ENHANCEMENT OF MECHANICAL PERFORMANCE OF PORTABLE OIL SPILL SKIMMER FOR OIL SPILLS RESPONSE AND RECOVERY (OSRR) ACTIVITIES

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

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DECLARATION

I hereby, declared this report entitled "Enhancement of Mechanical Performance of Portable Oil Spill Skimmer for Oil Spills Response and Recovery (OSRR) Activities" is the result of my own research except as cited in references.

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Date : 28 AUGUST 2021

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

……………………………………………………………

(IR. DR. LOKMAN BIN ABDULLAH)

ABSTRAK

Insiden tumpahan minyak boleh membawa kesan buruk kepada kehidupan manusia dan akuatik serta alam sekitar sekiranya tiada tindakan cekap yang diambil untuk menyelesaikan masalah itu. Antara cara konvensional bagi mengawal tumpahan minyak adalah menggunakan halangan dan bahan penyerap untuk mengambil minyak tumpah secara mekanikal. Sebuah prototaip iaitu "Portable Oil Spill Skimmer" telah dicipta untuk melengkapkan kaedah pengambilan semula tumpahan minyak yang sedia ada tetapi telah menghadapi beberapa masalah pada komponen mekanikal dalam operasi. Projek ini menekankan penambahbaikan "Portable Oil Spill Skimmer" dari segi prestasi mekanikalnya untuk menahan keadaan buruk di laut dengan lebih baik dan kebolehlaksanaan dalam kawasan air terbuka semasa tindak balas tumpahan minyak dan aktiviti pengambilan. Penambahbaikan ini melibatkan pemilihan bahan yang sesuai untuk aplikasi di kawasan yang berbeza seperti laut, sungai dan kawasan yang tertakluk kepada tumpahan minyak. Analisis "Stress-Strain" dan "Computational Fluid Dynamics (CFD)" telah digunakan untuk mengkaji reka bentuk prototaip yang sedia ada dan membuat perubahan untuk mengoptimumkan kawasan bawah model seperti bingkai, badan dan "thruster". Model 3D bingkai, badan dan "thruster" telah dihasilkan dengan menggunakan perisian pemodelan iaitu SOLIDWORKS. Selepas simulasi "Stress-Strain", keputusan menunjukkan bahawa bingkai aluminium yang direka mampu menampung beban komponen-komponen "Portable Oil Spill Skimmer". Selain itu, simulasi CFD telah digunakan untuk mendapatkan kuasa seretan dan tujahan pada badan dan "thruster" untuk membuat keputusan dan justifikasi pada bahagian yang dicadangkan. Kesimpulannya, penambahbaikan yang dicadangkan pada "Portable Oil Spill Skimmer" untuk meningkatkan keteguhan dan kemampuan bergerak dapat membantu dalam ketahanan dan kecekapan sistem semasa operasi pengambilan minyak.

ABSTRACT

Oil spill incidents can bring adverse effects to both human and aquatic life as well as the environment if there is not any efficient action taken to resolve the problem. Conventional ways of controlling the oil spillages which are using barriers and absorbent materials to recover the spilled oil mechanically. An earlier prototype of Portable Oil Spill Skimmer has been developed to compliment the recovery of oil spills of the existing methods but encounters limitations on the mechanical components during operation. This project emphasizes on the enhancement of the Portable Oil Spill Skimmer in terms of its mechanical performance for better seakeeping ability and maneuverability in the open water during oil spill response and recovery activities. The enhancement includes the selection of material suitable for the application in different areas such as sea, river and area subjected to oil spill. Stress-Strain and Computational Fluid Dynamics (CFD) analyses are employed to review the design of the existing prototype and make changes to optimize the underperformed area of the model like the frame, hull and thruster. 3D models of frame, hull and thruster are produced by using solid modelling software like SOLIDWORKS. After performing the stress-strain simulation, the results show that the designed aluminium frame is able to sustain the heavy loading of the various components of Portable Oil Spill Skimmer. Also, the CFD simulations are used to determine the drag and thrust force of the hull and thruster so that the results can be used to make decisions and justifications on the proposed parts. In conclusion, the enhancements proposed onto the Portable Oil Spill Skimmer to improve the robustness and maneuverability could help in the durability and efficiency of the system during oil recovery operations.

DEDICATION

I would like to dedicate this work to my

Beloved parents and siblings

Appreciated friends

Honourable supervisor and lecturers

For giving me moral support, knowledge, time, cooperation and encouragements.

Thank you so much.

ACKNOWLEDGEMENT

First and foremost, I am very grateful with the help and guide given directly or indirectly from respected parties throughout the completion of my final year project. I would like to express my utmost appreciation to Ir. Dr. Lokman bin Abdullah, my respected supervisor, for his great mentoring, valuable guidance, keen interest and encouragement throughout this project.

In addition, I would like to express my thanks to my friends and family who give unconditional help and support through the period of completing my final year project. Their comments and advice have meant so much and without these motivations, I would have faced many problems during this time of pandemic.

Lastly, I would like to express appreciation to everyone who directly or indirectly contributes to this project and extend my apology to those for not being able to mention each and every one of you.

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LIST OF ABBREVIATIONS

ABS	-	Acrylonitrile Butadiene Styrene
ASV	-	Autonomous surface vehicle
AUV	-	Autonomous Underwater Vehicle
CAD	-	Computer Aided Design
CFD	-	Computational Fluid Dynamics
CFRP	-	Carbon Fibre Reinforced Polymer
CNC	-	Computer Numerical Control
DC	-	Direct Current
EMF	-	Electromotive Force
FEA	-	Finite Element Analysis
FEM	-	Finite Element Method
GFRP	-	Glass Fibre Reinforced Polymer
GTAW	-	Gas Tungsten Arc Welding
HAZ	-	Heat Affected Zone
IOT	-	Internet of Things
LENS	-	Laser Engineered Net Shaping
LMD	-	Laser Metal Deposition
OSRR	-	Oil Spill Response and Recovery
PC	-	Polycarbonate
PP	-	Polypropylene
PVC	-	Polyvinylchloride
RANS	-	Reynolds-Averaged Navier-Stokes
RAO	-	Response Amplitude Operator
RBF	-	Radial Basis Function
ROV	-	Remotely Operated Vehicle
SWATH	-	Small Waterplane Area Twin Hull
TIG	-	Tungsten Inert Gas
USV	-	Unmanned Surface Vehicle
3D	-	3-Dimensional

LIST OF SYMBOLS

kg	-	Kilogram
kgf	-	Kilogram-force
%	-	Percent
N	-	Newton
Fr	-	Froude Number
RAO	-	Response Amplitude Operator
°C	-	Degree Celsius
kg/m^3	-	Kilogram per Cubic Meter
kg/mm^3	-	Kilogram per cubic Millimetre
MPa	-	Mega Pascal
Pa	-	Pascal
m	-	Metres
mm	-	Millimetre
rpm	-	Revolution per Minute
m/s	-	Meter per second
s	-	Seconds
W/m°C	-	Watts per Meter Degree Celsius
I_o	-	No-load Current
R_m	-	Winding Resistance
K_v	-	Speed Constant
A	-	Ampere
V	-	Voltage
W	-	Watt

CHAPTER 1

INTRODUCTION

1.1 Background of Study

According to Doerffer (1992), oil refers to all form of petroleum which includes crude oil, sludge, fuel oil, oil refuse and refined products. Appropriate guidelines are vital to make sure that the waste oil is securely kept inside containers and sent over to collection center for disposal (Abdullah et al., 2019). Without proper handling, the oil oftentimes ends up being released into the water sources like rivers and oceans. When the issues of oil spillage are resolved immediately, it will affect the environment and ecosystem around the oil spillages area in a negative way. An action plan for oil spill response is highly critical for maintaining the environment around the field of oil spills. During an emergency situation, the action taken must be sensitive and successful in order to prevent widespread spillage and cause more harm to the creatures around the area of incident. Dave & Ghaly (2011) claimed that the traditional methods of removing oil such as booms, skimmers, in-situ burning, chemical dispersion, etc. have common disadvantages of labour intensive, expensive, and high complexity as well as additional treatment to separate the water from the recovered oil.

As a result of these limitations, Abdullah et al. (2019) has developed a prototype of portable oil spill skimmer to serve as an alternative solution to current method of oil recovery from the water surface. The prototype has a vast area of operation that covers the ocean, seashore, water treatment plants, rivers and reservoirs. The prototype uses a roller-type of skimmer which is oleophilic and hydrophobic to capture oil from the water surface. Based on the results and observations obtained from the study, there are shortcomings in the prototype such as the low robustness of the frame structure when it reaches area of rough water condition, the usage of chain and sprocket which is inefficient in oil skimming system, design of propellers that is not optimized for low and high speed maneuvering and the selection of electric motor and power source. Moreover, it shows that if the machine broke down, capsized or power depleted in the middle of operation, there is not a way to recover it but to abandon which will result in a financially loss and failure of oil recovery operation.

This study is about developing and optimizing the drawbacks on the current portable oil spill skimmer to further enhance in terms of its mechanical functionality. This includes the optimal design of propellers, selection of appropriate electric motors and materials for each application in the enhanced version of portable oil spill skimmer. According to Windyandari et.al (2018), the geometry of the hull shape and the dimension of watercraft have to be taken into consideration when determine the suitable design of propeller in order to maximize the efficiency of the propulsion. Odetti et al. (2019) claimed that a catamaran design for the hull has an advantage of draft reduction while keeping the similar high payload of an autonomous surface vehicle (ASV). Besides, Carlson et al. (2019) also stated that design of catamaran is light in weight and robust and at the same time, increasing the stability to reduce the chance of the ASV to roll over on the water surface. With the ideal combination of the hull, frame structure, electric motor, skimming system and propeller, overall efficiency can be improved, so that the energy is conserved and at the same time, improving endurance over the operation of oil spill response and recovery.

1.2 Problem Statement

Oil spill is a form of water pollution whether it is released from the marine accidents, operations or from the irresponsible dumping into nearby water sources. When the oil is dumped into open or confined body of waters such as seas and rivers, the ecological damage on the ecosystem could be huge and irreversible. Currently, a prototype of mechanical oil skimmer called Portable Oil Spill Skimmer (Abdullah et al., 2019) as shown in Figure 1.1 has been developed specifically for the oil spill response and recovery activities. However, there are a few limitations regarding this prototype that have been observed during the testing. In real world situation, oil recovery activities might take hours to complete, and this will have a great impact on the durability of the frame, electronics and propulsion systems such as the electric motors and power sources. Other than that, the maneuverability and robustness as well as the stability of the oil skimmer are significantly reduced in rough water conditions due to the flaws in the frame, hulls and thrusters. Although the frame and hulls made of PVC pipe material is lightweight, but it is not strong and durable to withstand the force of the water waves and loading of the components as well as the recovered oil. Also, the poorly designed propellers and unsuitable electric motors are not producing sufficient thrust for agile movement. As a result, these flaws lead to water seepage and inefficient propulsion system in the Portable Oil Spill Skimmer and ultimately causing permanent damage or failure of machine.

Figure 1.1: Reference model of existing Portable Oil Spill Skimmer (Abdullah et al., 2019)

1.3 Objectives

The objectives of this project are as follows:

a) To conduct finite element analysis (Stress-Strain Analysis, deformation, factor of safety) for the designed Portable Oil Spill Skimmer frame by using ANSYS Mechanical Simulation.

b) To simulate and analyze the Portable Oil Spill Skimmer hull resistance by using ANSYS Fluent CFD analysis.

c) To determine the thrust force produced by thruster by using ANSYS Fluent CFD analysis.

1.4 Scope of Study

The project was carried out to review the current portable oil spill skimmer and make amends primarily focusing on the mechanical performances of the semi-autonomous machine. Improvements and new features will be analyzed through extensive research on the related field.

A number of scopes and guidelines are listed to ensure that the project is conducted within its intended boundary and heading in the right direction to achieve its objectives.

a) Study on the mechanical performance of structural parts of Portable Oil Spill Skimmer. Mechanical analysis will be performed on the frame to select the most appropriate materials and parts for the Portable Oil Spill Skimmer for enhanced capability in oil spill response and recovery activities.

b) Review current hull design of Portable Oil Spill Skimmer through journals and articles related to oil spill response activities. 3D-modelling will be performed on the appropriate hull design using computer aided design (CAD) software and simulated with computational fluid dynamics (CFD) analysis.

c) Study and select on the propeller design and the choice of electric motor to maximize propulsion and energy efficiency over the operation of oil spill response. Appropriate propeller design will be designed through computer aided design software for optimization and simulated by using computational fluid dynamics (CFD) analysis.

1.5 Significance of Study

Following the completion of this study, the current version of Portable Oil Spill Skimmer will be enhanced in terms of the robustness of the entire system and structure. Improving the design and selection of suitable material for the frame to house the electrical and mechanical parts could help it to perform well without fail under rough conditions like wavy sea. Furthermore, appropriate hull design coupled with optimized propeller design and electric motor will aid the propulsion efficiency with higher speed and maneuverability at the same time help saving energy for better endurance.

1.6 Organization of Report

In this project, there are five chapters consisting of introduction, literature review, methodology, results and discussion as well as the conclusion and recommendations. Each and every chapter of this project have its own purpose of describing the content.

The background of the study is discussed in the Chapter 1 of Introduction. The problems related to the field of study are identified through observation and analysis. This comes after the objectives to be achieved during the study and scope which narrows down the area of the study. Impact of this study will have shown how is the optimization of parts benefitted the performance of machine.

Thesis and research regarding to this project is discussed in Chapter 2 which covers literature review of the report. It focuses on the development of autonomous surface vehicle and the design and performance analysis of propeller as well as the manufacturing technique of material suitable for the application of this project. This usually covers the study subject hypotheses and prior papers, books, journals, articles and internet reviews.

The process to be performed on the Portable Oil Spill Skimmer is addressed throughout Chapter 3, Methodology. The flow of this project is illustrated and discussed with a flowchart. This chapter comprises the process flow which covers the selection of material, steps of conducting stress-strain analysis on the frame design and computational fluid dynamics analysis on the hull and thruster for Portable Oil Spill Skimmer.

The results obtained from the analyses is discussed in Chapter 4. The stress-strain analysis performed on the frame using ANSYS which includes the total deformation, equivalent stress and strain value. In addition, the values of hull resistance and thruster thrust force are obtained using the ANSYS FLUENT computational fluid dynamics are discussed in this chapter.

Project summarizing and conclusion are discussed in Chapter 5, which covers the important findings of the project, and recommendation of future works that can be carried out to enhance the system and fabrication of Portable Oil Spill Skimmer.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the literature review of study and work that are related to the enhancement of Portable Oil Spill Skimmer. This will also cover the areas of research regarding of autonomous surface vessels which is the foundation of the project. This chapter describes the finite element analysis and computational fluid dynamics which are covered in computer aided engineering for analyzing and optimization. Explanations regarding the materials used in marine application and the oil skimming system using roller are also discussed in this chapter. In addition, a literature review on the marine propeller and DC motor are covered as well.

2.2 Autonomous Surface Vessel (ASV)

Autonomous surface vessel is a type of watercraft that does not need the operators to be onboard in order to control the operation of the vessel. Over the years of developing ASV and with the integration of Internet of Things (IOT) technology, a compact-sized partially autonomous surface vessel is a revolutionary way for monitoring and carry out marine activities. As for the application of oil spill response and recovery activities, a specifically developed compact semi-autonomous vessel can serve as a replacement to the traditional method of oil spill recovery. In fact, this innovative way of exploring the waters is proven to lower the risk as there is no direct intervention from human at the site. Thus, the flexibility of the activity will be higher due to the low number of human involvements. With the usage of small-sized ASV, operational cost can be cut marginally as a result of less labour involved, high portability as well as low power consumption of machine (Romano & Duranti, 2012).

ASVs are often relied on electric power source, i.e., solar energy or battery to operate. When they run for an extended period of time during a mission, their source of energy can be depleted over time and leaving the ASV stranded at the site. Wang et al. (2009) highlighted that the speed and the endurance of the ASV can be improved through the ideal matching of the electric motors, propellers and hull resistance despite the small capacity of battery. Majid and Arshad (2016) pointed out that the capability to run continuously of an ASV can be achieved with a rechargeable battery and onboard power charging component. Moreover, the type of hull the ASV is based on often play a crucial role as they will affect the dynamics and resistance as well as the seaworthiness on rough environment.

2.2.1 Type of Hull

There are two different design of hull configurations to be reviewed in this project namely catamaran and small waterplane area twin hull (SWATH)

2.2.1.1 Catamaran Hull

Catamaran hull design is made up of two parallel hulls of the same size placed at the sides of the vessel as shown in Figure 2.1. A large usable area on the deck can be provided following the design of catamaran. Catamaran is so stable due to the wide beam at the sides and thus, eliminating the need of ballasting to counter the heeling moment due to the centrifugal force developed in turning. Therefore, twin-hull vessel can move more effective weight in water as compared to mono-hull vessel. Catamaran has a higher transverse stability than mono-hull due to the large moment of inertia given the separation between hulls. Furthermore, wave resistance of catamaran is reduced at displacement speed as the interference between the waves and the hull is lower than single hull vessel. However, there is limitation to the payload on a catamaran vessel if the bottom surface comes to contact with the wave, it will induce a large resistance to the vessel at low speed. Therefore, the payload is limited to 10% of the total displacement of the hull (Misra, 2016).

Figure 2.1: Design of ASV catamaran hulls (Wang et al., 2009)

Over the years, a lot of researchers have performed study on the related field to increase the seakeeping of catamaran vessels from various aspects such as the design and hydrodynamics. A. Fitriadly et al. (2018) have presented a computational fluid dynamics simulation approach to study on the seakeeping performance of catamaran of deep-v design for high speed application which is shown in Figure 2.2. Their results showed that by using different Froude number (Fr), wavelength and wave height on the catamaran model, seakeeping performance will be affected in the form of response amplitude operator (RAO) of the heave and pitch motions. They claimed that the increase of Froude number and the wavelength can lead to a better seakeeping performance while the increase of wave height lowers the model seakeeping performance.

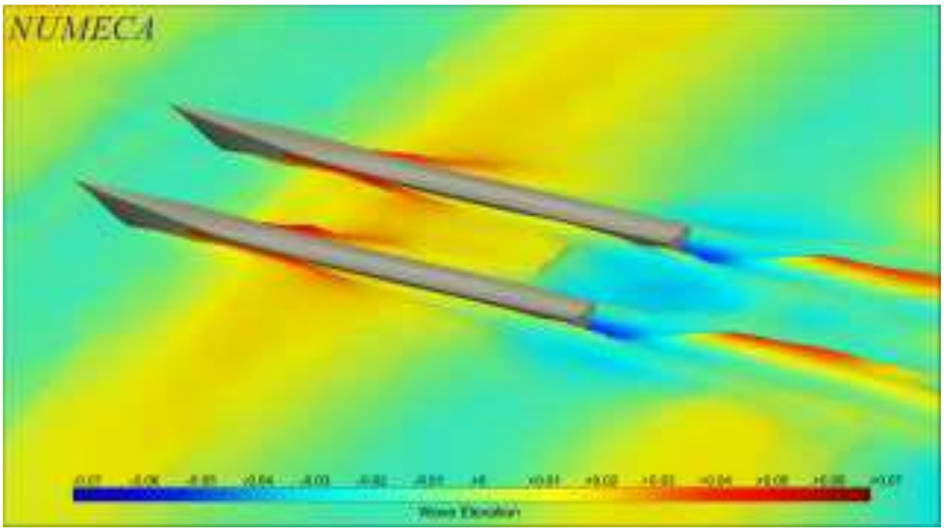

Figure 2.2: CFD visualization of deep-V catamaran hull (A. Fitriadly et al., 2018)

A bulbous bow is a bulb-like design that protrudes in front of the hull. It is designed to stay below waterline which intended to reduce the drag on the incoming wave produced by the forward motion of vessel. With the correct design, it can help increasing the speed and reduce the energy consumption of the vessel. Abdul Ghani and Wilson (2018) highlighted that the addition of bulbous bow onto catamaran hulls will provide significant benefits on the seakeeping capability of the vessel. The placement of the bulbous bulb below the water surface will affect its practicality on reducing the wave resistance. They claimed that out of three designs as shown in Figure 2.3, which are Delta, Nabla and O-Type, only O-Type bulbous bow shows promising result in reducing wave resistance and the wash height that is generated by the vessels.

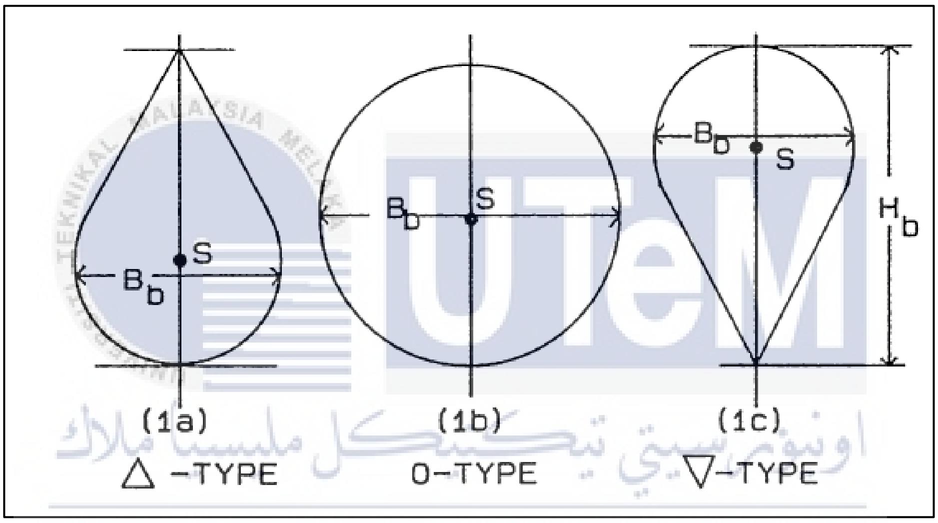

Figure 2.3: Types of bulbous bow (Abdul Ghani & Wilson, 2018)

2.2.1.2 Small Waterplane Area Twin Hull (SWATH)

Small Waterplane Area Twin Hull (SWATH) is a ship design comprises of two demi hulls. The hulls are semi-submerged in the water that resemble a body of revolution and a strut piercing the water surface. As the name implies, small waterplane area is where the contact between hull cross sectional area and the water surface is reduced in order to reduce the resistance of the wave. The features that make SWATH vessel different from catamaran vessel are that SWATH vessel has a larger wetted surface and low water plane area which induce large skin friction drag and low effect from the pitching and heaving of the sea respectively (Misra, 2016).

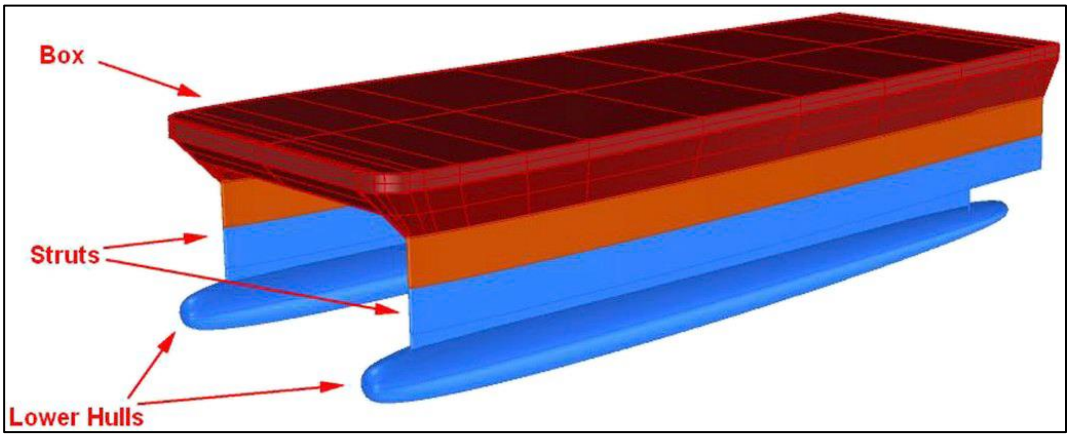

Figure 2.4: Geometry of SWATH vessel (Pérez-Arribas & Calderon-Sanchez, 2020)

According to Pérez-Arribas and Calderon-Sanchez (2020), the SWATH hulls are made up of two different geometries that are struts and lower hulls as shown in Figure 2.4. They claimed the struts are able to improve the hydrostatic stability and drag resistance reduction and wave exciting forces with the low waterplane area of SWATH. However, SWATH is not ideal to carry heavy cargoes due to the reduced waterplane area. Owing to the design of SWATH, it still has better seakeeping capability than monohulled vessel and can be used for the applications of pilot boats, offshore support vessels, passenger and patrol boat as well as yachts. Beena and Subramanian (2003) developed a parametric optimization technique that use the SWATH geometry as the variables to come up with a family of hull forms that can be used in different sea states.

Study by Begovic et al. (2019) shows that different configurations of struts and the lower hulls are also studied in calm water and wavy water to determine their seaworthiness in terms of RAO. Figure 2.5 illustrates the introduction of active stabilization system onto the SWATH design help improve the low speed motions and higher max speed in a test that mimics regular and irregular sea states.

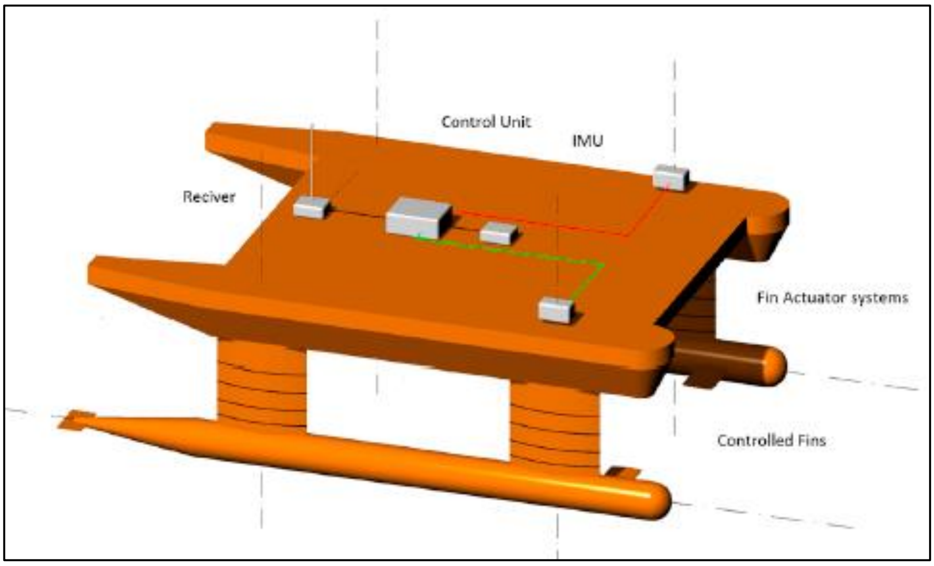

Figure 2.5: SWATH vessel with active stabilization system (Begovic et al., 2019)

2.3 Finite Element Analysis (FEA)

Finite element analysis (FEA) is a method known to simulate the nature and reaction of an assembly or part under certain boundaries so that assessment can be made on subject we defined by using the finite element method (FEM). Systems of partial differentiation equations can be resolved and set up by using of the FEM mathematical approach. From the engineering point of view, the reaction of a system is sometimes very difficult to be solved using the closed form equations. Therefore, the system is divided into elements in order to come up with the solutions or approximations. The meshes are defined as nodes in a specific geometry of the model where the input from the user to the system outlines the nodes according to the required set of degrees of freedom such as stress, strain and other mechanical properties. The input of mathematical interactions of the degrees of freedom to the interconnection between the nodes and the elements in order to come up with the solutions of common elements and continuum elements. Hence, the analyzation can be performed with the set of equations created for the particular elements and information regarding the reaction of the systems is shown to the user. Regarding to the number of elements whether it is small or large in size, the increasing set of equations is no longer practical to be solved by hand. Therefore, the approximation done by using finite element method is deemed good enough for engineering analysis purposes (Thompson & Thompson, 2017).

As mentioned by Kim (2011), violent free surface flows can now be solved successfully by using computational fluid dynamics (CFD) numerical approach. With the usage of CFD in the marine application, it can be a tool to design the vessels for better seakeeping capability by simulating fully nonlinear three-dimensional seawater slamming and green water on deck. As a result, the CFD analysis can also deduce the structural loads the vessel can handle. In a nutshell, computational fluid dynamics analysis emphasizes on the vessel motion and structural loads instead of a localized impact force on certain part of the vessel. Thus, this analysis will be able to assume the weak spot on the structural load on the vessel which makes it very reliable for ship design.

Zhang et al. (2006) claimed that computational fluid dynamics (CFD) has played an important role in designing complex ship geometry and simulating the wake wave pattern and the surface resistance against the incoming wave. This will enable the assumption of the performance of the ship hydrodynamics. Due to the lower cost and time than conventional modelling, CFD provides more information on the flow pattern to aid the designer in designing and refining a better ship design. Other than that, the practicality of CFD is vastly acceptable in the marine industry as it helps the engineers to further comprehend the flow around the hull, wake field, appendage alignment and so forth. From the result of their studies using numerical approaches of three-dimensional RANS equation, different Froude numbers and wake flow, it is deduced that CFD analysis is indeed helpful in simulating the ship hydrodynamics and designing the ship as well as the propeller.

Yang and Huang (2016) highlighted that by using a computational fluid dynamics simulation tool in the early stage of designing a ship hull has proven to be successful in optimizing the hydrodynamics of the ship which is highlighted in the flowchart in Figure 2.6. They mentioned that using two CFD tools namely, a simple and a high-fidelity, in the hydrodynamic module of the design optimization tool. Evaluation of hydrodynamic performances such as drag and seakeeping in the early phase of hull design can be performed using the simple CFD tools. Meanwhile, in the final stage, the high-fidelity CFD tool is used to finalize the optimal hull form. During the optimization process of the hull, a radial basis function (RBF) based modification is capable in various hull form such as monohull, catamaran and trimaran. By employing the RBF method, it can produce a smooth new hull form that meets the geometry constraints set by the user. As a result of using the CFD simulation, a considerable amount of drag reduction is achieved for the monohull, catamaran and trimaran which proven that hydrodynamic design optimization tool is very helpful in innovative ship designing.

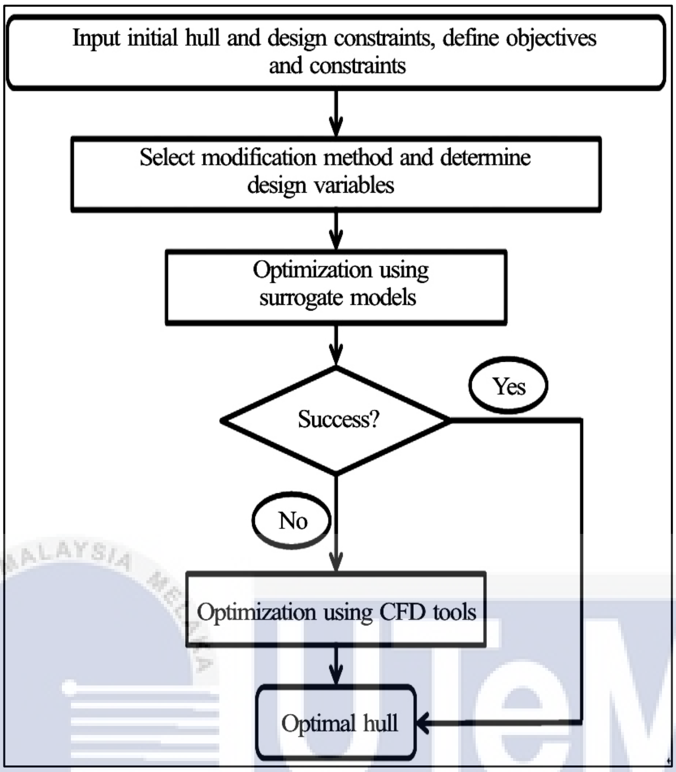

Figure 2.6: Flow chart of the hull optimization process (Yang & Huang, 2016)

2.4 Materials for Marine Application

2.4.1 Composite Material

Composite materials like glass fibre reinforced polymer (GFRP), carbon fibre reinforced polymer (CFRP) and other fibre reinforced polymeric materials have been extensively used in the marine industry over the few decades. Rubino et al. (2020) stated that by combining fibres with thermoset resin as matrix material can reduce the maintenance of parts substantially due to the ability of composites to withstand the harsh, corrosive and salty environment of the sea. Thermoset resin is preferable as it provides a lighter-weight durability and better dimensional stability. The lightweight properties of resin have contributed to better efficiency and reduced operation cost while remained high stiffness for stability. Subsequently, shipbuilding industry has shifted to composite sandwich structures in producing hull and deck of better durability and strength. The sandwich structure comprises of two high stiffness outer layer skins and a soft and thick core in the middle. The outer layer provides high bending stiffness while the middle core supports the shear and compressive stresses of the outer layer, preventing dimensional instability. Thus, as mentioned by Ertuğ (2013), these composite sandwiches are high favourable in small watercraft application due to its lower inertia, better stability and buoyancy.

Rohith et al. (2019) claimed that the superior attributes of fibre reinforced polymers like high durability, workability and lower cost of production are the reasons why the marine industry sought after. Almost all the components used in the shipbuilding industry are made up of glass fibres combined with polyester. However, these glass fibres are non-biodegradable, and hence bring harm to the aquatic ecosystem. Alternatively, this glass fibre is replaced with fishnet which is actually made up of nylon fibres. In comparison to glass fibre, nylon fibre excels in terms of impact strength and have the similar flexural strength and modulus rigidity, which make the nylon fibre as the substitute material for producing hull structures.

Another material commonly used to produce fibre reinforced polymer in the marine industry is called E-glass fibre. Ertuğ (2013) investigated that by combining the E-glass composite with steel to be a hybrid system that results to a low drag hydrodynamic hull design, lightweight and travel faster. A stealthy and high corrosion resistance towards seawater ship hull can be fulfilled using the composite material. Other than that, this hybrid between E-glass composite and steel can give the hull a more robust and reliable features as it can withstand a higher force at the seas.

2.4.2 Acrylonitrile Butadiene Styrene (ABS)

Acrylonitrile butadiene styrene (ABS) is a type of thermoplastic polymer, having a high glass transition temperature at approximately 105 °C. It is made up of three different monomers namely 15-35% acrylonitrile, 5-30% butadiene and 40-60% styrene and hence, known as terpolymer. ABS plastic is usually refined from the fossil fuels, making it non-biodegradable. Each of the monomers has different characteristics, and when combined together, it provides a strong, malleable, good workability and high temperature resistance as it can be used in a temperature range of -20 °C to 80 °C. Thus, ABS plastic has become the prime choice for the engineers and professional applications. ABS can be printed using current technology of rapid prototyping for parts using for marine applications, but it is suggestible to optimize the parameters of the 3D printing like layer thickness, shell thickness and infill density to enhance the strength and durability when in use in the water for a prolonged duration (Sewiko et al., 2019).

Table 2.1: Properties of the materials used in constructing ROV (Marzbanrad et al., 2011)

	Material	Density (kg/m^3)	Young's modulus (Pa)	Thermal conductivity (W/(m°C))
1	ABS	1.060E+003	2.890E+009	0.299
2	PVC	1.400E+003	2.585E+009	1.785
3	Bronze	8.874E+003	1.096E+011	62.000
4	SS 316	7.750E+003	2.067E+011	16.000

When it comes to surface or underwater remotely operated vehicle (ROV), ABS plastics is preferred for the frame construction. Marzbanrad et al. (2011) mentioned that low density, water corrosion resistant, accessible and easy to form materials is favourable for the construction of the frame of the ROV. As a result, ABS plate is used to construct the frame of the ROV due to its lightweight and high Young's modulus properties.

2.4.3 Aluminium Alloy

Aluminium alloy is a composition between pure aluminium and other alloying elements meant to increase the mechanical properties while remain light in weight. Common alloying elements consist of copper, magnesium, manganese, silicon, tin and zinc. Aluminium alloys are mostly used in the marine industry due to its lightweight and corrosion resistance properties. These alloys fall in the category of 5000 series and 6000 series which are for wrought alloys, a designation by the International Alloy Designation System. 5000 series aluminium alloy is made up of magnesium as the alloying element while 6000 series have silicon and magnesium. 5083 aluminium alloy is the mostly sought-after in the shipbuilding industry due to its remarkable high strength-to-weight ratio, high corrosion resistance to seawater and good weldability. When the hull is reduced in weight, overall weight will also drop and this leads to better performance and energy efficient as well as reduce stress on the moving parts especially the propulsion system (Ertuğ and Kumruoğlu, 2015; Gupta et al., 2020).

Jebaraj et al. (2020) found that after welding with filler metal ER5183 is performed on 5083 aluminium alloy plate using gas tungsten arc welding (GTAW), the weldment and the parent metal behave differently when subjected to tests like destructive physical analysis and electrochemical corrosion test. Results show that there is no change microstructurally in the heat affected zone (HAZ) in both weldment and base plate. There is decrease in hardness due to formation of magnesium aluminide in the weld region, but it is very minimal which make 5083 aluminium alloy the first choice in marine application as no post-weld heat treatment is needed. However, the weldment corrodes faster than the parent metal in the sodium chloride solution during the electrochemical test. The existent of magnesium aluminide speeds up the reaction between the alloy and the solution.

2.5 Oleophilic Drum Skimmer

Oleophilic drum type of skimmer is commonly used for oil spill response and recovery activities. Oil spillage is confined in an area by booms in order to prevent further spreading and then to be picked up by a rotating oleophilic drum whose material has the ability to adhere the oil but not water. Due to rotating momentum, it draws the oil towards the drum and subsequently be removed by the means of scrapping oil off the drum surface and stored in a storage tank.

According to Broje and Keller (2006), the oil recovery rate is corresponded to the surface area of the drum in every rotation. Figure 2.7 shows that by changing the pattern on the drum surface from smooth to triangle-shaped grooved pattern and use an identical pattern on scraper, surface area of the drum will increase, and hence maximized the amount of oil collected as illustrated in Figure 2.8. Oil recovery efficiency is also influenced by the layout of the grooves and viscosity of oil. Lighter oil needs grooves that is shallow and narrow while heavier oil requires grooves that is deep and wide in order to increase efficiency. As a result of the innovative pattern, oil recovery efficiency of the skimmer has increased threefold as compared to smooth surface drum and able to recover oils of various viscosities.

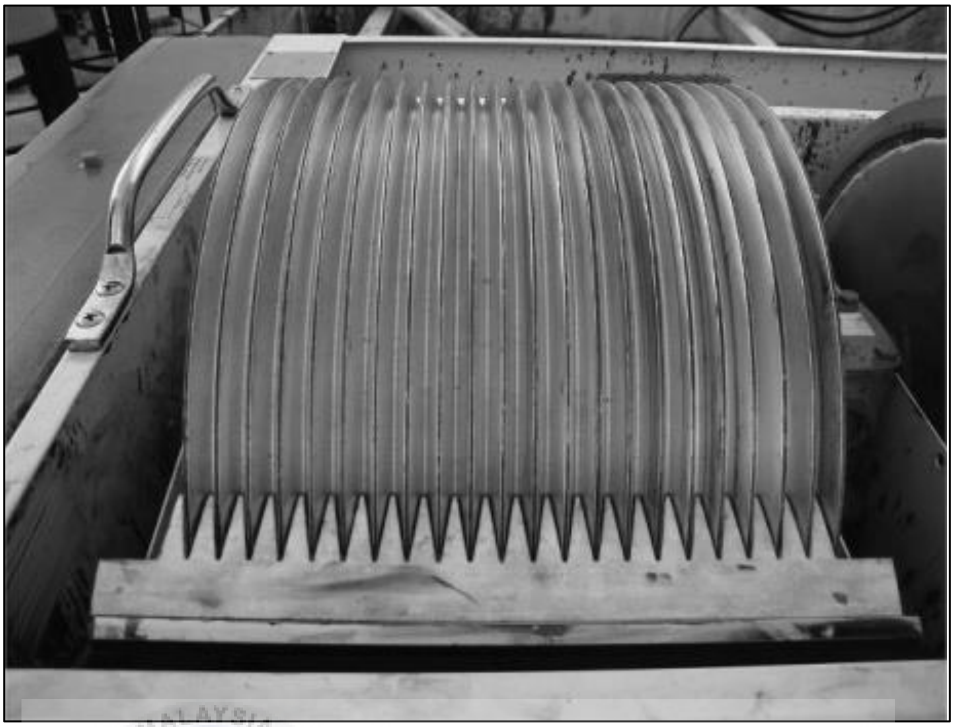

Figure 2.7: Drum with triangular-shaped grooves and matching scraper (Broje and Keller, 2006)

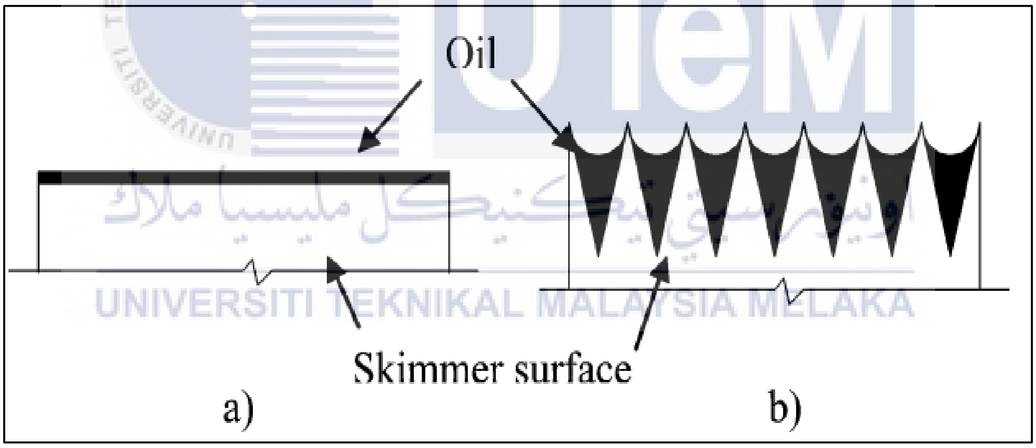

Figure 2.8: Cross-section of recovered oil on (a) smooth surface and (b) grooved surface (Broje and Keller, 2006)

Broje and Keller (2007) stated that material of the drum and its rotational speed play a major role in the oil recovery activities for oil of different viscosity. Three different materials are used in the experiment which are polyethylene, neoprene and aluminium. They found that neoprene drum has higher efficiency than polyethylene and aluminium in collecting low viscosity oil and oil slick of higher thickness. All these materials are able to recover more oil, in this case almost doubled, in thicker oil slick (25 mm) than thinner oil slick (10 mm) for high viscosity oil. Meanwhile, the results in Figure 2.9 shows that the ideal rotational speed for every drum is 40 rpm that draws little to no water as compared to 65 rpm that draws more water of the same oil slick thickness. However, oil recovery rate is higher across the different oil viscosity when the speed increases. Another study presented similar result, showing that the oil recovery rate is influenced by the oil slick thickness for both drum and disc skimmers as illustrated in Figure 2.10. Rotational speed for both skimmers have to be slower as oil slick thickness is decreasing in order to maintain the recovery efficiency (the amount of oil collected over the total amount of spillages recovered) above 70 % (McKinney et al., 2017).

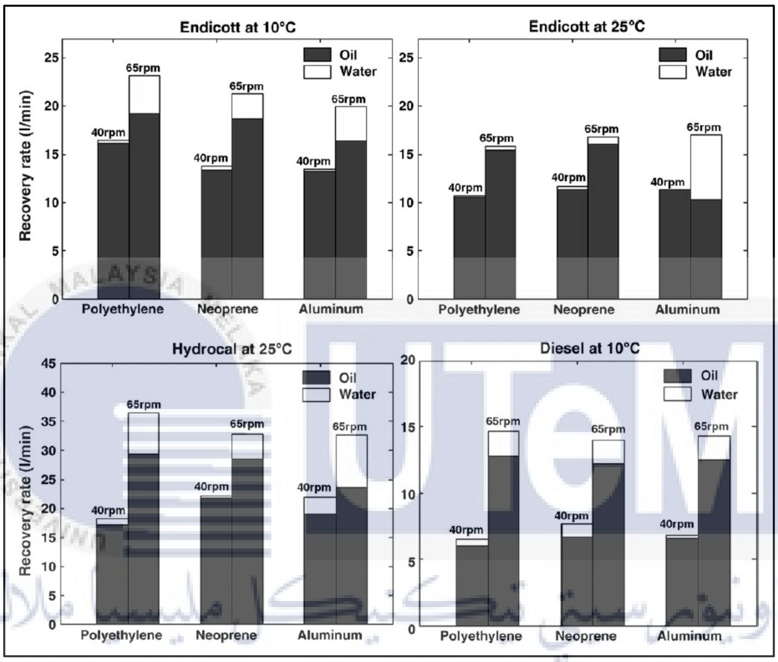

Figure 2.9: Comparison of the water and oil recovered by various drums at 40 rpm and 60 rpm of the same oil slick thickness (Broje & Keller, 2007)

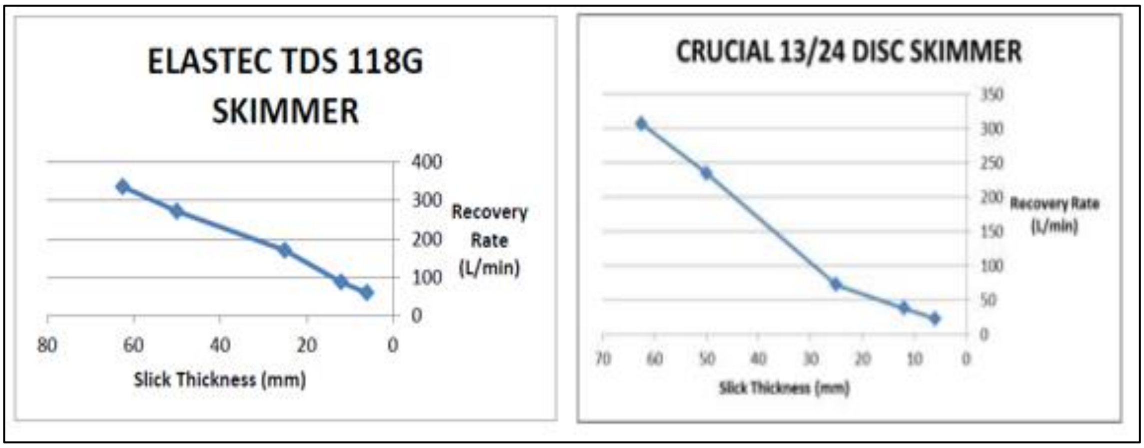

Figure 2.10: Graphed data of drum skimmer (left) and disc skimmer (right) of oil recovery rate against oil slick thickness (McKinney et al., 2017)

2.6 Marine Propellers

A propeller is a piece of hardware consists of a center hub and protruding blades around the hub set at a pitch angle that creates a helical shape. A forward propulsion force is created by rotating this propeller in water as fluid is pushed back by the blades similarly based on the principle of Archimedean screw. Presently, there are more than ten types of propellers innovated, for instance, fixed pitch propellers, ducted propellers, podded and azimuthing propulsors, contra-rotating propellers, overlapping propellers, tandem propellers, controllable pitch propellers, surface piercing propellers, waterjet propulsion, cycloidal propellers, paddle wheels, magnetohydrodynamic propulsion, and whale-tail propulsion. Each of the propellers has its own characteristics that are suitable for certain applications (Carlton, 2012).

Over the years, fixed pitch propeller is preferred by the marine industry due to its simple design and ease of manufacture. They are usually machined out of a big block of metal with weight ranging from few kilograms for a small watercraft to hundreds of tons for tankers and container ships. Owing to the reason that big sized propellers often utilize metals for example, nickel with manganese and nickel-aluminium bronze, as the prime materials due the corrosive resistance and high strength characteristics. On the other hand, polymers, aluminium, nylon and carbon fiber composites are commonly used to produce propellers for small applications as the materials are easier to be worked with (Carlton, 2012).

2.6.1 Geometry of Propeller

Before the selection of appropriate propeller for a particular application, it is essential to understand the basic geometry of propeller which is shown in Figure 2.11 and Figure 2.12. First of all, we start with the hub of a propeller which is the solid center disk that is coupled with the propeller shaft. Blades are the twisted fins or foils that are projected from the circumference of the hub. The blade root refers to the end of blade that is attached to the hub while the blade tip is the furthest edge of the blade from the center point of the hub. The radius of the propeller is the distance measured from the center of the hub to the blade tip. Next, is the pitch, which is defined as the forward movement of how far the propeller travels in one rotation when paired to a ship. The distance from the leading edge to the trailing edge measured with a straight line at a given station along the propellers radius is known as the chord and the angle where the propeller blade is offset from the center of the hub is called rake. Skew angle of the propeller is the angle measured at the center line of the hub when lines passing from hub center line through the mid-chord spot of any two sections on a projected front view. Figure 2.13 shows the two types of skew designs i.e., balanced and biased (Duelley, 2010; Carlton, 2012).

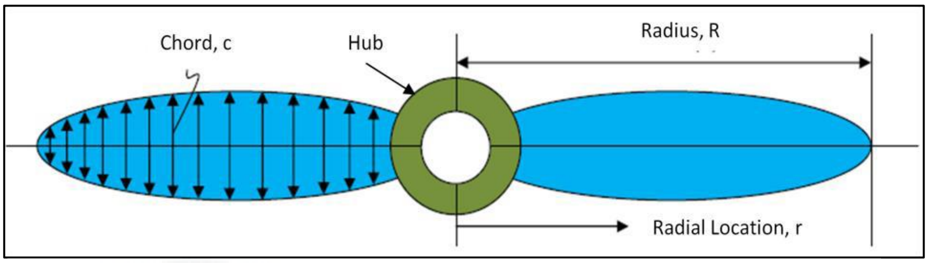

Figure 2.11: Terminology of propeller (Duelley, 2010)

Figure 2.12: Rake angle of a propeller (Duelley, 2010)

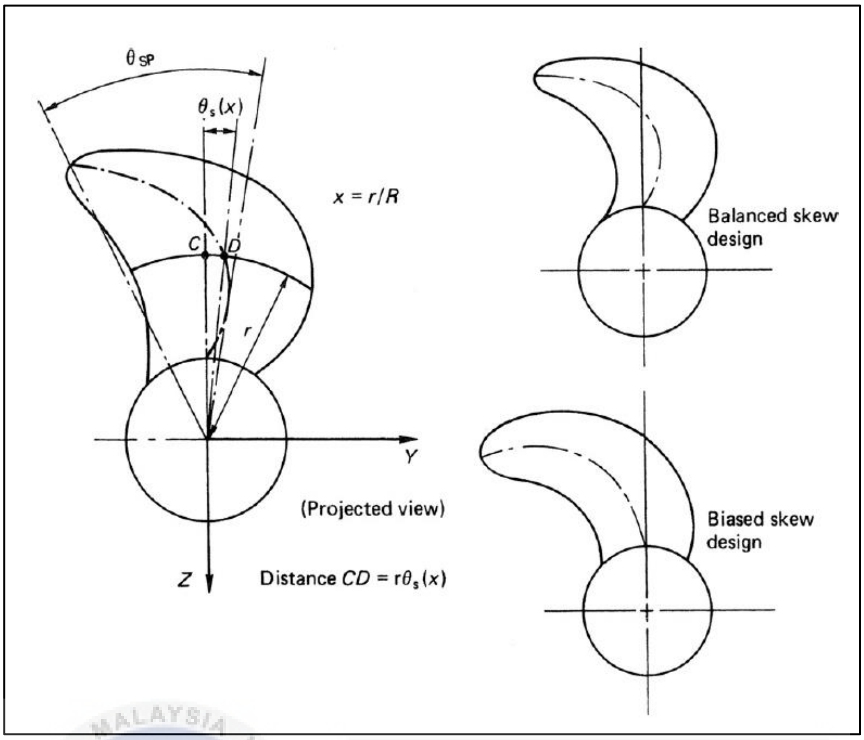

Figure 2.13: Skew angle of propeller (left) and designs of the skew (right) (Carlton, 2012)

2.6.2 Selection of Propeller

There are some parameters that need to be reviewed so that the propeller can perform for the intended applications. Wrong selection of propeller will lead to an inefficient system of the shaft and power unit. Small propeller hub produces the highest thrust ideally. Though, the hub must be balanced between the diameter size and the toughness in order to get the maximum thrust but without compromising the hub strength. Next, the propeller diameter is an important geometric parameter in determining the amount of power the propeller can withstand and produce, which influence the thrust force for propulsion. The diameter of propeller for a small AUV must not over 85% of the vehicle width so that ventilation problem can be prevented when running on the water surface. Ventilation is defined as the air draws toward the propeller from the surface of water and this leads to a drop of the thrust available for moving. Generally, a big propeller rotating at low speed is more efficient than a small one rotating at high speed, but propeller of too large of size will only result in poor maneuverability due to the ventilation. So, the diameter must be compatible with the vehicle itself to produce the most efficient system when combined with the motors. The pitch of propeller determines how far it moves the vehicle forward in one rotation but in the real world, slip will occur as a result of the difference between nominal pitch and the actual distance travelled. Higher propeller pitch paired with high speed motor will increase in top speed but reduced acceleration and vice versa. The optimal ratio of pitch to the diameter should stay between the range of 0.8 to 1.8 (Techet, 2004; Duelley, 2010).

2.6.3 Performance Characteristics of Propeller

When it comes to the maneuverability of a ship, propellers are the things that enable it to propel and change direction. Every propeller is matched to their respective vessel ranging from small ship to large container ship. Windyandari et al. (2018) found that different numbers of blades on the propellers, 3-bladed up to 6-bladed, have an effect on the efficiency and the thrust forced produced under the same flow condition. There is a trade-off between the thrust force and efficiency as 3-bladed propeller produces lowest thrust force but highest efficiency while 6-bladed propeller produces highest thrust force, but lowest efficiency as higher blades area contributes to higher thrust (Windyandari et al., 2018). Ideally, propeller with highest efficiency is more favorable for the propulsion system of an autonomous surface vehicle application as inefficiency will only lead to faster depletion of the power source.

Table 2.2: Comparison of propellers with various numbers of blade (Windyandari et al., 2018)

Number of Blade	Items	CFD	Data Series
3 Bladed Propeller	Advance Coefficient (J)	0.686	0.686
	Thrust Force (kN)	3.456	3.766
	Thrust Coefficient (KT)	0.18	0.14
	Torque Coefficient (10.KQ)	0.28	0.22
	Efficiency (η)	0.70	0.706
4 Bladed Propeller	Advance Coefficient (J)	0.697	0.697
	Thrust Force (kN)	3.462	3.801
	Thrust Coefficient (KT)	0.20	0.15
	Torque Coefficient (10.KQ)	0.35	0.25
	Efficiency (η)	0.66	0.662
5 Bladed Propeller	Advance Coefficient (J)	0.525	0.525
	Thrust Force (kN)	3.645	3.823
	Thrust Coefficient (KT)	0.20	0.114
	Torque Coefficient (10.KQ)	0.30	0.17
	Efficiency (η)	0.56	0.567
6 Bladed Propeller	Advance Coefficient (J)	0.375	0.375
	Thrust Force (kN)	3.746	3.872
	Thrust Coefficient (KT)	0.26	0.102
	Torque Coefficient (10.KQ)	0.39	0.13
	Efficiency (η)	0.49	0.474

Blaich et al. (2013) used azimuth thrusters in their twin hulled unmanned surface vehicle (USV) for enhanced maneuverability. Due to the nature of azimuth, the thrusters able to rotate to any horizontal angle and thus, giving more degree of freedom to the USV movement. They also state that complex tasks like docking, dynamic positioning or trajectory tracking can be accomplished by panning the thrusters to their respective angle. Another way of increasing the thrust is to use ducted propeller. Positive thrust is generated as a result of circulation around the duct itself, pushing an inward force towards the propeller. It is essential for heavy applications where high thrust at low speed is needed when the load of the vehicle increases (Carlton, 2012). He also claimed that the duct provides half of the total thrust produced by the propeller during bollard pull test. Xia et al. (2020) acknowledged the use of ducted propeller has improved the maneuverability of AUV given the increased torque of the shaft when the height of deflector of the duct increases. Go et al. (2017) highlighted that faster inflow into the propeller can be yielded by using duct with higher angle of attack that result in enhanced thrust of propeller, but at the same time, put a stress on the torque supplied.

2.6.4 Manufacturing of Marine Propeller

Over the years of technology advancement in the manufacturing industry, innovative process has been used for the production of propeller. Even though, there are still propellers manufactured using conventional method which is sand casting. However, cast metal propeller needs to go through secondary processes like grinding and polishing due to the poor surface finish and tolerance. All these elements will result in higher cost of production. Hence, additive manufacturing and CNC machining have become the alternate way in making propeller. Degu and Sridhar (2014) found an additive manufacturing technology called laser engineered net shaping (LENS) that can manufacture propeller in lesser time and cost as well as improve the mechanical properties and build quality. Another study by Korsmik et al. (2020) claimed that fabrication of optimized 3D model of propeller using laser metal deposition (LMD), an additive manufacturing technology, is as reliable as the solid counterpart while having a 20 percent weight reduction due to optimization of the propeller internals as shown in Figure 2.14. Bellala et al. (2017) highlighted the benefits of fabrication of propeller using CNC machining process such as enhanced mechanical properties and excellent surface finish and dimension accuracy as well as eliminate the need of propeller balancing.

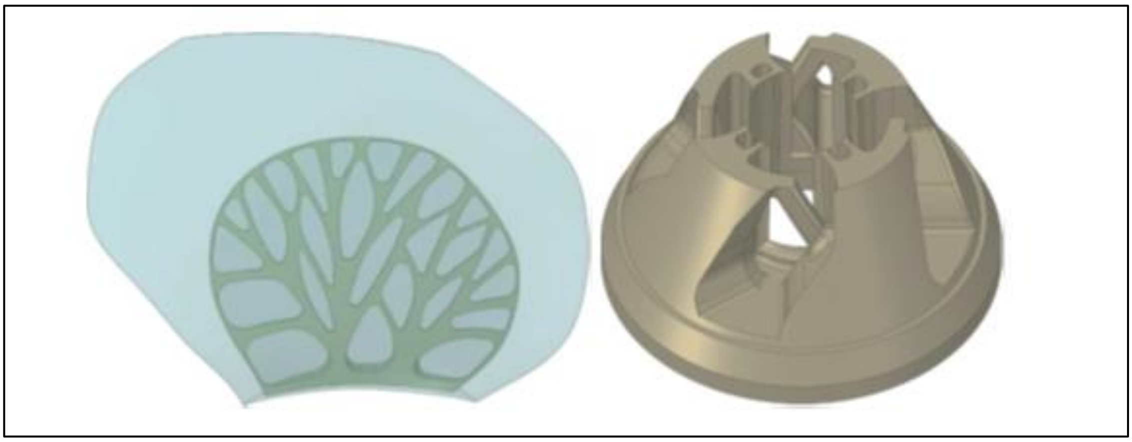

Figure 2.14: Optimized propeller blade and hub (Korsmik et al., 2020)

2.7 Direct Current (DC) Electric Motor

A direct current electric motor or DC motor is a rotational actuator that converts direct current electrical energy into mechanical energy to provide work. The rotational motion of the motor is depending on the Faraday's law of induction that generates electromagnetic field from the stator and rotor of the DC motor.

2.7.1 Selection of DC Motor

Electric motor used in an unmanned surface vehicle dictates the amount of power and torque delivered to the propeller to provide thrust. The weight of the vehicle and the drag produced are the elements that need to be assessed so that appropriate electric drive system can be chosen. For an unmanned surface vehicle, it is more practical to use direct current motors propulsion with battery as the power source so that it can control other electrical components and most importantly, zero emission of carbon dioxide. There are two main types of DC motors, brushed and brushless. Henry (2013) listed the pros and cons of brushed and brushless DC motor.

Table 2.3: Comparison between brushed and brushless DC motor (Henry, 2013)

Advantages	**Disadvantages**
Brushed	
Cheaper initial cost	Brushes eventually wear out
Older/Easier to find	Sparking/Electrical noise due to making/breaking connections
Simple construction	Brushes limit maximum speed of motor
Quick application	Harder to cool with internal, centered electromagnet
	Limit to no. of poles possible
	Less reliable
Brushless	
Better speed vs torque characteristics	Higher initial cost
Cost saving over time	Can become difficult to operate with motor controller
Less maintenance/More reliable	Most drivers slow BLDC motors by apply reverse current
Silent operation	Nearly as much power is used to stop the motor as to start it
Better speed ranges	

Budimir (2019) highlighted that the voltage availability for a certain application and the physical size of motor are the two most important criteria in selecting DC motor. He also stated that a brushless motor is able to run at higher speed than a brushed motor and when a high amount of torque needed, gearing can be added to the motors but at the expense of lower reliability. McMillan (2019) pointed out that the value of the three most important parameters of brushless motor to be as low as possible to maximize the efficiency of the overall system. The parameters are the no-load current (I_o), the current required to rotate the motor without external load, the winding resistance (R_m), and the speed constant (K_v), the generation of back-EMF by the motor at given rpm. By using these parameters, the required output power also known as the shaft power for the application can be calculated after the drag and propeller is known.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter covers the detailed explanations of methodology that have been applied in this project. Besides, the core principle of research methodology is to propose effective methods, suitable devices, strategies, and techniques to achieve this project's objectives. It comprises of the flow of process from design and modelling of the frame, hull and thruster, to conducting simulation using computer software and analysis of the results with respective to the objectives based on the scope of the project.

3.2 Project Flow

The purpose of constructing a flow chart is to illustrate the sequence of operations throughout the whole process of this project. It covers the identification of the product requirement, the design input of the parts, modelling, parts optimization, parameters for simulations, and mechanical performance analysis of stress-strain and CFD. The main goal is to arrange the time, expenses and capital for the activities needed and effectively handle risks by forecast implementation. The proposed flow chart comprises of the methods in sequential phases that will be applied to achieve our project objectives. The flowchart as illustrated in Figure 3.1 has shown processes and procedures to be taken in an orderly arrangement. Discussions and comparisons that have been made from the review of literature are used to determine the most suitable components and methods to be applied in this project.

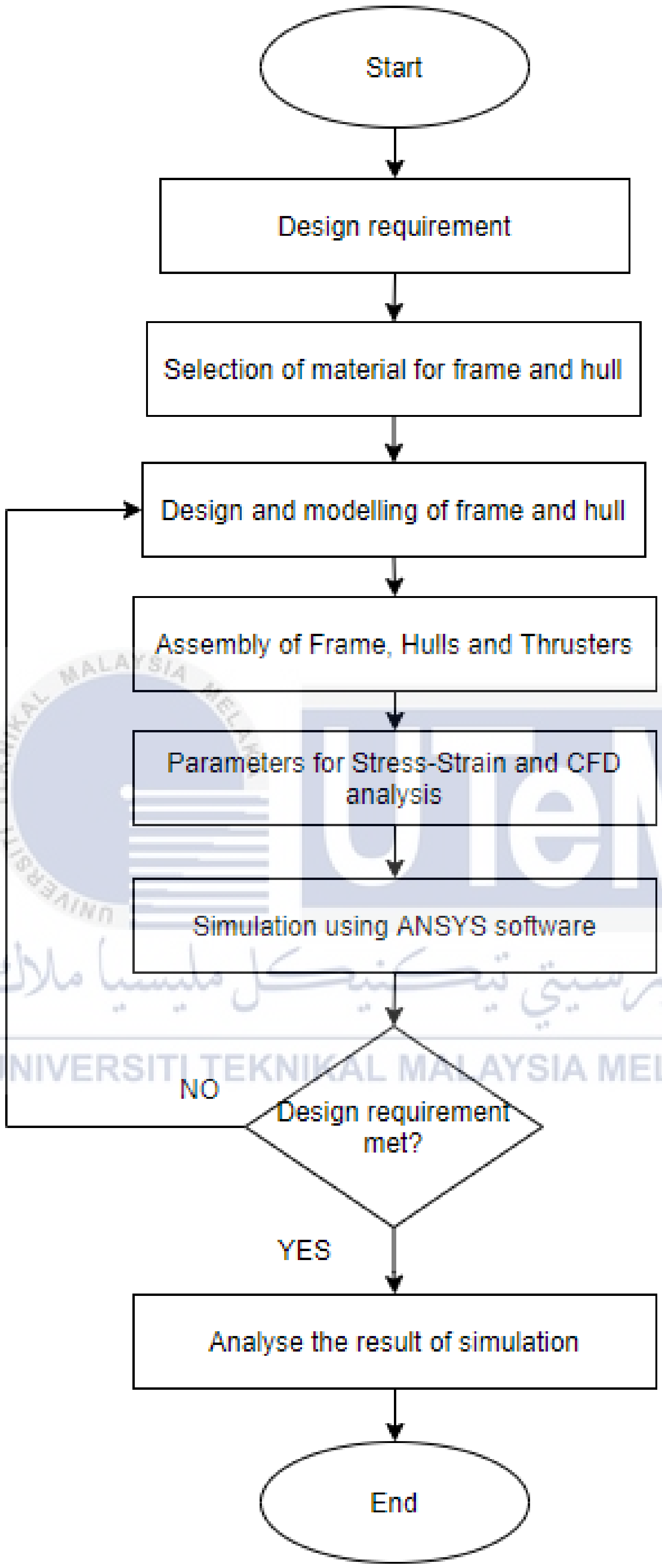

Figure 3.1: Flow chart of project

3.3 Design Requirement for Enhanced Features of Portable Oil Spill Skimmer

The product to be evaluated is defined by the functional requirements, objective of the materials selection process, constraints imposed by the requirements of the application, and the free variables. Few types of materials are selected for evaluating process using the selection matrix. The method of screening and scoring is used to choose the best material for the components. The material with the highest evaluation ranking will be selected as the most suitable material for parts of enhanced features of Portable Oil Spill Skimmer. Table 3.1 shows the design requirement for the enhancement of mechanical performance of Portable Oil Spill Skimmer.

Table 3.1: Design requirement for enhancement of Portable Oil Spill Skimmer.

Design Requirement	
Function	To collect oil spillages
Constraint	Adequate fracture toughness Lightweight Resist to corrosion Durable Easy to manufacture High strength
Objective	Maximize the robustness and stability Minimize the mass
Free variable	Choice of materials

3.4 Selection of Material

3.4.1 Selection of Material for Frame

The properties of the materials to be used must fulfil the following criteria to be chosen for the construction of the frame for Portable Oil Spill Skimmer which are:

i. Low Price
ii. Low Density
iii. High corrosion resistivity to saltwater

iv. High Young's modulus of elasticity
v. High fracture toughness

Based on the above criteria, there are four materials chosen for the screening process of frame for the enhanced stability and robustness which are polyvinylchloride (PVC), aluminium, stainless steel, and polycarbonate (PC). The materials properties listed on table are based on the constraints from the design requirements in Table 3.1 for screening purpose. All the materials listed for considerations for the frame since they have been known to be used in the construction of unmanned surface vehicle. For further determining the selection, screening and scoring method are used to select the most suitable option of materials based on the value obtained from the CES EduPack Software. The value of the properties of materials listed above obtained from the CES EduPack Software are tabulated in Table 3.2 and the result of scoring in Table 3.3.

Table 3.2: Properties of selected materials for frame

Material Properties	Polyvinylchloride (PVC)	Aluminium	Stainless Steel	Polycarbonate (PC)
Price (RM/kg)	10.3 – 10.5 @ 10.4	16.9 – 17.9 @ 17.4	12.2 – 13.1 @ 12.65	13 – 14.3 @ 13.65
Density (kg/m^3)	1290 – 1450 @ 1370	2670 – 2840 @ 2755	7610 – 7870 @ 7740	1190 – 1210 @ 1200
Corrosion resistivity to salt water	Excellent	Acceptable	Excellent	Excellent
Young's Modulus (GPa)	2.19 – 3.11 @ 2.65	68 – 76 @ 72	190 – 210 @ 200	2.24 – 2.52 @ 2.38
Fracture Toughness (MPa.m$^{0.5}$)	3.63 – 3.85 @ 3.74	25.7 – 41 @ 33.35	57 – 137 @ 97	1.94 – 2.48 @ 2.21

From the table above, stainless steel is eliminated because of its density. Based on CES software, stainless steel has density of 7740 kg/m^3 which is very heavy in layman's term. Therefore, the material is against the objective of minimizing mass.

Table 3.3: Scoring method of the selected materials for frame

Material Properties	Polyvinyl Chloride (PVC)	Aluminium	Polycarbonate (PC)
Price (RM/kg)	10	5.9	7.6
Density (kg/m^3)	8.76	4.4	10
Corrosion resistivity to saltwater	10	5	10
Young's Modulus (GPa)	1	10	1
Fracture Toughness (MPa.m$^{0.5}$)	1	10	1
Total	30.76	35.3	29.6

The results from the table of scoring shows that aluminium ranks first among the three materials based on the properties. Aluminium has a higher value of Young's modulus and fracture toughness which will give advantages over polyvinyl chloride (PVC) and polycarbonate (PC) when it comes to the robustness of Portable Oil Spill Skimmer. Other properties such as corrosion resistivity to saltwater and the density of aluminium are relatively good for the applications at the sea. We have to compromise between the strength and the density of material as the objectives of the design requirement are focusing on the robustness and mass. Thus, aluminium is chosen as the material for the frame for the enhancement of mechanical performance of Portable Oil Spill Skimmer and Figure 3.2 shows an example of an aluminium frame design.

Figure 3.2: Example of frame design for USV (Wang et al. 2009)

3.4.2 Selection of Material for Hull

As for the other components like propellers and hulls, four materials for the screening process which are acrylonitrile butadiene styrene (ABS), polylactide (PLA), polycarbonate (PC), and polyethylene terephthalate (PET). The materials properties listed in Table 3.4 are based on the constraints from the design requirement at Table 3.1 for screening and scoring.

Table 3.4: Properties of selected material for hull

Material Properties	Acrylonitrile Butadiene Styrene (ABS)	Polylactide (PLA)	Polycarbonate (PC)	Polyethylene Terephthalate (PET)
Fracture Toughness ($MPa.m^{0.5}$)	1.19-4.29 @2.79	0.7-1.11 @0.9	2.1-4.6 @3.35	4.5-5.55 @5
Density (kg/m^3)	1010-1210 @1110	1210-1250 @1230	1140-1210 @1175	1290-1400 @1345
Corrosion resistivity to saltwater	Excellent	Acceptable	Excellent	Excellent
Durability in marine environment	Excellent	Acceptable	Excellent	Excellent
Young's Modulus GPa)	1.1-2.9 @2	3.45-3.83 @3.64	2.0-2.44 @2.22	2.76-4.14 @3.45
Price (RM/kg)	8.85-9.76 @9.31	6.86-8.26 @7.56	12.80-14.10 @13.45	6.45-7.11 @6.78

Polyethylene terephthalate (PET) is eliminated during screening process due to its high density which is not suitable to be used in this enhancement application as the hull must be light in weight so that it can easily float on the water surface. Meanwhile, the other three materials will undergo scoring method in Table 3.5 to choose the most suitable material in the selection of hull for Portable Oil Spill Skimmer

Table 3.5: Scoring method of the selected materials for hull

Material Properties	Acrylonitrile Butadiene Styrene (ABS)	Polylactide (PLA)	Polycarbonate (PC)
Fracture Toughness ($MPa.m^{0.5}$)	5.48	1.8	6.7
Density (kg/m^3)	10	9	9.4
Corrosion resistivity to saltwater	10	5	10
Durability in marine environment	10	5	5
Young's Modulus (GPa)	5.5	10	6.1
Price (RM/kg)	7.3	9	5
Total	57.28	48.8	51.2

The results of scoring from the table above shows that acrylonitrile butadiene styrene (ABS) has the highest score among the materials listed. The ABS material has adequate fracture toughness value and light in weight as well as high corrosion resistivity and durability in the marine environment which are very ideal to be used for the enhancement of Portable Oil Spill Skimmer Thus, the selection of hull made of ABS material is based on the result of the screening and scoring of the proposed materials and Figure 3.3 shows the design of hull to be used for the Portable Oil Spill Skimmer.

Figure 3.3: Design of ABS hulls to be used for Portable Oil Spill Skimmer

3.5 Selection of Thruster

The thruster is an underwater propulsion device consisting of an electric motor and propeller. Technical specifications like the Kv, power, input voltage, current, thrust, weight and price are considered when choosing the suitable thruster for Portable Oil Spill Skimmer. There are three different thrusters as shown in Figure 3.4 to Figure 3.6 are to be compared and to select the best options based on the specifications . The specifications of the thrusters are listed in Table 3.6.

When choosing a thruster used in underwater, the Kv rating must be small so low RPM to voltage can produce more torque. The operating voltage must be in the range of 12 V to 16V because the weight of the power source will affect the performance of maneuverability. Other than that, low current draw by the motor is better to achieve longer duration using the compatible battery capacity. Furthermore, the thrust force produced must be high enough to propel the skimmer up to the desired speed and enhance the maneuverability. The weight of the thruster also affects the stability of the skimmer as the weight distribution will be imbalanced if the thruster is too heavy. Lastly, the price of thruster has to be within the budget of the project.

Figure 3.4: BlueRobotics T200 Thruster (https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/)

Figure 3.5: Hawk Hobby Underwater Thruster (https://www.amazon.com/dp/B08CK4BVCQ/ref=cm_sw_em_r_mt_dp_YMTZJMJXVNJTZKDQSXY0?_encoding=UTF8&psc=1)

Figure 3.6: VGEBY 180 ROV High Power Deep Water Thruster
(https://www.amazon.com/VGEBY-Thruster-Propulsion-Waterproof-Propeller/dp/B08L6LTSVR)

Table 3.6: Technical Specification of Thrusters

Properties	BlueRobotics T200	Hawk Hobby Underwater Thruster	VGEBY 180 ROV High Power Deep Water Thruster
Kv	490	860	120
Max Power (W)	645	300	2500
Input Voltage (V)	7-20	12-16	24-44
Current with load (A)	13-32	15-23	30
Thrust (kg.f)	2.93-6.72	1.88-2.6	13
Weight (g)	344	163	1845
Propeller Material	Polycarbonate	Nylon	Plastic
Price (USD)	179	55.99	310.49

Therefore, VGEBY thruster is not suitable for this application due to its large size and weight and expensive price of USD 310 due to budget constraint of the project. Thus, BlueRobotics T200 thruster is selected over Hawk Hobby thruster as T200 has lower Kv rating, higher thrust force and stronger material even though the price is almost three times more expensive, but it is still within the budget range.

3.6 Design and Stress-Strain Analysis of Frame

In this project, ANSYS Student 2019 is selected as the 3D modelling software for the design of components of Portable Oil Spill Skimmer. Parts like the frame and hull will be designed and combined to be an assembly for part simplification as well as the propellers based on the current design of Portable Oil Spill Skimmer as shown in Figure 3.7. Upon successful design, the 3D model of the assembly will be analyzed using ANSYS Mechanical software with FEA method to know the limitation of the design. Parameters will be redefined in order to obtain the design with the highest mechanical properties like stress-strain and factor of safety.

There are steps to be taken prior to conducting a finite element analysis on any CAD model. In this case, we are using ANSYS Mechanical software to analyze, and the steps are done in three different processor modules: pre-processor, solution, and postprocessor. Pre-processor covers the creation of solid model, defining of material, elements, real constants and meshing of model. Solution covers the loads and constraints and the solution options to be defined for the model. Postprocessor covers the viewing, evaluation, and export of model results. There are 10 steps of conducting a simple finite element analysis which are listed in Table 3.7(Thompson & Thompson, 2017).

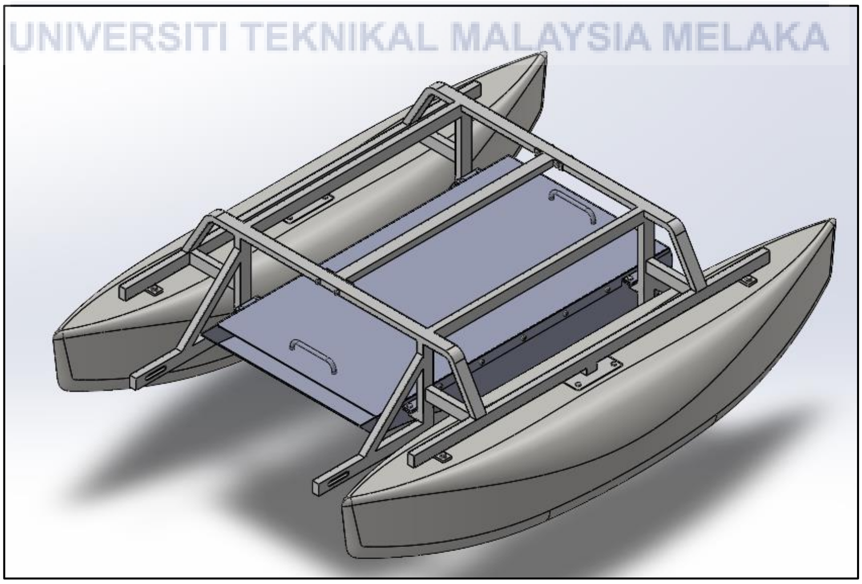

Figure 3.7: Isometric view of preliminary design assembly

Table 3.7: 10 steps of finite element analysis (Thompson & Thompson, 2017)

Pre-processor	
1.	Define the Solid Model Geometry
2.	Select the Element Types
3.	Define the Material Properties
4.	Mesh
Solution	
5.	Define the Boundary Conditions
6.	Define the Loads
7.	Set the Solution Options
8.	Solve
Post-processor	
9.	Plot, View, and Export the Results
10.	Compare and Verify the Results

3.6.1 Boundary and Loading Conditions

For the simulation of the Portable Oil Spill Skimmer by using finite element analysis, the boundary and loads must be defined at the appropriate location of the 3D model in order to produce results with accurate data in the form of equivalent von Mises stress to determine if there is any failure in the design stage.

The finite element analysis simulation is mainly performed on the structure which the frame and hull are connected together and uses static loading with uniform distribution.to mimic the components during assemble. There are different loadings to be applied on the frame; one is the overall weight of the Portable Oil Spill Skimmer moving components attached to frame with load of 21 kg or 206.01 N and the other is the loading of the storage tank which has the capacity of storing ± 18 kg of oil. So, to determine the changes in the frame, a series of loads of 3 kg, 6 kg, 9 kg, 12 kg, 15 kg and 18 kg are applied. Standard earth gravity will be applied on the simulation to mimic real life condition. Figure 3.8 highlighted the red area marked 'A' is for the load for components while 'B' is for the storage tank. The Fixed Support features are placed at the base plate where the frame joins the hull which are shown with blue arrows. There are forces acting on the frame by the weight of the oil skimmer roller of 5kg at the front marked with black arrows and thrusters of 1 kg at the rear with red arrows.

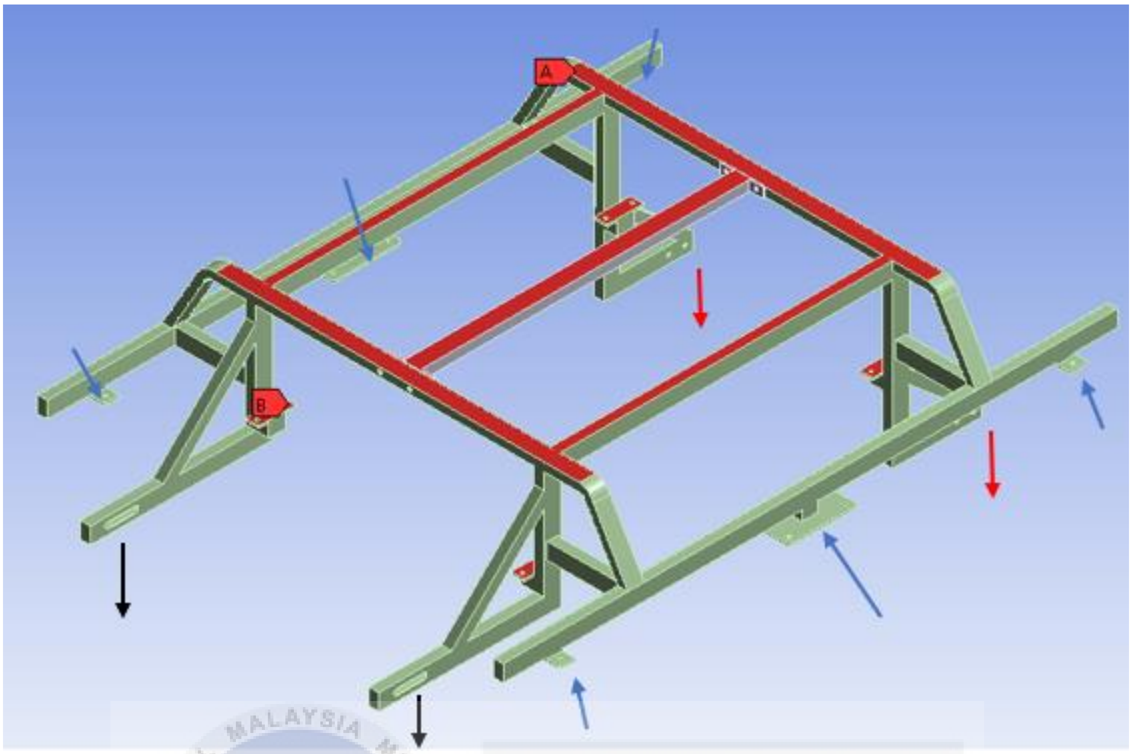

Figure 3.8: Static loading and applied constraint on the frame geometry

3.6.2 Material and Meshing

The material assigned for the frame in the stress-strain analysis is aluminium alloy. It is because the frame is the main structural part of the assembly which holds the components, so aluminium alloy is considered as the most appropriate material in terms of weight, density, and strength as stated in the selection of material. The characteristic of aluminium alloy is shown in Table 3.8.

Table 3.8: Engineering data of aluminium alloy

Properties	**Value**
Density	2.77e-06 kg/mm³
Young's Modulus	71000 MPa
Poisson's Ratio	0.33
Bulk Modulus	69608 MPa
Shear Modulus	26692 MPa
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	280 MPa
Tensile Ultimate Strength	310 MPa
Tensile Yield Strength	280 MPa

Prior to the solution of simulation, meshing must be applied on the design. Meshing is a geometric shaping formed over the design to help defining the physical shape. The higher the detail of meshing, the higher the data accuracy produced. The parameter set for the meshing in ANSYS is shown in Table 3.9. Figure 3.9 displays the applied mesh on the frame which has 202881 nodes and 101378 elements.

Table 3.9: Data of meshing for the aluminium frame

Element Order	Program Controlled
Element Size	5.0 mm
Resolution	3
Transition	Fast
Span Angle Center	Fine
Smoothing	High
Nodes	202881
Elements	101378

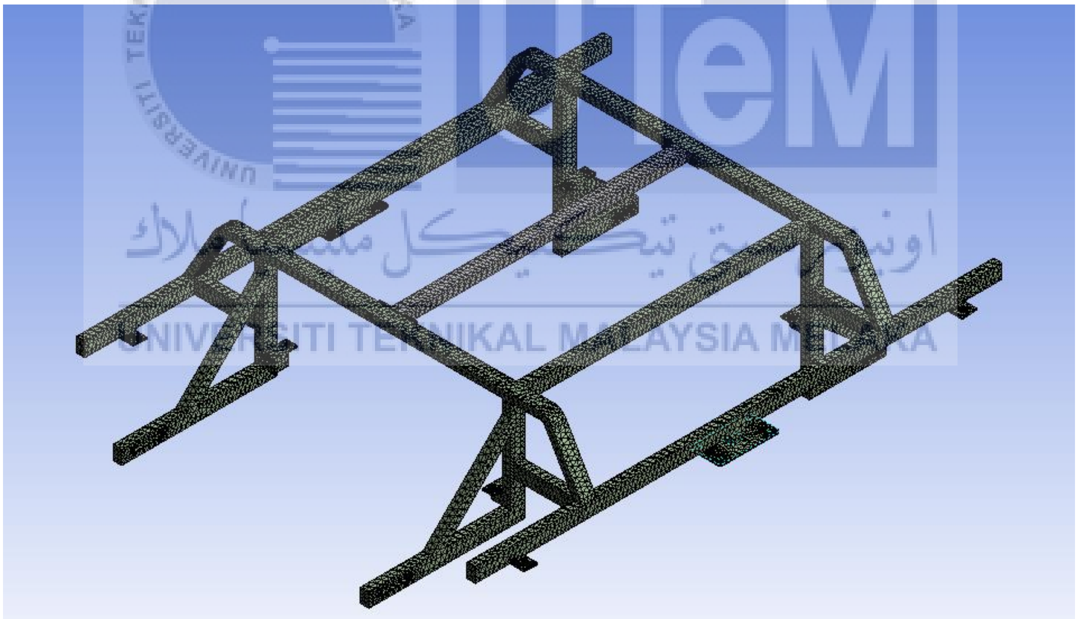

Figure 3.9: Frame with applied mesh

3.7 CFD Analysis for Hull Resistance

ANSYS Fluent is a state-of-the-art computer program for modelling fluid flow in complex geometries. ANSYS Fluent permits the user to input different model for mesh generation of different shapes and refine or coarsen the model's mesh based on the flow solution. In this project, the hull is drawn into 3D model by using SolidWorks and then simulated in ANSYS Fluent to determine the hull resistance when moving on surface of water. Below shows the steps of determining the resistance of the hull.

Step 1: Draw 3D model of the hull in SolidWorks.

- Dimension of the hulls are measured using measurement tools such as measuring tape and vernier caliper. The distinctive shapes of the hull are taken using camera to get its top, side and front view. Next, the solid modelling of the hull follows the dimensions measured beforehand.

Step 2: Export to ANSYS program

- The 3D model of hull is imported into ANSYS DesignModeler as SAT format.

Step 3: Generation of domains for hull

- The stern of hull is placed at the origin of the plane and the domains are drawn around the hull. The domains are divided into 2 domains, global domain and sub-domain. The global domain shape is a cuboid with dimensions of length of 4 m, width of 0.5 m and height of 1.5 m while the sub-domain has dimension of 4.22 m, width of 0.6 m and height of 0.17 m. The domain is generated as shown in Figure 3.10.

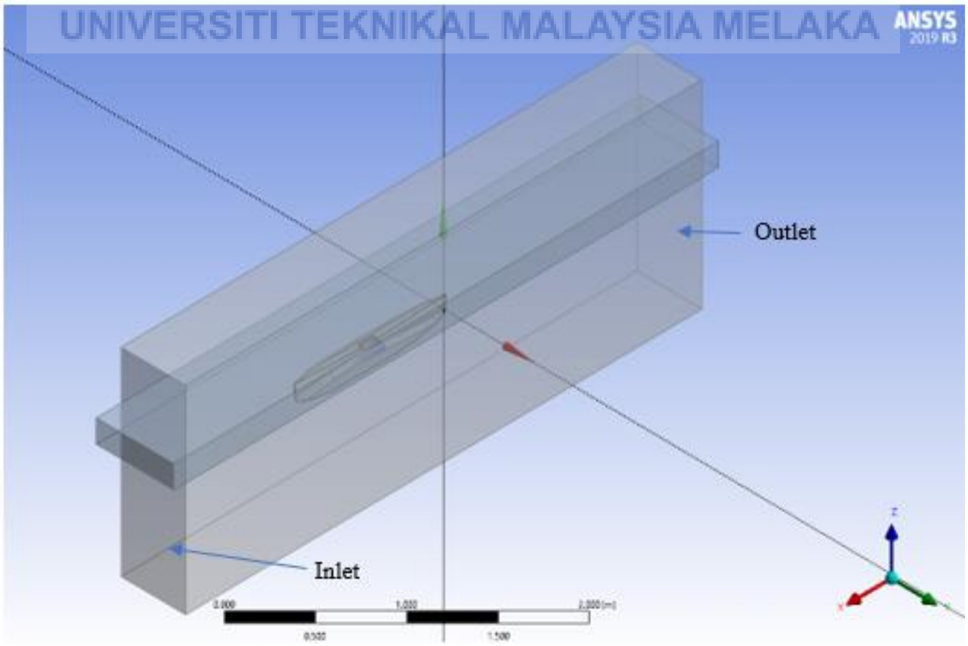

Figure 3.10: Hull analysis with domain and sub-domain

Step 4: Mesh Generation

- The generation of fine mesh is a critical step in the simulation of the hull resistance so that the solution can produce a more accurate result. Suitable meshing can reduce the computational time and but put on a heavy on the computer's CPU. The inlet of the main domain is facing the bow and the outlet is the stern of hull. Two sizing of mesh are used which are body sizing on the global domain and face sizing on the hull which are displayed at Figure 3.10 and the meshing properties are shown in Table 3.10.

Table 3.10: Meshing properties of hull analysis

Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
Element Size	Default (225.92 mm)
Body Sizing	
Type	Body of Influence
Element Size	30.0 mm
Growth Rate	Default (1.2)
Face Sizing	
Type	Element Size
Element Size	15.0 mm
Capture Curvature	Yes
Curvature Normal Angle	18°
Local Min Size	Default (2.2592 mm)
Growth Rate	Default (1.2)
Proximity Size Function Sources	Faces and Edges
Statistics	
Nodes	102612
Elements	540272

Step 5: ANSYS Fluent Setup

- In this study, pressure-based solver type, absolute velocity formulation function, steady time condition and gravitational acceleration are selected for the solution. For the models setting, viscous model is set to k-epsilon (2 equation), Standard k-epsilon model and near-wall treatment of standard wall functions.
- Other than that, the multiphase model is set to volume of fluid with open channel flow and implicit body force formulation. For the materials setting, there are two fluid

materials which are water and air, and the water density is 1000 kg/m^3. They are selected for this multi-phase models because the hull is partially submerged in body of water where the operation is carried out. The hull is assigned as acrylonitrile butadiene styrene (ABS) which is chosen as the solid material.

- For the boundary conditions, five different velocities which are 1.39 m/s, 1.53 m/s, 1.67 m/s, 1.81 m/s and 1.95 m/s in the inlet that facing the bow are being studied against the hull to get the force acting on it. For the solution, it is set to standard initialization, automatic time step method, 0.5 time scale factor and 250 number of iterations.

Step 6: ANSYS Fluent Post Processing

- In Fluent Post Processing, the iso-surface and vector are generated and the force acting on the hull can be determined by using the calculator function. The force on the hull is similar to the resistance when the hull is moving forward.

3.8 CFD Analysis for BlueRobotics T200 Propeller

In this project, CFD analysis is performed on the BlueRobotics T200 thruster propeller to validate the data provided by BlueRobotics performance chart. From the CFD analysis of the propeller, we can determine the thrust force generated at certain rotational speed. The result of the CFD analysis will then be contrasted with the experimental data of the thruster by BlueRobotics to justify the selection of thruster for Portable Oil Spill Skimmer. Below shows the steps of using ANSYS Fluent for T200 propeller analysis.

Step 1: Conversion of 3D Model of BlueRobotics T200 propeller to STEP

- The 3D model of the thruster can be obtained from the official website of BlueRobotics in the form of SolidWorks format. Then, the propeller is isolated from the thruster as an individual component and save as STEP format for ANSYS.

Step 2: Export to ANSYS Program

- The 3D model of propeller is imported into ANSYS DesignModeler as STEP format.

Step 3: Generation of domains for propeller

- The propeller is placed at the origin and the domains are drawn around the propeller. There are two domains which are the enclosure and rotating body. The enclosure is a cuboid with length of 500 mm, height and width of 250 mm, and it acts as the surroundings of water with the rotating body inside of it. The rotating body is a cylinder and has a diameter of 85 mm and thickness of 32 mm that covers the propeller. There are two subtracting Booleans for the analysis that involve the rotating body, enclosure and the propeller. The domain generated as shown in Figure 3.11.

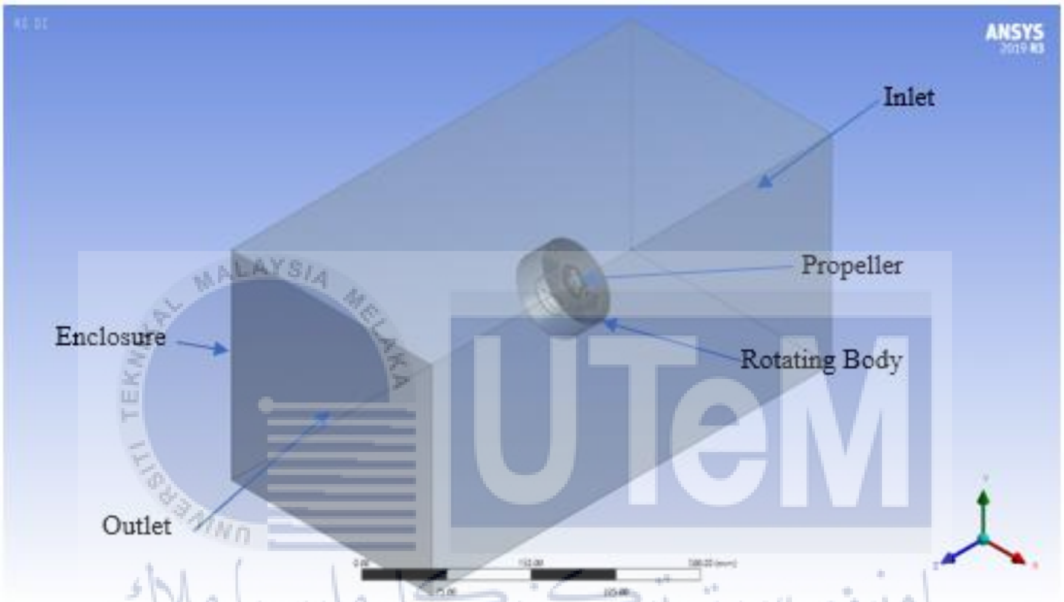

Figure 3.11: Propeller analysis with generated domains

Step 4: Mesh Generation

- For this analysis, the propeller is subjected to face sizing with element size of 20 mm. The propeller, inlet and outlet are highlighted in Figure 3.11 which the propeller is turning clockwise on the Z-axis. The rotating body and enclosure mesh size remain default which is 30.619 mm. The meshing properties are shown in Table 3.11.

Table 3.11: Meshing properties of propeller analysis

Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
Element Size	Default (30.619 mm)
Face Sizing	
Type	Element Size
Element Size	20.0 mm
Capture Curvature	No
Statistics	
Nodes	30618
Elements	156656

Step 5: ANSYS Fluent setup

- In this study, pressure-based solver type, absolute velocity formulation function, transient time condition and gravitational acceleration are selected for the solution. For the models setting, viscous model is set to k-epsilon (2 equation), Realizable k-epsilon model and near-wall treatment of scalable wall functions.
- The materials assigned to the CFD analysis is water with density of 1000kg/m^3.
- For the cell zone conditions setting, the rotating body zone is set to Mesh Motion and the propeller is set to turn at rotational velocity of 3000 rpm and for the boundary conditions, the inlet is subjected to velocity of 3.8 m/s.
- For the solutions, it is set to hybrid initialization which the program predicts the variables. Time step size is set to 0.05s with 100 time steps and max iterations of 10.

Step 6: Post Processing

- In Fluent Post Processing, streamline is generated in the enclosure to display the flow pattern. The force by the propeller can be determined by using the calculator function. The force produced by the propeller is the thrust force when the propeller is rotating in its blade direction.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter covers the evaluation of the current project which is Portable Oil Spill Skimmer. This consists of the stress-strain analysis, free surface flow analysis and thrust simulation. The preliminary design of Portable Oil Spill Skimmer will be analyzed by using ANSYS simulation software to obtain the results of stress, strain, deformation values. Furthermore, simulation is performed on the prototype to obtain the resistance or drag force acting on the hull. The results from the computational fluid dynamics analysis of the thruster will then be compared with the resistance to verify the ability of propulsion of Portable Oil Spill Skimmer.

4.2 3-Dimensional Model of Portable Oil Spill Skimmer

The conceptual design of the Portable Oil Spill Skimmer has been produced by using SolidWorks. This oil spill skimmer design is made up of a catamaran hull held together by a frame structure. The frame structure also acts as the mounting of components like the skimmer, electronics and thrusters as well as the oil storage tank. So, the design of frame is analyzed thoroughly in order to prevent design failure and flaw as it is the most susceptible for failure during operation of oil recovery on the surface of water. A three-dimensional modelling of Portable Oil Spill Skimmer partial assembly is shown in the Figure 4.1.

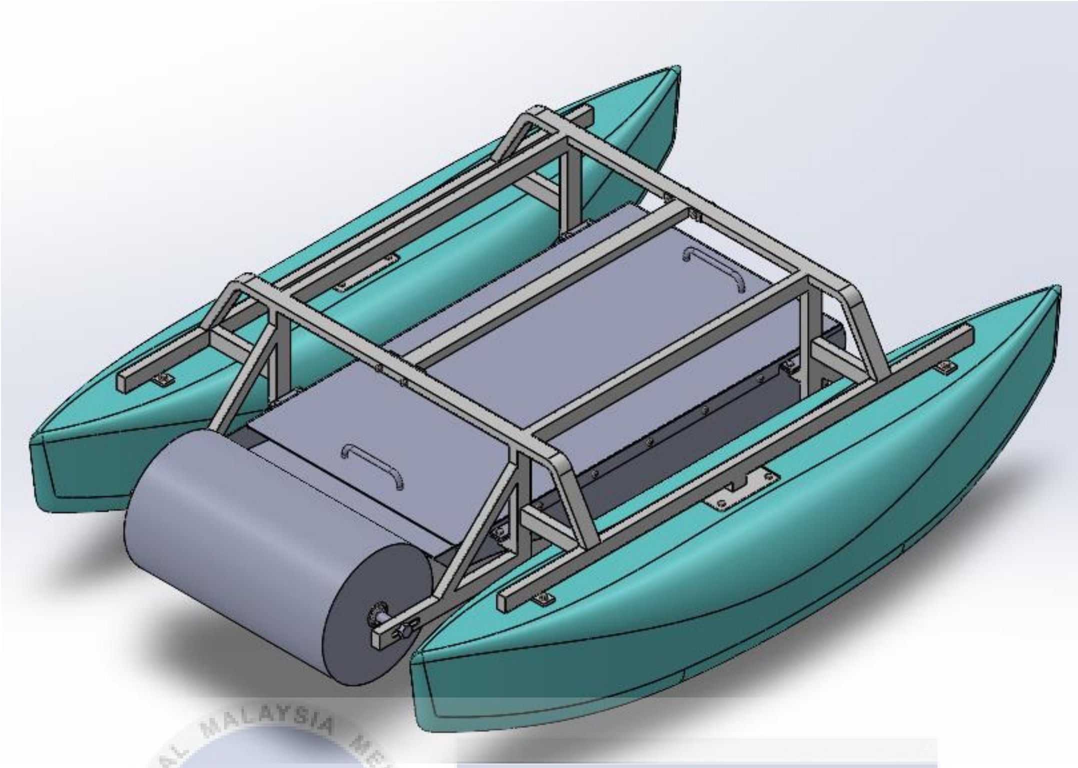

Figure 4.1: Partial Assembly of Portable Oil Spill Skimmer

4.2.1 Bill of Materials

The design of Portable Oil Spill Skimmer assembly has included the bill of materials which consists of the part and material used. Details are shown in Table 4.1, including the name of part, total number of parts used for the design assembly.

Table 4.1: Bill of material for the design assembly of Portable Oil Spill Skimmer

Part No	Part Name	Material	Quantity
1	Structural Frame	Aluminium Hollow Bar (15 mm x 25mm)	1 unit
2	Hull	ABS	2 units
3	Skimmer Roller	Polypropylene	1 unit
4	Storage Tank and Cover	Aluminium Sheet	1 unit
5	Thruster	Polycarbonate	2 units

4.3 Stress-Strain Analysis of Frame

The results of stress-strain analysis simulation performed by using ANSYS on the frame are stress, strain, displacement which help to predict the behavior of the structure whether it is robust enough to hold together the components.

4.3.1 Equivalent Stress Simulation

The result from the simulation when a total static loading of 21 kg or 206.01 N that includes the weight of skimmer of 5kg and two thrusters of 0.5 kg each as well as the electronics components like battery and control unit shows the maximum equivalent stress value of 16.851 MPa as shown in Figure 4.2. This design of frame is safe as the stress value presented is lower than the yield strength of the material of 280 MPa which has a factor of safety value of 16.62.

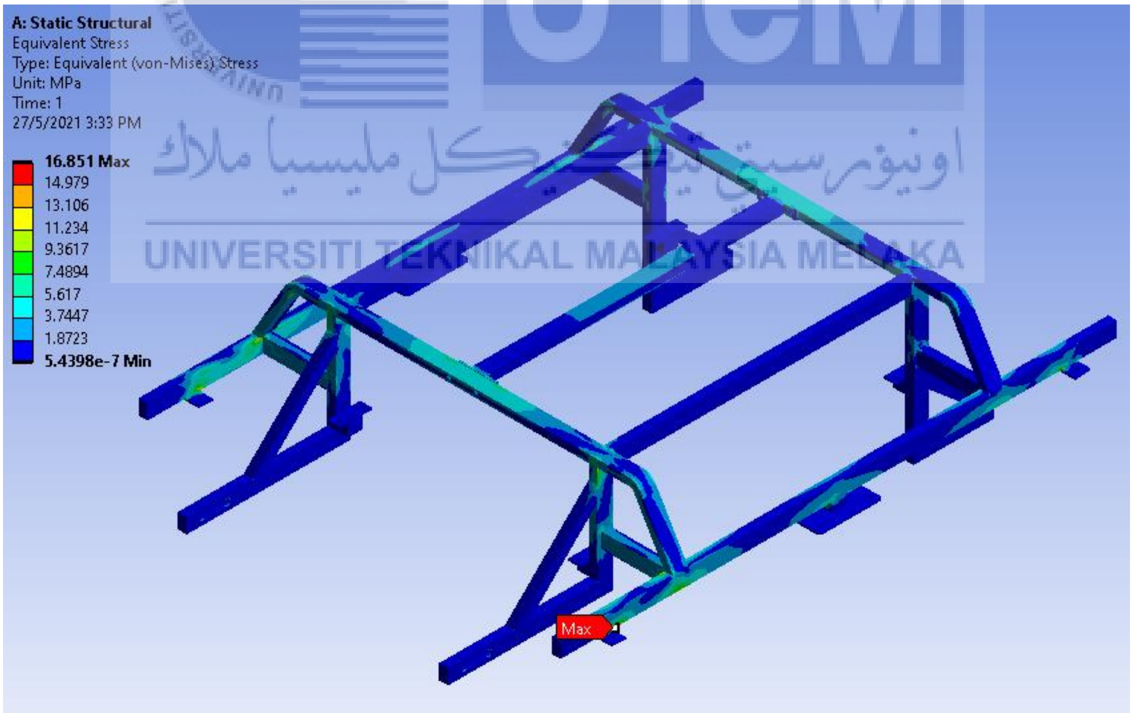

Figure 4.2: Equivalent stress simulation with contour view

4.3.2 Equivalent Strain Simulation

The result from the stress-strain analysis simulation shows the maximum equivalent strain value of 0.25896×10^{-3} mm/mm given the static loading of 21 kg, or 206.01 N. Figure 4.3 shows the result of the strain simulation.

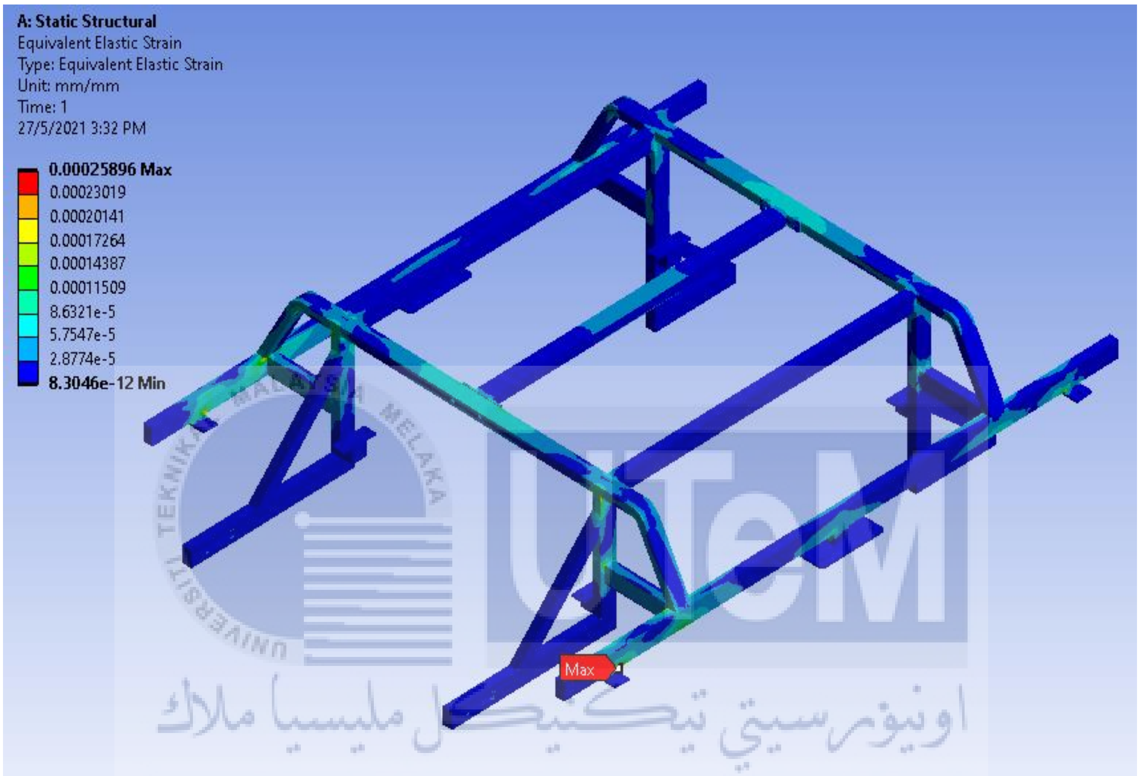

Figure 4.3: Equivalent strain simulation with contour view

4.3.3 Total Deformation

The result from stress-strain analysis simulation shows the maximum deformation of 0.3742 mm given the static loading of 21 kg or 206.01 N. The maximum deformation occurs at the top middle bar of the frame as shown in Figure 4.4, and the value is very small to be noticed in real life condition. Therefore, the frame for Portable Oil Spill Skimmer is rigid and will not distort.

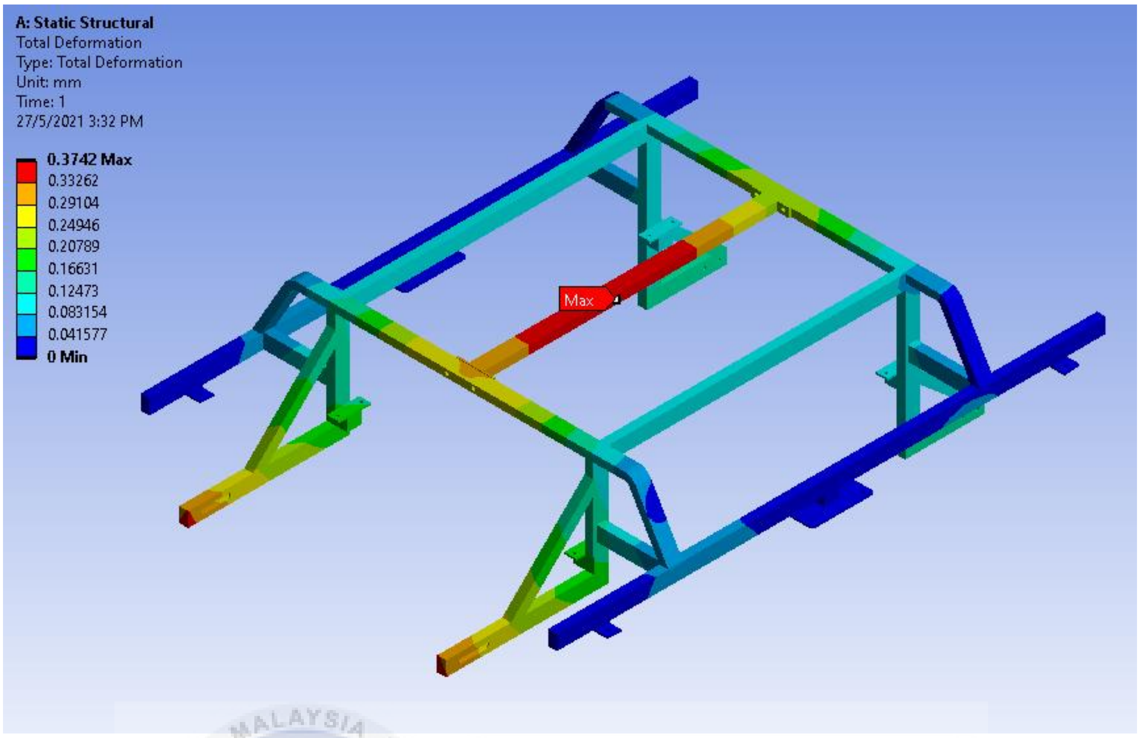

Figure 4.4: Total deformation simulation with contour view

4.3.4 Variable Loading on Oil Storage Tank

From the simulation performed on the frame when different loads are applied on the mounting surface of storage tank to replicate when the tank is filled with liquid. According to the design of storage tank, it has the capacity to hold up to 18 kg of liquid. So, a series of loads begins from 3 kg, 6 kg, 9 kg, 12 kg, 15 kg, to 18 kg in addition to the weight of other components are applied to the frame.

The results from the simulation show an additional 3 kg of load up to 18 kg are tabulated in Table 4.2. The results of stress simulation on the variable load are shown in Figure 4.5. The results show a very consistent increase in the stress values, and this indicates the enhanced Portable Oil Spill Skimmer has the capability to hold the maximum weight of 39 kg without failure during the operation in the water as it has a factor of safety value of 10.22.

Table 4.2: Simulation result of stress of different load applied

Loading of tank (kg)	Static loading of components (kg)	Total loading applied on the frame (kg) (Tank + Static)	Stress value (MPa)
0	21	21	16.851
3	21	24	18.610
6	21	27	20.369
9	21	30	22.128
12	21	33	23.888
15	21	36	25.647
18	21	39	27.406

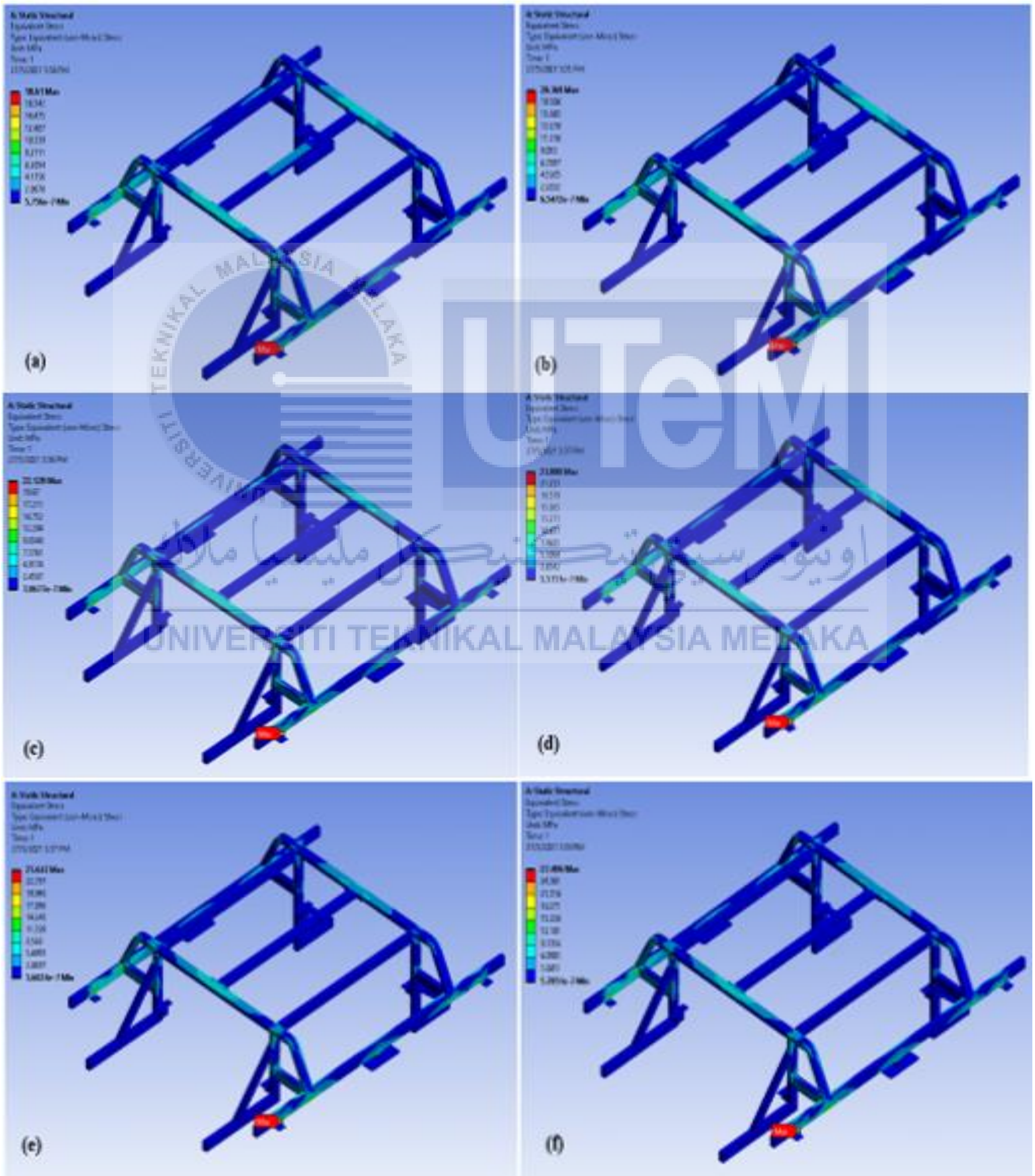

Figure 4.5: Stress of the frame with different loading of oil (a) 3 kg load; (b) 6 kg load; (c) 9 kg load; (d) 12 kg load; (e) 15 kg load; (f) 18 kg load

4.4 CFD Analysis of Hull Resistance

From the analysis performed using ANSYS Fluent on the hull design of Portable Oil Spill Skimmer, the results have been obtained using 250 iterations to get an appropriate level of solution convergence. Five different cases have been investigated as shown in and the results are tabulated in Table 4.3. It can be seen from the CFD analysis that the hull has a drag force of 2.7312N acting on it when moving forward on water at speed of 1.39 m/s or 5.0 km/h. As the speed increases by 1 km/h to 6.0 km/h, the drag on the hull escalates to 9.2366N, an increase of 238.19% which is 3 times the value of 5.0 km/h. Meanwhile, an increase of speed of 2 km/h to 7.0 km/h produces drag of 13.5542N shows an increase of 396.27% which is almost 5 times the value of speed 5.0 km/h. These drag forces shows increment when the speed Portable Oil Spill Skimmer is going faster. Graph in Figure 4.6 shows the relationship of drag force against the hull speed and the increasing trend.

Table 4.3: Values for hull drag force from CFD simulation

Case	Velocity		Drag Force of one hull (N)	Drag Force of two hulls (N)	Percentage increase from 5.0 km/h
	(m/s)	(km/h)			
1	1.39	5.0	2.7312	5.4624	-
2	1.53	5.5	3.5844	7.1688	31.24%
3	1.67	6.0	9.2366	18.4732	238.19%
4	1.81	6.5	12.1222	24.2444	343.84%
5	1.95	7.0	13.5542	27.1084	396.27%

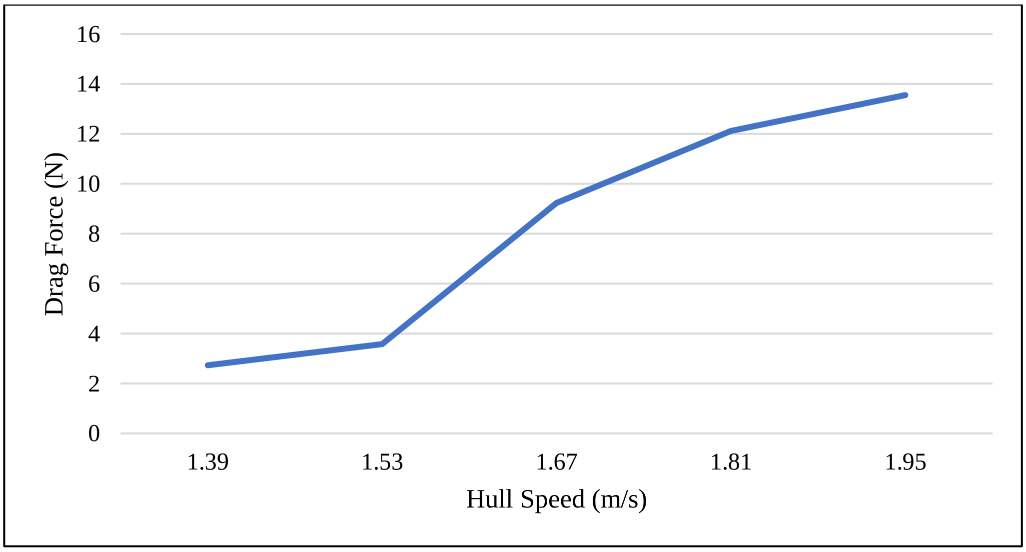

Figure 4.6: Relationship between the drag force and hull speed

The flow patterns of water are shown from Figure 4.7 to Figure 4.11 when moving forward at different speeds. It can be seen that the wake velocity generated at the stern of the hull is increasing with the hull speed . In addition, smaller wave hits the bow of the hull at 1.39 m/s, and it is becoming more aggressive when the speed increases to 1.81 m/s and 1.95 m/s. It is because water is viscous in nature and this results to the resistance of the hull submerged in water when the fluid particles hold on to the wetted surface of the hull, forming a boundary layer that is the wake at the stern of hull. The friction of the water acting over the hull produces a net force as opposed to the motion in any direction. The faster the speed, the larger the opposing force acting on the hull. Other than that, the movement of hull will generate waves that can also slow down its speed. Therefore, the thruster must generate thrust force high enough to overcome the resistance acting on the wetted surface of the hull so that the Portable Oil Spill Skimmer can move at speed of 1.95 m/s or lower. In this case, the skimmer is using catamaran which there are two hulls side by side and have a total drag of 27.1084 N. Hence, the two thrusters must generate forward thrust more than 27.1084 N to be able to achieve the hull speed of 1.95 m/s.

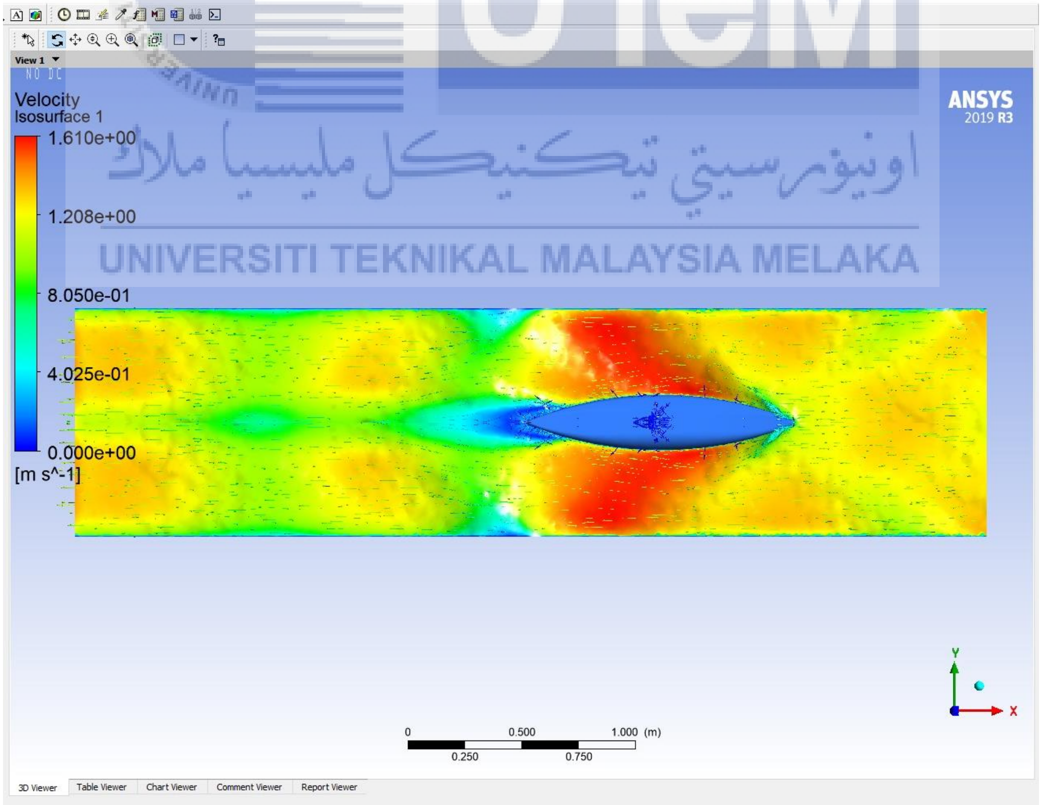

Figure 4.7: Flow pattern of water at speed of 1.39 m/s

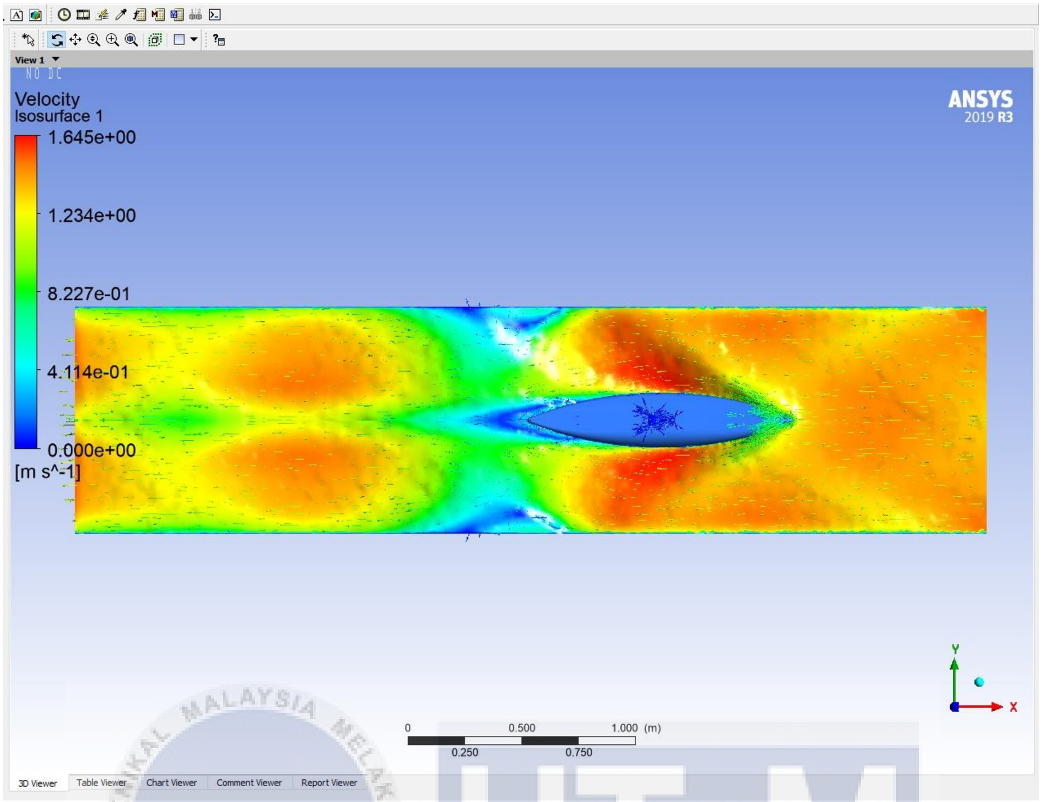

Figure 4.8: Flow pattern of water at speed of 1.53 m/s

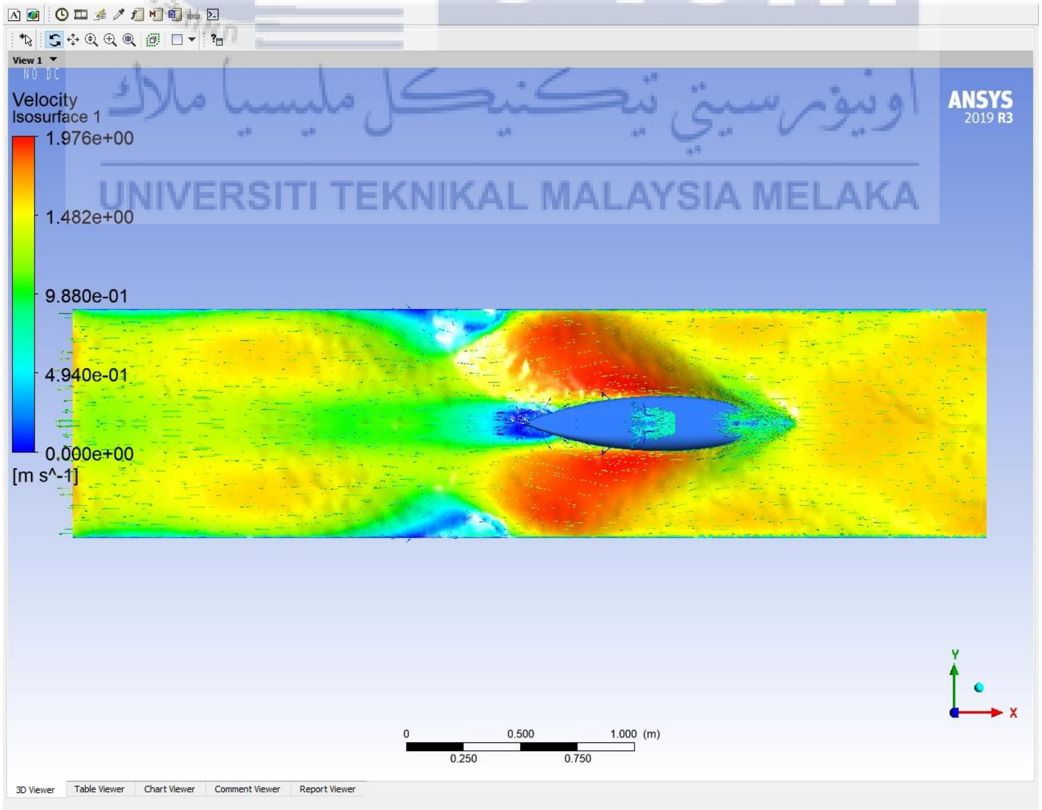

Figure 4.9: Flow pattern of water at speed of 1.67 m/s

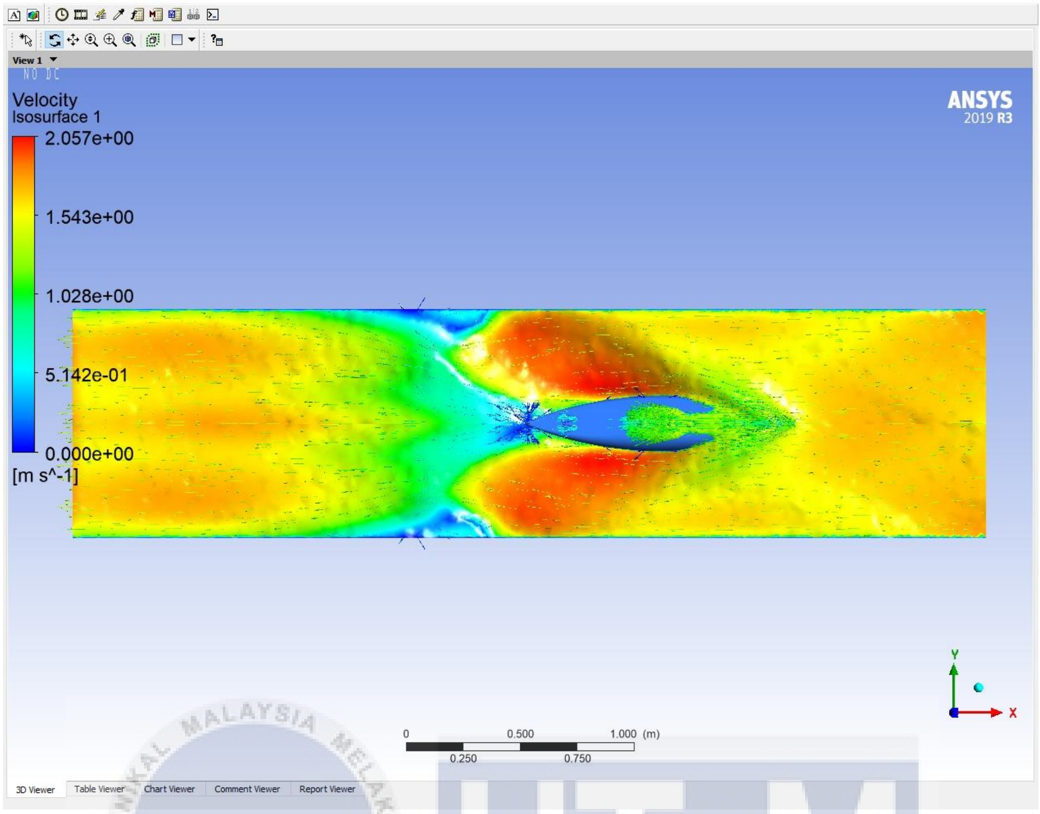

Figure 4.10: Flow pattern of water at speed of 1.81 m/s

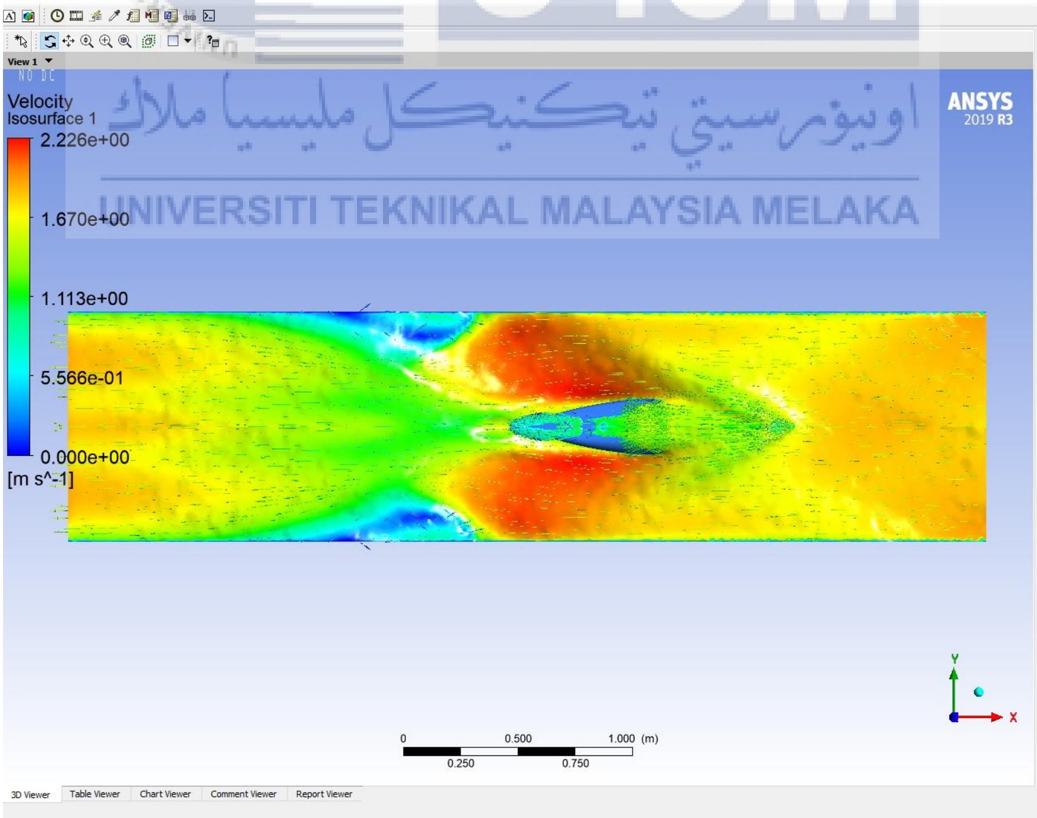

Figure 4.11: Flow pattern of water at speed of 1.95 m/s

4.5 CFD Analysis of Propeller Thrust Force

From the CFD analysis that has been performed on the BlueRobotics T200 propeller, it is found that the propeller is able to generate a thrust force of 36.8246 N at 3000 rpm and inlet velocity of 3.8m/s. This value of thrust is obtained from the ANSYS Fluent Post Processor of result, namely the function calculator which the function is thrust force and the location is the selection of propeller as shown in Figure 4.12. In addition to that, the pressure contour in Figure 4.13 shows the maximum pressure of $5.109e^{+04}$ Pa and minimum pressure of $-1.284e^{+05}$ Pa on the propeller blades.

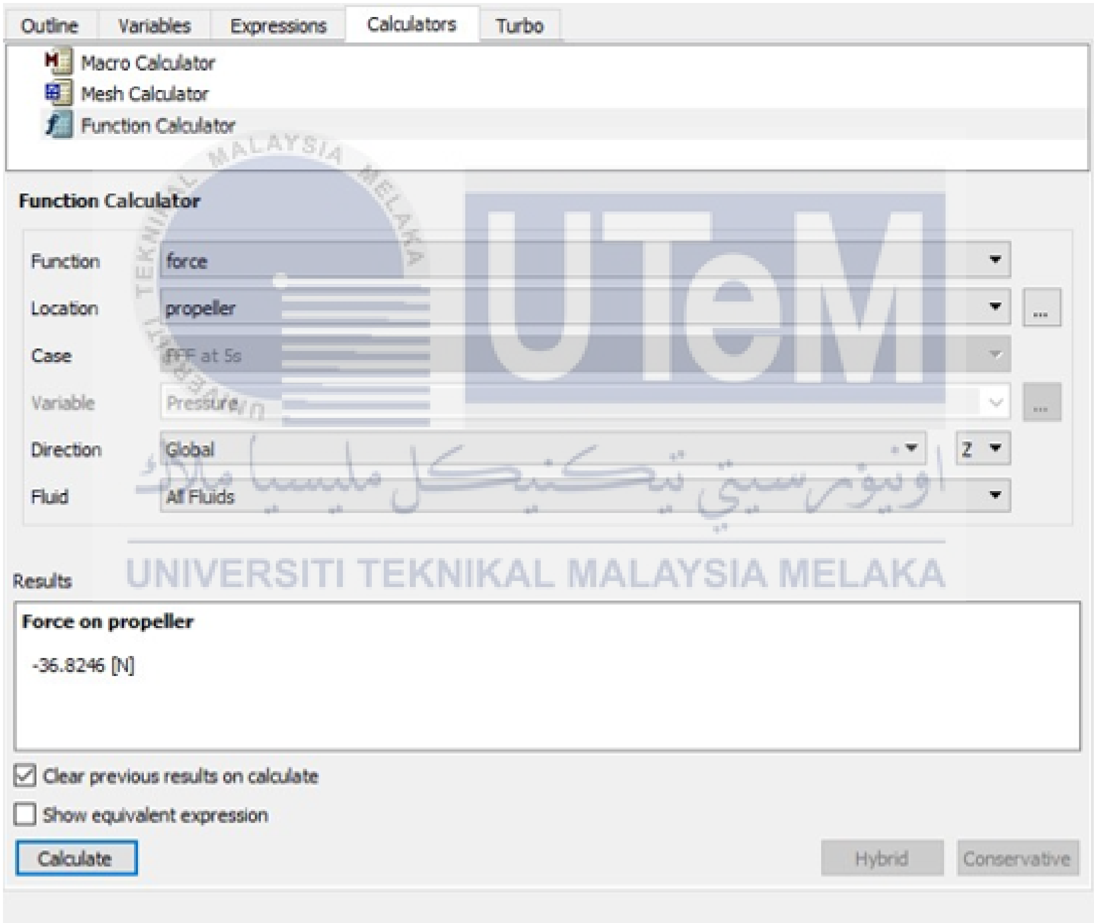

Figure 4.12: Result of thrust force retrieved from ANSYS Fluent Post Processor

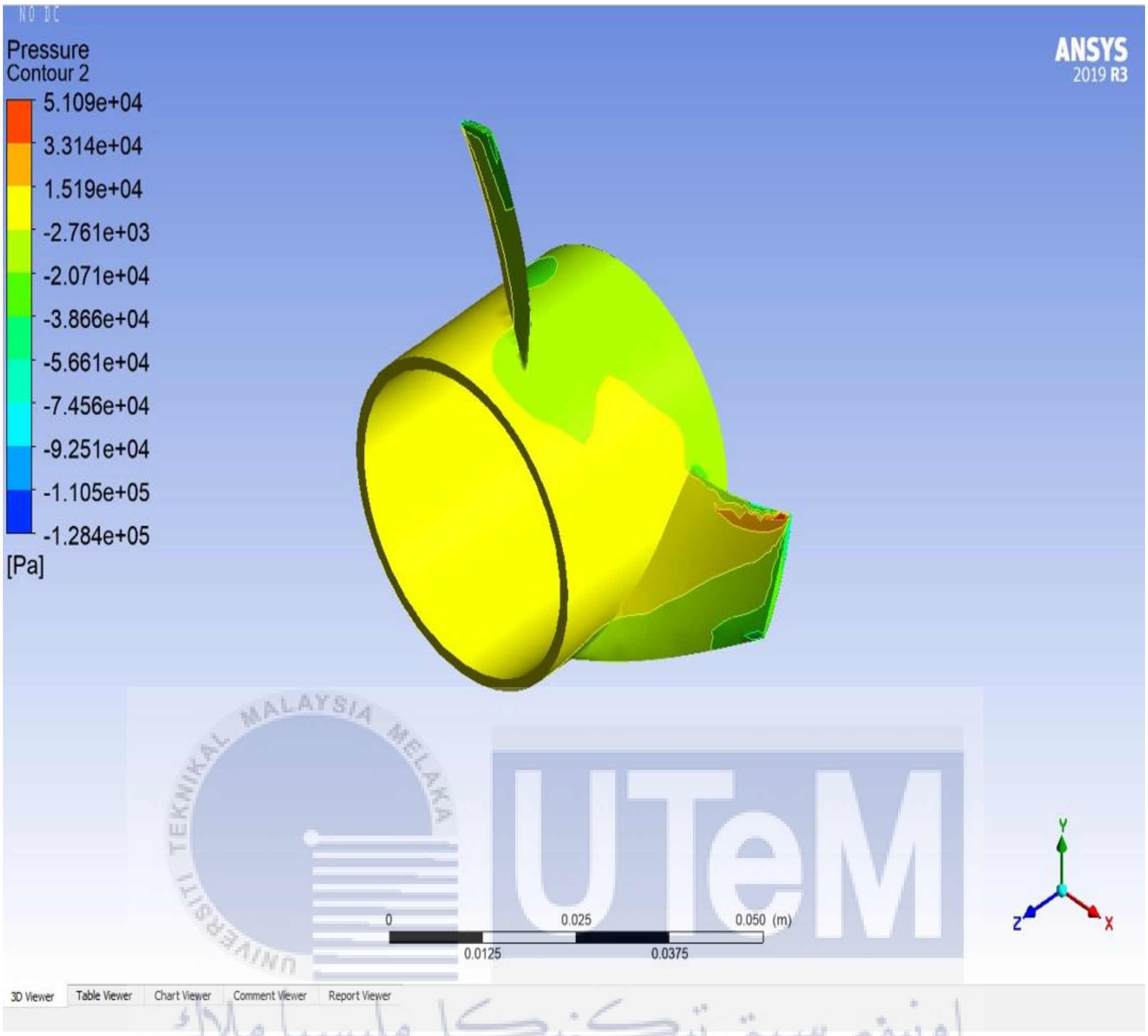

Figure 4.13: Pressure contour on propeller

Additionally, the data provided by the thruster manufacturer, BlueRobotics, shows that the maximum thrust can be produced by T200 is 3.71 kg.f or 36.383 N, at rotational speed of 2995 rpm at 12 V power supply. From the result of the CFD simulation on the propeller, it only has a difference of 1.21% of the thrust value and it can be concluded that the setup parameters of the CFD calculations are accurate. According to the design of Portable Oil Spill Skimmer, there are two T200 thrusters installed at the rear part of the frame to facilitate its movement on water and with these thrusters, the combined thrust force is about 72.8 N which is very sufficient to overcome the hull drag of 27.1084 N to propel up to speed of 1.95 m/s or even higher provided that the condition of water is ideal. With these data, it is justifiable to use T200 thrusters on the enhanced Portable Oil Spill Skimmer.

4.6 Full Assembly of Enhanced Portable Oil Spill Skimmer

A solid modelling of the full assembly of enhanced Portable Oil Spill Skimmer is produced by using SolidWorks as shown in Figure 4.14 and Figure 4.15. The parts are arranged accordingly to help distribute the weight evenly throughout the skimmer. The frame is the most crucial part as it holds all the parts together namely, the hulls at the two sides, which are the port and starboard of the skimmer, oil storage tank in the bottom middle, oleophilic roller in the front or bow.

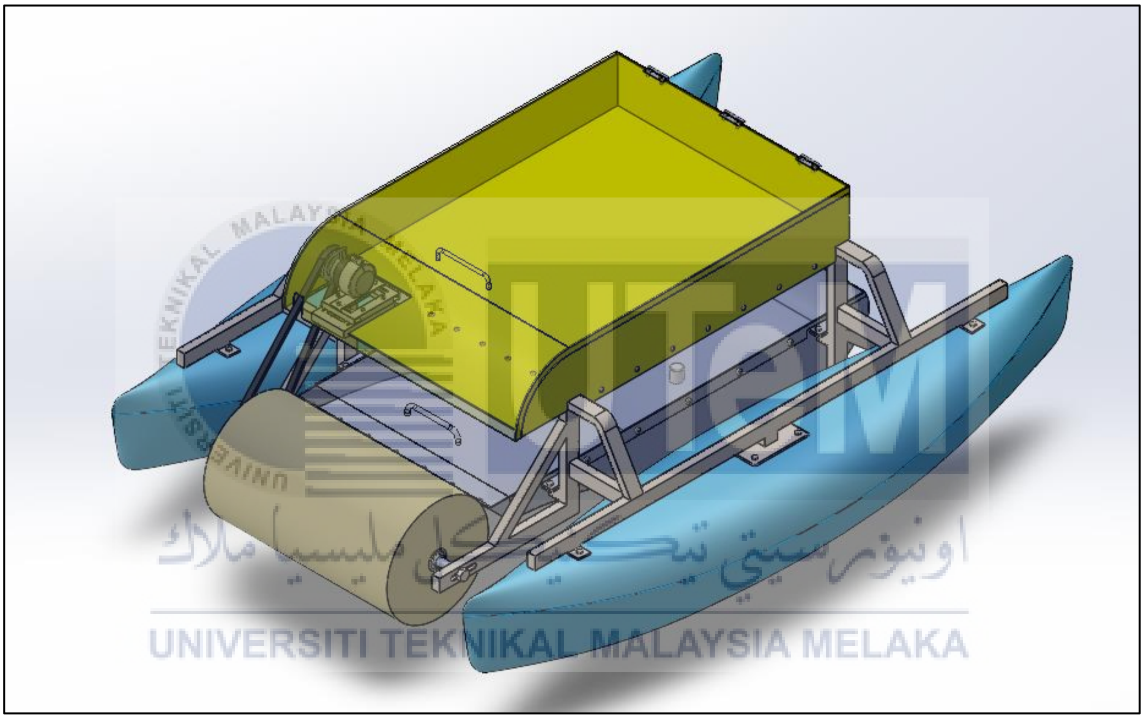

Figure 4.14: Isometric view of enhanced Portable Oil Spill Skimmer assembly

The oleophilic skimmer is connected to an electric motor that provides rotational motion through belt and pulley which is more silent and efficient than the previous prototype that was using chain and sprocket. Meanwhile, the box on the top houses all electrical parts like electric motor, power supply and circuit boards. Both the storage tank and top box are covered to prevent water from entering and damaging the parts. The thrusters are placed at the rear or stern of the skimmer. This helps to compensate the heavy weight of oleophilic roller from nose dive.

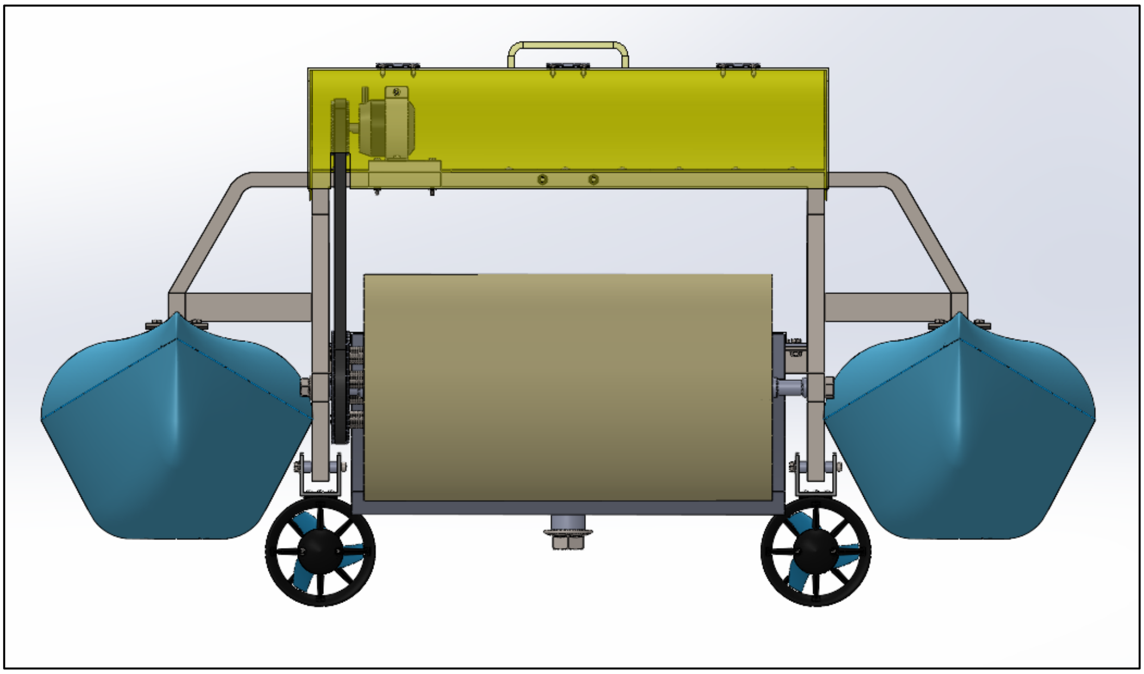

Figure 4.15: Front view of enhanced Portable Oil Spill Skimmer assembly

CHAPTER 5

CONCLUSION AND FUTURE WORKS

This chapter concludes the overall outcome of the project. Additionally, this chapter also provides suggestions on the future works that can be used to improve the findings on strength and effectiveness of Portable Oil Spill Skimmer that have been achieved throughout the entire project.

5.1 Conclusion

Portable Oil Spill Skimmer is an innovative development that helps in the recovery of oil spillages on water surface and also acts as a tool to compliment the limitations of existing methods of oil spill response and recovery activities. The application of Portable Oil Spill Skimmer has proven to be practical in removing residual oil that left out on the water surface. Selection of material and design are influencing the structural integrity and propulsion ability of Portable Oil Spill Skimmer considerably. For this project, new design of frame is produced by using solid modelling software. Furthermore, the procurement of components such as hull and thrusters are made which the parts are used for the enhancement of the Portable Oil Spill Skimmer in terms of maneuverability. Results from the stress-strain and the computational fluid dynamics simulations performed on the frame, hull and thrusters are analyzed and discussed thoroughly in the previous chapter.

In the stress-strain analysis, a load of 21 kg or 206.01 N which consist of the weight of skimmer, thrusters and electrical component, is applied onto the designed frame and it yields a stress value of 16.851 MPa and strain value of 0.25896×10^{-3} mm/mm. It is estimated that the oil storage tank can hold a maximum weight of 18kg when it is filled with oil. With that, the loading on the frame is increased to 39 kg so as the stress, but the stress-strain analysis shows that it yields a maximum stress value of 27.406. These stress values are lower than the yield strength of aluminium of 280 MPa. In other words, the aluminium frame is able to bear load up to 39 kg without distorting even if the oil storage tank is full.

Furthermore, after performing the CFD simulation on the hull, the results show that the hull is experiencing a drag or opposing force of 13.5542 N on one hull or 27.108 4N on two hulls when moving at speed of 1.95 m/s. When the hull is moving at 1.39 m/s, the hull drag is only 2.7312 N on one hull or 5.4624 N on two hulls the latter is one-fifth of the former's value. This indicates that the speed of the hull has a great effect on the resistance as the faster the speed, the higher the resistance. So, the thrusters must produce thrust force that is more than the drag in order to move forward. The result from CFD simulation shows that a T200 thruster is able to generate thrust of 36.8246 N at 3000 rpm which is very similar to the value of 36.383 N provided by the manufacturer. Thus, the two thrusters can generate a combined thrust of 72.8 N which is adequate to propel the Portable Oil Spill Skimmer to the speed of 1.95 m/s and the thrust force can improve the maneuverability. Since the readings of the stress, strain, hull resistance, and thrust force are obtained from the respective analyses, it is concluded that Objective 1, 2 and 3 of this project are successfully achieved.

5.2 Future Works

Based on this project, several recommendations can be applied to the future work of Portable Oil Spill Skimmer. First of all, fabrication of aluminium frame can be performed by using conventional method and assemble together the components as well as test running the prototype. Other than that, solar panels can be installed on the Portable Oil Spill Skimmer to provide additional power to prolong the duration of oil recovery activities with less battery charging intervals. Furthermore, determine the relationship between different type of oil spillages and the oleophilic surface. Lastly, install a four-thrusters propulsion system to give Portable Oil Spill Skimmer the ability to move in omnidirectional to facilitate and improve the oil recovery activities.

5.3 Sustainability

Existing methods of oil spill response and recovery are very costly and using a great number of resources of manpower and transportation. There, the novel development of Portable Oil Spill Skimmer has created an alternative to complement the existing methods to reduce the running costs of OSRR activities. Also, the skimmer has a high portability which can be deployed easily at any time. With the enhancement performed onto the Portable Oil Spill Skimmer, it has increased the durability and the robustness which means it can be used for a long time without maintenance and replacement. In short, Portable Oil Spill Skimmer is an environmentally friendly product that helps reduce the water pollution and does not have a high impact on the environment during its life cycle.

5.4 Complexity

The challenges that arise from this project are developing the solid modelling of frame and hull as well as the stress-strain and CFD simulations. During the design of frame, elements such as the positioning of components, dimensions, and ease of fabrication are considered all the time to facilitate the placement of the hulls, skimmer, and thrusters as well as the electrical components. Besides, high proficiency in solid modelling of SolidWorks and ANSYS is needed to be able to develop a complex design and run simulations. The design and simulation of the frame, hull, and thrusters require a lot of theoretical and practical knowledge to produce the results. Generating suitable mesh in the simulation is a complex process that has to set up manually to obtain the appropriate number of nodes and elements while keeping the skewness within the good range. As the stress-strain and CFD simulations are very complex, it requires a long period of time for the computer to solve the problem.

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APPENDICES

A Gantt Chart of FYP I

No	Activities	SEMESTER 1 (WEEK)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	PSM Title Registration								MID SEMESTER BREAK							
2	First Briefing of Title															
3	Searching for related journals/articles															
4	Chapter 1 Introduction															
5	Chapter 2 Literature Review															
6	Chapter 3 Methodology															
7	Abstract															
8	Table of Content															
9	References															
10	Logbook submission															
11	Online Presentation															
12	FYP 1 Report Submission															

B Gantt Chart of FYP II

No	Activities	SEMESTER 2 (WEEK)															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Frame Design								MID SEMESTER BREAK								
2	Meeting with Supervisor																
3	Hull Design																
4	Simulations																
5	Chapter 4 Result and Discussion																
6	Chapter 5 Conclusion																
7	Logbook Submission FYP 2																
8	Video Presentation Submission for FYP2																
9	Online Q&A Session																
10	Final Report Submission																

C Properties of Acrylonitrile Butadiene Styrene (ABS)

Acrylonitrile butadiene styrene (ABS)

Description

Image

Caption

1. ABS pellets. © Shutterstock 2. ABS allows detailed moldings, accepts color well, and is non-toxic and tough enough to survive the worst that children can do to it. © Gettyimages

The material

ABS (Acrylonitrile-butadiene-styrene) is tough, resilient, and easily molded. It is usually opaque, although some grades can now be transparent, and it can be given vivid colors. ABS-PVC alloys are tougher than standard ABS and, in self-extinguishing grades, are used for the casings of power tools.

Composition (summary)

Block terpolymer of acrylonitrile (15-35%), butadiene (5-30%), and styrene (40-60%).

General properties

Density	1.03e3	-	1.06e3	kg/m^3
Price	* 10.9	-	13.1	MYR/kg
Date first used	1937			

Mechanical properties

Young's modulus	2.08	-	2.75	GPa
Shear modulus	* 0.743	-	0.983	GPa
Bulk modulus	* 3.85	-	4.01	GPa

Poisson's ratio	* 0.39	-	0.41	
Yield strength (elastic limit)	34.5	-	49.6	MPa
Tensile strength	37.8	-	51.8	MPa
Compressive strength	* 39.3	-	86	MPa
Elongation	5	-	60	% strain
Hardness - Vickers	* 10	-	14.9	HV
Fatigue strength at 10^7 cycles	* 15.1	-	20.7	MPa
Fracture toughness	* 1.47	-	4.29	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.015	-	0.019	

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Excellent
Soils, acidic (peat)	Excellent
Soils, alkaline (clay)	Excellent
Wine	Excellent

D Properties of Polycarbonate (PC)

Polycarbonate (PC)

Description

Image

Caption

1. Personal computer casing made of polycarbonate. © Chris Lefteri 2. Polycarbonate is tough and impact-resistant: hence its use in hard hats and helmets, transparent roofing and riot shields.

The material

PC is one of the 'engineering' thermoplastics, meaning that they have better mechanical properties than the cheaper 'commodity' polymers. The family includes the plastics polyamide (PA), polyoxymethylene (POM) and polytetrafluorethylene (PTFE). The benzene ring and the -OCOO- carbonate group combine in pure PC to give it its unique characteristics of optical transparency and good toughness and rigidity, even at relatively high temperatures. These properties make PC a good choice for applications such as compact disks, safety hard hats and housings for power tools. To enhance the properties of PC even further, it is possible to co-polymerize the molecule with other monomers (improves the flame retardancy, refractive index and resistance to softening), or to reinforce the PC with glass fibers (giving better mechanical properties at high temperatures).

Composition (summary)

(O-(C6H4)-C(CH3)2-(C6H4)-CO)n

General properties

Density	1.19e3	-	1.21e3	kg/m^3
Price	* 13	-	14.3	MYR/kg
Date first used	1958			

Mechanical properties

Young's modulus	2.24	-	2.52	GPa
Shear modulus	* 0.78	-	0.927	GPa
Bulk modulus	* 3.78	-	4.09	GPa
Poisson's ratio	* 0.39	-	0.41	

Yield strength (elastic limit)	55.9	-	68.9	MPa
Tensile strength	60.7	-	74.8	MPa
Compressive strength	* 68.9	-	86.4	MPa
Elongation	110	-	150	% strain
Hardness - Vickers	* 17.1	-	21.1	HV
Fatigue strength at 10^7 cycles	* 23.7	-	30.8	MPa
Fracture toughness	1.94	-	2.48	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.014	-	0.02	

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Excellent
Soils, acidic (peat)	Excellent
Soils, alkaline (clay)	Excellent
Wine	Excellent

E Properties of Polyvinylchloride (PVC)

Polyvinylchloride (tpPVC)

Description

Image

Caption

These boat fenders illustrate that PVC is tough, weather resistant and easy to form and color.

The material

PVC - Vinyl - is one of the cheapest, most versatile and - with polyethylene - the most widely used of polymers and epitomizes their multi-facetted character. In its pure form - as a thermoplastic, tpPVC - it is rigid, and not very tough; its low price makes it a cost-effective engineering plastic where extremes of service are not encountered. Incorporating plasticizers creates flexible PVC, elPVC, a material with leather-like or rubber-like properties, and used a substitute for both. By contrast, reinforcement with glass fibers gives a material that is sufficiently stiff, strong and tough to be used for roofs, flooring and building panels. Both rigid and flexible PVC can be foamed to give lightweight structural panels, and upholstery for cars and domestic use. Blending with other polymers extends the range of properties further: vinyl gramophone records were made of a vinyl chloride/acetate co-polymer; blow molded bottles and film are a vinyl chloride/acrylic copolymer.

Composition (summary)

(CH2CHCl)n

General properties

Density	1.29e3	-	1.45e3	kg/m^3
Price	* 10.3	-	10.5	MYR/kg
Date first used	1940			

Mechanical properties

Young's modulus	2.19	-	3.11	GPa
Shear modulus	0.751	-	1.1	GPa

Bulk modulus	4.7	-	4.9	GPa
Poisson's ratio	0.4			
Yield strength (elastic limit)	37.6	-	45.5	MPa
Tensile strength	37.7	-	43.9	MPa
Compressive strength	* 37.1	-	44.1	MPa
Elongation	40	-	80	% strain
Hardness - Vickers	12			HV
Fatigue strength at 10^7 cycles	* 16.5	-	21.1	MPa
Fracture toughness	* 3.63	-	3.85	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.0097	-	0.017	

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Excellent
Soils, acidic (peat)	Excellent
Soils, alkaline (clay)	Excellent
Wine	Excellent

F Properties of Aluminium

Age-hardening wrought Al-alloys

Description

Image

Caption

1. Close-up of a building cladding made of wrought aluminum alloy . © John Fernandez 2. Chassis of a personal computer. © Chris Lefteri 3. The 2000 and 7000 series age-hardening aluminum alloys are the backbone of the aerospace industry.

The material

The high-strength aluminum alloys rely on age-hardening: a sequence of heat treatment steps that causes the precipitation of a nano-scale dispersion of intermetallics that impede dislocation motion and impart strength. This can be as high as 700 MPa giving them a strength-to-weight ratio exceeding even that of the strongest steels. This record describes for the series of wrought Al alloys that rely on age-hardening requiring a solution heat treatment followed by quenching and ageing. This is recorded by adding TX to the series number, where X is a number between 0 and 8 that records the state of heat treatment. They are listed below using the IADS designations (see Technical notes for

details).2000 series: Al with 2 to 6% Cu -- the oldest and most widely used aerospace series.6000 series: Al with up to 1.2% Mg and 1.3% Si -- medium strength extrusions and forgings.7000 series: Al with up to 8% Zn and 3% Mg -- the Hercules of aluminum alloys, used for high strength aircraft structures, forgings and sheet. Certain special alloys also contain silver. So this record, like that for the non-age hardening alloys, is broad, encompassing all of these.

An alternative name for Aluminum in many countries is Aluminium.

Composition (summary)

2000 series: Al + 2 to 6% Cu + Fe, Mn, Zn and sometimes Zr

6000 series: Al + up to 1.2%Mg + 0.25% Zn + Si, Fe and Mn

7000 series: Al + 4 to 9 % Zn + 1 to 3% Mg + Si, Fe, Cu and occasionally Zr and Ag

General properties

Density	2.67e3	-	2.84e3	kg/m^3
Price	* 16.9	-	17.9	MYR/kg
Date first used	1916			

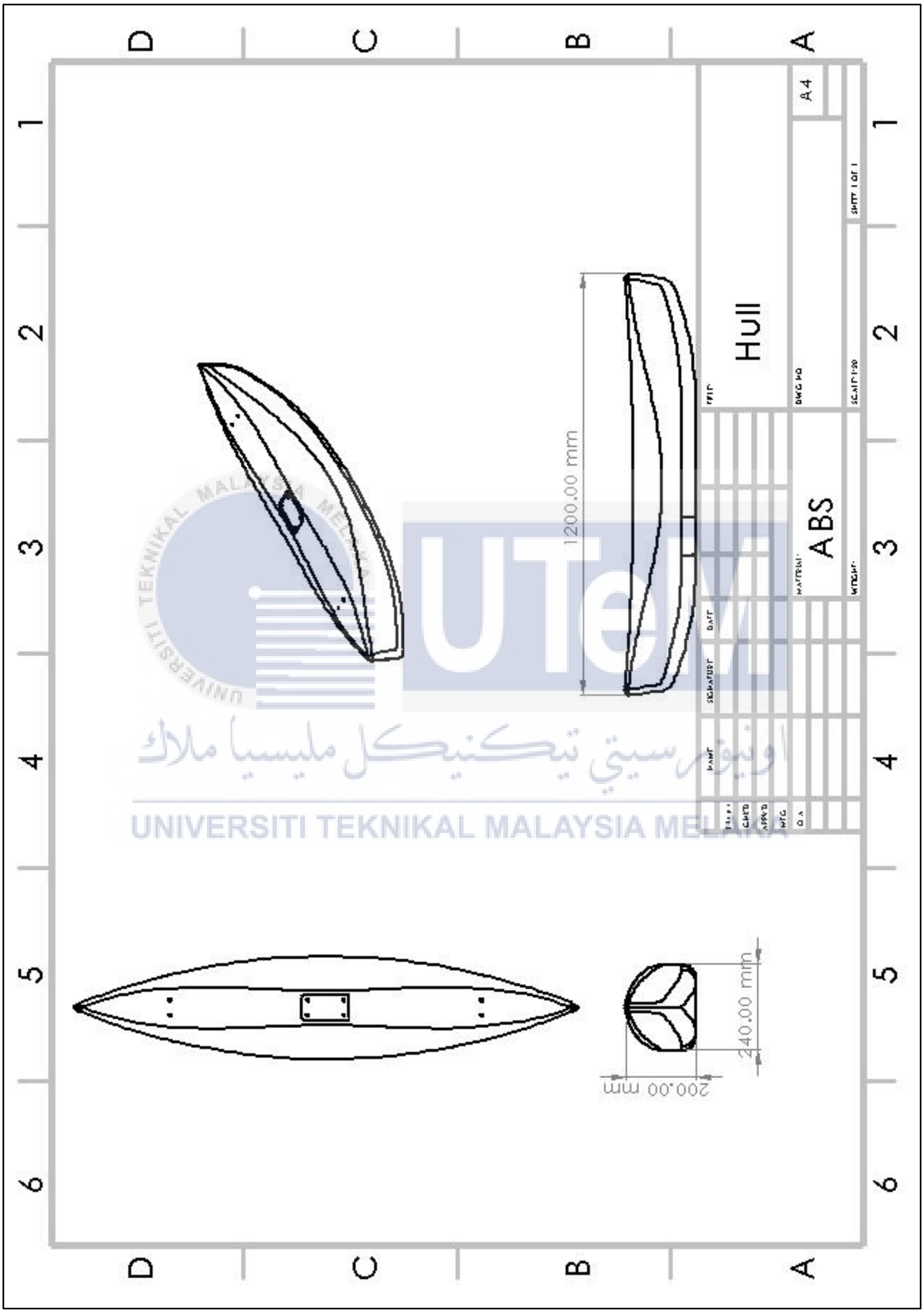
Mechanical properties

Young's modulus	68	-	76	GPa
Shear modulus	26	-	29	GPa
Bulk modulus	68	-	75	GPa
Poisson's ratio	0.33	-	0.34	
Yield strength (elastic limit)	241	-	520	MPa
Tensile strength	288	-	571	MPa
Compressive strength	* 245	-	521	MPa
Elongation	3.4	-	12	%strain
Hardness - Vickers	* 85.4	-	168	HV
Fatigue strength at 10^7 cycles	* 100	-	219	MPa
Fracture toughness	* 25.7	-	41	MPa.m^0.5
Mechanical loss coefficient (tan delta)	0.0011			

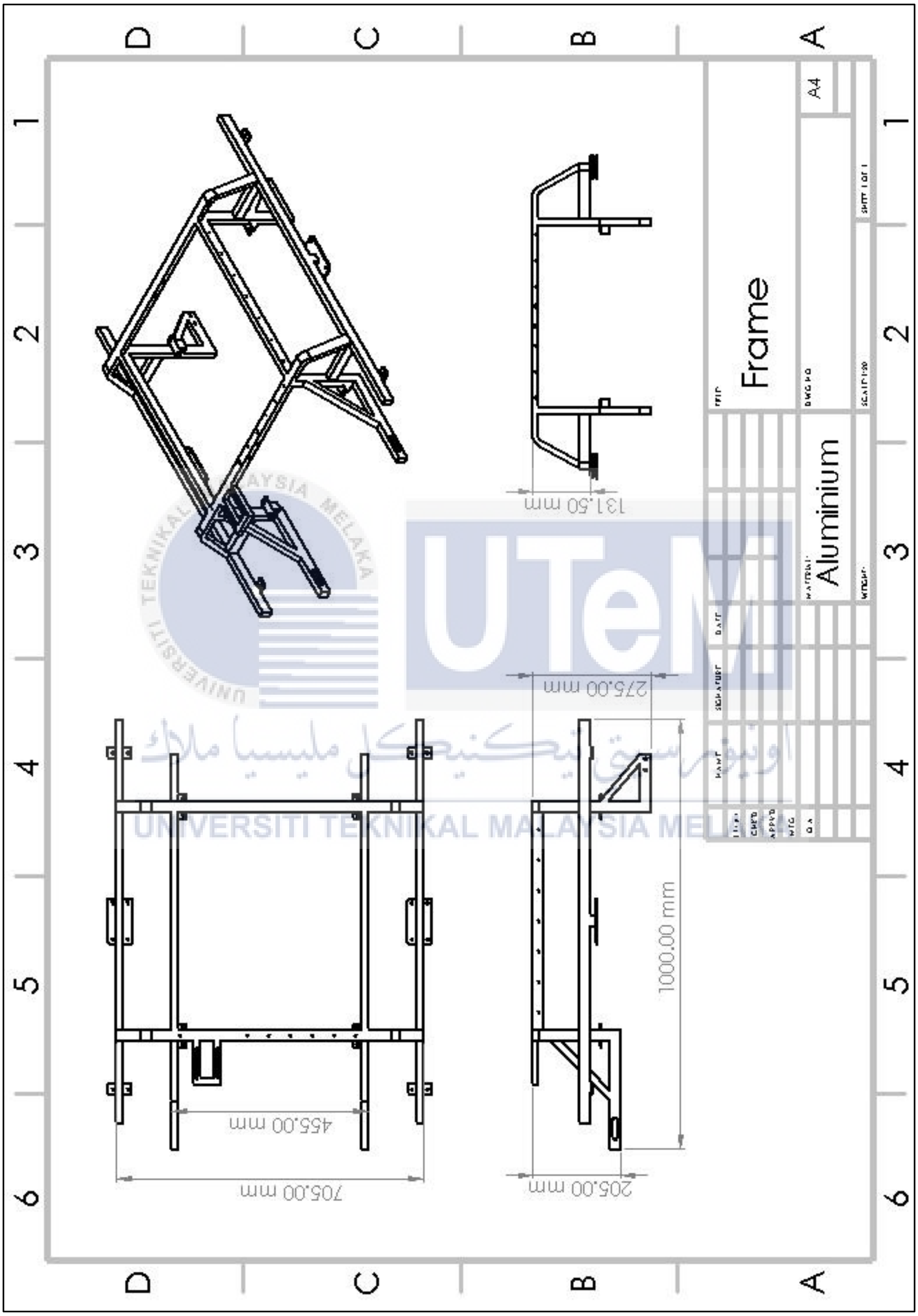
Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Acceptable
Soils, acidic (peat)	Unacceptable
Soils, alkaline (clay)	Excellent
Wine	Excellent

G Technical Drawing of Hull



H Technical Drawing of Frame



I Technical Drawing of Portable Oil Spill Skimmer Assembly