 cm after the window region followed by a 9 cm separation distance. Then, the chair is placed after that at 0.69 m. The center of the paddle is aligned to the center of the submarine. The diameter at 1.8m is 0.64m so that the center of the paddle is at 0.32 m. The rest of the dimension is shown in the drawing in the Appendix.

The size of the shaft length is around 40 cm which is more proper for stability in rotation. On the other hand, losses increase rapidly through the chain system which can reduce efficiency of working.

The team has followed plan A as major plan and the rest analysis is based on this plan. This choice is because of its benefit in using the ultimate human power at full stage.

Although, using long shaft is disadvantage but it can be overcome by using coupling and bearings.

3.4.4 Gearbox Position:

The most important part to be positioned is the gearbox. It will generate the knowledge about:

1- Available length to the front

2- Shaft diameter

3- Specification and limitation of the paddle and lever

The average length of the team is 172 cm but the rider will move his legs to paddle. Those we introduce the compressed length term for the rider. The driver will be lying in the longitudinal position with stomach downward and with the head toward the nose of the submarine. This position is estimated by a bicycle rider compressed length (figure 38).

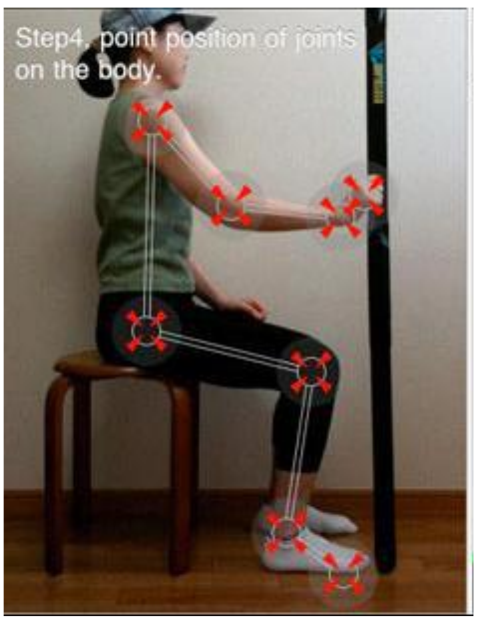


Figure 38 driver compressed length

Previous studies for the compressed length of bicycle rider conclude that a proper estimation of the cycler length is his length multiply by a ratio of 0.65. The compressed of the team is around 112 cm.

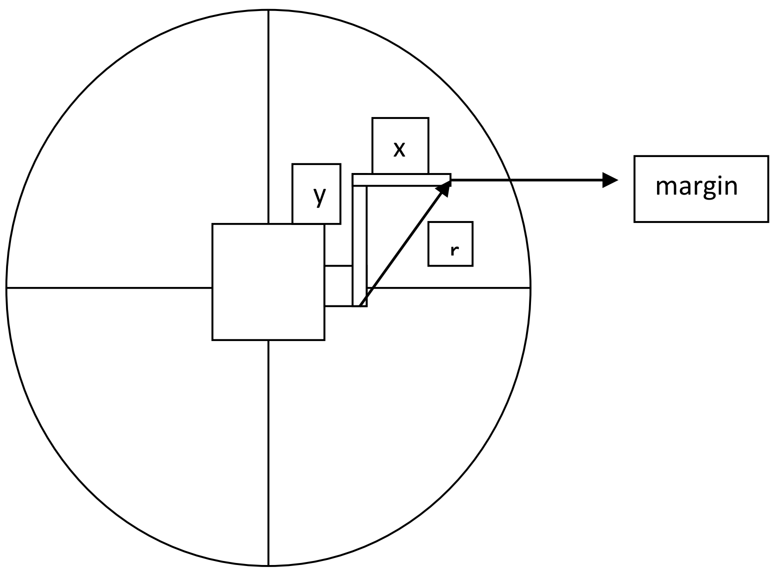
We consider this length as the compressed length of the team. Adding the window length (55 cm) the total length of the gear position became 167 cm. A margin of 13 cm used for the error of calculation and variation of length between members.

The final gear position is at 180 cm. By using the design of the hull the range for placing the gearbox falls in 0.77-1.87 m.

3.4.5 Pedal

One major consideration is the paddle size because it should not touch the hull. The procedure to calculate the lever and paddle is as follow:
- determine gearbox position
- determine radius at that position
- use iteration to find proper dimensions

The calculation of the paddle and lever is based on the simple Pythagorean theory. The following explanation shows how to calculate the lever and paddle dimension.



The above figure shows the assumed dimension where:
x= paddle size
y= lever length
r= maximum radius of paddle rotation

The radius of the submarine at 1.8 is 0.321 m. We reduce that radius to avoid paddle and hull interaction. The radius we choose is 29 cm.
The governor equation is $x^2+y^2= r^2$
By fixing two variables and change one we use iteration to get best results. The radius of rotation chosen to be less than 25 cm, fixing the lever length (y) and change paddle size (x).
Best iteration was as follow:
R=20 cm y=18 cm x= 8.72 cm margin= 5.438 cm

R=19 cm	y=16 cm	x= 10.4 cm	margin= 5.18 cm
R=20 cm	y=16 cm	x= 12 cm	margin= 3.5 cm
R=19 cm	y=15 cm	x= 11.7 cm	margin= 4.529 cm
R=18 cm	y=14 cm	x= 11.3 cm	margin= 5.467 cm

The best radius of rotation range found to be 18-20 cm and a margin of more than 5 cm required to avoid any contradiction. We choose the first iteration with y=18 cm and x=8.72 cm for the paddle size. This because we need to maximize arm length to increase the input torque (T= F . y) .

3.4.6 Chair Material

There are three alternative of material can be used such as wood, Steel and aluminum. (Table 4) shows the problem of each material.

Table 4 Problems of the alternatives

Material	Constrains
Wood	Water effect it
Steel	Corrosion will happened
Aluminum	Bend at high load

Aluminum is selected because it can be strengthen by increasing the thickness of it, less density and water will not affect it.

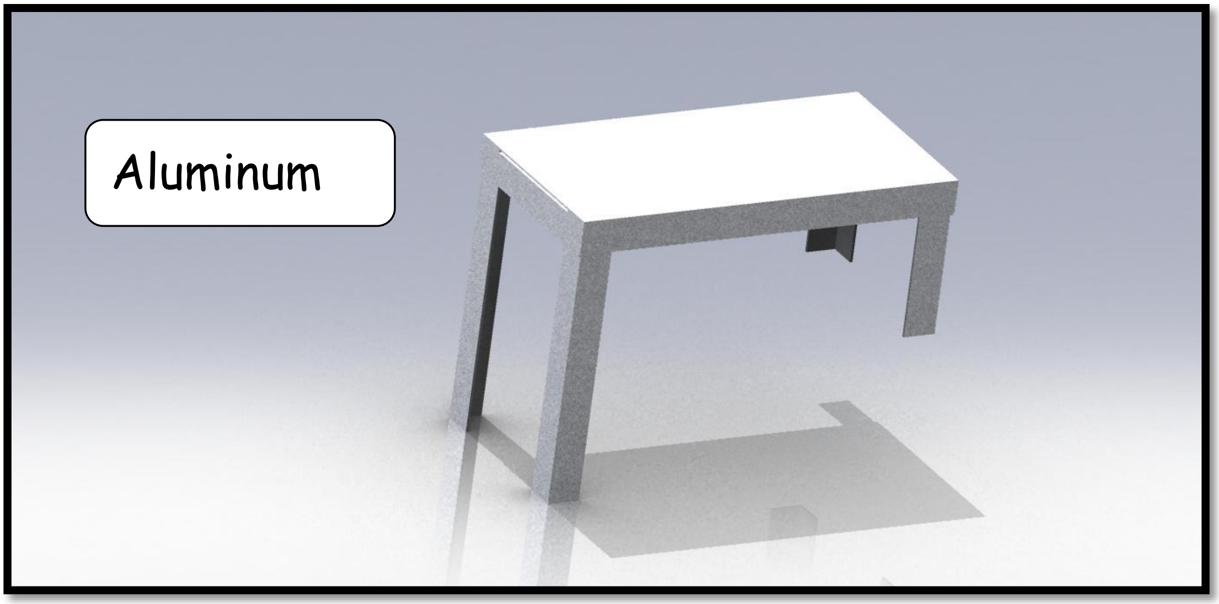


Figure 39 Design of the chair

3.4.7 Stress analysis

Using SolidWorks and Abaqus to make the stress and strain analysis the following are the specification used.

Average Weight of the pilot is specified to be 80 Kg (800 N).

Cross section Area = 0.3 x 0.6 = 0.18 m^2.

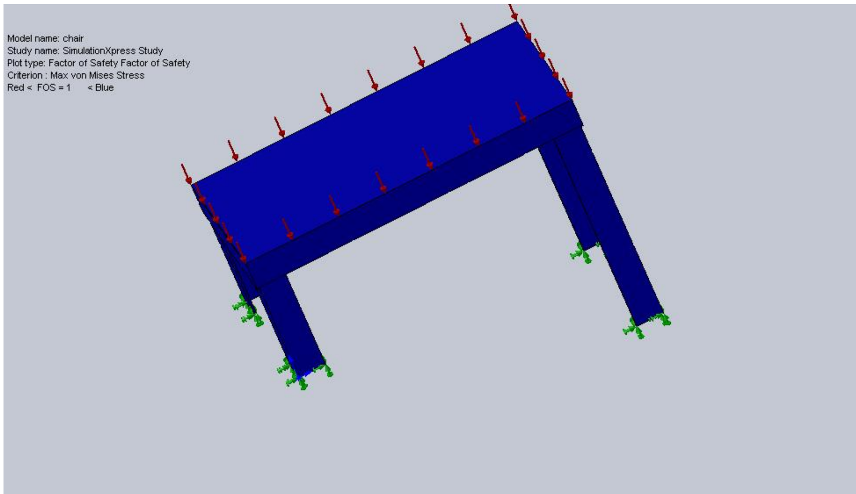


Figure 40 Applying load on the chair

Table 2.7 Result of stress analysis

Name	Type	Min	Max
Stress	VON: von Mises Stress	0.00758492 N/mm^2 (MPa)	11.7705 N/mm^2 (MPa)

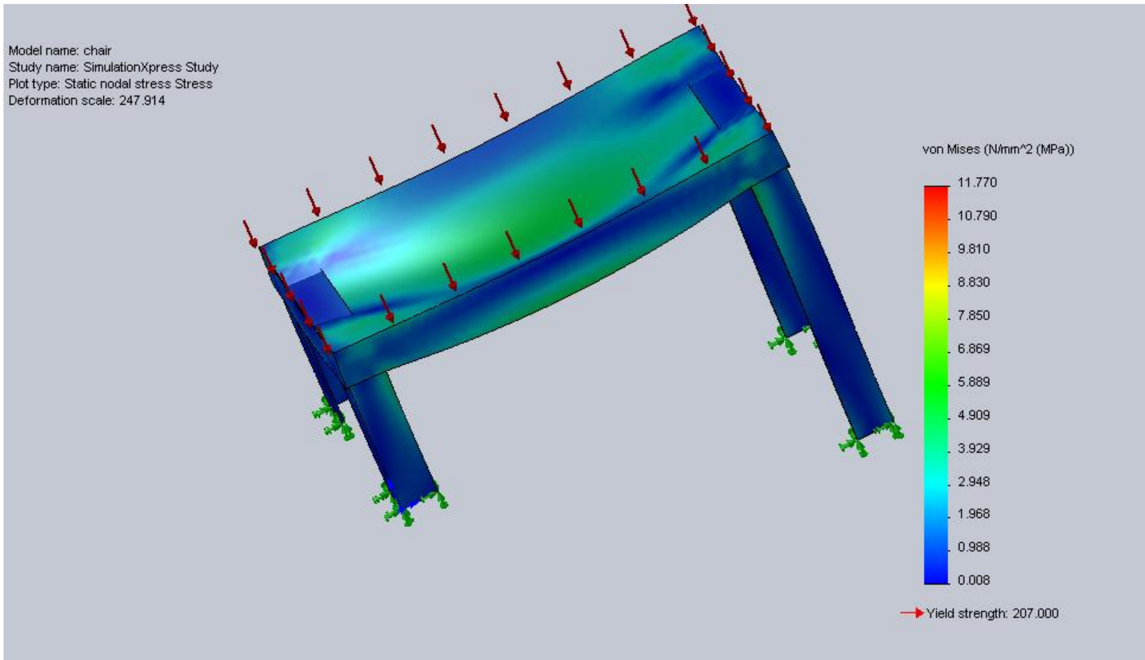


Figure 41 Result of stress analysis

3.4.8 Displacement analysis

Table 2.8 Displacement analysis results

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm	0.245663 mm

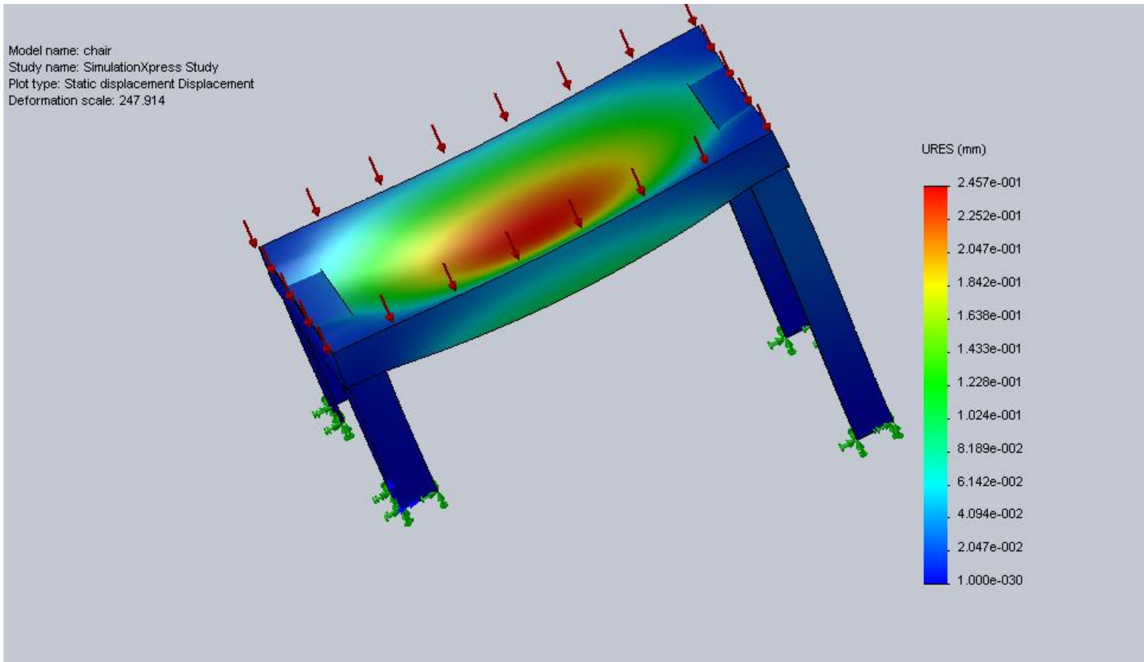


Figure 42 Displacement Analysis Results

To solve the problem of bending more sheet of aluminum added under the chair and the final shape is shown in figures 43 and 44.

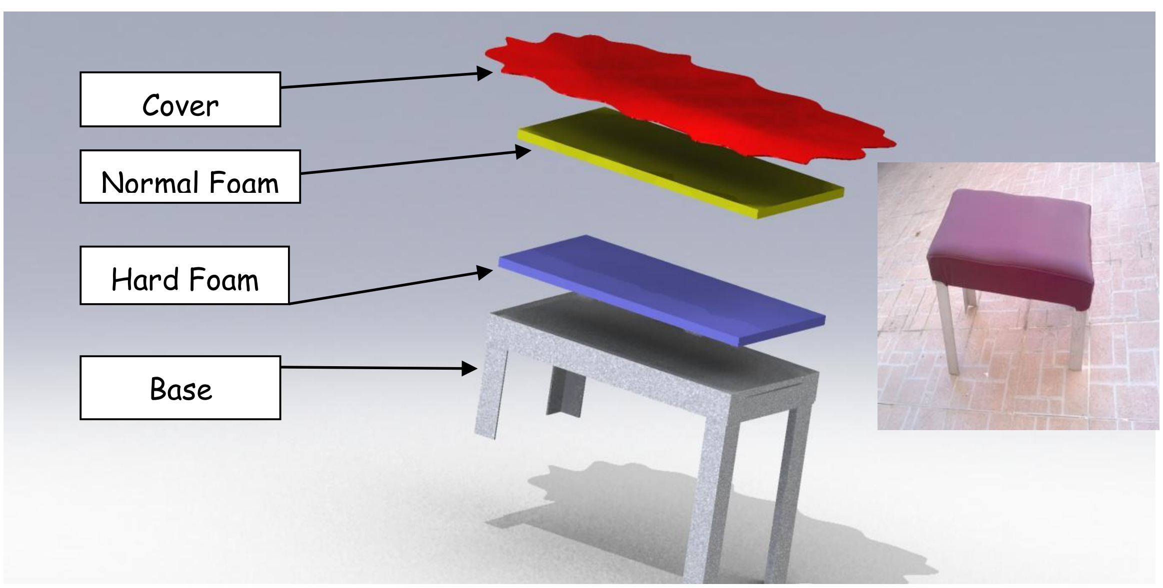


Figure 43 Final design of the chair

Figure 44 Chair modification and process of dis-assembly

3.5 SUMMARY

The hull of the submarine was designed based on the latest updates of profilers. The material was chosen based on its properties and how they affect the project directly. The configuration of the sub was designed according to the main component included in the submarine. The hull configuration was designed to be as compact as possible. The hull manufacturing starts and it will take more weeks to be ready. The driver chair design and manufacturing was conducted in this semester.

CHAPTER 4: PROPELLER DESIGN

4.1 INTRODUCTION

As stated earlier, the propeller is the most significant component of the submarine for providing thrust. To gain the required speed, the propellers design is required to be at highest achievable performance. Moreover, the hub cap plays a role in minimizing the drag force created due to the extension of the hub out of the submarines profile. In other words, the hubs diameter is greater than the diameter of the submarines end or tail which creates drag force opposing the thrust force generated by the propeller itself. The efficiency then decreases. Solving this problem requires a new design for the propellers hub with smoother profile to allow laminar flow of water.

4.2 THEORETICAL BACKGROUND OF JAVAPROP

JavaProp is a relatively simple program, which is based on the blade element theory. The blade is divided into small sections, which are handled independently from each other. Each segment has a chord and a blade angle and associated airfoil characteristics. The theory makes no provision for three dimensional effects, like sweep angle or cross flow. But it is able to find the additional axial and circumferential velocity added to the incoming flow by each blade segment.

This additional velocity results in an acceleration of the flow and thus thrust. Usually this simplified model works very well, when the power and thrust loading of the propeller (power per disk area) is relatively small, as it is the case for most aircraft propellers.

4.2.1 AIRFOIL DESIGN

The design procedure creates the blade geometry in terms of the chord distribution along the radius as well as the distribution of the blade angle. The local chord length *c* depends mainly on the prescribed lift coefficient C_L to have wider blades, having to choose a smaller design lift coefficient (resp. angle of attack) and vice-versa. It should be noted, that the design procedure does not work accurately for high thrust loadings as they occur under static conditions. If the power coefficient *Pc* is less than 1.5, otherwise the theory is not fully applicable and may lead to errors. Figure 45 shows the flowchart of the design process.

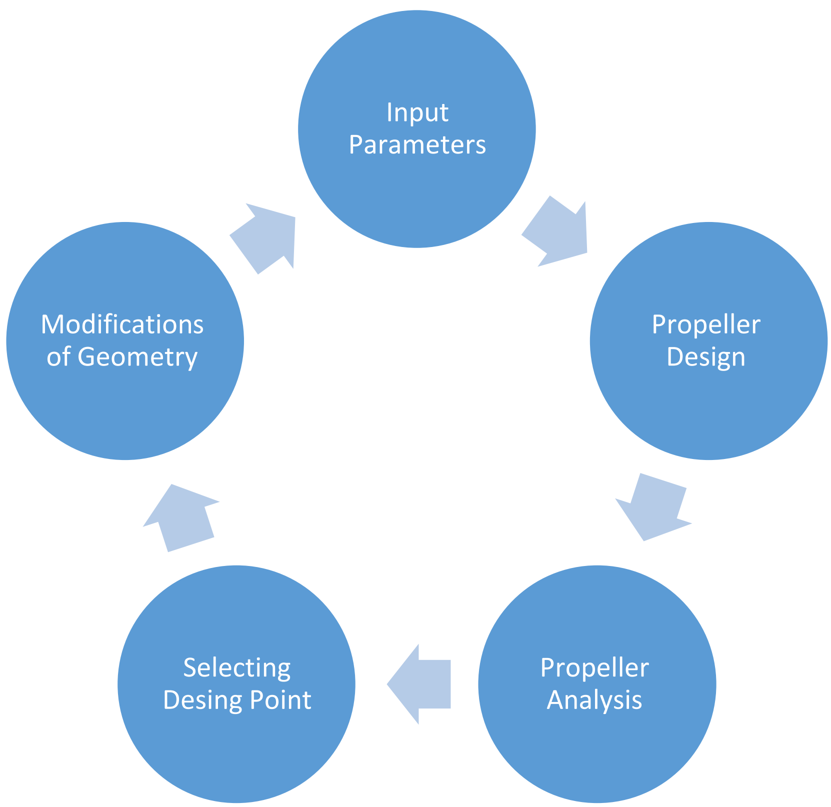


Figure 45 Flow Chart of Design Process

4.2.2 Propeller Concept and Evaluation

In order to move submarine forward the thrust force must be large enough to generate output power. This thrust is generated due to the difference between the angle of attack of the airfoil. As previse teams decide to have two blade propeller .Also .we will design the propeller according to their studies because our design for lower speed application and lager diameter.

- Constraints and requirements to the design

There are several constraints regarding the project. The first constraint is the power delivered by the pilot. The power is decided to be 280W according to previous studies on average power of a cyclist. The density of water is another constraint since the competition is carried in a sea water pool. The density of salt water is about 2.5% higher than the density of fresh water. The temperature of the water is assumed to be around 10°C. Therefore, the corresponding density to this temperature is 1024.2825kg/m^3. The salinity of water is taken to be around 31545(mg/L or PPM). The kinematic viscosity that corresponds to this density is 0.0000013m^2/s.

- Input Variables and Constants

The first variable to be given for the design is the number of blades. It is decided for the propeller to have 2 blades according to the capabilities available. The output speed of the propeller is 180 revolutions per minute. This is obtained from the gearbox design which has a ratio of 1:3 and since the pilot can produce about 1 revolution per second. Another variable is the diameter of the propeller which has to be less than the maximum diameter of the submarine body by 0.01-0.03m. This is to avoid turbulent flow from occurring and to prevent the submarine from rotating around its self. The axial velocity of the flow is selected to be 8knots which equals 4.112m/s and it is the target required to be achieved.

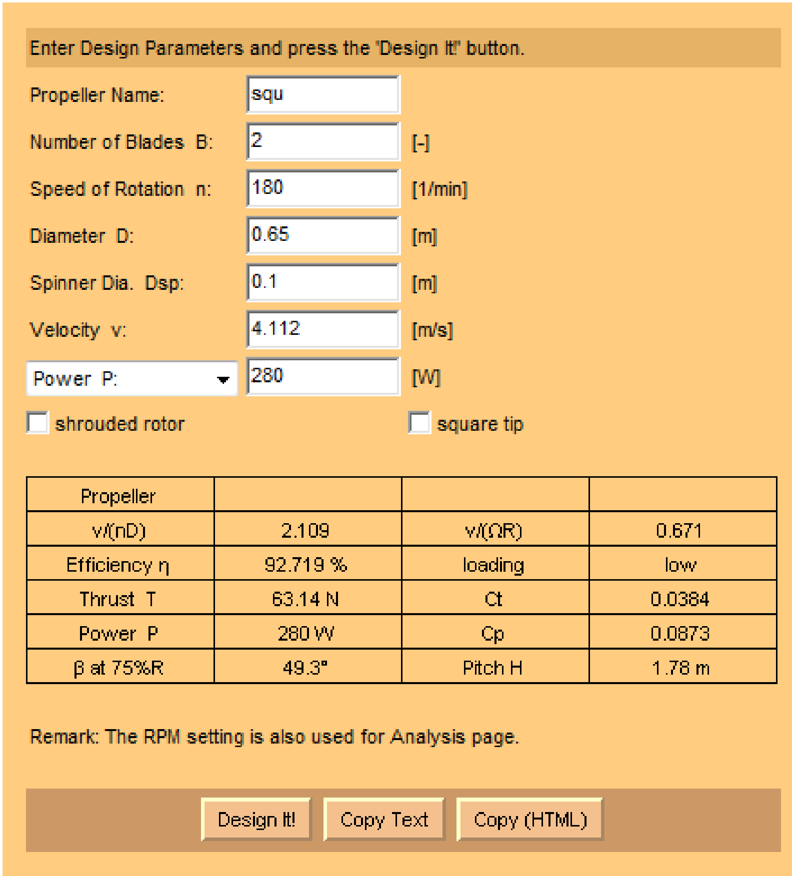


Figure 46 Design Parameters

Basically, hydrofoils are like airfoils, just used in water. They can be used on propeller blades, as lifting surfaces or in keels and rudders. In most of these applications a high lift to drag ratio is required, which usually drives the design to higher lift coefficients.

The airfoils selected were the Clark-Y, NACA6416, NACA6416, MH114 with corresponding angles of attack 18°, 12°, 8°, 3° which are shown in figure 46. This is selected to give us maximum efficiency, high thrust, and high velocity. And also because of the characteristic that met the design constraints. The first step while carrying out a propeller design to choosing an airfoil is looking into the airfoil characteristics such as the L/D ratio, the maximum C_L, stall angle depending on the desired thickness as well.

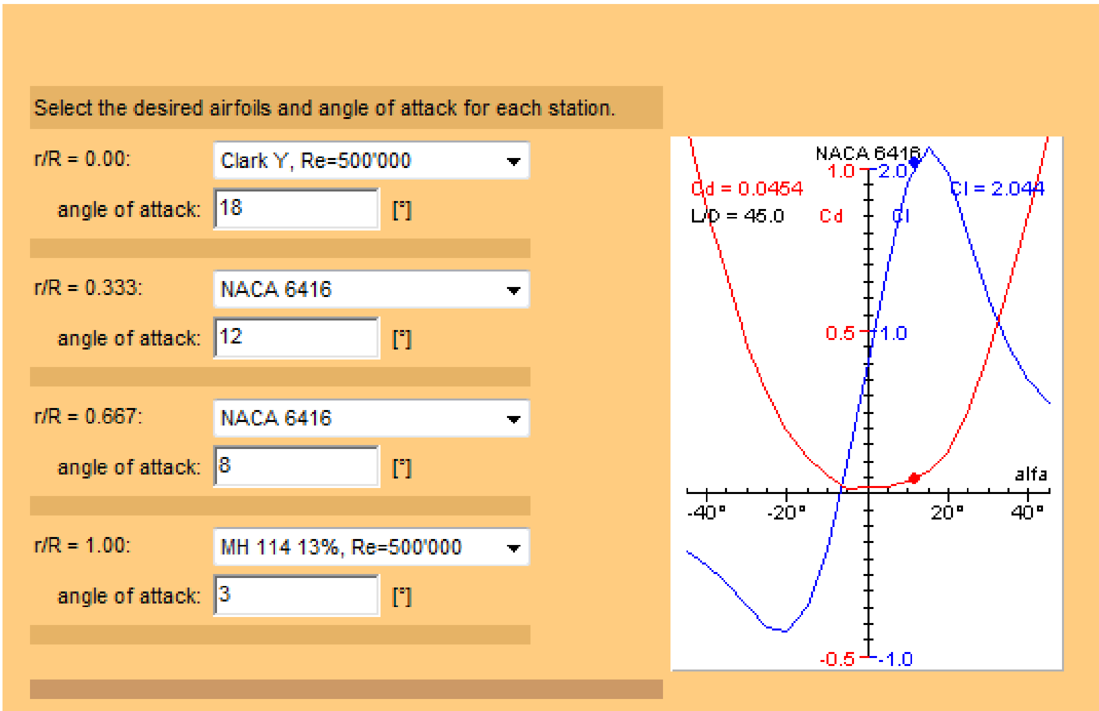


Figure 47. Airfoils Design

Figure 47 below shows the distribution of efficiency that corresponds to the dimensionless advance ratio. The results show that at maximum efficiency 92.24% the velocity reaches 9.8knots (5.07m/s). At 50% efficiency the velocity reaches 4knots (2.14m/s) and at 60% efficiency the velocity reaches 5knots (2.55m/s).

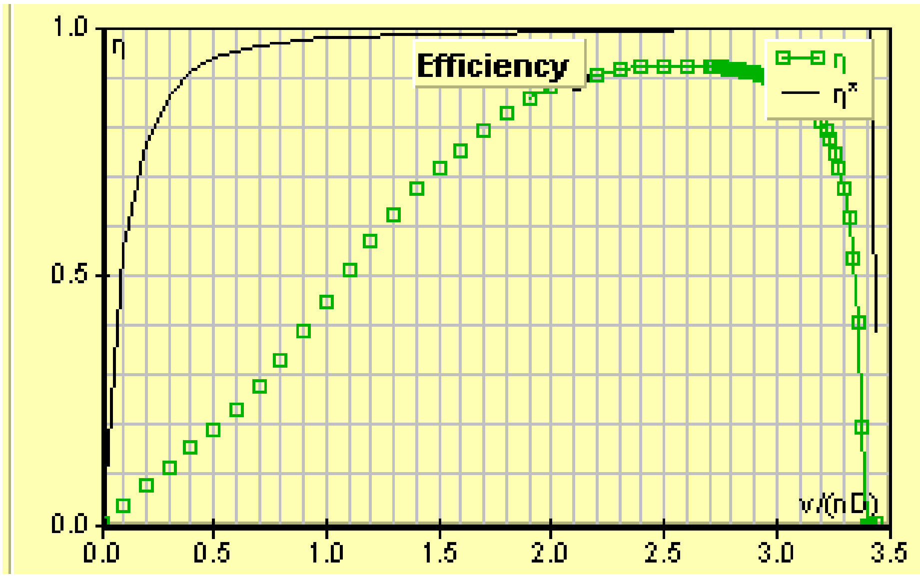


Figure 48. Efficiency of the Propeller vs. the Advance Ratio

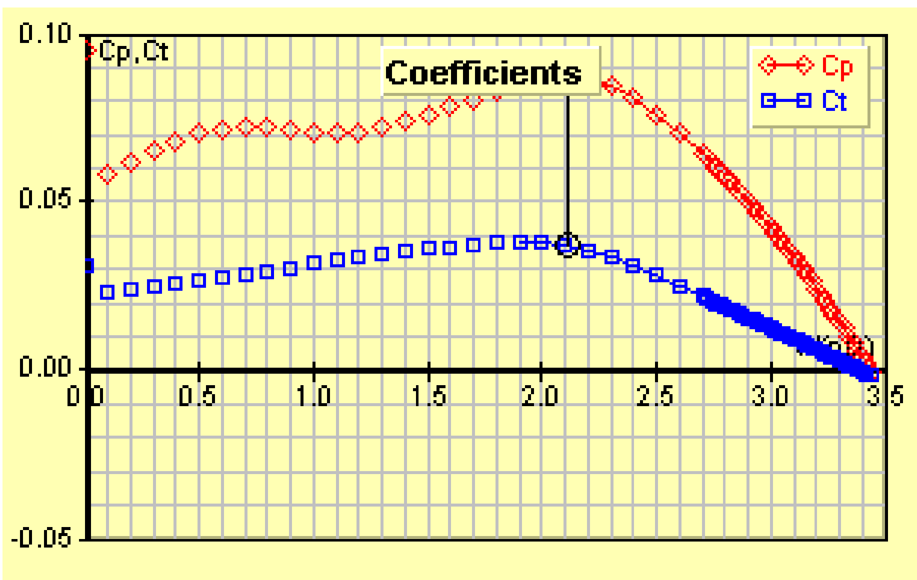


Figure 49. Power and Thrust Coefficients vs. Advance Ratio

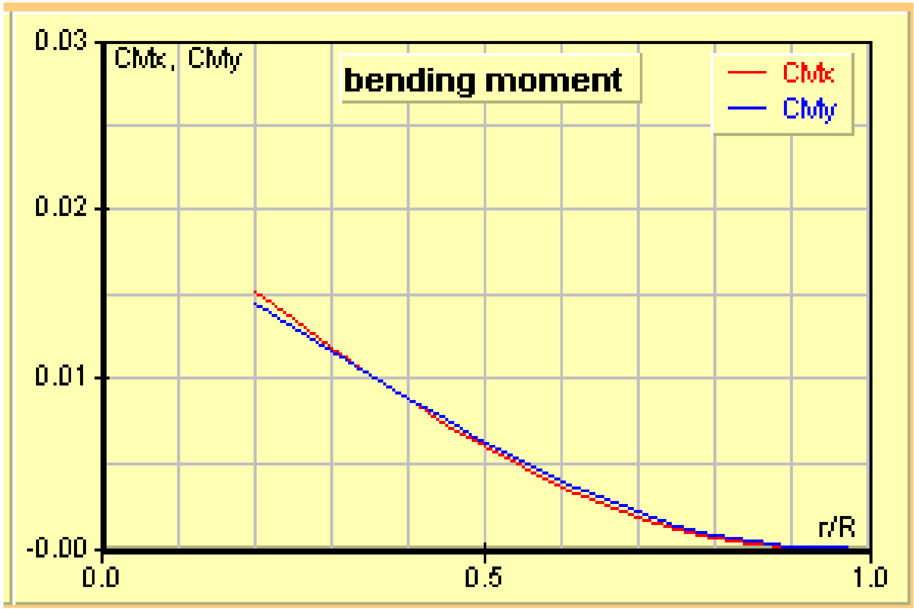


Figure 51 Bending Moment

The bending moments on each blade decreases as we approach the tip of the blade.

4.2.3 Summary

All parts of the propulsion system have been designed and still in manufacturing stage. The main two functions of the gearbox are to convert motion by 90 degree, and to increase the number of cycle's provider by the pilot. The ratio of the gearbox is 1:3, where the input rpm will be 60 therefore the output rpm is 180.The design of the propeller is different from Sultana 1, where different airfoils have been selected in order to give maximum efficiency and maximum velocity.

4.2 Blade Manufacturing

The blade that has been designed in the first semester was manufactured using two types of manufacturing processes. First, it was manufactured by using sand casting method. One blade was printed as 3D prototype using 3D printer to get the pattern of the sand mold. The material of the molten metal is brass. We made three blades. One of them was as a spar. As a result of using brass metal the blades were heavy so, their bases were drilled in order to reduce some material. They were filed well to get better surface finish.

Figure 53 : Brass blade using casting method

Figure 52: Drilled blade

The second method of manufacturing the blades was by using five axes CNC machine. Stainless steel 304 was used. The blades used in the previous submarine generation were used to compare it with the new blades.

Figure 54: Stainless Steel blade using CNC machine

Figure 55: the blade used in previous submarine generation

Another set of blades were manufactured manually in the workshop. A 3D printed model was used as a reference in the manufacturing process. The blade is illustrated in the figure 56 below.

Figure 56: A blade manufactured manually in the workshop

4.3 Blade Redesign

During the submarine testing, one of the blades was bended. The bending occurred at a stress concentrated region. To avoid this problem in the future, the blade was redesigned to correct the region where stress concentrates. The modified design is shown in the figures 57 and 58 below. The blade has a smoother profile in the region of stress concentration.

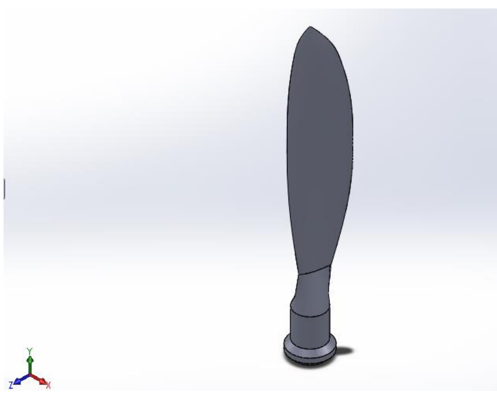


Figure 57: Original design

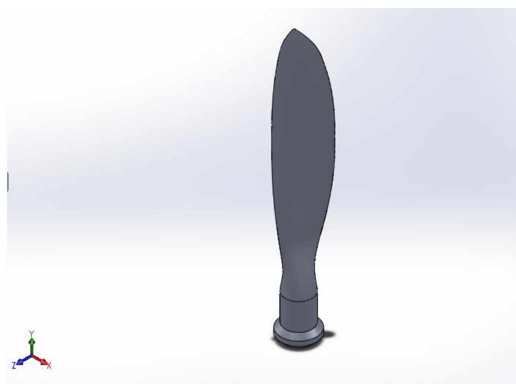


Figure 58: the Modified design

Stress analysis of the modified blade are shown in figure 59 below.

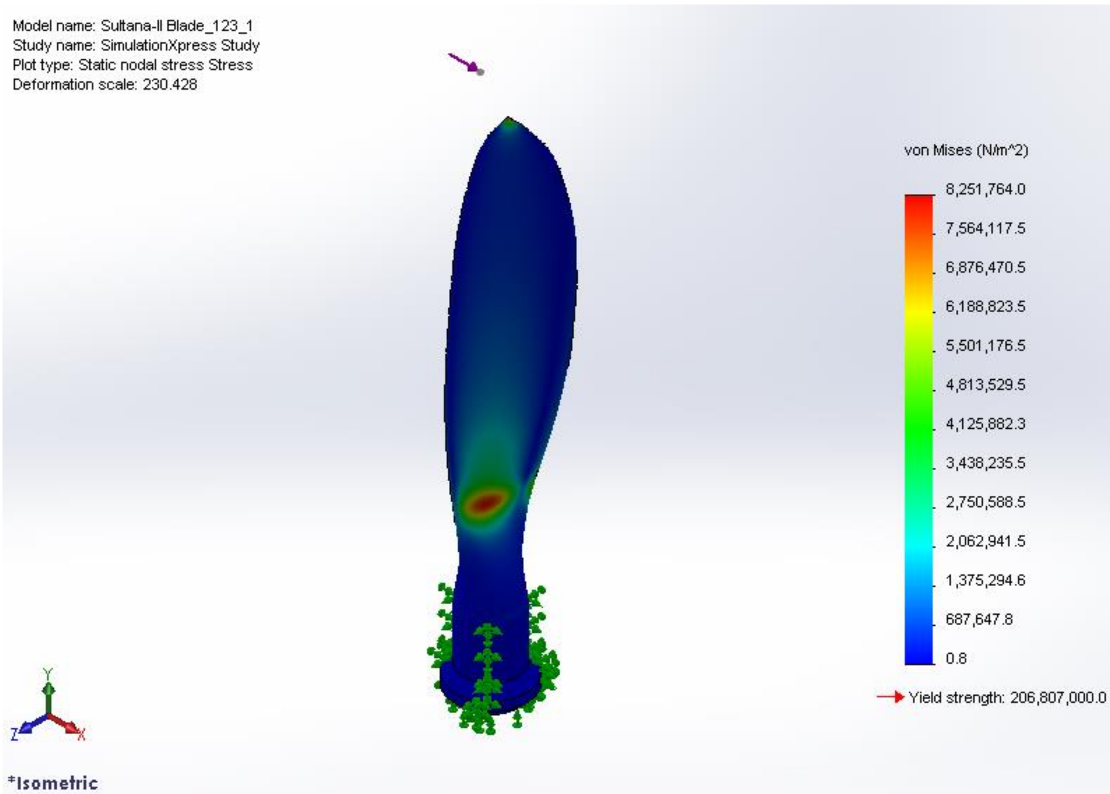


Figure 59: Stress analysis of the modified blade

The maximum stress is $8.25 \times\ 10^{9}\ {}^{N}/_{m^2}$ at the area indicated in red color.

Moreover, displacement study was performed and the results are shown in the figure 60 below.

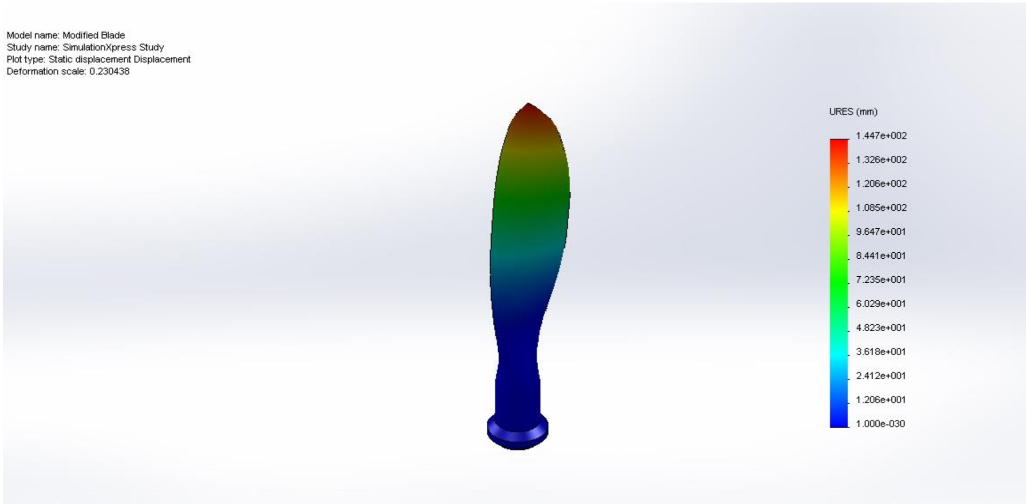


Figure 60: Displacement Study of Modified Blade

The maximum displacement is 144.704 mm at the area indicated in red color.

4.4 HUB CAP DESIGN AND MANUFACTURING

4.4.1 Introduction

The aim of redesigning the hub cap was to provide a solution for minimizing the drag force acting in opposite direction of the submarines direction of movement. Another aim was supporting the blades.

The hub cap was designed using SolidWorks software. The profile of the hub was designed in a smoother manner than the previous conical shape. The profile of the hub is a continuation of the profile of the hub itself. This design provides laminar flow of water directly in contact with the hull and moving towards the hub cap. As a result, vortices that cause turbulence in the water flow were minimized. Moreover, minimal drag force is ensured with this profile of the hub cap which satisfies its objective.

The dimensions of the hub cap were consistent with the hull. Starting at the base of the hub cap, the diameter of the base of the hub cap was exactly the same as the diameter of the end of the hull of the submarine, and starts decreasing along the profile to finally reach the tip of the hub cap.

4.4.2 Material Selection

After the concepts were generated and evaluated, some important design aspects are to be considered. Material selection is very significant step in the design process. The main objective of material selection is to meet performance criteria with minimum cost possible. This process begins with setting the required properties and cost. Strength is one mechanical property to be considered since the part usage involves rotation and needs to resist drag forces. Density, an important physical property that is linearly related to mass, is needed to be at level which will not affect the stability of the submarine. In other words, if the material is very heavy, the submarine will tilt backwards and vice versa. Moreover, the material is required to withstand temperatures as low as $0°C$ and to resist corrosion effectively due to the wet operational environment. Electrical properties such as conductivity and resistivity are not an issue in this case and thus not considered. And finally, for manufacturing or processing properties, ductility to some extent is needed for easier fabrication. A basic decision matrix for material selection was generated as shown below.

Table 5 Basic Decision Matrix for Material Selection

Criteria	Alternatives					
	Stainless Steel (AISI type 304)		Aluminium (Anealed)		Wood (Teakwood)	
Strength	215 MPa	+	180 MPa	Datum	95 MPa	-
Corrosion Resistance	Resists most oxidizing acids and salts	0	Excellent corrosion resistance due to formation of oxide layer		No corrosion, but effected by water if not painted with waterproof material	0
Temperature ($0°C$)	Ductile to brittle transition occurs much below $100°C$	0	Can sustain very low temperatures effectively		Good to some extent	0
Density	8 g/cm^3	-	2.7 g/cm^3		0.75 g/cm^3	+
Manufacturability		-				-
Cost		-				0
Total		-2		0		-1

As shown in the table above, although aluminum and wood (Teakwood) have the close relative score, aluminum is more reliable than wood in general.

4.4.3 Manufacturing the Hub Cap

The cone is the part at the end of the submarine and is attached to the hub from one side. It is used to reduce the drag and provide smoother flow of the water and eliminate vortices that might initiate beside the hub.

The diameter of the cone is 11cm which is consistent with the hub. Below are two figures showing the shape of the cone and its multi-view drawing.

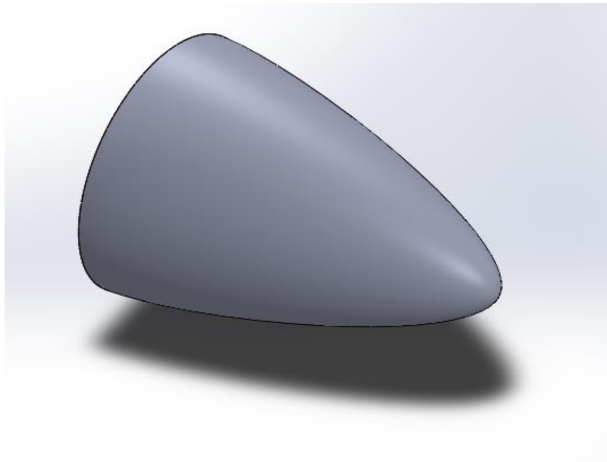


Figure 61: Isometric View of the Cone

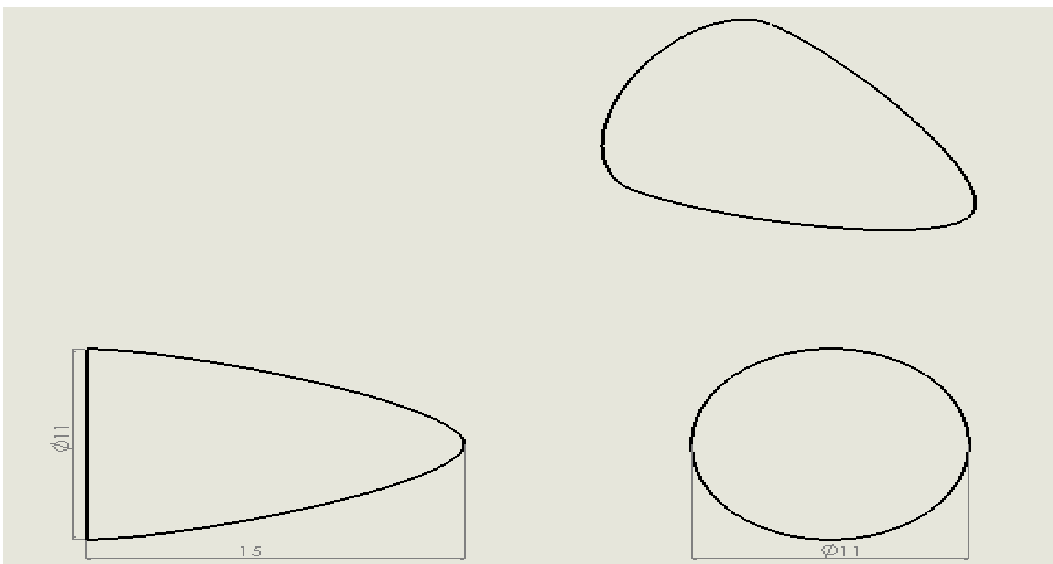


Figure 62: Multiview Drawing of the Cone

The figures 63 and 64 below illustrate the cone after manufacturing.

Figure 64: The hub cap after manufacturing

Figure 63: The hub cap after manufacturing

4.4.4 Summary

The main objective of redesigning the hub cap was because the previous design was not efficient. There was some turbulence because the profile did not allow smooth water movement. The design started with designing a better and smoother profile. Then, concept generation phase included searching for a ways to separate the part into two to allow easy installation of the blades. Moreover, it included the search for ways to attach the two parts together. The designs were evaluated using both weighed and basic decision matrices. Based on them, the symmetric split part was selected as well as bolts for attaching the two split parts. The last subsection included material selection. A basic decision matrix was used to determine the material which was aluminum.

4.5 Design and Manufacturing the Hub

The propulsion system is the part that provides motion or thrust to the submarine. It consists of a hub which is connected to a hub from one side and a shaft from the other side.

The hub is the part that joins the two blades bases and secure them. It is a very important part in the propulsion system of the submarine. The hub consists of two identical parts that are connected with each other to close on the blades bases. Their shape is similar to a disk that has a cavity for the blades to rest on. Figure 65 below shows a part of the hub.

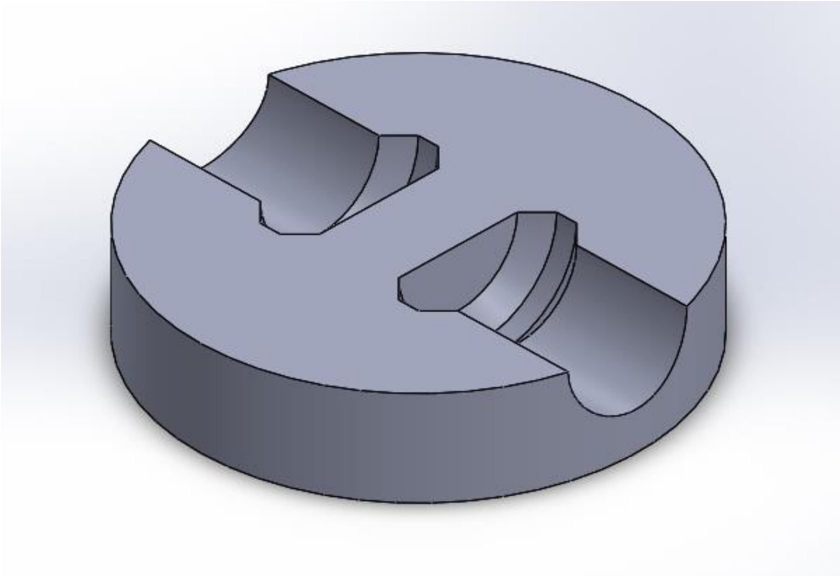


Figure 65: Isometric View of the Hub

The dimensions of the hub are consistent with the blades' base. The Multi-view drawing of the hub is shown in figure 66 below. The figure shows that the thickness of the disk is 2.5cm and its diameter is 11cm. The features inside the disk are semi-circular cylindrical cut of 3cm diameter and 3cm length. Moreover, another semi-circular cylindrical cut is at the end of the previous cut with a diameter of 4cm and 1.5cm thickness with chamfered edges. The hub is made of aluminum and has a mass of 1.1 kg.

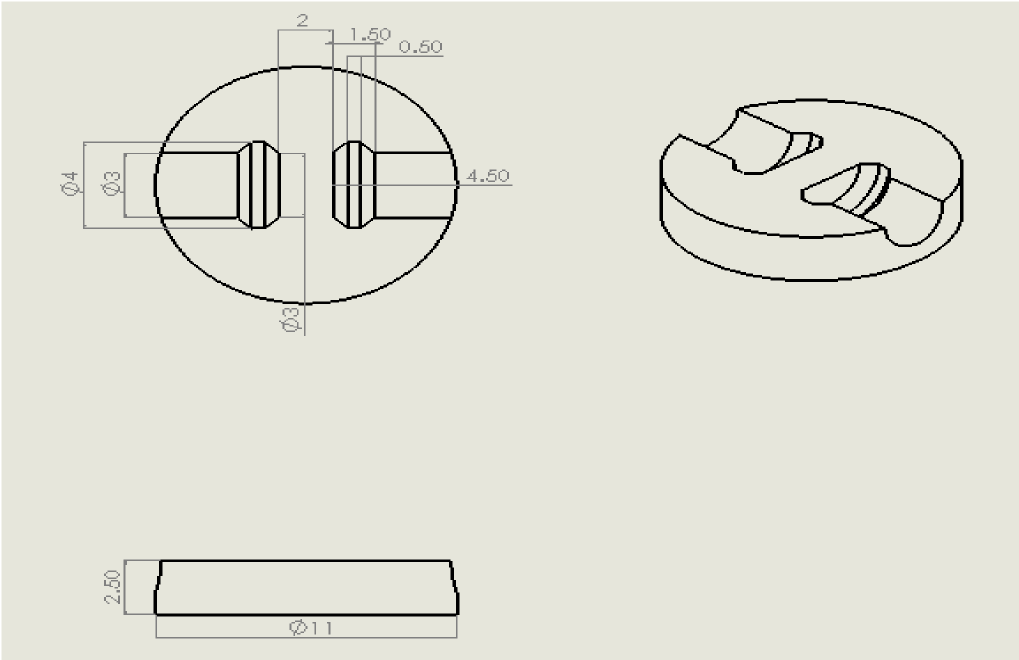


Figure 66: Multiview Drawing of the Hub

A figure of the hub after manufacturing is shown below.

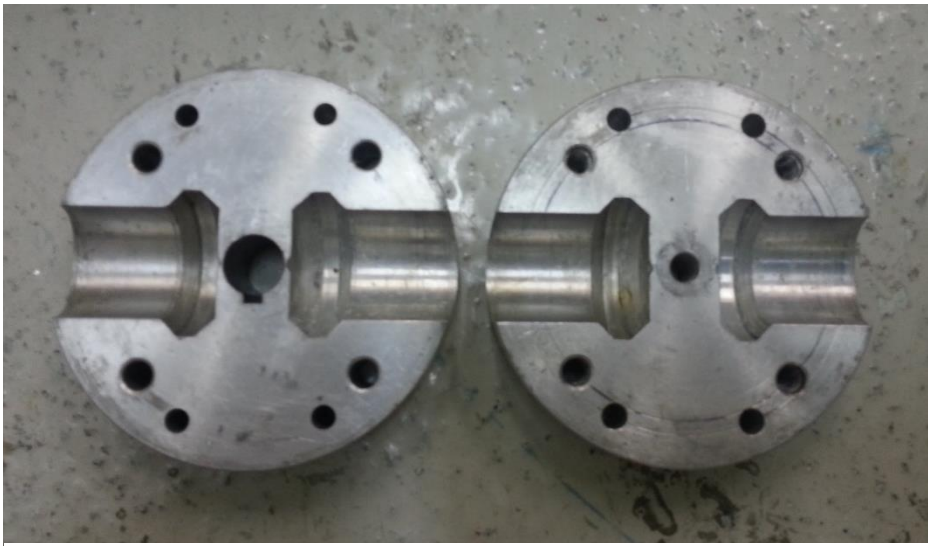


Figure 67: The hub after Manufacturing

4.6 Configuration of the propulsion system

The parts are attached to each other as shown in figure 68 below.

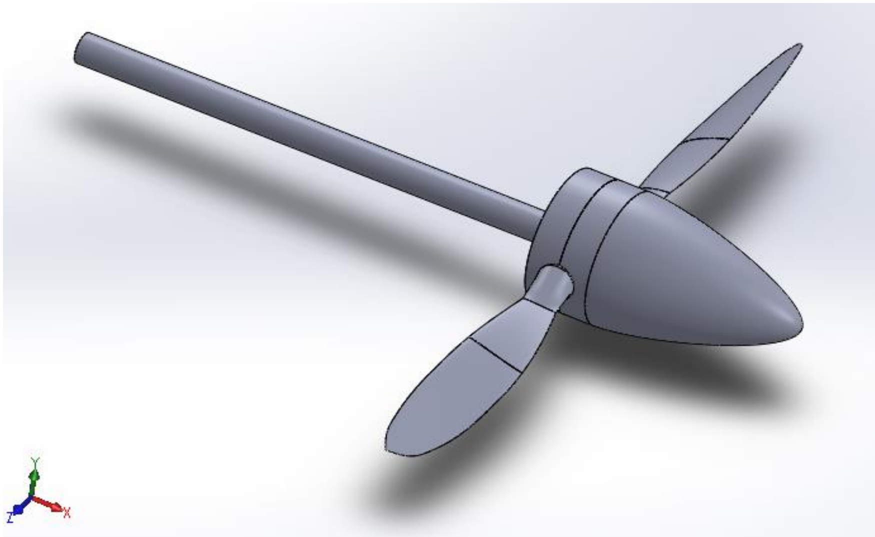


Figure 68: Configuration of the Parts

CHAPTER 5: GEARBOX DESIGN

5.1 INTRODUCTION

One of the main tasks that have to be accomplished by the team is designing and selecting a gearbox that can provide high speed to the submarine with less required torque. Torque is the power generated through pedals that are rotated by the pilot. This power needs to be transmitted to submarine propeller with high efficient system which is the job of the gearbox. A less wasted power, more comfort configuration and avoiding problems that have been faced with the previous teams are important concerns in designing the gearbox.

As it is mentioned earlier, the team decided to replace the used gearbox with higher ratio one. A 1:5 ratio gearbox selected to be used that means that the quicker the acceleration will be. On the other hand, the pilot should be strong enough to be able to handle this high ratio.

5.2 CONCEPT GENERATION OF GEAR BOX

5.2.1 Bevel Gears

When gears are used to transmit motion between intersecting shafts, some form of bevel gear is required. It can take the force from one direction and change it to another direction. A bevel gear set is shown in Figure 69. Although bevel gears are usually made for a shaft angle of 90◦, they may be produced for almost any angle. [shigly]

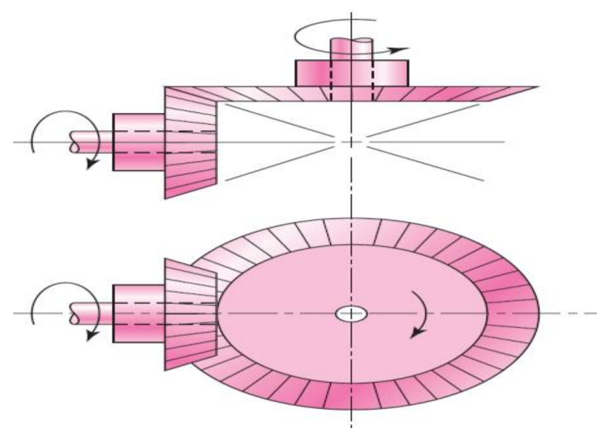


Figure 69: Bevel Gearbox

This type of gears is commonly used, that because it has many advantages. Bevel gears have good flexibility, unlike standard ones; bevel gears have an adjustable angle of operation. It's easy to tweak their force output by simply changing the number of teeth. Also, they not only transfer force from one direction to another, but also increase the force generated after the transfer. [Article Source: http://EzineArticles.com/5674966]

A bevel gearbox, 1:5 ratio, with two inputs pedals and one output which is a direct shaft, as shown in figure 70 below, connecting the propeller at the back of the submarine to the bevel gear was set to be the first alternative.

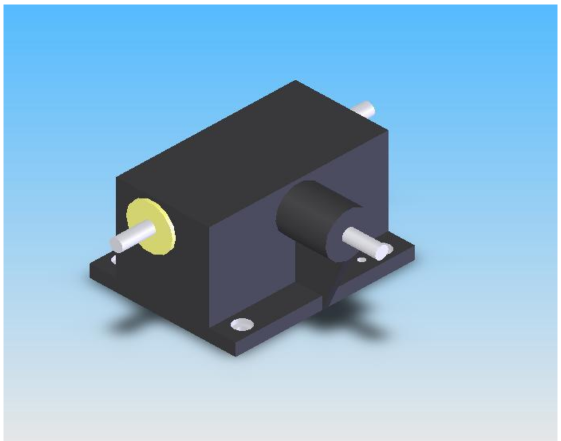


Figure 70: 5:1 Ratio Gearbox

5.2.2 CONTINUOUSLY VARIABLE TRANSMISSION GEARBOX (CVT)

CVT (Continuously variable transmission) gear set is considered to be the latest available technology in transmission systems. CVT gives an infinite number of gear ratios between the maximum and the minimum ratio required which will solve the ratio problem.

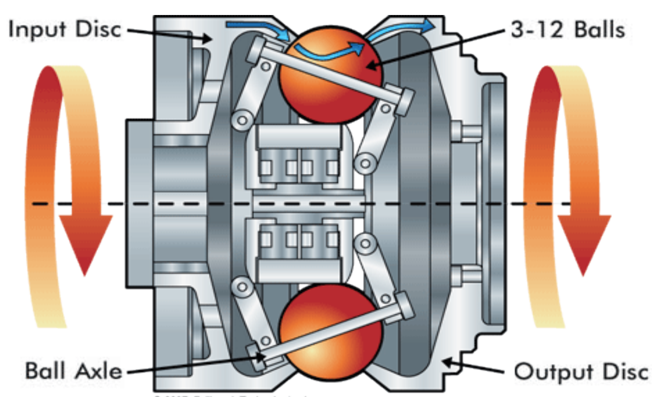


Figure 71: CVT MECHANISM

The feedback disc and the outcome disc are held onto the balls tightly so that the necessary quantity of clamping force is provided for the amount of torque being passed on. However, as indicated above, the torque is passed on through the traction liquid, which stops wearing between metal to metal contact, which is the balls and disks, while providing traction for the balls and rings and lubrication for bearings and other parts. The speed of the output disc compared to the speed of the input disc, or speed ratio is controlled by the position of the balls and its angle compared with the axis of the all CVT.

5.2.2.1 The Specifications of CVT

Table6 : Specifications of CVT

Dimension	Value
Weight	2.45 kilograms
Variable ratio	0.5 to 6.5
Max diameter	125.0 mm
Width	183 mm

5.2.3 IN-LINE PLANETARY GEARBOX

Another alternative for the transmission system is using in-line gearbox. In-line gearbox is a system of gears that consists of three main components: The Sun Gear, Ring Gear, and two or more Planet Gears. The Sun gear is located at the center, the ring gear is the outermost gear, and the planet gears are the gears surrounding the sun and inside the ring gear.

The input and the output are in the same direction. This alternative could be used if the Right-Angle bevel gearbox with the desired ratio cannot be available. In-Line gearbox with a ratio of 1:2 installed at the rear of the submarine with the current 1:3 gearbox will solve the problem of ratio. The resulted ratio will be 1:6 which is more enough to be used. Figure 72 shows an in-line gearbox with 1:2 ratio.

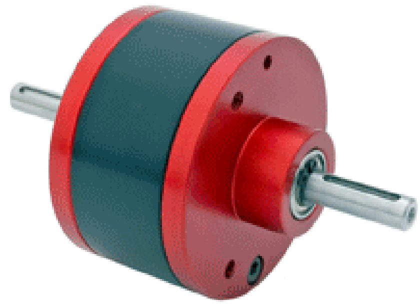


Figure 72: In-Line Gearbox

5.2.3.1 Specifications of the in-line gearbox

Table 7: Specifications of the in-line gearbox

Dimension	**Value (Unit)**	
Ratio	1 : 2	
length	150 mm	
Height	60 mm	
Face Width	60 mm	
Shaft	OD	16 mm
	ID	0 mm

5.3 CONCEPTUAL DESIGN EVALUATION

5.3.1 Selecting the type of the gear train

There are many types of gears. The four common types are bevel gears, spur gears, helical gears and worm gears. Each type has its own advantages and limitations. To choose the appropriate type of these gears, many criteria have been set to compare the alternatives with each other. These criteria are listed below.

- **Back-Drive ability:**

  Back-drive-ability is generally defined as the degree of ease of which a gear can be driven by its attached load when power is removed. When being back-driven, a gear reducer becomes a shaft speed multiplier, so the higher the gear reduction ratio, the more torque it takes to back-drive the gear box

- **Size:**

  The available size for the gear box makes a limitation. So, the gearbox with the smaller size will be preferred.

- **Cost:**

  Often the most critical factor in any product, the cost ceiling impacts many design choices. Material and processing selection comprise a high percentage of the overall cost of the gears.

- **Efficiency:**

  Efficiency of a gear is an important selection factor that is often overlooked. It determines the power losses of gear systems. It can be calculated by [output shaft power / Input shaft power].100 %.

Limitations of spur, helical and worm gears:

Spur Gear

Spur gears has been excluded from the comparison because they in generally cannot be used when a direction change between the two shafts is required.

Helical Gear

- Expensive and difficult to find
- Efficiency of helical gear is less because helical gear trains have sliding contacts between the teeth which in turns produce axial thrust of gear shafts and generate more heat. So, more power loss and less efficiency

Worm Gear

- Worm gear materials are expensive.
- A potential for considerable sliding action, leading to low efficiency
- The worm drives the drive gear primarily with slipping motion, thus there are high Friction losses.

Advantages of bevel gears:

- Occupies less space
- High efficiency
- Cheaper than helical and worm gears

Table8 : Weighted Decision Matrix for Concept Selection

Criteria	Weight	Alternatives								
		Helical Gearbox			Bevel Gearbox			Worm Gearbox		
		Value	Score	**Total**	Value	Score	**Total**	Value	Score	**Total**
Back-Drive - Ability	25	-	3	**75**	-	3	**75**	-	1	**25**
Efficiency for 1:5 ratio*	25	90%	2	**50**	94%	3	**75**	90%	2	**50**
Cost	10	-	2	**20**	-	2	**20**	**-**	2	**20**
Size	15	-	2	**30**	-	3	**45**	**-**	2	**30**
Total	**100**	**175**			**215**			**125**		

*According to AGMA

Rating system:

3: Very good 2: Good 1: Bad

It is clear from the above weighted decision matrix that the Bevel Right-Angle gearbox is the best type and it is the one that will be compared with the other transmission systems.

5.3.2 Selecting the transmission system

In order to decide which system is most practically, a comparison of the bevel gear systems, Chain belt and CVP gear was done using Pugh method with the datum being the Chain belt kept neutral in terms of pros and cons as shown in table below.

Table9 Description of the criteria

Criterion	Description
Installing	Easiness of installing and mounting the gearbox
Resistance	Amount of power loosed
Weight	Weight of the unit
Resistance to corrosion	Ability of gearbox material to resist the corrosion that can be caused by fresh water
Durability	The period that the gearbox can work efficiently
Efficiency	[Output shaft power / Input shaft power].100 %.
Assembly time	Time needed to assemble components of the gearbox
cost	Cost per unit

Table10 : Basic Decision Matrix for Concept Selection

Criteria	CVT Gear	Chain belt (Datum)	Bevel Gear
Installing	0	Datum	0
Resistance	+		+
Weight	+		+
Resistance to corrosion	+		0
Durability	+		+
Efficiency	+		+
Assembly	+		+
cost	-		+
Sum of +	**6**	**0**	**6**
Sum of -	**1**	**0**	**0**
Total	**5**	**0**	**6**

According to the second comparison carried out using normal decision matrix, the bevel gearbox system surpasses the two other systems by 1 point from CVT. It is the system that is to be endorsed for the design.

Another criterion that has to be considered is the availability of the desired transmission system. Bevel gearbox is more available compared to CVT system.

5.4 CONFIGURATION DESIGN OF POWER TRANSMISSION SYSTEM ALTERNATIVES

5.4.1 First alternative: Chain belt design

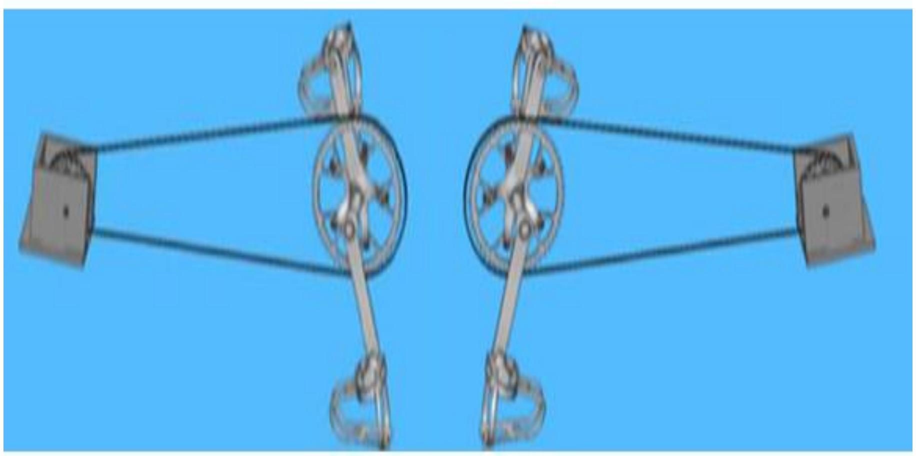


Figure 73: Chain Belt Design

5.4.2 Second alternative: CVT design

Figure 75: CVT Design

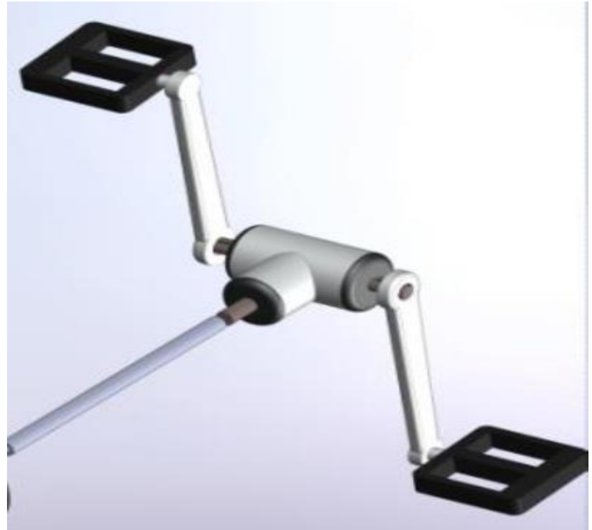


Figure 74: CVT Pedals Design

5.4.3 Third alternative: In-line gearbox design

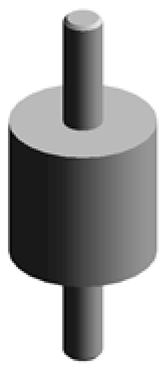


Figure 76: In-line gearbox design

5.4.4 Fourth alternative configuration design and specifications

Figure 77: Bevel Gearbox

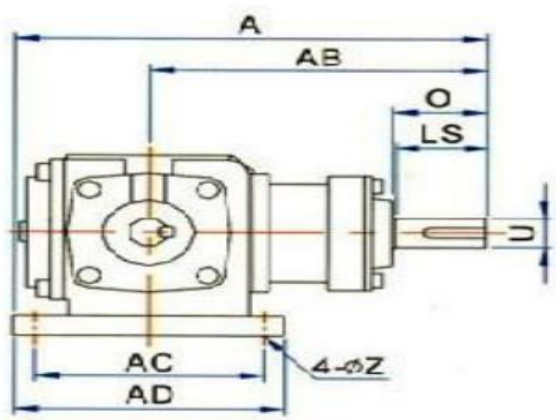


Figure 78: Bevel Gearbox Specifications

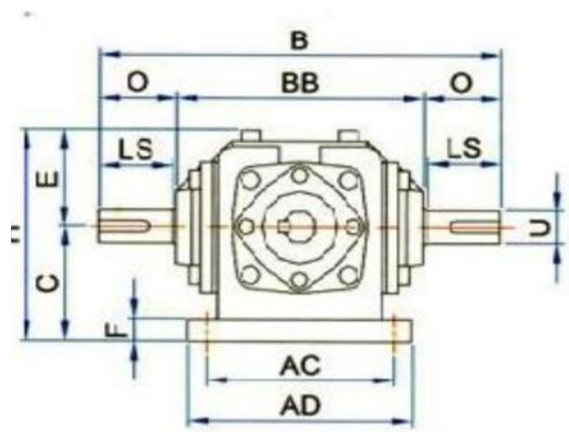


Figure 79 Bevel Gearbox Specifications

** Dimensions are in (mm)

A	174
AB	124
O	35
LS	33
U	15
Z	4- ¢ 9
AC	84
AD	100
B	180
BB	110
C	52
E	45
F	10
H	97

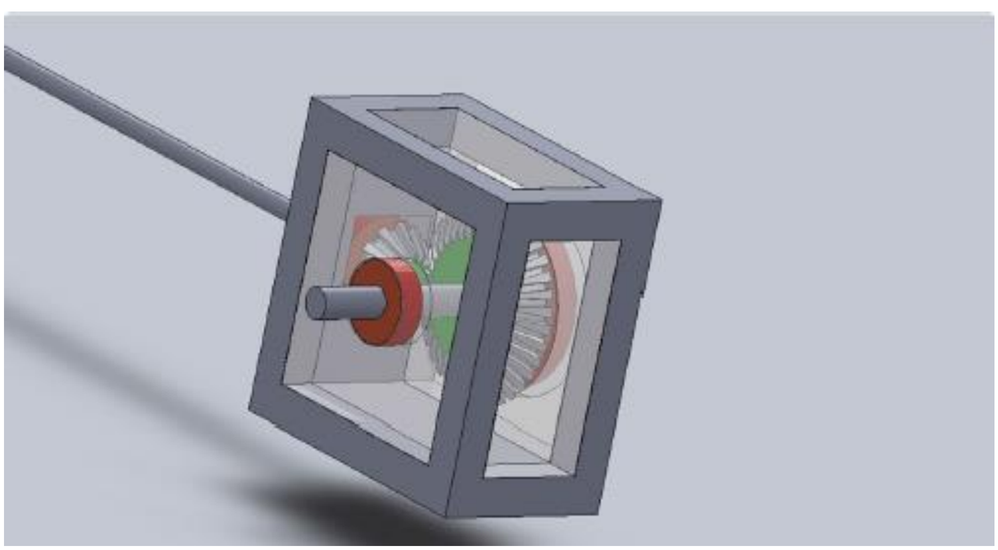


Figure 80: Configuration Design of the Bevel Gearbox

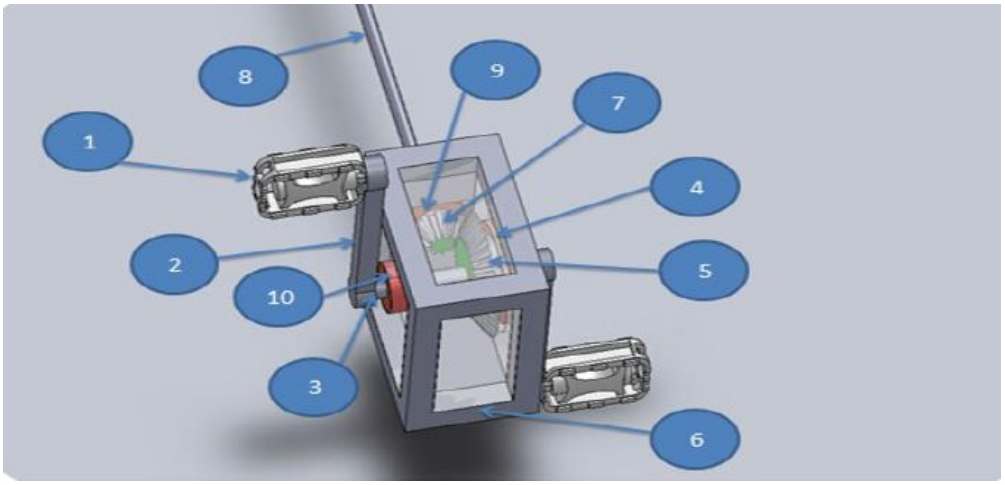


Figure 81: Components of the Bevel Gearbox

1. Pedal
2. Lever of pedal
3. Paddling shaft
4. Big gear bearing
5. Big bevel gear
6. Gear box case
7. Small bevel gear
8. Driving shaft
9. Small gear bearing
10. Paddling shaft bearing

5.5 Bevel Gear Force Analysis

According to AGMA standard the following calculations are conducted. A GCC normal person can provide approximate power of 280 Watt

$$Power = Angular\ velocity\ \times Torque$$

Also, approximated RPM provided by a person is 60 rpm. So:

$$\omega_{in} = 60\ rpm = 60\ \times \frac{2\pi}{60} = 6.3\ rad/s$$

$$p_{in} =\ \omega\ _{in} \times T_{in}$$

$$\mathrm{T_{in}} = \frac{p_{in}}{\omega_{in}} = \frac{280}{6.3} = 44.4\ N.m$$

The ratio of the gear box is 1: 5,

$$\frac{\omega_{in}}{\omega_{out}} = \frac{1}{5} \rightarrow \omega_{\mathrm{out}} =\ \omega_{in}\ \times 5 = 60\ \times 5 = 300\ rpm$$

$$\frac{T_{in}}{T_{out}} = \frac{5}{1} \rightarrow\ T_{\mathrm{out}} = \frac{T_{in}}{5} = \frac{44.4}{5} = 8.88\ N.m$$

So, a gearbox with a ratio of 1:5 is more enough.

5.6 Selection and Manufacturing the Gearbox

The gearbox that has been designed in the first semester was manufactured. Two bevel gears were manufactured using stainless steel 304 with a ratio of 1:4.5. Then cast iron was used to manufacture the casing of the gearbox. At a later stage, the gearbox turned to be very heavy, so, Aluminum was used instead. Figures 82 and 83 below show the bevel gears.


Figure 82: Bevel Gear


Figure 83: Bevel Gear

The figures below show the aluminum casing of the gearbox and the assembled unit.


Figure 85: Aluminum casing of the gearbox

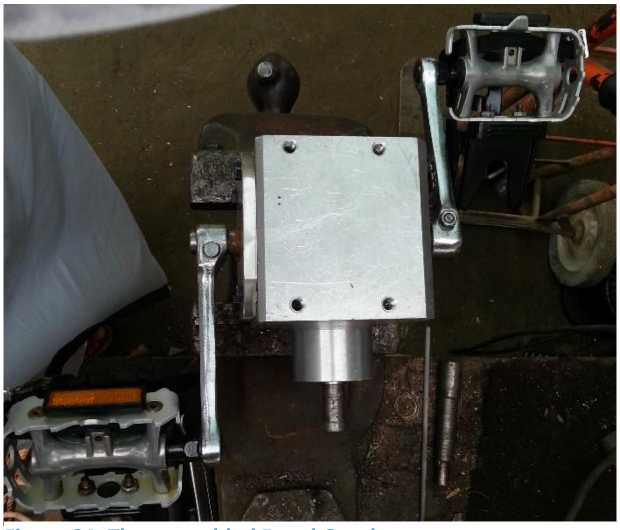


Figure 84: The assembled Bevel Gearbox.

Another gearbox of worm type with a ratio of 1:5 was ordered. Both of them were used to compere the results. A supporting stand that matches each of the gearboxes was made. The supporting stands are made of Aluminum which is strong and light. Figure 86 below shows the worm gearbox. The gearbox used in previous submarine generation was also used to compare it with the new gearboxes.

Figure 86: Worm Gearbox

5.7 SUMMARY

In conclusion, the main constrains of the selection design of gearbox have been listed. The aim of the gearbox is to transmit power and torque from the pedals to the propeller. A high efficiency performance and a suitable configuration setup are required. Three alternatives have been introduced and compared to each other, a bevel gearbox, CVT, and Chain belt. The bevel gear is used where the axes of two shafts normally intersect and the desired ratio is 1:5, also it is available in the market. A comparison of the bevel gear system chain belt and CVT gear using weighted decision matrix was conducted to choose the best option. The gear box has been selected to be a Bevel gearbox with a ratio of 1: 5. Availability, maintainability and cost made the CVT not to be the best alternative. Another alternative has been established, which is using an in-line gear box with a ratio of 1: 2 with the current 1:3 gearbox to give a ratio of 1:6.

CHAPTER 6: STEERING SYSTEM

6.1 STEERING CONTROL

The steering system is the tool that enables the pilot to control the submarine and direct it to the wanted path. It also, gives the submarine the stability and overcome the turbulence that happens due to the propeller's torque. The maneuver that the steering system can do is rotating only about its pitch axes (up/down) and yaw axes (left/right). These fins are controlled by front steering system, shown in figure 87.

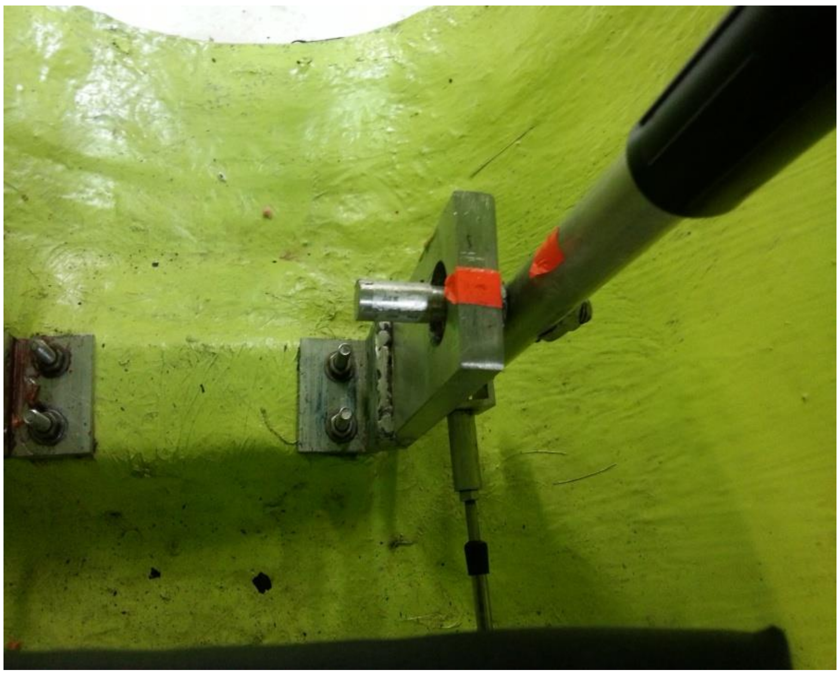


Figure 87: Steering System

The Figure above shows one joystick of the steering system after it manufactured. It has been manufactured in the SQU workshop. The material used was aluminum because it seen to be the most suitable after doing weighted decision matrix in the design stage in FYP I. Ball bearing was used to enable smooth rotation of the joystick and it is waterproof due to the role that requires the submarine full with water.

6.2 FINS

The fins are essential to allow the Driver to have a certain control on his trajectory. Sultana 2 has four fins: two lateral fins to control vertical motion and two other over and under the hull to control lateral movements. They were designed as thin as possible in order to minimize drag without compromising their mechanical properties. Furthermore, given the cable mechanism used for the direction system, the surface of the mobile part of the fin had to be small enough for being activated manually by the Driver while pedaling, thus without hard effort. This is the reason why a design combining a fixed and a mobile part was chosen.

6.2.1 Fins Shape Design

The areas of the mobile and fixed part of the fin were calculated following the same kind of lift computation used in aeronautic. In aviation, a lift force is created when the wing shape creates a difference of pressure between its both sides. This creates a vertical force under the wing, allowing the plane to take off. This phenomenon can also be applied in hydrodynamics. The following figure illustrates this force on a sketch of the fin.

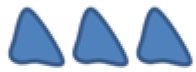
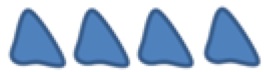
A pressure difference is created between both sides of the fin when the flap is activated, thus creating a thrust force on the fin. The fin's profile conforms to a NACA profile. NACA profiles are amongst the most trustful in aviation, and can thereby by used with confidence in hydrodynamics. Therefore, NACA 64-010 shape was chosen for the fin. We can see that the last two digits are "10", because it is required to have a fin with a length of 20cm and a maximum thickness of 2cm.

The same procedure used in generating the hull shape was repeated to design the fin. However, NACA 67-024 shape was revolved to get the hull and NACA 64-010 was extruded to get the fin. As requested from the other team (internal team), who is responsible for designing the steering system, the fins are selected to move completely with a small base. This type of fins consists of two parts. One part is stationary and responsible of the stability of the submarine. The other part is movable in order to change the direction of the submarine, horizontally or vertically.

6.2.2 Number of Fins

Based on the concept generation for the number of fins to be used, shown in table 4, we chose four fins. The fins will be placed just before the tail of the submarine where two of them will be placed horizontally on the right and left and the other two vertically on the top and bottom. Each fin will have an aileron on it where the ailerons on the horizontal fins are responsible for the up and down motion whereas the ailerons on the vertical fins are responsible for the right and left motion.

Table 11 Concept Generation for Fins

Feature	Importance (1-5)	Relative Importance	Concept (1)		Concept (2)		Concept (3)	
			Three 		Four 		Five 	
			Weight	Relative weight	Weight	Relative weight	Weight	Relative weight
Easy to turn	5	0.31	3	0.93	4	1.24	5	1.55
Easy to manufacture	3	0.19	5	0.95	4	0.76	3	0.57
Less cost	2	0.13	5	0.63	4	0.50	3	0.38
More stability	4	0.25	3	0.75	4	1.00	5	1.25
Less drag force	2	0.13	5	0.63	4	0.50	1	0.13
Total	16	1		**3.89**		**4.00**		**3.88**

6.2.3 Material

The search for an appropriate material for the fins led to a full carbon fiber construction. This material has incredible mechanical properties and still has an unmatched very low weight. Since the propulsion system and other essential devices are built with heavier materials such as metals, most of the submarine's weight is concentrated in its tail section. Thereby, lightweight materials became an evident choice for the fabrication of the fins. As previously mentioned, they were designed to be has thin as possible. This characteristic makes them relatively fragile and subject to failure in the event of an impact. Therefore, their final shape would not have been an option without an extremely resistant material such as carbon fiber. Also, let's not forget to mention that it is highly workable and it gives, at the end, an undeniable professional look.

Table 12 Fins Material Concept Evaluations

Feature	importance (1-5)	relative importance	Concept(1)		Concept(2)		Concept(3)	
			Fiber glass		Fiber Carbon		Eglass	
			Weight	Relative Weight	Weight	Relative Weight	Weight	Relative Weight
strenght	5	0.28	4	1.12	5	1.4	3	0.84
Less density	5	0.28	2	0.56	5	1.4	2	0.56
Less Cost	4	0.22	4	0.88	2	0.44	5	1.1
Easy to use	4	0.22	4	0.88	4	0.88	4	0.88
Total	18	1		3.44		4.12		3.38

6.2.4 Finite Element Analysis:

The tridimensional computer model allowed the team to perform a finite element analysis on the fin to put its design to the test. Since the submarine is designed to go straight in a normal competition situation and have perfect neutral buoyancy, the flaps are supposed to rarely be used in order to give minor correction to the submarine's orientation. Therefore, to reduce computational time, they have been neglected from the analysis model. The analysis was thus only made on the regular fixed part of the fin. The purpose of this analysis was to observe the water flow around the geometry and detect any excessive distortion. The first step of any finite element analysis is the meshing of the model. This was made using the software ANSYS Mesh from ANSYS Workbench 12.1. The objective here was not to mesh the solid geometry, but the actual environment around it. Note how precise is the mesh is around the profile's perimeter. This particularity is to ensure a good reading of the flow near the fin's surface where the flow boundary layer is formed. Although, it requires considerable computational power and time. Once the environment meshing is combined with the tridimensional model, the finite element analysis on fluid dynamics can be performed. ANSYS Fluent is the software used to perform this analysis.

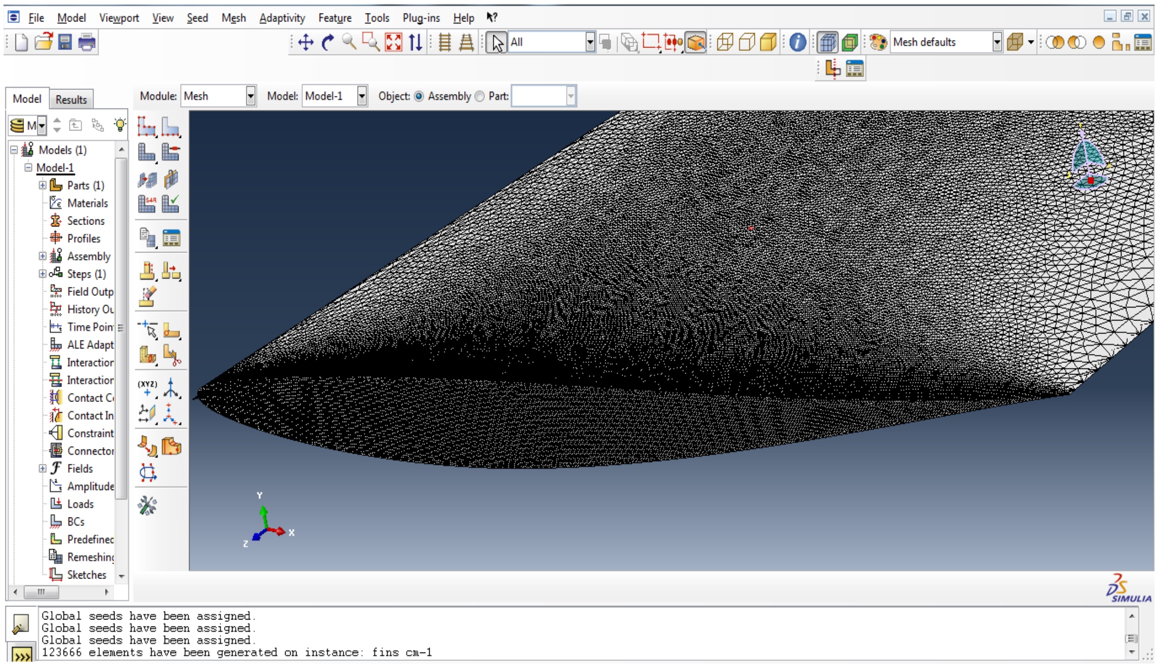


Figure 88 Fins Mesh

6.2.5 Results

The software now has every condition and specifications it needs to perform a fluid analysis. Many different types of results can be graphically illustrated once every calculation is completed. The first results, illustrated present, on a general manner, the main path lines of the water flow around the fin. These lines are definitely regular all the way around the fin and present a clear straight trajectory. Therefore, no major water turbulence is created when the fin is travelling underwater. The next illustration presents another very important parameter when it comes to design a fin. In this situation the magnitudes of flow velocity around the fin. What we want to make sure, here, is that velocity dissipates well after hitting the fin, but still smoothly follows the outline. The colored scale presents a dark red area right at the front of the fin. This is normal since it is the area of impact with water. Although, following the fin’s perimeter, the color rapidly changes to lower colors. That is the behavior we are looking for. Finally, a second area, at the rear end of the fin, presents another concentration of vectors. This is where the water flows from both sides meet and thus it proves that the water flow was gliding along the contour.

Finally the path lines of the pressure flow around the fin. The pressure around an object in a flow is directly linked to its drag. As it is possible to observe, the only area where a significant pressure is created is at the airfoil's front edge. This pressure is absolutely normal. It is created by the fluid's separation on each side of the fin and is inevitable. Note that it does not have a significant influence on the fin's total drag. Every fluid dynamics analysis presented above proved the efficiency of the design. It is important to remind that these analyses were made for the specific case where the flap is not activated. The results would have been clearly different in such case. When activated, a flap builds considerable distortion behind itself. However, knowing the fact that the submarine is designed to be perfectly neutral in water and should go in straight line with no major help from the directional fins, this simplification is definitely acceptable for the required analysis.

6.3 Manufacturing Redesigned Fins

There are four fins connected with the steering system by push pull cable. The figure below shows the fins after it manufactured. The fins were redesigned in the design stage in FYP I by using SolidWorks program. The new design reduce the drag force by reducing the surface that face the flow of water. The fins manufactured in a workshop outside the SQU. The material used was fiberglass

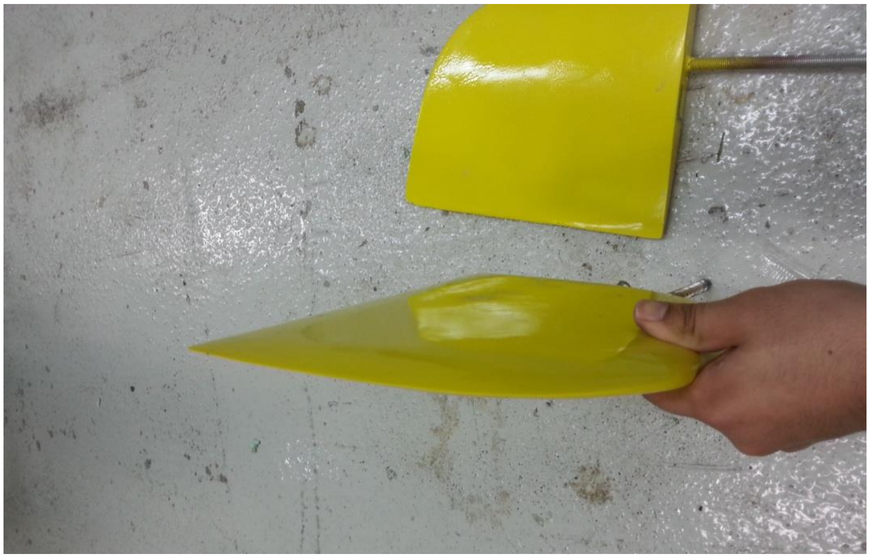


Figure 89: Redesigned Fins

6.4 Summary

The hull of the submarine was designed based on the latest updates of profilers. The material was chosen based on its properties and how they affect the project directly. The configuration of the sub was designed according to the main component included in the submarine. The hull configuration was designed to be as compact as possible.

CHAPTER 7: TESTING THE SUBMARINE

The testing stage comes directly after manufacturing. Preparation for testing included installing the submarine parts and sub-systems, reserving the summing pool, arranging a truck to carry the submarine to the summing pool, filling air cylinders and ready the diving equipment.

The first test was performed on the 18th of April. The main objective of this test was to adjust the buoyancy of the submarine. Small rectangular shaped pieces were attached to the submarine hull from inside.

The worm gearbox was used but its performance was very weak. Pedaling was very hard and the driver had to exert a lot of effort. Moreover, the brass blades were used but they didn't fit into the hub because the base of the blade was not perfectly circular and had elliptical shape, so, the stainless steel blades made manually in the workshop were used. A series of blade angles were tried and the performance of each was observed.

On 25th of April, the second test was performed. The Stainless Steel blades which were manufactured by CNC machine in China were used in the first run. The run was successful until the submarine reached the middle of the pool. The propeller hit the floor of the pool and it bended severely. Also, one of the pedals was not fixed properly because the nut was corroded. Unfortunately, there wasn't any nut with the same size at that time and a stud with two nuts was used as a temporary solution.

The third test was on Thursday 30th of April. During the test, the submarine kept sinking and required adjustments in the buoyancy. After returning it to shape by heating, the bended stainless steel blade was used once again. The blade was weak and bended again due to water resistance. Moreover, at the end of one of the runs, the submarine hit the wall which broke the lower plastic cover.

Another test was conducted on the 7th of May. During the test, the push-pull cable broke which made the driver lose the control of the steering. After replacing the broken cable with a new one, two runs with two different blade angles were performed.

Pictures during the Test:

Figure 90; Pictures during the Test

Figure 91: Pictures during the Test

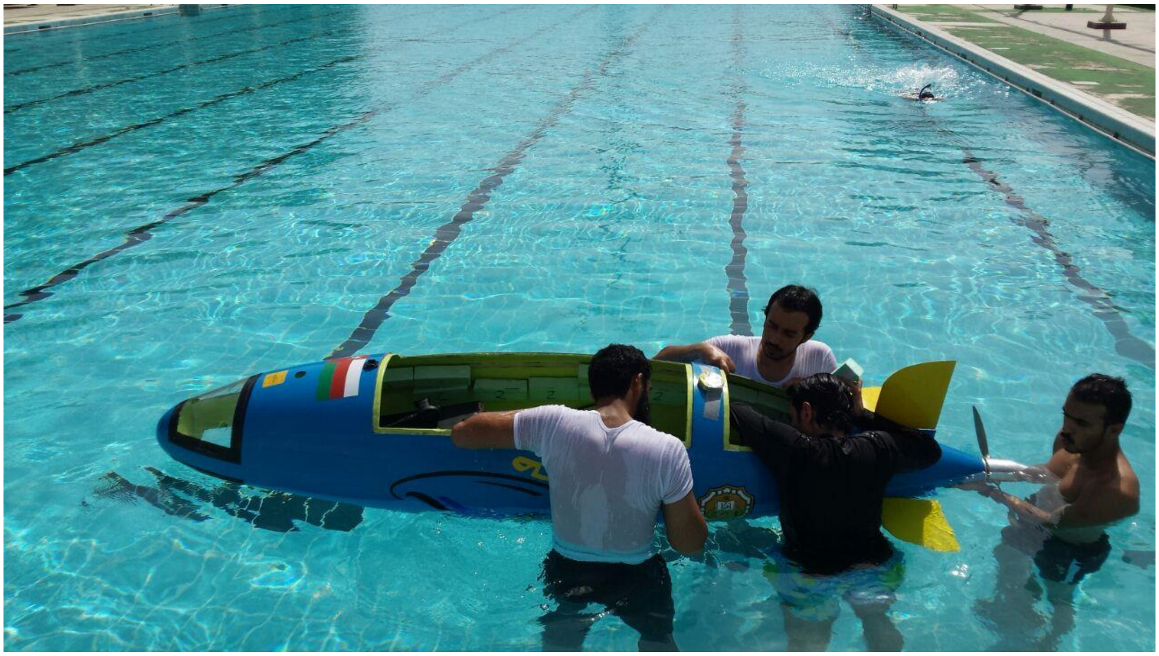


Figure 92: Pictures during the Test

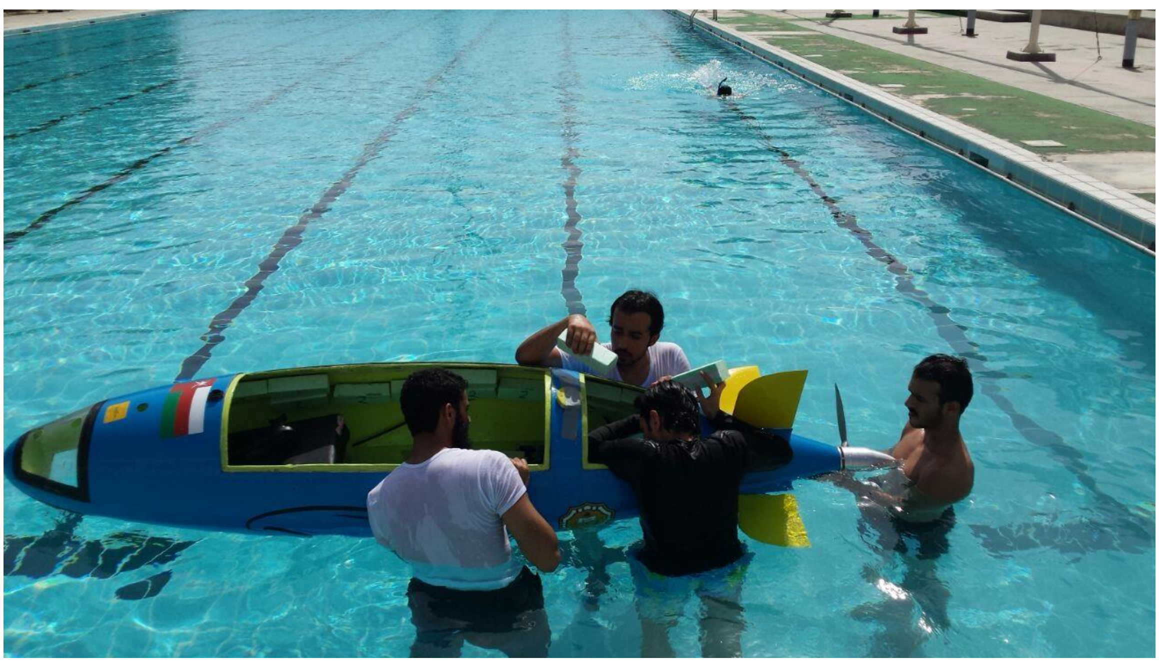


Figure 93 Pictures during the Test

CHAPTER 8: SAFETY ISSUES

8.1 INTRODUCTION

Safety is the first concern in any engineering design. Safety is defined as the control of recognized hazards. As engineering target to find solutions for human being that must be safe and ergonomically designed.

8.2 SUBMARINE COLRATION

It is advised for the purpose of easy location that each submarine be painted with high-visibility coloration. Blue color for the submarine was used in SultanahIII. Sultanah III is chosen to be the name of our submarine. It will be written on the hull in order to be identified in the race since numbers will not be used to each submarine. Propeller tips will be painted with a flashy color for easy visibility. As Advised by the organizers, any and all moving parts, plus any small parts extending away from the hull of a submarine, should have their tips painted with hi-visibility orange, to maximize their visibility to other pilots. Otherwise, color schemes are up to the team to set as they wish.

8.3 CREW VISIBILITY

The face and head of each crew member must be easily seen by the support pilots outside the submarine. It is highly recommended, even in the case of sonar (or otherwise) guided submarines, in which the pilot has sufficient vision forward and sideways to see the course and where the submarine is going. For this aim a big window was installed at the front of the submarine.

8.4 STROBE MARKING LIGHT

Each submarine shall carry a flashing white strobe light that is visible 360 degree in the horizontal plane. The light should flash at an approximate rate of once per second, be visible for at least thirty feet under normal visibility conditions. To satisfy this requirement, a strobe marking light will be installed between the entrance and the maintenance door.

8.5 EMERGENCY POP-UP BUOY

All submarines shall carry a high visibility buoy that will release from the hull and float to the surface when an emergency occurs. The crew member will have a dead-man switch that will automatically release the float in the event of disablement. This switch will be installed inside the submarine. As the rules say; each submarine shall be equipped with a surface marker buoy which is released by the pilot to signal that help is required. The float must be attached to the submarine by 10 m of floating, highly visible line, at least 1.5 mm in diameter. The release mechanism shall be of the "dead-man" type, that is to say that it will release automatically in the event that the pilot is incapacitated, and unable to continue preventing its release. Override mechanisms are permitted to ease operations while the sub is behind the starting line, but they must be disengaged, and the safety buoy system armed before the sub starts its run onto the course. The buoy is a signal to the rescue divers that something has gone wrong, and that the pilot needs to be extracted as fast as possible. Accidental release of the buoy beyond the starting line will automatically abort a run, and the sub will have to be returned to the pits to reenter the queue.

8.6 CREW RESTRAINT

Any method of attachment of a crew member to the submarine must have the release system that is clear therefore we colored every restrain mechanism clearly so it can be seen. If pilots and crew are restrained in any way inside the submarine (e.g. toe clips or shoulder straps), then release mechanisms must be clearly identified with orange paint or fluorescent tape. Any such releases will be inspected by the judging team during the dry test, and their function will have to be demonstrated as part of the wet test.

8.7 RESCUE EGRESS

Handles and release mechanisms for all exits must be clearly marked on the outside of the submarine. A 10 cm square hi-visibility orange patch bearing the word "Rescue" is recommended as a marker. The handle or release mechanism must be easily accessible from both inside and outside the submarine. Its use will have to be demonstrated as part of the wet test before the submarine is allowed on the course.

8.8 SUMMARY

Safety should be considered in the submarine design. There are too many things must the submarine have like visible color, emergency pop-up buoy and strobe marking light. The team gears must be clear so that the rescue team will notice them when emergency situation occurs.

CHAPTER 9: CONCLUSION

Sultanah II scored good rank in the ISR race which was the fourth place. The propulsion system was the main disadvantage that affected the speed of the submarine. For Sultanah III designing the propulsion system, the power transmission system and the steering system were the main tasks in FYP I.

The hub cap was redesigned to provide a solution to minimize the drag force that acts in an opposite direction of the submarines direction of movement. Another aim was supporting the blades along with the variable pitch hub mechanism.

The main idea of the adjustable pitch mechanism is to set the blades at a certain angle and try it out. After applying brainstorming and research for concept generation, basic decision matrix was used to evaluate the generated concepts. The evaluation resulted in choosing the concept adopted from the helicopter propeller mechanism. Then, SolidWorks software was used to simulate the mechanism.

A variable pitch propeller required an additional controller. The controlling system used is a simple push-pull cable control lever with ball lock pins as described in the previous sections. Another solution can be used to control the propeller pitch which is adjustable locking mechanism. The selected design is a simple mechanical system consists of a bolt, a nut, a ring with a hole and a shaft with holes.

The gear box has been selected to be a Bevel gearbox with a ratio of 1: 5. Availability, maintainability and cost made the CVT to not be the best alternative. The steering system was designed to be a mechanical joystick with lateral and vertical movement after the alternative evaluation of different design. The system will make the pilot comfortable to operate the submarine

9.1 PROBLEMS ENCOUNTERED

9.1.1 Propeller Problems

The propellers blade which was made in China by CNC turning method was bended during one of the tests which required redesign of the blade and send the modified design to be manufactured in China.

9.1.2 Steering System Problems

Combining the two handles into one handle was a main problem in designing new steering system. Introducing a joystick with lateral and vertical movement provides great advantages rather than using two handles. On the other hand, the joystick is sensitive to motion and manufacturing related. The team provided a design with the ability to be easy constructed and built. The manufacturing will be accomplished next semester.

9.1.3 Gearbox Problems

The gear box was a big issue for the team of Sultanah III. Searching for a gearbox provides high speed to the submarine with less required torque was not easy. Using a gearbox with high ratio such as 1:5 will solve the problem of the speed, but on the other hand, it will be heavier to the pilot to rotate the pedals. The pilot should be strong enough to be able to handle this high ratio.

Another difficulty was related to the communication with manufacturers and suppliers of the desired gearbox.

9.1.4 Testing Problems

- A swimming pool with depth of more than 2m is not available in Oman.
- The 20 liters cylinders available in the workshop cannot be used since they are out of date and need hydrostatic test.
- Filling the cylinders since the compressor available in the workshop is broken.
- Using one 7-liters cylinder for the driver is not enough. Another cylinder is required.
- Some of the tools are not available.

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