DEVELOPMENT OF MODULAR HULL OF A SUBMERSIBLE VEHICLE FOR ENGINEERING SERVICES

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**A thesis submitted
in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Honours**

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DECLARATION

I Ibrahim Bin Mohamad declares that this project report entitled "Development of modular hull of a submersible vehicle for engineering services", under the guidance of Dr. Shamsul Anuar Bin Shamsudin, is my original work except references material.

Signature : ______________________________

Name : Ibrahim Bin Mohamad

Date : ______________________________

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature	:	________________________________
Supervisor	:	Dr. Shamsul Anuar Bin Shamsudin
Date	:	________________________________

DEDICATION

I dedicated this study to my beloved parent Mohamad Bin Rasid and Normah Binti Saad, who always give their support and motivation to finish my study until the end. I also want to thank my siblings who never fail to always be by my side cheering and supporting me to work harder to complete my study. Also, a token of appreciation to my friends who were always helping me throughout the process. All their efforts, guidance and support will always be appreciated especially to Dr. Shamsul the person who always guide me towards completing my work. Again, a very special thanks to everyone, knowing or without knowing who contributed towards helping me finishing this work and supported me till the end.

ABSTRACT

As the need and applications of Autonomous Underwater Vehicles (AUVs) increase day by day, the research on AUVs become a popular and important topic nowadays. A respectable number of publications are available periodically. Among the existing candidate vehicles for autonomous underwater application are the Bluefin-21 from Bluefin robotics. It is a torpedo-shaped multipurpose AUV capable of conducting oceanic military, scientific and search and rescue operations. Utilizing a modular design powered by interchangeable Lithium-polymer batteries, it can operate on the Sea floor for up to sixteen hours at a time. In 2014, the Bluefin-21 was deployed to conduct undersea sensor sweeps during the international effort to locate the wreckage of Malaysia Airlines Flight 370. Next is the Bluefin SandShark Micro-AUV. This is an autonomous UUV weighing less than 15 pounds that was developed by General Dynamics Mission Systems subsidiary also from Bluefin Robotics. Its functions include intelligence missions, small-scale survey missions recovering data, communications relays, conducting training, or functioning as a decoy for the United States Navy unfortunately till now a review report on current status of the works done on AUVs is hard to find in literature. This paper presents a comprehensive survey on recent works done on AUVs and its applications in real life. Scientific researches on AUVs and the great achievements in India and abroad are presented. A brief history of chronological development of technologies of AUVs is established. A note on possible directions and works may be done in future is also mentioned. This paper is intended to serve as an immense reference for the future researchers working in the field of AUV.

ABSTRAK

Memandangkan keperluan dan penggunaan Kenderaan Bawah Air Autonomi (AUVs) meningkat setiap hari, penyelidikan mengenai AUV menjadi topik yang popular dan penting pada masa kini. Bilangan penerbitan yang dihormati tersedia secara berkala. Antara kenderaan kandidat sedia ada untuk aplikasi bawah laut autonomi ialah Bluefin-21 dari robotfin Bluefin. Ia adalah AUV serba guna yang berbentuk torpedo yang mampu menjalankan operasi ketenteraan, saintifik dan mencari dan menyelamat lautan. Dengan menggunakan reka bentuk modular yang dikuasakan oleh bateri lithium-polimer yang boleh ditukar ganti, ia boleh beroperasi di dasar laut sehingga enam belas jam pada satu masa. Pada tahun 2014, Bluefin-21 telah digunakan untuk melakukan kebolehtelapan sensor bawah laut semasa usaha antarabangsa untuk mencari bangkai Penerbangan Malaysia Airlines 370. Seterusnya ialah Bluefin SandShark Micro-AUV. Ini adalah kenderaan yang beratnya kurang daripada 15 paun yang dibangunkan oleh anak syarikat General Dynamics Mission Systems juga dari Bluefin Robotics. Fungsi-fungsinya termasuk misi perisikan, misi survei kecil-kecilan yang memulihkan data, relay komunikasi, menjalankan latihan, atau berfungsi sebagai umpan untuk Tentera Laut Amerika Syarikat Malangnya sehingga kini laporan kajian mengenai status semasa kerja-kerja yang dilakukan di AUV sukar ditemui dalam kesusasteraan . Makalah ini membentangkan tinjauan komprehensif mengenai kerja-kerja terkini yang dilakukan pada AUV dan aplikasinya dalam kehidupan sebenar. Penyelidikan saintifik mengenai AUV dan pencapaian hebat di India dan luar negara telah dibentangkan. Sejarah ringkas perkembangan kronologi teknologi AUVs ditubuhkan. Nota mengenai arah dan kerja yang mungkin dilakukan pada masa akan datang juga disebutkan. Inilah tesis yang dimaksudkan untuk menjadi rujukan besar bagi penyelidik masa depan yang bekerja di bidang AUV.

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First, I would like to take this opportunity to express my gratitude to my supervisor Dr. Shamsul Anuar Bin Shamsudin from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for being able to supervise, give support and encouragement towards the completion of this final year project. I also want to thank the staff of Faculty of Mechanical Engineering laboratory who always support and give good cooperation to finish this project smoothly. Not forgotten to express my appreciation to technician of Faculty of Mechanical Engineering who always assist and sharing the knowledge to used equipment and tools. Finally, I want to express special thanks to my family especially to my parents, to my beloved siblings, and to my colleague for their moral support in completing this degree.

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LIST OF ABBREVIATION

AUV Autonomous Underwater Vehicle

FEA Finite Element Analysis

CFD Computational Fluid Dynamic

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Over the past few decades AUVs have matured from research and experimental vessels to commercially available systems. Commercially available AUVs are expensive and complex. Most AUVs are single hull systems with centralized electronics. With advancement in technology, newer sensors have been developed for a variety of operations which can be integrated in AUV systems.

With single hull AUVs it is not easy to integrate newer and upgraded sensors without making significant changes to the mechanical and electrical systems. This has given rise to interest in modular designs for AUVs. Modular AUV structures in hardware as well as software have significant advantages. Modules for different sensors can be made and interchanged to `configure the same basic AUV for different missions.

With a team of such modular AUVs, configurable sections can allow the user to setup the team for different group missions as per requirements. In case of failures, individual sections can be easily replaced and debugged, which significantly reduces time.

To model the design process of pressure hull, a dedicated system based on VISUAL BASIC was developed. During the design process, the principle “simple, convenient and smart” is an essential step to follow. The patterns for calculating and checking were built by computer programming language. Using this system, the designer will get the results quickly and correctly. Figures 1.1 and 1.2 are the examples of an underwater vehicle and how it is used for engineering work

Figure 1 Underwater Vehicle By Tesla Offshore

Figure 2 Use of AUV for engineering services

1.2 PROBLEM STATEMENT

The highly cost and risky situation faced by the people that are involve in submersible and autonomous underwater robots encounters one general issue which is to come up with an effective and efficient solution for underwater missions. The intention of reducing the cost and risks produces opportunity for the communities practicing unmanned marine vehicles. This makes it possible to come up with a solution on how unmanned marine vehicles interact with users and other support systems, and how much work that they can manage on their own or working with other unmanned marine vehicle. The challenge is to develop a body that can withstand high pressure deep underwater without crushing the body and of course cause leakage that could gravely affect the robot in a whole. The challenge also took account the hydrodynamic features of the body. Therefore, a new and lower cost design requires a degree of certainty regarding all the challenges.

1.3 OBJECTIVES

The objectives of this project are as follows:

1. To design and develop a modular hull of a submersible vehicle for engineering services.
2. To apply the knowledge of an engineering software CATIA by designing the modular hull of a submersible vehicle.
3. To provide a complete analysis on the development of the modular hull and to propose to engineering solutions.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1. To conduct the literature review.

2. The process covers the full design in CATIA software which will be presented in this report.

3. The conduct drawing, strength testing analysis, and the hydrodynamics of the AUV parts using Ansys software.

4. Developing the hardware for the modular hull and doing a test run simulation.

5. Report writing.

CHAPTER 2

LITERITURE REVIEW

2.1 DESIGN AND CONSTRUCTION OF AN UNDERWATER VEHICLE

Autonomous underwater vehicle (AUV) has become a widely known topic used for industrial applications, military and of course to explore the ocean. Regarding that, AUVs has become one of the main option for underwater search or survey operations as they cost less than manned vehicles. Previous plans on developing an AUV focuses more on functional designs instead of identifying optimum designs. Through time, as the importance to minimizing the use of recourses (e.g. fuel, building cost, time for design etc.) becomes very clear, the approach of optimization becomes increasingly popular. (Khairul Alam, Tapabrata Ray and Sreenatha G. Anavattiet. al, 2013).

2.2 EXISTING DESIGN

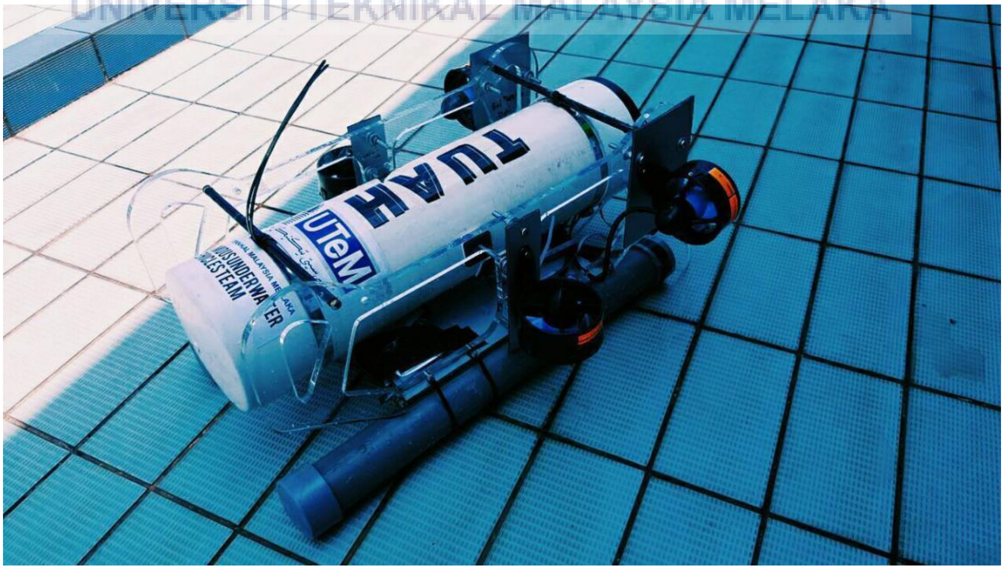

Figure 3 Tuah Autonomous Underwater Vehicle

The Figure 1.3 above shows the design of autonomous underwater vehicle named TUAH which is design by the students of University Technical Malaysia Melaka (UTeM). This AUV is used in the international robotics competition SAUV which stands for Singapore Autonomous Underwater Vehicle in the year 2017. Among all the contestant. The AUV Tuah turns out to be the 3rd fastest vehicle during the qualification rounds. The design of the AUV in this project is roughly based on the design of TUAH's but with an improvement being made.

2.3 STABILITY ANALYSIS

The design of the body of an AUV needs to be stable underwater. The body needs to balance and must ensure that it does not disturb the electronic parts. Among all the electronic parts, the censor that is used to balance the AUV is called IMU. Its function is to balance the AUV, therefore the position of the AUV must be stable for the IMU to work efficiently. To make sure the quality of the data collected, underwater inspection mission requires an AUV with high stability, especially in roll and pitch direction. However, AUV with adopt torpedo-shaped body, has limited passive restoring moment in roll and pitch direction (Y.S Song et al., 2015).

2.4 HYDRODYNAMIC FLOW

The body of an autonomous underwater vehicle should be hydrodynamic. This means the drag force should not be high. This is to ensure the smoothness of the movement of the vehicle. Among the ways of making sure that the body is hydrodynamic is that the position of the thrusters or steerers needs to be placed at a suitable position. (Lingbo Geng, Zhi Qiang Hu and Yang Lin et al., 2017)

2.5 THE DEVELOPMENT OF NEW AUTONOMOUS UNDERWATER VEHICLE

Among the development of new autonomous underwater vehicle focuses on an AUV that can travel for a long distance. It is called the next generation of AUV. The process of developing defines vehicle specification for the AUV to travel far distance. This includes the configurator, censor and water testing. The test to analyze the body includes the fluid property test and maneuvering control properties to examine the body before further developing it. (Ikuo Yamamoto et al., 2015).

2.6 PROPERTIES OF MATERIAL

The most crucial decision that needs to be made is the selection of material before designing the whole body. The overall design is based on the design of Blue ROV from blue robotics. Blue ROV is an AUV that is commercially available worldwide. The differences lie on the type of material used to build the frame, and its efficiency. The material that is chosen for this study is the Acrylic. Therefore, the properties of the acrylic are crucial information that needs to be obtain, before proceeding with the design. The properties that are considered for this project are physical properties, mechanical properties, electrical properties and thermal properties. The material chosen for this design is acrylic.

The information of the properties of acrylic is as shown in table below.

Table 1 Physical properties of Acrylic

Physical Properties	Metric
Density	1.18 - 1.19 g/cc
Water Absorption	0.130 - 0.800 %
Water Absorption at Saturation	0.650 - 2.60 %
Moisture Expansion	0.500 %
Moisture Vapor Transmission	55.0 cc-mm/m^2-24hr-atm

Table 2 Mechanical Properties of Acrylic

Mechanical Properties	Metric
Hardness, Barcol	49.0 - 50.0
Hardness, Rockwell M	94.0 - 105
Ball Indentation Hardness	175 MPa
Tensile Strength, Ultimate	62.0 - 83.0 MPa
Tensile Strength, Yield	64.8 - 83.4 MPa
Elongation at Break	3.00 - 6.40 %
Modulus of Elasticity	2.76 - 3.30 GPa
Flexural Yield Strength	98.0 - 125 MPa
Flexural Modulus	2.96 - 3.30 GPa
Compressive Yield Strength	110 - 124 MPa
Compressive Modulus	2.76 - 3.03 GPa
Poissons Ratio	0.370
Shear Modulus	1.70 GPa
Shear Strength	25.5 - 62.1 MPa
Izod Impact, Notched	0.160 - 0.220 J/cm
Izod Impact, Notched (ISO)	1.60 kJ/m^2
Charpy Impact Unnotched	1.20 - 2.17 J/cm^2
Coefficient of Friction	0.450 - 0.800

Table 3 Electrical Properties of Acrylic

Electrical Properties	**Metric**
Electrical Resistivity	1.00e+15 - 1.60e+16 ohm-cm
Surface Resistance	5.00e+13 - 1.90e+15 ohm
Dielectric Constant	2.70 - 4.00
Dielectric Strength	17.0 - 30.0 kV/mm
Dissipation Factor	0.0200 - 0.0600
Comparative Tracking Index	600 V

Table 4 Thermal Properties of Acrylic

Thermal Properties	**Metric**
CTE, linear	61.0 - 198 µm/m-°C
Specific Heat Capacity	1.46 - 2.16 J/g-°C
Thermal Conductivity	0.187 - 0.209 W/m-K
Maximum Service Temperature, Air	70.0 - 200 °C
Deflection Temperature at 0.46 MPa (66 psi)	110 - 115 °C
Deflection Temperature at 1.8 MPa (264 psi)	86.0 - 115 °C
Vicat Softening Point	105 - 118 °C
Minimum Service Temperature, Air	-40.0 - -32.2 °C
Flammability, UL94	HB
Flame Spread	5.84 - 36.0 mm/min
Flash Point	425 - 488 °C
Smoke Density	5.00 - 65.0

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION OF METHODOLOGY

This chapter describes the methodology used in this project to design and analyses the body of autonomous underwater vehicle. The flow chart shows the process stage. This project starts by studying the best way to obtain the best design preparation and to compare it with the existing design. By obtaining the best design, it can be a good result in experiment testing and to prove the efficiency compared to an existing design.

3.2 GENERAL PROCESS

The overall process of the project can be visualized by referring to the flow chart in Figure 4. The first stage of process focuses on information study and gathering related data s from the journal, book, newspaper, websites and relevant sources. From the information data, the suitable material and the process method that can be used to developed new submersible hull can be determined and the type of impact test can be used for testing. References based on journals, articles, books and any related material regarding this project will be reviewed.

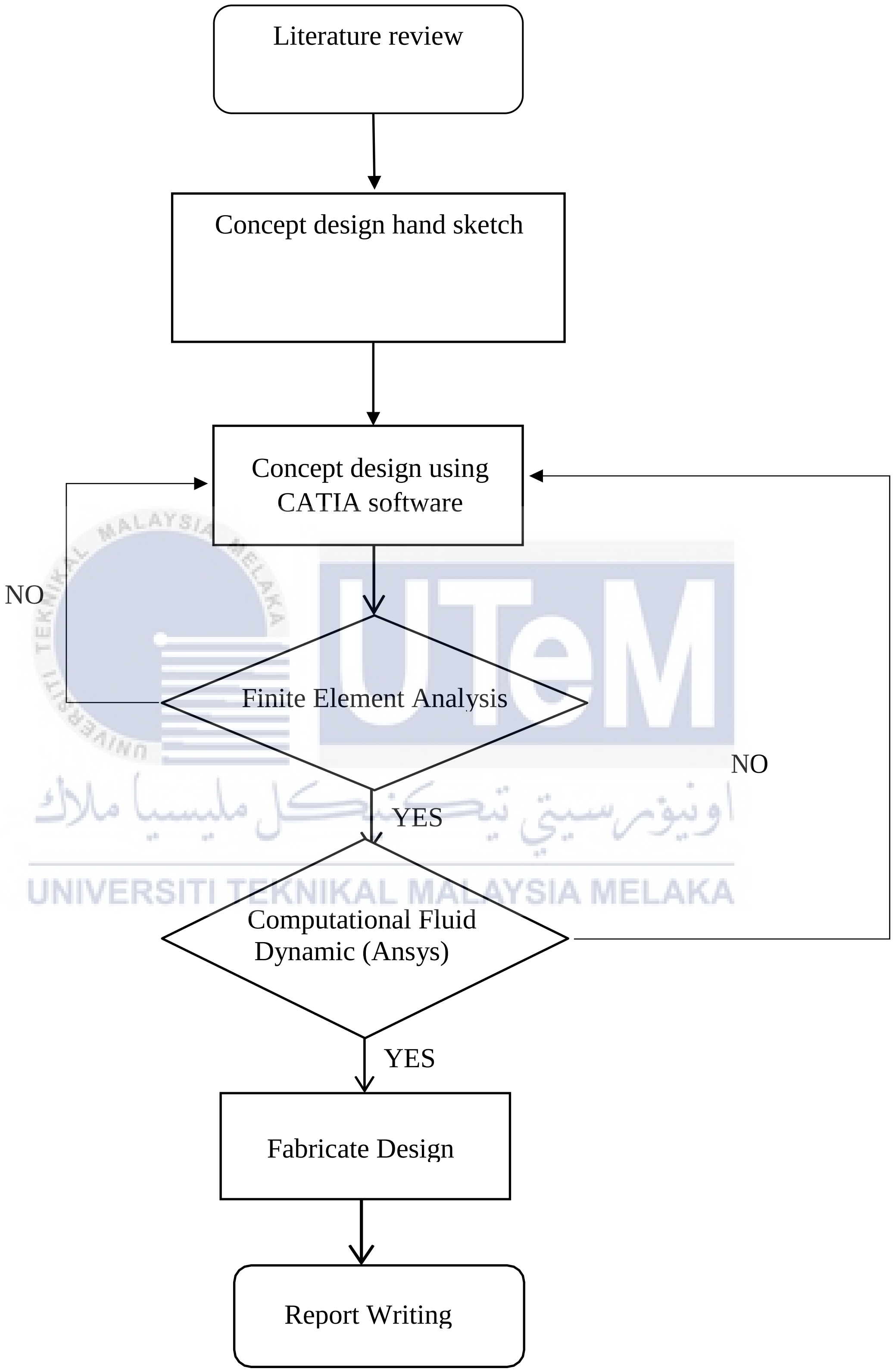

Figure 4 Flow Chart

CHAPTER 4

RESULT AND ANALYSIS

4.1 DESIGNING BODY PARTS (CATIA)

4.1.1 MIDDLE BODY (MAIN)

The middle body is the main body that houses all the important components of the vehicle itself, like the electrical circuits, wirings and the battery which is the main power source for the AUV. This means that without the main body, they wouldn’t be any robot. The concept of designing this part is by using a cylindrical shape middle body. The reason for this is that cylinders are proved to be more hydrodynamic than rectangular shapes. Figure 5 shows the frame of the main body designed in CATIA

Figure 5 Middle body frame

The design of the middle body doesn’t only consist of the main body. To make it more waterproof and withstand pressure. The vessel needs to be watertight and closed tightly. Therefore, on both ends of the middle frame. It is closed with a flanged that is attached with 2O-rings to ensure it is water proof. Figure 6 and Figure 7 shows the flange and the O-rings that is to be attached at both ends of the cylinder body designed in CATIA

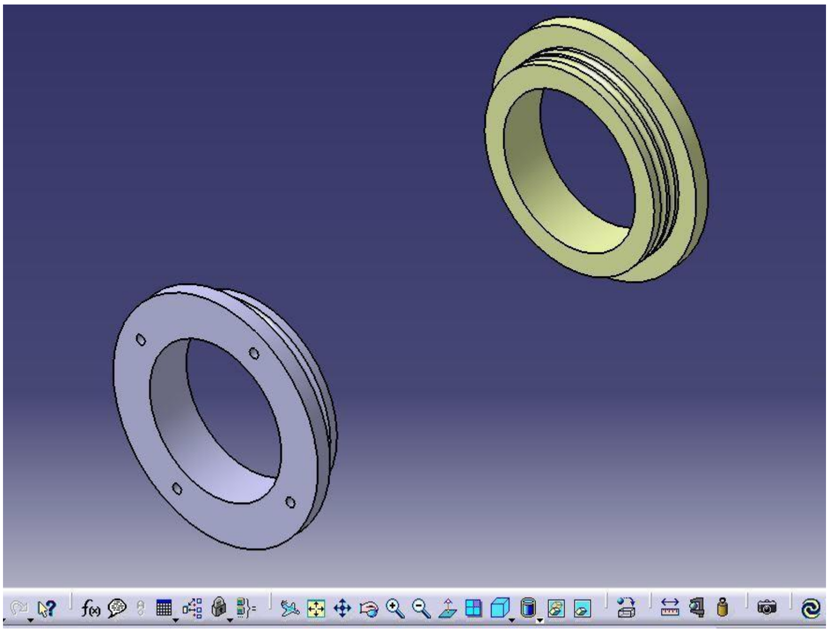

Figure 6 Flanges

Figure 7 O-rings

To differentiate the front and the back of the main body, both end caps are design differently. The from cap is designed to be dome shaped and the suggested material is clear acrylic as it may be the placement of the camera for visual purpose of the AUV. The back end is designed to be a flat plate with an amount holes needed for the wiring connected to the thrusters. Depending on the internal electrical components used. The dome cap and end cap designed in CATIA as shown below in Figure 8 and Figure 9

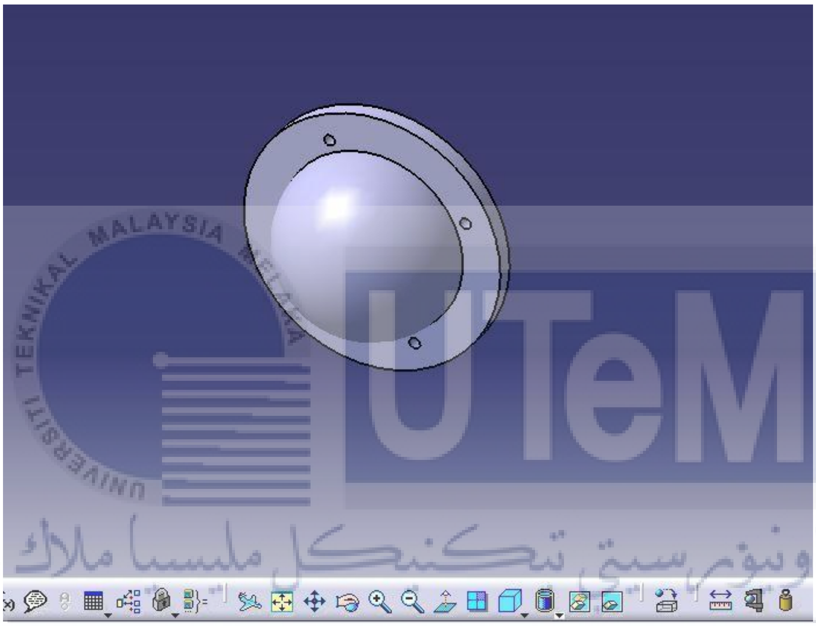

Figure 8 Dome cap

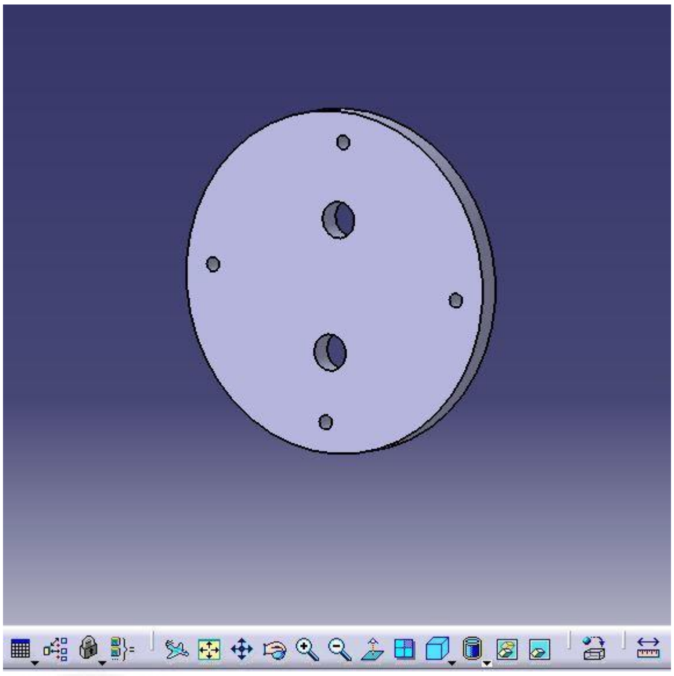

Figure 9 End cap

After finishing the design of the middle body. The focus moves to designing side body. The side act as the main structure for the whole AUV. The side body holds the main body, the weight platform plus its weight and all the thrusters. This means that the design of the side body is very important. It must be strong enough to hold all three of the main components mentioned, as well as the hydrodynamic concern. The side body should be able to stand still on land without disturbing other components that it supports and provides a handle so the user can easily move the AUV on land when necessary. Figure 1.13 shows the design of the side body in CATIA

4.1.2 SIDE FRAME

After finishing the design of the middle body. The focus moves to designing side body. The side act as the main structure for the whole AUV. The side body holds the main body, the weight platform plus its weight and all the thrusters. This means that the design of the side body is very important. It must be strong enough to hold all three of the main components mentioned, as well as the hydrodynamic concern. The side body should be able to stand still on land without disturbing other components that it supports and provides a handle, so the user can easily move the AUV on land when necessary. Figure 10 shows the design of the side body in CATIA

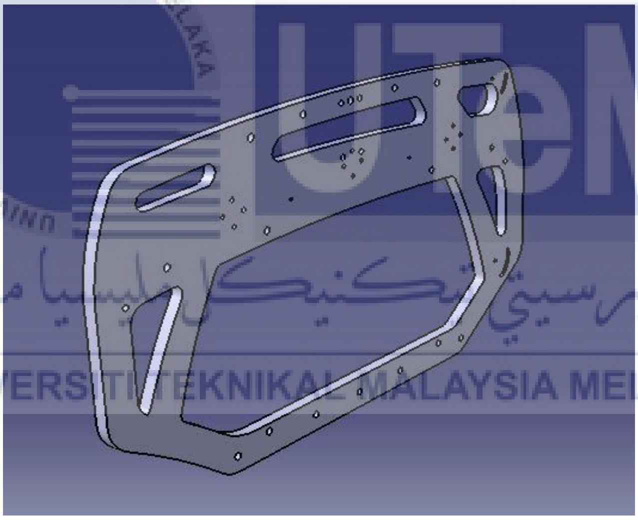

Figure 10 Side Body

4.1.3 FRONT AND REAR PANEL

The next component for the concept design is the front and the rear panel for the placement of the floater which control the buoyancy of the body. These parts play a crucial role to make sure that the AUV body is stable under water. Figure 11 and Figure 12 shows the design of the front and rear panel.

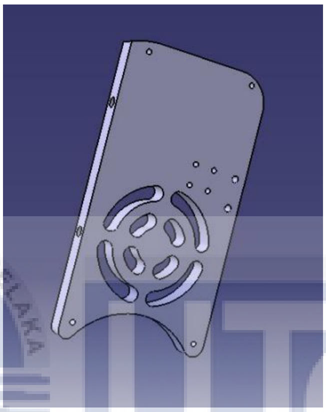

Figure 11 Front Panel

Figure 12 Bottom Panel

4.1.4 BOTTOM BODY (BASE)

Next is the design for the bottom body. This act as the connector of the side body which means without it, the structure of the body would be completely impossible to stand. Figure 13 below shows the design for the bottom body.

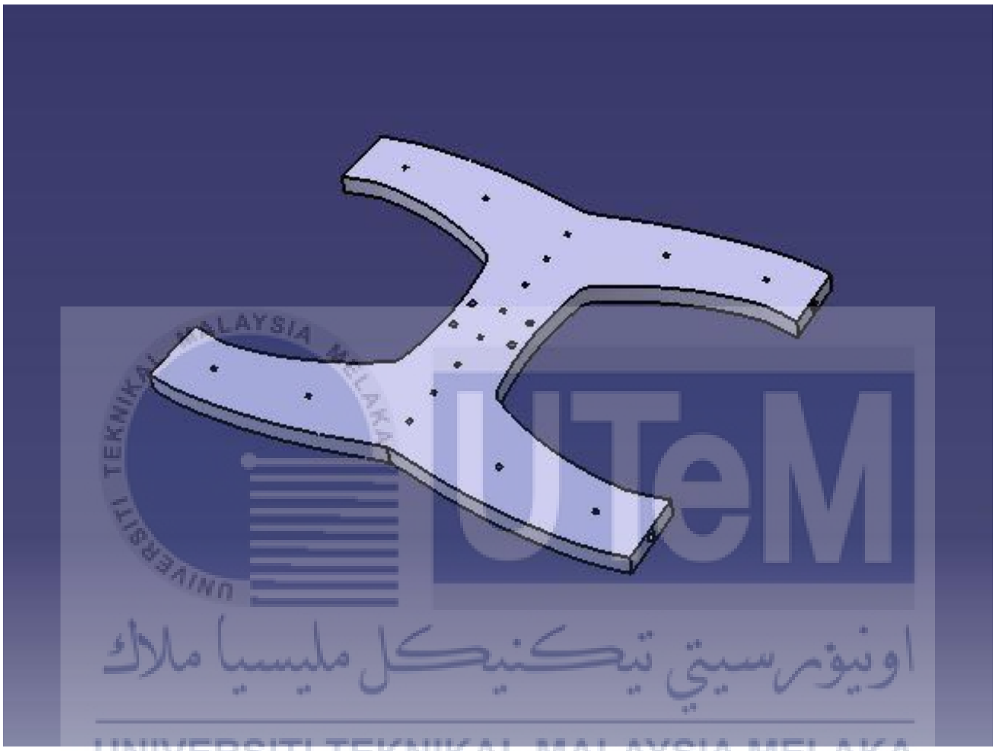

Figure 13 Bottom Body

4.1.5 THRUSTERS

The attachment of thrusters is next to decide. The thrusters used for this project is the ready-made T-200 thrusters. The Figure of the thrusters in the software are shown in Figure 14.

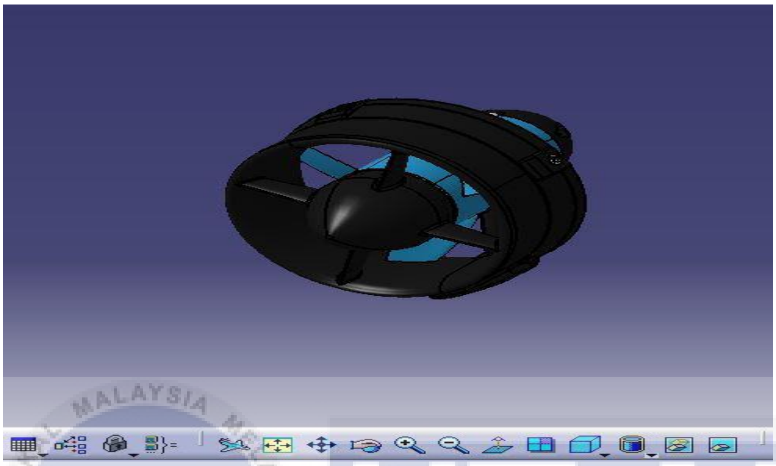

Figure 14 T-200 thruster

Now all the components are there. The management of the components are to be made. By arranging all the components mentioned. The concept design of the AUV can be seen clearly. This includes the placement of the thrusters. This design uses four units of T-200 thrusters. Two will be stationed at the back facing forward as its purpose is to move forward and backward. Another two thrusters will be stationed at the middle body facing upwards. These two thrusters at the middle are responsible for the movement of submerging and diving. The exploded view of the AUV in the CATIA software are as shown below in Figure 15

4.1.6 ASSEMBLE PARTS

Figure 15 Assembly

4.2 FINITE ELEMENT ANALYSIS (CATIA)

The finite element analysis, FEA is made by also using the software CATIA. The analysis is made part by part of the frames. The results of the analysis are as shown below:

4.2.1 BOTTOM BODY FEA

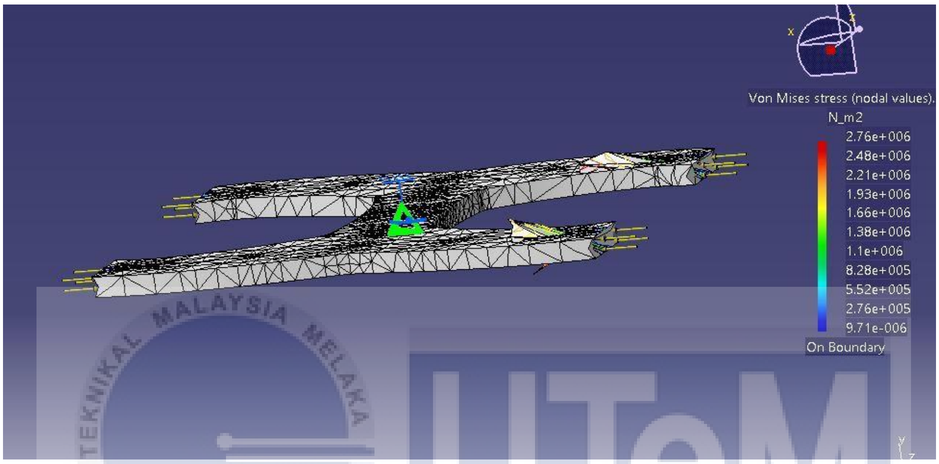

Figure 16 Bottom Body 400N force compression

Figure 16 shows the application of finite element analysis, FEA on the bottom body, also known as the base of the overall frame. This part holds and connects the side frame together and it is also the platform for the attachment of the battery compartment. Using all that information on its basic role towards the overall body, the bottoms body compression ability needs to be tested. First, a force of 400N is applied in the software to test the compression strength. Based on this design, the bottom body theoretically will not receive a lot of compression force much less a 300N force, instead it will experience more tensile force. However, the compression strength is still crucial to consider. As shown in Figure 16, when a 300N compression force is applied on the bottom body, the body starts to deform. Due to the result, the analysis is repeated with the force being decrease each test.

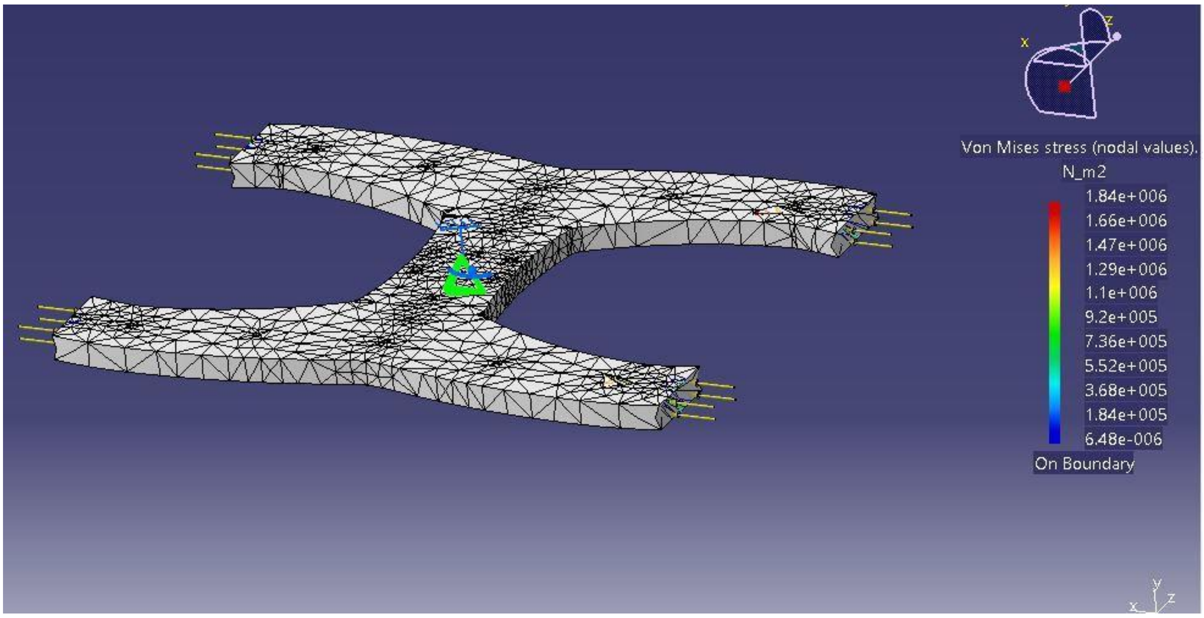

Figure 17 Bottom Body 200N force Compression

Figure 17 shows the application of finite element analysis, FEA on the bottom body, also known as the base of the overall frame. This part holds and connects the side frame together and it is also the platform for the attachment of the battery compartment. Using all that information on its basic role towards the overall body, the bottoms body compression ability needs to be tested. When a force of 300N is applied in the software to test the compression strength, the bottom body undergoes deformation. The test is then repeated using less force which each time, and until it reaches the maximum compression force that it can withstand which is 200N. As shown in Figure 17, when a 200N compression force is applied on the bottom body, the body does not undergo deformation.

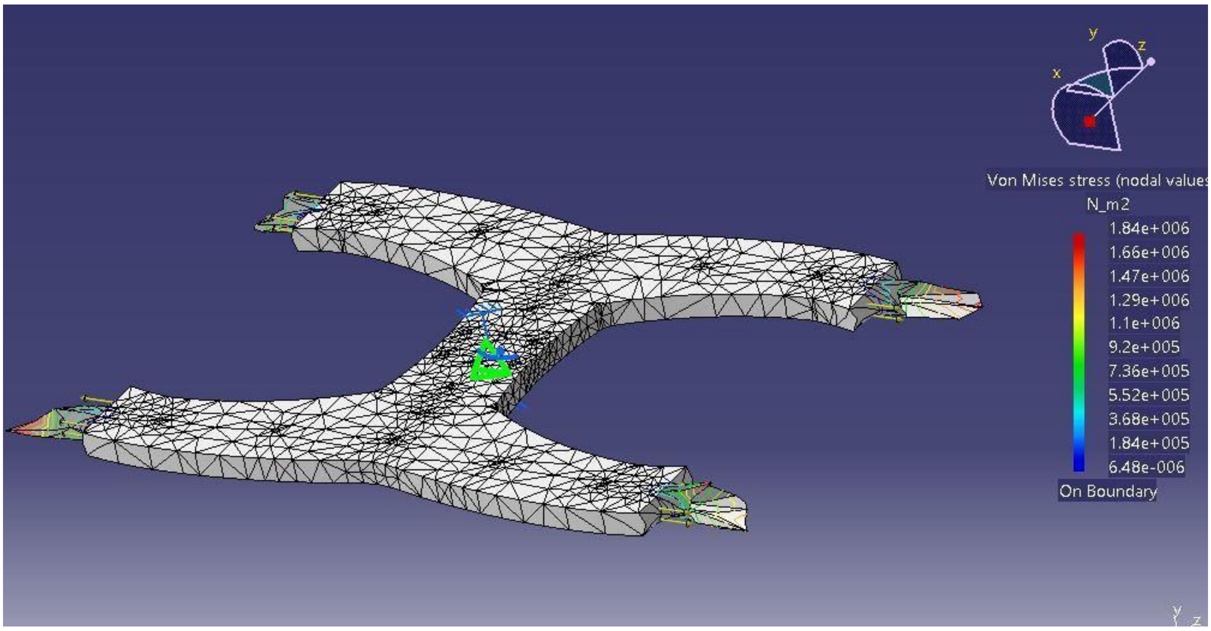

Figure 18 Bottom Body 200N force Tension

Figure 18 shows the application of finite element analysis, FEA on the bottom body, also known as the base of the overall frame. This part holds and connects the side frame together and it is also the platform for the attachment of the battery compartment. Using all that information on its basic role towards the overall body, the bottoms body tensile ability needs to be tested. As mention in the previous Figure, the design of the bottom body theoretically will experience more tensile force instead of compression force. Dealing with tensile strength, the starting force is less than that of compression force. The analysis is started using a force of 200N. The force is applied in the software to test the tensile strength. As shown in Figure 18, when a 200N tensile force is applied on the bottom body, the body starts to deform. Due to the result, the analysis is repeated with the force being decrease each test.

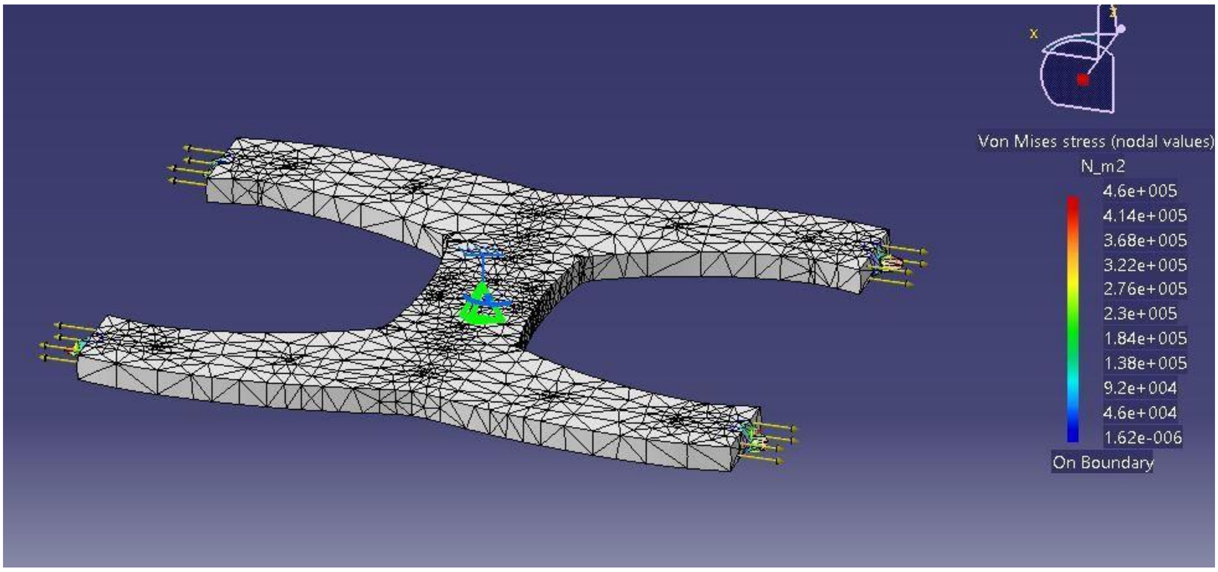

Figure 19 Bottom Body 50N force Tension

Figure 19 shows the application of finite element analysis, FEA on the bottom body, also known as the base of the overall frame. This part holds and connects the side frame together and it is also the platform for the attachment of the battery compartment. Using all that information on its basic role towards the overall body, the bottoms body tensile ability needs to be tested. As mention in the previous Figure, the design of the bottom body theoretically will experience more tensile force instead of compression force. Dealing with tensile strength, the starting force is less than that of compression force. In the previous Figure, the analysis is started using a force of 200N, however, the body starts to deform. The analysis is repeated with the force being decrease each test, and the body still undergoes deformation until a 50N tensile force is applied in the software. As shown in Figure 19, when a 50N tensile force is applied on the bottom body, the body does not undergo deformation.

4.2.2 REAR PANEL

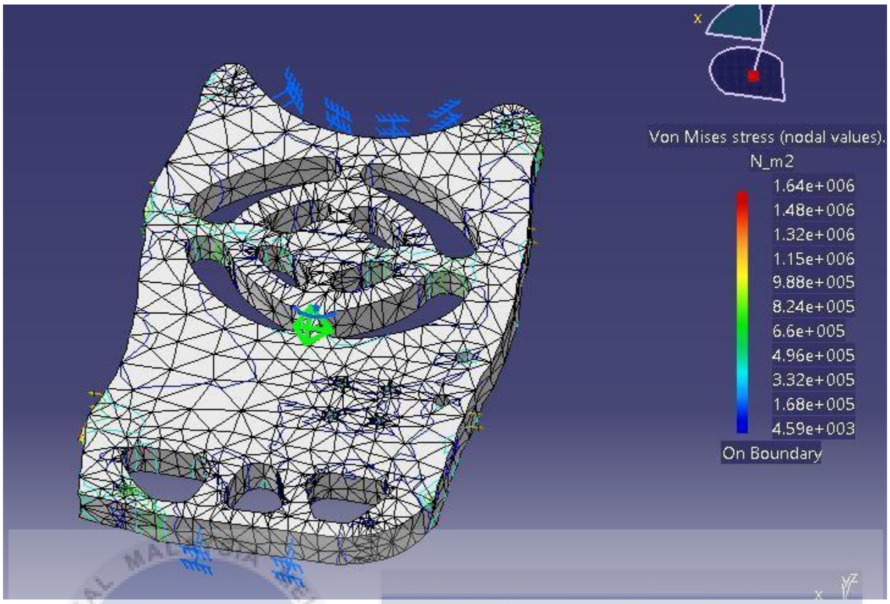

Figure 20 Rear Panel 300N Force tension

Figure 20 shows the application of finite element analysis, FEA on the rear panel, which is the support for the main body at the rear side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the rear panel tensile ability needs to be tested. As usual, a force of 300N is applied in the software to test the tensile strength. As shown in Figure 20, when a 300N tensile force is applied on the bottom body, the body starts to deform. Due to the result, the analysis is repeated with the force being decrease each test.

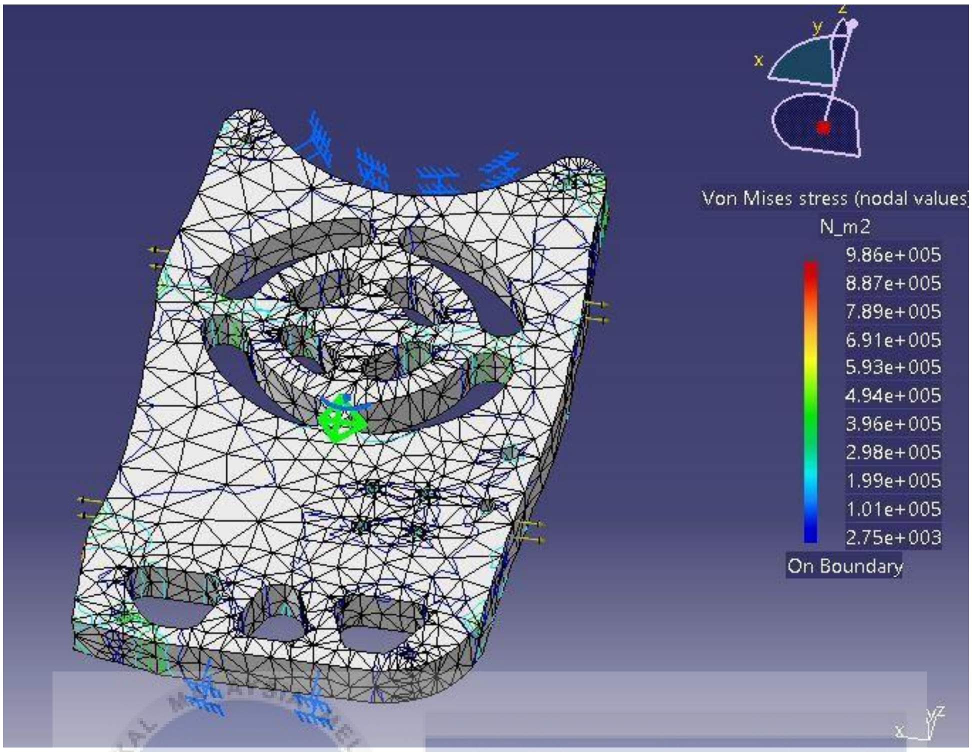

Figure 21 Rear panel 180N Tension

Figure 21 shows the application of finite element analysis, FEA on the rear panel, which is the support for the main body at the rear side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the rear panel tensile ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until a 180N tensile force is applied in the software. As shown in Figure 21, when a 180N tensile force is applied on the rear panel, the rear panel reaches it maximum point before undergoing deformation.

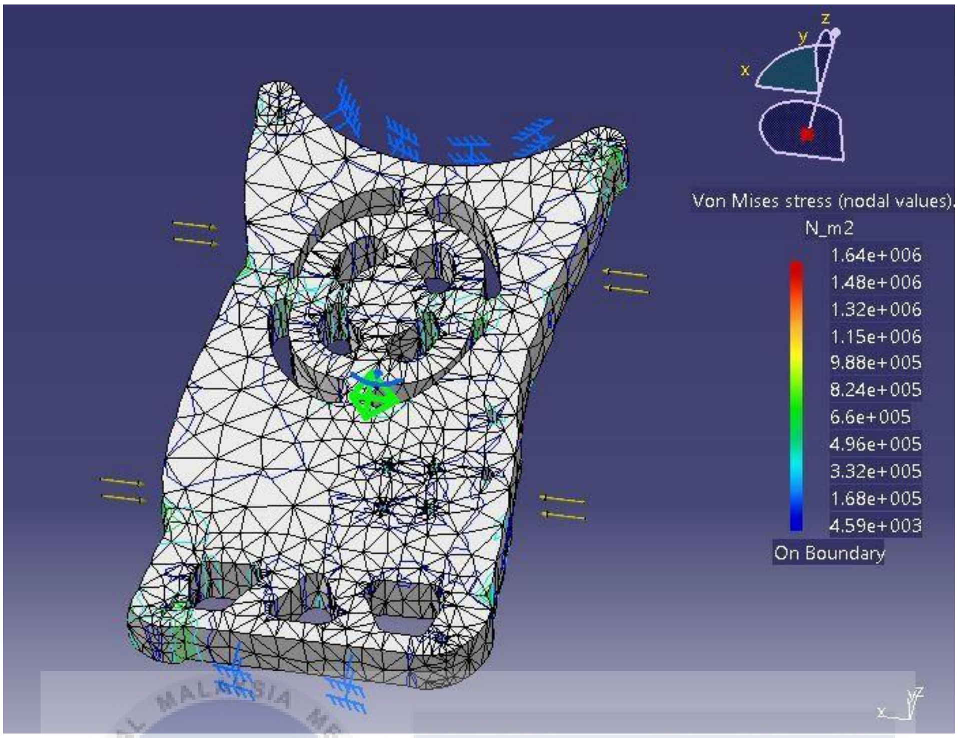

Figure 22 Rear panel 300N force compression

Figure 22 shows the application of finite element analysis, FEA on the rear panel, which is the support for the main body at the rear side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the rear panel compression ability needs to be tested. As usual, a force of 300N is applied in the software to test the compression strength. As shown in Figure 22, when a 300N compression force is applied on the bottom body, the body starts to deform. Due to the result, the analysis is repeated with the force being decrease each test.

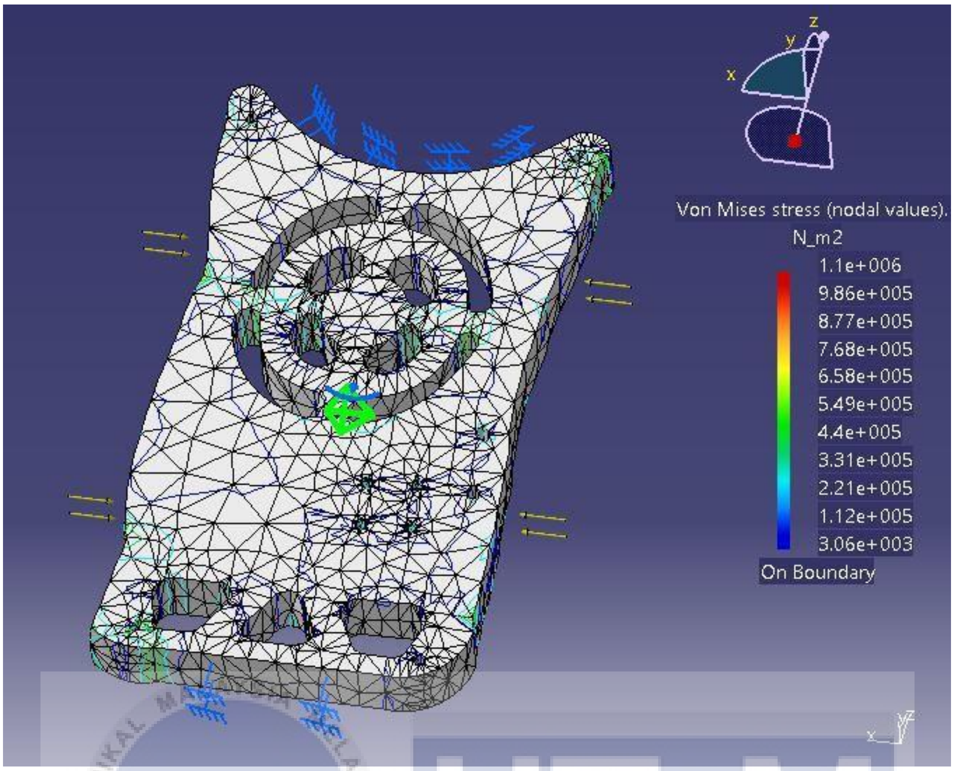

Figure 23 Rear panel 200N force compression

Figure 23 shows the application of finite element analysis, FEA on the rear panel, which is the support for the main body at the rear side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the rear panel compressive ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until a 200N compression force is applied in the software. As shown in Figure 23, when a 200N compression force is applied on the rear panel, the rear panel still undergoes deformation but only a small deformation. Therefore, the test continues.

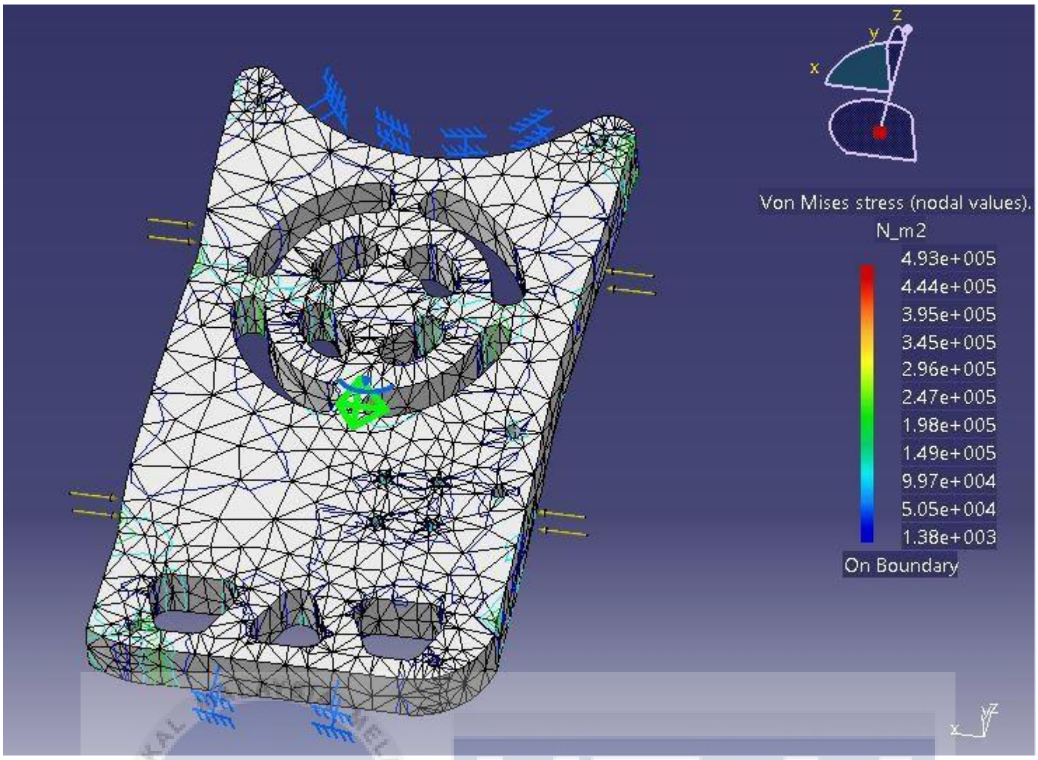

Figure 24 Rear panel 90N force compression

Figure 24 shows the application of finite element analysis, FEA on the rear panel, which is the support for the main body at the rear side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the rear panel compressive ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until 90N compression force is applied in the software. As shown in Figure 24, when a 90N tensile force is applied on the rear panel, the rear panel does not undergo deformation.

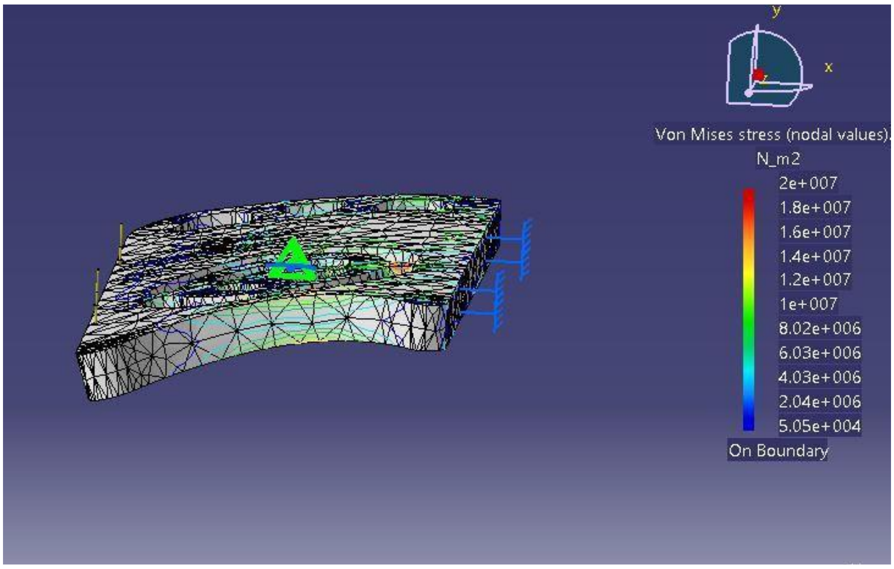

Figure 25 Rear Panel 300N Force bending

Figure 25 shows the application of finite element analysis, FEA on the rear panel, which is the support for the main body at the rear side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the rear panel bending ability needs to be tested. Based on this design, the rear panel theoretically will not receive a lot of compression force nor tensile force much less a 300N force, instead it will experience more bending force due to its main purpose which is to hold the main body that houses all the electronic components. Figure 25 shows the maximum point of bending that the rear panel can withstand when a 300N force is applied to it before undergoing deformation. The data shows a promising result as the main body only weights at most 30N depending on the usage of the electronic parts.

4.2.3 FRONT PANEL

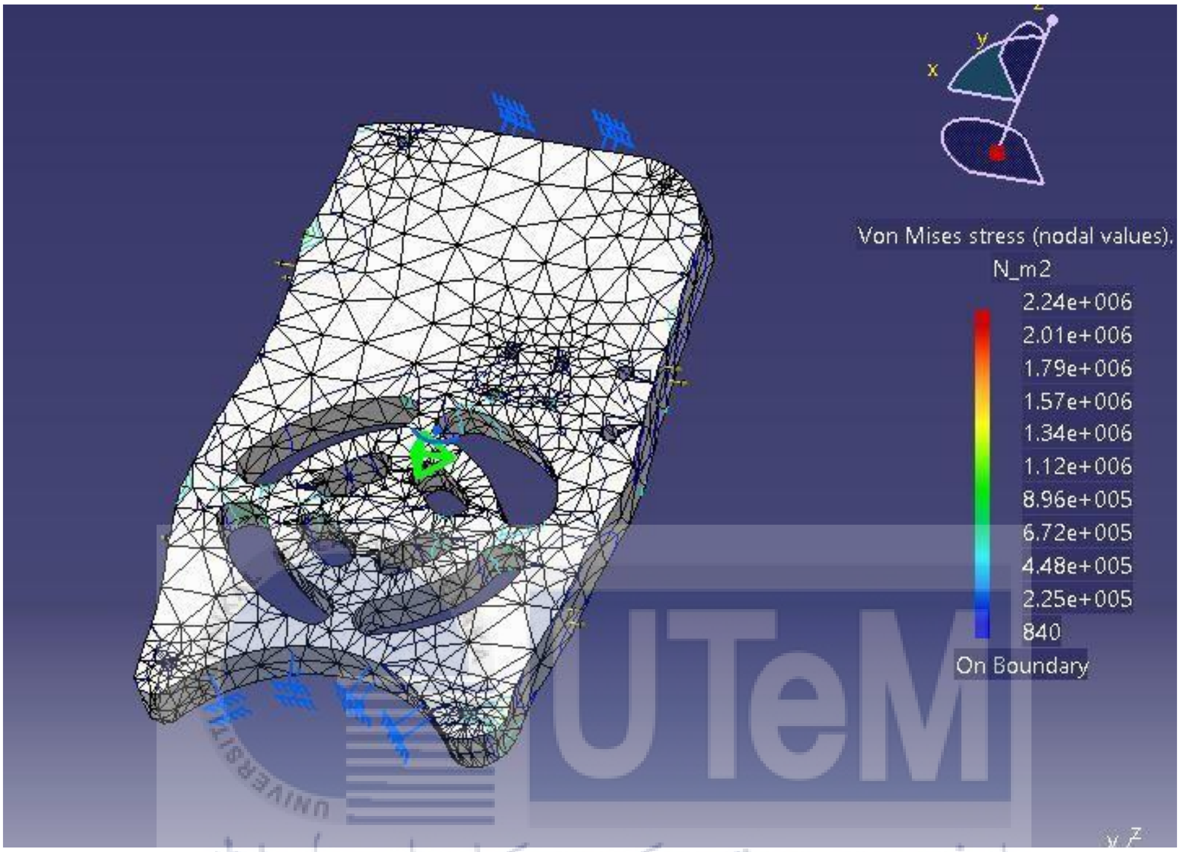

Figure 26 Front panel 300N force tension

Figure 26 shows the application of finite element analysis, FEA on the front panel, which is the support for the main body at the front side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the rear panel tensile ability needs to be tested. As usual, a force of 300N is applied in the software to test the tensile strength. As shown in Figure 26, when a 300N tensile force is applied on the bottom body, the body starts to deform. Due to the result, the analysis is repeated with the force being decrease each test.

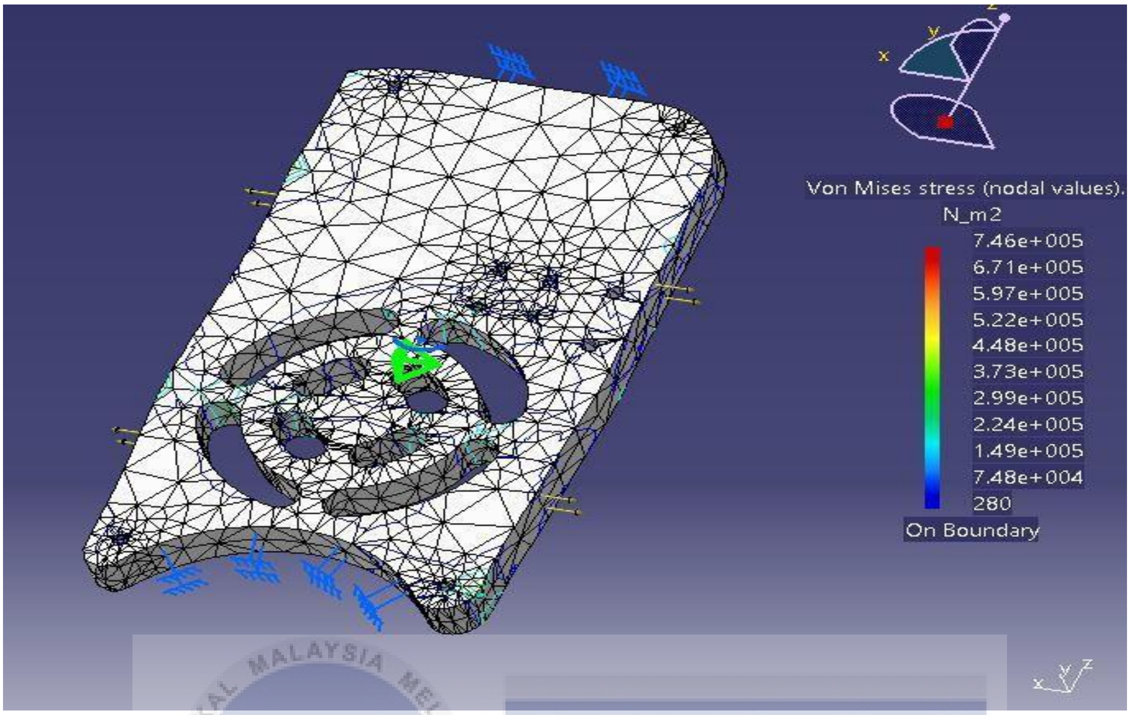

Figure 27 Front panel 100N force tension

Figure 27 shows the application of finite element analysis, FEA on the front panel, which is the support for the main body at the front side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the rear panel tensile ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until a 100N tensile force is applied in the software. As shown in Figure 27, when a 100N tensile force is applied on the front panel, the front panel reaches it maximum point before undergoing deformation.

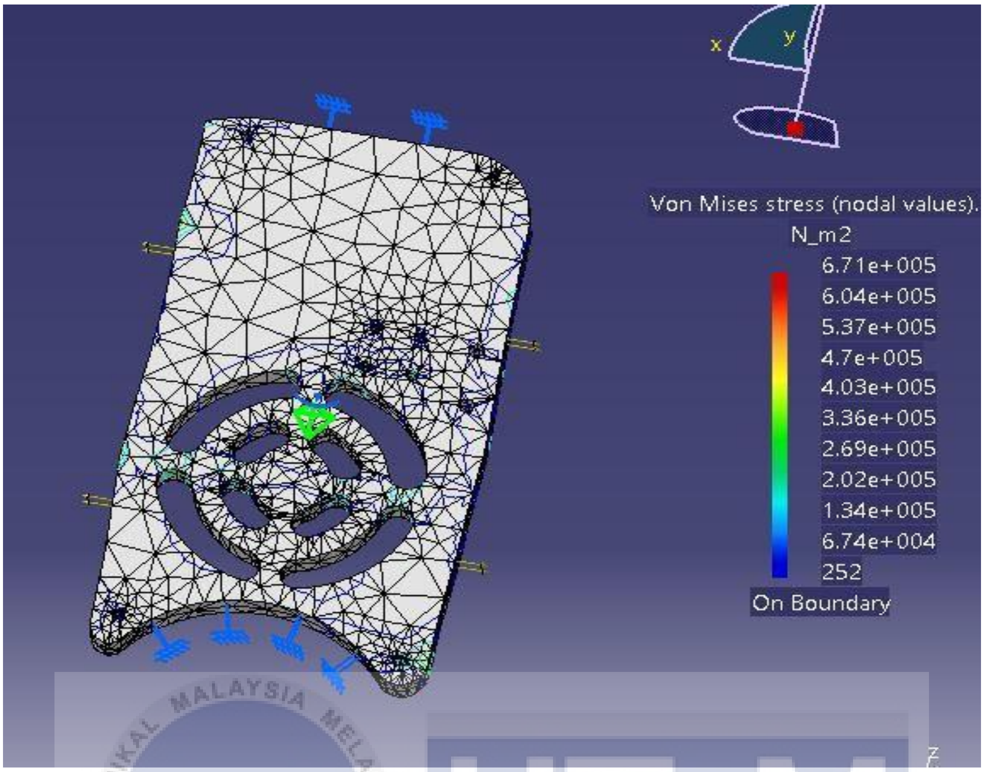

Figure 28 Front panel 90N force tension

Figure 28 shows the application of finite element analysis, FEA on the front panel, which is the support for the main body at the front side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the front panel tensile abilityneeds to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until a 90N tensile force is applied in the software. As shown in Figure 28, when a 90N tensile force is applied on the rear panel, the rear panel does not undergo deformation.

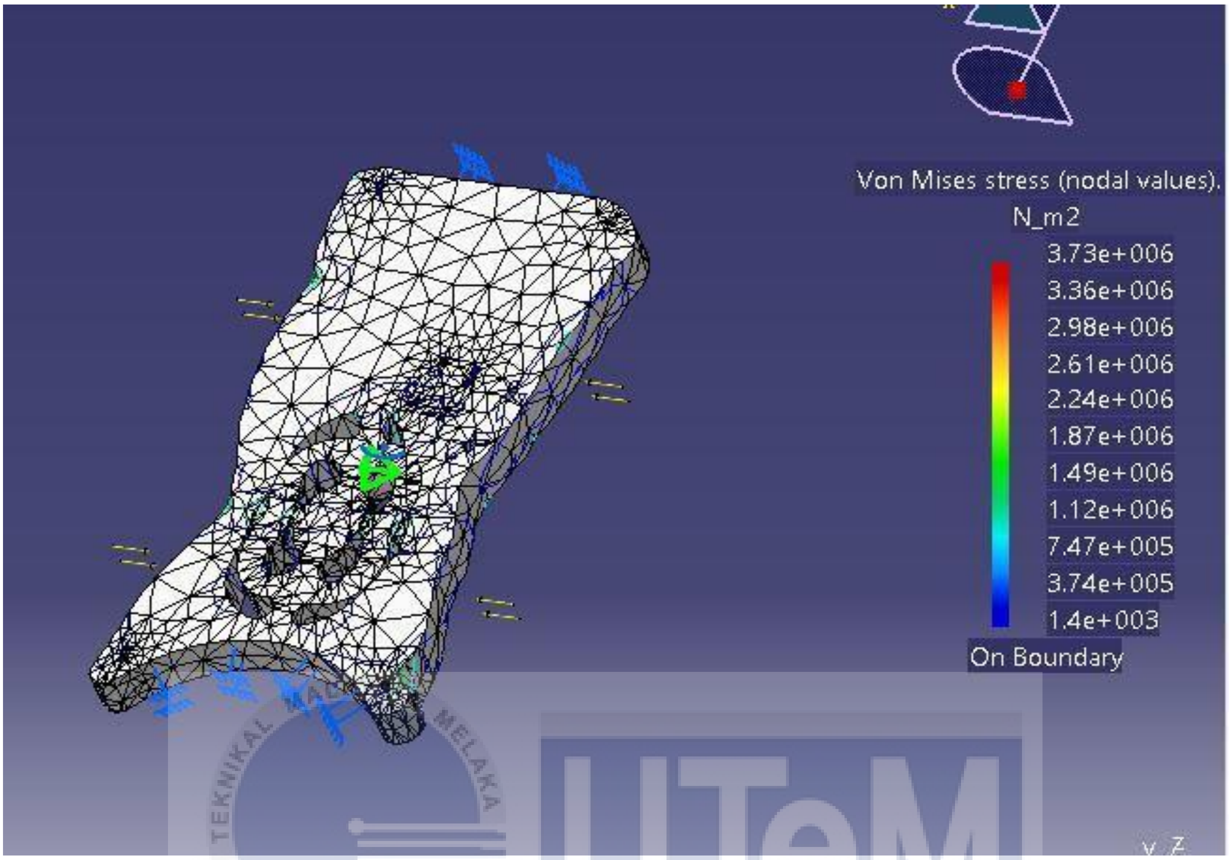

Figure 29 Front panel 500N force compression

Figure 29 shows the application of finite element analysis, FEA on the front panel, which is the support for the main body at the front side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the front panel compression ability needs to be tested. This time, a force of 500N is applied in the software to test the compression strength. As shown in Figure 29, when a 500N compression force is applied on the bottom body, the body starts to deform. Due to the result, the analysis is repeated with the force being decrease each test.

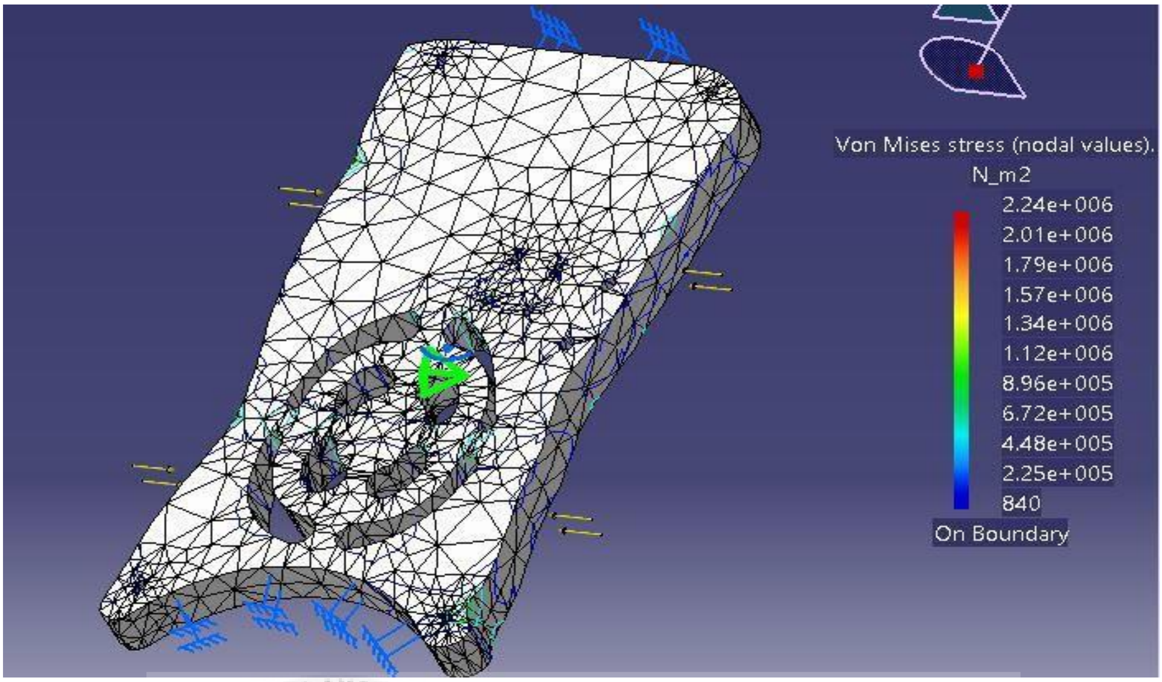

Figure 30 Front panel 300N compression

Figure 30 shows the application of finite element analysis, FEA on the front panel, which is the support for the main body at the front side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the rear panel compression ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until a 300N compression force is applied in the software. As shown in Figure 30, when a 30kg compression force is applied on the rear panel, the rear panel still undergoes deformation but only a small deformation. Therefore, the test continues.

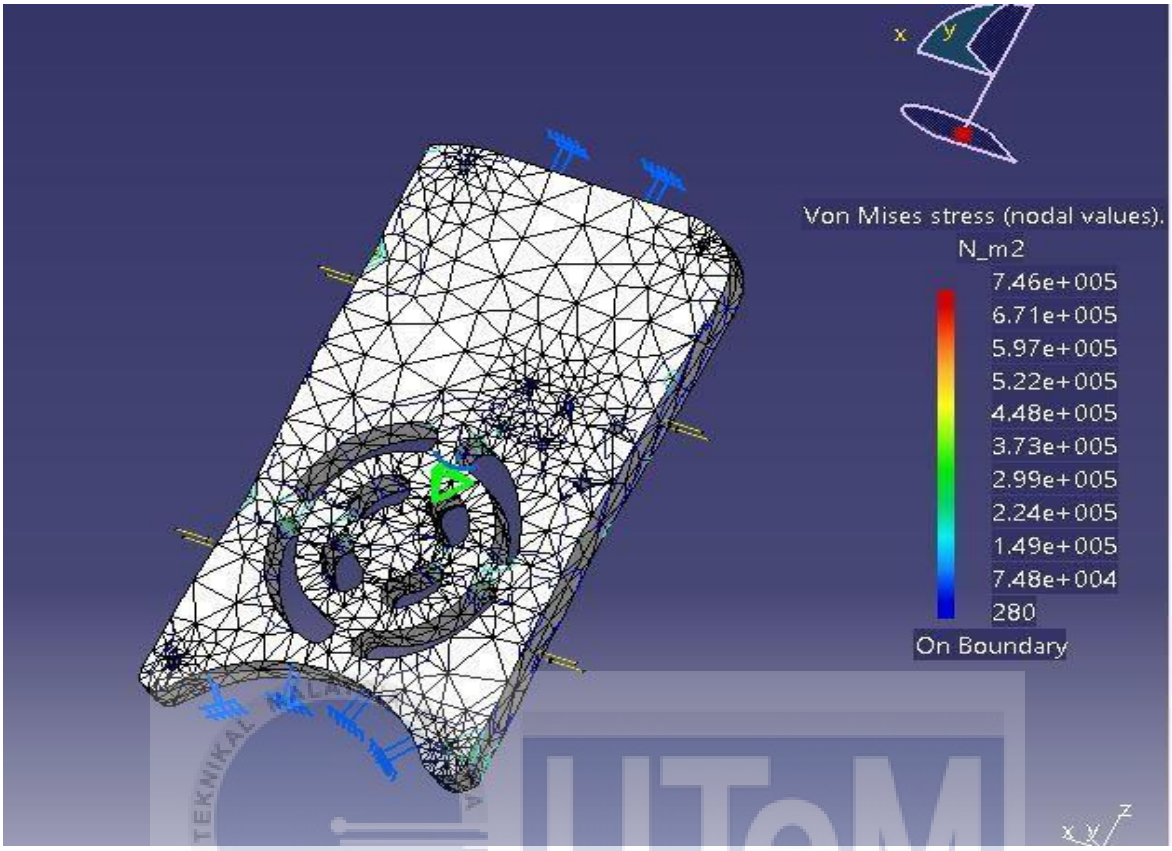

Figure 31 Front panel 100N compression

Figure 31 shows the application of finite element analysis, FEA on the front panel, which is the support for the main body at the front side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the rear panel compression ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until a 100N compression force is applied in the software. As shown in Figure 31, when a 100N compression force is applied on the front panel, the front panel still undergoes deformation but only a small deformation. Therefore, the test continues.

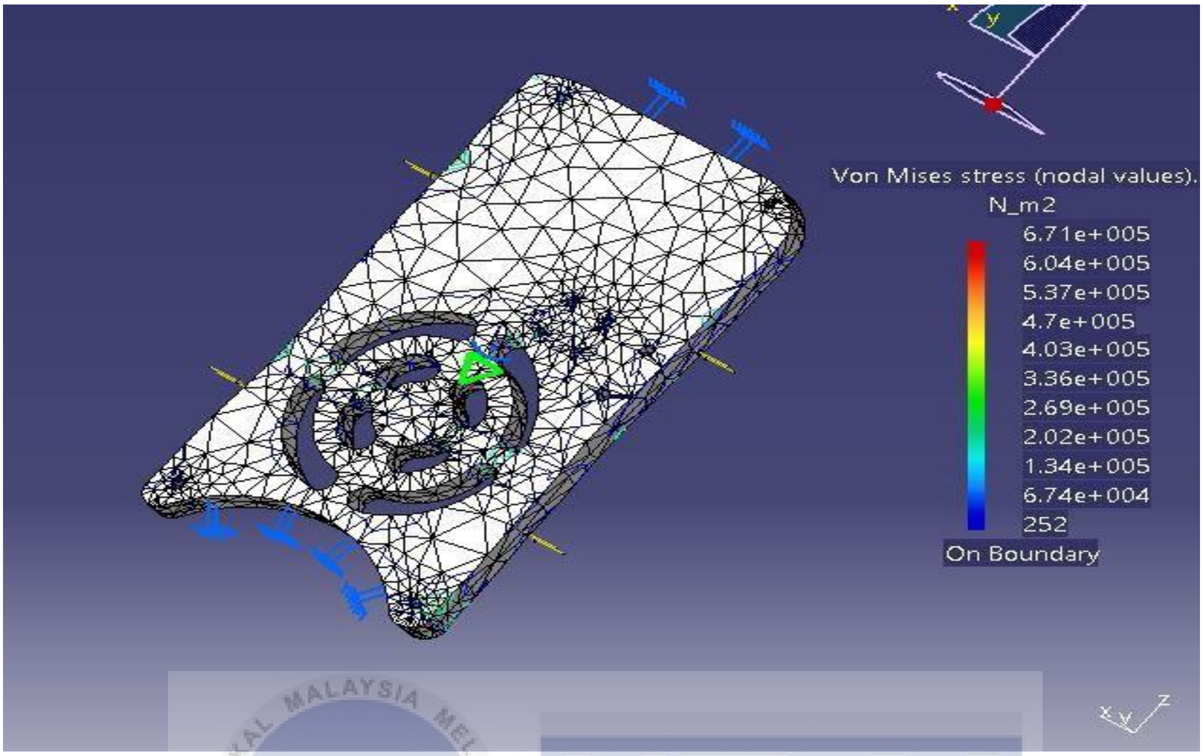

Figure 32 Front panel 90N force compression

Figure 32 shows the application of finite element analysis, FEA on the front panel, which is the support for the main body at the front side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the front panel compression ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until 90N compression force is applied in the software. As shown in Figure 32, when a 90N compression force is applied on the rear panel, the rear panel does not undergo deformation.

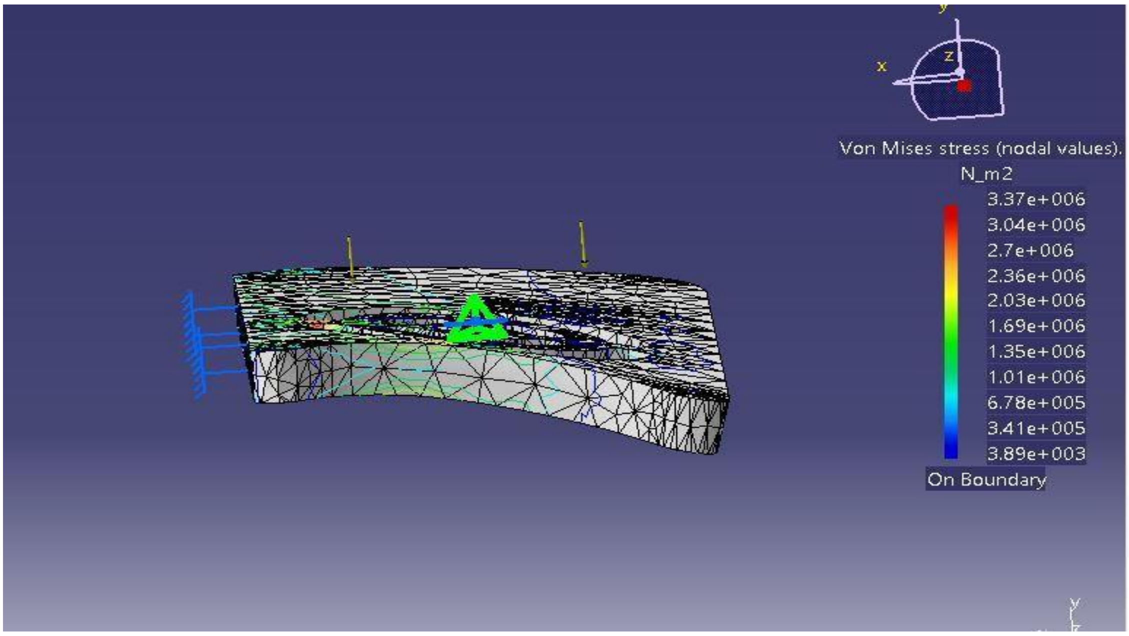

Figure 33 Front panel 300N force bending

Figure 33 shows the application of finite element analysis, FEA on the front panel, which is the support for the main body at the front side of the overall frame. This part also plays the role of connecting the side body as it is attached to enclosure cradles which holds the main body (a cylinder body which houses all the electronic parts excluding the battery). Using all that information on its basic role towards the overall body, the rear panel bending ability needs to be tested. Based on this design, the front panel theoretically will not receive a lot of compression force nor tensile force much less a 300N force, instead it will experience more bending force due to its main purpose which is to hold the main body that houses all the electronic components. Figure 33 shows the maximum point of bending that the front panel can withstand when a 300N force is applied to it before undergoing deformation. The data shows a promising result as the main body that the panel holds only weights at most 3kg depending on the usage of the electronic parts.

4.2.4 SIDE BODY

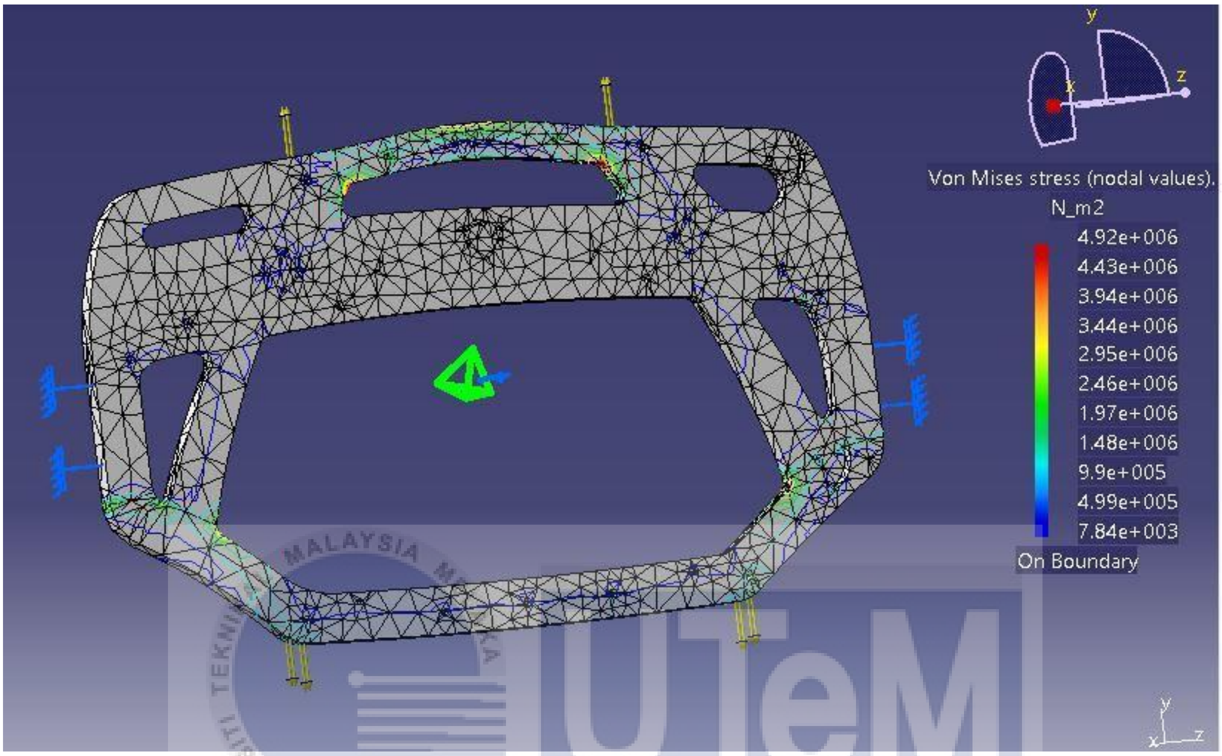

Figure 34 Side body 300N force tension

Figure 34 shows the application of finite element analysis, FEA on the side body. The side body is the most important part amongst the others as it is connected to all parts including the bottom and the panels. This part also plays the role for the user to hold or lift the AUV when needed for maintenance. Using all that information on its basic role towards the overall body, the side body tensile ability needs to be tested. A force of 300N is applied in the software to test the tensile strength. As shown in Figure 34, when a 300N tensile force is applied on the bottom body, the body starts to deform. Due to the result, the analysis is repeated with the force being decrease each test.

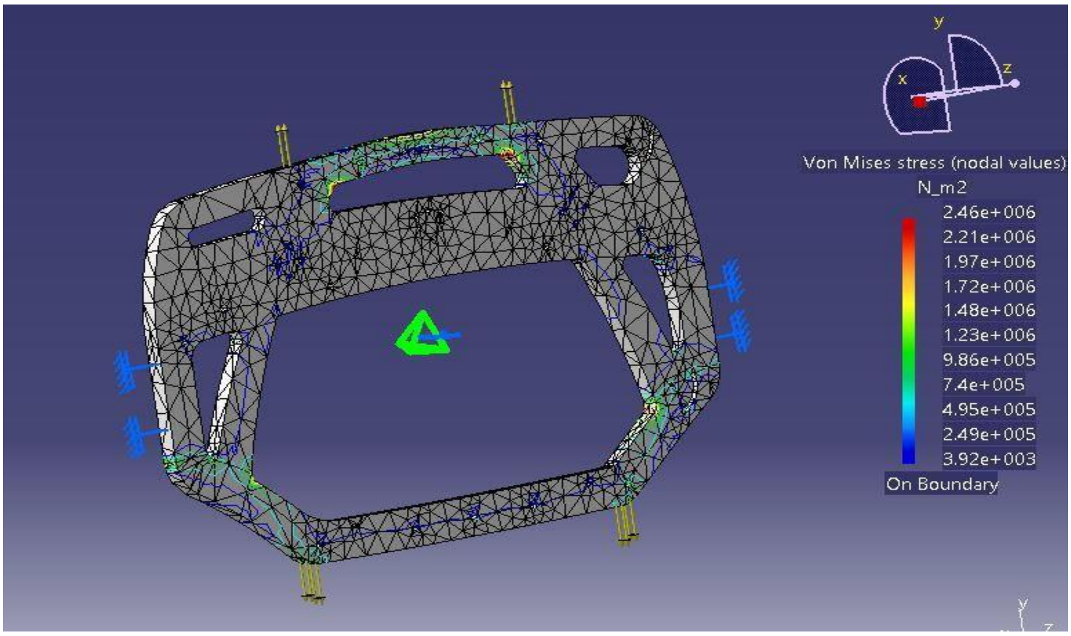

Figure 35 Side body 150N force tension

Figure 35 shows the application of finite element analysis, FEA on the side body. The side body is the most important part amongst the others as it is connected to all parts including the bottom and the panels. This part also plays the role for the user to hold or lift the AUV when needed for maintenance. Using all that information on its basic role towards the overall body, the side body tensile ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until a 150N tensile force is applied in the software. As shown in Figure 35, when a 150N tensile force is applied on the front panel, the front panel reaches it maximum point before undergoing deformation.

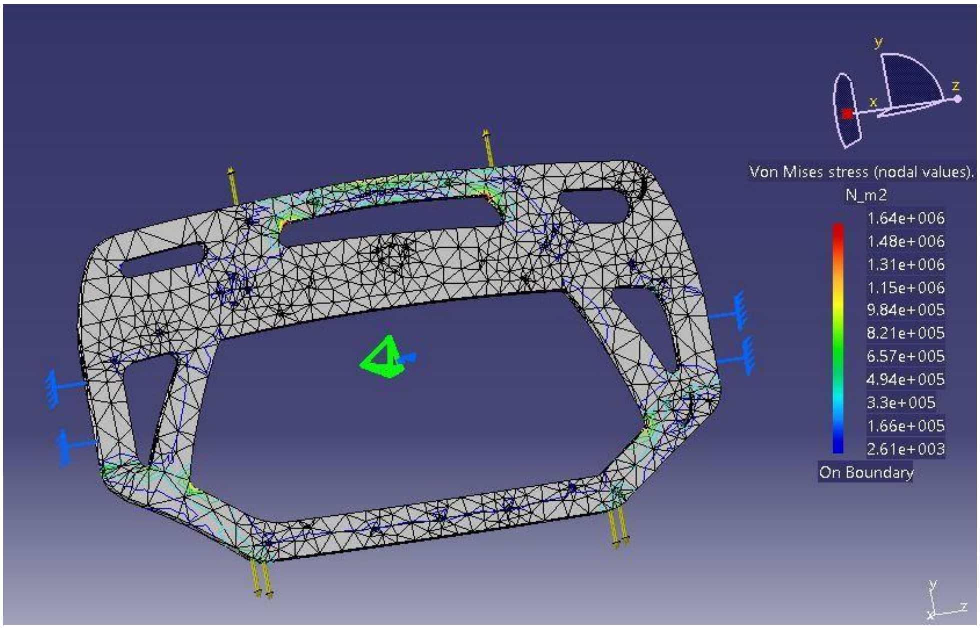

Figure 36 Side body 100N force tension

Figure 36 shows the application of finite element analysis, FEA on the side body. The side body is the most important part amongst the others as it is connected to all parts including the bottom and the panels. This part also plays the role for the user to hold or lift the AUV when needed for maintenance. Using all that information on its basic role towards the overall body, the side body tensile ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until a 100N tensile force is applied in the software. As shown in Figure 36, when a 100N tensile force is applied on the rear panel, the rear panel does not undergo deformation.

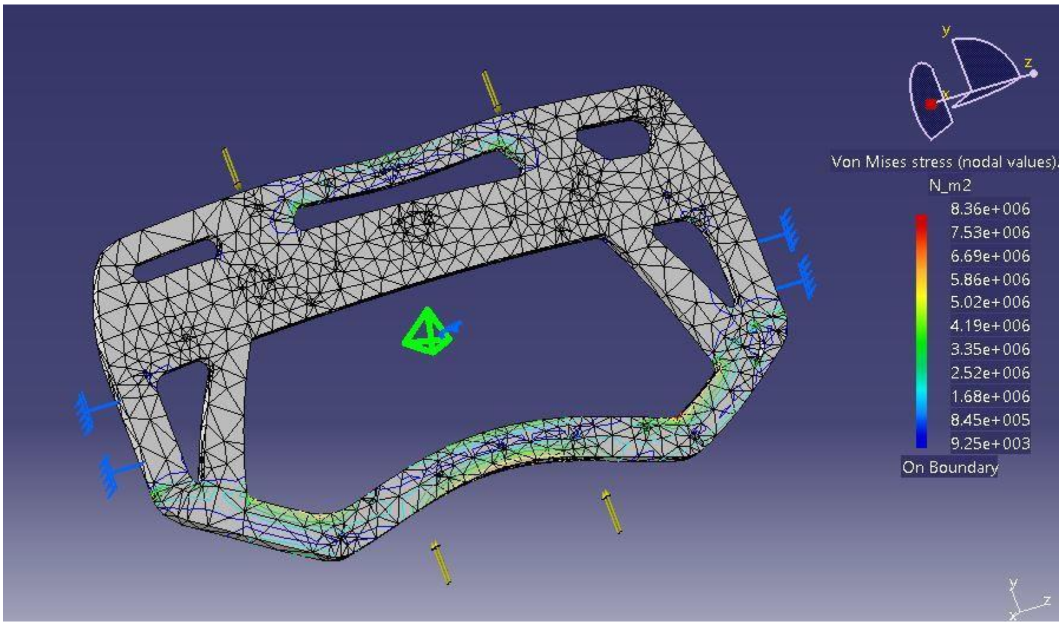

Figure 37 Side body 300N force compression

Figure 37 shows the application of finite element analysis, FEA on the side body. The side body is the most important part amongst the others as it is connected to all parts including the bottom and the panels. This part also plays the role for the user to hold or lift the AUV when needed for maintenance. Using all that information on its basic role towards the overall body, the side body compression ability needs to be tested. For this design and for this part body particularly, the significance of both tensile and compression capabilities is equally important. Therefore, just like other parts the test for compression is also done for the side body. First a 300N compression force is applied to the body in the CATIA software. As shown in Figure 37, when a 300N compression force is applied on the side body, the side body undergoes deformation. Therefore, the test continues.

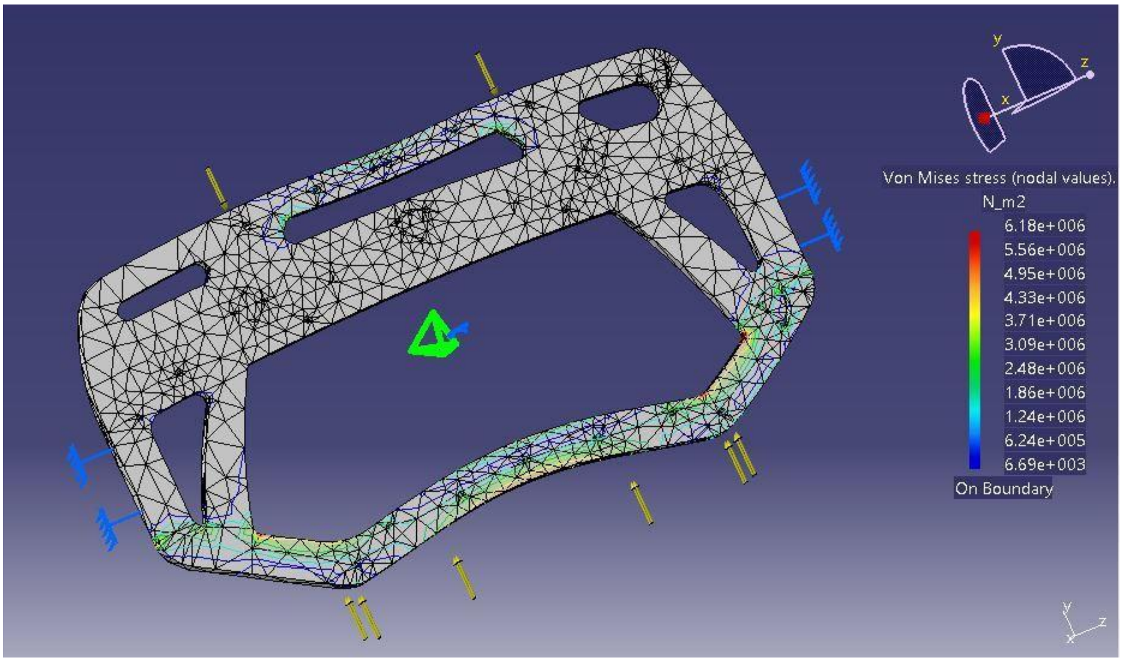

Figure 38 Side body 200N force compression

Figure 38 shows the application of finite element analysis, FEA on the side body. The side body is the most important part amongst the others as it is connected to all parts including the bottom and the panels. This part also plays the role for the user to hold or lift the AUV when needed for maintenance. Using all that information on its basic role towards the overall body, the side body compression ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until a 200N compression force is applied on it in the software. As shown in Figure 38, when a 200N compression force is applied on the front panel, the side body still undergoes deformation which is not satisfying. Therefore, the test continues.

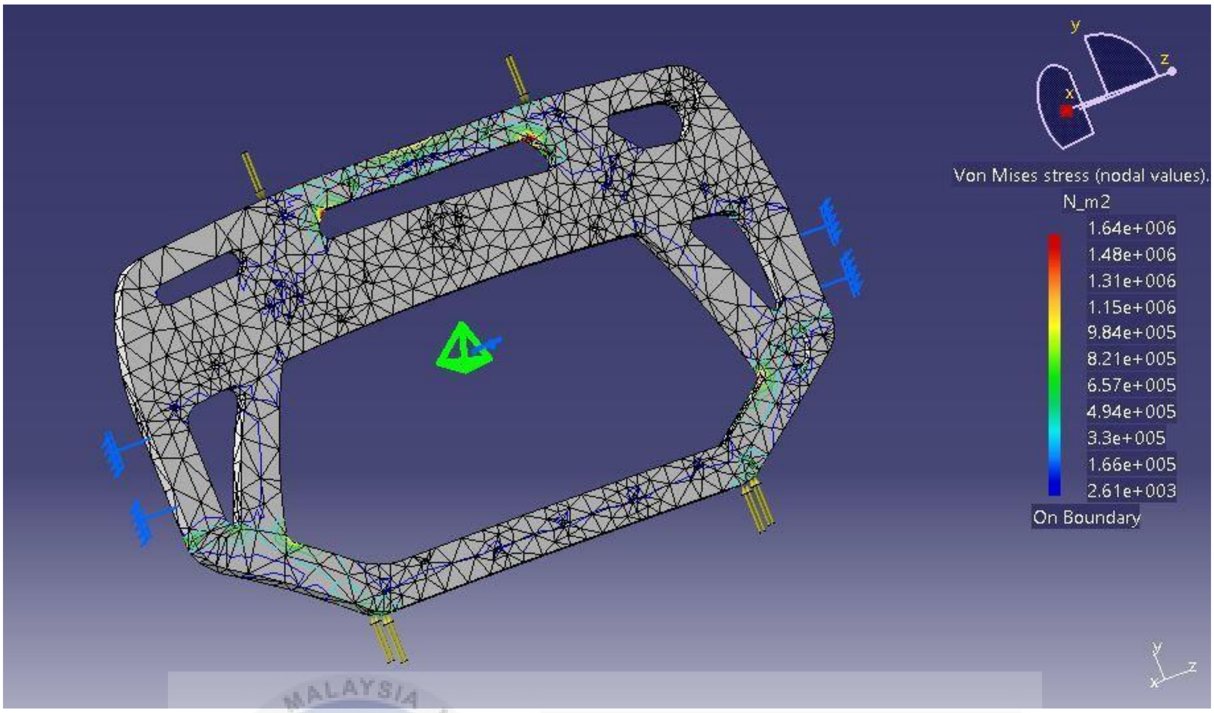

Figure 39 Side body 100N force compression

Figure 39 shows the application of finite element analysis, FEA on the side body. The side body is the most important part amongst the others as it is connected to all parts including the bottom and the panels. This part also plays the role for the user to hold or lift the AUV when needed for maintenance. Using all that information on its basic role towards the overall body, the side body tensile ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until 100N compression force is applied in the software. As shown in Figure 39, when a 100N compression force is applied on the side body, the side body does not undergo deformation.

4.2.5 MIDDLE CYLINDER (MAIN BODY)

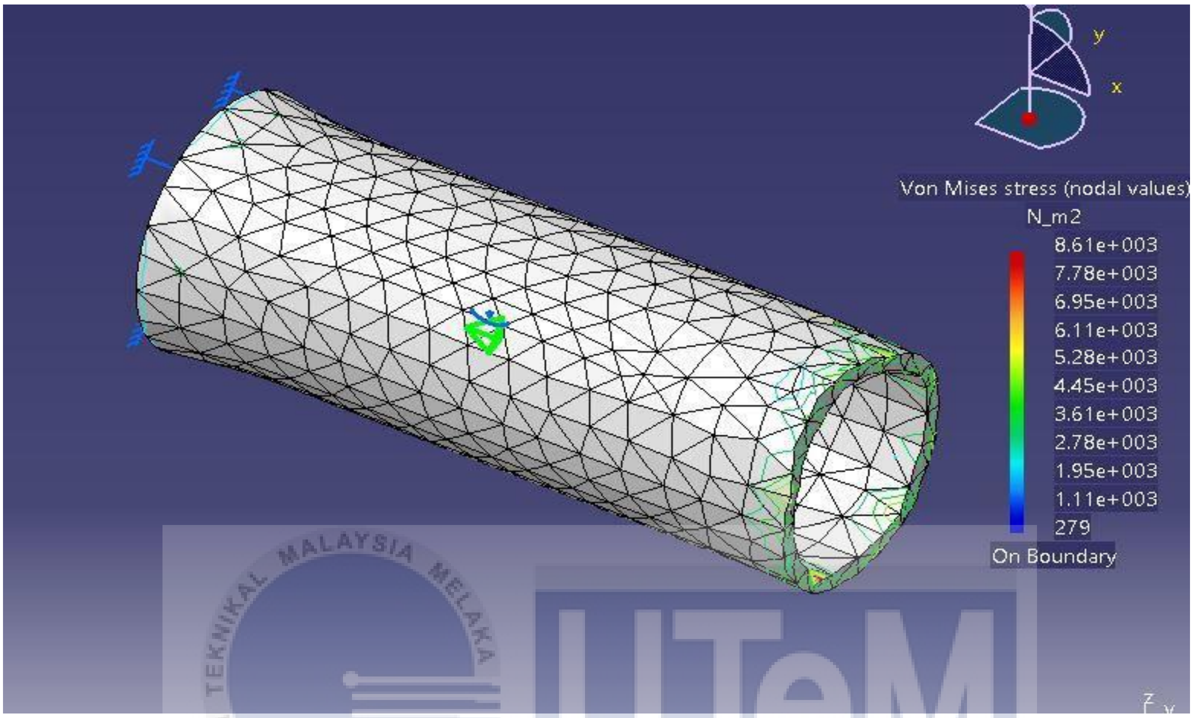

Figure 40 Middle cylinder body 200N force tension

Figure 40 shows the application of finite element analysis, FEA on the main body. The main body as mention previously houses all the electronic parts excluding the battery which is the source of power. Without the electronic parts, the AUV is no longer usable. This means that the importance of the main body parts and the side body are equally important. Using all that information on its basic role towards the overall body, the main body tensile ability needs to be tested. As the material is the same for all parts, the starting force for the finite element analysis is the same. A force of 300N is applied in the software to test the tensile strength. As shown in Figure 40, when a 300N tensile force is applied on the main body, the body starts to deform. Due to the result, the analysis is repeated with the force being decrease each test.

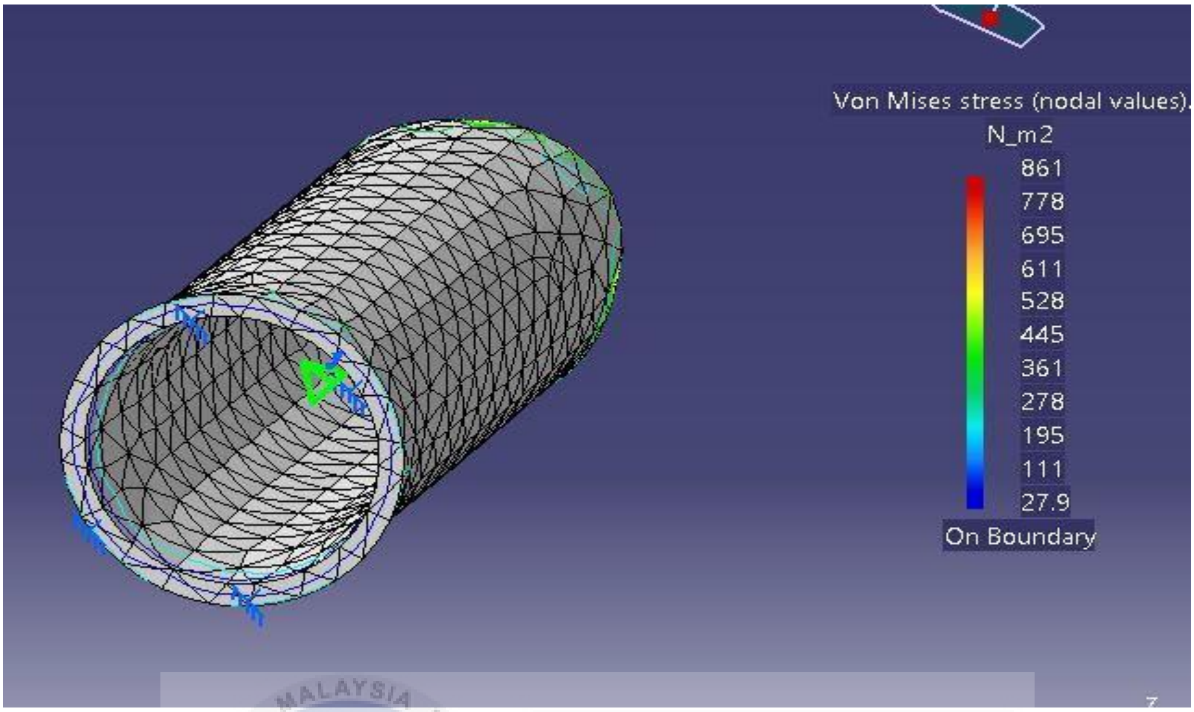

Figure 41 Middle cylinder body 100N force tension

Figure 41 shows the application of finite element analysis, FEA on the main body. The main body as mention previously houses all the electronic parts excluding the battery which is the source of power. Without the electronic parts, the AUV is no longer usable. This means that the importance of the main body parts and the side body are equally important. Using all that information on its basic role towards the overall body, the main body tensile ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until a 100N tensile force is applied in the software. As shown in Figure 41, when a 100N tensile force is applied on the main body, the main body does not undergo deformation.

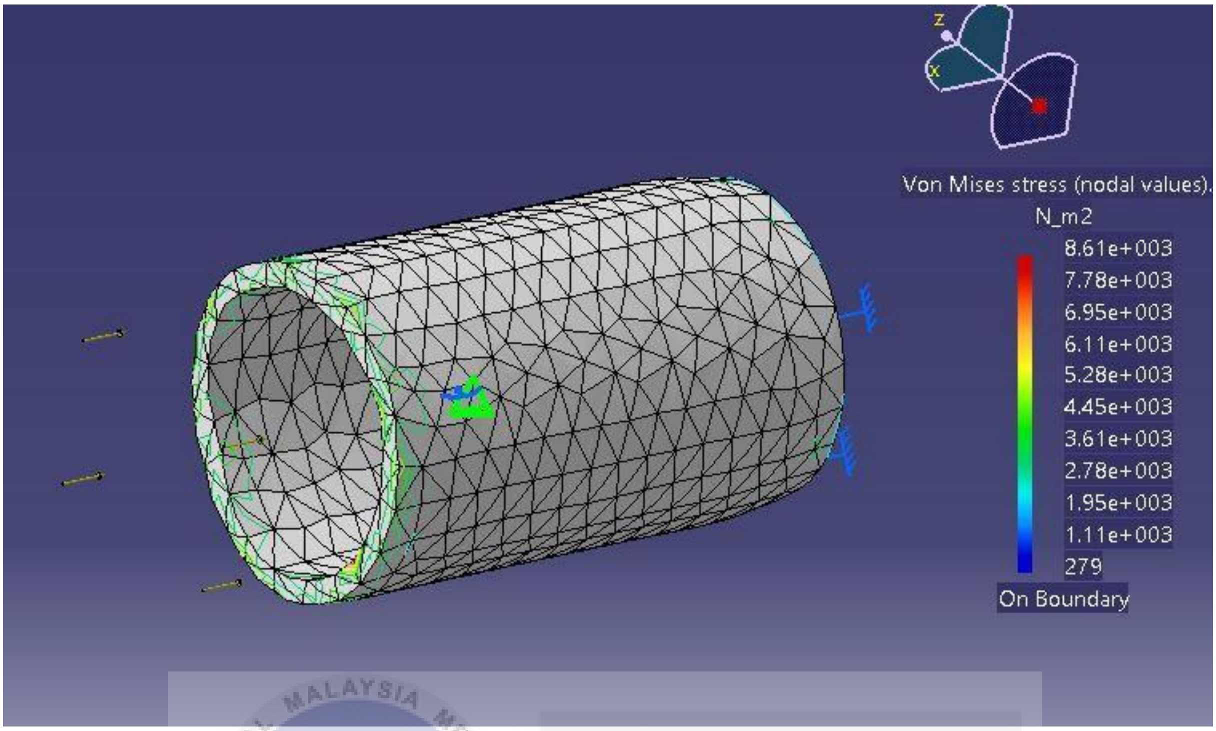

Figure 42 Middle cylinder body 500N force compression

Figure 42 shows the application of finite element analysis, FEA on the main body. The main body as mention previously houses all the electronic parts excluding the battery which is the source of power. Without the electronic parts, the AUV is no longer usable. This means that the importance of the main body parts and the side body are equally important. Using all that information on its basic role towards the overall body, the same process for all parts of the design, after the analysis for the tensile capabilities is done, what comes next is the compression analysis. A 300N compression force is applied on the body in the software. As shown in Figure 42, when a 300N compression force is applied on the main body, the body undergoes deformation which therefore indicates that the test must continue.

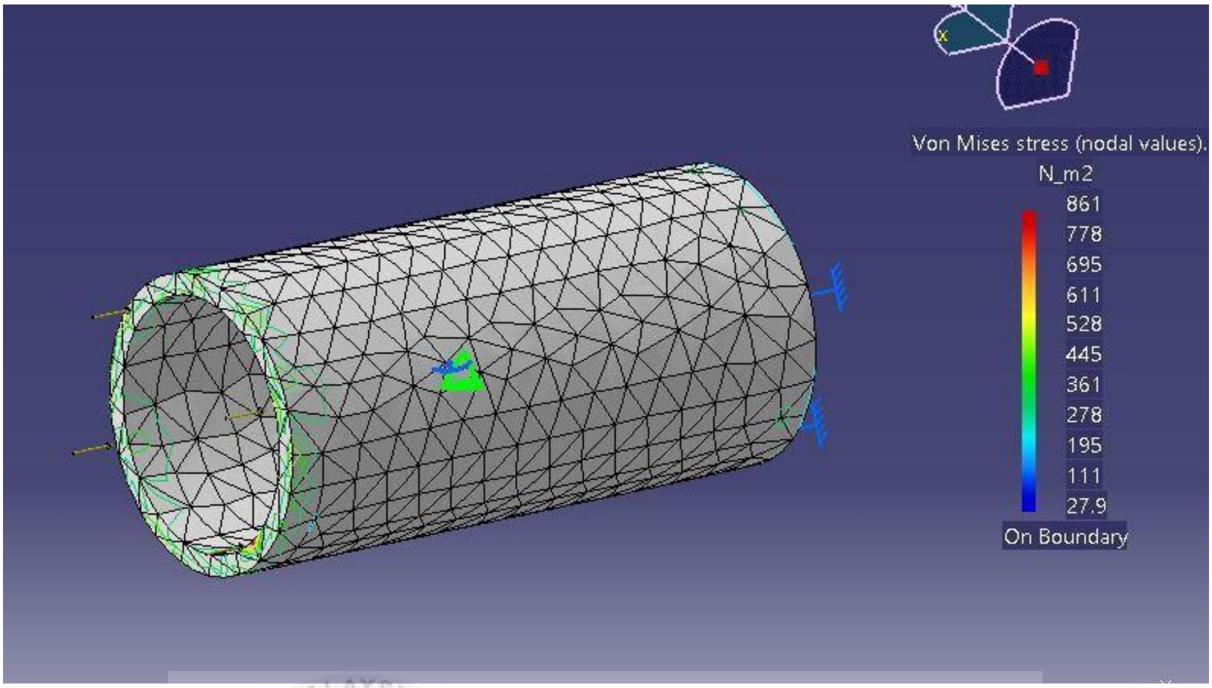

Figure 43 Middle cylinder body 100N force compression

Figure 43 shows the application of finite element analysis, FEA on the main body. The main body as mention previously houses all the electronic parts excluding the battery which is the source of power. Without the electronic parts, the AUV is no longer usable. This means that the importance of the main body parts and the side body are equally important. Using all that information on its basic role towards the overall body, the main body compression ability needs to be tested. As the result of the FEA on the previous Figure ends up with a deformation, the analysis is repeated with the force being decrease each test, and the body still undergoes deformation until 100N compression force is applied on the body in the software. As shown in Figure 43, when a 100N compression force is applied on main body, the body does not undergo deformation.

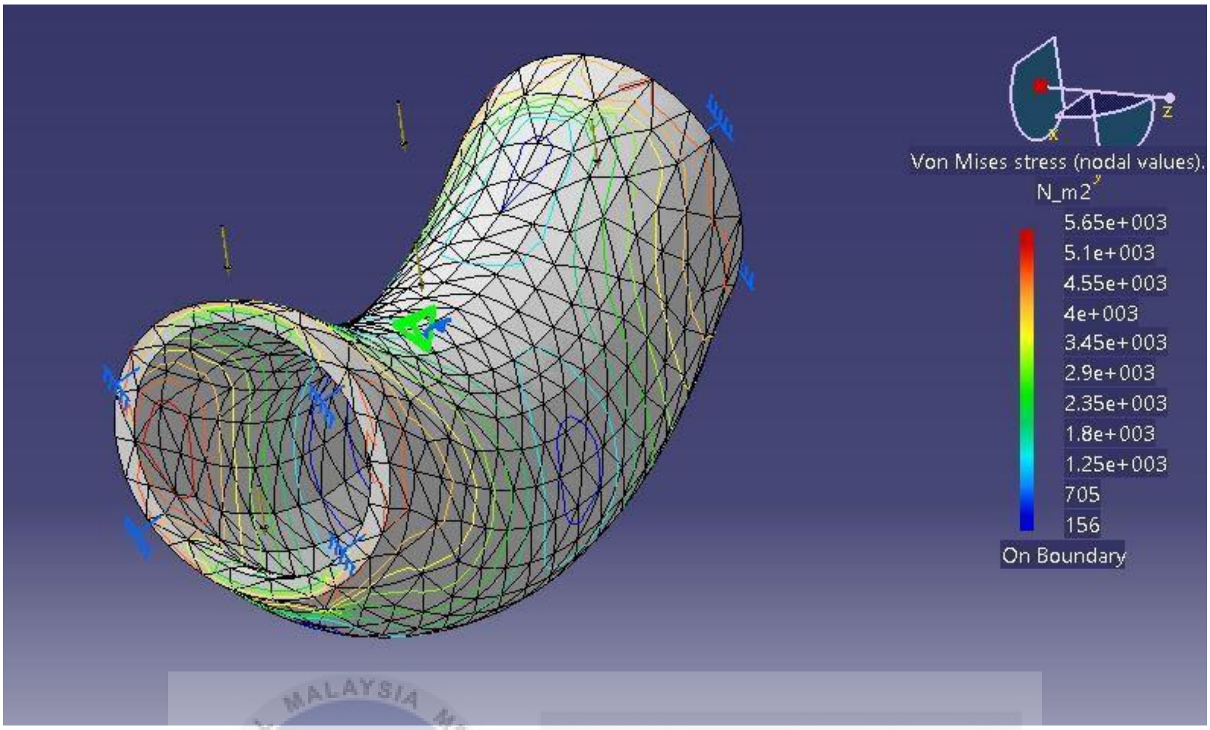

Figure 44 Middle cylinder body 50N force load

Figure 44 shows the application of finite element analysis, FEA on the main body. The main body as mention previously houses all the electronic parts excluding the battery which is the source of power. Without the electronic parts, the AUV is no longer usable. This means that the importance of the main body parts and the side body are equally important. Based on this design, the main body theoretically will not receive a lot of compression force nor tensile force much less a 300N force, instead it will experience more bending force due to its main purpose which is to contain all the electronics part inside it. Figure 44 shows the deformation of the main body when a 50N force is applied at the center of the body. The data does not show a promising result when a weights 50N is applied, but that weight is not logical for this design as the electronic parts used for this design in the cylinder volume will be at most 10N.

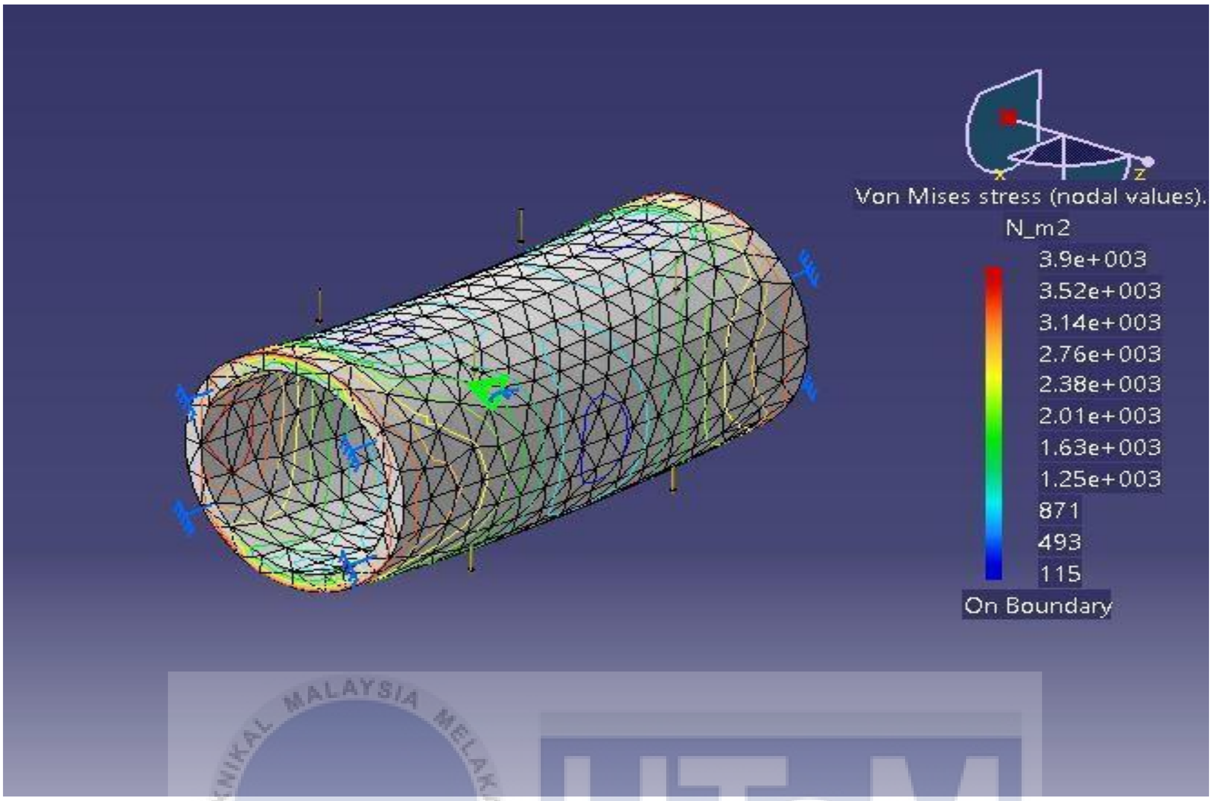

Figure 45 Middle cylinder body 1kg force load

Figure 45 shows the application of finite element analysis, FEA on the main body. The main body as mention previously houses all the electronic parts excluding the battery which is the source of power. Without the electronic parts, the AUV is no longer usable. This means that the importance of the main body parts and the side body are equally important. As the bending abilities are tested with the force of 50N applied on the center of the main body using finite element analysis in the CATIA software, next is to redo the analysis but using the weight of 10N which is the average weight of all the electrical components that will be placed inside the main body. As shown in Figure 45, the main body can withstand the force of 10N as it does not undergo deformation.

4.3 COMPUTATIONAL FLUID DYNAMIC

The simulations are made using the software ANSYS. The test is made for all the crucial parts in the body (as it were tested for finite element analysis). It is made part by part. The simulation is made in two conditions of flow. The first is flow that comes from front, in other words the water flows on through the thin side of body and the second flow is the flow that comes from the side of the part which is the flat part of the body. The results are as shown below.

4.3.1 SIDE BODY

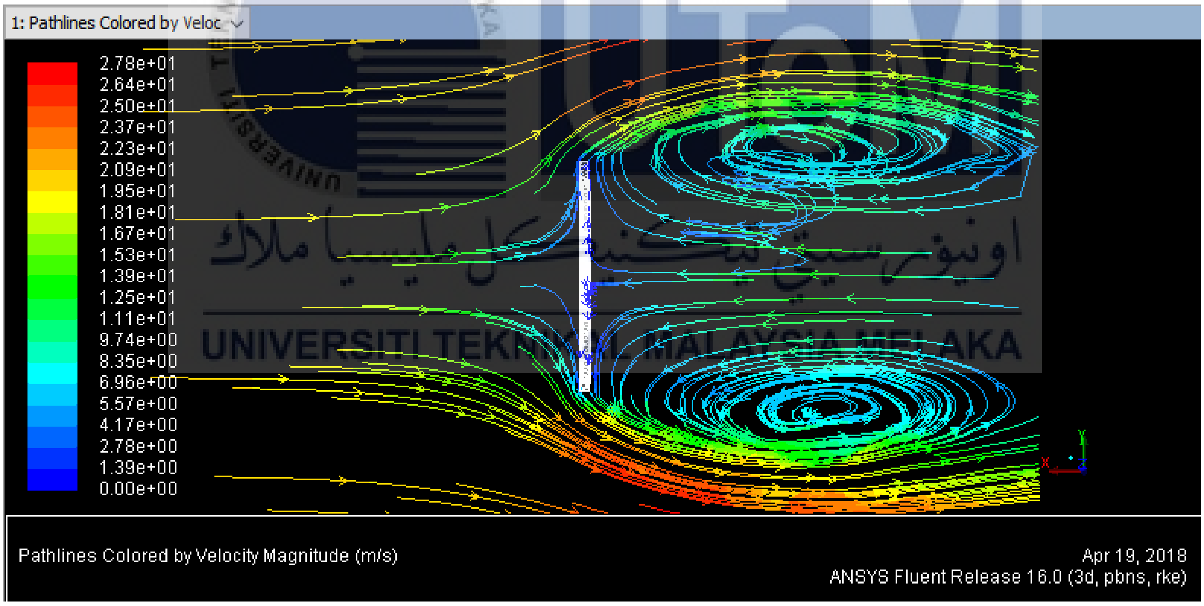

Figure 46 Side body (side flow)

Figure 46 shows the result of the simulation run in the software of ANSYS. The simulation is done using water as the medium of the flow as AUV will be used almost all the time underwater except for maintenance purposes. For clearer explanation, the white line at the center of the image is the body part, in this case the side body, it is seen as a white line due to its position viewed from the front/back. This is the same for all the components that will be explain after this. The color of the simulation is based on the velocity profile. The color bar at the side of the Figure 46 shows the velocity guidance. The bottom color (dark blue) is the lowest velocity and it increases as it works its way up the color bar (light blue, green, yellow, red). Red is the highest velocity. The Figure shows the flow of water towards the side of the body. The result shows that it has a huge drag of flow as the velocity is low around the body. The movement of the AUV in the water will be from the front and not from the side, but the flow must also be considered.

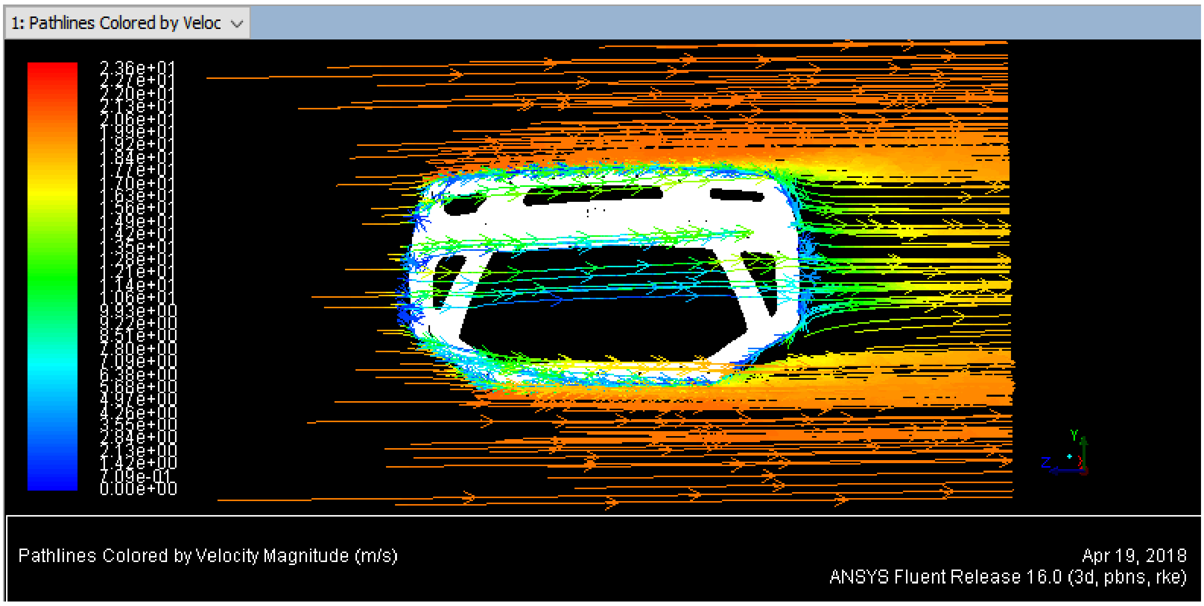

Figure 47 Side body (front flow)

The color bar at the side of the Figure shows the velocity guidance. The bottom color (dark blue) is the lowest velocity and it increases as it works its way up the color bar (light blue, green, yellow, red). Red is the highest velocity. The Figure 47 shows the flow of water towards the front of the body. The result shows that it has a less drag of flow as the velocity is high around the body (orange color). The movement of the AUV in the water will be from the front and not from the side thus the result of the flow for this part is suitable for the AUV to do its work.

4.3.2 FRONT AND REAR PANEL

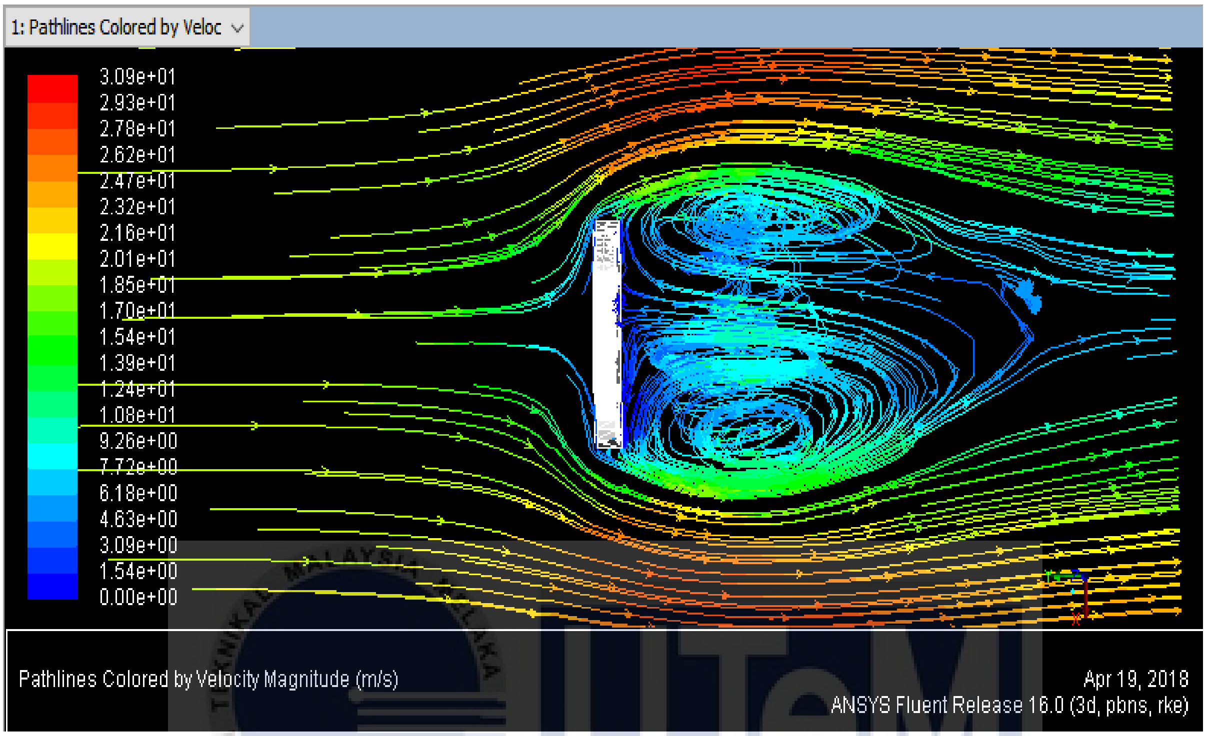

Figure 48 Front and rear panel (side flow)

The color bar at the side of the Figure shows the velocity guidance. The bottom color (dark blue) is the lowest velocity and it increases as it works its way up the color bar (light blue, green, yellow, red). Red is the highest velocity. The Figure shows the flow of water towards the side of the body. The result shows that it has a huge drag of flow as the velocity is slow around the body. The movement of the AUV in the water will be from the front and not from the side, but the flow must also be considered. The Figure 48 shows the flow of water towards the side of the panel. As the front and rear panels are identical they would share the same result which is represented in the Figure. The result shows that it has a huge drag of flow as the velocity is low around the body (blue and green). The movement of the AUV in the water will be from the front and not from the side, but the flow must also be considered.

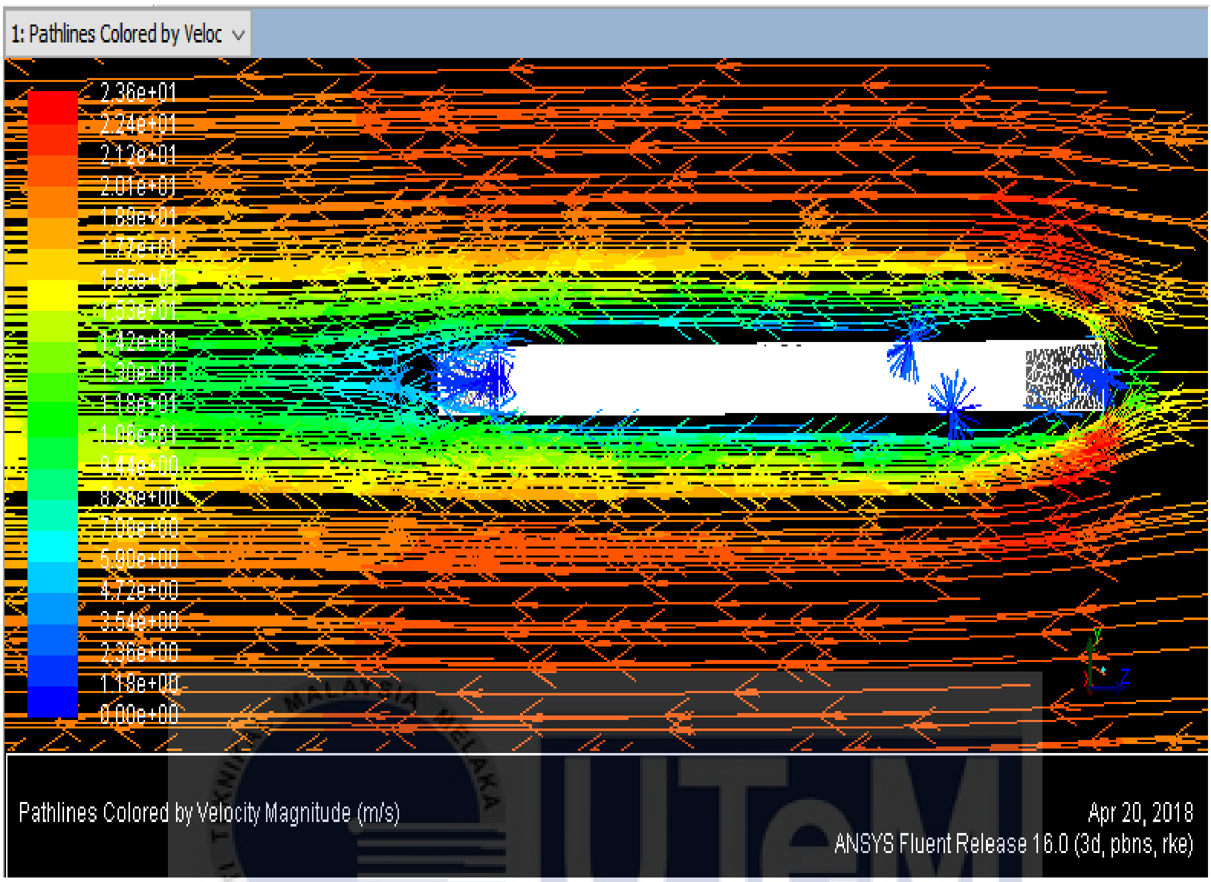

Figure 49 Front and rear panel (front flow)

The color bar at the side of the Figure shows the velocity guidance. The bottom color (dark blue) is the lowest velocity and it increases as it works its way up the color bar (light blue, green, yellow, red). Red is the highest velocity. The Figure 49 shows the flow of water towards the side of the body. The movement of the AUV in the water will be from the front and not from the side. The result shows that it has a less drag of flow as the velocity is high around the body (orange color). The movement of the AUV in the water will be from the front and not from the side thus the result of the flow for this part is suitable for the AUV to do its work.

4.3.3 MAIN BODY

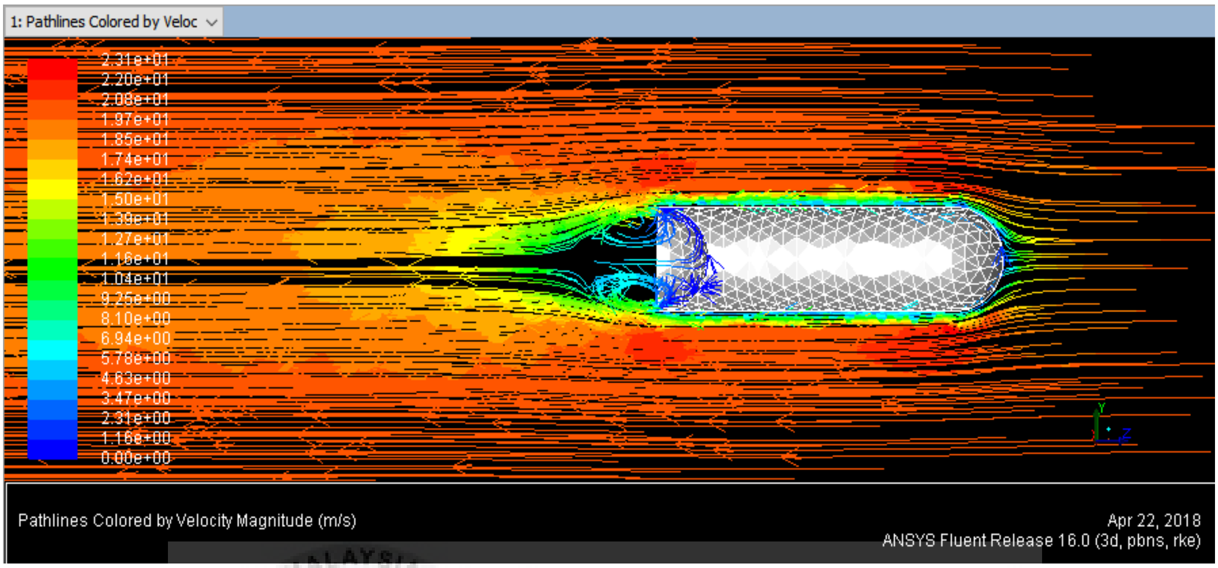

Figure 50 Middle cylinder body (front flow)

The color bar at the side of the Figure shows the velocity guidance. The bottom color (dark blue) is the lowest velocity and it increases as it works its way up the color bar (light blue, green, yellow, red). Red is the highest velocity. The Figure 50 shows the flow of water towards the side of the body. The movement of the AUV in the water will be from the front and not from the side. But the flow from the side still needs to be considered as turbulence may come in any direction. The main body's design is different compared to other body parts. If the side body, bottom and the panels are considered as plate flat shape, the main body is more to a cylindrical shape. Therefore, the simulation in ANSYS has been done and the results of the simulation is different from other body parts due to its cylindrical shape. As shown in Figure. the velocity is orange color (high velocity) as the water can go through easily around the body. The flow from the side is similar due to the cylindrical same diameter. The result for simulation for the side flow are shown in Figure 51 and Figure 52

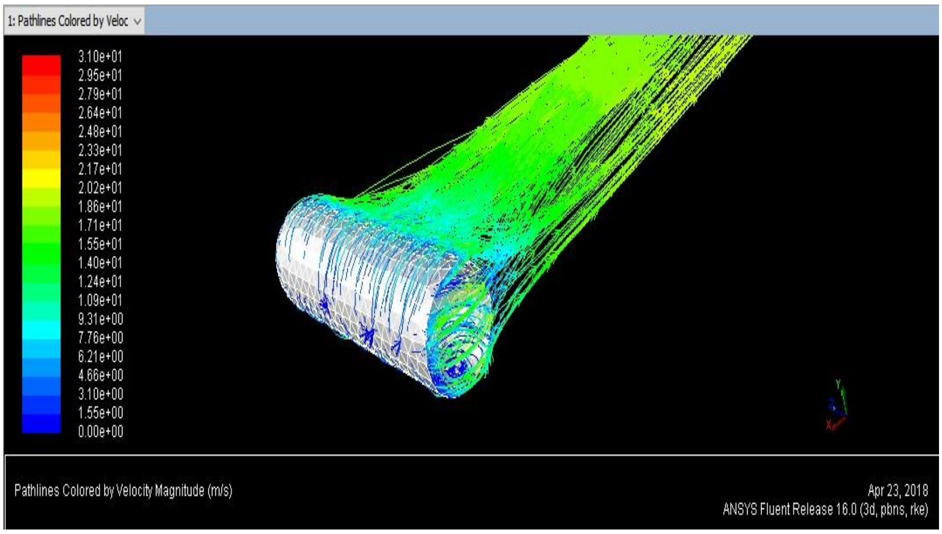

Figure 51 **Middle cylinder body (side flow)**

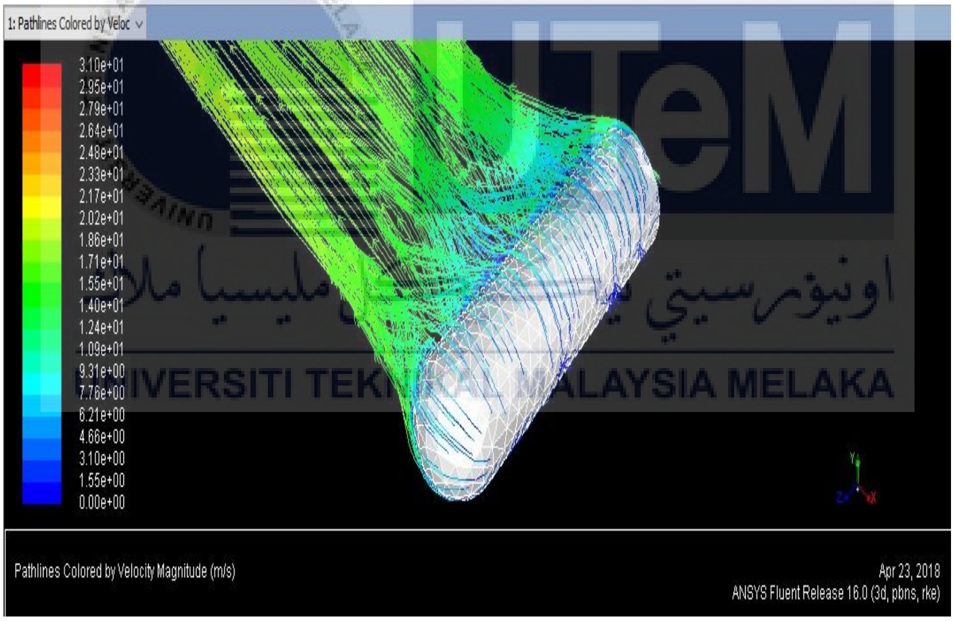

Figure 52 Middle cylinder body (side flow) 2

4.3.4 BOTTOM BODY (BASE)

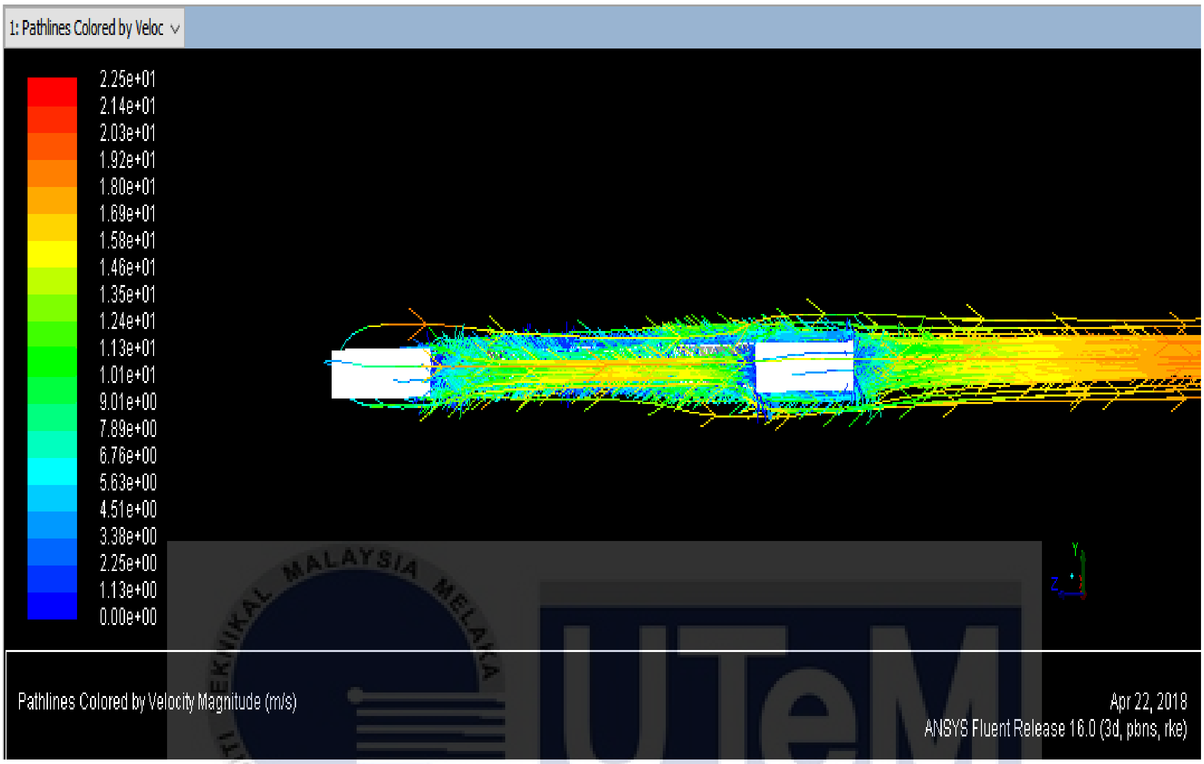

Figure 53 Bottom body (front flow)

The color bar at the side of the Figure shows the velocity guidance. The bottom color (dark blue) is the lowest velocity and it increases as it works its way up the color bar (light blue, green, yellow, red). Red is the highest velocity. The Figure 53 shows the flow of water towards the side of the body. The movement of the AUV in the water will be from the front and not from the side. The result shows that it has a less drag of flow as the velocity is high around the body (orange color). The movement of the AUV in the water will be from the front and not from the side thus the result of the flow for this part is suitable for the AUV to do its work.

The simulation for the flow to the side part of the bottom body is not shown as the design of the AUV needs the bottom body to be place in a flat manner. Which means no matter in which direction the water flows through the result would be similar. The view for the simulation result at different angle is as shown below.

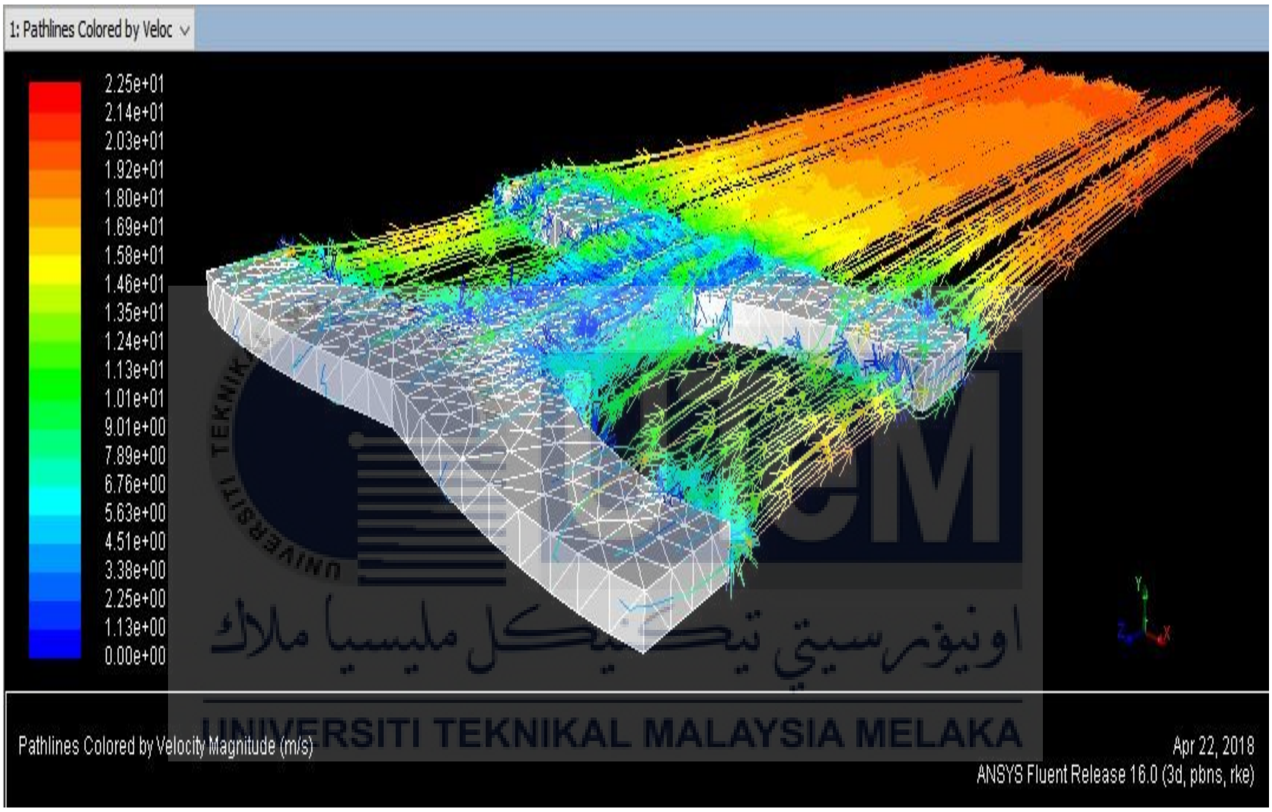

Figure 54 Bottom body (side flow)

4.4 FABRICATING PARTS

The last step after designing, testing the strength using finite element analysis and doing the simulation test for the computational fluid dynamic. The fabrication of these designs is made. Using the material of acrylic. The visual of the fabricated parts are as shown below:

4.4.1 REAR PANEL

Figure 55 Acrylic rear panel

4.4.2 FRONT PANEL

Figure 56 Acrylic front panel

4.4.3 BOTTOM BODY (BASE)

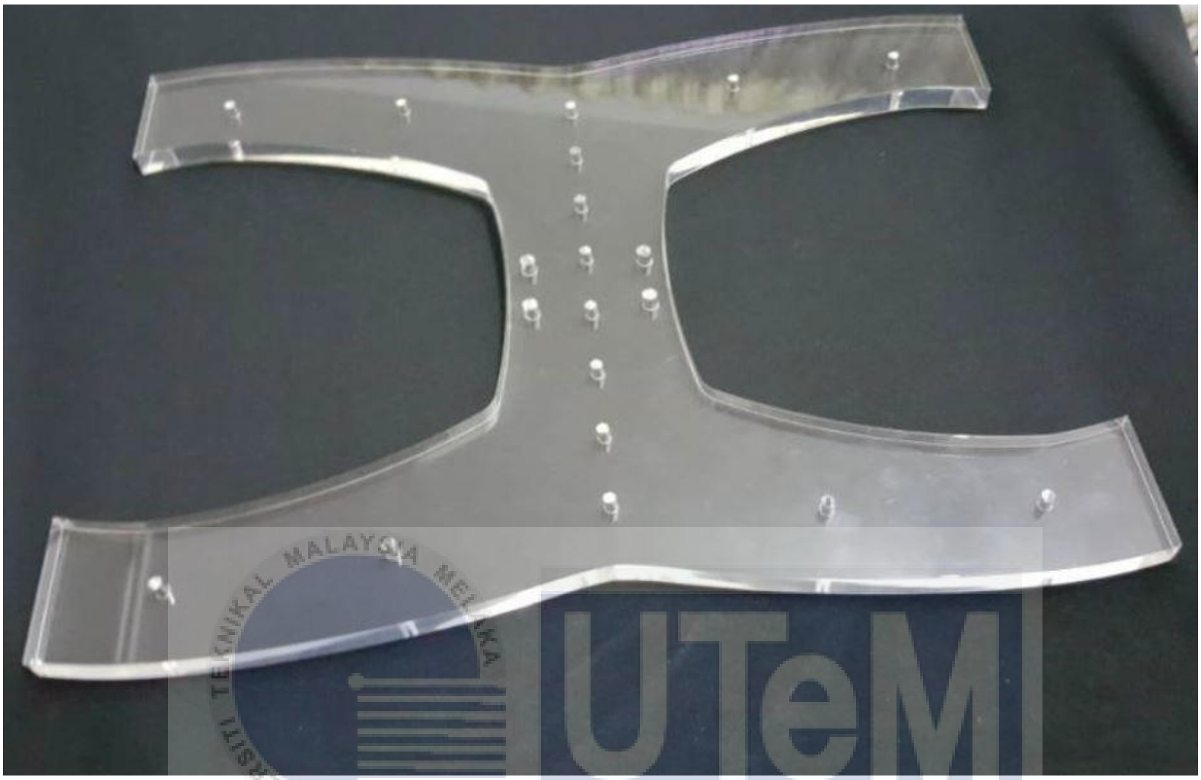

Figure 57 Acrylic bottom body

4.4.4 SIDE BODY (FRAME)

Figure 58 Acrylic side body

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In this present study on development of modular hull of a submersible vehicle for engineering services. The results from the study reveal that by using different material using similar design the process of designing a submersible hull for an autonomous underwater vehicle requires ideas and data from various resources to come up with the needed design. The process needs to be done in a proper manner starting from hand sketching, then to using the CATIA software. The design for this project are done part by part. Starting from the main body, the side body, until the completion where the thrusters are put in place. The factors that affects the body includes the stability, the hydrolytically and the strength. The test is conducted using CATIA with the command of finite element analysis FEA and the use of ANSYS software to check the hydro capabilities. The test is conducted on the design of main body, the weight platform and the poles connecting the side bodies. The result is obtained from the finite element analysis and the computational fluid dynamic, CFD.

5.2 RECOMMENDATION

Several recommendations for future works on this project are listed as below: -

1. Study the literature review more thoroughly.
2. Studythe process covers the full design in CATIA software which will be presented in this report.
3. Study the conduct drawing, strength testing analysis, and the hydrodynamics of the AUV parts using Ansys software.
4. Study developing the hardware for the modular hull and doing a test run simulation
5. The CFD and FEA analysis shall be made on the assembly rather than the components.
6. Thruster design may be tuned to achieve certain goal like completing 10 m distance in 15 s.

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