DESIGN AND DEVELOPMENT OF UNDERWATER THRUSTER FOR AUTONOMOUS UNDERWATER VEHICLE (AUV)

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2019

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A report submitted
in partial fulfilment of the requirements for the degree of
Bachelor of Mechatronics Engineering with Honours

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitled "DESIGN AND DEVELOPMENT OF UNDERWATER THRUSTER FOR AUTONOMOUS UNDERWATER VEHICLE (AUV) "is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : GRACE WONG MEE SING

Date :

APPROVAL

I hereby declare that I have checked this report entitled "DESIGN AND DEVELOPMENT OF UNDERWATER THRUSTER FOR AUTONOMOUS UNDERWATER VEHICLE (AUV)" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

I am GRACE WONG MEE SING as an undergraduate student from University Teknikal Malaysia Melaka (UTeM). In preparing this report, I would wish to show my greatest admiration and deepest gratitude to my supervisor, DR. Mohd Shahrieel Bin Mohd Aras for his patient, guidance, encouragement and valuable advice during this project. His methodical approach to problem-solving and encouraging words always filled me with optimism, vitality and enthusiasm. Still, his leadership and guidance made it a neat learning experience for me.

Also, I would like to offer my grateful thanks to my panel DR. Saifulza bin Alwi @ Suhaimi and DR. Rozaimi bin Ghazali for their patient and encouraging words. My grateful thanks also extended to Professor Madya Dr. Ahmad Zaki bin Shukor and also University Teknikal Malaysia Melaka (UTeM) for offering me resources in running the program during the Final Year Project.

ABSTRACT

In the underwater research, Autonomous Underwater Vehicle (AUV) and Remotely Operated Vehicle (ROV) are created to assist human due to the efficiency, safe approach and lower operating cost. AUV was an Unmanned Underwater Vehicle with simply computer-control system operating underwater and thruster is one of the important parts which is for moving mechanism in the water and allow the AUV to submerge. The cost for developing the thruster is expensive and it is no fixed procedure to design the thruster based on the propeller design such as size and number of blades of the propeller. Thus, this project is focused on the design and development of the affordable, easy to fabricate and can produce high thrust underwater thruster. In designing the underwater thruster, SolidWorks software is used to design and undergoes stress and strain test. Hardware that discusses and included propeller, nozzle, type of motor and submersion that achieve a certain performance in terms of speed and thrust. Propeller which design in 30 degrees and with two, three, four and five blades. Nozzle design also follow the Kort design to produce high thrust for the thruster. Type of the motor used are A2212 dc brushless motor, D2830 power series dc brushless motor, M100 and M200 for comparing the thrust and speed for the motor. D2830 has the highest speed when compare to others type of motor which means that D2830 have higher speed than others. AUV used thruster to move in pitch, raw and yaw direction by using programming code. The analysis for the thruster can be recorded which is speed, thrust, stress and strain. A2212 DC brushless motor has cheapest price and the speed also approximate to the D2830 DC brushless motor.

ABSTRAK

Dalam penyelidikan bawah air, Kenderaan Bawah Air Autonomi (AUV) dan Kenderaan Bergerak Di Bawah Tanah (ROV) diwujudkan untuk membantu manusia kerana kecekapan, pendekatan yang selamat dan kos operasi yang lebih rendah. AUV adalah Kenderaan Bawah Air yang tidak dikendalikan dengan hanya sistem kawalan komputer yang beroperasi di bawah air dan pembusukan adalah salah satu bahagian yang penting untuk mekanisme bergerak di dalam air dan membenarkan AUV untuk menenggelamkan. Kos untuk membina penebat adalah mahal dan tidak ada prosedur tetap untuk merancang penebat berdasarkan reka bentuk kipas seperti saiz dan bilangan bilah kipas. Oleh itu, projek ini memberi tumpuan kepada reka bentuk dan pembangunan yang berpatutan, mudah untuk menghasilkan dan boleh menghasilkan tusukan bawah air yang tinggi. Dalam merekabentuk pencuri bawah air, perisian SolidWorks digunakan untuk merekabentuk dan menjalani ujian tekanan dan ketegangan. Perkakasan yang membincangkan dan termasuk kipas, muncung, jenis motor dan penyerapan yang mencapai prestasi tertentu dari segi kelajuan dan teras. Propeller yang direka dalam 30 darjah dan dengan dua, tiga, empat dan lima bilah. Reka bentuk muncung juga mengikuti reka bentuk Kort untuk menghasilkan tujahan tinggi untuk pemancet. Jenis motor yang digunakan ialah motor brushless A2212 dc, motor D2830 siri kuasa tanpa motor, M100 dan M200 untuk membandingkan tujahan dan kelajuan motor. D2830 mempunyai kelajuan tertinggi apabila dibandingkan dengan jenis motor yang lain yang bermaksud bahawa D2830 mempunyai kelajuan yang lebih tinggi daripada yang lain. AUV menggunakan pemalut untuk bergerak di padang, mentah dan hala dengan menggunakan kod pengaturcaraan. Analisis untuk pencungkil boleh direkodkan iaitu kelajuan, tujah, stres dan ketegangan. Motor brushless DC A2212 mempunyai harga termurah dan kelajuan juga berkisar kepada motor brushless DC D2830.

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LIST OF SYMBOLS AND ABBREVIATIONS

UTeM	-	University Teknikal Malaysia Melaka
AUV	-	Autonomous Underwater Vehicle
ROV	-	Remotely Operated Vehicle
UUV	-	Unmanned Underwater Vehicle
ESC	-	Electronic speed controller

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The earth is a watery place. Figure 1 shows the Earth's surface is covered by the water which is about 71 percent out of 100 percent. [1] Ocean is a continuous body of the saltwater that covers 96.5 percent of all Earth's water. [2] Ocean is divided into four major section by geographers which are Pacific, Atlantic, Indian and Arctic. Seas, gulfs and bays such as the Mediterranean Sea, Gulf of Mexico and the Bay of Bengal are stated as smaller ocean region. [3] Ocean is the place that life began and remains home to the majority of Earth's plants and animal. The ocean remains one of the most expansive, mysterious and diverse places on Earth. Nowadays, activity-activity that carries out by human impact nearly all parts of the ocean. [4] These activities affect the whole oceanic ecosystem which threatened by various sources of pollution. [5] First and foremost, plastic pollution is one of the pollutions that affect the oceanic ecosystem.

Figure 1.1: Earth's surface

Figure 1.2 shows that the plastic pollution has become a global crisis. The statistic shows that billions of pounds of the plastic that make up about 40 percent of the world's ocean surface can be found in swirling convergences. Thousands of seabirds, sea turtles and other marine mammals are entangled in plastic and accidentally ate the plastic. [6]

Figure 1.2: Plastic pollution on the ocean.

Figure 1.3: Oil pollution in the ocean.

Besides, large reserves of oil and gas trapped deep beneath the earth's surface. Oil and gas seep out at these reserves develops cracks and this phenomenon rarely causes any major damage. Human interference can cause a great deal of damage to marine ecosystems. Offshore drilling operations can cause oil waste and pollute the ocean due to flowline and pipeline leaks and disposal of oil-based drilling fluid wastes. [7] Phenomenon water whirl is swirling at a velocity of over 20mph and it have a diameter of over 65 feet. [8] This phenomenon in the ocean is dangerous for diver which can make it hard for even the most skilled of diver. [10] Through this phenomenon and the pollution in the ocean, Autonomous Underwater Vehicle (AUV) or Remotely Operated Underwater vehicle (ROV) need to be implemented to solve this problem.

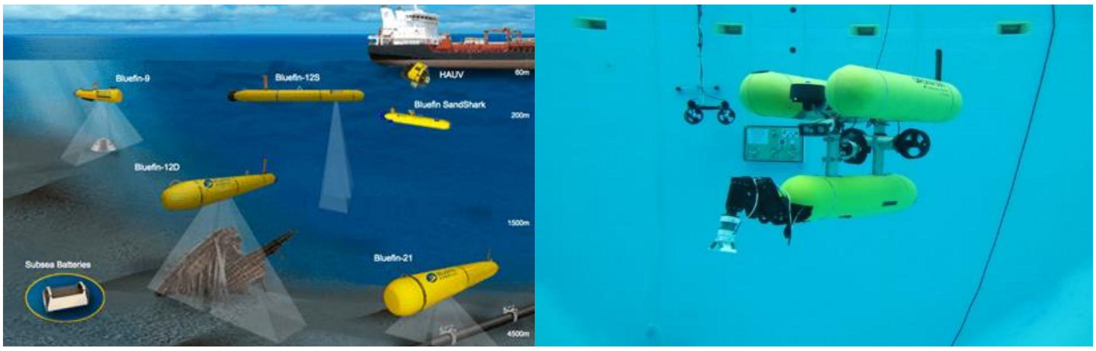


Figure 1.4: Autonomous Underwater Vehicle.

Autonomous Underwater Vehicle (AUV) is commonly known as an unmanned underwater vehicle which operates independently from the ships and has no any cable connected to it. [11] AUV is a programmable robotic vehicle without real-time control of human operators which can drift, drive and glide depends on their design. [11] AUV offers numerous advantages over offshore survey platforms. For deep sea field development and seabed mapping, oil and gas industry utility sector or government agencies can use AUVs to collect high resolution data. Besides, AUVs are used in shallow water for ports and harbor surveys and offshore wind sector. [12]

Figure 1.5: AUV that standby for research purpose.

Human diver and boat have limitation at the deeper and shallower water. Thus, AUVs are implemented to save the diver’s life and able to collecting data at a very high data-to-signal ration. [13]

Figure 1.6: AUV thruster for moving forward, backward, downward and upward.

Underwater robot, Autonomous Underwater Vehicle (AUV) and submarine needs electrical underwater thruster which produces electric propulsion to move in the water. This electrical thruster is fitted with a motor and propeller which is an electromechanical device that generates the thrust to move the underwater vehicle. [14] Generally, thrust force is affected by motor model, the design of the propeller and the number of blades. Thruster modelling is important in controlling the AUV. This is because the lowest control loop of the system would benefit from accurate and practical modelling of the pusher. The kinetics of the thruster dominate the control problem and must be properly considered to receive exact solutions. [15] The operation of the thruster is greatly influenced by thruster design such as axial and cross-flow effects nonlinearities related to thruster dynamic behavior which is important and influence overall system behavior in a way fundamentally different from most hydrodynamic and inertial nonlinearities. The dynamics of the thrusters dominate the behavior of the vehicle by restricting the maximum closed-loop bandwidth and creating a limit cycle.

1.2 Motivation

According to Free Malaysia Today, the divers were looking for a 17-year-old boy who had fallen into a mining pond in Taman Putra Perdana, Puchong. Abdul Aziz Ali, who is district police chief Assistant Commissioner at Sepang mention that during the operation, the divers were caught in strong whirlpool. [16] Through this new, AUV or ROV are very important to observe the situation in the water. Thus, this project is used to develop an AUV and thruster for the AUV, which are the most important part for the AUV to move forward, backward, downward and upward.

Figure 1.7: Divers who are trying to save the 17-year-old boy.

There are many facts that need to consider which make the modelling procedure difficult. Appropriate motor alternatives are chosen through a process of elimination assisted by a computerized script based on extensive propeller series. Propeller and motor which used in a hostile environment such as ocean, corrosion and other external influences which may cause damage to the system must consider in the design. Thus, the consequence of this project design and develop the versatile underwater thruster with low cost, high performance and high quality to commercialize and to research purposes. The paper starts with design and fabricate the thruster and common movement control.

1.3 Problem Statement

There are some of the problem statements that need to be considered in design and develop the underwater thruster. There is no any procedure in design and develop the propeller and duct for the thruster. The performance of the thruster is hard to determine, based on the speed, thrust and power. Also the size, diameter and the angle of the propeller is not stated clearly for designing the propeller. Furthermore, the size of the thruster needed to be considered to have high efficiency.

There is an important thing that need to learn are constructed of the thruster, type of propeller and type of motor. Construction of the motor need to be learned to know the design, function and how the thruster work. The propeller is one of the important parts in the thruster. The static and dynamic efficiency of thruster increases when the propeller is mounted in a duct or shroud. Moreover, the diameter of the propeller can influence the amount of thrust available for propulsion by determining the amount of power that the propeller can absorb and deliver. Furthermore, there are few parameters that need to be learned during analysis, which are speed of the thruster, thrust produced by the propeller and power that need to be optimized. Thrust that produced by the propeller is depend on the diameter and the angle of the propeller. The speed of the thruster depends on the torque of the motor and the type of the motor used. Type of the motor is needed to consider so that the high efficiency of the motor has been chosen to produce high torque and give faster speed to thruster.

In short, these are the problem that needs to be considered in the FYP so that it can achieve the objectives.

1.4 Objective

There are three objectives that need to achieve are to:

i) Design and analysis of the underwater thruster for Autonomous Underwater Vehicle (AUV) by using SolidWorks.

ii) Develop and fabricate the underwater thruster for Autonomous Underwater Vehicle (AUV).

iii) Investigate the performance of thruster in terms of thrust produced, propeller with difference numbers of blade and speed of the thruster.

1.5 Scope

The thruster is important for AUV that can move and submerge in the water. Configuration of the thruster needs to learn to develop the thruster. SolidWorks software is used to design the thruster and run flow simulation and some testing. The diameter of the propeller and number of blades needs to be considered for the design so that it can produce large propulsion or high thrust for moving the AUV. Furthermore, thruster must be designed and developed with safety, efficiency and power. Moreover, the type of the motor is an important component that produces torque to move the propeller.

a) Solidwork software is used to design and analysis.

b) The voltage of the power source used by each thruster should be less than 24V.

c) The electronic part used microcontroller Arduino Uno and Raspberry Pi.

d) Thruster must have high thrust, efficiency and safety.

1.6 Organization of Report

Chapter 1 is focused on the introduction about the thruster. There is some problem that needs to be considered during doing the FYP. Besides, there are also have a main objective why needs to design and develop the thruster and some scope to keep on the right way to achieve the objective.

Chapter 2 is mentioned about the literature review, which are describing the theoretical background by another journal or paper that had been done by the researchers. There are also discuss and compare the type of motor used to produce high torque, type of propeller used and how is the number of blades that affect the thrust.

Chapter 3 is the method that used to get a clear view of the design and development of the thruster. SolidWorks software will use to design and fabricate it by using a 3D printer. There are comparisons between the shape and materials of mechanical parts. Besides, experiments will be carried out for testing the hardware.

Chapter 4 shows the result and discussion after the experiment is carried out. The simulation and test by using SolidWorks software such as a stress test, flow simulation and strain test will be discussed in this chapter. The performance of the thruster will also discuss in this chapter in terms of thrust, efficiency, speed and power.

In short, chapter 5 is the last chapter, which is conclusive for whole FYP. It is summarized of the design and develop the thruster. There are additional proposal and suggestion for future research purpose.

1.7 Summary

AUV was implemented for many purposes and it's had many advantages to those who are doing research. The thruster was the important part that used to move the AUV or ROV. Thus, the thruster was designed and developed for the AUV. Thruster that available in the market was expensive, high thrust and efficient for the AUV or ROV. It focuses more on the size of the thruster, price and the design of the thruster. FYP was focused on design and develop the thruster which are low cost, efficient, high performance and reliable and rugged.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussed the literature review from journals or conference paper which were related to this project title in order to achieve the objectives of this project. There were different kind of sources to get the important information about the thruster. Methodology for the hardware and software were extracted from these sources. In hardware development, type of motor, configuration of the thruster, nozzle, size of the propeller and a number of the propeller are studied, compared and selected. Thus, it was important to study the basic operation of every part of the thruster before every part of the thruster has been selected for this project. In software development, SolidWorks was used to design the thruster and run the simulation about the stress and strain test.

2.2 Size of the Propeller

Diameter and pitch were most important considering the size of the propeller. [17] Figure 2.1 shows the overall diameter of the propeller which are measured from the tips. The power is affected by the size of the propeller which means that the larger diameter propeller has more power than small diameter propeller due to large diameter propeller can push more water.

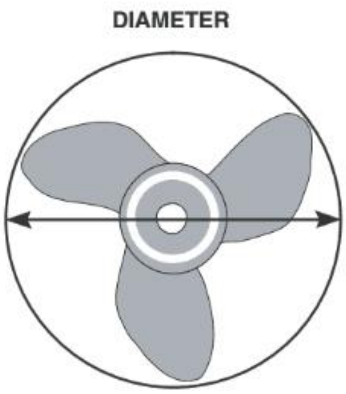


Figure 2.1: Diameter for the propeller.

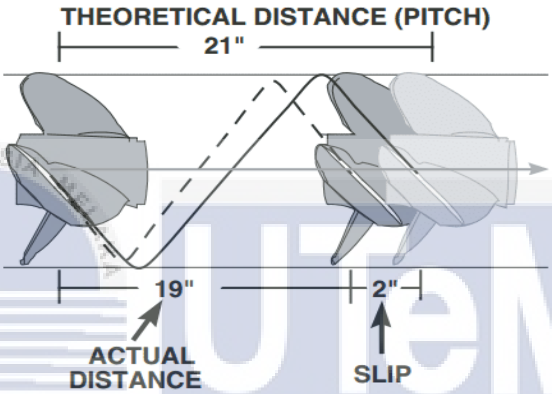


Figure 2.2: Pitch of the propeller.

Figure 2.2 shows the pitch of the propeller which is the distance of the propeller move for one revolution. In simple word, pitch can be defined as the forward distance which propeller make in a complete rotation. Smaller pitch has more acceleration which means that it had less curvature and a limited top speed while larger pitch has more curvature and a higher top speed. [18]

2.3 Number of Blades

Number of blades are one of the criteria that need to be considered in developing the thruster with high thrust, high efficiency and less power consumption. The most common of the number of blades usually have 2, 3, 4 or 5 blades. Two blade propeller offers the lower resistance when in the sailing condition and two bladed propellers are used on sailing ships with auxiliary power. [19] Propeller with more blades distributes its power and thrust more evenly. Thus, it can be said that the performance will be increased when the blades of the amount of propeller increase. The number of blade increase means that narrow blade with reducing the chord length of the propeller. Three-bladed propellers have generally proven to be the best compromise between blade area and efficiency. Furthermore, propeller that more than three blades are used to reduce the vibration. A propeller with more blades will often solve the problem which is rhythmic thumping and humming. However, propeller more than 3 blades seldom are as efficient as the three-bladed due to the closer blades create additional turbulence. This cause the water flow scrambling up each other's. In short, two or three number of blades have more efficiency than the higher number of blades while the higher number of blades has smoothest and uniform performance. [20]

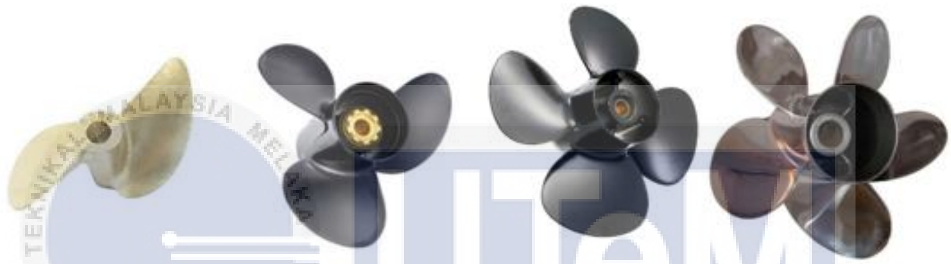


Figure 2.3: Different blades of the propeller.

Figure 2.3 shows different blades of the propeller and three blade propellers usually offers better top-speed performance. Three blade propellers are made as a compromise for vibration, convenient size, efficiency and cost. Two blades and three blade propellers have the efficiency difference which is considered less significant than the vibration difference. [21]

2.4 Type of Motor

The motor will eventually lead to failure due to it operate for several hours in seawater which may corrode the metal of the motor. The motor increases their reliability and longevity of the system by incorporating preventing the barriers. By incorporating preventing the barriers, both maintenance and acquisition of spare parts will be reduced and thus reduce the cost of the maintenance for customers. [22]

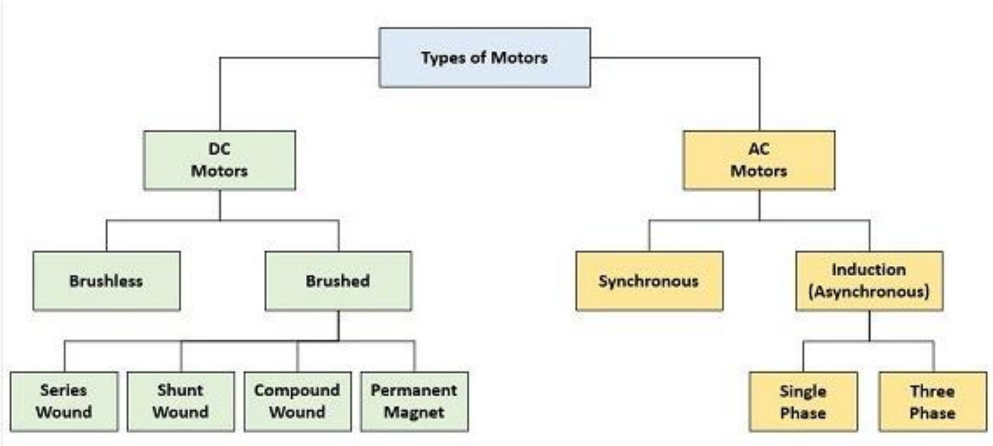


Figure 2.4: Chart for the type of motor.

Figure 2.4 shows the type of the motor which can be considered for the thruster. DC motor was the first type of motor widely used and the systems (motors and drive) initial costs less than AC systems for low power unit but with higher power. The DC motor speed can be controlled by the supply voltage and it is also available in wide range voltage which are 12 and 24 volts. DC motor divided into two types which are brushed and brushless. Brushed motor can be divided into four types which are series wound, shunt wound, compound wound and permanent magnet. Another type of the motor is AC motor. Ac motor is highly flexible in speed control and have a much larger installed base compared to DC motors. AC motor divided into synchronous motor and induction motor. The AC induction motor may be single phase or three phases. Table 2.1 shows the comparison for DC motor and AC motor. [23]

Table 2.1: Comparison for DC motor and AC motor.

CHARACTERISTICS	AC MOTOR (INDUCTION)	DC MOTOR
Supply	Works on AC supply	Works on DC supply (mainly from batteries, and cells)
Starting	Needs starting mechanism for single phase NOT for three phases	Self-starting
Supply system	Can be single and three phase	Single phase ONLY
Brushes & Commutator	Do not have brushes and commutator; very rugged and have long life	Have brushes and commutator which limit the speed and reduce the life expectancy
Speed control	By changing frequency	By changing armature winding's current
Speed & Torque	Use for high speed and variable torque	Use for variable speed and high torque
Load change	Slow response to change in load	Quick response to load change
Efficiency	Less efficient because of induction current loss and motor slip	More efficient since no motor slip and induction current loss
Use	AC motors are primarily used in large industries and factories	They are used in most of the domestic applications.
Maintenance	Requires less maintenance because of absence of brushes and commutation process	Demands extensive maintenance frequently

2.4.1 DC Motor

DC motor is rotating motor which capable converts DC energy into mechanical energy or convert mechanical energy into DC energy. DC motor converts mechanical energy into electrical energy when it is running as a generator and vice versa for the DC motor. [24] Stator and rotor are two major components for DC motor. The stator is used to produce the magnetic field and it remains stationary during the motor running. The rotor is another part of the DC motor which run together with the motor and its produce induced electromotive force and electromagnetic torque. [25] There are two main kinds of DC motors which are DC motor with brushes and DC motor without brushes. There are four types of brushed motor which are series wound, shunt wound, compound wound and permanent magnet. The permanent magnet is used in application where precise control and low torque, such as robots. [26] Table 2.2 shows the comparison of the characteristic of the brushes DC motor. [27]

Table 2.2: Comparison of the Series DC motor, Shunt DC motor and Compound DC motor.

TYPE OF MOTOR / CHARACTERISTIC	SHUNT	SERIES	COMPOUND WOUND
SPEED	Approximately constant or adjustable	Adjustable	Adjustable
TORQUE	Medium	High	High
APLLICATIONS	Lathes, vacuum cleaners, conveyors & grinders	Automotive, hoists, lifts and cranes	Rotary presses, circular saws, shearing machines, elevators and continuous conveyors

Brushless DC motor has specialized circuitry to control speed and direction. Magnets mounted around the rotor in brushless motor to improve the efficiency of the motor. [28] Brushless motor does not have current carrying commutator contacts while brushes inside the electric motors are used to deliver current to the motor windings through commutator contacts.

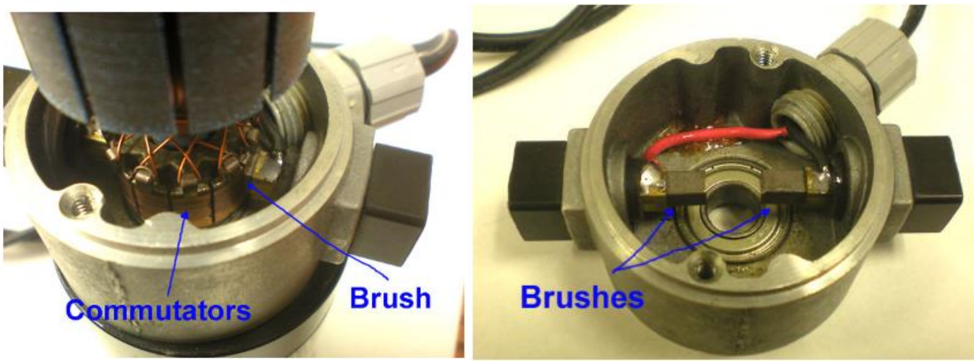


Figure 2.5: Brush DC motor.

Moreover, brushless motor has windings on the stator while the brush motor has windings on the rotor. Brush motor can be wired directly to DC power such as the battery and the control of the brush motor can be simple as a switch. Low cost brush motor has less efficiency and a great deal of electrical and electromagnetic noise are created when the switching of the commutators constantly creating and breaking inductive circuits. Brush motor has shorter lifespan when compare to brushless lifespan this is because brush motor was in perpetual physical contact with the shaft, brushes and commutators wear out. Brushless motor has a long lifespan and high efficiency because no brushes to wear out and replace. Furthermore, brushless motor has a high initial cost which need for a commutating device like an encoder and a drive or controller. [29]

Figure 2.6: Brushless DC motor.

2.4.2 AC Motor

Ac motor is the motor which using an electromagnetic induction to convert the alternating current into mechanical power. AC motor is driven by an alternating current and the stator and rotor are two of the most important parts of the AC motor. AC motor may be single phase and three phase. Three phase AC motor is mostly applied in industry for conversion from electrical to mechanical. The single phase AC motor is mostly used in small power conversion. Synchronous AC motors and induction AC motors are two basic type of the AC motor. [30]

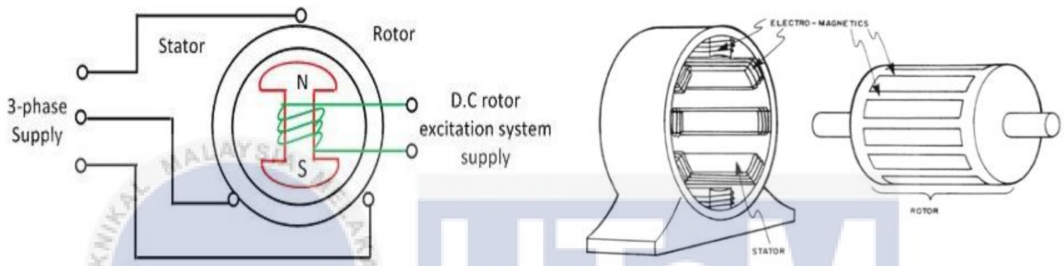


Figure 2.7: Synchronous motor.

Figure 2.7 shows the synchronous motor with stator and rotor which convert the AC electrical power into mechanical power and operated at synchronous speed. Three phase supply is used for exciting the stator while DC supply is used for exciting the rotor. The rotor also known as armature which consists of an electromagnet formed by conducting oil. The aim of the excitation is to convert the stator and rotor into an electromagnet. Rotating magnetic field develops on the stator because of the polarity of their wave changes after every half cycle. Moreover, the stationary magnetic field develops on the rotor due to the fixed polarity of the DC supply. Synchronous speed is the speed at which the rotating magnetic field rotate.

$$NS = 120f/P \qquad 2.1$$

The synchronous speed of the motor depends on the frequency of the supply and the number of poles of the motor. The force of attraction occurs between stator and rotor when both of them are facing each other. Torque is the kind of force which moves the object in the rotation. The torque in the anti-clockwise direction depends on the attractive force. Thus, the poles of rotor dragged towards the poles of the stator. The pole of the stator is reversed after every half cycle. The inertia used to remain the position of the rotor. [31]

Another type of the AC motor is an induction motor. Induction motor also known as asynchronous motor because the synchronous speed is higher than the speed of induction motor. Synchronous speed means the speed of the rotating magnetic field in the stator. There are two types of induction motor which are single phase and three phase induction motors. AC supply is supplied to the stator winding in an induction motor. This will produce an alternating flux around the stator winding. This alternating flux revolves with synchronous speed which called rotating magnetic field. According to the Faraday's law of electromagnetic induction, the relative speed between stator rotating magnetic field and rotor conductors causes an induced emf in the rotor conductors. Rotor current is produced due to induced emf and this can say that the rotor conductors are short circuit. Alternating flux will produce due to the induced current in the rotor and the rotor flux lags behind the stator flux. According to the Lenz's law, direction of the induced rotor current will tend to oppose the cause of its production. The rotor rotates in the direction of stator flux to minimize the relative velocity. The rotor will catch up with the stator RMF because of the production of rotor current is the relative velocity between the rotating flus and the rotor. The production of rotor current.

The most suitable option is a brushless DC motor due to the high efficiency, low maintenance to function and long lifespan. Operational costs for a brushed motor was higher than a brushless motor because the operational cost of the brush motor will accumulate the total cost even though the brushes DC motor is cheaper than brushless DC motor. [32]

2.5 Nozzle

The nozzle is important for the thruster to protect the propeller collision with any foreign object such as a coral reef. Figure 2.8 shows that the nozzle or duct that used to protect the propeller and also prevent damage to the environment. Besides than that, the nozzle can increase the efficiency of the propeller by assisting with the acceleration of the water. [33]

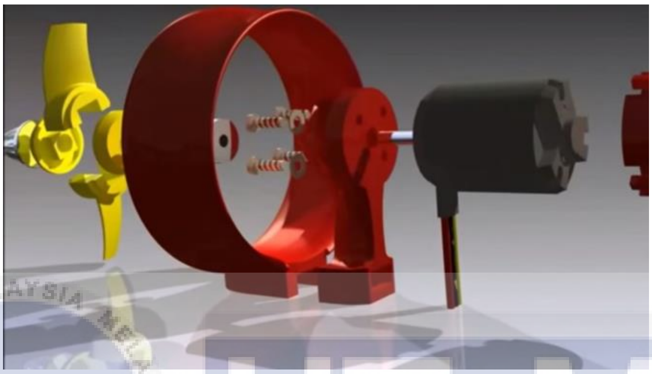


Figure 2.8: Nozzle for the thruster.

Nozzle cannot be neglected to produce high thrust at a low ship speed. High pressure areas behind each blade and lower pressure areas in front will be generated as the propeller blades rotate in the water and this pressure differential produces the force to drive the vessel. As a water escape from higher pressure side of the blade to the lower pressure side causes the losses at the tip of each blade and this does not bring any benefit in pushing the vessel forward. This loss can be reduced when the nozzle is presented by restricting the water flow to the propeller tips. Entrance of the nozzle has a greater area than at the trailing throat. Water must accelerate from one to the other due to the density of the water is constant. Hence the water flow through the propeller is faster than a conventional open propeller. Thus, more thrust is created for the same input power and torque for duct propeller when water is moved. However, nozzle design also can increase the efficiency gain. There are two types of the nozzle design which are Kort nozzle and Rice speed nozzle. As the speed of the advance increases, both of these designs will drag and the coefficient of drag for the Rice speed nozzle is 17 times less than the Kort nozzle. Figure 2.9 shows the comparison of drag coefficient between Kort and Rice speed nozzle.

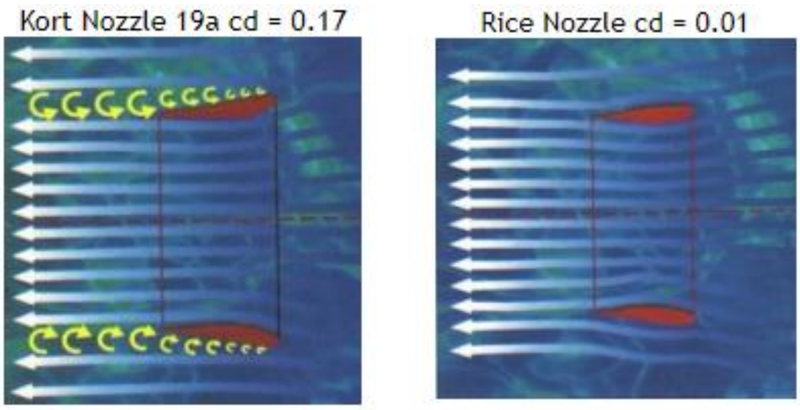


Figure 2.9: Comparison of drag coefficient between Kort and Rice speed nozzle.

Propeller in the center of the nozzle is approximately 40 percent smaller than the area of the nozzle entrance as shown in the Figure 2.10. This resulted in an increase of water speed and a decrease of internal pressure in relation to external pressure which remains more or less constant.

Figure 2.10: Transverse view of the rice nozzle.

Figure 2.11 shows the force is created on the external surface of the nozzle due to the pressure difference which is always perpendicular to the surface. The horizontal component of the force creates an additional forward thrust due to the design of the outside trailing end part of the nozzle and thus increase the total thrust of the vessel. In short, the nozzle is very important for the thruster due to the force created can increase the total thrust for the thruster and also the efficiency of the thruster. [34]

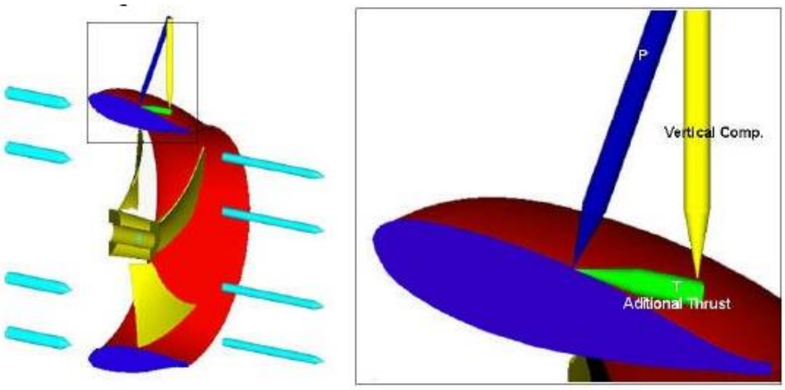


Figure 2.11: Pressure differences create additional forward thrust.

Table 2.3: Comparison of the nozzle.

Nozzle	Vessel Length	Vessel HP	Nozzle ID	Free Running Speed	Bollard Pull Ahead	Bollard Pull Astern
Rice TN	98 Feet	2 x 1950	106 Inches	13 Knots	61.3 Tons	42 Tons
Kort 37	98 Feet	2 x 2150	103 Inches	12 Knots	54.4 Tons	39 Tons

2.6 Summary

As a closing, it presents a summary for the whole mechanical, electronics component and software part. It also discussed about the size of the propeller, number of blades, type of motor and nozzle which was important to the. All the parts were studied and compared to find the clear measures that required for this project. All the knowledge was important for performing this task.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the overall process or procedure or technique was explained and discussed to achieve the objective of this project. There was some methodology need to be discussed in order to test the functionality and performance of the thruster. Figure 3.1 shows the overall process flow chart for this project. It briefly explained how the project start till the end. In this project, methodology was divided into three main parts which are software development, hardware development and hardware testing. SolidWorks software was used to design the thruster and some criteria need to be considered in the design. These criteria were the size of the propeller, number of blade and nozzle of the propeller. AUV also needed for this project for testing the performance of the thruster in the water. Stress and strain can be tested by using SolidWorks software. Basic circuit was designed and connected to the motor to test the function with microcontroller before the thruster was assembled to the AUV. After that, all the thrusters were assembled on the AUV for collecting data in the water. The tachometer was used to collect the speed of the thruster. Besides, the performance of the thruster in terms of thrust was recorded in table form. Last but not least, all the data collect were recorded and repeated to get the accurate result.

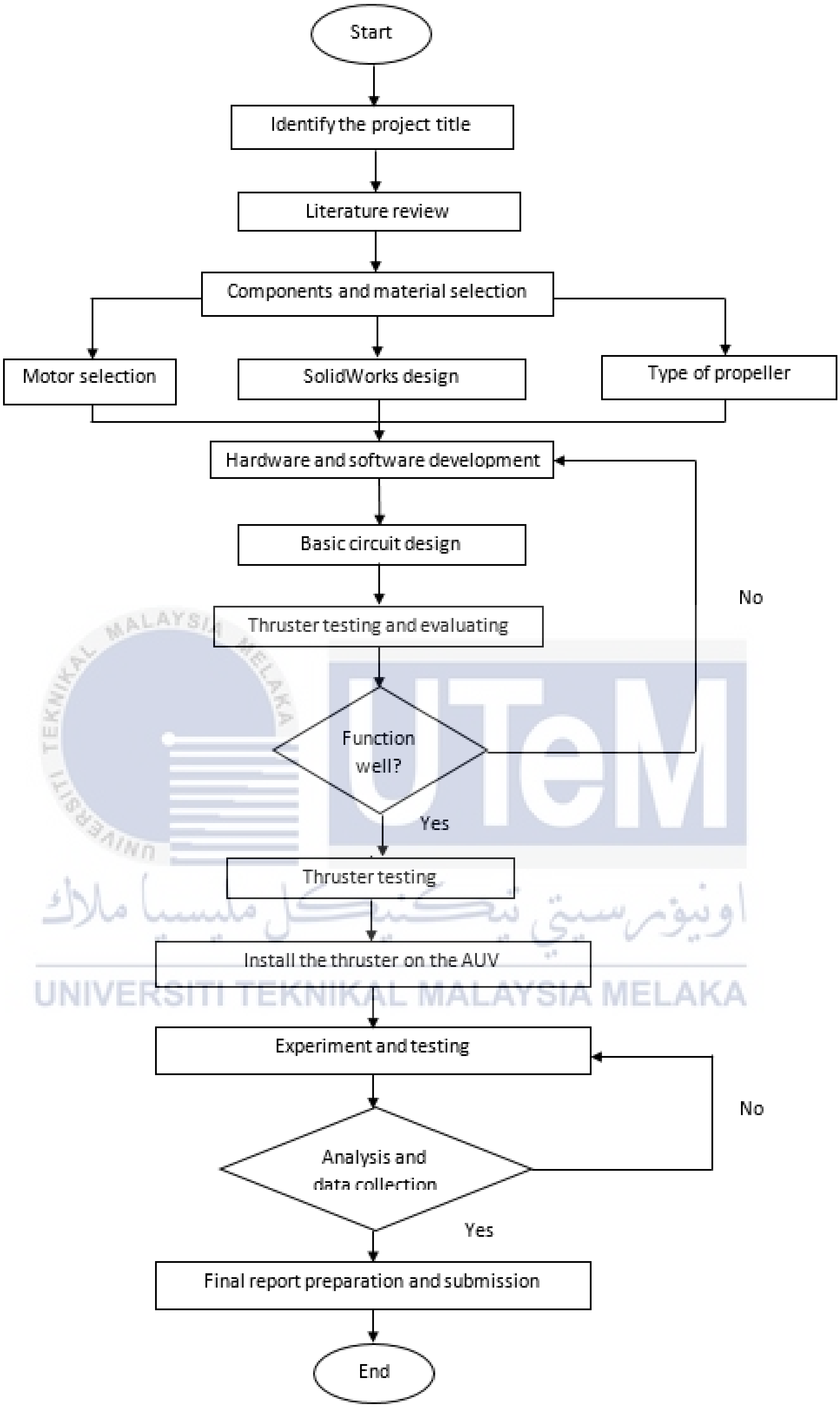


Figure 3.1: Overall process flow of the methodology.

3.2 Research Design

In developing the hardware of the thruster, 3D printer was used to print the part of the thruster which was the different number of blades propeller, nozzle and cover for the Autonomous Underwater Vehicle (AUV). Besides than that, microcontroller was very important for controlling the motor move. Arduino UNO, Arduino Mega and raspberry pi was compared and chosen the suitable controller. Furthermore, PVC pipe was also used to developed the body of the AUV.

3.2.1 Microcontroller

Table 3.1: Comparison for the Raspberry Pi.

Raspberry Pi Platform	Raspberry Pi Zero wireless	Raspberry Pi B+	Raspberry Pi 2 B	Raspberry Pi 3 B
RAM	512MB	512MB	1GB	1GB
Processor	1 GHz single-core ARM11	700 MHz ARM11	900 MHz Quad-Core ARM Cortex-A7	1.2 GHz 64-bit ARM Cortex A53
USB	1 Micro USB	4 Ports	4 Ports	4 Ports
Ethernet	-	10/100Mbps	10/100Mbps	300/Mbps/PoE
Wi-fi	802.11n	-	-	802.11ac
Bluetooth	4.1	-	-	4.1
HDMI	Mini-HDMI	Yes	Yes	Yes
Other Video	-	DSI, Composite	DSI, Composite	DSI, Composite
Micro SD	Yes	Yes	Yes	Yes

Table 3.2: Comparison between the microcontrollers

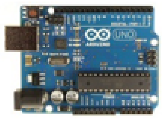
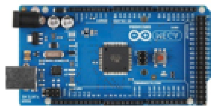
Type of microcontroller / Aspects	Arduino UNO 	Arduino Mega2560 
Operating voltage	5V	5V
Digital I/O pins	14	54
Analog input pins	6	16
Flash memory	32 KB	256 KB
SRAM	2KB	2KB
Clock speed	16 MHz	16 MHz

Table 3.1 shows the comparison for the different model of Raspberry Pi while Table 3.2 shows the comparison for the different model of Arduino. Raspberry Pi Model B was compared with the Raspberry Pi Zero Wireless because Model B can be used for a project where price is no object and the most powerful Pi is needed. This model of Pi also contains easy-to-use I/O while Raspberry Pi Zero Wireless was compared with the Module B due to it wireless specification. Thus, Raspberry Pi 3 B+ was chosen as a controller for this project. This is because the specification for the Raspberry Pi 3 B+ was better than other Raspberry Pi. Moreover, Arduino also compared to get the suitable controller. In this project, 5 digital I/O pins was used. Thus, Arduino Uno was chosen for control purpose.

3.2.2 3D Printer

In developing the hardware of the thruster, 3D printer was used to fabricate the part of the thruster and the AUV. Propeller with different number of blades, nozzle and other part of the AUV were fabricate by using PLA material. The setting of the 3d printer was set to the suitable setting for printing the better and smooth propeller, nozzle and other part of the AUV. Besides, the dimension of the 3D printer plate needed to be known for the printing purpose. If the dimension of the nozzle, propeller and other part of the AUV was greater than the plate, then it needed to modify to suit the plate.

Figure 3.2: 3D printer used to fabricate the part of the thruster.

3.2.3 Type of Motor

There are four types of the motor that was used to compared and get the low cost, high thrust and power efficiency motor. A2212 DC brushless motor, D2830 power series DC brushless motor, M100 and M200 were chosen and compare the specification of each motor and choose the low cost, high speed and power efficiency.

Figure 3.3: Brushless DC motor A2212.

Table 3.3: Technical data for Motor A2212.

Number of Cells	2 - 3 Li-Poly 6 - 10 NiCd/NiMH
Kv	1000 RPM/V
Maximum Efficiency	80%
Maximum Efficiency Current	4 - 10A (>75%)
No Load Current	0.5A @10V
Resistance	0.090 ohms
Maximum Current	13A for 60S
Maximum Watts	150W
Weight	52.7 g / 1.86 Oz
Size	28 mm DIA x 28 mm bell length
Shaft Diameter	3.2 mm
Poles	14
Model Weight	300 - 800g / 10.5 - 28.2 Oz

Figure 3.4: D2830 power series Dc brushless motor

Table 3.4:Technical data for D2830 power series Dc brushless motor.

Rpm/V	1000kv
Shaft	3.17mm
Voltage	2S~4S (7.4v to 14.8v)
Weight	52g
Watts	210w
Max Current	21A
ESC	30A
Suggested Prop	8x4 (4S) ~ 10x7 (2S)
Mounting Hole Bolt Circle	16mm or 19mm

Figure 3.5: M100 brushless DC motor.

Table 3.5: Specification for M100.

Parameter	**Value**	
	Performance	
Torque[1]	0.28 N m	2.5 in-lb
RPM/V (Kv Rating)	540 RPM/V	
	Electrical	
Operating Voltage	6 - 16 V	
Maximum Power	135 Watts	
Maximum Current	12.5 Amps	
	Physical	
Mounting Hole Threads	M3 x 0.5	
Weight in Air	90 g	0.2 lbs

Figure 3.6: M200 brushless DC motor.

Table 3.6: Specification for M200.

Parameter	Value	
Physical		
Mounting Hole Threads	M3 x 0.5	
Weight in Air	174 g	6.14 oz
Electrical		
Operating Voltage	6-20 Volts	
Max Current	22 amps	
Max Power	350 Watts	
Performance		
RPM/V (Kv Rating)	490 RPM/V	
Torque[1]	0.5 Nm	4.5 in-lb

Table 3.7: Comparison of price for different type of motor.

Type of motor	**A2212/13T**	**D2830**	**M100**	**M200**
Price	RM 26	RM 100	RM 293.23	RM 376

According to the specification of the Table 3.3 to Table 3.6, A2212 and D2830 DC brushless motor have higher speed when compare to the M100 and M200. This is because the revolution per minute is higher than the M100 and M200. Moreover, A2212 DC brushless motor also have better power efficiency than D2830 DC brushless motor, M100 and M200. Besides than that, the price of the motor is also needed to consider in this project which shown in Table 3.7. This is because the main objective was to develop lower cost thruster with high speed, high thrust and better power consumption. Thus, A2212 was chosen for the end of the project due to the high speed, low cost and best power consumption.

3.2.4 Type of Propeller

Propeller was designed in different number of blades which were two, three, four and three blades of propeller. Different number of blades was chosen to test the thrust and its speed. Propeller with different number of blades have different thrust among each other.

3.3 Software Description

3.3.1 SolidWorks Software

Figure 3.7 shows the SolidWorks icon in the laptop. SolidWorks software was used to design the thruster. This was because SolidWorks software can used to test the stress and strain of the thruster and the AUV. This software can help to design a thruster with high performance. SolidWorks software was used to design different type of propeller such as the propeller with different number of blades and different angle.

Figure 3.7: SolidWorks software icon.

3.3.2 Arduino software

Arduino is an open-source computing platform that created a microcontroller board for building digital devices and interactive objects to control the physical devices. Basic circuit is used to connect the electronic speed controller to control the motor direction. Arduino coding is needed to program the motor to test the performance in forward and downward direction.

Figure 3.8: Arduino software.

3.3.3 TeamViewer

TeamViewer is a software that can easy access to computers and networks remotely. TeamViewer can use for meeting purpose, maintaining a cloud-based service desk and other purpose due to its wide range of powerful remote access. TeamViewer was installed in laptop and connect to the Raspberry Pi 3 B+ for upload the coding to the Arduino Uno. This can easily control the movement for the AUV.

Figure 3.9: TeamViewer software.

3.4 Design and Assembly of the thruster.

Solidwork was used to design the part of the thruster and other part of the AUV.

3.4.1 Hardware Development

Figure 3.2 shows the 3D printer which used to fabricate the parts of the thruster and AUV. After all the parts of the thruster and AUV had fabricated, all the parts were assembly for experimental purpose. Every electronic part and the hole that expose to the water was seal with the silicone to avoid the short circuit for the electronic part. The U-frame and i-joint was designed for holding the thruster which shown in Figure 3.10.

Figure 3.10: AUV design with the printing part.

3.4.2 Basic Circuit Design

Basic circuit was design as shown in Figure 3.11. Arduino was used as a controller and the coding was written and imported to the Arduino for control the motor. Electronic Speed Control (ESC) was used in this circuit for control and regulates the speed of the motor. 12V Lipo battery or Seal Leas acid (SLA) battery was used to power the motor.

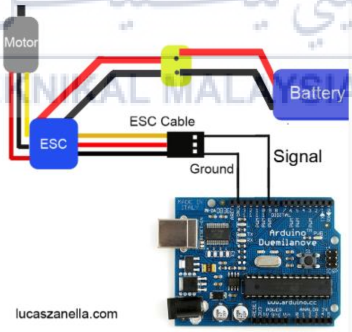


Figure 3.11: Basic circuit design for the thruster.

3.5 Experiment and Analysis

3.5.1 Experiment 1: Software Analysis for Thruster

Objective:

To design and analysis of the underwater thruster for Autonomous Underwater Vehicle (AUV) by using SolidWorks.

Parameter:

Manipulated variable: SolidWorks design.

Responding variable: Analysis for flow simulation.

Equipment:

- SolidWorks software

Procedure:

i) Experiment 1 was carried out by using the SolidWorks software.

ii) Research was done before designing the propeller and the nozzle.

iii) Figure 3.12 shows the SolidWorks design for the thruster.

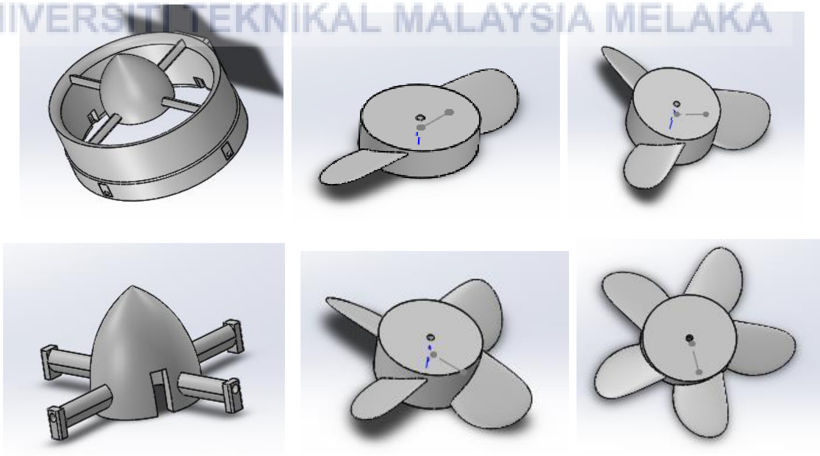


Figure 3.12: SolidWorks design for the thruster

iv) The design shown in Figure 3.12 was analyzed in terms of pressure, stress and strain.

v) The result was recorded at the table 3.8 and discussed it in Chapter 4.

Table 3.8: Result from SolidWorks.

Part of the thruster	Stress test	Strain test
Nozzle		
Propeller with two blades		
Propeller with three blades		
Propeller with four blades		
Propeller with five blades		

3.5.2 Experiment 2: Performance of the Electronic Component

Objective:

To develop and fabricate the underwater thruster for Autonomous Underwater Vehicle (AUV).

Parameter:

Manipulated variable: Electronic component

Responding variable: Performance of the electronic component

Equipment:

- Thruster
- Arduino Uno
- USB cable
- Electronic speed control (ESC)
- 12V SLA battery
- Brushless DC motor

Procedure:

i) The experiment 2 was carried out as shown in the Figure 3.13.

Figure 3.13: Thruster development.

Figure 3.14: DC-DC converter.

Figure 3.15: Arduino performance test.

Figure 3.16: Raspberry Pi 3 B+ performance test.

ii) Arduino Uno was connected to the ESC ground the output pin. The power pin for the ESC cannot connect to the 5V power from Arduino Uno to avoid the short circuit.

iii) Power cable from ESC was connected to the 12V battery and another 3 wires from ESC was connected to the motor A2212 DC brushless motor.

iv) Step 3 was repeated for the motor D2830 DC brushless motor.

v) DC-DC converter was connected to the battery and adjust the voltage which shown in blue circle in Figure 3.14 and current which shown in blue circle in Figure 3.14 to make sure it can function.

vi) Raspberry Pi 3 B+ was connected to the power source to make sure it has red light or green light for its performance.

vii) All the possible result was recorded in the Table 3.9.

Table 3.9: Performance of the thruster.

Electric component	Work	Not work
ESC 1		
ESC 2		
ESC 3		
ESC 4		
ESC 5		
ESC 6		
A2212 DC Brushless Motor 1		
A2212 DC Brushless Motor 2		
D2830 DC Brushless Motor 1		
D2830 DC Brushless Motor 2		
DC-DC converter		
Arduino Uno		
Raspberry Pi 3 B+		

3.5.3 Experiment 3: Stability and Buoyancy Test for the AUV

Objective:

To Investigate the performance of thruster in terms of thrust produced, propeller with difference numbers of blade and speed of the thruster.

Parameter:

Manipulated variable: Steel bar

Responding variable: Stability of the AUV and buoyancy of the AUV

Equipment:

- AUV with thruster
- Propeller with different numbers of blade
- Steel bar

Procedure:

i) AUV was set up as shown in Figure 3.17.

Figure 3.17: Autonomous Underwater Vehicle

ii) Steel bar was added to stable and overcome the buoyancy force for the AUV.

iii) Step 2 was repeated for adding the steel bar one by one until the AUV was stable and overcome the buoyancy test.

iv) The picture was taken for the discussion part.

3.5.4 Experiment 4: Thrust Analysis for Thruster with Nozzle

Objective:

To investigate the performance of thruster in terms of thrust produced, propeller with difference numbers of blade and speed of the thruster.

Parameter:

Manipulated variable: Propeller with different numbers of blade.

Responding variable: Thrust that produce by the thruster.

Equipment:

- Tripod stand
- Electronic weight balance
- Thruster
- Propeller with different numbers of blade
- Arduino Uno
- 12 V battery
- Electronic Speed Controller
- A2212 Dc brushless motor

Procedure:

i) The experiment 4 was set up as shown in Figure 3.18.

Figure 3.18: Electronic weight balance set up.

ii) Electronic part was set up as shown in Figure 3.19.

Figure 3.19: Circuit set up for thruster.

iii) Arduino coding was written and upload to the Arduino board for moving the motor.

iv) After the coding was uploaded complete, ESC was connected to the battery to power the motor.

v) Step 3 to 4 was repeated for the propeller with different numbers of blade.

vi) The result was collected and recorded in Table 3.10.

Table 3.10: Thrust for different numbers of blade.

Number of Blades	Weight	Thrust
Two		
Three		
Four		
Five		

3.5.5 Experiment 5: Thrust Analysis for Thruster with Different Type of Motor

Objective:

To investigate the performance of thruster in terms of thrust produced, propeller with difference numbers of blade and speed of the thruster.

Parameter:

Manipulated variable: Propeller with different numbers of blade and different type of motor

Responding variable: Thrust that produce by the thruster.

Equipment:

- Tripod stand
- Electronic weight balance
- Thruster
- Propeller with different numbers of blade
- Arduino Uno
- 12 V battery

- Electronic Speed Controller
- A2212 Dc brushless motor
- D2830 Dc brushless motor
- M100
- M200

Procedure:

i) The experiment 5 was set up as shown in Figure 3.20.

Figure 3.20: Thrust measurement.

ii) Electric part was set up as shown in Figure 3.21.

Figure 3.21: Circuit set up for thruster.

iii) Submerge the thruster in the water.

iv) Arduino coding was written and upload to the Arduino board for moving the motor.

v) After the coding was uploaded complete, ESC was connected to the battery to power the motor.

vi) Thruster was pilling downward and the weight was recorded

vii) Step 3 to 6 was repeated for the propeller with different numbers of blade and also different type of motor.

viii) The result was collected and recorded in Table 3.11.

Table 3.11: Thrust for different numbers of blade and different type of motor.

Type of Motor / Number of blades	A2212	
	Weight (kg)	Thrust (N)
Two		
Three		
Four		
Five		

Type of Motor / Number of blades	D2830	
	Weight (kg)	Thrust (N)
Two		
Three		
Four		
Five		

Type of Motor / Number of blades	M100	
	Weight (kg)	Thrust (N)
Thrust		

Type of Motor / Number of blades	M200	
	Weight (kg)	Thrust (N)
Thrust		

3.5.6 Experiment 6: Speed Test for the Thruster with Different Type of Motor

Objective:

To investigate the performance of thruster in terms of thrust produced, propeller with difference numbers of blade and speed of the thruster.

Parameter:

Manipulated variable: Propeller with different numbers of blade and different type of motor.

Responding variable: Speed for thruster.

Equipment:

- Tachometer
- Thruster
- Propeller with different numbers of blade
- AUV
- A2212 Dc brushless motor
- D2830 Dc brushless motor
- M100
- M200

Procedure:

i) The experiment 6 was set up as shown in Figure 3.22.

Figure 3.22: Reflective tape and Tachometer.

ii) Reflective tape which shown in Figure 3.18 was used at the surface on the propeller.

iii) Arduino coding was written and upload to the Arduino board for moving the motor.

iv) After the coding was uploaded complete, ESC was connected to the battery to power the motor.

v) Tachometer was ready and set the function to photo source Place the photo source parallel to the reflective tape and test the speed for the thruster which shown in Figure 3.18.

vi) Step 3 to 5 was repeated for the propeller with different numbers of blade and also different type of motor.

vii) The result was collected and recorded in Table 3.12.

Table 3.12: Speed for different numbers of blade and different type of motor.

Type of Motor / Speed	A2212 DC brushless motor		
	1 (RPM)	2 (RPM)	Average (RPM)
Two			
Three			
Four			
Five			

Type of Motor / Speed	D2830 DC brushless motor		
	1 (RPM)	2 (RPM)	Average (RPM)
Two			
Three			
Four			
Five			

Type of Motor / Speed	M100		
	1 (RPM)	2 (RPM)	Average (RPM)
Two			

Type of Motor / Speed	M200		
	1 (RPM)	2 (RPM)	Average (RPM)
Two			

3.6 Summary

In short, this chapter described the mechanical and electronic part of the thruster that was designed and developed. The overall flow of this thruster project was illustrated in the flowchart. Besides than that, procedure on the draftsmanship and design was discussed in SolidWorks. Moreover, SolidWorks was used to run the simulation for getting the result and experiments for different part was carried out and listed out in the last part of Chapter 3.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter study all the simulation and results obtained from various experiment. The discussion and explanation of the results obtained were recorded in this Chapter. The results obtained were tabulated in the table and the picture was attach to provide a better understanding of the results. The analysis was done in SolidWorks which included stress and strain test. Other than that, various experiment was carried out for thrust and speed analysis.

4.2 Hardware and Software Development

4.2.1 Hardware Development

Figure 4.1: Propeller with different numbers of blade and nozzle for the thruster.

Figure 4.1 shows the printing propeller and nozzle for the thruster of AUV. Propeller with different number of blades and the nozzle were fabricated by using 3D printer. Each propeller with different number of blades was print in pair and four nozzles were fabricated.

4.2.2 Software Development

SolidWorks software was used to design the propeller, nozzle and other part of the AUV. Moreover, SolidWorks software was also used to test the stress and strain for the thruster. Besides, Arduino software and TeamViewer were used to control the speed of the motor. TeamViewer software was used to remote the AUV due to its wireless specification while Arduino software was used to write the coding for the ESC and motor and upload the coding through the TeamViewer.

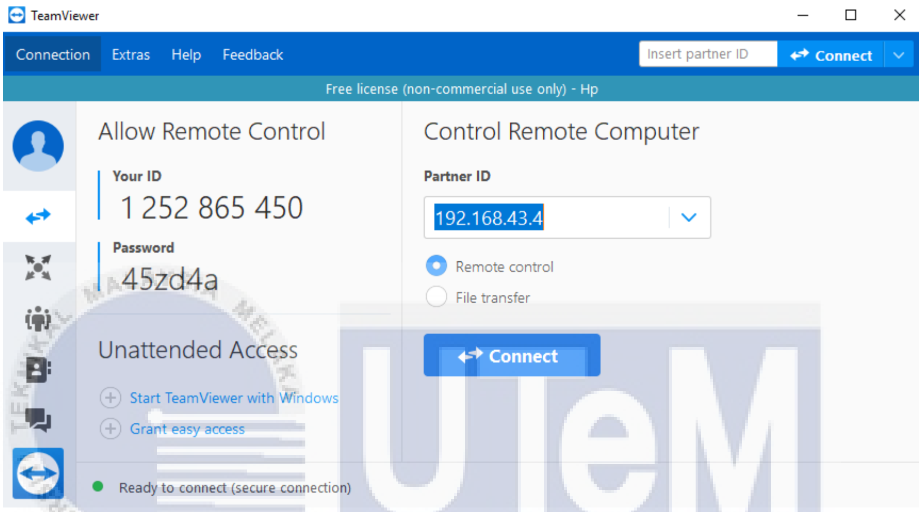


Figure 4.2: TeamViewer software

Figure 4.3: Arduino Software

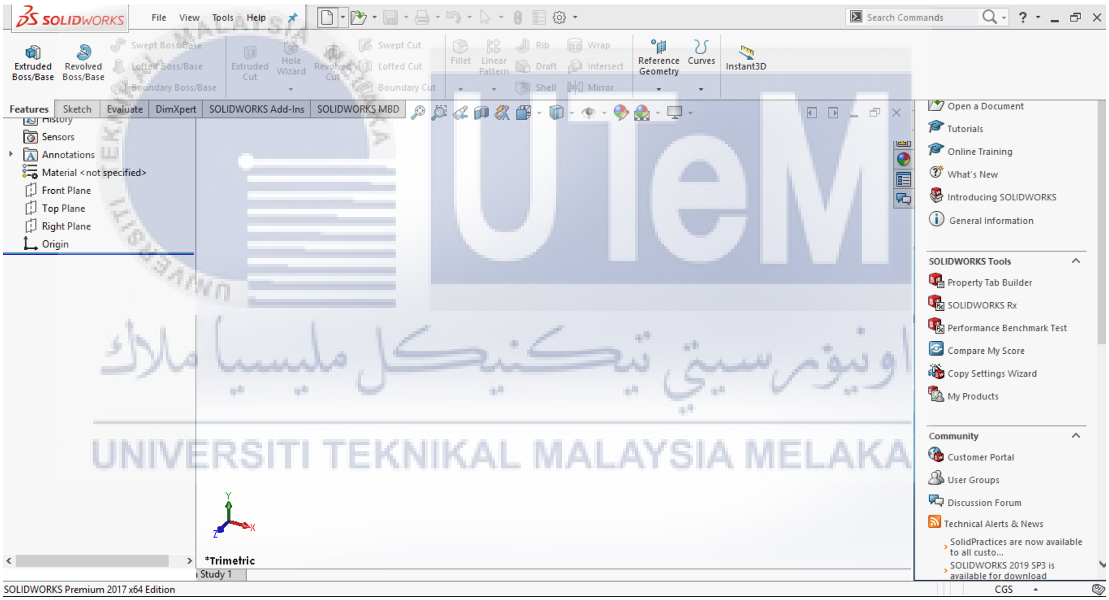


Figure 4.4: SolidWorks software

4.3 Experimental Result

4.3.1 Experiment 1: Software Analysis for Thruster

SolidWorks was used to test the material by adding load on thruster and the color difference was used to differentiate the pressure at different part of the thruster. Figure 4.5 shows one part of the simulation result for thruster. Table 4.1 show the result of the pressure acts on the nozzle and propeller.

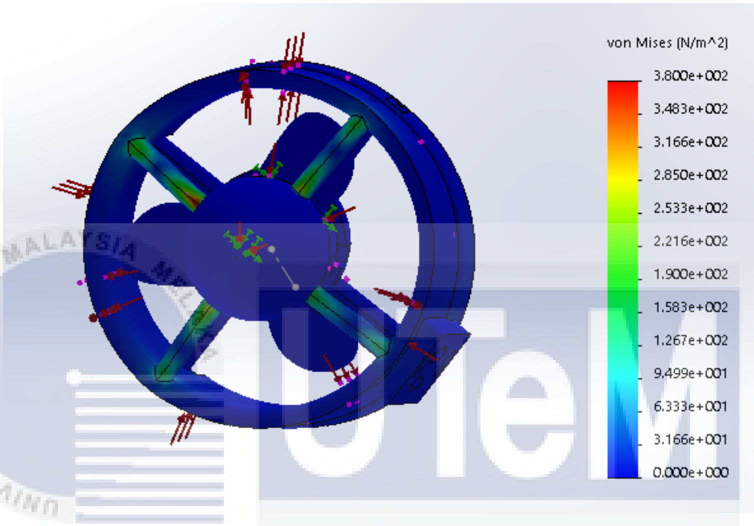
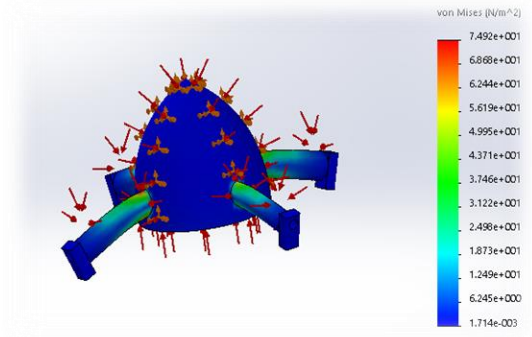
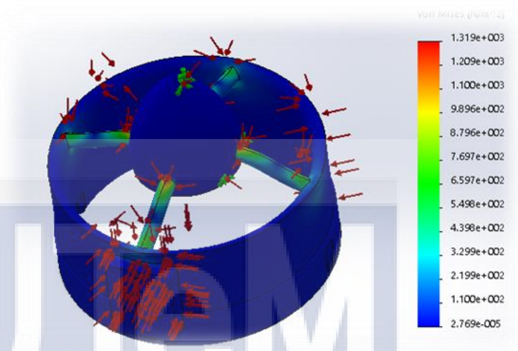
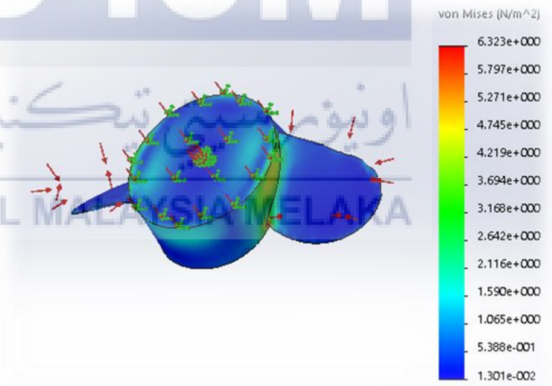
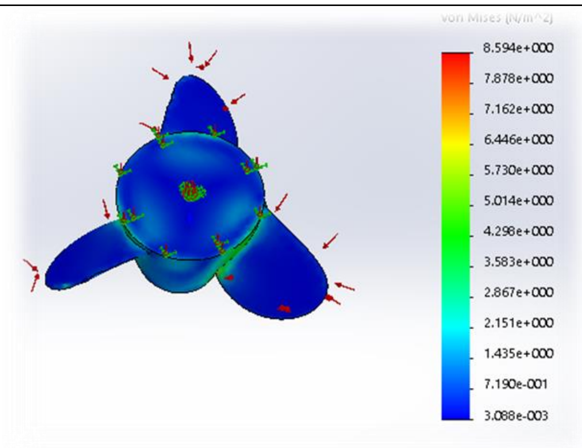


Figure 4.5: Stress and Strain test for thruster.

Table 4.1 shows that the stress test from SolidWorks software. 1N/m^2 force was applied on the surface of the nozzle and propeller. Blue color part shows that nozzle or propeller can withstand the pressure that act on it. When the color from blue to light blue then change to green, yellow, orange and red which means that the stress was higher at that part. As the figure shown in the Table 4.1, red color arrow shows that the pressure acting on it. Simulation was run in the SolidWorks software and the result was shown in figure in Table 4.1. When the pressure was higher, some part of the nozzle and propeller was deformed at that part which was clearly shows in Table 4.1. Propeller with more blades that shows in Table 4.1 was deformed seriously when compare to the less blade propeller.

Table 4.1: Stress test from SolidWorks software with pressure 1 N/m^2.

Part of the thruster	Stress test
Nozzle	 
Propeller with two blades	
Propeller with three blades	

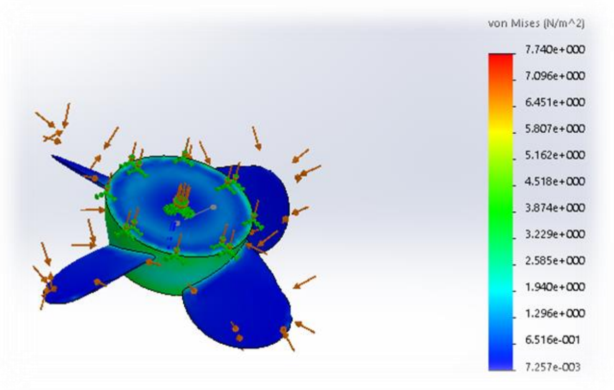
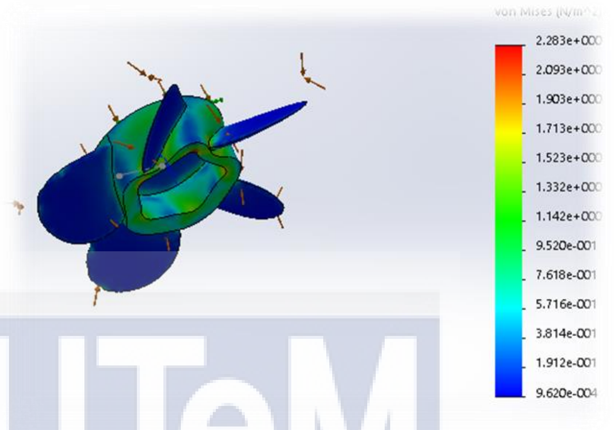
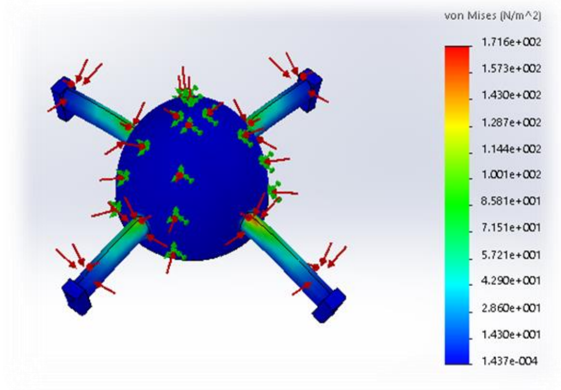
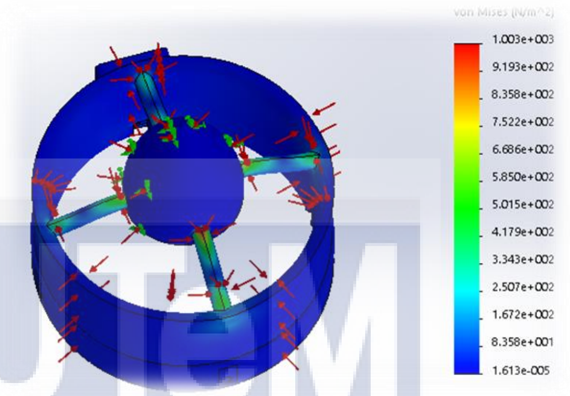
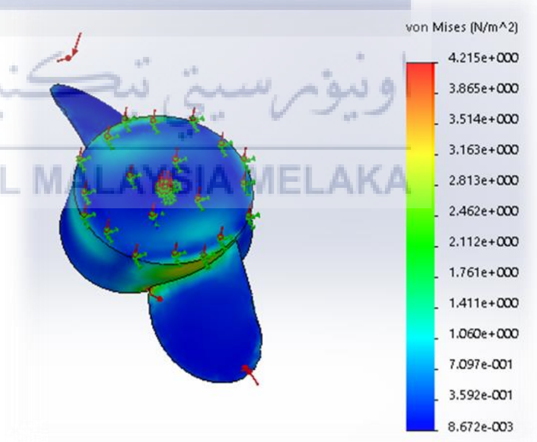
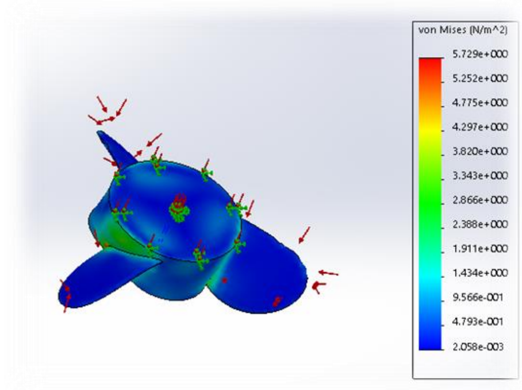
Part of the thruster	Stress test
Propeller with four blades	
Propeller with five blades	

Table 4.2: Stress test from SolidWorks software with pressure 2 N/m2.

<table>
<tr><th>Part of the thruster</th><th>Stress test</th></tr>
<tr><td>Nozzle</td><td>


</td></tr>
<tr><td>Propeller with two blades</td><td>
</td></tr>
<tr><td>Propeller with three blades</td><td>
</td></tr>
</table>

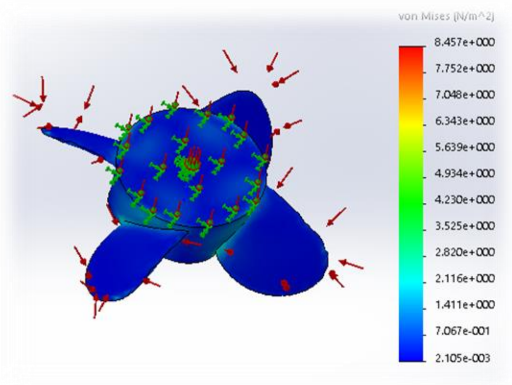
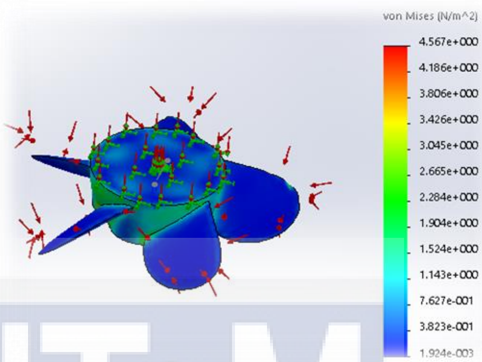
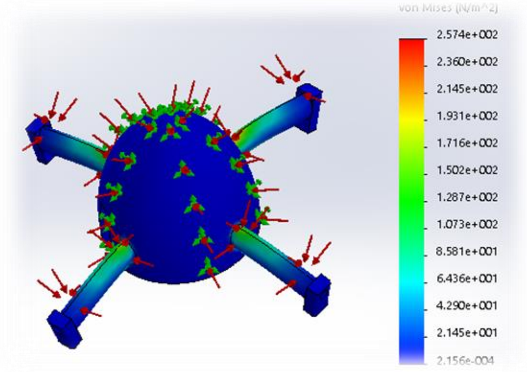
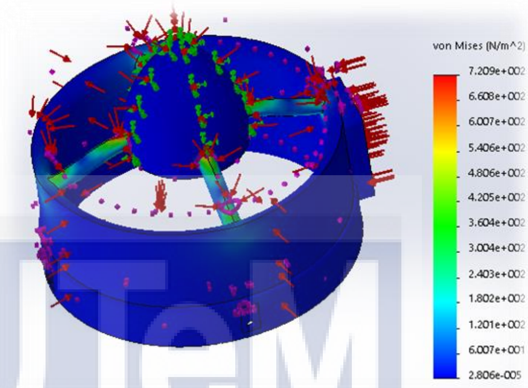
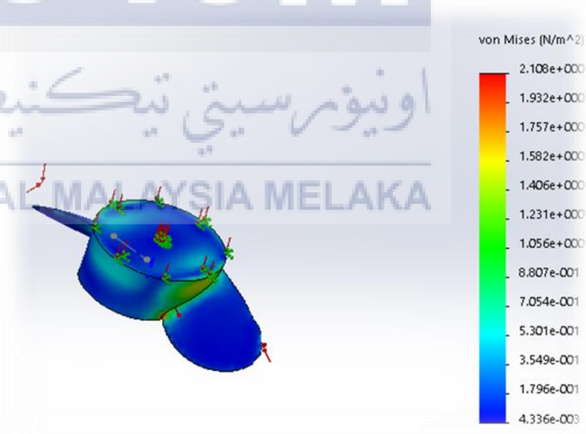
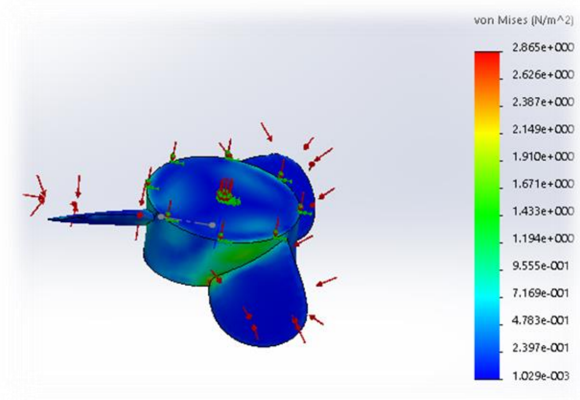
Part of the thruster	Stress test
Propeller with four blades	
Propeller with five blades	

Table 4.3: Stress test from SolidWorks software with pressure 3 N/m2.

<table>
<tr><th>Part of the thruster</th><th>Stress test</th></tr>
<tr><td>Nozzle</td><td>


</td></tr>
<tr><td>Propeller with two blades</td><td>
</td></tr>
<tr><td>Propeller with three blades</td><td>
</td></tr>
</table>

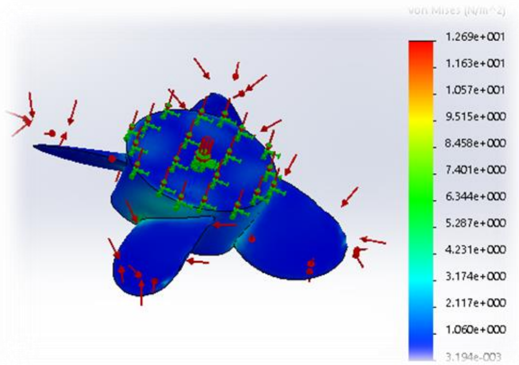
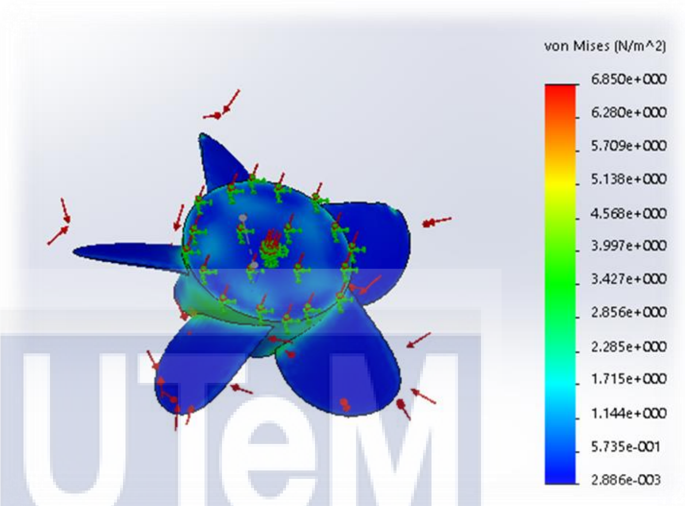
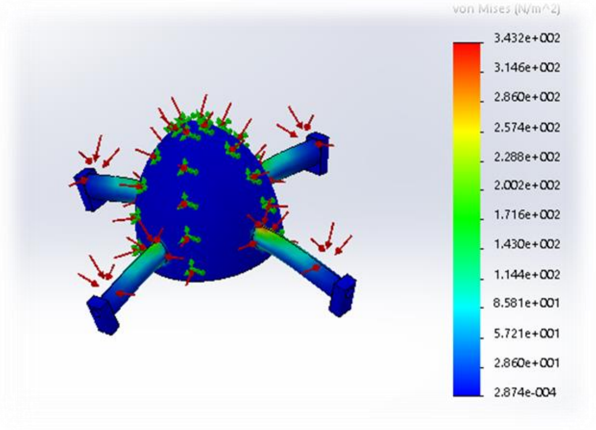
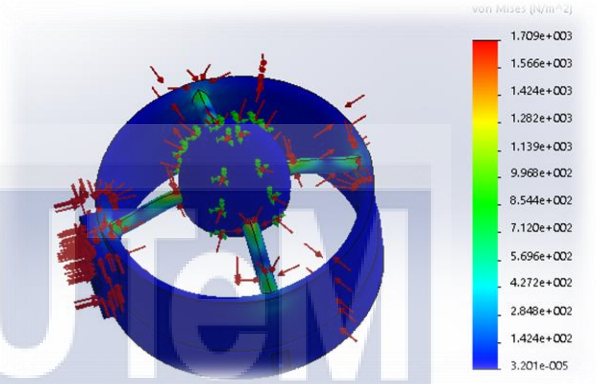
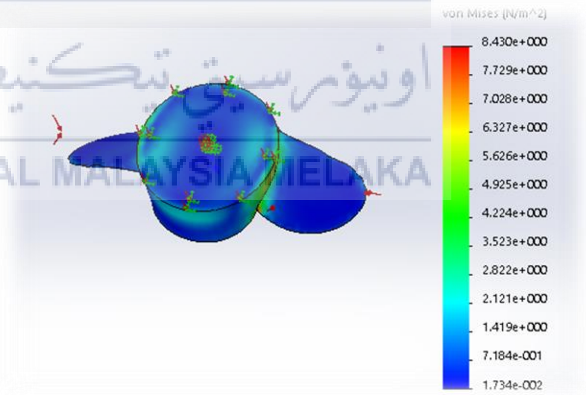
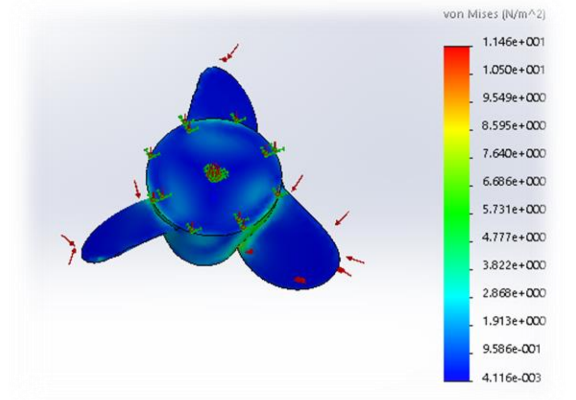
<table>
<tr><th>Part of the thruster</th><th>Stress test</th></tr>
<tr><td>Propeller with four blades</td><td></td></tr>
<tr><td>Propeller with five blades</td><td></td></tr>
</table>

Table 4.4: Stress test from SolidWorks software with pressure 4 N/m2.

Part of the thruster	Stress test
Nozzle	 
Propeller with two blades	
Propeller with three blades	

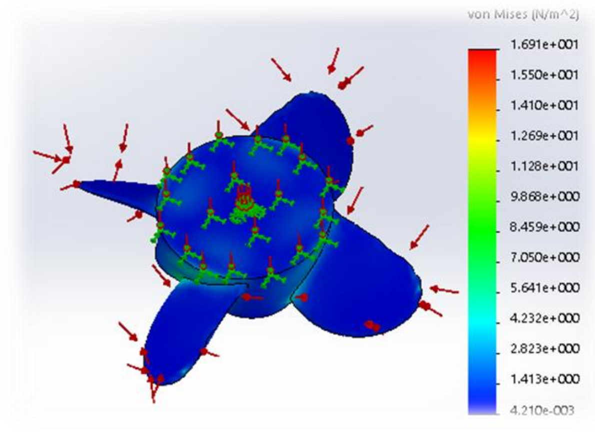
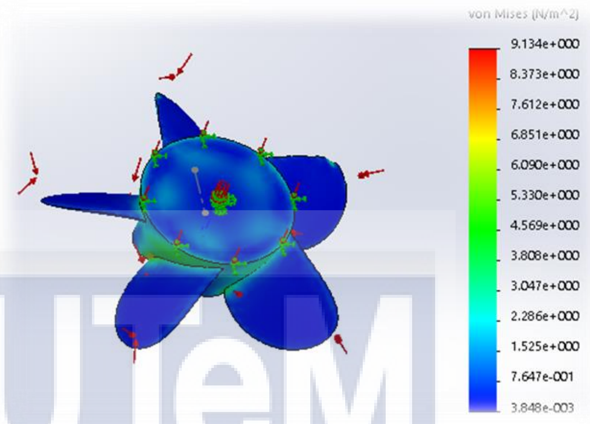
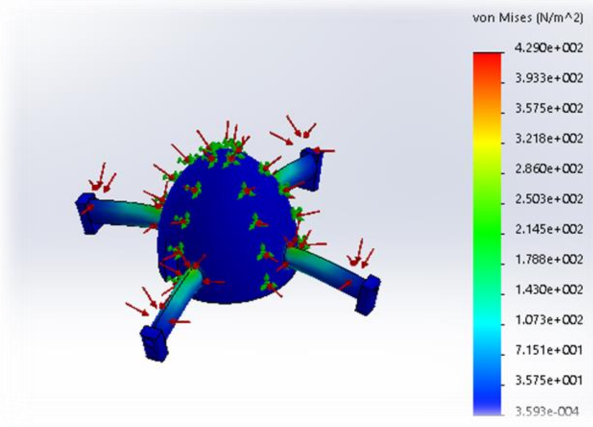
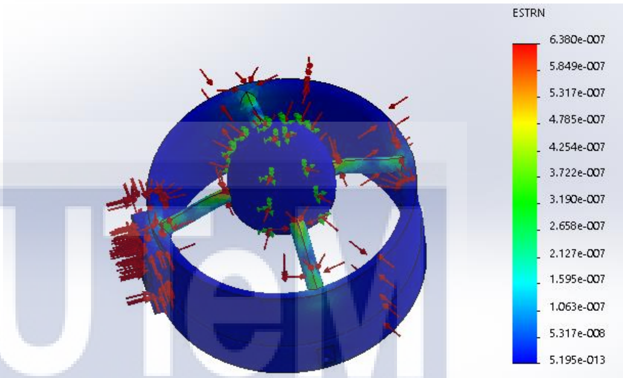
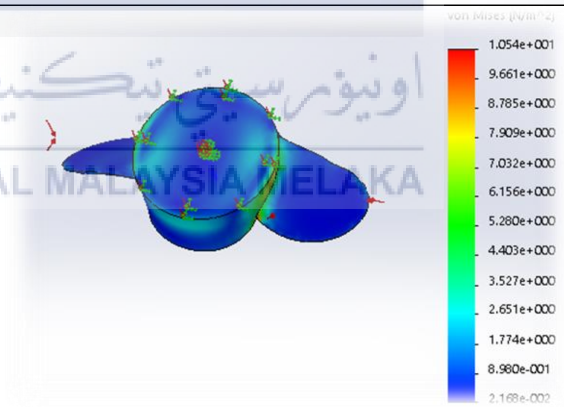
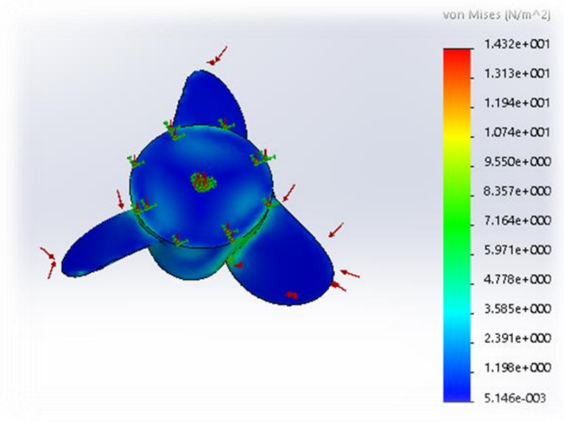
Part of the thruster	Stress test
Propeller with four blades	
Propeller with five blades	

Table 4.5: Stress test from SolidWorks software with pressure 5 N/m2.

Part of the thruster	Stress test
Nozzle	 
Propeller with two blades	
Propeller with three blades	

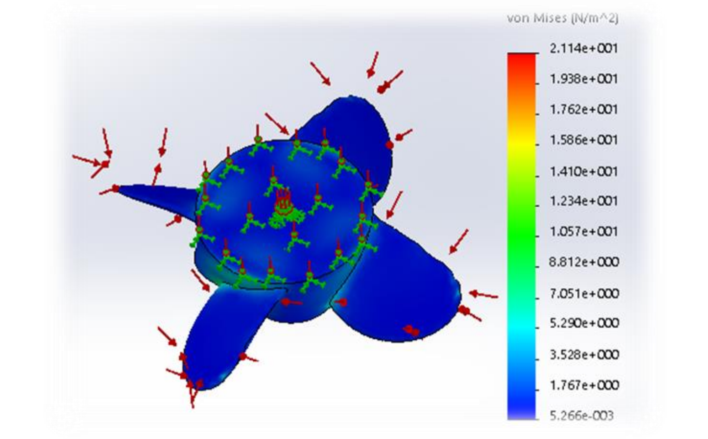
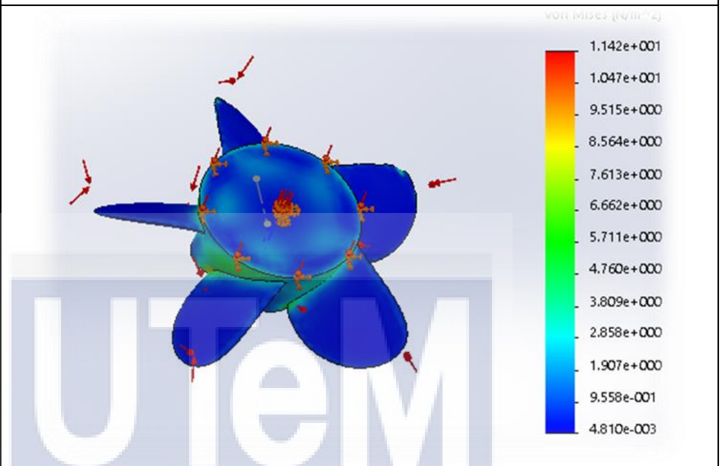
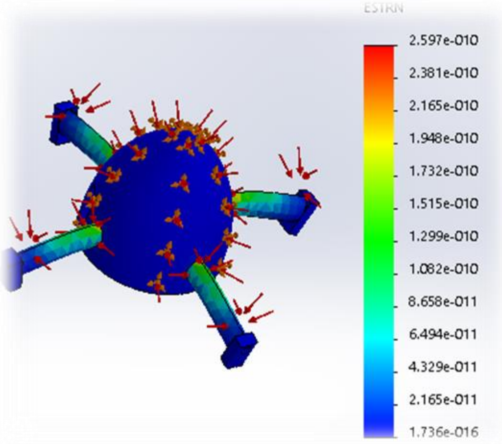
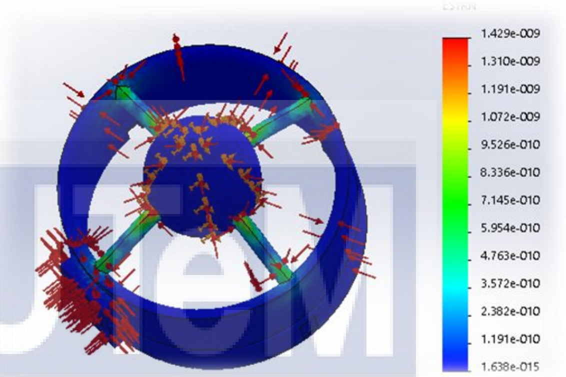
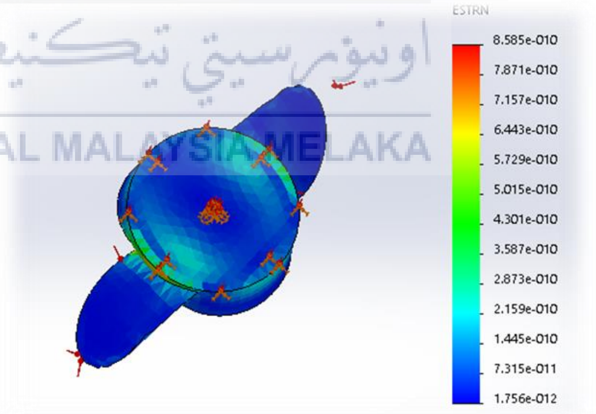
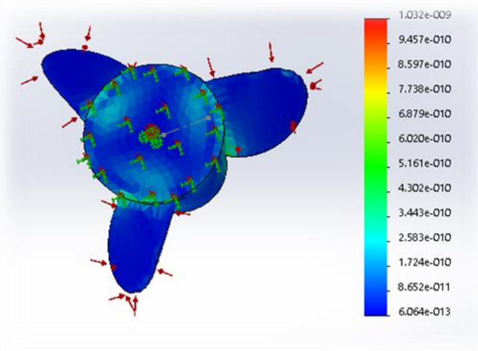
Part of the thruster	Stress test
Propeller with four blades	
Propeller with five blades	

Table 4.1 to Table 4.5 shows that the stress test from SolidWorks software. 1 to 5 N/m^2 force were applied on the surface of the nozzle and propeller. Blue color part shows that nozzle or propeller can withstand the pressure that act on it. When the color from blue to light blue then change to green, yellow, orange and red which means that the stress was higher at that part. As the figure shown in the Table 4.1 until Table 4.5, red color arrow shows that the pressure acting on it. Simulation was run in the SolidWorks software and the result was shown in figure in Table 4.1 until Table 4.5., Some part of the nozzle and propeller was deformed when the pressure was higher at that part which was clearly shows in Table 4.1 to Table 4.5. Propeller with more blades that shows in Table 4.1 to Table 4.5 was deformed seriously when compare to the less blade propeller.

Table 4.6: Strain test from SolidWorks software with pressure $1N/m^2$.

Part of the thruster	Strain test
Nozzle	 
Propeller with two blades	
Propeller with three blades	

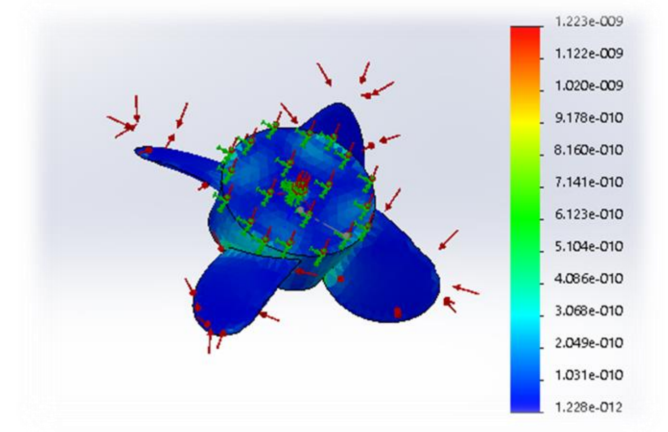
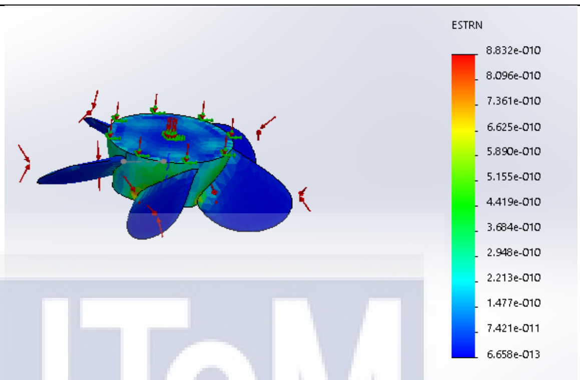
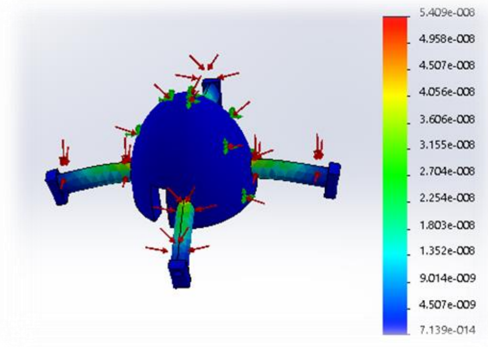
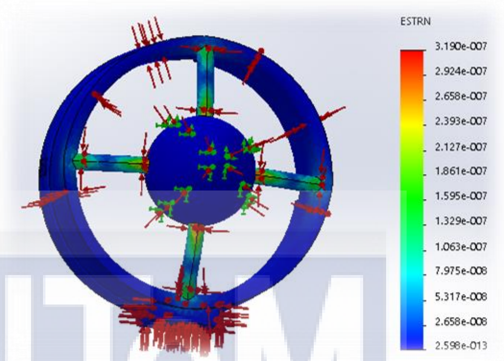
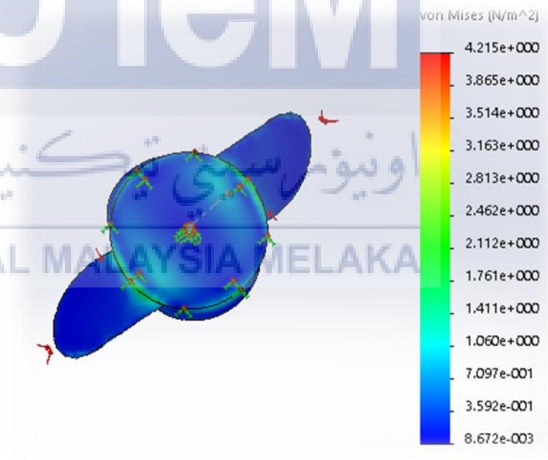
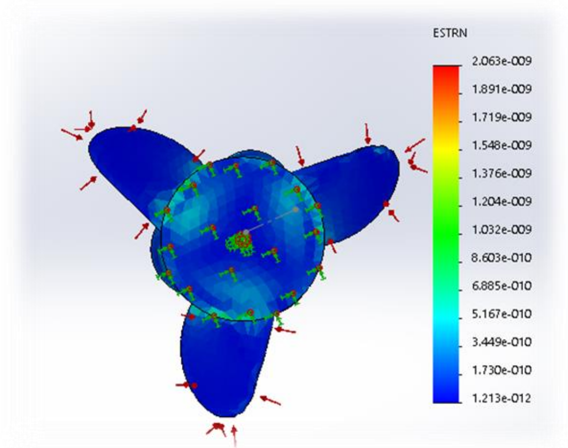
<table>
<tr><th>Part of the thruster</th><th>Stress test</th></tr>
<tr><td>Propeller with four blades</td><td>
</td></tr>
<tr><td>Propeller with five blades</td><td>
</td></tr>
</table>

Table 4.7: Strain test from SolidWorks software with pressure 2 N/m^2.

Part of the thruster	Strain test
Nozzle	 
Propeller with two blades	
Propeller with three blades	

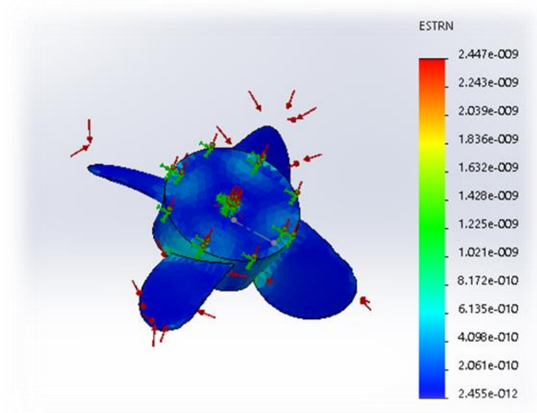
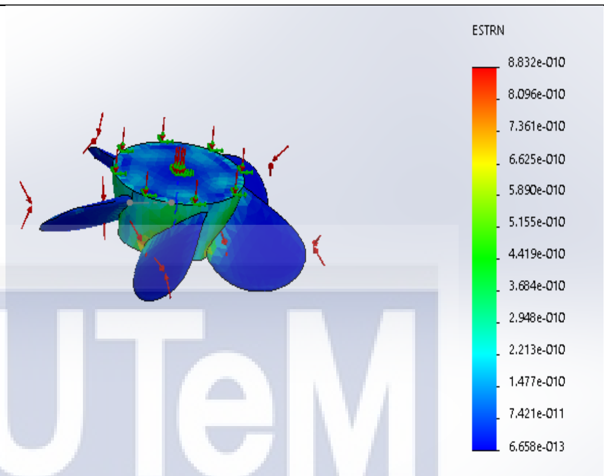
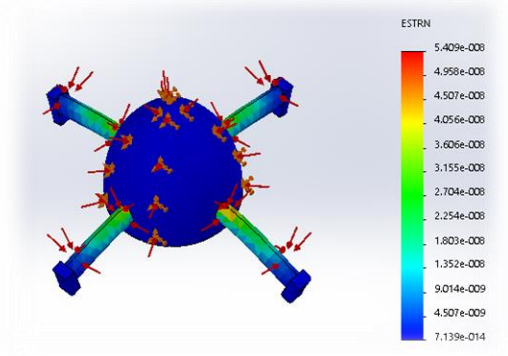
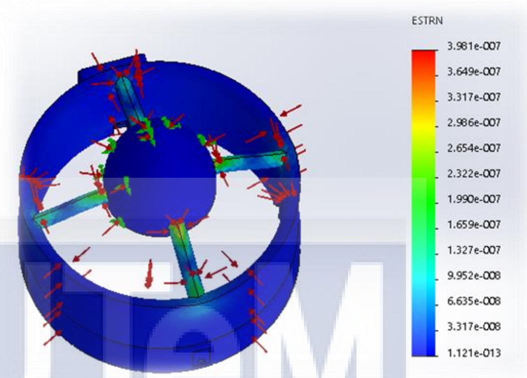
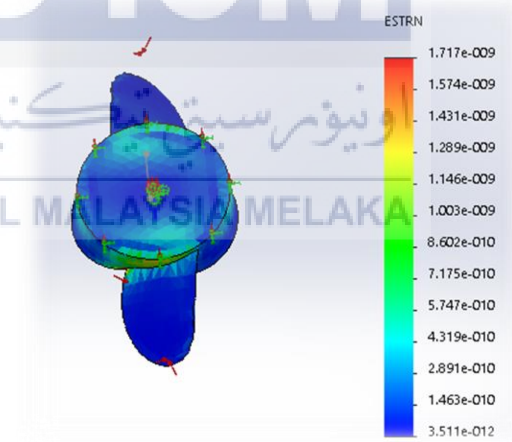
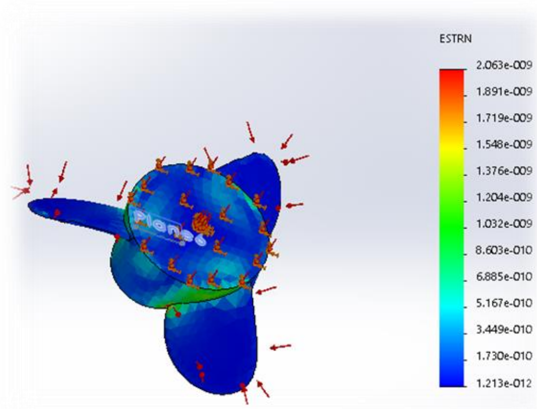
Part of the thruster	Stress test
Propeller with four blades	
Propeller with five blades	

Table 4.8: Strain test from SolidWorks software with pressure 2 N/m^2.

Part of the thruster	Strain test
Nozzle	 
Propeller with two blades	
Propeller with three blades	

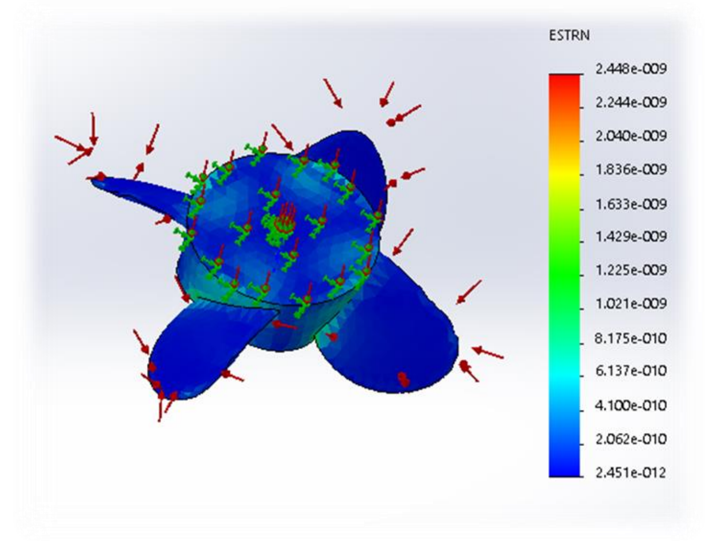
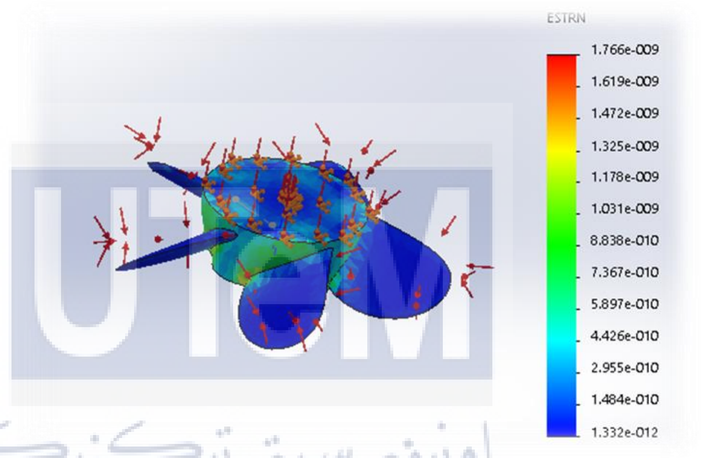
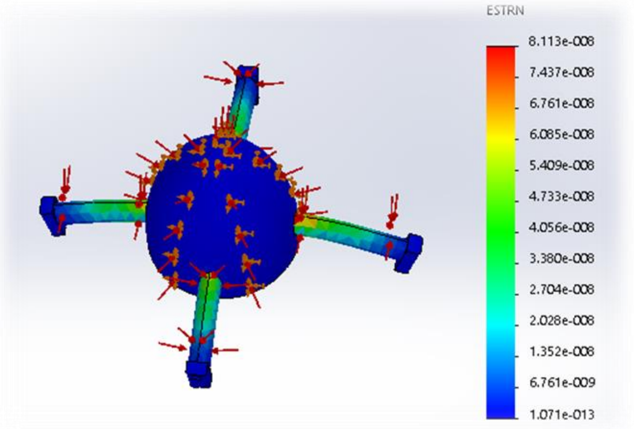
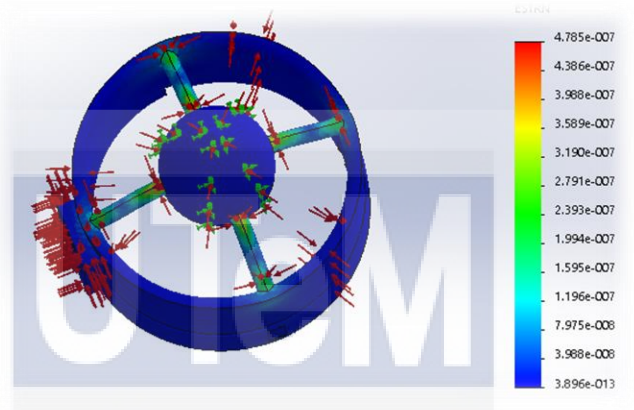
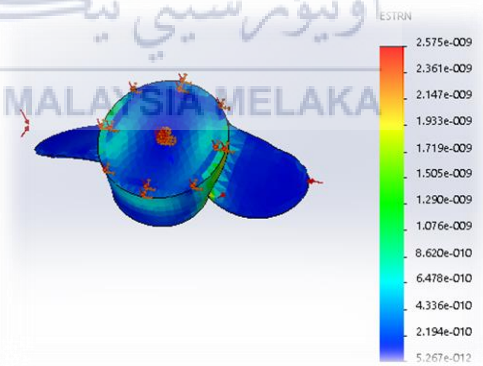
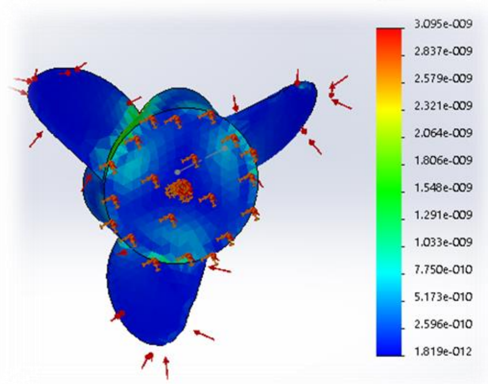
Part of the thruster	Stress test
Propeller with four blades	
Propeller with five blades	

Table 4.9: Strain test from SolidWorks software with pressure 3 N/m^2.

<table>
<tr><th>Part of the thruster</th><th>Strain test</th></tr>
<tr><td>Nozzle</td><td>




</td></tr>
<tr><td>Propeller with two blades</td><td>


</td></tr>
<tr><td>Propeller with three blades</td><td>


</td></tr>
</table>

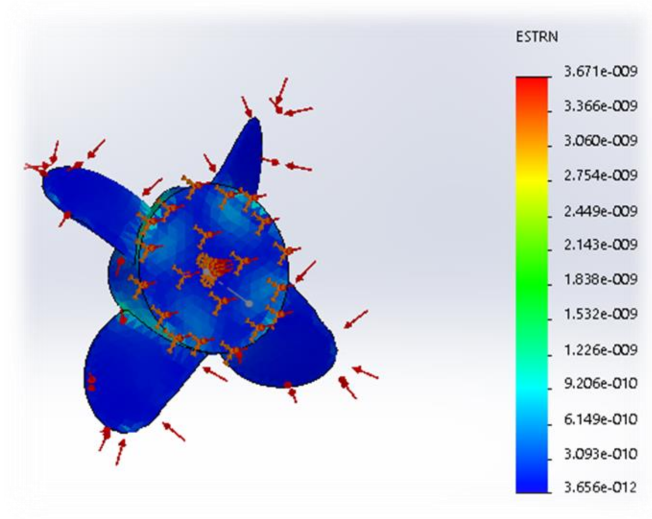
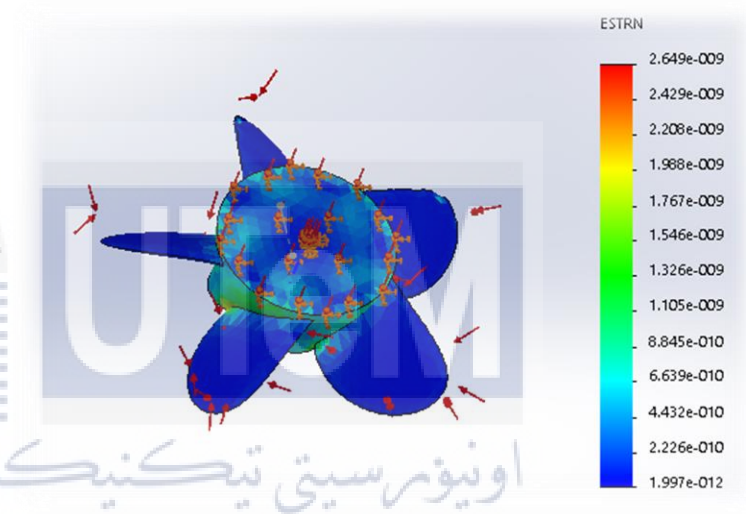
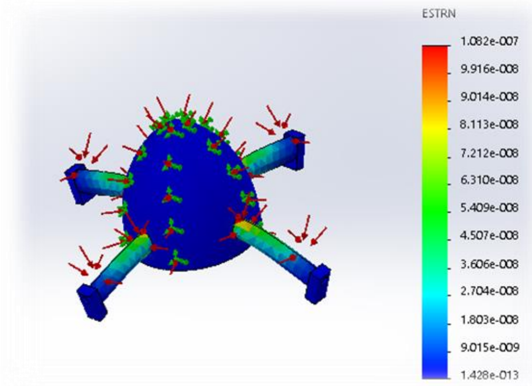
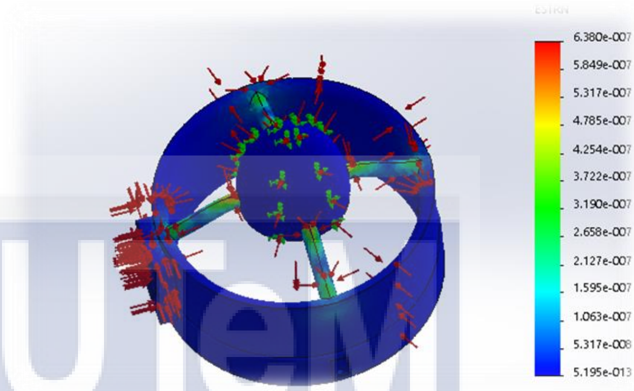
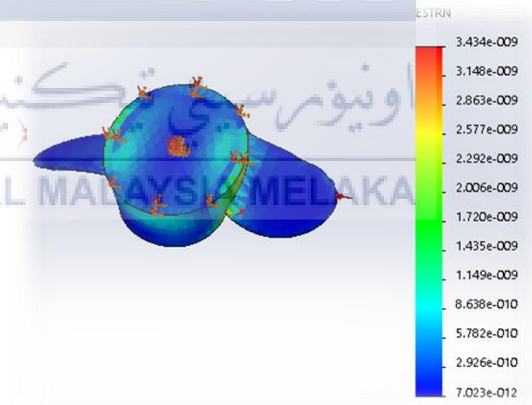
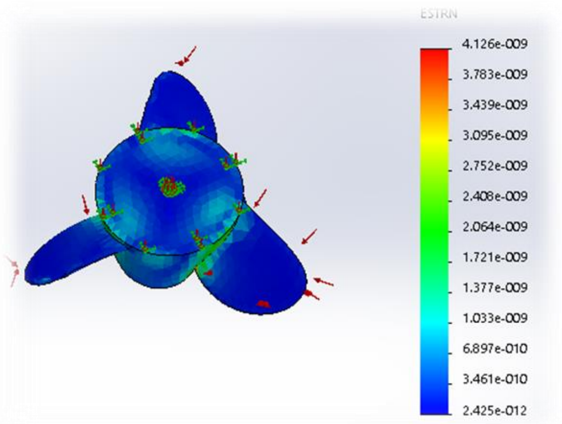
Part of the thruster	Stress test
Propeller with four blades	
Propeller with five blades	

Table 4.10: Strain test from SolidWorks software with pressure 4 N/m^2.

Part of the thruster	Strain test
Nozzle	 
Propeller with two blades	
Propeller with three blades	

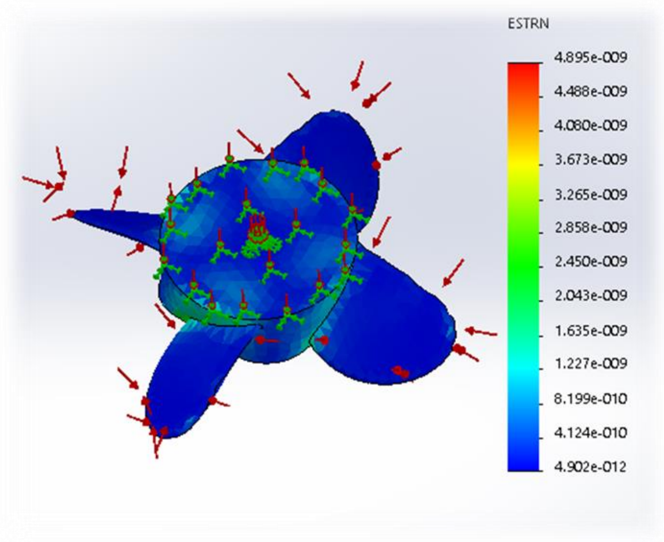
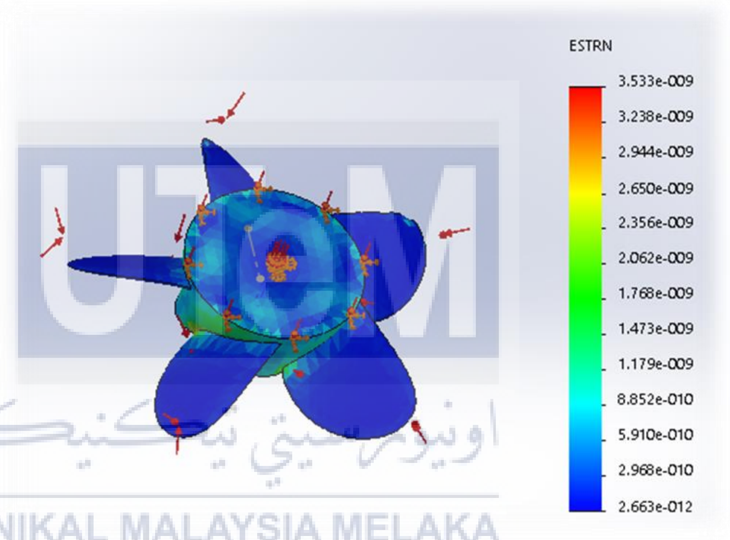
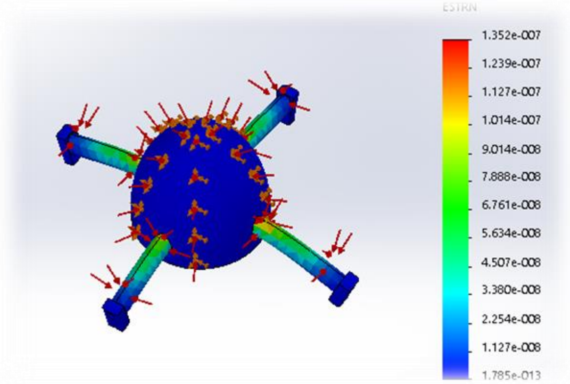
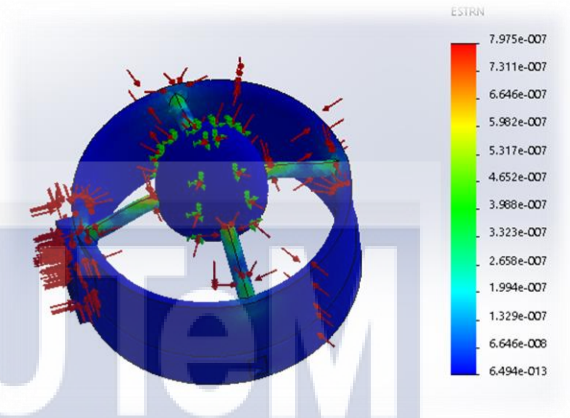
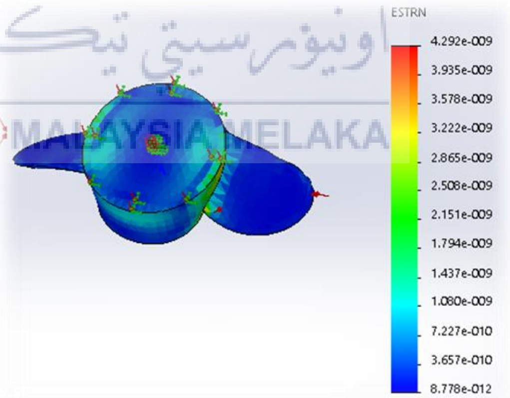
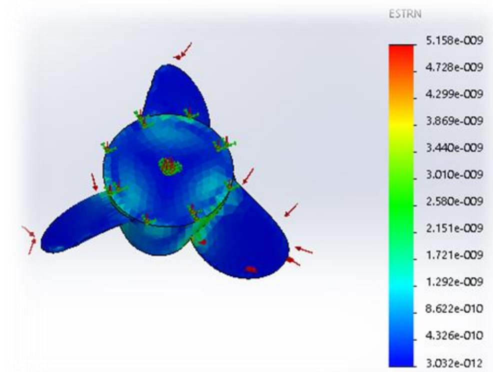
Part of the thruster	Stress test
Propeller with four blades	
Propeller with five blades	

Table 4.11: Strain test from SolidWorks software with pressure 5 N/m^2.

Part of the thruster	Strain test
Nozzle	 
Propeller with two blades	
Propeller with three blades	

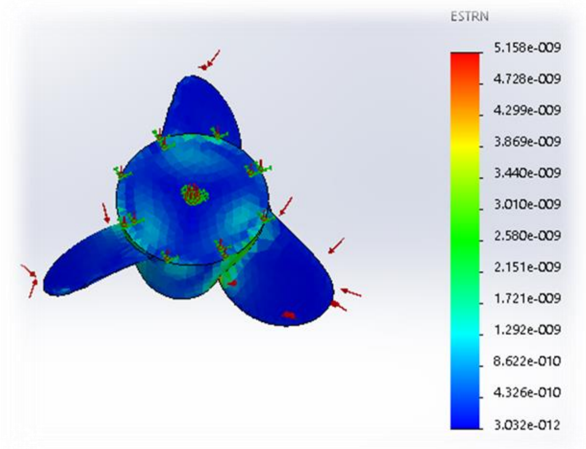
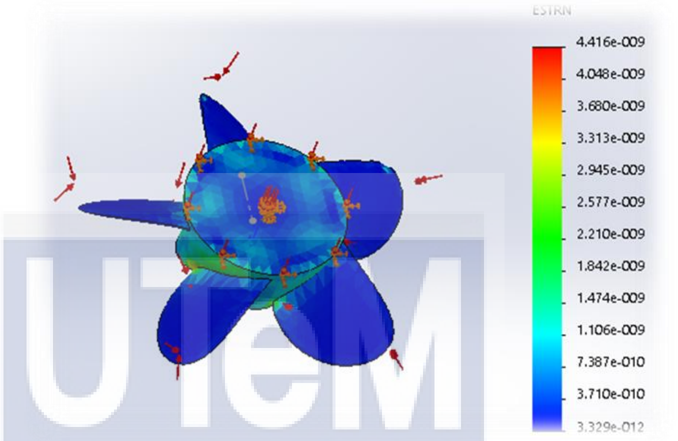
Part of the thruster	Stress test
Propeller with four blades	
Propeller with five blades	

Table 4.6 to Table 4.11 shows that the strain test from SolidWorks software. 1 to 5 N/m^2 force were applied on the surface of the nozzle and propeller. Blue color part shows that nozzle or propeller can withstand the pressure that act on it. When the color from blue to light blue then change to green, yellow, orange and red which means that the strain was higher at that part. As the figure shown in the Table 4.6 until Table 4.11, red color arrow shows that the pressure acting on it. Simulation was run in the SolidWorks software and the result was shown in figure in Table 4.6 until Table 4.11., Some part of the nozzle and propeller was deformed when the pressure was higher at that part which was clearly shows in Table 4.6 to Table 4.11. Propeller with more blades that shows in Table 4.6 to Table 4.11 was deformed seriously when compare to the less blade propeller.

4.3.2 Experiment 2: Performance of the Electronic Component

The performance of the electric component was tested and recorded in the Table 4.13. Before all the part has been assembled, both A2212 and D2830 DC brushless motor were tested for the function so that the motor can be function well after assembled. Besides, ESC for the motor also need to be tested to make sure the ESC can function well for controlling the speed. Furthermore, DC-DC converter also need to make sure that the voltage and the current can be adjust and give the right amount of voltage and current. Moreover, Arduino Uno and Raspberry Pi 3 B+ were the important controller for the whole AUV. If the controller has any problem, the coding for the Arduino cannot uploaded to the board and the AUV cannot function.

Table 4.12: Function of electronic component.

Electric component	Work	Not work
ESC 1	√	
ESC 2	√	
ESC 3	√	
ESC 4	√	
ESC 5		×
ESC 6		×
A2212 DC Brushless Motor 1	√	
A2212 DC Brushless Motor 2	√	
D2830 DC Brushless Motor 1	√	
D2830 DC Brushless Motor 2	√	
DC-DC converter	√	
Arduino Uno	√	
Raspberry Pi 3 B+	√	

4.3.3 Experiment 3: Stability and Buoyancy Test for the AUV

Figure 4.6 shows the steel bar which act as a weight to overcome the buoyancy force of the AUV so that AUV can submerge in the water. Steel bar need to add one by one to make sure the AUV submerge slowly in the water. Figure 4.7 shows the AUV in air which was not affect by any buoyancy while Figure 4.8 shows that the AUV which float on the water. This is because inside the PVC pipe have higher pressure than air in atmosphere. Another reason was the buoyancy force that act on the AUV's surface, thus the AUV cannot submerge in the water. The weight was added one by one to overcome the buoyancy force for the AUV. Besides than that, the steel bar also can adjust to the center of the AUV to stable the AUV in the water. Thus, the AUV submerge into the water which shown in the Figure 4.9. This step was very important to get the thrust for the thruster. If the AUV does not submerge more than 95%, the thrust cannot measure accurately. This was because AUV got buoyancy force act on it.

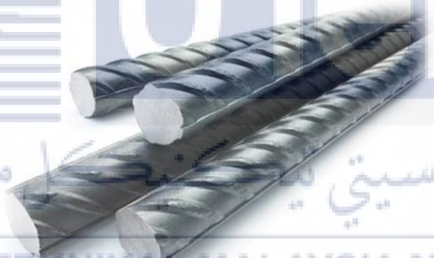


Figure 4.6: Steel bar.

Figure 4.7: AUV that on air.

Figure 4.8: AUV in water with buoyancy force.

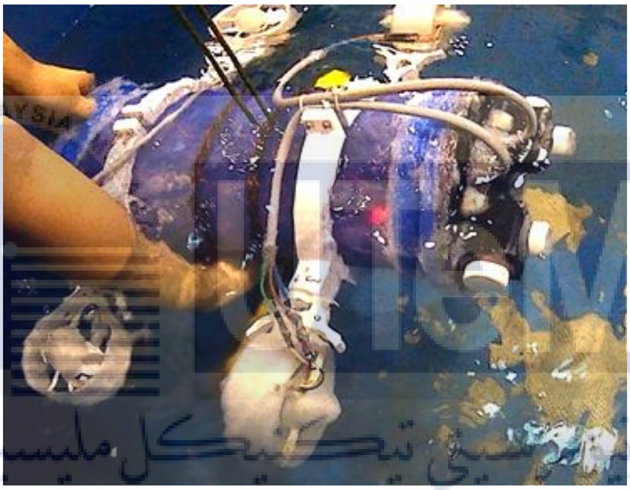


Figure 4.9: Adjust the weight for the AUV to stabilize it.

Figure 4.10: AUV submerge 95% in the water.

4.3.4 Experiment 4: Thrust Analysis for Thruster with Nozzle

Table 4.4 shows the result for thrust for different numbers of blade propeller while Figure 4.11 shows that the thruster tested the thrust in the water. Thruster was hold by the electronic weight balance for measure the downward force. When the thruster was powered by the battery and the full speed was given to the motor, the thruster pulls downward and the weight that shows on the screen of the electronic weight balance was recorded in the Table 4.4. Figure 4.12 shows the result of the weight which was in KG. Thus, the formulae were needed to calculate the thrust.

$$\boldsymbol{thrust = weight \times 9.81} \tag{4-1}$$

Table 4.4 shows the result of thrust for different number of blades of the propeller. Three blades propeller and two blades propeller have nearest amount of thrust produce. This was because the thruster with two and three blades were suitable for the smaller submarine such as the AUV and Remote Underwater Vehicle (ROV). Therefore, two and three blades propeller were had higher thrust which was 2.35N and 2.45N when compare to the four and five blades propeller which was 1.96N and 1.47N.

Table 4.13: Thrust value for the propeller with different numbers of blade.

Number of Blades	Weight (KG)	Thrust (N)
Two	0.24	2.35
Three	0.25	2.45
Four	0.20	1.96
Five	0.15	1.47

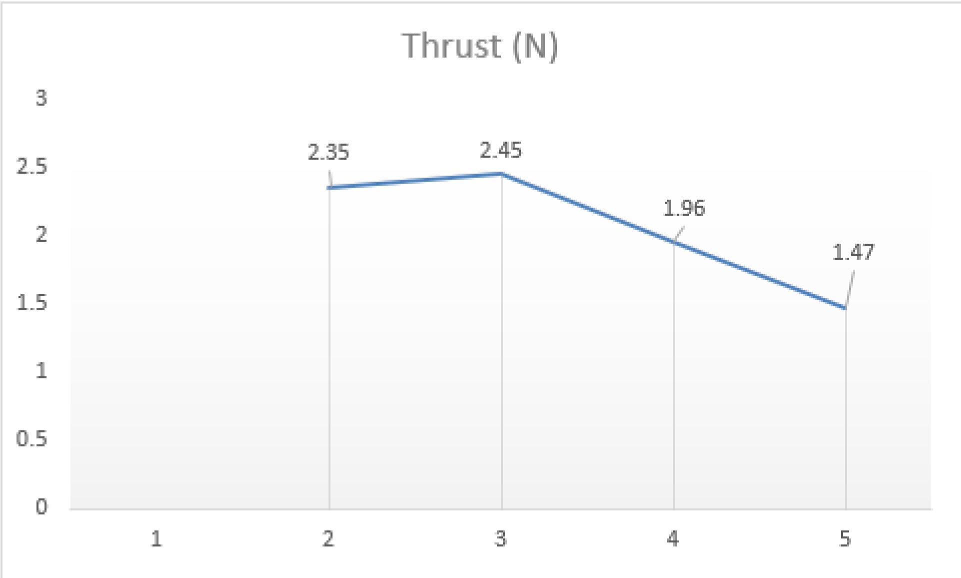


Figure 4.11: Graph for thrust against number of blades.

Figure 4.12: Thruster test in the water.

Figure 4.13: Electronic weight balance.

4.3.5 Experiment 5: Thrust Analysis for Thruster with Different Type of Motor

Table 4.15 shows the result of thrust for different number of blades of the propeller. Three blades propeller and two blades propeller have nearest amount of thrust produce for different type of motor. This was because the thruster with two and three blades were suitable for the smaller submarine such as the AUV and Remote Underwater Vehicle (ROV). Therefore, two and three blades propeller had higher thrust which was 2.35N and 2.45N when compare to the four and five blades propeller which was 1.96N and 1.47N for A2212 DC brushless motor. Furthermore, two and three blades propeller had higher thrust which was 2.35N and 2.55N when compare to the four and five blades propeller which was 1.96N and 1.57N for D2830 DC brushless motor. Besides, M100 and M200 also had nearest value of thrust which was 2.058N and 2.156N respectively when compare to the other two motor. Therefore, A2212 was suitable for develop lower cost thruster due to the thrust produce was considered higher and cost for the motor also cheaper than other motor. Figure 4.14 shows the graph of type of motor against thrust which shows clearly about the different type of motor and the thrust produce by different numbers of blade.

Table 4.14: Thrust for propeller with different number of blades and different type of motor.

Type of Motor / Number of blades	A2212	
	Weight (kg)	Thrust (N)
Two	0.24	2.35
Three	0.25	2.45
Four	0.2	1.96
Five	0.15	1.47

Type of Motor / Number of blades	D2830	
	Weight (kg)	Thrust (N)
Two	0.25	2.45
Three	0.26	2.55
Four	0.2	1.96
Five	0.16	1.57

Type of Motor / Number of blades	M100	
	Weight (kg)	Thrust (N)
Thrust	0.21	2.058

Type of Motor / Number of blades	M200	
	Weight (kg)	Thrust (N)
Thrust	0.22	2.156

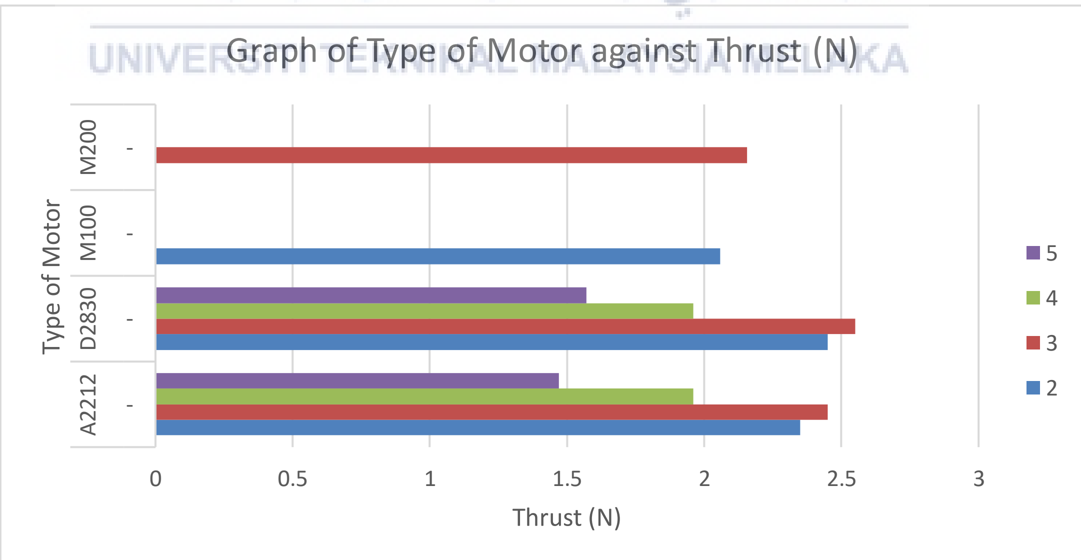


Figure 4.14: Graph for type of motor against thrust (N)

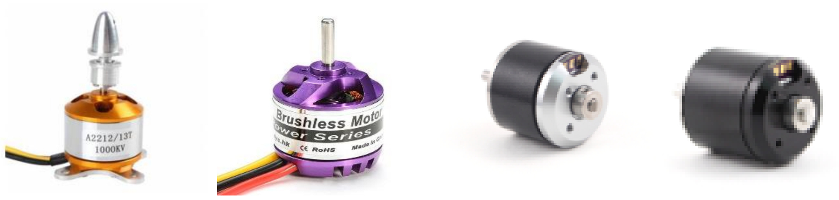


Figure 4.15: Different type of brushless DC motor.

4.3.6 Experiment 6: Speed Test for the Thruster with Different Type of Motor

Table 4.16 shows the result of speed for different type of motor. A2212 DC brushless motor and D2830 DC brushless motor had similar speed for the motor. Propeller with three blades had the higher speed for the A2212 DC brushless motor and D2830 DC brushless motor which was 994.75 RPM and 995.35 RPM. Even though the speed of the motor was not affected much by the propeller design. This was because all the speed from different blades of propeller were in the range of 985 to 1000 RPM. Moreover, M100 have higher speed than M200 which was 629.7 RPM and 460.75 RPM. Thus, the speed result shows that the A2212 DC brushless motor have higher speed and it is lower cost compare to other motor. Figure 4.16 shows the graph of type of motor against speed which shows clearly about the different type of motor and the speed produce by different numbers of blade.

Table 4.15: Speed for different numbers of blade and different type of motor.

Type of Motor / Speed	A2212 DC brushless motor		
	1 (RPM)	2 (RPM)	Average (RPM)
Two	989.4	990.6	990
Three	995.3	994.2	994.75
Four	988.4	987.1	987.75
Five	985.9	984.8	985.35

Type of Motor / Speed	D2830 DC brushless motor		
	1 (RPM)	2 (RPM)	Average (RPM)
Two	990.4	990.6	990.5
Three	995.8	994.9	995.35
Four	989.4	988.1	988.75
Five	985.9	986.8	986.35

Type of Motor / Speed	M100		
	1 (RPM)	2 (RPM)	Average (RPM)
Two	630.1	629.3	629.7

Type of Motor / Speed	M200		
	1 (RPM)	2 (RPM)	Average (RPM)
Two	460.7	460.8	460.75

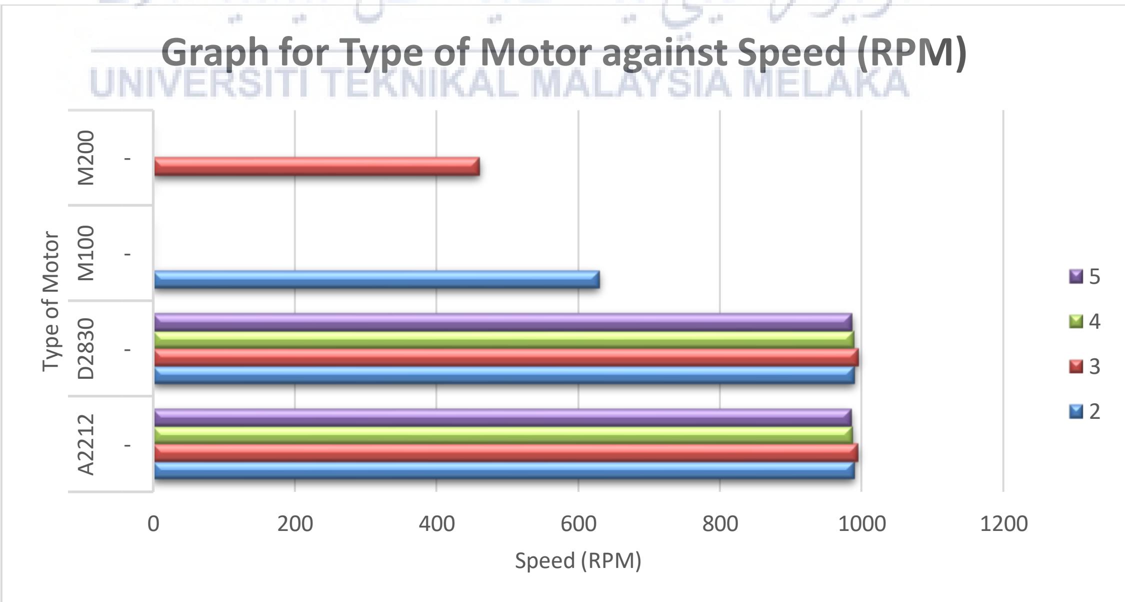


Figure 4.16: Graph for type of motor against speed (RPM)

4.4 Summary

In a nutshell, Chapter 4 discussed all the results which obtained from the analysis in SolidWorks and from various type of experiments. The analysis was done in SolidWorks and the result of stress and strain test was obtained and record in the table. The results obtained was analyzed in table form or in figure for easy understanding. The discussion was written to explain all the result for better understanding for the whole experiment.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

Conclusion, recommendation and future work of this project was discussed in this chapter. The final result for various experiment was discussed in this chapter and some recommendations was suggested in this chapter for improvement the result. Besides, future work was also mentioned in this chapter to improve the project.

5.2 Conclusion

In a nutshell, all the objective was achieved through out various type of experiment. Thus, the project of design and developed the thruster for Autonomous Underwater Vehicle was successfully done. SolidWorks software was used to design the thruster and do some analysis such as the stress and strain test to achieve the objective 1. The color difference shows that the different part has different stress and strain act on it. Blue color has the strongest stress and strain for the part of the thruster. If the color changed to light color and become red means that that part of the propeller or nozzle have weakest stress and strain. Besides than that, electronic part needed to be test before all the part was assembled. This was because some of the electronic part was not the new one and it may be broken.

Furthermore, buoyancy test and stability test were also important for the thrust test. This was because the AUV with buoyancy and unstable condition were affected the thrust that produced by the propeller. Other than that, propeller with different number of blades was tested for thrust and recorded in table form. The result shows that the propeller with three blades and two blades have similar thrust produce when compare to the propeller with four and five blades. Additionally, different type of the motor was also used to compare the result of thrust value. The results show that the A2212 DC brushless motor and D2830 DC brushless motor have nearer thrust when compare to the M100 and M200.

Last but not least, speed test was carried out for each type of propeller. A2212 DC brushless motor and D2830 DC brushless motor have nearer speed result and higher speed than M100 and M200. Thus, the thruster used for the small Autonomous Underwater Vehicle can produced in low cost in this project. Two or three blades of propeller were the most suitable propeller for the small AUV. The propeller and the nozzle for the thruster can be 3D print by using PLA material and A2212 DC brushless motor can be used for produced the lower cost thruster in this project. Therefore, all three objectives design and analysis of the underwater thruster by using SolidWorks, develop the underwater thruster for autonomous underwater vehicle (AUV) and investigate the performance of thruster in terms of thrust produced, propeller blades and speed were achieved in this project.

5.3 Recommendation to Future Work

In future, student can design the AUV for which the motor can attach on the AUV surface for getting the thrust value that without nozzle. This is because the thruster that without nozzle will simply move to any direction if the motor of the thruster does not attach on the surface of the AUV. Besides, the thruster design can be more complicated. Student can design a thruster that can change the direction for raw, yaw and pitch. IMU sensor can be used to give the feedback to the thruster to adjust the direction of the thruster.

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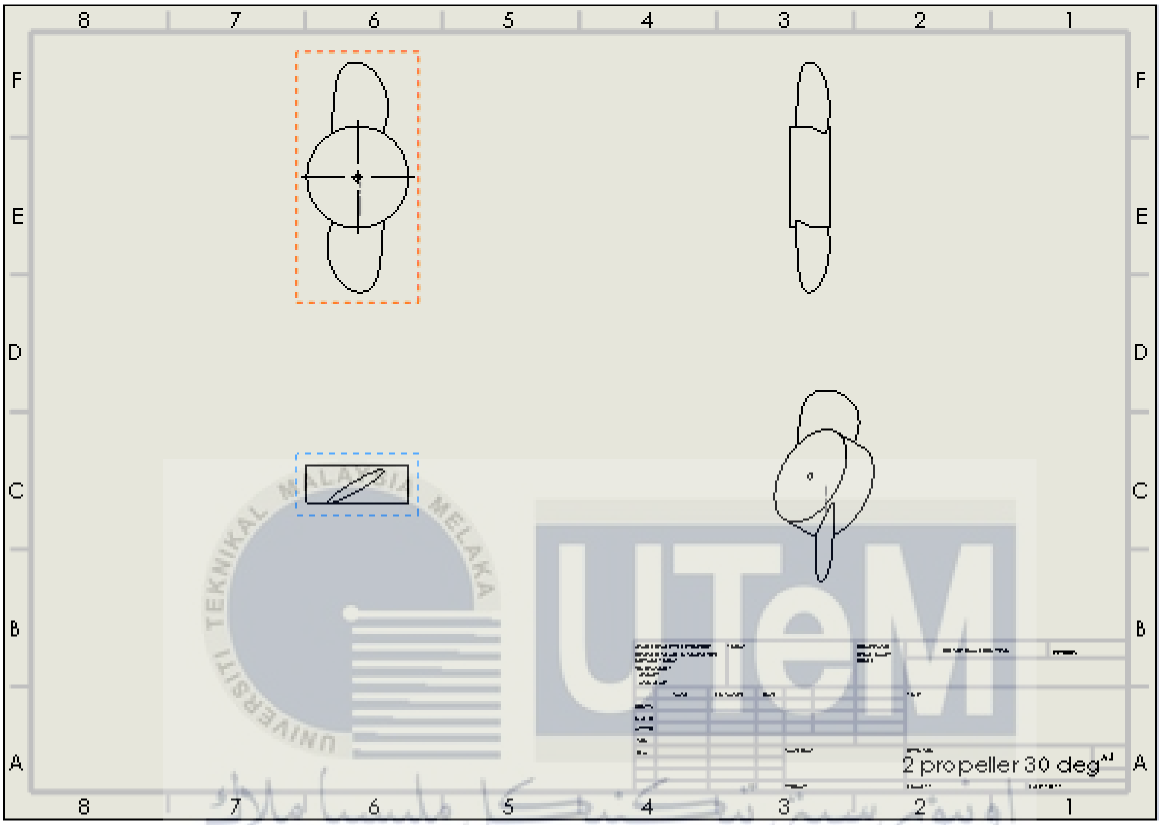
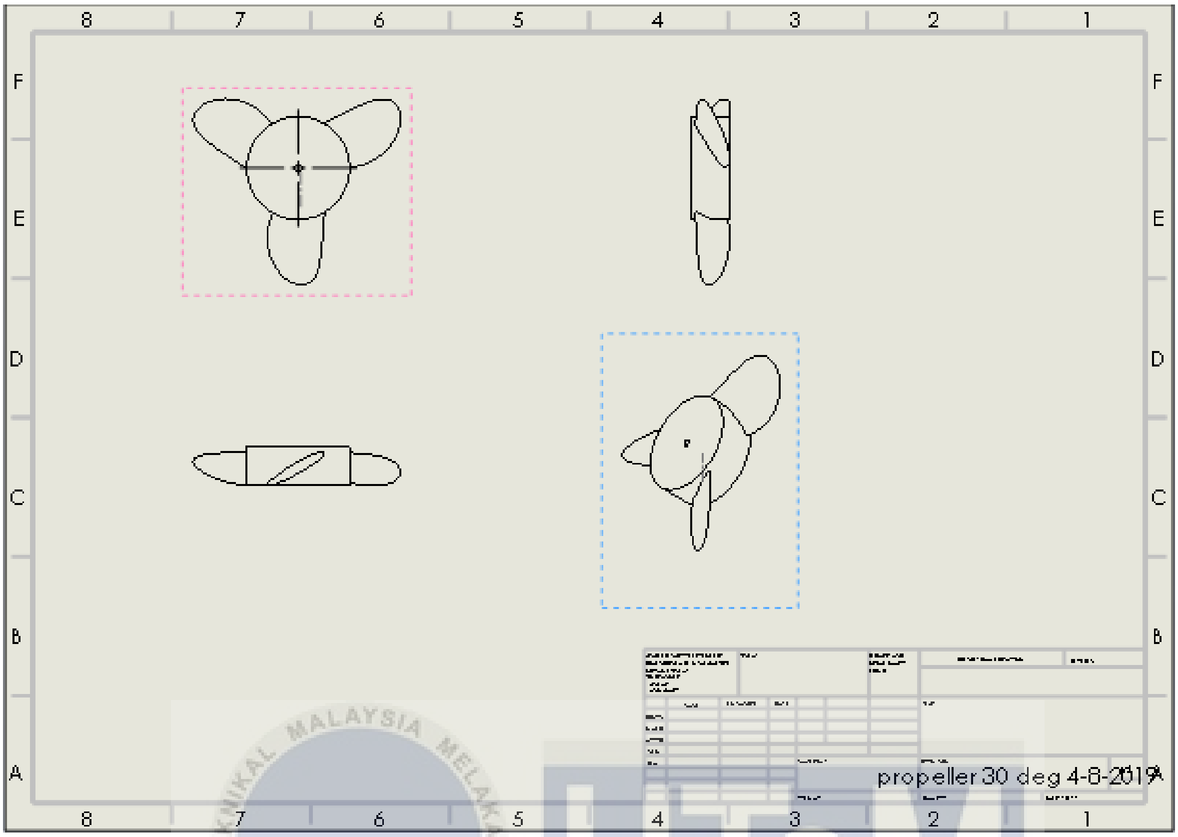
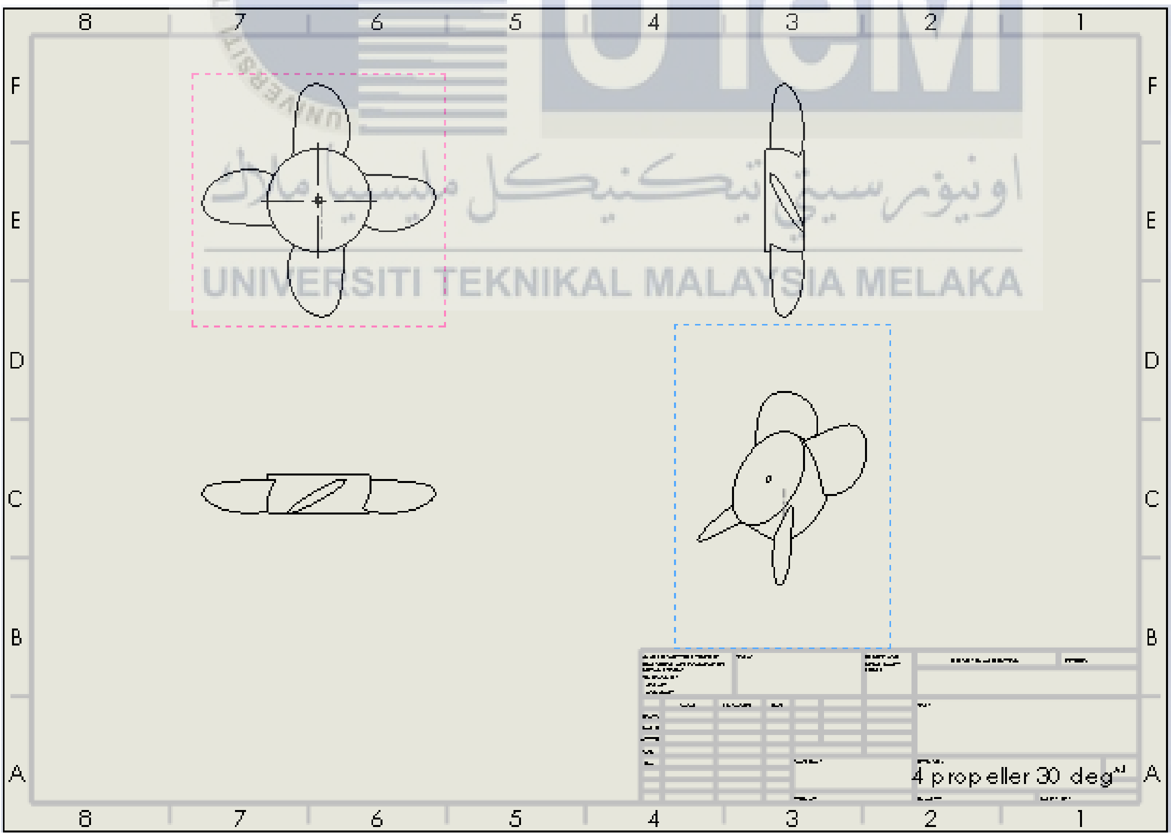
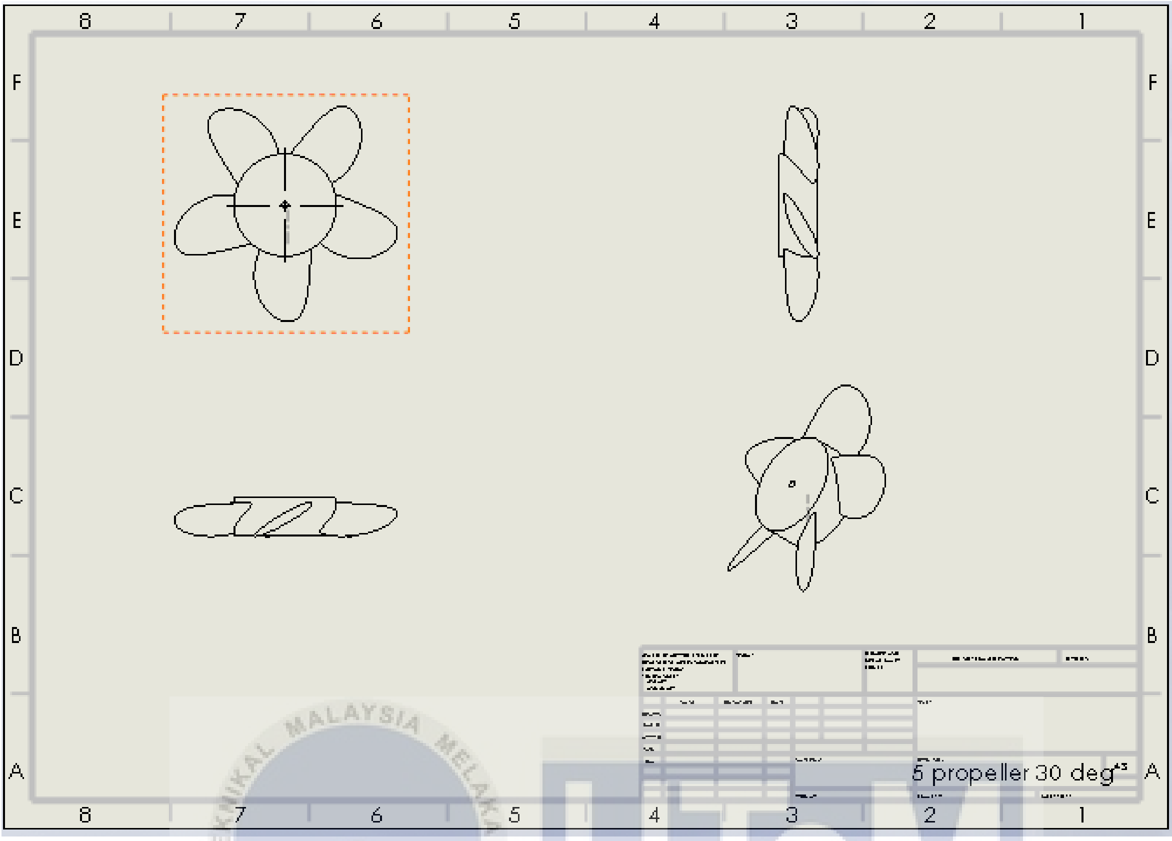
APPENDICES

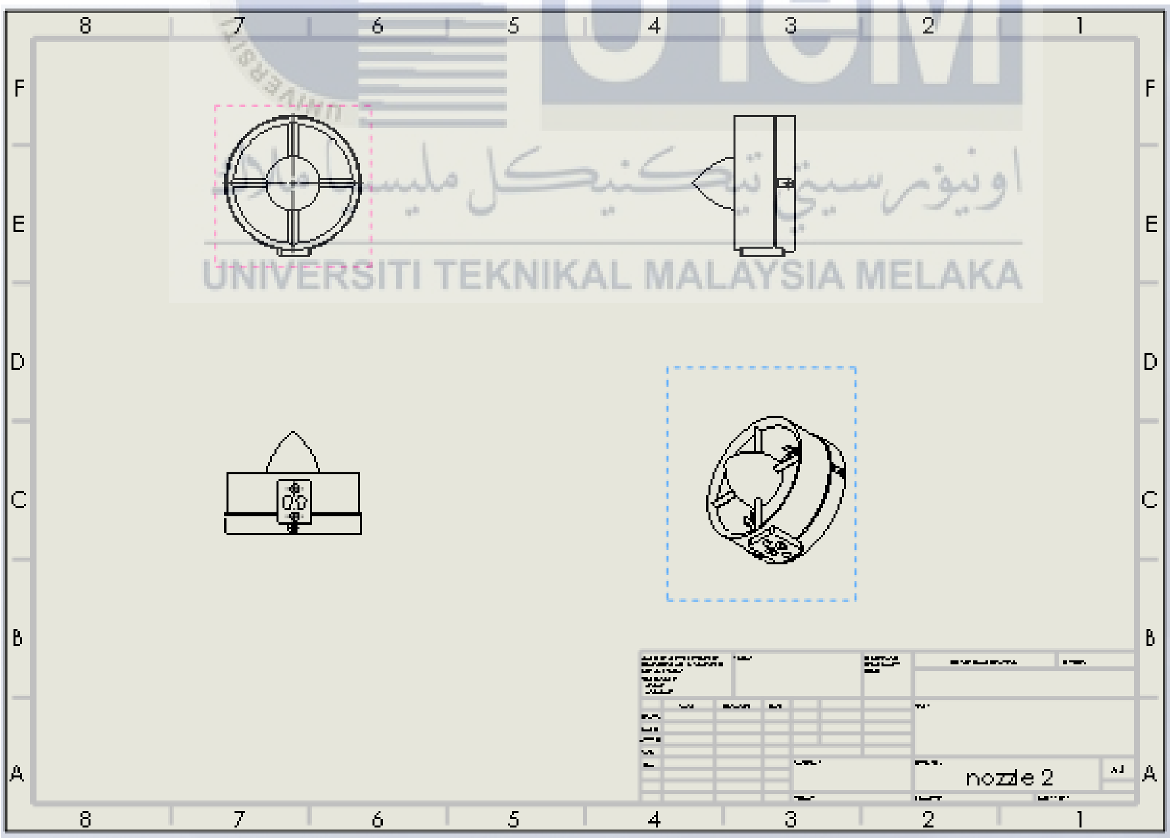
APPENDIX A SOLIDWORKS DESIGN

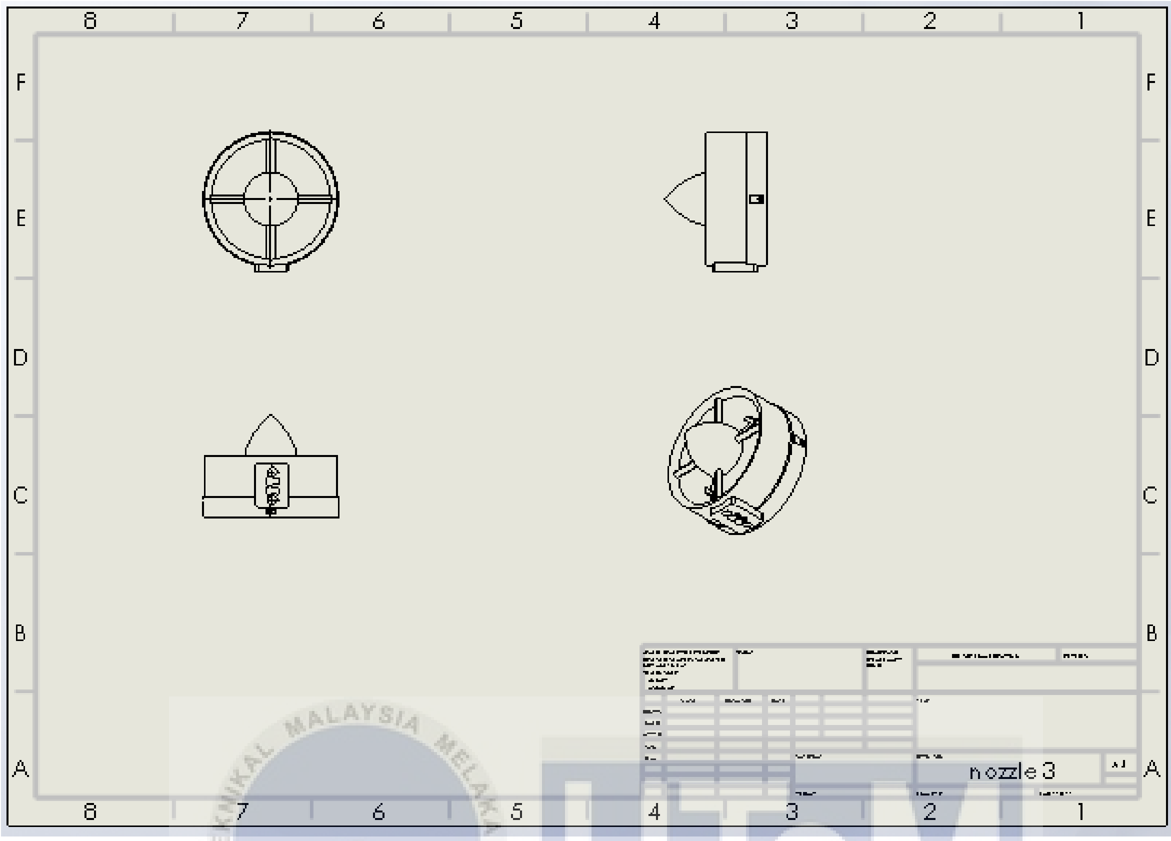


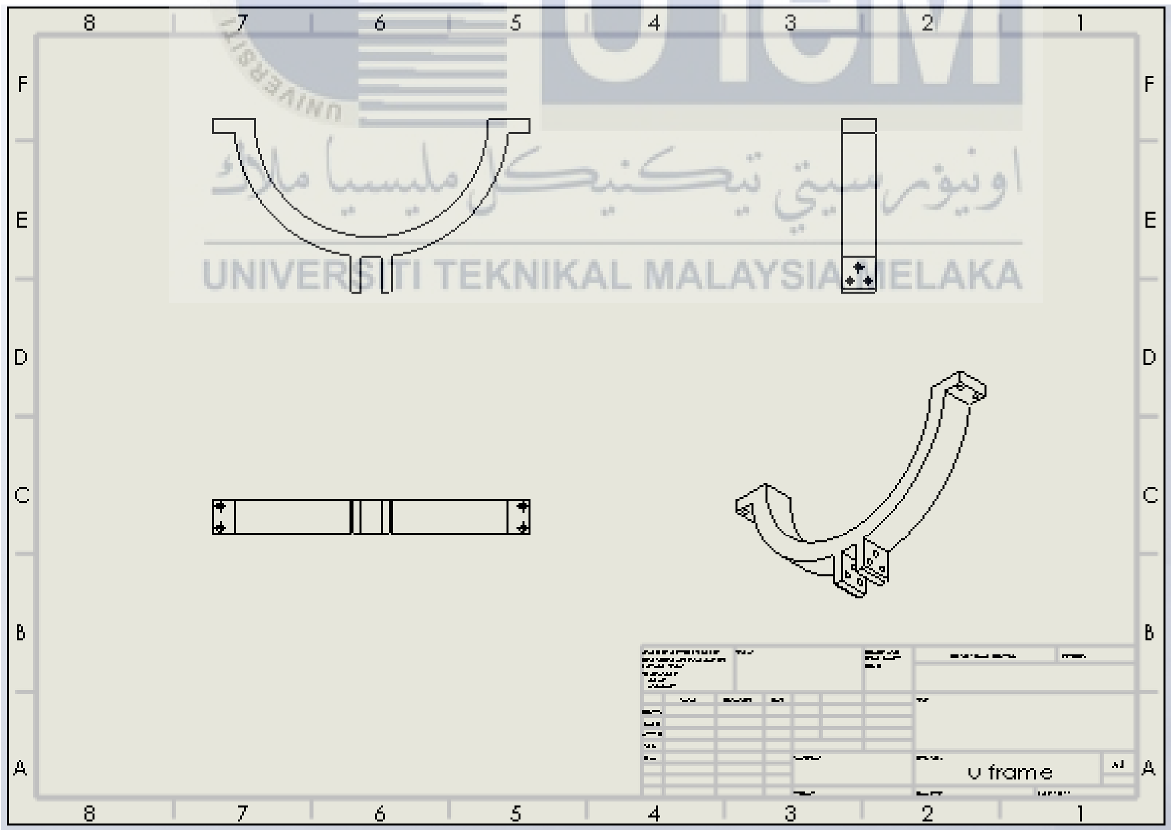

propeller 30 deg 4-8-2019

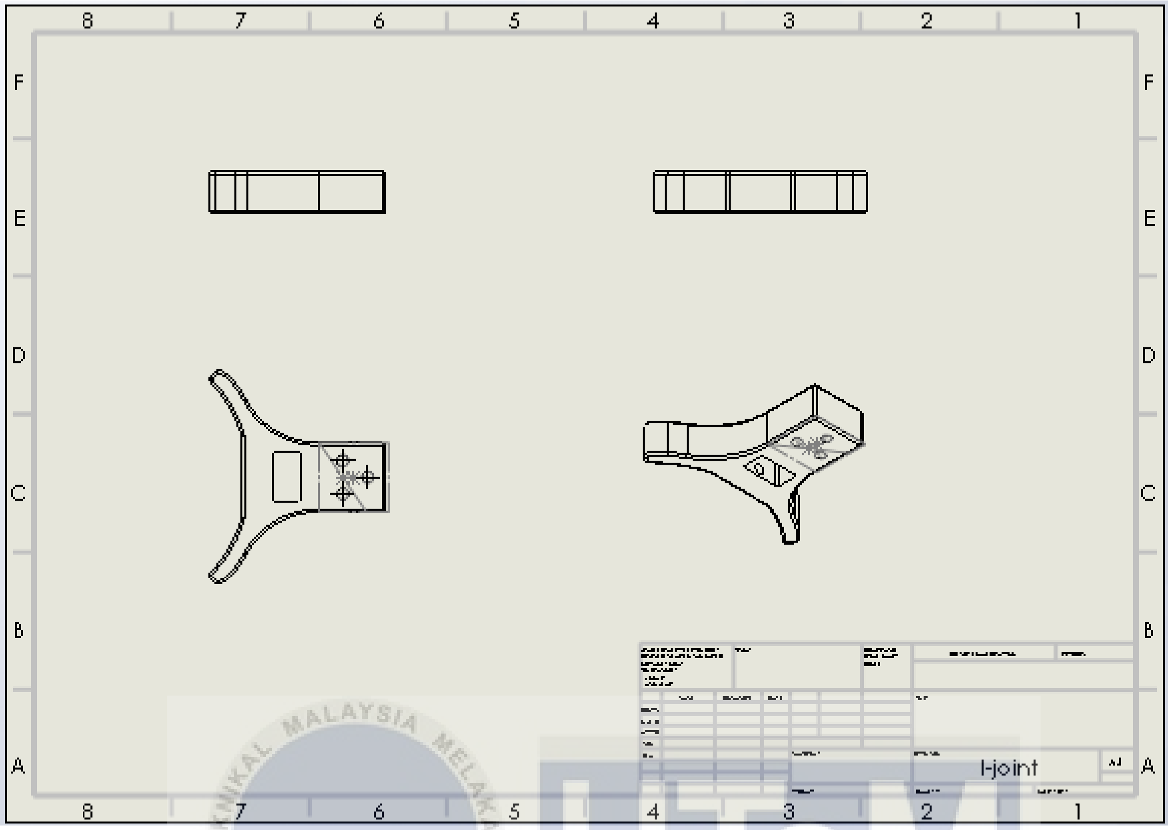

4 propeller 30 deg

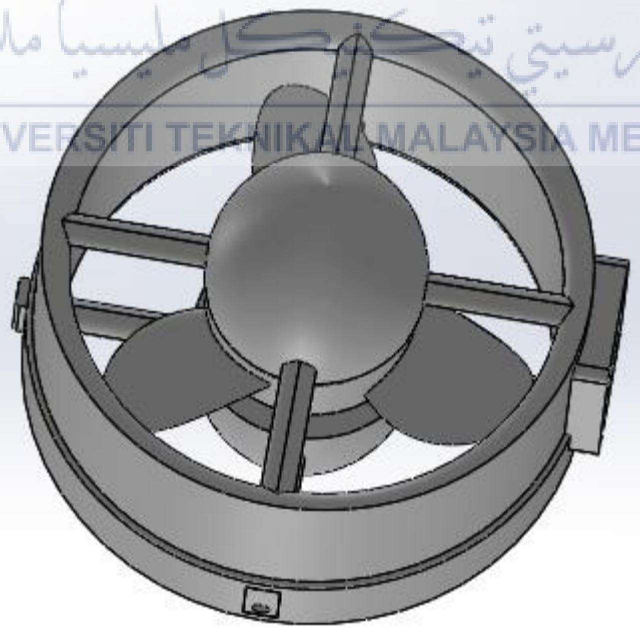

5 propeller 30 deg

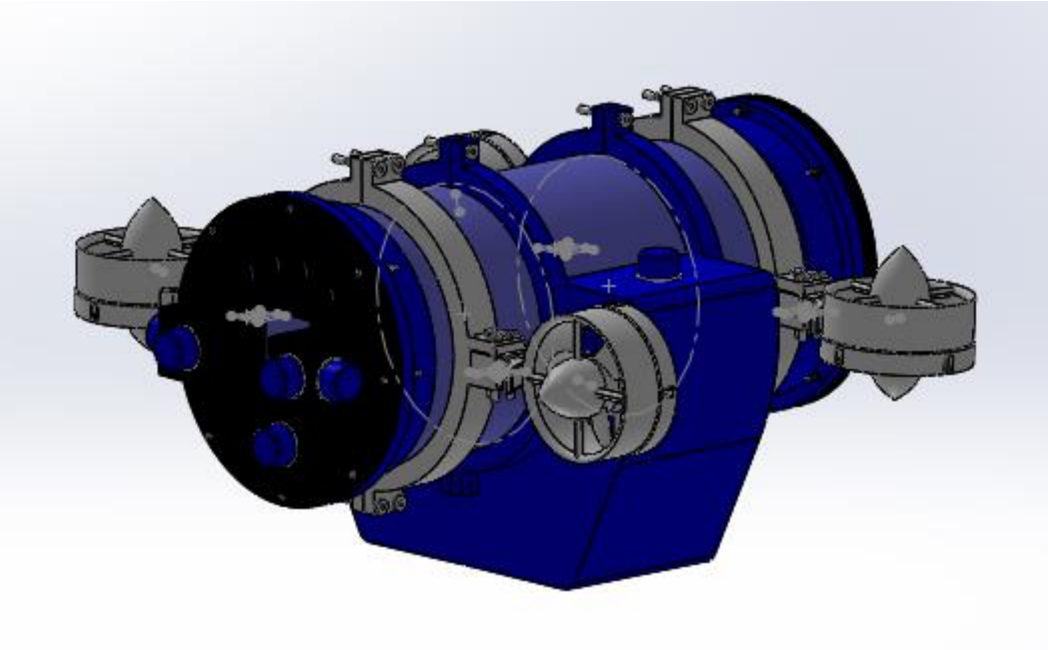

nozzle 2


nozzle 3


u frame


I-joint





APPENDIX B ARDUINO CODE FOR ESC AND MOTOR

motor_code | Arduino 1.8.5

```
#include <Servo.h>
Servo esc_signal;
Servo esc_signall;
long int divetimeinterval = 2000;
long int startdive = 3000;
long int startforward = 5000;
void setup()
{
 esc_signal.attach(12);
 esc_signall.attach(10);
 esc_signal.write(1000);
 esc_signall.write(1000);
 delay(100);
}

void loop() {
 if (millis()<16000){
  if (millis()>3000){
  esc_signall.write(1800);
 }
 if (millis()>6000){
  esc_signal.write(1500);
 }
 }else{
  esc_signal.write(1000);
  esc_signall.write(1000);
 }
```

Arduino/Genuino Uno on COM5

APPENDIX C GANTT CHART

Activity	2018/2019 (Semester 1) FYP 1																		2018/2019 (Semester 2) FYP 2																
	1	2	3	4	5	6	7	8	9	Mid-term Break	10	11	12	13	14	15 Study Week	16 Final Exam Week	Semester Break	1	2	3	4	5	6	7	8	Mid-term Break	9	10	11	12	13	14	15 Study Week	16 Final Exam Week
Final Year Project 1																																			
Title Registration																																			
FYP Talk																																			
Discussion with Supervisor																																			
Literature Review																																			
Software Development																																			
Hardware Development																																			
Software Analysis																																			
Design Experiment																																			
Preparation Draft Report and Slide																																			
Submission Draft Report																																			
Presentation of FYP 1																																			
Submission Final Draft Report																																			
Final Year Project 2																																			
Complete Software Development																																			
Complete Hardware Development																																			
Complete Designed Experiment																																			
Submission Draft Report																																			
Submission Final Report																																			
Preparation of FYP 2																																			