Faculty of Mechanical Technology and Engineering

DESIGN AND DEVELOPMENT OF ELECTRIC TRACTOR'S HOOD USING COMPOSITE MATERIALS

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Bachelor of Technology and Mechanical Engineering (Automotive Technology) with Honours.

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in fulfilment of the requirements for the degree of Bachelor of Technology and Mechanical Engineering (Automotive Technology) with Honours

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DECLARATION

I declare that this thesis entitled "DESIGN AND DEVELOPMENT OF ELECTRIC TRACTOR'S HOOD USING COMPOSIT MATERIALS." is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………………………..

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Date : 9 JAN 2025

………………………………………………

APPROVAL

I hereby declare that I have read this thesis, and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Bachelor of Mechanical Technology and Engineering (Automotive Technology) with Honours.

Signature	:	....
Supervisor Name	:	MOHD RAFI BIN OMAR
Date	:	30 JAN 2025

DEDICATION

I dedicate this project to the Almighty God, Allah SWT, the Creator of all entire beings in the universe. He has been the main source, the strength and inspiration for this project. "He has given everything from Him as the pay for what the people has done their work". I also dedicate this project to my family, especially my parents. My father, Mr. Mohd Zahid Hashim. Thank you for the great support you have given me for this entire life. My mother, Mrs Azura Zainuddin. Thank you for being the best mother I have ever had. Not to forget, I dedicate this project to my supervisor, En. Mohd Rafi bin Omar who has guide me through this project, including Ts. Dr. Mohd Rizal bin Alkahari as the main researcher on the project, Ts. Dr. Syahibudil Ikhwan bin Abdul Kudus, Ts. Dr. Mohd Yuhazri bin Yaakob and Ts. Dr. Muhd Ridzuan bin Mansor as co-researcher on this project, my siblings as well as my friends. Thank you for all the words, the motivation, the inspiration and everything. Without their support and prayers, I may not be able to do this as far as I could.

ABSTRACT

This research focuses on developing an advanced electric vehicle (EV) tractor design to address the limitations of traditional tractors, enhancing efficiency, sustainability, and operator well-being in modern agriculture. Traditional tractors face significant challenges, including heavy weight, which leads to high fuel consumption and soil compaction, negatively affecting soil health and crop yields. It relies on internal combustion engines, producing high greenhouse gas emissions that contribute to environmental pollution and climate change. Additionally, many traditional tractors lack ergonomic features, causing operator discomfort, fatigue, and compromised safety due to poor visibility, inadequate seat design, and non-intuitive controls. Maintenance issues, extended downtimes, and high costs further hinder their efficiency. Traditional tractors are also less durable in harsh agricultural environments, suffer from faster wear and tear, and have low energy efficiency due to outdated engine designs and the absence of energy recovery systems. This project aims to develop an innovative and efficient EV tractor body using lightweight, sturdy materials to optimize battery life and energy efficiency. It focuses on ideal weight distribution for stability, ergonomic features for operator comfort and safety, and modular components for easy maintenance. The goal is to create a durable, high-performing electric tractor body that meets the evolving demands of the agricultural sector, promoting sustainable agriculture.

REKABENTUK DAN PEMBANGUNAN BADAN TRAKTOR ELEKTRIK MENGGUNAKAN BAHAN KOMPOSIT

ABSTRAK

Penyelidikan ini memberi tumpuan kepada membangunkan reka bentuk traktor elektrik (EV) termaju untuk menangani traktor-traktor tradisional, meningkatkan kecekapan, kemampanan dan kesejahteraan pengendali dalam pertanian moden. Traktor tradisional menghadapi cabaran yang ketara, termasuk berat keseluruhan, yang membawa kepada penggunaan bahan api yang tinggi dan pemadatan tanah, menjejaskan keadaan tanah dan hasil tanaman secara keseluruhan. Mereka bergantung pada enjin pembakaran dalaman, menghasilkan pelepasan gas rumah hijau yang tinggi dan menyumbang kepada pencemaran alam sekitar mahupun perubahan iklim. Selain itu, kebanyakan traktor tradisional tidak mempunyai ciri-ciri ergonomik, menyebabkan ketidakselesaan pengendali, keletihan dan menjejaskan keselamatan akibat sudut penglihatan yang lemah, reka bentuk tempat duduk yang tidak mencukupi dan kawalan yang tidak intuitif. Isu penyelenggaraan, masa henti yang dilanjutkan dan kos yang tinggi menghalang lagi kecekapannya. Traktor tradisional juga kurang ketahan dalam persekitaran pertanian yang keras, mengalami ketandusan dan kelusuh yang lebih cepat, dan mempunyai kecekapan tenaga yang rendah disebabkan reka bentuk enjin yang ketinggalan zaman dan ketiadaan teknologi pemulihan tenaga. Projek ini bertujuan untuk membangunkan badan tractor EV yang inovatif dan cekap menggunakan bahan yang ringan dan kukuh untuk mengoptimumkan hayat bateri dan kecekapan tenaga. Ia memberi tumpuan kepada pengagihan berat ideal untuk kestabilan, ciri rekaan untuk keselesaan dan keselamatan pengendali, termasuk komponen modular untuk penyelenggaraan yang mudah. Matlamatnya adalah untuk mencipta badan traktor elektrik yang tahan lasak dan berprestasi tinggi yang memenuhi permintaan sektor pertanian yang berkembang dan menggalakkan proses pertanian.

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Initially, a big thank you to my supervisor, En Rafi. If he didn't provide his help, assistance, and advice in the project of Design and Development of electric tractor Body and Hood using composite materials, the project wouldn't have been as successful and perfect as it is now. I am grateful for the guidance and enthusiasm shown by En Rafi in helping me with this topic, which has always given me strength to complete the project journey. His enthusiasm, patience, and dedication to this project, along with his valuable feedback, have greatly improved the quality of the thesis. I have always held onto fond memories of this project.

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I also express gratitude to my parents for their constant encouragement and support. Describing our family's journey over the past three years as having had its share of highs and lows would be an understatement. Each time I felt like giving up, you never allowed me to stop, and I will always be thankful. This thesis serves as evidence of your unwavering love and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

EV	-	Electric Vehicle
ICE	-	Internal Combustion Engine
SI	-	Spark Ignition
CI	-	Compression Ignition
DC	-	Direct Current
CO2	-	Carbon Dioxide
NOx	-	Nitrogen oxide
CFD	-	Computational Fluid Dynamics
CAD	-	Computer-Aid Design
UV	-	Ultra-Violet

CHAPTER 1

INTRODUCTION

1.1 Introduction

The shift towards electric vehicles (EVs) is primarily motivated by their significant advantages to the environment and economy, in addition to their expanding range of uses in many industries. Since electric cars (EVs) have no tailpipe emissions, it provides a sustainable alternative to traditional internal combustion engine vehicles. This helps to reduce air pollution and greenhouse gas emissions, both of which are important in the fight against climate change. Because electricity is less expensive than petrol and because EVs require less maintenance because it have fewer moving components, they are more economical to operate. Their adaptability is being highlighted by the fact that their uses are growing beyond personal transportation to include shared mobility services, commercial fleets, and public transit. The ability of EVs to combine with renewable energy sources to further reduce the carbon footprint of transportation emphasizes how important EVs are for the environment. As battery technology and charging infrastructure improve, EVs are becoming increasingly viable and essential for sustainable urban development and global efforts to mitigate environmental degradation.

In agriculture industries, tractors have completely changed farming methods and productivity, revolutionizing the agricultural industry. Tractors were first driven by steam in the late 19th century, but in the early 20th century, internal combustion engines replaced them, greatly improving their efficiency and usefulness. Tractors are essential to agriculture because it can do a variety of jobs, such as planting, harvesting, tilling, and ploughing, which automates labour-intensive procedures and boosts agricultural productivity. The first significant agricultural revolution began with the invention of the tractor, which allowed farmers to cultivate more regions faster and with less manual labour. The emergence of autonomous machinery are examples of subsequent technical innovations that have further transformed modern agriculture, optimizing resource management and precision farming. These innovations continue to drive agricultural efficiency and sustainability, supporting the global demand for food production amidst growing populations and changing environmental conditions.

Designing the body of an electric vehicle (EV) tractor requires careful consideration of several critical factors to ensure functionality, durability, and efficiency. Lightweight but sturdy materials must be used to build the body to extend battery life and improve overall energy efficiency. The massive battery pack and electric motor must also fit into the design, allowing for the ideal weight distribution for traction and stability on a variety of surfaces. With an emphasis on operator comfort and safety, ergonomics plays a critical role. Features like movable seating, simple controls, and good visibility are all part of this. The body should also be built with modular components that are easily modified or changed, and easy access for maintenance and repairs. The body design of EV tractors can greatly improve their performance and dependability in agricultural operations by taking these factors into consideration.

The aim of this project is to design an innovative and efficient body for an electric vehicle (EV) tractor that enhances functionality, durability, and energy efficiency for modern agricultural applications. To maximize battery life and performance, this project will concentrate on using sturdy, light materials, making sure that the weight is distributed optimally for traction and stability. Ergonomic elements will also be incorporated into the design to enhance operator comfort and safety and enable simple maintenance and repair.

The goal of this project is to provide a long-lasting, highly effective electric tractor body that satisfies the changing demands of the farming sector while promoting sustainable agriculture.

1.2 Problem Statement

Traditional tractor designs face several significant challenges that inhibit their efficiency and sustainability in modern agriculture. One of the primary issues is their heavy weight, which not only results in substantial fuel consumption but also leads to soil compaction, negatively impacting soil health and crop yields (Hamza and Anderson, 2005). Moreover, these tractors rely on internal combustion engines that produce high levels of greenhouse gas emissions, contributing to environmental pollution and climate change (Bacenetti et al., 2018). Additionally, many tractors lack ergonomic features, causing operator discomfort and fatigue during prolonged use. Poor visibility, inadequate seat design, and non-intuitive controls further compromise safety, increasing the risk of accidents and injuries (Mehta and Tewari, 2000). Maintenance and accessibility issues also plague traditional tractors, with complex designs leading to extended downtimes and higher maintenance costs, which adversely affect farm productivity.

Furthermore, traditional tractors may not be sufficiently durable in harsh agricultural environments, leading to faster wear and tear from exposure to dust, moisture, and varying temperatures. The energy efficiency of tractors is generally low due to outdated engine designs and the absence of energy recovery systems, resulting in higher operational costs and increased reliance on fossil fuels. By addressing these issues, the project aims to develop an advanced EV tractor design that overcomes the limitations of current tractors, promoting sustainability, efficiency, and operator well-being in agricultural operations.

1.3 Objectives

The main aim of this project is to produces a design for an Electric tractor. Specifically, the objectives are as follows:

i. To design Electric Tractor's hood and main body by using SolidWorks Software.
ii. To perform selection method and analysis on various designs including material and components.
iii. To fabricate selected design of the Electric Tractor's hood using vacuum infusion method.

1.4 Scope of Research

The scope of this research are as follows:

i. Create and develop innovative design for Electric Tractor's hood and body using SolidWorks Software.
ii. Select the best design and materials for the Electric Tractor by analysing using Ansys Software.
iii. Fabrication of the selected design of the hood and body of Electric Tractor using fibre infusion method and sandwich structure composite.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

One potential way to improve the efficiency and sustainability of present farming methods is to electrify agricultural equipment, especially tractors. The agricultural industry can benefit from electric vehicle (EV) technology as a means of reducing fossil fuel consumption and easing greenhouse gas emissions. With a weight on important topics including design innovation, material selection, and performance optimization, this attempts to examine the present level of research and development in the field of electric vehicle tractors. This review is to provide insights into the opportunities and problems related to the use of electric vehicle (EV) tractors in agricultural operations by synthesizing the existing literature and identifying knowledge gaps. Referring to K-Chart in Figure 2.1, this chapter will discover all these topics in general.

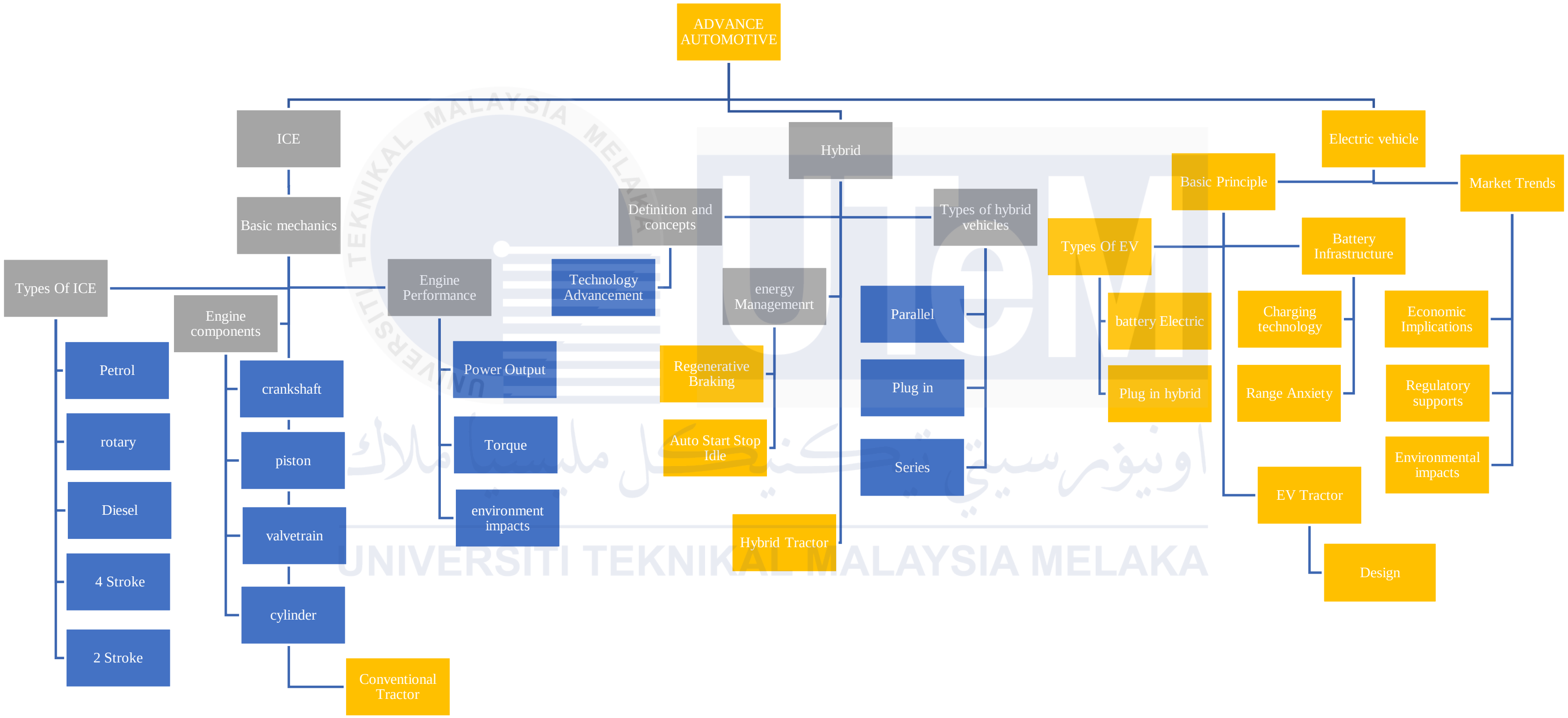


Figure 2.1 shows the K-chart for Literature Review

2.2 Internal Combustion Engine

An internal combustion engine (ICE) is a type of engine in which fuel is burned in a combustion chamber, a compact space. Through the rapid expansion of gases, this method drives turbines, pistons, and other components to generate mechanical work. ICEs are widely used in industry, cars, and other applications requiring portable, reliable power. Every stroke in an ICE follows a thermodynamic cycle. Air or an air-fuel combination enters the combustion chamber during the intake stroke. Thermodynamic stroke cycles are what an ICE follows. On the intake stroke, air or an air-fuel combination enters the combustion chamber. The piston then compresses this mixture, greatly raising its temperature and pressure, during the compression stroke. The power stroke follows, when an explosion that propels the piston down is produced when the compressed air-fuel mixture is ignited (by a spark plug in gasoline engines or by compression in diesel engines). At last, the chamber is evacuated of the combustion gases by the exhaust stroke. Different cycles can contain these strokes, such the Diesel cycle for diesel engines or the Otto cycle for petrol engines (Kamil et al., 2014).

2.2.1 Types of Internal Combustion Engine

An engine is a simple machine that converts heat energy to mechanical energy. The engine does this through either internal or external combustion. Combustion is the act of burning. Internal means inside or enclosed. Thus, in internal combustion engines, the burning of fuel takes place inside the engine where burning takes place within the same cylinder that produces energy to turn the crankshaft. ICEs differ in kind according to their cycle and igniting method. Like petrol engines, spark ignition engines (SI) light the air-fuel mixture with spark plugs. Typical of diesel engines, compression ignition engines (CI) use compression to ignite the mixture. While four-stroke engines need four strokes intake, compression, power, and exhaust while two-stroke engines finish a power cycle with two strokes of the piston (Prakash Vishwakarma and Kumar, 2016).

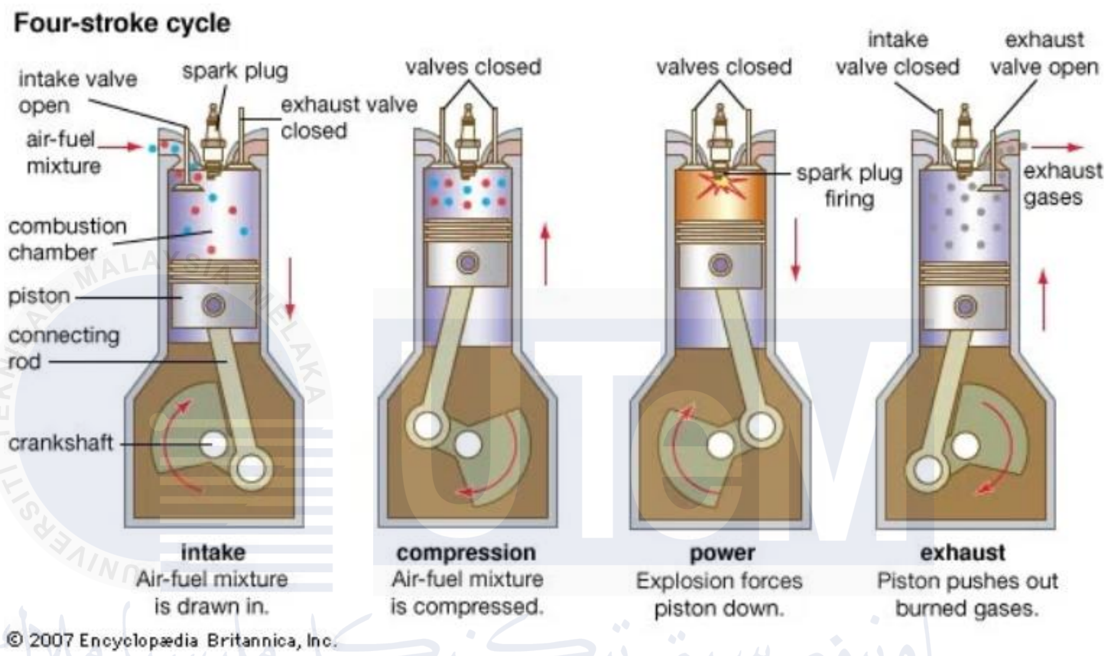


Figure 2.2 shows the basic four-stroke cycle of internal combustion engines (https://www.leadingedgeonly.com/article/the-four-stroke-cycle)

2.2.2 Internal Combustion engine: Basic Components

An ICE is made up of various important components. The cylinder is the chamber where fuel combustion occurs. As the pistons move up and down within the cylinder, the crankshaft translates their motion into rotational action. The camshaft governs valve opening and closure, allowing air and fuel to enter the cylinder and exhaust to depart. In spark-ignition engines, spark electrodes ignite the air-fuel combination, while fuel injectors supply fuel to the combustion chamber. Additional components include the connecting rod, which joins the piston to the crankshaft; the flywheel, which maintains rotational momentum; and the timing belt or chain, which synchronizes the rotation of the crankshaft and camshaft.

2.2.3 Internal Combustion engine: Engine Performance

There are a lot of different factors and technological advances that affect how well an internal combustion engine (ICE) works. There are a few important things to think about when talking about engine efficiency. There are a lot of things to think about, like how well the system can turn thermal energy into power, how much force or twisting power it can create, how fuel-efficient it is, and how much pollution it makes.

How well an engine works is heavily influenced by how efficient it is. "Engine efficiency" refers to how much useful work an engine does for the energy it needs. To make engines more efficient, new technology and engine design are often used. Direct fuel injection technology also makes it easier to control the exact amount of fuel and air in the engine, which improves burning efficiency and lowers fuel use.

Power flow and torque are two of the most important factors that determine how well an engine works. Power output is usually measured in horsepower (HP), which shows how well an engine can do a job in a certain amount of time. To figure out how well an engine works in different driving conditions, it need to know its torque. Torque is a way to measure the engine's spinning force. It is very helpful for trucks and other big machinery to have strong spinning power at low engine speeds. How power and torque work together is very important for how well an engine works.

Fuel economy is a very important factor in how well an engine works. It's also known as litters per 100 kilometres (L/100 km) or miles per gallon (MPG). There are several things that can affect how well a car uses gas. The size, shape, and type of fuel an engine uses are a few of the things that can affect how well it works (Agarwal, 2007). Variable valve timing (VVT) and cylinder deactivation are two new technologies that can make engines much more fuel-efficient by adjusting how they work in different situations.

When judging how well an engine works, it's important to look at the pollution it causes. It's important to know that strict rules are in place to help clean up the environment. Nitrogen oxides (NOx), carbon monoxide (CO), and unburned hydrocarbons (HC) levels have gone down since more improved technologies have been used to control emissions. Exhaust gas recirculation (EGR), selective catalytic reduction (SCR), and catalytic converters are some of the technologies that cars use to cut down on pollution (Kozina A, 2020). These technologies are very important for making engines that are safer, cleaner, and better for the environment, and it also make sure that engines meet government standards.

How well an engine works can be affected by how long it lasts and how reliable it is. The kind of materials used, how well things are put together, and how well it is taken care of all affects how good an engine is (Leach Felix, 2020). For business and industry, it's important to have engines that are strong and dependable. I want them to last a long time and be easy to maintain. While looking at an internal combustion engine, there are several things that can check to see how well it works. When deciding between different choices, it's important to think about things like dependability, dependability, sturdiness, fuel economy, power output, and torque.

2.2.4 Conventional Tractor

Design and performance of the conventional farm tractor remained relatively unchanged since the 1940s. It is proven that the traditional tractor has been a staple in agricultural practices for several decades. However, with the advancements in technology and the increasing demand for sustainable farming practices, there is a growing need to reevaluate the design and functionality of these tractors. In recent years, manufacturers have been introducing innovative features such as electric or hybrid powertrains, precision agriculture technologies, and autonomous capabilities to address the evolving needs of modern farming.

This is to change towards more efficient and environmentally friendly tractor designs which is essential for the continued progress of the agricultural industry.

The traditional tractor is typically powered by an internal combustion engine, usually running on diesel fuel. These engines operate on the principle of converting the chemical energy in diesel fuel into mechanical energy through a series of controlled explosions within the engine cylinders. This mechanical energy is then transmitted to the tractor's wheels through a transmission system, allowing the tractor to perform various tasks such as ploughing, tilling, and hauling (Schlosser et al., 2020).

The engine's operation involves a basic four-stroke combustion cycle, which includes intake, compression, power, and exhaust strokes. During the intake stroke, the engine draws in air, which is then compressed in the cylinder during the compression stroke. The compressed air is mixed with diesel fuel and ignited, generating power that drives the piston down during the power stroke. Finally, the exhaust stroke releases the combustion by-products from the cylinder. This conventional engine operation has been the important feature of tractor power for many years, offering reliability and robust performance in agricultural settings. However, with the emergence of alternative power sources and the push for sustainability, there is an increasing exploration of electric and hybrid powertrains in modern tractor.

Figure 2.3 shows example of traditional tractor, Kubota B7000

(https://tractor.info/tractors/kubota-b7000/)

2.3 Hybrid Vehicles

Hybrid cars are a big step forward in car technology because it combines the best parts of internal combustion engines (ICEs) and electric power systems. Hybrid engines do a better job generally, use less gas, and put out less pollution. The auto industry is under more and more pressure to be better for the environment and follow stricter government rules (Szász et al., 2021). Hybrid cars are a useful and short-term answer to this problem. There are petrol or diesel engines in these cars but also have electric motors and current battery systems. This makes these cars easy to drive and gives us more options.

2.3.1 Regenerative and advance in hybrids

Some of the most basic things that hybrid cars have are dual powertrain, regenerative braking, and smart energy management systems. There are no issues when the internal combustion engine and the electric motor work together thanks to the two-motor drivetrain (Louback et al., 2024). This gives the best power output for the road conditions. When you stop, the kinetic energy is turned into electrical energy that is stored in the battery (Erhan and Özdemir, 2021)This is an important function. This method not only saves power but also keeps brake parts from breaking down too quickly.

A hybrid car can work in three different modes: electric-only, engine-only, and dual mode. When the car is in electric-only mode, it only uses the electric motor. This mode is great for short drives and driving in cities because it does not pollute. If the battery is low or you're on the highway, engine-only mode will turn on the petrol engine. The engine and electric motor work together in hybrid mode to get the best speed and gas mileage. How these modes work together is controlled by a computer system on board. It checks the road conditions, battery charge, and power needs all the time to make sure it gets the best gas mileage and performance

(Namirian, 2020). Hybrid cars are very innovative and important for moving towards more eco-friendly ways to get around because of how well these technologies work together.

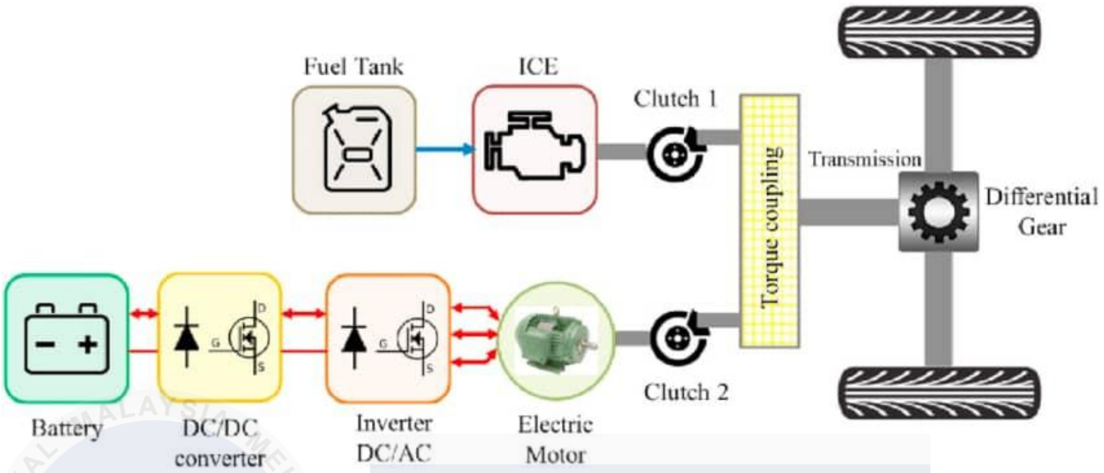


Figure 2.4 shows the basic principles of hybrid vehicle. (Namirian, 2020)

2.3.2 Hybrid Tractor

Hybrid Tractors are revolutionizing the agricultural industry with innovative design and sustainable features. The implementation of electric and traditional diesel power systems in tractors has not only reduced fuel consumption but also minimized emissions, making it an environmentally friendly option for farmers. In addition, the advanced technology and precision in the operation of hybrid tractors have significantly increased efficiency and productivity on the field.

With the growing demand for sustainable farming practices, hybrid tractors are shaping the future of agriculture. Hybrid tractors have brought a significant shift in the agricultural sector by integrating electric and diesel power systems. A study by (Beligoj et al., 2022) found that hybrid tractors can reduce fuel consumption by up to 25% compared to traditional diesel tractors, thereby contributing to substantial cost savings for farmers. Moreover, the decrease in emissions from hybrid tractors aligns with the goals of sustainable agriculture, as highlighted by (Gao et al., 2024).

Furthermore, the technological advancements in hybrid tractors have been instrumental in improving operational efficiency and productivity on the field. (Pascuzzi et al., 2024) demonstrated that the precision and automation features of hybrid tractors allow for more accurate and consistent performance compared to conventional tractors, ultimately leading to higher yields and reduced operational costs.

Table 2.1 Powertrain of a tractor comparison. (Beligoj et al., 2022)

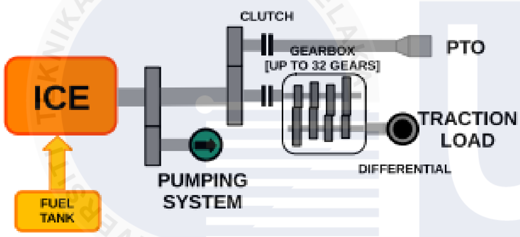
<table>
<tr><th>Powertrain of a tractor</th><th>Description</th></tr>
<tr><td>

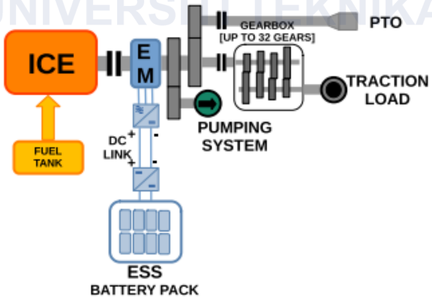
Figure 2.5 Traditional Powertrain</td><td>Traditional powertrain of a tractor. Internal combustion engine directly powers the gearbox and traction load.</td></tr>
<tr><td>

Figure 2.6 Hybrid Powertrain</td><td>Hybrid powertrain of a tractor. The internal combustion engine powers the gearbox and traction load, but also supply power to charge battery pack.</td></tr>
</table>

In conclusion, the integration of electric and traditional diesel power systems in hybrid tractors has not only reduced fuel consumption and emissions but has also significantly enhanced efficiency and productivity in agricultural operations. The evidence from recent studies and reports supports the pivotal role of hybrid tractors in shaping the future of sustainable agriculture and emphasizes the need for further technological advancements and adoption in the field. It is evident from the studies conducted by (Mocera et al., 2022) that hybrid tractors offer significant benefits in terms of fuel efficiency, reduced emissions, and improved operational performance compared to traditional diesel tractors.

2.4 Electric Vehicle

Electric vehicles (EVs) are changing the car business by providing a cleaner and more environmentally friendly option to standard internal combustion engine (ICE) vehicles. As worries about pollution and running out of fossil fuels grow, electric vehicles (EVs) have gotten a lot of attention and are becoming more popular because it can cut down on greenhouse gas emissions and oil use (Muratori et al., 2021). These cars run on electricity alone, with batteries storing power and electric motors moving the wheels. Compared to regular cars, usually it is quieter, smoother, and more fuel-efficient to drive(Tiwari et al., 2023)

An electric motor, a battery pack, and a controller are the main parts of an electric car. The electric motor turns the battery's electricity into mechanical energy that moves the wheels of the car. The electric power for the motor is stored in the battery pack, which is usually made up of lithium-ion cells. The controller is like the EV's brain, it controls the flow of power between the battery and the motor to make sure the best performance and fuel economy (Wen et al., 2020). EVs also have regenerative braking systems that turn kinetic energy into electrical energy when the wheels stop. This lets the battery charge faster, which increases the range of the car (Hosseini Salari et al., 2023).

Electric cars use a simple but very effective system to work. When the driver speeds up, the processor controls how much power goes from the battery to the electric motor. This gives the motor smooth torque right away (Louback et al., 2024). Electric vehicles don't need a complicated system of gears and transmissions. This means they have fewer moving parts and need less upkeep. EVs need to be connected to an outside power source, which can be anything from a regular wall outlet to a high-speed charging station (Ravindran et al., 2023). EVs can now go longer distances on a single charge, thanks to improvements in battery technology. Many types now have ranges that are like regular cars.

2.4.1 Types Of Electric vehicle: Fully Battery Electric

Purely electric-powered, electric vehicles represent a big development in automobile technology. While electric cars use electric energy only for propulsion, conventional cars, which have internal combustion engines, usually run on fuel like petrol or diesel. Rechargeable battery packs will power one or more electric motors mounted on these cars. So, electrical energy is stored in the battery packs (Thangavel et al., 2023). There is less moving part, hence reduced maintenance, and driving is quieter and smoother because there is no ICE.

A fully electric car will include a power electronics controller, a battery pack, an electric motor, and a regenerative braking system. Mechanical energy, which is converted by an electrical motor from electrical energy, drives the car wheels (Thangavel et al., 2023). It is from this that the car gains instant torque and smooth acceleration. Lithium-ion cells make up the energy storage component for the battery pack. The motor and other auxiliary devices are fed this electric energy (M. J. Wang et al., 2021). Power electronics controllers are meant to regulate the effective transfer of electrical energy between the battery and the motor. Their major objective is to ensure the system runs at its best efficiency and performance. The regenerative braking systems are specifically made to collect and utilize the energy that results from a car's deceleration or stoppage. The process of conversion makes it into electrical energy, which is then stored in the car battery for recharging (Erhan and Özdemir, 2021). This approach enhances the total distance the car can go.

The broad use of completely electric cars depends on the infrastructure for charging. Three tiers are distinguished for charging stations according to the speed and power output.

Level 1 chargers charge slowly and are appropriate for use at home over night using regular household outlets. Because of the use of greater voltage, level 2 chargers are widely available in homes, offices, and public spaces which charge more quickly. Level 3 chargers, sometimes known as DC fast chargers, allow drivers to quickly recharge their cars up to 80% capacity in around thirty minutes (M. R. Khalid et al., 2021). Supporting the increasing number of EVs on the road and reducing range anxiety require the network of charging stations such as public, residential, and workplaces.

2.4.2 Battery Infrastructure in Electric vehicles

To be used and maintained, electric vehicles, or EVs, need a battery infrastructure. Proper operation of the vehicle depends on the charging, upkeep, and management of the EV batteries. Use of facilities and equipment made especially for these uses is part of this. The need to have a dependable and effective battery infrastructure grows as the demand for electric cars (EVs) keeps growing (Das et al., 2020). Supporting broad EV use and resolving issues with range anxiety, charging times, and the sustainability of energy sources require this infrastructure.

Lithium-ion batteries are the most often utilized kind of batteries in electric vehicles (EV). Its low weight, long cycle life, and high energy density make it prized. Battery efficiency is increasing as technology does (McGinnis, 2020). These days it can last longer, charge more quickly, and store more energy. Researchers are looking into many materials and designs. Comparing solid-state batteries to other kinds, the former are thought to be safer and to have greater energy densities (M. J. Wang et al., 2021). These changes must be made to improve and lower the cost of electric cars (EVs).

Points for charging electric cars are part of the infrastructure. Usually, these facilities classify the charging speeds into three levels (M. R. Khalid et al., 2021):

- Level 1 Charging: Uses standard household outlets (120 volts) and provides a slow charging rate, suitable for overnight charging at home.
- Level 2 Charging: Utilizes specialized charging equipment (240 volts) and offers faster charging, commonly found in homes, workplaces, and public areas.
- Level 3 Charging (DC Fast Charging): Provides the fastest charging available, using direct current (DC) at high voltages. These stations can recharge an EV battery to 80% capacity in about 30 minutes and are typically located along highways and in urban centres for quick recharging during long trips.

Table 2.2 Charging Power level. (M. R. Khalid et al., 2021)

Power level Type	Charger Location	Usage	Supply Interface	Power Level	Charging Time	Vehicle Technology
Level-1 120 VAC (U.S.) 230 VAC (E.U.)	On-board 1-Phase	Domestic	Convenience Outlet	1.4kW (12A) 1.9kW (20A)	4-11 hours 11-36 hours	PHEVs (5-15kWh) EVs (16-50kWh)
Level-2 240 VAC (U.S.) 400 VAC (E.U.)	On-Board 1-/3-Phase	Private and Public	Dedicated EVSE	4kW (17A) 8kW (32A) 19.2kW (80A)	1-4 hours 2-6 hours 2-3 hours	PHEVs (5-15kWh) EVs (16-30kWh) EVs (3-50kWh)
Level-3 (208-600 VAC or VDC	Off-Board 3-Phase	Commercial parallel to refueling stations	Dedicated EVSE	50kW 100kW	0.4-1 hours 0.2-0.5 hours	EVs (20-50kWh)

Integration of the Grid and Energy Management Extended life of EV batteries depends on efficient energy management. The electricity grid is stabilized in part by smart grid technology and energy control systems as sales of electric cars rise (Hussain et al., 2021). Thank you to Vehicle-to-Grid (V2G) technology, electric cars (EVs) can return power to the grid during periods of high demand. This raises energy efficiency and helps to stabilize the network. To supply clean energy, EV charging stations are using solar and wind power. Reduced carbon footprint of electric vehicles can lessen its negative environmental effects.

Ecological battery recycling is becoming more and more in demand as electric vehicle (EV) sales rise. Schemes for recycling obsolete batteries gather nickel, cobalt, and lithium. The environment can benefit from our less dependence on natural materials. In what are known as "second-life applications," old electric vehicle (EV) batteries are used to store energy in homes, businesses, and factories. Both the product's value and the battery's life are extended by this.

2.4.3 Type of Batteries in Electric Vehicles

To power the EV, different types of batteries are used, such as lithium-ion, nickel-metal hydride, solid-state, and lead-acid batteries. It is important to understand these different battery technologies in order to figure out how does it affect the performance, range, charging time, and general viability of electric vehicles.

1. Batteries with lithium ion

   Lithium-ion batteries are the most popular type used in electric vehicles today. It is light, have a high energy density, and last a long time. Li-ion batteries have three main parts: an anode, which is usually made of graphite; a cathode, which is usually made of lithium cobalt oxide, lithium iron phosphate, or another lithium metal compound; and an electrolyte, which helps Li ions move between the electrodes when the battery is charging or discharging (Wen et al., 2020). Some of the best things about Li-ion batteries are:

- High Energy Density: It can hold more energy per unit of weight, which lets it go farther on a single charge.
- Long Cycle Life: It has a longer life and can be charged and discharged many times.
- Efficiency: There is high charge and release efficiency

Figure 2.7 Li-Ion Battery Structure. (Wen et al., 2020)

However, Li-ion batteries also have some drawbacks, such as thermal stability issues, which require robust thermal management systems to prevent overheating and ensure safety (Shahjalal et al., 2021).

2. Nickel-Metal Hydride Batteries

Nickel-metal hydride batteries had been commonly used in earlier generations of hybrid vehicles but were less often in full electric vehicles. NiMH batteries use a nickel hydroxide cathode, a metal hydride anode, and a potassium hydroxide electrolyte. The key benefits to NiMH batteries include High Energy Density. NiMH batteries have a higher energy density compared to other battery types, although slightly lower than Li-ion batteries, but it is still sufficient for many hybrid applications (Arun et al., 2022).

- Durability: Better thermal stability and robustness in different conditions.
- Safety: This will be less subject to thermal runaway than the Li-ion battery.

Table 2.3 Comparison of Lithium-ion to Nickel-Metal Hydride batteries (Arun et al., 2022).

No.	Specifications	Li-on	NiMH
1	Energy	160	90
2	Voltage	3.6 V	1.2 V
3	Size and capacities	Customized and 2000-6000 mAh	3XAA and 2000 mAh
4	Self-discharge rate per month	2-8%	30-50%
5	Price Range (Depends on battery type)	30-500 USD	20-150 USD
6	Maintenance	No	Low

The principal drawbacks to NiMH batteries are their higher self-discharge rate and lower overall efficiency when compared with Li-ion batteries, making them less suitable for modern EV requirements (Arun et al., 2022).

3. Solid-State Batteries

Solid-state batteries are an emergent technology that holds great potential to improve over Li-ion batteries. These batteries replace a solid electrolyte in place of a liquid. The solid electrolyte can be made from ceramics, glass, or polymers. Potential advantages of solid-state batteries are higher energy density which can potentially be higher than Li-ion batteries, allowing for larger driving ranges (J. Chen et al., 2021).

- Improved Safety: Reduced risks of leaks and thermal runaway since solid electrolytes tend to be more stable.
- Long Life: More durability and an increased cycle life.

However, solid-state batteries remain under development, and their high manufacturing costs and the technical difficulties of scaling up production for commercial use remain outstanding issues.

4. Lead-Acid Batteries

The lead-acid battery is among the oldest forms of rechargeable batteries, still applied in a few EV applications, mainly in low-cost or utility vehicles. These batteries have lead dioxide as cathode, sponge lead as the anode, and sulfuric acid as the electrolyte. The benefits of lead-acid batteries are low in cost, which are relatively inexpensive to produce and widely available (Mohammadi and Saif, 2023).

- Recyclability: High recycling rate compared to other battery types.

However, the major drawbacks of lead-acid batteries include low energy density, limited cycle life, and heavy weight, making them unsuitable for modern EVs, which have long-range and high-performance requirements.

2.4.4 Range Anxiety

To overcome range anxiety and enhance the appeal of EVs to consumers, several measures and technologies are at work:

1. Increase Battery Capacity:

    EV batteries, primarily lithium-ion, have seen tremendous technological strides in energy density. Today, EVs can travel much greater distances on a single charge than in the past. Some currently have driving ranges of over 300 miles which is comparable to many gas-powered internal combustion engine vehicles (Tamor, 2019).

2. Grow the Charging Infrastructure's Capacity:

    A widespread and convenient charging station network is essential to addressing range anxiety. Governments are spending billions to build new and upgrade existing charging stations, including DC fast-charging (Level 3) stations that can replenish an EV's battery quickly while a car is held on a charger (Afshar et al., 2021).

3. Add Faster Charging Rates:

    Innovations in charging technology like DC fast charging and ultra-fast charging enable EVs to charge much quicker than the current standard. These chargers can provide significant range in very little time, increasing the feasibility of long-distance travel and minimizing driver downtime during a trip (Collin et al., 2019).

4. Create Smart Energy Management Systems:

    Smart energy management systems in EVs optimize battery power usage to maximize overall vehicle efficiency. Regenerative braking, capturing otherwise lost energy as a car decelerates, is one such feature that increases an EV's driving range (Lotfi et al., 2022). Predictive energy management utilizes data on navigation systems and driving habits to optimize battery power usage.

5. Real-Time Data:

    Modern EVs have sophisticated onboard systems that provide real-time information on battery charge, estimated range, and locate nearby charging stations. A navigation system can plot a route based on charging infrastructure availability to assist drivers in avoiding range anxiety (Lotfi et al., 2022).

6. Battery Swap Technology:

Rather than charge, some manufacturers are developing technology for battery swapping. The idea is that a spent battery would be quickly swapped out with a fully charged battery at designated stations, significantly decreasing the time it takes to "refuel" an EV (Sun et al., 2019). Still in the early development stages, battery swap technology could effectively eliminate range anxiety.

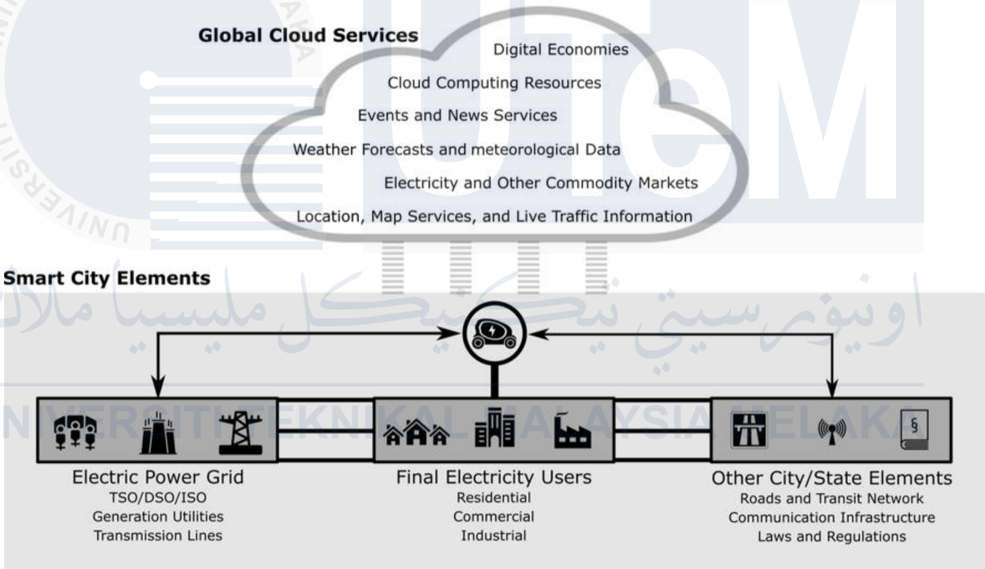


Figure 2.8 Battery Services Components (Lotfi et al., 2022).

2.5 Market Trends

The electric vehicle (EV) market has experienced significant growth and transformation over the past decade, driven by technological advancements, regulatory policies, and shifting consumer preferences. The global electric vehicle market is expected to continue its rapid expansion, with electric cars projected to account for 58% of global passenger car sales by 2040 (Ghandi and Paltsev, 2020). This upward trajectory is underscored by the increasing commitment of automakers to electrification, as well as substantial investments in battery technology and charging infrastructure.

This growth is the significant reduction in battery costs, which has made EVs more accessible to a broader range of consumers. Battery prices have declined by approximately 85% from 2010 to 2020, reaching around $137 per kilowatt-hour (Mauler et al., 2021). This cost reduction is pivotal in making EVs more competitive with traditional internal combustion engine vehicles, both in terms of upfront price and total cost of ownership.

Government policies and incentives also play a crucial role in shaping the EV market. Many countries have implemented stringent emissions regulations and offered financial incentives to encourage the adoption of electric vehicles. For instance, the European Union's Green Deal aims to achieve climate neutrality by 2050, significantly boosting the demand for EVs across member states (Wolf et al., 2021).

Moreover, advancements in charging infrastructure are crucial for alleviating range anxiety and supporting the widespread adoption of EVs. The proliferation of fast-charging networks is essential for making long-distance travel more feasible and convenient for EV owners (Anjos et al., 2020). As the infrastructure continues to expand, it is expected to further enhance consumer confidence and accelerate market growth.

2.5.1 Economic Implications

Widespread use of electric vehicles (EVs) has important economic ramifications that touch many economic sectors, both positive and negative. Consumer operating costs being lower is one of the main economic advantages. According to Liu Z, overall, EVs are less expensive to run and maintain than internal combustion engine cars, mostly because of lower fuel and maintenance expenses (Z. Liu et al., 2021). This cost advantage should grow as battery costs keep falling and charging infrastructure spreads around the world.

Macroeconomically speaking, the move to electric mobility may lower national oil import spending, which would strengthen energy security and trade balances. By switching to electric cars, for instance, the European Union may save billions of euros a year on oil imports and lessen its reliance on nations that produce oil (Leonard et al., 2021). Along with promoting energy independence, this change focuses funds on regional infrastructure and renewable energy projects.

Still, there are serious transitioning issues for the automotive sector. Because the manufacture of electric cars needs various parts and skills than those of conventional cars, supply chains and employment may be disrupted. Although the changeover could mean job losses in the conventional automobile manufacturing sectors, it also presents fresh prospects in the EV and battery manufacturing sectors. Depending on the capacity of businesses to adjust and reskill their workforce, the long-term impact may be neutral or even beneficial even if there may be short-term job losses in traditional automotive sectors (Nikitas et al., 2021).

Moreover, the growth in electric cars is causing significant expenditures in the battery industry. To satisfy the rising demand for electric vehicles, governments and businesses are making significant investments in battery production facilities. China, for example, is now a world leader in the EV industry thanks to its aggressive investments in battery technology and production capacity, which has an impact on international supply chains and trade dynamics (Sarah Ladislaw Ethan Zindler Nikos Tsafos Logan Goldie-Scot Lachlan Carey Pol Lezcano Jane Nakano Jenny Chase, 2021). Countries that lead in EV technology will probably gain a competitive edge in the automobile sector, which will affect the global economic power structures.

2.5.2 Regulatory Supports

The adoption of electric vehicles (EVs) can be accelerated by the execution of government policies and regulations. These measures provide incentives and build frameworks that encourage sustainable transportation. Monetary incentives, such as tax credits, rebates, and subsidies, greatly diminish the initial expense of electric cars (EVs), hence enhancing their competitiveness in comparison to vehicles powered by internal combustion engines. As an example, the federal government of the United States provides a tax credit of up to $7,500 for individuals who buy a new electric vehicle. The amount of the credit depends on the battery capacity of the vehicle (H. Liu et al., 2022). Numerous European governments offer substantial incentives to incentivize the use of electric vehicles. Norway grants electric vehicles an exemption from purchase taxes and value-added tax (VAT), resulting in a substantial reduction in their purchase price (Bjerkan et al., 2016). This policy has played a significant role in Norway's achievement of one of the highest rates of electric vehicle ownership per capita globally.

Governments utilize stringent emissions limits as a potent mechanism to promote the transition to electric mobility. The European Union's CO2 emissions regulations for new cars impose restrictions on the average emissions of automakers' fleets. This compels manufacturers to increase the production of electric and low-emission vehicles to meet the rules and risk substantial penalties (Haas and Sander, 2020).

The California Zero Emission Vehicle (ZEV) program mandates that automakers must sell a designated percentage of vehicles that generate no emissions, such as electric or hydrogen fuel cell vehicles. The objective of this strategy is to promote the expansion and commercial success of electric vehicles (EVs) (Trencher, 2020).

Governments have a vital role in enabling the development of charging infrastructure, which is essential for the widespread adoption of electric vehicles (EVs). Efficient execution of regulations and funding initiatives that support the creation of public and private charging stations is essential for alleviating range anxiety and enhancing the convenience of electric vehicle utilization.

Funding research and development (R&D) is very important for the progress of electric vehicle (EV) technology, especially in the areas of battery technology, energy economy, and self-driving cars. Governments often give funds and money to encourage new ideas in these areas. The Vehicle Technologies Office of the U.S. Department of Energy funds research projects that aim to make vehicles more fuel-efficient, add renewable energy sources to electric transportation systems, and make electric vehicle (EV) batteries work better and cost less (Cao et al., 2021).

Several countries have been able to get a lot of people to buy electric cars through large-scale government programs. China has put strict limits on the production of new energy vehicles (NEVs), given buyers of EVs big incentives, and put a lot of money into building charging stations for them. So, China's sales of electric vehicles (EVs) have gone up a lot, proving that it is still the world's biggest EV market (N. Wang et al., 2019).

2.5.3 Environmental Impact

Adoption and development of electric vehicles (EVs) are heavily influenced by their environmental effects, which present both major advantages and problems. The possibility of EVs to lower greenhouse gas emissions is one of their biggest environmental benefits. When driven by renewable energy sources in particular, electric cars emit far less pollutants over their lifetime than traditional internal combustion engine cars (Albatayneh et al., 2020). Reaching global climate targets and slowing down climate change depend on this emissions reduction.

Furthermore, by lowering locally produced pollutants like particulate matter (PM) and nitrogen oxides (NOx), which are dangerous to human health, electric cars help to improve the quality of the urban air. Broad use of electric vehicles in cities can result in notable drops in air pollution, which enhances public health and lowers the expenses of healthcare related to air pollution (Manisalidis et al., 2020).

Energy mix utilized to produce electricity greatly affects how environmentally friendly EVs are whether the electricity used to charge electric cars comes from renewable sources or fossil fuels can have a big difference in the overall environmental impact of the cars (Sathre and Gustavsson, 2021). Where coal-fired power plants predominate in the electrical grid, the potential of EVs to reduce emissions is smaller than in areas where renewable energy makes up a larger portion of the energy mix.

EV battery manufacture and disposal present environmental issues as well. Crucially important environmental and social effects of the mining of raw materials for battery manufacture include habitat loss, water contamination, and human rights issues (Berthet et al., 2024). Moreover, significant thought must go into the end-of-life management of EV batteries to prevent environmental pollution and to recover valuable components through recycling procedures.

Strong recycling programs and the creation of more environmentally friendly battery technology are two ways that these effects are being lessened. According to study by (Martins et al., 2021), battery chemistry developments, such the use of less crucial elements and better recycling techniques, can drastically lower the environmental impact of electric cars. Furthermore, laws encouraging the use of renewable energy for EV charging can improve the environmental advantages.

In conclusion, even if electric cars have significant environmental benefits, especially in terms of lowering greenhouse gas emissions and enhancing air quality, the energy mix used to generate electricity, and the environmental impact of battery manufacture and disposal affect their overall effect. Maximizing the environmental advantages of electric transportation requires addressing these issues through technological innovation and supportive legislation.

2.6 Electric tractor

The agricultural sector is undergoing a transformative shift with the advent of electric tractors, offering a promising alternative to traditional diesel-powered machinery. Electric tractors are increasingly recognized for their potential to enhance sustainability, reduce greenhouse gas emissions, and improve operational efficiency in farming practices. As highlighted by (L. Chen et al., 2022), the integration of electric vehicles in agriculture aligns with broader environmental goals, addressing the pressing need to mitigate the impact of climate change and reduce reliance on fossil fuels.

Electric tractors operate using battery-electric powertrains, which provide several advantages over conventional internal combustion engines. These advantages include lower operating costs, reduced noise pollution, and the elimination of exhaust emissions, thereby contributing to a cleaner and quieter working environment. Research by (L. Chen et al., 2022) indicates that electric tractors can achieve significant reductions in operational costs due to lower energy consumption and maintenance requirements, offering long-term economic benefits to farmers.

The transition to electric tractors is supported by advancements in battery technology, which have resulted in increased energy density, longer operational ranges, and faster charging times. Ongoing innovations in lithium-ion batteries and emerging battery technologies are critical to enhancing the performance and feasibility of electric tractors in various agricultural applications (Lagnelöv et al., 2021). Furthermore, the development of renewable energy sources and on-farm energy storage systems can complement the adoption of electric tractors, promoting energy independence and sustainability in agriculture (Gorjian et al., 2021).

In conclusion, electric tractors represent a significant innovation in the agricultural machinery market, offering environmental, economic, and operational benefits. The continued development and adoption of electric tractors are expected to play a crucial role in advancing sustainable agricultural practices, contributing to the reduction of carbon emissions and the overall environmental footprint of farming activities. This transition is underpinned by technological advancements and supportive policies that encourage the integration of electric vehicles in agriculture.

2.6.1 Application of Electric Tractor in Agriculture

Electric tractors are more efficient and environmentally friendly than diesel-powered implements, making them a major farming innovation that protects the environment, saves costs, and boost energy efficiency when utilized in farming. (Gołasa et al., 2021) suggest electric tractors reduce greenhouse gas and other farming equipment emissions. This can help farmers adopt greener methods.

Electric tractors are mostly used for field preparation, including tilling, harrowing, and ploughing. Due to the speed and power requirements, these jobs are excellent for electric power trains. (Ghobadpour et al., 2022) study found that electric tractors make field preparation as efficient as conventional tractors while using less fuel and emitting fewer pollutants.

Electric tractors are increasingly employed for planting and seeding instead of field preparation. Electric drivetrains provide farmers with more planting control and accuracy, improving food yields and resource utilization. (Sivakumar, 2019) suggest electric tractors can boost plant growth by altering planting spacing and depth. This will boost crop yields.

Electric tractors are needed for weeding, spraying, and fertilizing. Electric tractors can precisely apply pesticides and fertilizers, saving money and reducing environmental impact. (Shirokov and Tikhnenko, 2021) found that electric tractors give farmers more control and reduce pollution, improving crop care. This would aid environmentally friendly pest and nutrient management.

Electric tractors can move commodities and crops about the farm after harvesting due to their flexibility. Add solar or wind power to electric tractors to make them greener. (Lombardi and Berni, 2021) say farm green energy systems can charge electric tractors. This can make farmers' energy independent and less dependent on fossil fuels.

To conclude, electric tractors are used in agriculture to manage crops, move objects after harvest, and prepare land for sowing. It makes farming more accurate and efficient and benefit the economy and ecology. For long-lasting farming systems, electric tractors must be developed and integrated.

2.6.2 Advantages of Electric Tractor against Conventional Tractor

Electric tractors have several obvious advantages over conventional diesel-run tractors such as environmental impact, operational efficiency, and economic benefits. In fact, many are coming to realize how essential these advantages are in the future of sustainable agriculture.

The environmental benefit provided by electric tractors is significantly high. The level of greenhouse gas emissions and other gases normally emitted by other standard tractors can be substantially reduced. (Lovarelli and Bacenetti, 2019) reported that electric tractors do not emit any gases into the exhaust pipe. This contributes to a reduction in CO2 and NOx emissions into agricultural settings. This reduction of emission plays a vital role in combating climate change, purifying the air, and improving air quality in rural settings.

Electric tractors feature improved operational efficiency because of the electric drivetrain. This electric drivetrain offers high torque at low speeds and smooth and precise control. (Amongo et al., 2020) reported that electric motors show greater efficiency compared to internal combustion engines, especially under changing conditions. Because of this, their performances are better while plowing, planting, and harvesting. In addition to this, electric tractors offer less noise to the operator and reduce noise pollution in rural areas.

The financial advantages of electric tractors include having low running and maintenance costs. This is because electric tractors have fewer movable parts compared to diesel engines. (Vogt et al., 2021) explain that there is less wear and tear on parts from an electric tractor. The article also indicates that electricity tends to be more affordable and stable in price compared to diesel fuel. This leads to massive savings in fuel costs over the lifetime of a tractor. Small and medium-scale farms can go a long way in realizing these savings, primarily since they are usually on limited budgets.

This electric tractor will integrate with farm-based renewable energy systems, such as solar and wind power, to ensure a more sustainable and independent energy system that means energy independence and integration with renewable energy. According to (S. Wang et al., 2020) generating and storing renewable energy on-site can help reduce reliance on external fuel sources and reduce the impacts of fluctuating energy prices. This integration will not only enhance the sustainability of farming operations but also support energy security and resilience.

Advancing technology is also making battery technology and electric drive trains more efficient and viable. (Tomaszewska et al., 2019) explain that the improvement in lithium-ion battery technology is demonstrating higher energy densities, longer battery lives, and faster charging. This is what is making electric tractors increasingly viable and competitive for a wide range of agricultural applications. Electric tractors will surpass the level of conventional models due to further technological advancement, hence becoming more attractive for the agricultural sector.

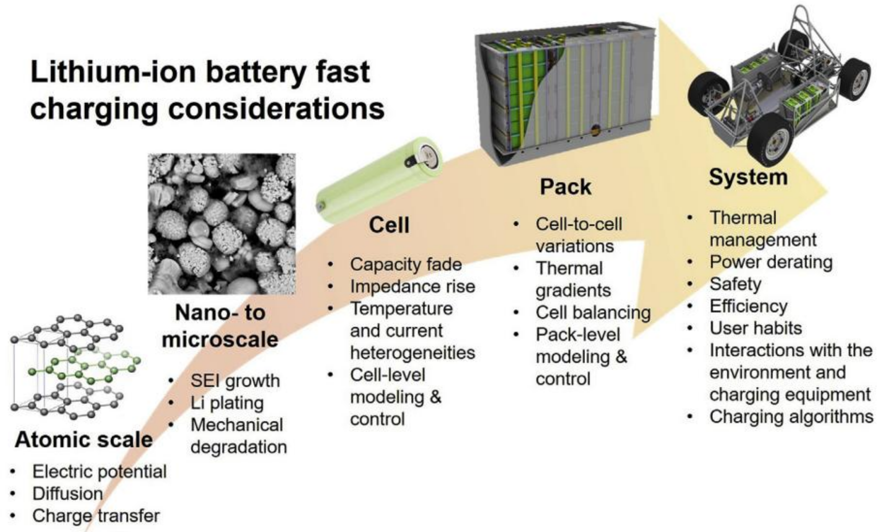


Figure 2.9 shows system advantage of an electric tractors (Tomaszewska et al., 2019).

From the above, electric tractors have more advantages over the traditional diesel tractors. These include environmental benefits, enhanced efficiency in operations, cost-saving, and the potential realization of energy independence by integrating renewable sources. These benefits emphasize the need to transition toward electric tractors as being a part of other extensive initiatives aimed at promoting sustainable and resilient agricultural practices.

2.7 Composite Materials

In the realm of engineering and material science, understanding the properties of materials is fundamental to the development and optimization of mechanical components. The properties of materials determine their suitability for various applications, especially in high-performance requirements. According to (Zhang and Xu, 2022), the selection of materials based on their specific properties can significantly influence the efficiency, durability, and overall performance of engineered products.

2.7.1 Natural Fibers

According to (M. Y. Khalid et al., 2021), fibrous materials, such as natural fibres and composites, have gained considerable attention in various fields of engineering due to their unique properties and potential applications in areas ranging from clothing, infrastructure, aerospace industries to energy generation and storage. The advantages of fibrous materials are their high strength-to-weight ratio, making them particularly attractive for use in structural applications. The flexibility and durability of these materials make them suitable for a wide range of engineering needs.

In recent years, there has been a growing interest in the use of natural fibres, such as jute, flax, and hemp, as sustainable alternatives to traditional synthetic fibres. These natural fibres offer the advantage of being renewable and biodegradable, making them an appealing choice for environmentally conscious engineering applications (Elfaleh et al., 2023). Additionally, natural fibre composites have shown promising mechanical properties, comparable or even superior to conventional composites, further fuelling their popularity in engineering applications.

Furthermore, the development of fibrous composites, which combine fibres with a matrix material, has opened new possibilities for engineering design. The ability to adjust the properties of composites by selecting different types of fibres and matrix materials has led to advancements in fields such as automotive manufacturing, construction, and renewable energy. These advancements have led to the discovery and exploration of new fibrous materials and their applications in engineering, creating a shift towards more sustainable and environmentally friendly practices (Andrew and Dhakal, 2022).

Overall, fibrous materials are important in engineering. As research in this field progresses, the potential for further advancements in fibrous materials and their engineering applications are very good. The use of fibrous materials, including natural fibres and composites, has gained significant attention in various engineering fields due to their unique properties and potential applications.

2.7.2 Fiber Glass

One of the commonly used fibrous materials in engineering applications is glass fibre. Glass fibre is a synthetic material that has gained popularity due to its excellent mechanical properties, durability, and resistance to chemicals and temperature. These properties make glass fibre suitable for a wide range of applications in the engineering industry, including construction, aerospace, automotive, and agriculture sectors. Glass fibre is known for its high tensile strength and stiffness, making it an ideal choice for reinforcing materials in composite structures (Morampudi et al., 2020). The use of glass fibre composites in engineering applications has led to the development of lighter and stronger components, contributing to improved performance and fuel efficiency in industries.

(Rajak et al., 2021) the versatility of glass fibre also extends to its electrical properties, which make it suitable for applications in electronic and telecommunications industries. Additionally, its resistance to environmental factors such as moisture, UV radiation, and corrosion further enhances its suitability for long-term engineering applications in challenging conditions. In recent years, research and development in the field of glass fibre composites have focused on improving their properties and exploring new applications. These advancements targeted to enhance the performance of glass fibre composites, expand their range of applications, and promote sustainable engineering practices.

Figure 2.10 shows example of fibreglass cloth
(https://cen.acs.org/materials/inorganic-chemistry)

The advance in glass fibre technology have resulted in the development of tailored forms and compositions, catering to specific engineering requirements. As a result, the use of glass fibre continues to evolve, paving the way for innovative and efficient solutions in engineering design and manufacturing. Overall, glass fibre offers immense potential for engineering applications due to its excellent mechanical properties, durability, resistance to chemicals and temperature, and electrical properties.

In conclusion, glass fibre stands as a versatile and reliable fibrous material that continues to drive advancements in various engineering sectors. Its unique combination of mechanical, chemical, and thermal properties makes it a valuable component in the pursuit of sustainable and high-performance engineering solutions.

2.8 Aerodynamic in Tractor

Aerodynamics role in the design and performance of electric tractors, significantly impacting their energy efficiency and operational effectiveness. According to (Afianto et al., 2022), optimizing the aerodynamic properties of vehicles can lead to substantial reductions in drag, which directly translates to improved fuel efficiency and reduced energy consumption.

For electric tractors, this improvement in aerodynamics is vital, as it extends the range and performance of the vehicle by reducing the amount of energy required to overcome air resistance.

One of the main focuses on aerodynamic design is the reduction of drag. As (Palanivendhan et al., 2021) notes, drag is a force that opposes the motion of a vehicle through the air, and it is influenced by the shape, surface smoothness, and frontal area of the vehicle. By refining the hood and body contours of electric tractors, designers can create streamlined shapes that reduce the coefficient of drag (Cd). Computational Fluid Dynamics (CFD) simulations, allowing for precise adjustments that enhance aerodynamic efficiency (Immonen, 2023).

Additionally, effective aerodynamic design contributes to better cooling efficiency, which is particularly important for electric tractors where thermal management of the electric powertrain and batteries is critical. Proper airflow management can enhance the cooling of key components, thereby improving the overall reliability and performance of the tractor. Adjusting vent placements and sizes based on aerodynamic principles ensures that thermal management systems operate efficiently without compromising the vehicle's aerodynamic profile.

In conclusion, the aerodynamic design of electrical tractors is a multifaceted undertaking that involves decreasing drag, enhancing cooling performance, and seamlessly integrating practical additives. Leveraging advanced equipment like CFD simulations and adhering to aerodynamic standards can cause widespread enhancements within the electricity efficiency and overall performance of electrical tractors, thereby contributing to their universal effectiveness and sustainability.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology employed in the design process and fabrication of the product. The conceptual designs that created targeted to satisfies the requirements given corresponding to a tractor identity. Features the modern and 'Electric' looks is the main requirement in making the design for Electric Tractor. Multiple conceptual designs are being developed. The methodology includes flowchart analysis, concept development, conceptual design, mock-up generating, design constraints and fabrication. Constraints upon the development of the mock-up such as wheel turns, steering shaft and pedal placement were analysed during the process. Aerodynamic measures and air flow for components cooling also inquired in the process.

3.2 Process Flowchart

The flowed chart was a diagrammatic representation of process or system by used action involves. It used for document, analyse and convey complex process or workflows. Figure 3.1 shows the process flow chart for PSM 1 and PSM 2. PSM 1 is the process for designing the tractor main body hood. In PSM 2, the process will involve fabrication of design, improvement and analysis.

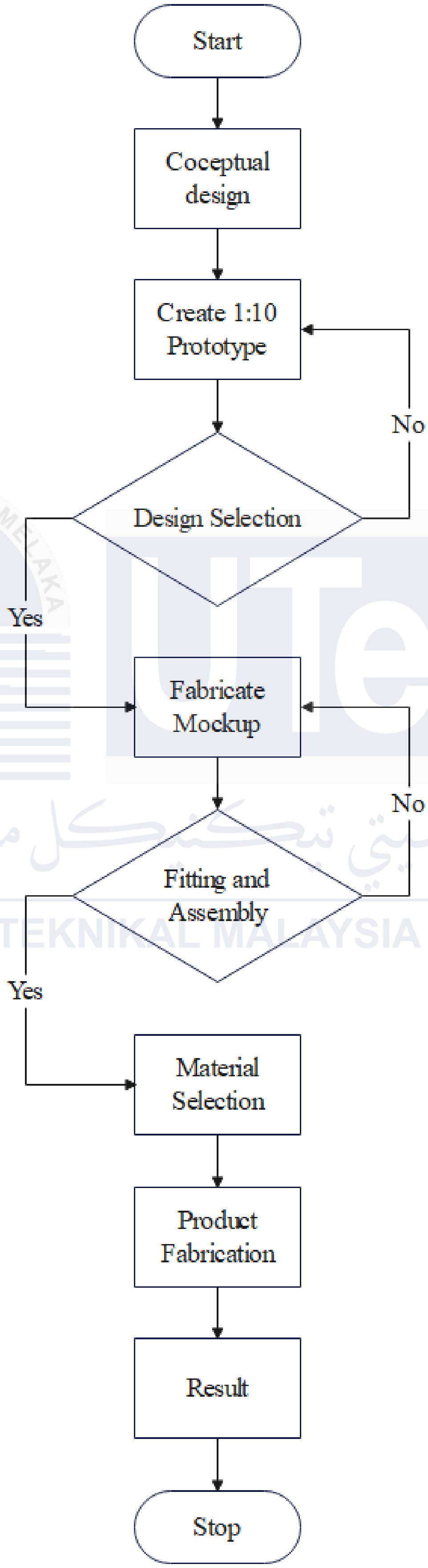


Figure 3.1 Flowchart Process

A process flow chart describes the steps that make up a workflow. Figure 2.1 shows the procedure from beginning to end of this design and fabrication process. The design overview will be the first step to be analysed which include web surfing, conventional tractor design view and modern tractor design concepts. Prior to that, design requirements were reviewed to meet the best expectations to the looks of the tractor. From the reviews, concepts of the design were generated with design sketches. The sketches then will be selected accordance with the main identity, criteria requirements, cost-effectiveness, aerodynamic measures and manufacturability.

To finalise the design, mini prototypes from the design sketches were produced to understand clearer about the design sketches. The process also will be studied to ensure that it meets the requirements and comply with the constraints of the tractor. The constraints will be viewed with the making of the 1:1 mock-up or prototype on the tractor itself. With the final design adjustments, the process will continue with the material selection for the product and starts the fabrication process to the end.

3.3 Conceptual Design Development

The concept development phase in tractor design is pivotal in shaping the overall functionality, efficiency, and aesthetics of the vehicle. This phase involves extensive research, brainstorming, and iterative design processes. By reviewing traditional and modern tractor designs through web surfing, one can appreciate the evolution of tractor concepts and the integration of contemporary technologies and materials that enhance performance and sustainability.

3.3.1 Conventional Tractor Design

Traditionally, tractors have been made with strength, dependability, and usefulness in mind. Some important things about classic tractors are:

1. Mechanical Simplicity: Most conventional tractors have simple mechanical systems that are simple to fix and keep up. This includes basic hydraulic systems, simple engine designs, and gears that consumer must shift by hand.
2. Durable Materials: Heavy-duty materials like steel are used to build traditional tractors so that it can stand up to rough conditions and long periods of use. The goal has been on making things last a long time.
3. Basic Ergonomics: The first tractors were made with usefulness over comfort in mind. The layout of the seats and controls in driver cabins is usually very simple, with an emphasis on practical efficiency over ergonomics.
4. Fixed Design Aesthetics: Most standard tractors are made in a way that is functional and does not put much thought into how it looks. The main objective is to create a dependable tool for farming chores.

Figure 3.2 shows typical traditional tractor design.

3.3.2 Modern Tractor Design Concepts

Newer tractors use high-tech materials and technologies to make them work better, be more efficient, and make the operator more comfortable. Some important parts of modern tractor design are:

1. Advanced Powertrains: Modern tractors often have advanced engine technologies, such as hybrid and electric systems. The goal of these new ideas is to make vehicles use less fuel, put out less pollution, and give power reliably.
2. Lightweight Materials: High-strength steel, aluminium, and alloys are some of the new materials that are often used. These materials lighten the tractor, make it use less gas, and make it easier to move around.
3. Ergonomic Improvements: Modern tractors have a lot of features that make it more comfortable and easier to use. Cabins with air conditioning, seats that can be adjusted, and easy-to-use control panels are now standard to make operators less tired and boost output.

4. Design aesthetics: Many modern tractors have designs that look good and work well together. Sleek, aerodynamic designs not only make things look better, but they also make them work better by lowering drag and making fuel use more efficient. Advanced instrument panels and LED lights make the car more useful and look more modern.

Figure 3.3 shows example of modern tractor.

3.3.3 Concept Development through Web Surfing

Surfing the web to come up with new ideas means looking at a lot of different online sources, like company websites, forums, and academic papers. This method helps designers keep up with the newest styles, tools, and customer tastes.

1. Publications from the industry: Websites of farm equipment associations and industry journals help about new tractor design trends and technological advances.
2. Manufacturer Websites: The websites of the biggest tractor makers often show off their newest models and technological advances. Manufacturers do this by giving full specs and stressing important features.
3. Groups and User Reviews: Online groups and review sites also give useful information. These sites can give useful information about the pros and cons of current tractor models, which can help improve design ideas.

Figure 3.4 shows example of tractor concepts made by designers.

3.3.4 Design Requirements

The body design of an electric tractor is critical to its overall performance, efficiency, and user experience. Modern design concepts prioritize technological integration, aerodynamics, efficient airflow management, and the use of lightweight materials to enhance the tractor's functionality and sustainability.

3.3.5 Modern Design Approach

The body design of an electric tractor is critical to its overall performance, efficiency, and user experience. Modern design concepts prioritize in technological integration, aerodynamics, efficient airflow management, and the use of lightweight materials to enhance the tractor's functionality and sustainability.

A modular approach to body design allows for easier customization and upgrades. Components such as the cabin, battery pack, and tool attachments should be designed for quick replacement or enhancement. This flexibility ensures that the tractor can adapt to different tasks and evolving technological advancements, thereby extending its operational lifespan.

The body design must prioritize operator comfort and safety. This includes spacious, climate-controlled cabins with ergonomic seating, intuitive control layouts, and advanced safety features such as roll-over protection structures (ROPS) and comprehensive visibility. Enhanced ergonomics reduce operator fatigue and improve productivity during long working hours.

3.3.6 Aerodynamics measure

Aerodynamic efficiency is crucial for reducing energy consumption, especially during transport. The body should have a streamlined shape to minimize drag. This involves smooth, contoured surfaces and rounded edges that allow air to flow over the tractor with minimal resistance. Reduced drag leads to improved battery efficiency and extended operational range as the tractor will be used in agriculture.

3.3.7 Airflow Management

Effective airflow management is essential for cooling the electric powertrain components, including the battery pack and electric motor. The body design will incorporate strategically placed air intakes, vents, and ducts that direct airflow to these critical areas especially under the hood. The airflows for the tractor core components such as batteries, motors and other parts that are covered by the hood design are also crucial to ensure the components stays in optimal temperatures. Batteries and motors generate heat in operation which requires enough air flows that can cool down the overall temperature for efficiency and lifespan of the components.

In addition to cooling the powertrain, proper ventilation is necessary to maintain a comfortable cabin environment. This includes designing air circulation systems that provide consistent airflow to the operator's cabin, ensuring a comfortable and safe working environment regardless of external conditions. Other than that, open-air concept can also be an option for the cabin design which allow more natural air around for the conductor. These alternative saves battery and gives more range to the tractor.

3.3.8 Lightweight Material Options

1. High-Strength Steel and Aluminium Alloys:

   Using high-strength steel and aluminium alloys in the tractor's body design offers a balance between strength and weight reduction. These materials are suitable for load-bearing structures and critical components, providing durability without significantly increase the tractor's weight.

2. Composite Materials:

   Advanced composite materials, such as carbon fibre reinforced polymers (CFRP) and glass fibre reinforced polymers (GFRP), are ideal for reducing weight while maintaining high strength. These materials can be used for body panels, hoods, and other non-structural components, contributing to overall weight reduction and improved energy efficiency.

3. Thermoplastic Polymers:

   Thermoplastic polymers are lightweight and versatile, making them suitable for various interior components, trims, and fittings. The ease of moulding and recyclability make it cost-effective options for large-scale production.

4. Nanomaterials:

   Incorporating nanomaterials into the body design can enhance the properties of traditional materials. For instance, nanocomposites can improve the strength, thermal stability, and corrosion resistance of materials, leading to a more solid and durable tractor body.

Designing the body of an electric tractor requires a deep approach that incorporates modern design concepts, aerodynamics, efficient airflow management, and lightweight materials. By focusing on these areas, tractors are not only energy-efficient and environmentally friendly but also offer enhanced performance, durability, and operator comfort. These advancements ensure that electric tractors will meet the demands of modern agriculture while contributing to sustainable farming practices.

3.3.9 Design Sketching

The initial stage of the design process, known as conceptual design, is when the main concepts for how something will function, and look are established. It entails planning the exchanges, occasions, procedures, and tactics that will be employed to accomplish the objective. This action is crucial since it ensures that the finished good or service satisfies the needs of the intended user base and sets the tone for the remainder of the design process. To generate a range of potential solutions that can be tried out and refined over time, conceptual design also frequently incorporates ideation sessions and brainstorming sessions along with user needs and preference research.

The process of determining a design's primary idea and aesthetic presentation is known as conceptual design. The conceptual design technique includes brainstorming, research, and sketching and functions as the basis design prior to proceeding to more detailed stages. After the conceptual design is created, it acts as an outline for the other design steps, ensuring that every component of the final product corresponds to the original concept.

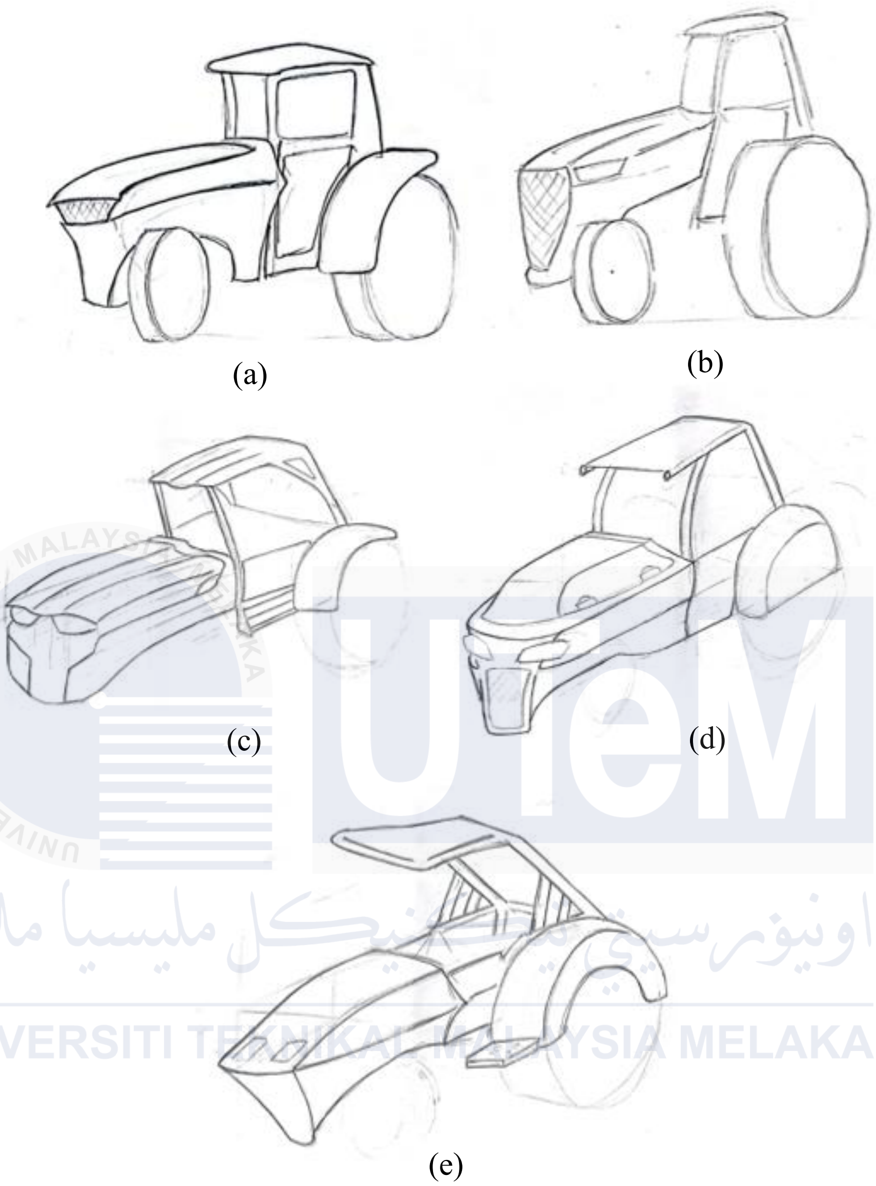


Figure 3.5 shows the design proposed for evaluation in design selection.

The picture shows a few concept drawings for an electric tractor that highlight many design variations that stress contemporary style and utility. Every concept investigates several ways to the front grille, cabin structure, and overall shape, combining ergonomics with streamlined aerodynamics. The drawings demonstrate how to go from conventional, boxy forms to more fluid, modern ones, emphasizing the value of effective airflow control and the use of suitable materials. These designs, which follow current trends in agricultural machinery innovation, seek to improve not only the tractor's performance and energy efficiency but also the operator comfort and visual appeal.

3.3.10 Sketch design Selection

Table 3.1 Pugh Method table for Design Selection.

		Design Selection Matrix						
Criteria	Weighting	Design (a)	Design (b)	Design (c)	Design (d)	Design (e)	Totals	Rank
Aesthetic	0	+	+	+	0	0	3	1
Manufacturability	0	+	0	+	−	−	0	4
Maintenance	0	−	−	+	+	+	1	2
Part Design feasibility	0	+	−	+	−	−	-1	5
Assembly Feasibility	0	0	0	+	−	0	0	3
	Totals	2	-1	5	-2	-1		
	Rank	2	3	1	5	3		

Design selection is an important phase in the development of an electric tractor hood design, where various conceptual designs sketch is evaluated to identify the most viable option that meets both functional and aesthetic requirements. This process involves assessing each design against a set of criteria, including aesthetics, aerodynamics, manufacturability, cost, and sustainability. The goal is to select a design that not only aligns with modern agricultural looks but also enhances efficiency, operator comfort, and environmental impact.

From the Table 3.1, design (c) was selected as the base design for improvement. Model base design will serve as a basis or guideline for the development of a specific product or system. A model base design would encompass the design and configuration of the tractor hood itself including the component's aesthetics, aerodynamics and durability of the design.

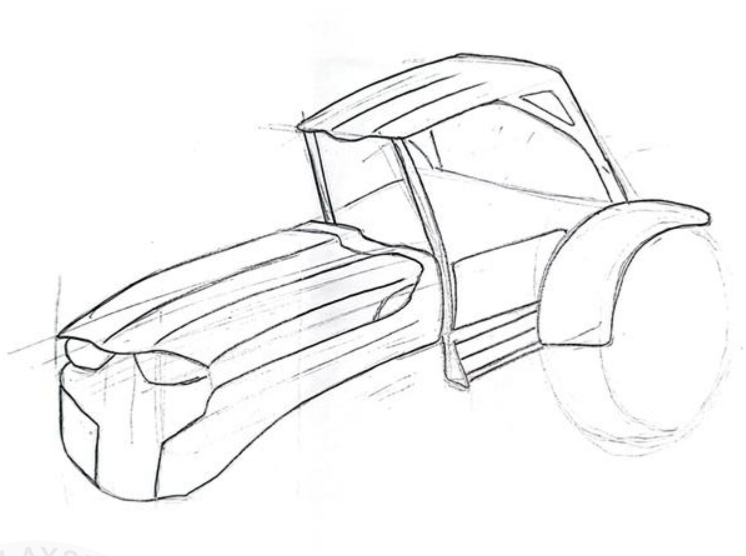


Figure 3.6 Selected sketch drawing design.

However, the design needs refinement to accommodate the constraints such as battery size, and improvement in overall design. From the base design, new design was generated which allows more aerodynamic benefits with modern characteristics. The new design sketch was drawn over the tractor main structure for more accurate understanding of the design.

Figure 3.7 New tractor design sketch.

The chosen design for the electric tractor, as shown in the provided sketch, offers a range of advantages that align with the key criteria mentioned during the design selection process. Here are the primary reasons for selecting this design:

1. Aerodynamic Efficiency

- Streamlined Shape: The design features a streamlined, angular body that minimizes air resistance. The smooth surfaces and rounded edges indicate efficient airflow over the tractor, reducing drag and improving overall energy efficiency. This aerodynamic efficiency is crucial for enhancing battery performance and extending operational range.

2. Component Protection
   - The innovated design as shown in Figure 3.7 shows added bumper around the body of the tractor to absorb impact from the front and both side of the tractor.
   - This addition will help protect all the important components inside the body of the tractor, especially the batteries that highly flammable.
3. Advanced Lighting:
   - This design includes modern LED lighting systems such as headlights and brake light, which are more energy-efficient and provide better visibility in low-light conditions. This is essential for safety and operational efficiency during early morning or late evening work.
4. Minimal Design:
   - The design indicates a minimal approach, where basic components can be easily replaced or upgraded. This reduces maintenance time and costs while allowing for future enhancements in technology and functionality.

3.4 Create 1:10 Scale Prototype

This phase involves transforming conceptual designs into a tangible prototype, providing an opportunity to evaluate the design's practical viability and performance. The chosen design features a streamlined and angular form, optimized for aerodynamics and constructed from lightweight, durable materials. To achieve precision and detail in the prototype, we first used a flower span carving technique, to initiate first looks with details on the product.

Figure 3.8 shows the carved prototype model.

This prototype in Figure 3.8 is a 1:10 scale to the real product. The detail on this prototype follows the sketch with few adjustment upgrades for better aesthetics. The technique produces a smooth, high-quality finish that not only enhances the aesthetic appeal of the prototype but also provides a more accurate representation of the final product's surface characteristics.

3.5 Mock-up Fabrication

The creation of a 1:1 scale mock-up of the electric tractor hood is a fundamental step in the design and development process. This actual model serves as an overall representation of the final product, allowing us to identify and address potential constraints and challenges that may not be noticeable in smaller prototypes. By constructing a full-scale mock-up, we can evaluate the design's practical aspects to make sure that the final product meets all functional and ergonomic requirements.

3.5.1 Body Panel Dimensions

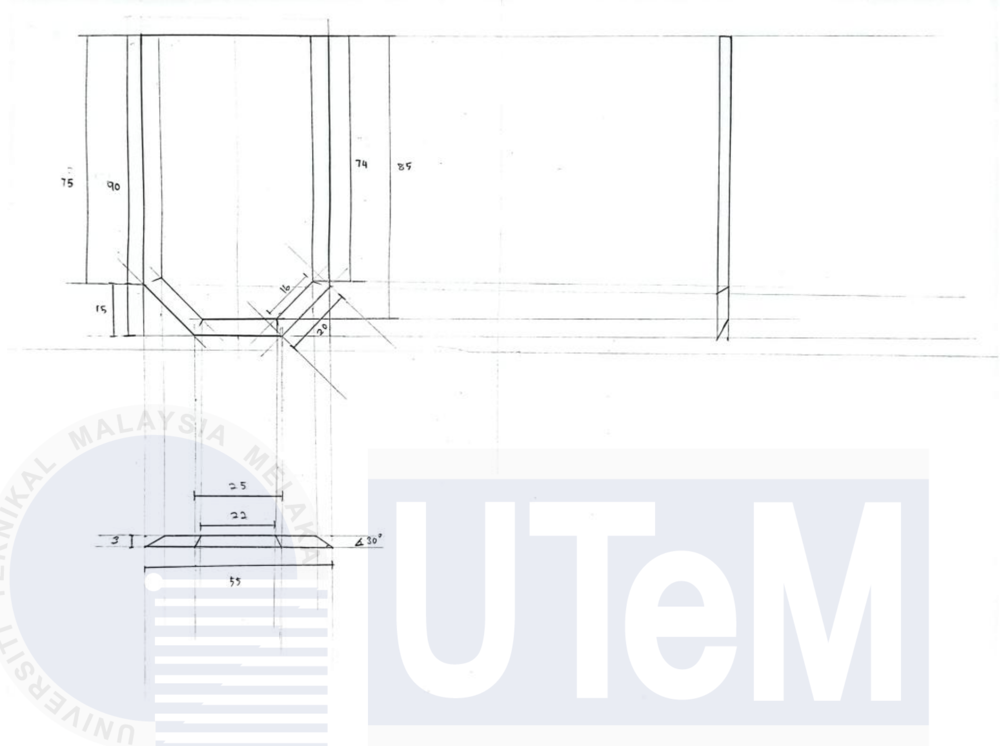


Figure 3.9 Hood dimensions.

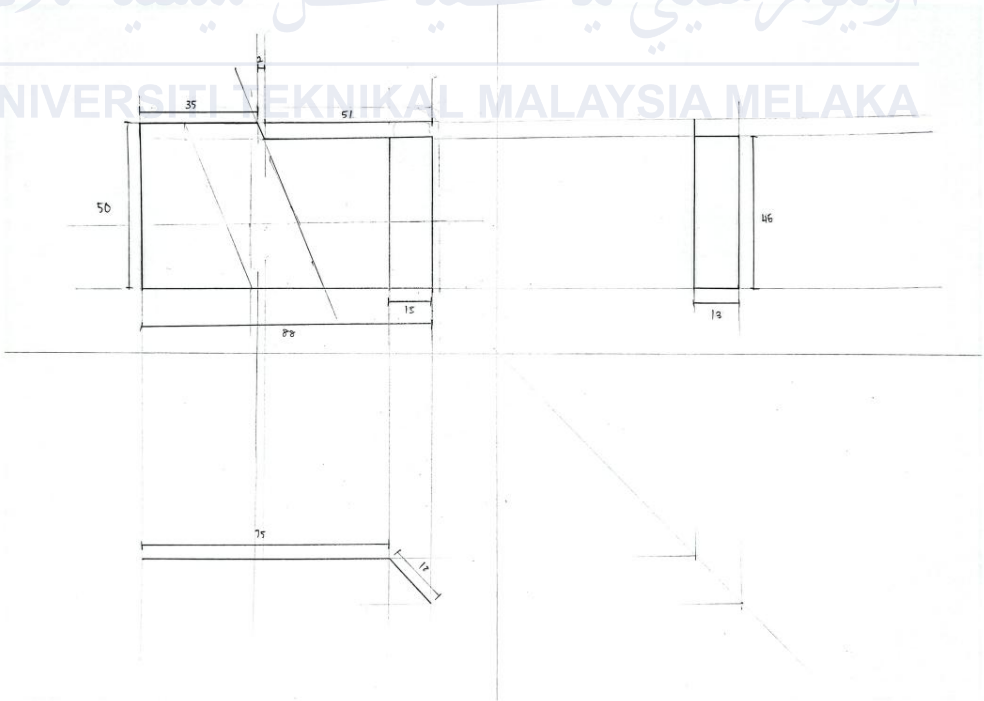


Figure 3.10 Side panel dimensions.

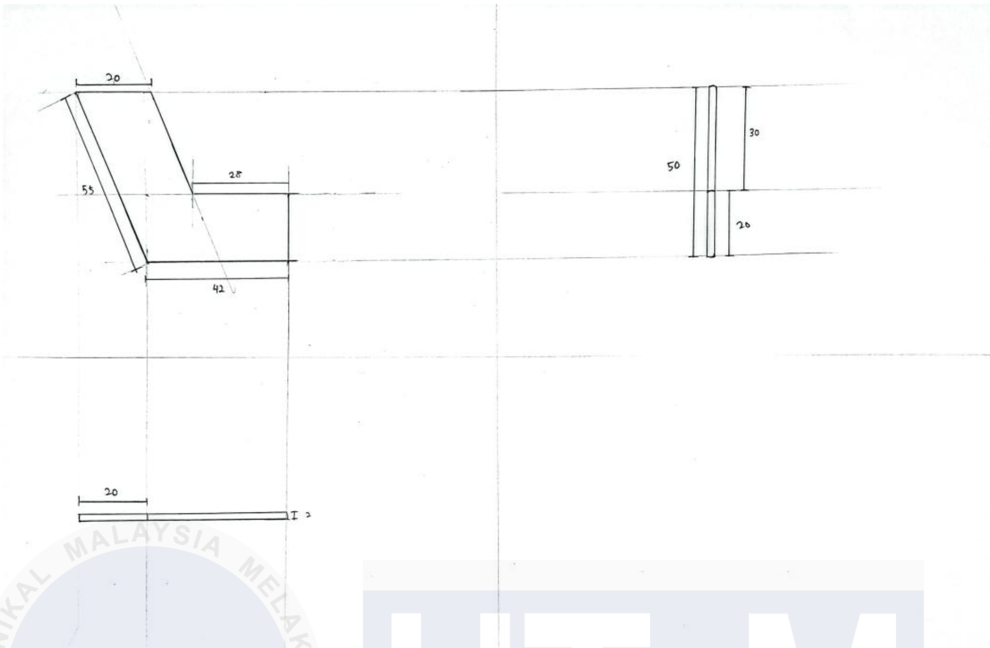


Figure 3.11 Side bumper dimensions.

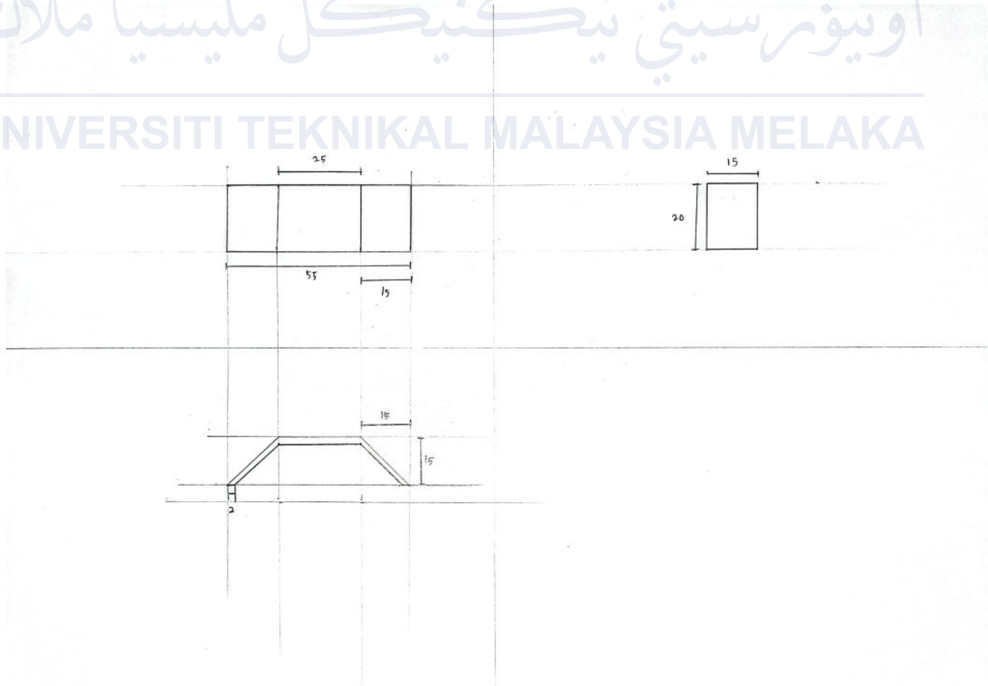


Figure 3.12 Front bumper dimensions.

The primary dimensions of the tractor body and hood are separated into four parts. The first part is the hood of the tractor body (Figure 3.9) which only one whole part. Same goes to the front bumper (Figure 3.12), it also a whole single part. The side panel (Figure 3.10) and side bumper (Figure 3.11) dimensions however have two parts each which are left and right. Overall, there are only six parts altogether.

3.5.2 Fabrication process

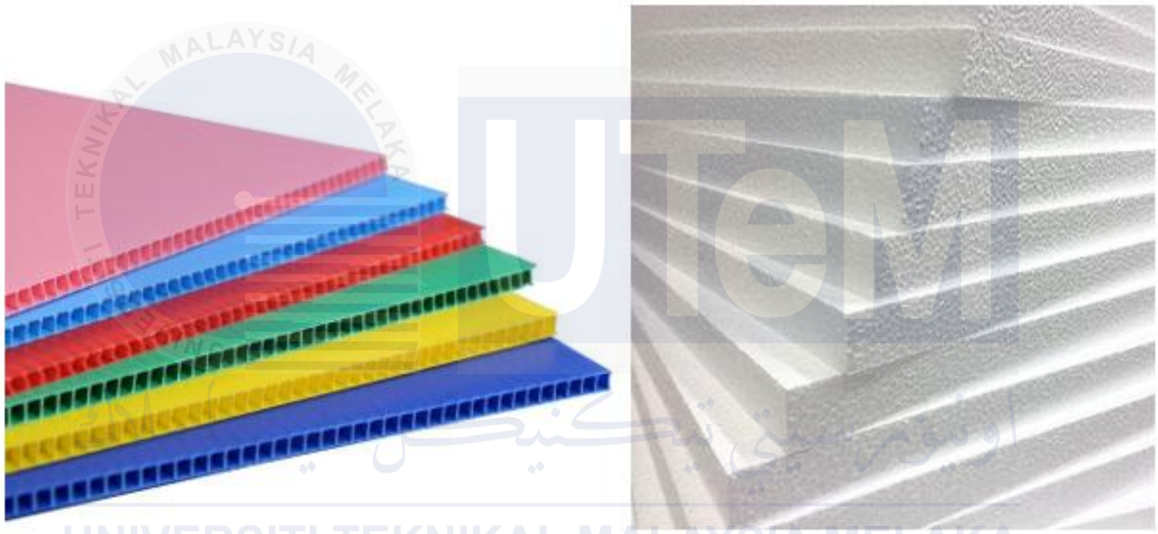


Figure 3.13 Material for mock-up fabrication 1. Strawboard, 2. Polystyrene foam sheet.

Mock-up is a 1:1 scale model that can be put onto the tractor for overall viewing of intended final product. From the mock-up, other interferences such as constraints, actual sizes, and overall aesthetics can be analysed before proceeding to adjustments to the mock-up model. To achieve this, the main panels such as hood and side panels were built using strawboard according to the fact that it is strong enough for the whole structure as shown in Figure 3.13. The side and front bump uses polystyrene sheet to display the original thickness of the whole bumper itself. Figure 3.14 shows the process of making the mock-up until the end of the process.

Figure 3.14 shows the fabrication process.

Figure 3.15 shows the mock-up fabricated.

Figure 3.15 shows the outcome of the process. From cutting process to assembly of the body and hood, everything was done using precise measurements to get the best results. It is then placed onto the tractor to get the idea of the tractor’s appearance.

3.6 Fitting and Assembly

As moving towards finalizing the design of the electric tractor hood and body, this phase involves making precise adjustments based on insights gained from the 1:1 scale mock-up, prototype evaluations, and stakeholder feedback. The goal is to refine the design to ensure optimal performance, manufacturability, and user satisfaction. Below are the key parameters and steps to consider during this process.

3.6.1 Key Parameters for Final Design Adjustments

The final design adjustments for the electric tractor hood and body design focus on several critical parameters to ensure optimal performance, durability, and user satisfaction.

The first one is aerodynamic performance. This involves the refinement of the hood and body contours to minimize drag and improve airflow. This can be achieved through the utilization of Computational Fluid Dynamics (CFD) simulations to test various shapes and surface modifications. Additionally, the design must ensure efficient cooling of the electric powertrain and batteries, which may involve adjusting vent placements and sizes to improve thermal management without disturbing the overall aerodynamics.

Structure durability is essential to ensure that the materials chosen for the hood and body can withstand operational stresses and environmental conditions. This involves validating material strength and potentially adjusting material thickness or adding reinforcements where necessary. Moreover, impact resistance is crucial, especially in areas prone to impacts, such as the front and sides of the hood. Enhancing these areas with energy-absorbing materials or structures can significantly improve durability.

Ergonomics and operator comfort are also important in the design process. The hood design must allow easy access to critical components for maintenance and repairs. Plus, it is important to verify that the hood design does not obstruct the operator's line of sight. Adjusting the height and angle of the hood as necessary can enhance visibility and overall operator safety.

Other than that, design aesthetic and functionality must be carefully balanced to ensure the tractor has a modern and appealing look while maintaining its function. This involves refining the aesthetics, such as surface finishes, colours, and design lines. Functional integration is to ensure that all components, such as lights, sensors, and cameras, are seamlessly integrated into the design. Proper placement and housing of these components protect them while maintaining their functionality.

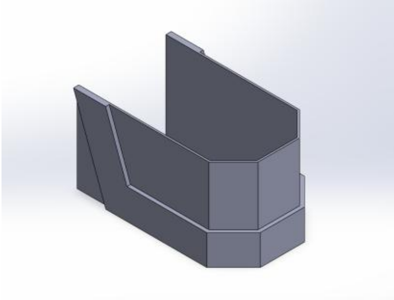
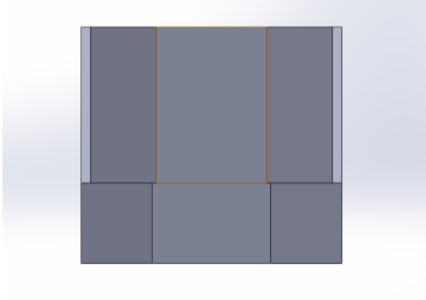
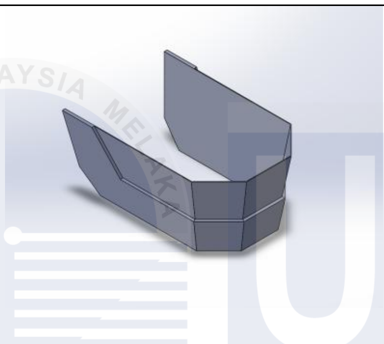
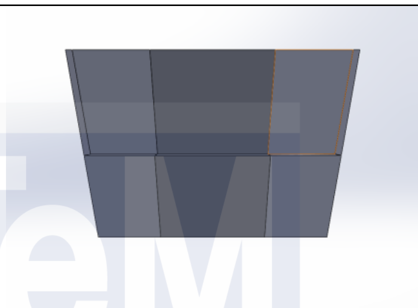
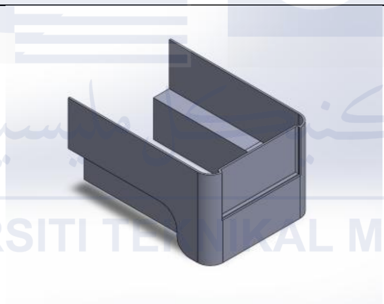
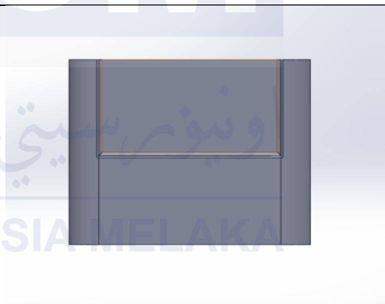
Manufacturing feasibility is another critical parameter to be examine. The design must be compatible with efficient manufacturing processes, which might involve simplifying complex geometries to reduce production time and cost. Additionally, the design should allow easy assembly and disassembly, which is important for both initial manufacturing and maintaining the tractor.

Sustainability and Environmental Impact are increasingly important considerations in modern design. This involves ensuring that the materials chosen to have minimal environmental impact throughout their lifecycle and optimizing the design for energy efficiency during operation. This includes refining the weight and aerodynamic profile to reduce energy consumption.

3.6.2 Final Design Adjustments

The steps for final design adjustments begin with the thorough analysis of test results. Gathering all feedback from mock-up testing and prototype evaluations is very important. This includes analysing results from aerodynamic, structural, and ergonomics to identify areas that need improvement.

Table 3.2 Different design of EV tractor body.

Design No.	Iso View	Front View
Design 1		
Design 2		
Design 3		

There were three designs generated using SolidWorks. The first design is the original design idea of the EV tractor, which the body is totally vertical and the sturdiest based on analysis in Chapter 4. The problem came when this design does not fully fit the EV tractor's components. The second design is the selected design, which have a wider top, allowing more spaces for the tractor's component to fit perfectly. Lastly on the third design, which is very wide. The wideness of the design supresses the component fitment problem entirely, however the size matter is too big, and less overall aesthetics.

From the observation, Design 2 were chosen from others. Final design then proceeded into another final product mock-up. The purpose of the second mock-up is to ensure that the design fit perfectly on the tractor chassis. Figures below shows the body design, hood design and the assembly of the final design.

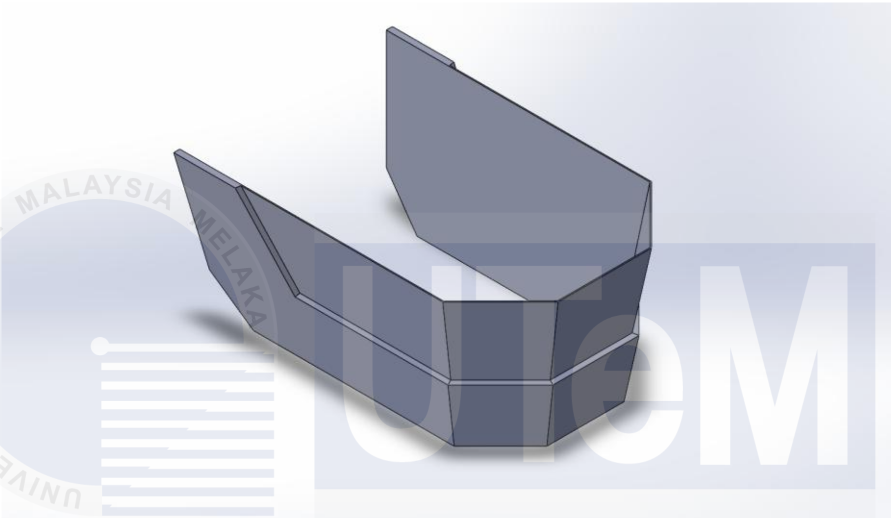


Figure 3.16 Main body design selected.

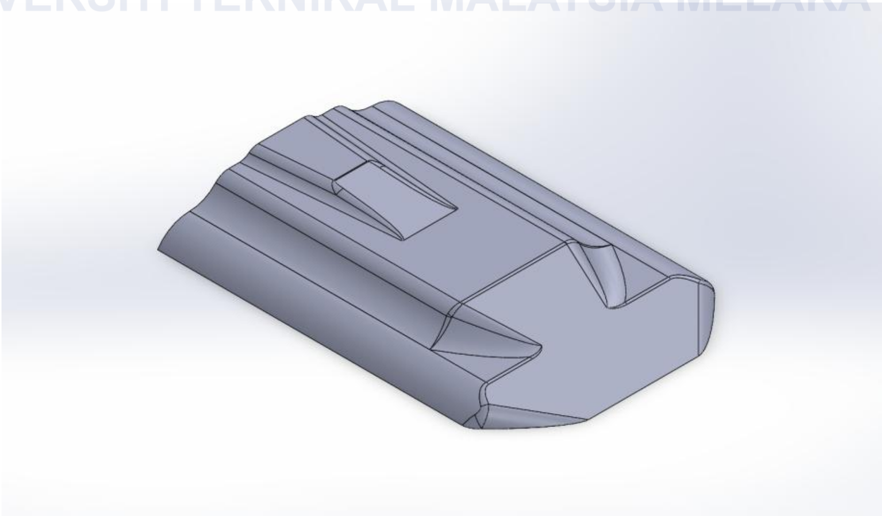


Figure 3.17 Hood design generated on SolidWorks.

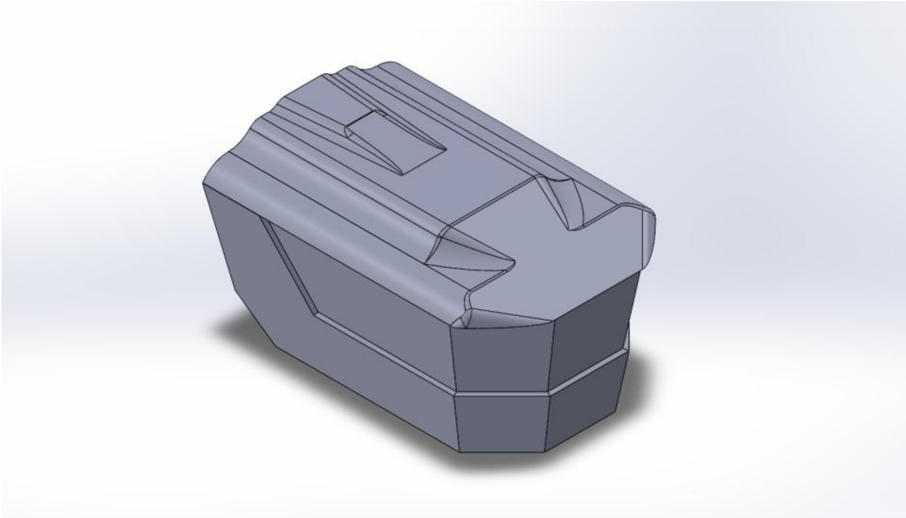


Figure 3.18 Assembly of the body and hood.

Figure 3.19 Final prototype design.

From the Figure 3.19, the prototype of the hood for the electric vehicle (EV) tractor is made with a slight slandered angle on the bottom of the design to accommodate battery size on the upper side and gives space for steer angle of the wheels. Other than that, the overall aesthetics were improved neglecting boxy straight forward design.

Next, the CAD models must be refined which involves updating the CAD models to incorporate the necessary adjustments identified during the testing phase. Performing additional simulations, such as CFD and Finite Element Analysis (FEA), can validate these adjustments and ensure the design meets all required specifications.

3.7 Material Selection

Material selection is a crucial aspect of the design process for the electric tractor hood and body. The right materials can significantly enhance the performance, durability, and efficiency of the tractor. This process involves evaluating various types of materials based on specific parameters that align with the design goals and functional requirements.

3.7.1 Parameters for Material Selection

The first one is material strength and durability. The materials must be able to withstand mechanical stresses and impacts during operation, which requires assessing tensile strength, compressive strength, and impact resistance. Additionally, analysing the material's ability to endure usability over time without failure is crucial for ensuring long-term reliability and performance.

Other than that, reducing the overall weight of the tractor is essential for enhancing energy efficiency and performance. Lightweight materials such as composites and aluminium alloys are often preferred due to their high strength-to-weight ratios. However, it is equally important to ensure that weight reduction does not compromise the structural integrity or stability of the tractor, maintaining a balance between lightness and durability.

Next, the materials must be resistant to environmental factors such as corrosion caused by exposure to moisture, chemicals, and other elements. The materials should withstand prolonged exposure to sunlight without degrading. This involves selecting materials with excellent corrosion resistance and UV to maintain their appearance over time.

Effective thermal management is vital, especially around components that generate heat. Materials should efficiently manage heat dissipation, which involves selecting those with good thermal conductivity. Additionally, considering the coefficient of thermal expansion is important to prevent deformation under temperature changes, ensuring that the materials remain stable and functional under varying thermal conditions.

The chosen materials should be easy to mould, cut, and assemble using available manufacturing techniques. Relating to the cost-effectiveness of materials is also important, considering both raw material costs and processing expenses. This ensures that the materials not only meet performance criteria but also align with budget constraints and production capabilities.

Lastly, the materials should allow for high-quality finishes that enhance the tractor's visual appeal. Consideration should also be given to how well the materials can be coloured or textured to meet design aesthetics. This ensures that the final product is not only functional but also visually appealing.

3.7.2 Material Selection Method

The first step is to outline the specific requirements and constraints for the tractor hood and body, including pedal placement, thermal, environmental, and aesthetic criteria. This initial step is the main idea for the material selection process by clearly defining what the materials need to achieve.

Next is conducting comprehensive research on various materials that meet the defined requirements. This includes exploring metals for example aluminium, stainless steel and composites such as carbon fibre and fiberglass or even polymers like ABS and polycarbonate. With all the materials reviewed, create a comparison matrix to evaluate potential materials against the key parameters such as strength, weight, cost, and environmental impact. This helps in systematically comparing materials to identify the most suitable options.

For the final selection, a decision must be made on the materials to be used for the hood and body to ensure that the selected materials align with the overall design goals, including performance, manufacturability, and sustainability. This step finalizes the material selection.

Table 3.3 Material Selection Matrix

		Alternatives					
Criteria	Baseline	CARBON FIBER	FIBERGLASS	METAL SHEET	POLYMERS	Totals	Rank
COSTING	0	-1	1	0	1	1	3
STRENGTH	0	0	1	1	-1	1	3
WEIGHT	0	1	1	-1	1	2	1
FEASABILITY - FABRICATION	0	-1	0	1	1	-1	5
SUPPLY	0	0	1	1	0	2	2
	Totals	-1	4	2	2		
	Rank	4	1	2	2		

From the table above, the best option for material selection is Fiberglass. From costing criteria, the most expensive material is Carbon Fiber, while metal sheet, polymers and fiberglass is cheaper. The strength is one of the most important criteria as it defines the overall structure of the body. It shows that Fiberglass and metal sheets is the best option for strength as the carbon fibre needs to be thick to withstand high impact and polymers are softest among all options.

Next criteria are the weight of the materials. Obviously, carbon fibre and fiberglass are lighter other than polymers and especially sheet metal. Weight is important to ensure that the overall weight of the electric tractor stay light which gives much more advantages. Polymers and Metals are the easiest to fabricate and takes less time than fiberglass and carbon fibre.

Lastly, carbon fibre and polymers are not easy to obtain especially in big amount while fiberglass and sheet metal are easier to find.

Figure 3.20 The materials used for all body parts (fibreglass cloth, GRP)

3.8 Product Fabrication

As the final step, to fabricate the hood and the body panels, it must follow all the parameters mentioned above. Finalizing the design is as important to produce the best outcome. Aesthetically, the design of the electric tractor must have modern looks to it, with fine details on the curves, and simply keep the minimalism which related to modern vehicles.

The fabrication process includes materials selection, which is important to keep the tractor lightweight as it is carrying a big battery that already contributing the total weight on the tractor, as far as keeping sure that the material have enough durability and longevity. Methods on the fabrication also important. The hood and the body need to have different methods applied to ensure best quality on the product. For example, the hood needs to use fibre infusion method, which include mould making, and fibre laminations to reduce weight and improve maintenance feasibility. The body panels however can use sandwich fibreglass method as it is sturdier and gives an extra impact absorption during collision. This is important as the main component such as battery that the body panels protecting is prone to burn and explode if impaled with metals.

Fiber infusion is a technique commonly used in manufacturing and enhancement of composite materials, usually applied in the aerospace, automotive, and construction industries. This method involves placing resin into a dry fiber preform, which is typically made of materials like carbon, glass, or aramid fibers. The process starts by placing the dry fibers into a mold, then a vacuum is applied to remove air and make sure that the fibers are tightly packed. Resin is then infused into the fibers under vacuum or pressure, thoroughly saturating the material. Once the resin cures, it forms a solid, rigid composite with specific shape demanded. Fiber infusion is valued for its ability to produce high-quality, durable components with complex shapes and minimal voids.

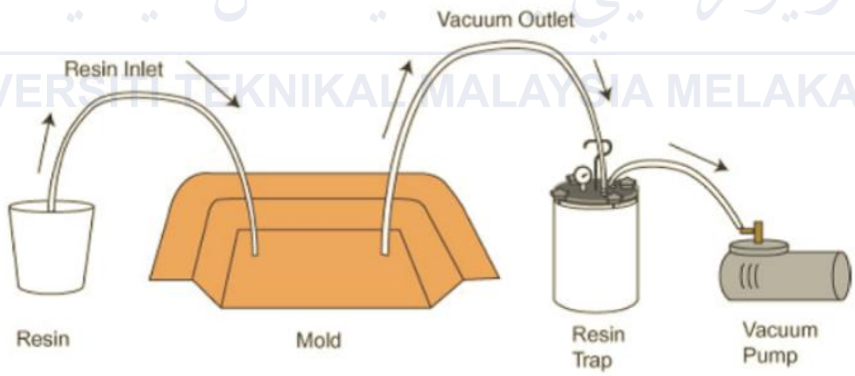


Figure 3.21 Vacuum Infusion Method

3.8.1 Fabrication of Body Panels

Figure 3.22 shows the body part fabricated using Vacuum Infusion Method.

There are two types of fibreglass technique used in this process, the first one is Glass Fibre Plastic (GRP) honeycomb and fibre plating using infusion method as shown in Figure 3.21. The GRP was cut and placed according to it shape and size as shown in APPENDIX C, then plated with layers of fibre cloth on top and vacuumed with resin. The process takes a bit longer time but gives excellent strength on the whole structure especially with the present of GRP panels.

Figure 3.23 shows the cutting process of body panels.

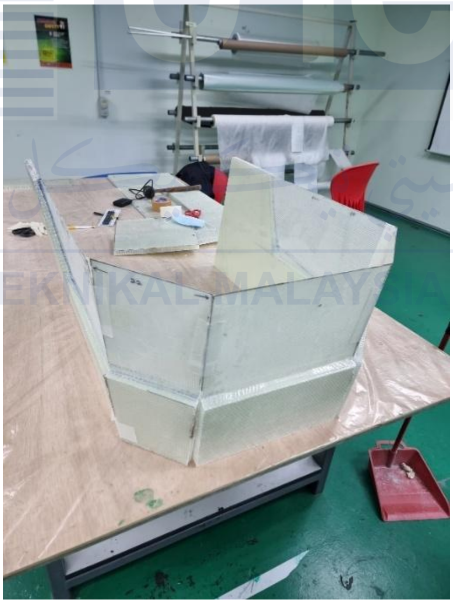


Figure 3.24 shows the process of assembling all parts to form the shape of the body.

After precisely cut and trimmed as shown in Figure 3.23, the panels of the body were assembled as shown on Figure 3.24. The panels then were bonded together using Polyurethane Adhesive which form strong bonds between composite panels. The advantage of using this adhesive material is that it has good tensile strength, adhesion to variety of substrates and importantly cure at room temperature.

3.8.2 Fabrication of Body Hood

Figure 3.25 shows the Rib and Spine Mold Construction using laser cut.

The ribbed mould construction method is an efficient and cost-effective way to make moulds for products. It uses a framework of interlocking ribs and spines, cut from materials like wood or MDF, to form the shape of the mould. Once assembled, a surface material like foam, plaster, or fiberglass is applied over the framework to create a smooth mould surface. This method is ideal for making large or complex moulds because it saves material, is lightweight, and can be easily adjusted. This method also commonly used in industries like automotive, aerospace, and prototyping.

Figure 3.26 Rib and Spine Construction filled with high dense Polyurethane Foam.

High-density polyurethane foam is a great material for making large patterns and prototypes. It is easy to cut and shape by hand or machine, making it quick to work with. Its high density makes it strong and durable, even sturdy enough to walk on. The foam does not expand or shrink, so it stays accurate and stable. It works well with different resin types like epoxy, polyester, and vinyl ester, and it can be finished smoothly with various coatings, making it a reliable choice for high-quality moulds.

Based on Figure 3.26, the surface then cut and shaped according to rib and spine design, which create a surface of the hood design. It is then filled with plaster. The plaster filled the gaps on the surface of the structure which make it a continuous surface. Material of the plaster also easier to sand and shaped for fine adjustment of the hood design. For final mould making, the smooth surface then painted with primer and applied with wax for next process which include Vacuum Infusion Method as shown in Figure 3.21 with same fibreglass cloth/sheet.

3.8.3 Body Parts paint.

Painting serves a crucial role beyond mere aesthetics. It acts as a protective shield for surfaces, guarding against the damaging effects of moisture, ultraviolet radiation, and general wear and tear. This protective layer prevents corrosion and helps maintain the structural integrity of various materials. Additionally, paint can contribute to hygiene by creating a surface that is easier to clean and less hospitable to mold and bacteria. Ultimately, paint enhances the longevity and durability of objects and structures, while also providing an opportunity for decoration and personalization.

The paint consists of a two-part epoxy primer and two-part polyurethane topcoat. The primer will be applied in two coats, two layers of colored paint, and the topcoat will be applied in three coats which gives smooth and even finish. The choice of color for the body parts is blue and silver which pay homage to Universiti Teknikal Malaysia Melaka (UTeM) official logo. The theme of the tractor also is silver and blue including fenders, rims and all body parts.

Figure 3.27 Finished paint of body and hood of tractor.

3.8.4 Part Accessories

There are a few accessories that are important for the overall aesthetics of the tractor. For example, the tractor needs a grill that adds aggressiveness to the looks of the tractor and a headlamp and foglamp as a source of light in the dark.

These accessories were printed using 3D printer using Fused Deposition Modelling (FDM). Fused Deposition Modeling (FDM) 3D printing builds objects layer by layer using plastic filament. First, a 3D model is designed on a computer. Then, the printer heats and melts the plastic filament. A nozzle moves around, squeezing out the melted plastic to create each layer. These layers stick together to form the final shape. After printing, any extra support material is removed, and the object can be smoothed or finished.

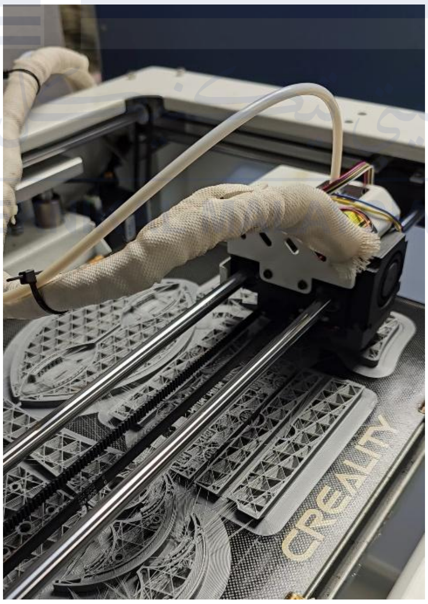


Figure 3.28 FDM machine printing 3D parts.

Figure 3.29 Accessories finishing process.

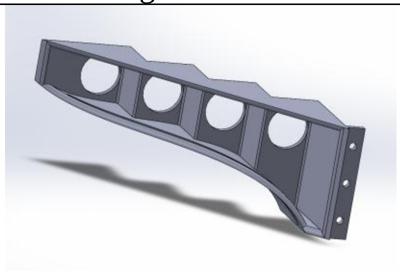
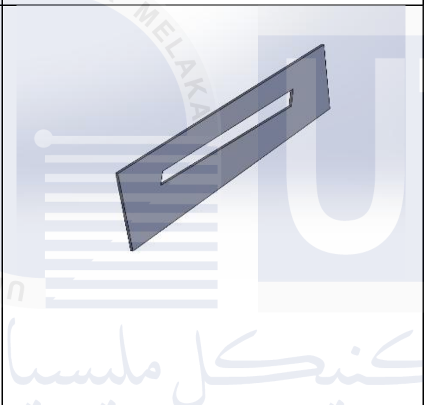
Finishing the printed parts is crucial to ensure the surfaces are smooth and even when painted. The finishing process includes sand, filling print line gaps with putty, paint and coatings. Below are accessories parts that are printed and finished.

1. Front Grill

Figure 3.30 grill design for EV Tractor with (UTeM) logo

2. Headlamp

Table 3.4 Proposed design of the main Headlamp.

No	CAD Design	Fabrication Product	Evaluation
1.			More complex Better projection
2.			Simpler design Easier assembly

This table compares two designs for the main headlamp, focusing on their CAD models, final products, and performance. Design 1 has a more detailed and complex structure with multiple circular cutouts in the CAD model. The final product matches the design closely, showing a well-built structure with integrated lights. This design is noted for providing "better projection," meaning it offers better lighting performance. However, it is harder to make and assemble due to its complexity, which could increase time and cost.

Design 2 is much simpler. The CAD model shows a basic rectangular shape, and the final product is straightforward with fewer parts. The design is easy to assemble and less complicated to produce. This makes it faster and cheaper to manufacture, but it may not provide the same level of lighting performance as Design 1.

In summary, Design 1 is a better choice if excellent lighting performance is the main goal, even though it is more complex and costly. Design 2 is a good option if simplicity, lower cost, and quick assembly are more important.

3. Fog Lamp Ring

Table 3.5 Foglamp Ring cover design.

No	CAD Design	Fabrication Product	Evaluation
1.			Clip to Foglamp Black Finishing

The foglamp ring cover is designed with a simple circular structure, as shown in the CAD model. It features clips that allow easy attachment to the foglamp, enhancing the overall assembly process. The fabrication product closely matches the CAD design, showing successful translation of the digital model into the physical component. The final product is finished in black, giving it a sleek and professional appearance. This design is practical and functional, with the clip mechanism ensuring a secure fit to the foglamp. Additionally, the black finish enhances the aesthetic appeal and blends well with the tractor's overall design. The simplicity of the design contributes to ease of manufacturing, while the functionality ensures it meets the requirements for use in the electric tractor's front body.

3.9 Assembly and installation

Figure 3.31 Final product of EV-Tractor body, hood and accessories.

Based on Figure 3.31, the tractor body were assembled and installed on the electric tractor. Main part as the body and hood were perfectly mounted on the tractor structure. The accessories, from the headlamp, grill and foglamp ring were also installed. This installation gives the overall looks to the (E-ORV) tractor.

3.10 Summary

This chapter explains the steps taken to design and build a modern tractor. It begins with an overview of the process and a flowchart to show the steps clearly. The conceptual design phase focuses on improving traditional tractor designs by gathering ideas from web research and setting clear design goals. Important factors like aerodynamics, airflow, and using lightweight materials are considered to make the tractor more efficient. After sketching several design ideas, the best sketch is selected for further development, leading to the creation of a small 1:10 scale model.

Next, the process moves to making a full-size mock-up, starting with measuring and creating the body panels. The fabrication phase explains how the parts are made and assembled, with adjustments made to improve the final design. The right materials are chosen based on strength, weight, and durability. The final steps involve building the body parts, painting them, and adding any necessary accessories to complete the tractor design. This approach ensures a well-built, modern tractor with improved performance and appearance.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

Modern tractor design is parallel to automotives light-duty vehicles design approach such as cars. Either it is an Electric Vehicle (EV) or Internal combustion engine (ICE), the design generally more minimal with simpler form factor. With blend of art, science, and technology, engineers manage to produce more bold and expressive design. Traditional tractors mainly have similar design for few decades. Designing electric off-road vehicle (E-ORV) needs a different perspective aligning with modernity of current vehicle designs.

This chapter discusses the overall material cost, overall weight, strength of different design development and the strength between different types of materials.

4.2 Material cost comparison

When building a tractor body, the cost of materials is one of the most important things to consider. Different materials, like metal steel, fiberglass composites, and plastic, have their own prices and benefits. Steel is strong and affordable, composites are lightweight and durable but more expensive, and plastic is versatile and priced in between. By analysing the cost of these materials, understanding which one is the best choice for the design while staying within the budget is simpler. This analysis helps make smarter decisions for a high-quality and cost-effective tractor body.

4.2.1 Cost for each material

1. Metal Steel plate (2mm)

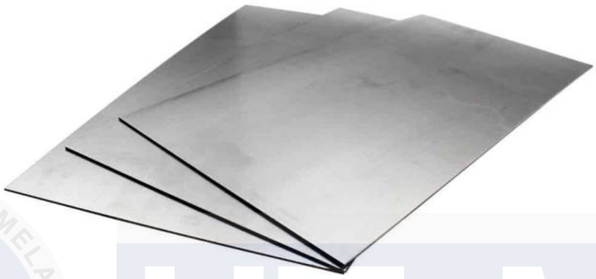


Figure 4.1 shows the example of steel metal plate

The price of a 2mm thick mild steel plate in Malaysia varies based on size and supplier. For a standard 4ft x 8ft (approximately 1.22m x 2.44m) sheet, prices are around RM150.37 according to (https://rakanjayahardware.com/). Smaller pieces, such as a 300mm x 500mm (0.3m x 0.5m) sheet, are available for approximately RM429.78 for a lot of five pieces. These prices are subject to change and may vary between suppliers.

Steel is a widely used material due to its strength, durability, and affordability. It can withstand heavy loads and harsh conditions, making it an excellent choice for structural parts of a tractor body. Steel is also easy to weld and shape, allowing for flexible designs. However, it is heavy and prone to rust if not properly coated or treated, which can increase maintenance costs over time.

2. Fiberglass Composites

Figure 4.2 shows the sample of fiberglass woven fabric from (https://honted.en.made-in-china.com/)

The market price for fiberglass woven fabric in Malaysia varies depending on the type and specifications, such as weight in grams per square meter (gsm) and the supplier. For instance, a 600 gsm fiberglass woven roving mat measuring 1 meter by 1 meter is priced at approximately RM15. This type of fiberglass is commonly used in structural applications for its strength and durability. Another example retrieved from (https://honted.en.made-in-china.com/) is E-glass woven roving fiberglass fabric, which ranges from RM2.50 to RM3.70 per kilogram, depending on the supplier and the order quantity. These prices can vary based on factors like order volume, quality, and market demand.

Fiberglass composites are light weight yet strong materials made by combining glass fibers with a resin. They are highly resistant to corrosion and can endure harsh weather conditions, making them ideal for parts exposed to the elements. Fiberglass is more expensive than steel due to its labor-intensive manufacturing process, but its weight savings can improve battery efficiency.

3. Plastic (ABS)

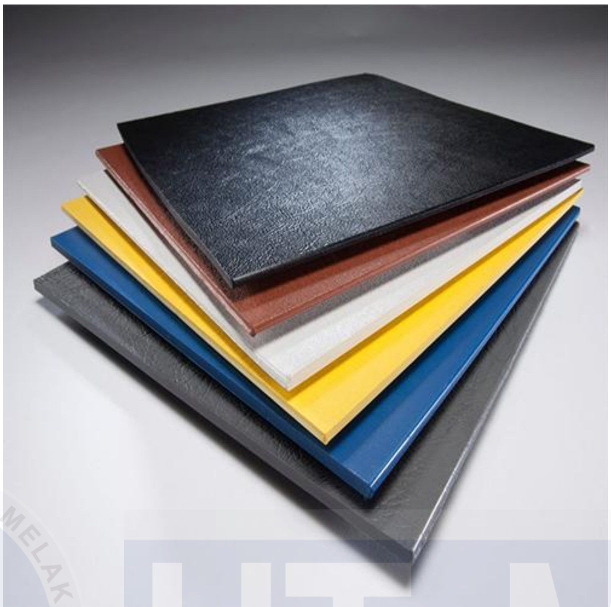


Figure 4.3 shows the sample of plastic ABS sheets.

The market price of ABS plastic sheets in Malaysia depends on the thickness and supplier. Standard ABS sheets are typically priced between RM40 and RM80 per square meter. This cost varies based on factors like the sheet's thickness, surface finish, and the supplier's pricing strategy. Thicker sheets or those with specialized finishes (such as textured or UV-resistant surfaces) generally cost more. Additionally, bulk purchases or direct orders from manufacturers may offer discounts, reducing the overall price per square meter.

Plastic ABS (Acrylonitrile Butadiene Styrene) is a durable and lightweight thermoplastic material. It is resistant to impact, corrosion, and UV exposure, making it suitable for a range of tractor body components. ABS is easy to mold and assemble, which can reduce manufacturing costs for intricate designs. While it is not as strong as steel or fiberglass, it offers a good balance of affordability and flexibility for less demanding applications. Its lightweight nature also helps improve fuel efficiency in the final product.

4.2.2 Material Cost Evaluation

Table 4.1 shows the materials cos per square meter

Material	Cost per square meter
Metal Plates (2mm)	RM50.51
Fiberglass Composites (woven fabric 600gsm)	RM15.00
Plastic ABS (2mm)	RM40.00

The table compares the cost per square meter of three materials: metal plates, fiberglass composites, and plastic ABS. Metal plates (2mm) are the most expensive at RM50.51 per square meter, reflecting their strength and durability. Fiberglass composites (woven fabric, 600gsm) are the most economical option at RM15.00 per square meter, making them a cost-effective choice for lightweight and strong designs. Plastic ABS (2mm) is priced at RM40.00 per square meter, offering a balance between cost and performance. However, using fiberglass and plastics will cost more due to its fabrication processes.

4.3 Overall weight comparison

Table 4.2 shows the weight of different materials on different designs

Designs	Metal	Composite	Plastic ABS
Design 1	150872.85g	46598.70g	20434.68g
Design 2	102366.77g	31617.08g	13864.87g
Design 3	108838.19g	33615.84g	14741.37g

This table compares the weights of three materials according to SolidWorks material data which are Metal Steel (AISI1020), Composite Fiberglass (A-Glass Fiber), and Plastic ABS (ABS-PC) across three different designs. These materials were applied to the original design structure and calculated using SolidWorks' Mass Properties for each design.

1. Material Comparison

- Metal: This is the heaviest material across all designs. For example, (Design 1) weighs 150,872.85g, which is significantly higher than composite and plastic ABS.
- Composite: This material is lighter than metal but heavier than plastic ABS. Its weight ranges from 31,617.08g (Design 2) to 46,598.70g (Design 1).
- Plastic ABS: This is the lightest material across all designs, with weights ranging from 13,864.87g (Design 2) to 20,434.68g (Design 1).

2. Design Comparison
   - Design 1: All materials are at their heaviest in this design, indicating a larger surface area or more structural components.
   - Design 2: All materials are at their lightest here, suggesting that the design has a simpler and more compact structure compared to the other designs.
   - Design 3: The weights for all materials fall between the values for Design 1 and Design 2, indicating a moderate design in terms of size or material usage.
3. Insight into all three materials
   - Metal: While strong and durable, its weight may affect fuel efficiency and handling, especially in Design 1.
   - Composite: Offers a good balance between strength and weight, being much lighter than metal but heavier than plastic.
   - Plastic ABS: Ideal for weight-sensitive applications but may lack the durability of the other two materials.

4.3.1 Conclusion

Based on the analysis, composite material was the most suitable choice for the tractor body due to its balance between strength, durability, and significantly lower weight compared to metal. While plastic ABS is the lightest, it may not offer the required durability for a heavy-duty application like a tractor body. Composite material provides the needed durability while reducing the overall weight, improving fuel efficiency, and maintaining structural integrity.

Among the three designs, Design 2 was selected as it utilizes the least amount of material weight for all types. For composite, it weighs 31,617.08g, which is lighter than both Design 1 and Design 3, indicating a more efficient and compact design. This choice ensures reduced material usage and manufacturing costs without compromising performance. Thus, using composite material with Design 2 is the optimal solution for balancing cost, weight, and functionality in the tractor body construction.

4.4 Strength, stress, strain of different designs

To ensure the structural integrity and safety of the tractor's frontal body design, comprehensive tests were implemented. This chapter will focus on evaluating the strength, stress, strain, and factor of safety under various loading conditions. Static load tests were conducted to determine the yield strength and ultimate tensile strength of the frontal structure, while strain gauges strategically placed to measure strain distribution under load.

Finite Element Analysis (FEA) were employed to simulate stress concentrations and predict structural behaviour under complex loading scenarios, including frontal impacts. These tests validate that the design meets or exceeds industry safety standards and can withstand the rigors of real-world agricultural applications. This rigorous testing approach will provide valuable insights into the structural performance of the frontal body, allowing for design optimization and validation.

4.4.1 Different design Analysis

The objective of this subtopic is to evaluate the structural performance of each design by comparing their Total Deformation, Equivalent Stress, and Elastic Strain when constructed from different materials. This evaluation aims to provide evidence supporting the selection of Design 2 as the most suitable option for the tractor body.

The analysis was conducted on Ansys System's Finite Element Analysis (FEA). The load used on this analysis is assumed to be 1960N which aligned with at least 200kg of impact with partial fixed supports. Each design was referred to design in (Table 3.2 Different design of EV tractor body.).

4.4.2 Material Properties

When designing and constructing a tractor body, selecting the right material is crucial to ensuring performance, durability, and cost-effectiveness. The properties of a material directly influence its suitability for specific applications, impacting factors such as strength, weight, corrosion resistance, and environmental impact. The purpose is to understand the characteristics of potential materials that allow for an informed decision that balances functionality, budget, and sustainability. The material properties as shown in Table 4.3 below.

Table 4.3 Structural properties of each material

Material	Structural Steel	Composite, Epoxy/Glass fibre	Plastic ABS (High Impact)
Density (kg/mm³)	7.85e-06	1.857e-06	1.03e-06
Young's Modulus (MPa)	2e+05	26400	2090
Poisson's Ratio	0.3	0.1543	0.8049
Bulk Modulus (MPa)	1.6667e+05	12728	3823.6
Shear Modulus (MPa)	76923	11436	741.71
Tensile Ultimate Strength (MPa)	460	440.1	36.26
Tensile Yield Strength (MPa)	250	440.1	27.44

4.4.3 Data analysis of materials between different designs

Analyzing data is an important step when choosing the best material for different tractor body designs. Materials like steel, fiberglass composites, and plastic ABS each have unique strengths, weaknesses, and costs. By comparing these materials in various designs, finding the best option that balances cost, durability, weight, and ease of production become easier. This analysis helps to make informed decisions to ensure the tractor body works well, fits the budget, and meets all performance needs. It also helps to understand how each material will affect the design's overall quality and sustainability.

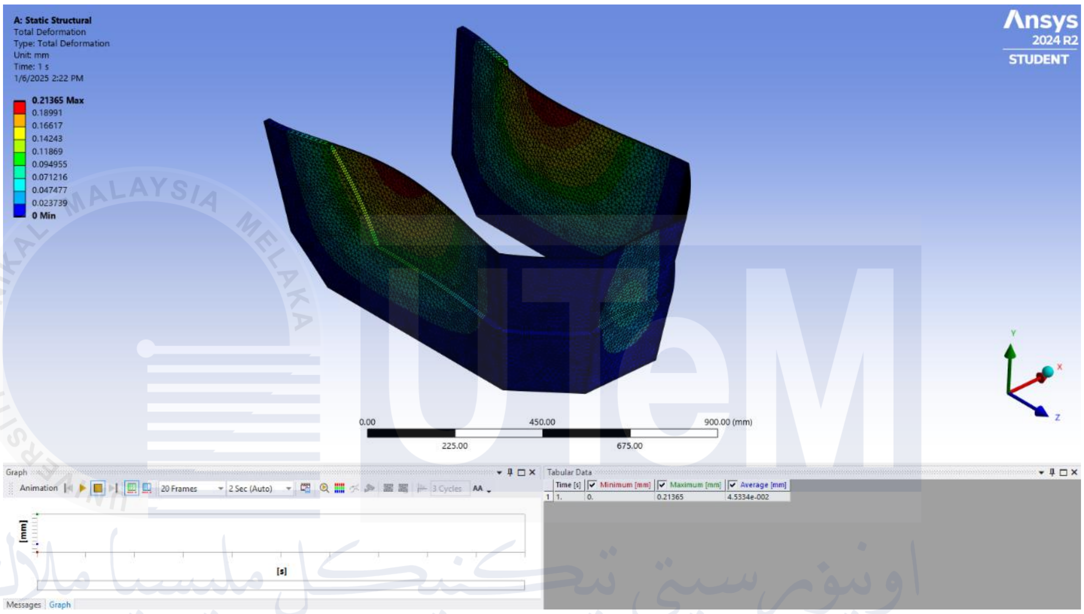


Figure 4.4 shows the example of analysis conducted on Ansys System.

Table 4.4 shows tabulated data for analysis between different materials and design.

	Designs	Total Deformation	Equivalent Stress (MPa)	Elastic Strain (mm/mm)
Metals	Design 1	0.022359	10.727	0.0000741
	Design 2	0.029262	2.8714	0.00001537
	Design 3	0.30302	18.019	0.00009177
Composites	Design 1	0.18049	13.449	0.00068107
	Design 2	0.21365	3.2276	0.00013836
	Design 3	2.2311	17.971	0.00068073
Plastics	Design 1	2.1674	8.7916	0.0054004
	Design 2	2.0846	3.0387	0.0014635
	Design 3	29.189	19.655	0.0095192

Metal components show varying performance across the three designs. Design 1 experiences the lowest total deformation (0.022359) and the lowest elastic strain (0.0000741), suggesting the highest rigidity. Design 3, on the other hand, exhibits the highest total deformation (0.30302) and elastic strain (0.00009177), indicating the least rigidity. Stress levels are moderate in Design 1 (10.727) and Design 3 (18.019), while Design 2 has the lowest stress (2.8714).

Composite components demonstrate similar trends to metals, but with higher values across all parameters. Design 1 has the lowest total deformation (0.18049) and elastic strain (0.00068107), suggesting higher rigidity. Design 3 shows the highest total deformation (2.2311) and elastic strain (0.00068073), indicating the least rigidity. Stress levels are moderate in Design 1 (13.449) and Design 3 (17.971), while Design 2 has the lowest stress (3.2276).

Plastic ABS components exhibit the highest values for total deformation, stress, and elastic strain across all designs. Design 1 has a total deformation of 2.1674 and an elastic strain of 0.0054004, indicating the least rigidity among the plastic components. Design 3 shows the highest total deformation (29.189) and elastic strain (0.0095192), suggesting the least rigidity. Stress levels are moderate in Design 1 (8.7916) and Design 3 (19.655), while Design 2 has the lowest stress (3.0387).

Overall, Design 1 appears to be the most rigid and experiences the least deformation and strain across all materials. Design 3 experiences the highest deformation, stress, and strain, indicating it is likely the least structurally sound under the tested conditions. Metal components consistently show the lowest deformation and strain, while Plastic ABS exhibits the highest. Composites fall in between. The analysis results for each material and design are shown in APPENDIX C.

4.4.4 Conclusion

Choosing Design 2 with a composite material offers an ideal balance of performance and resilience. Among the designs, Design 2 exhibits the lowest stress levels for composite components at 3.2276, which indicate the efficient load distribution and reduced stress concentration. This characteristic enhances the material's durability and ensures it can withstand operational conditions with minimal risk of failure. While the total deformation is not the lowest, it remains within an acceptable range, providing a structure that can flex and absorb energy without compromising its integrity.

Composites are particularly well-suited for this application due to their unique combination of lightweight properties and strength. Compared to metals, composites offer greater energy absorption with moderate deformation, while significantly outperforming plastics in terms of rigidity and stress resistance. This makes them an excellent choice for scenarios where reducing weight is critical without sacrificing structural performance. Additionally, the elastic strain for composites in Design 2 strikes a balance, ensuring the material remains within safe deformation limits under load.

Overall, Design 2 with composite material represents the most versatile choice, combining low stress with a balanced rigidity-to-flexibility ratio. It provides a middle ground between the high rigidity of Design 1 and the flexibility of Design 3, making it adaptable to various operational demands. This selection optimally leverages the advantages of composites, offering a durable, lightweight, and reliable solution for performance-critical applications.

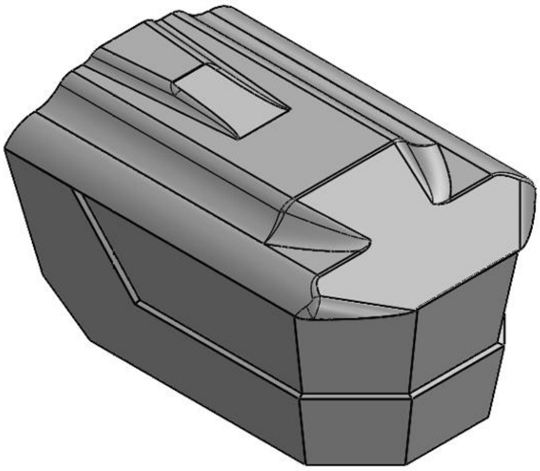


Figure 4.5 shows the Isometric view of the body.

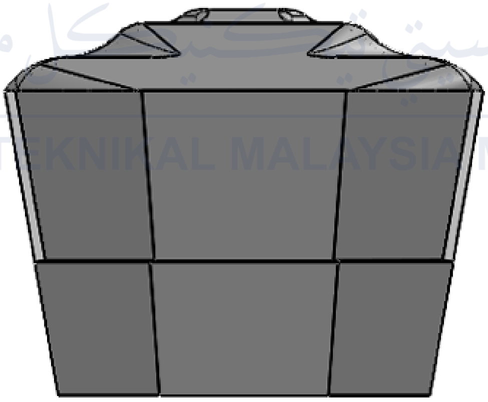


Figure 4.6 shows the Front view of the tractor body.

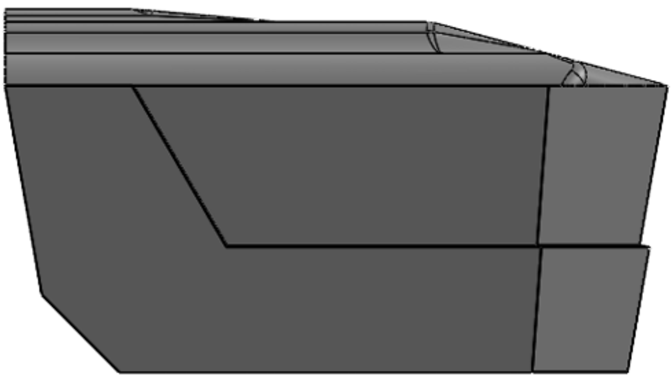


Figure 4.7 shows the Side view of the tractor body.

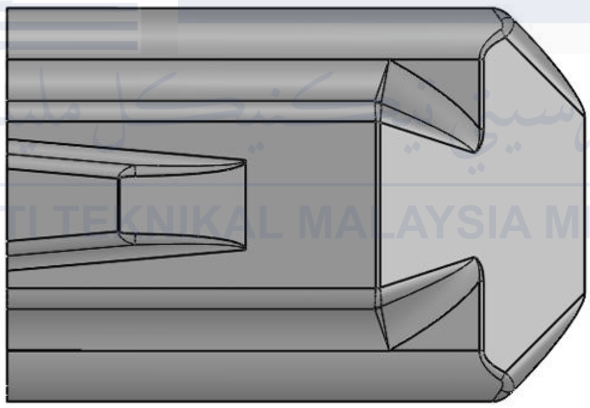


Figure 4.8 shows the Top view of the tractor body.

4.5 Gantt chart

4.5.1 Gantt chart of the project

As shown in Appendix A and Appendix B.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The design and development of the electric tractor's hood and body were carried out with a focus on innovation, efficiency, and sustainability. The methodology describes the process beginning with the conceptualization and design of the tractor body using SolidWorks software. Multiple design concepts were explored, with Design 2 emerging as the most viable option based on a thorough evaluation process. The material selection process was also critical, with composites chosen for their lightweight yet durable properties, which contribute to the tractor's overall energy efficiency and sustainability. This decision was backed by detailed material analysis using Ansys software, where fiberglass and other composite materials were tested for their structural integrity and cost-effectiveness.

Fabrication of the prototype involved the vacuum infusion method, which was selected for its precision in manufacturing and its ability to produce high-strength, lightweight components. This process not only optimized the material usage but also ensured that the components were durable enough to withstand harsh agricultural environments. Other than that, the results of various performance tests conducted on the designs, such as material cost comparison, weight reduction, and strength testing. The data gathered confirmed that the selected design offered a considerable reduction in weight compared to traditional materials while maintaining the necessary strength for operational durability. Furthermore, the strength, stress, and strain analyses showed that the composite materials used were well-suited for the harsh conditions of agricultural work.

The final prototype was assembled with focus on modularity, making sure that each component was easily replaceable or maintainable, which will help reduce operational downtime in real-world agricultural settings. The assembly and installation of the parts went smoothly, confirming the design's practicality and ease of use. Additionally, the cost analysis conducted revealed that the use of composites in the body panels, while slightly more expensive upfront, results in long-term cost savings due to reduced energy consumption and maintenance costs. The innovative approach to design and materials not only enhances the tractor's performance but also supports a shift toward more sustainable agricultural practices.

5.2 Recommendations

To further enhance the electric tractor design and its implementation, several recommendations can be made. First, there is room for optimization in material selection. While composites such as fiberglass have proven effective, further research into advanced composite materials like carbon fibre-reinforced polymers (CFRPs) could lead to even lighter and stronger components. These materials might reduce the weight of the tractor more, improving energy efficiency and extending battery life, which is critical for agricultural machinery used over long periods.

Second, the scalability of the design should be explored. The modular design approach used in this project should be applied across various tractor models and agricultural machinery to ensure adaptability to different farming environments. By creating interchangeable parts, manufacturers can design tractors to specific agricultural tasks, increasing their versatility and cost-effectiveness for small and large-scale farms alike.

Another recommendation is to focus on the sustainability of the production process. While composite materials like fiberglass offer environmental advantages over metal alternatives, further research should be done on sourcing environmentally friendly composites and improving the manufacturing process to reduce its carbon footprint. Investigating eco-friendly composites, such as bio-based polymers or recycled materials, could significantly contribute to the overall environmental sustainability of the project.

Finally, it is recommended that extensive field testing be conducted in a variety of agricultural conditions. This will provide actual data on the tractor's performance under real-world conditions, helping to validate the findings on the design and testing phases. Testing will ensure that the tractor's durability, energy efficiency, and ergonomic features perform as expected, allowing for adjustments before mass production.

By following these recommendations, future iterations of the electric tractor will be even more efficient, environmentally friendly, and practical, contributing to the broader goals of sustainable agriculture and the reduction of fossil fuel dependence in the agricultural sector.

REFERENCES

Afianto, D., Han, Y., Yan, P., Yang, Y., Elbarghthi, A. F. A., & Wen, C. (2022). Optimisation and Efficiency Improvement of Electric Vehicles Using Computational Fluid Dynamics Modelling. *Entropy*, *24*(11). https://doi.org/10.3390/e24111584

Afshar, S., Macedo, P., Mohamed, F., & Disfani, V. (2021). Mobile charging stations for electric vehicles — A review. In *Renewable and Sustainable Energy Reviews* (Vol. 152). Elsevier Ltd. https://doi.org/10.1016/j.rser.2021.111654

Agarwal, A. K. (2007). Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. In *Progress in Energy and Combustion Science* (Vol. 33, Issue 3, pp. 233–271). https://doi.org/10.1016/j.pecs.2006.08.003

Albatayneh, A., Assaf, M. N., Alterman, D., & Jaradat, M. (2020). Comparison of the Overall Energy Efficiency for Internal Combustion Engine Vehicles and Electric Vehicles. *Environmental and Climate Technologies*, *24*(1), 669–680. https://doi.org/10.2478/rtuect-2020-0041

Amongo, R. M. C., Quilloy, E. P., Ranches, M. A. F., Larona, M. V. L., & Madlangbayan, M. S. (2020). Development of an electric hand tractor (e-Tractor) for agricultural operations. *IOP Conference Series: Earth and Environmental Science*, *542*(1). https://doi.org/10.1088/1755-1315/542/1/012027

Andrew, J. J., & Dhakal, H. N. (2022). Sustainable biobased composites for advanced applications: recent trends and future opportunities – A critical review. In *Composites Part C: Open Access* (Vol. 7). Elsevier B.V. https://doi.org/10.1016/j.jcomc.2021.100220

Anjos, M. F., Gendron, B., & Joyce-Moniz, M. (2020). Increasing electric vehicle adoption through the optimal deployment of fast-charging stations for local and long-distance travel. *European Journal of Operational Research*, *285*(1), 263–278. https://doi.org/10.1016/j.ejor.2020.01.055

Arun, V., Kannan, R., Ramesh, S., Vijayakumar, M., Raghavendran, P. S., Siva Ramkumar, M., Anbarasu, P., & Sundramurthy, V. P. (2022). Review on Li-Ion Battery vs Nickel Metal Hydride Battery in EV. In *Advances in Materials Science and Engineering* (Vol. 2022). Hindawi Limited. https://doi.org/10.1155/2022/7910072

Bacenetti, J., Lovarelli, D., Facchinetti, D., & Pessina, D. (2018). An environmental comparison of techniques to reduce pollutants emissions related to agricultural tractors. *Biosystems Engineering*, *171*, 30–40. https://doi.org/10.1016/j.biosystemseng.2018.04.014

Beligoj, M., Scolaro, E., Alberti, L., Renzi, M., & Mattetti, M. (2022). Feasibility Evaluation of Hybrid Electric Agricultural Tractors Based on Life Cycle Cost Analysis. *IEEE Access*, *10*, 28853–28867. https://doi.org/10.1109/ACCESS.2022.3157635

Berthet, E., Lavalley, J., Anquetil-Deck, C., Ballesteros, F., Stadler, K., Soytas, U., Hauschild, M., & Laurent, A. (2024). Assessing the social and environmental impacts of critical mineral supply chains for the energy transition in Europe. *Global Environmental Change*, *86*. https://doi.org/10.1016/j.gloenvcha.2024.102841

Bjerkan, K. Y., Nørbech, T. E., & Nordtømme, M. E. (2016). Incentives for promoting Battery Electric Vehicle (BEV) adoption in Norway. *Transportation Research Part D: Transport and Environment*, *43*, 169–180. https://doi.org/10.1016/j.trd.2015.12.002

Cao, J., Chen, X., Qiu, R., & Hou, S. (2021). Electric vehicle industry sustainable development with a stakeholder engagement system. *Technology in Society*, *67*. https://doi.org/10.1016/j.techsoc.2021.101771

Chen, J., Wu, J., Wang, X., Zhou, A., & Yang, Z. (2021). Research progress and application prospect of solid-state electrolytes in commercial lithium-ion power batteries. In *Energy Storage Materials* (Vol. 35, pp. 70–87). Elsevier B.V. https://doi.org/10.1016/j.ensm.2020.11.017

Chen, L., Msigwa, G., Yang, M., Osman, A. I., Fawzy, S., Rooney, D. W., & Yap, P. S. (2022). Strategies to achieve a carbon neutral society: a review. In *Environmental Chemistry Letters* (Vol. 20, Issue 4, pp. 2277–2310). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s10311-022-01435-8

Collin, R., Miao, Y., Yokochi, A., Enjeti, P., & Von Jouanne, A. (2019). Advanced electric vehicle fast-charging technologies. *Energies*, *12*(10). https://doi.org/10.3390/en12101839

Das, H. S., Rahman, M. M., Li, S., & Tan, C. W. (2020). Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. In *Renewable and Sustainable Energy Reviews* (Vol. 120). Elsevier Ltd. https://doi.org/10.1016/j.rser.2019.109618

Elfaleh, I., Abbassi, F., Habibi, M., Ahmad, F., Guedri, M., Nasri, M., & Garnier, C. (2023). A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials. In *Results in Engineering* (Vol. 19). Elsevier B.V. https://doi.org/10.1016/j.rineng.2023.101271

Erhan, K., & Özdemir, E. (2021). Prototype production and comparative analysis of high-speed flywheel energy storage systems during regenerative braking in hybrid and electric vehicles. *Journal of Energy Storage*, *43*. https://doi.org/10.1016/j.est.2021.103237

Gao, D., Zhi, Y., & Yang, X. (2024). Assessing carbon emission reduction benefits of the electrification transition of agricultural machinery for sustainable development: A case study in China. *Sustainable Energy Technologies and Assessments*, *63*. https://doi.org/10.1016/j.seta.2024.103634

Ghandi, A., & Paltsev, S. (2020). Global CO2 impacts of light-duty electric vehicles. *Transportation Research Part D: Transport and Environment*, *87*. https://doi.org/10.1016/j.trd.2020.102524

Ghobadpour, A., Monsalve, G., Cardenas, A., & Mousazadeh, H. (2022). Off-Road Electric Vehicles and Autonomous Robots in Agricultural Sector: Trends, Challenges, and

Opportunities. In *Vehicles* (Vol. 4, Issue 3, pp. 843–864). MDPI. https://doi.org/10.3390/vehicles4030047

Gołasa, P., Wysokiński, M., Bieńkowska-gołasa, W., Gradziuk, P., Golonko, M., Gradziuk, B., Siedlecka, A., & Gromada, A. (2021). Sources of greenhouse gas emissions in agriculture, with particular emphasis on emissions from energy used. *Energies*, *14*(13). https://doi.org/10.3390/en14133784

Gorjian, S., Ebadi, H., Trommsdorff, M., Sharon, H., Demant, M., & Schindele, S. (2021). The advent of modern solar-powered electric agricultural machinery: A solution for sustainable farm operations. In *Journal of Cleaner Production* (Vol. 292). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2021.126030

Haas, T., & Sander, H. (2020). Decarbonizing transport in the European Union: Emission performance standards and the perspectives for a European green deal. *Sustainability (Switzerland)*, *12*(20), 1–15. https://doi.org/10.3390/su12208381

Hamza, M. A., & Anderson, W. K. (2005). Soil compaction in cropping systems: A review of the nature, causes and possible solutions. In *Soil and Tillage Research* (Vol. 82, Issue 2, pp. 121–145). Elsevier. https://doi.org/10.1016/j.still.2004.08.009

Hosseini Salari, A., Mirzaeinejad, H., & Fooladi Mahani, M. (2023). A new control algorithm of regenerative braking management for energy efficiency and safety enhancement of electric vehicles. *Energy Conversion and Management*, *276*. https://doi.org/10.1016/j.enconman.2022.116564

Hussain, M. T., Sulaiman, D. N. Bin, Hussain, M. S., & Jabir, M. (2021). Optimal Management strategies to solve issues of grid having Electric Vehicles (EV): A review. In *Journal of Energy Storage* (Vol. 33). Elsevier Ltd. https://doi.org/10.1016/j.est.2020.102114

Immonen, E. (2023). *ADVANCES IN OPTIMAL DESIGN OF SHAPES AND PROCESSES BY COMPUTATIONAL FLUID DYNAMICS*.

Kamil, M., Rahman, M. M., & Bakar, R. A. (2014). An integrated model for predicting engine friction losses in internal combustion engines. *International Journal of Automotive and Mechanical Engineering*, *9*(1), 1695–1708. https://doi.org/10.15282/ijame.9.2013.19.0141

Khalid, M. R., Khan, I. A., Hameed, S., Asghar, M. S. J., & Ro, J. S. (2021). A Comprehensive Review on Structural Topologies, Power Levels, Energy Storage Systems, and Standards for Electric Vehicle Charging Stations and Their Impacts on Grid. In *IEEE Access* (Vol. 9, pp. 128069–128094). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ACCESS.2021.3112189

Khalid, M. Y., Al Rashid, A., Arif, Z. U., Ahmed, W., Arshad, H., & Zaidi, A. A. (2021). Natural fiber reinforced composites: Sustainable materials for emerging applications. In *Results in Engineering* (Vol. 11). Elsevier B.V. https://doi.org/10.1016/j.rineng.2021.100263

Kozina, A., Radica, G., & Nižetić, S. (2020). Analysis of methods towards reduction of harmful pollutants from diesel engines. *Journal of Cleaner Production*, *262*. https://doi.org/10.1016/j.jclepro.2020.121105

Lagnelöv, O., Dhillon, S., Larsson, G., Nilsson, D., Larsolle, A., & Hansson, P. A. (2021). Cost analysis of autonomous battery electric field tractors in agriculture. *Biosystems Engineering*, *204*, 358–376. https://doi.org/10.1016/j.biosystemseng.2021.02.005

Leach, F., Kalghatgi, G., Stone, R., & Miles, P. (2020). The scope for improving the efficiency and environmental impact of internal combustion engines. In *Transportation Engineering* (Vol. 1). Elsevier Ltd. https://doi.org/10.1016/j.treng.2020.100005

Leonard, M. ;, Pisani-Ferry, J. ;, Shapiro, J. ;, Tagliapietra, S. ;, & Wolff, G. B. (2021). *The geopolitics of the European Green Deal Standard-Nutzungsbedingungen*. https://hdl.handle.net/10419/237660

Liu, H., Dai, Z., Rodgers, M. O., & Guensler, R. (2022). Equity issues associated with U.S. plug-in electric vehicle income tax credits. *Transportation Research Part D: Transport and Environment*, *102*. https://doi.org/10.1016/j.trd.2021.103159

Liu, Z., Song, J., Kubal, J., Susarla, N., Knehr, K. W., Islam, E., Nelson, P., & Ahmed, S. (2021). Comparing total cost of ownership of battery electric vehicles and internal combustion engine vehicles. *Energy Policy*, *158*. https://doi.org/10.1016/j.enpol.2021.112564

Lombardi, G. V., & Berni, R. (2021). Renewable energy in agriculture: Farmers willingness-to-pay for a photovoltaic electric farm tractor. *Journal of Cleaner Production*, *313*. https://doi.org/10.1016/j.jclepro.2021.127520

Lotfi, M., Almeida, T., Javadi, M. S., Osório, G. J., Monteiro, C., & Catalão, J. P. S. (2022). Coordinating energy management systems in smart cities with electric vehicles. *Applied Energy*, *307*. https://doi.org/10.1016/j.apenergy.2021.118241

Louback, E., Biswas, A., Machado, F., & Emadi, A. (2024). A review of the design process of energy management systems for dual-motor battery electric vehicles. In *Renewable and Sustainable Energy Reviews* (Vol. 193). Elsevier Ltd. https://doi.org/10.1016/j.rser.2024.114293

Lovarelli, D., & Bacenetti, J. (2019). Exhaust gases emissions from agricultural tractors: State of the art and future perspectives for machinery operators. In *Biosystems Engineering* (Vol. 186, pp. 204–213). Academic Press. https://doi.org/10.1016/j.biosystemseng.2019.07.011

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020). Environmental and Health Impacts of Air Pollution: A Review. In *Frontiers in Public Health* (Vol. 8). Frontiers Media S.A. https://doi.org/10.3389/fpubh.2020.00014

Martins, L. S., Guimarães, L. F., Botelho Junior, A. B., Tenório, J. A. S., & Espinosa, D. C. R. (2021). Electric car battery: An overview on global demand, recycling and future approaches towards sustainability. In *Journal of Environmental Management* (Vol. 295). Academic Press. https://doi.org/10.1016/j.jenvman.2021.113091

Mauler, L., Duffner, F., Zeier, W. G., & Leker, J. (2021). Battery cost forecasting: A review of methods and results with an outlook to 2050. In *Energy and Environmental Science* (Vol. 14, Issue 9, pp. 4712–4739). Royal Society of Chemistry. https://doi.org/10.1039/d1ee01530c

McGinnis, R. (2020). CO2-to-Fuels Renewable Gasoline and Jet Fuel Can Soon Be Price Competitive with Fossil Fuels. In *Joule* (Vol. 4, Issue 3, pp. 509–511). Cell Press. https://doi.org/10.1016/j.joule.2020.01.002

Mehta, C. R., & Tewari, V. K. (2000). Seating discomfort for tractor operators } a critical review. In *vktfeb@agfe.iitkgp.ernet.in (V.K. Tewari) International Journal of Industrial Ergonomics* (Vol. 25).

Mocera, F., Martini, V., & Somà, A. (2022). Comparative Analysis of Hybrid Electric Architectures for Specialized Agricultural Tractors. *Energies*, *15*(5). https://doi.org/10.3390/en15051944

Mohammadi, F., & Saif, M. (2023). A comprehensive overview of electric vehicle batteries market. In *e-Prime - Advances in Electrical Engineering, Electronics and Energy* (Vol. 3). Elsevier Ltd. https://doi.org/10.1016/j.prime.2023.100127

Morampudi, P., Namala, K. K., Gajjela, Y. K., Barath, M., & Prudhvi, G. (2020). Review on glass fiber reinforced polymer composites. *Materials Today: Proceedings*, *43*, 314–319. https://doi.org/10.1016/j.matpr.2020.11.669

Muratori, M., Alexander, M., Arent, D., Bazilian, M., Dede, E. M., Farrell, J., Gearhart, C., Greene, D., Jenn, A., Keyser, M., Lipman, T., Narumanchi, S., Pesaran, A., Sioshansi, R., Suomalainen, E., Tal, G., Walkowicz, K., & Ward, J. (2021). The rise of electric vehicles-2020 status and future expectations. In *Progress in Energy* (Vol. 3, Issue 2). Institute of Physics. https://doi.org/10.1088/2516-1083/abe0ad

Namirian, Z. (2020). COMPREHENSIVE OVERVIEW OF HYBRID VEHICLE DRIVETRAINS. *International Research Journal of Engineering and Technology*. www.irjet.net

Nikitas, A., Vitel, A. E., & Cotet, C. (2021). Autonomous vehicles and employment: An urban futures revolution or catastrophe? *Cities*, *114*. https://doi.org/10.1016/j.cities.2021.103203

Palanivendhan, M., Chandradass, J., Saravanan, C., Philip, J., & Sharan, R. (2021). Reduction in aerodynamic drag acting on a commercial vehicle by using a dimpled surface. *Materials Today: Proceedings*, *45*, 7072–7078. https://doi.org/10.1016/j.matpr.2021.01.884

Pascuzzi, S., Łyp-Wrońska, K., Gdowska, K., & Paciolla, F. (2024). Sustainability Evaluation of Hybrid Agriculture-Tractor Powertrains. *Sustainability (Switzerland)*, *16*(3). https://doi.org/10.3390/su16031184

Prakash Vishwakarma, R., & Kumar, M. (2016). Internal Combustion Engine. *International Research Journal of Engineering and Technology*. http://www.siu.edu/~autoclub/frange.html

Rajak, D. K., Wagh, P. H., & Linul, E. (2021). Manufacturing technologies of carbon/glass fiber-reinforced polymer composites and their properties: A review. In *Polymers* (Vol. 13, Issue 21). MDPI. https://doi.org/10.3390/polym13213721

Ravindran, M. A., Nallathambi, K., Vishnuram, P., Rathore, R. S., Bajaj, M., Rida, I., & Alkhayyat, A. (2023). A Novel Technological Review on Fast Charging Infrastructure for Electrical Vehicles: Challenges, Solutions, and Future Research Directions. In *Alexandria Engineering Journal* (Vol. 82, pp. 260–290). Elsevier B.V. https://doi.org/10.1016/j.aej.2023.10.009

Sarah Ladislaw Ethan Zindler Nikos Tsafos Logan Goldie-Scot Lachlan Carey Pol Lezcano Jane Nakano Jenny Chase, A. (2021). *Industrial Policy, Trade, and Clean Energy Supply Chains A Report of the CSIS Energy Security and Climate Change Program & BloombergNEF*. www.bnef.com

Sathre, R., & Gustavsson, L. (2021). A lifecycle comparison of natural resource use and climate impact of biofuel and electric cars. *Energy*, *237*. https://doi.org/10.1016/j.energy.2021.121546

Schlosser, J. F., de Farias, M. S., Bertollo, G. M., Russini, A., Herzog, D., & Casali, L. (2020). Agricultural tractor engines from the perspective of Agriculture 4.0. *Revista Ciencia Agronomica*, *51*(5), 1–12. https://doi.org/10.5935/1806-6690.20200094

Shahjalal, M., Shams, T., Islam, M. E., Alam, W., Modak, M., Hossain, S. Bin, Ramadesigan, V., Ahmed, M. R., Ahmed, H., & Iqbal, A. (2021). A review of thermal management for Li-ion batteries: Prospects, challenges, and issues. In *Journal of Energy Storage* (Vol. 39). Elsevier Ltd. https://doi.org/10.1016/j.est.2021.102518

Shirokov, Y., & Tikhnenko, V. (2021). Analysis of environmental problems of crop production and ways to solve them. *E3S Web of Conferences*, *273*. https://doi.org/10.1051/e3sconf/202127301025

Sivakumar, S. (2019). *Precision Agriculture Technologies*. https://www.researchgate.net/publication/377811776

Sun, B., Sun, X., Tsang, D. H. K., & Whitt, W. (2019). Optimal battery purchasing and charging strategy at electric vehicle battery swap stations. *European Journal of Operational Research*, *279*(2), 524–539. https://doi.org/10.1016/j.ejor.2019.06.019

Szász, L., Csíki, O., & Rácz, B. G. (2021). Sustainability management in the global automotive industry: A theoretical model and survey study. *International Journal of Production Economics*, *235*. https://doi.org/10.1016/j.ijpe.2021.108085

Tamor, M. A. (2019). Examining the case for long-range battery electric vehicles with a generalized description of driving patterns. *Transportation Research Part C: Emerging Technologies*, *108*, 1–11. https://doi.org/10.1016/j.trc.2019.09.003

Thangavel, S., Mohanraj, D., Girijaprasanna, T., Raju, S., Dhanamjayulu, C., & Muyeen, S. M. (2023). A Comprehensive Review on Electric Vehicle: Battery Management System, Charging Station, Traction Motors. In *IEEE Access* (Vol. 11, pp. 20994–21019). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ACCESS.2023.3250221

Tiwari, N., Verma, P., Kumar, S., Kumar, S., Dutt, H., Ahmad, S., & Singh Chauhan, S. (2023). Converting gasoline vehicle into an electric vehicle (EV)-A review. *Materials Today: Proceedings*, *79*, 379–388. https://doi.org/10.1016/j.matpr.2022.12.161

Tomaszewska, A., Chu, Z., Feng, X., O'Kane, S., Liu, X., Chen, J., Ji, C., Endler, E., Li, R., Liu, L., Li, Y., Zheng, S., Vetterlein, S., Gao, M., Du, J., Parkes, M., Ouyang, M., Marinescu, M., Offer, G., & Wu, B. (2019). Lithium-ion battery fast charging: A review. In *eTransportation* (Vol. 1). Elsevier B.V. https://doi.org/10.1016/j.etran.2019.100011

Trencher, G. (2020). Strategies to accelerate the production and diffusion of fuel cell electric vehicles: Experiences from California. *Energy Reports*, *6*, 2503–2519. https://doi.org/10.1016/j.egyr.2020.09.008

Vogt, H. H., de Melo, R. R., Daher, S., Schmuelling, B., Antunes, F. L. M., dos Santos, P. A., & Albiero, D. (2021). Electric tractor system for family farming: Increased autonomy and economic feasibility for an energy transition. *Journal of Energy Storage*, *40*. https://doi.org/10.1016/j.est.2021.102744

Wang, M. J., Kazyak, E., Dasgupta, N. P., & Sakamoto, J. (2021). Transitioning solid-state batteries from lab to market: Linking electro-chemo-mechanics with practical considerations. In *Joule* (Vol. 5, Issue 6, pp. 1371–1390). Cell Press. https://doi.org/10.1016/j.joule.2021.04.001

Wang, N., Tang, L., Zhang, W., & Guo, J. (2019). How to face the challenges caused by the abolishment of subsidies for electric vehicles in China? *Energy*, *166*, 359–372. https://doi.org/10.1016/j.energy.2018.10.006

Wang, S., Mason, S. J., & Gangammanavar, H. (2020). Stochastic optimization for flow-shop scheduling with on-site renewable energy generation using a case in the United States. *Computers and Industrial Engineering*, *149*. https://doi.org/10.1016/j.cie.2020.106812

Wen, J., Zhao, D., & Zhang, C. (2020). An overview of electricity powered vehicles: Lithium-ion battery energy storage density and energy conversion efficiency. *Renewable Energy*, *162*, 1629–1648. https://doi.org/10.1016/j.renene.2020.09.055

Wolf, S., Teitge, J., Mielke, J., Schütze, F., & Jaeger, C. (2021). The European Green Deal — More Than Climate Neutrality. *Intereconomics*, *56*(2), 99–107. https://doi.org/10.1007/s10272-021-0963-z

Zhang, W., & Xu, J. (2022). Advanced lightweight materials for Automobiles: A review. In *Materials and Design* (Vol. 221). Elsevier Ltd. https://doi.org/10.1016/j.matdes.2022.110994

APPENDIX A

Table 1 Gantt Chart of Activities for PSM 1

ACTIVITIES	STATUS	WEEK 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Title and supervisor selection	Plan															
	Actual															
Briefing on PSM 1	Plan															
	Actual															
Planning and research	Plan															
	Actual															
Problem statements and objectives determination	Plan															
	Actual															
Research on literature review	Plan															
	Actual															
Chapter 1 writing	Plan															
	Actual															
Chapter 2 writing	Plan															
	Actual															
Chapter 3 writing	Plan															
	Actual															
Product Development	Plan															
	Actual															
Report and Log Book Submission	Plan															
	Actual															

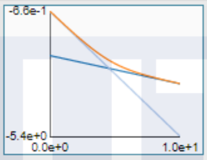
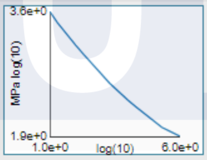
APPENDIX B

Table 2 Gantt Chart of Activities for PSM2

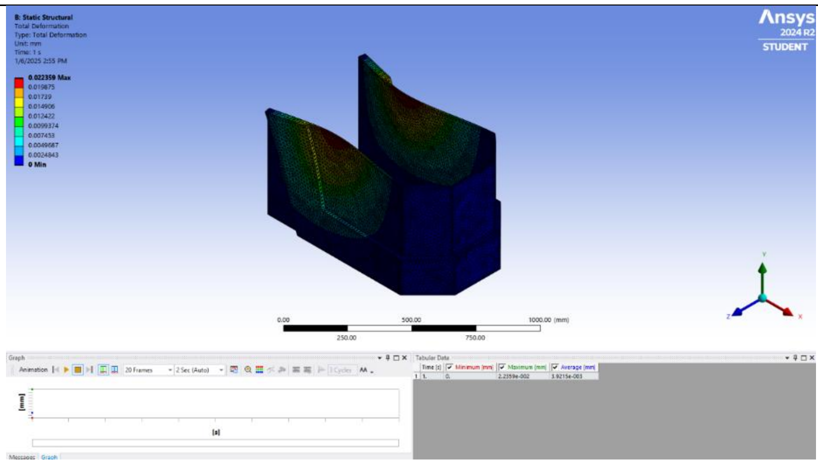
ACTIVITIES	STATUS	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project brief for BDP2 by supervisor	Plan	■														
	Actual	■														
Literature review	Plan	■	■	■												
	Actual		■	■												
Chapter 4 and 5 writing	Plan				■	■	■	■	■	■	■	■	■	■	■	
	Actual					■	■	■	■	■	■	■	■	■	■	
Detail design	Plan		■	■	■											
	Actual		■	■	■											
Fabrication process	Plan				■	■	■	■	■	■	■	■	■			
	Actual				■	■	■	■	■	■	■	■	■			
Product Testing	Plan					■	■	■	■	■	■					
	Actual					■	■	■	■	■	■	■				
Product Assembly	Plan					■	■	■	■	■	■	■	■	■		
	Actual				■	■	■	■	■	■	■	■	■	■		
Finishing	Plan							■	■	■	■	■	■	■		
	Actual							■	■	■	■	■	■	■		
Structural analysis	Plan				■	■	■	■								
	Actual				■	■	■	■								
Report and logbook submission	Plan													■	■	
	Actual													■	■	

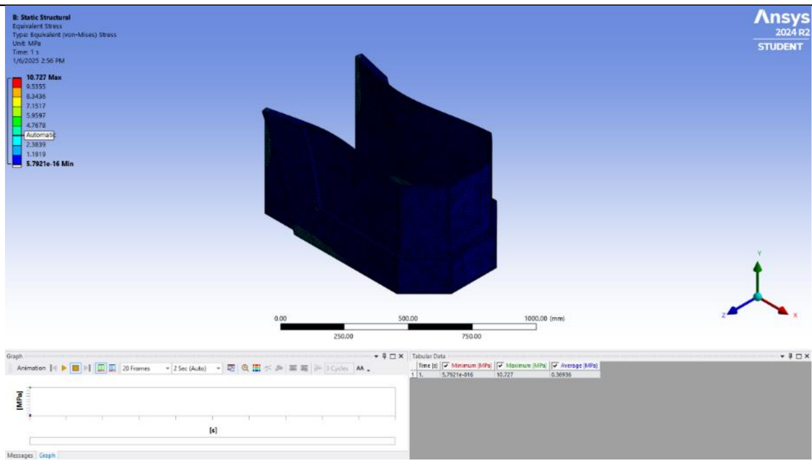
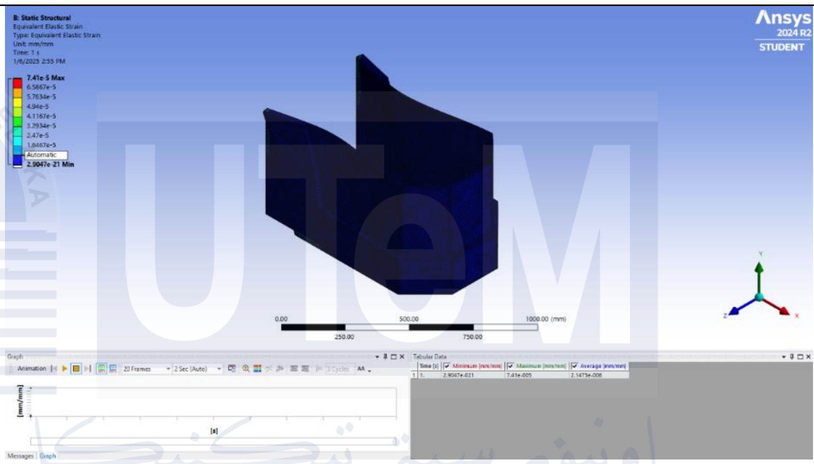
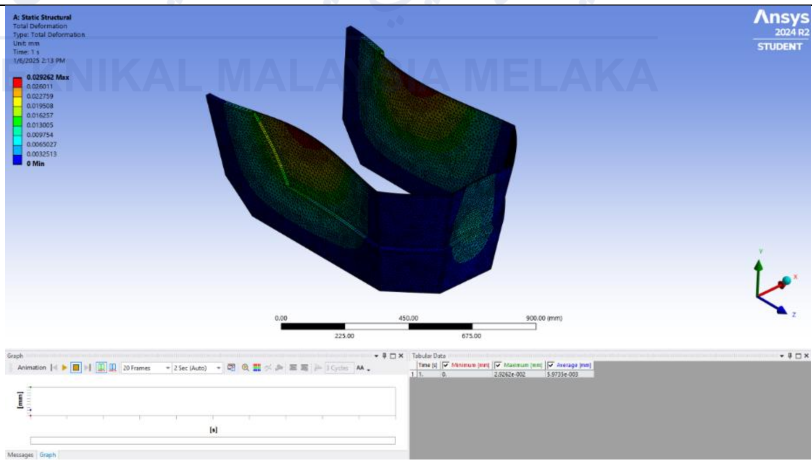
APPENDIX C

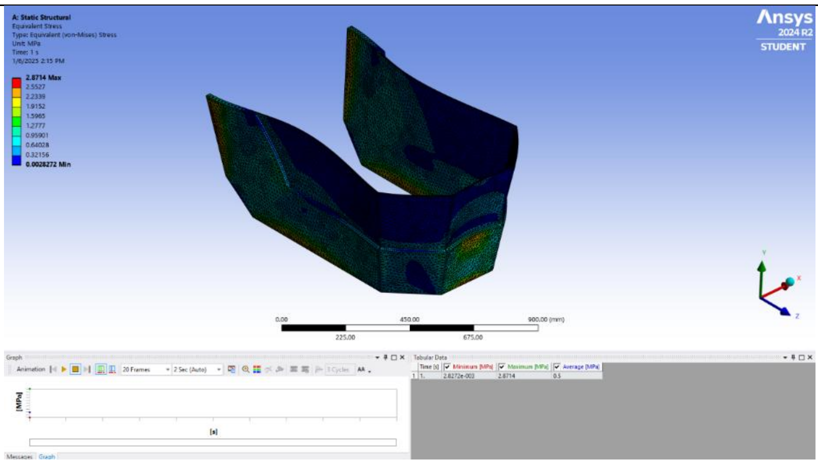
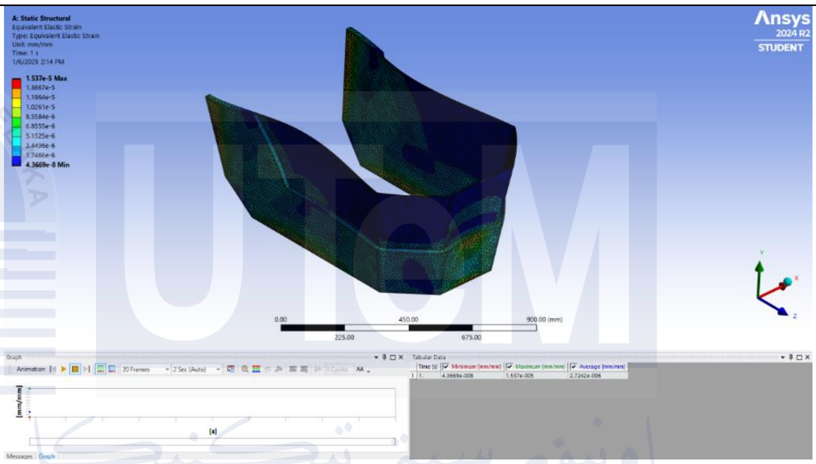
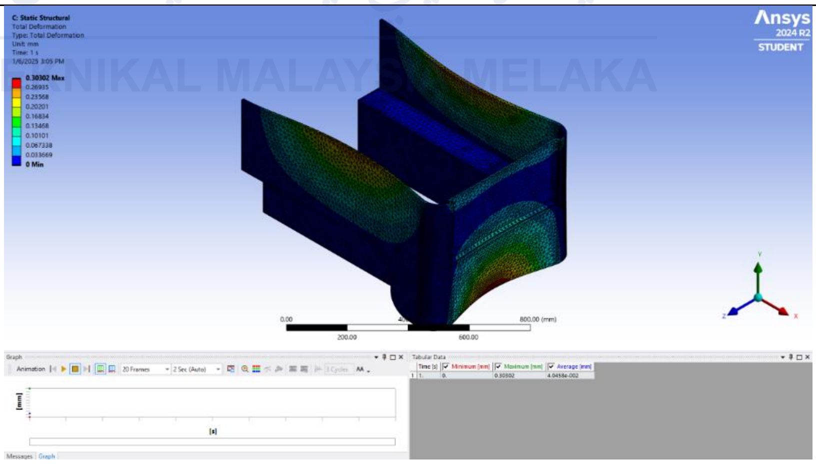
Table 3 Tables of Analysis

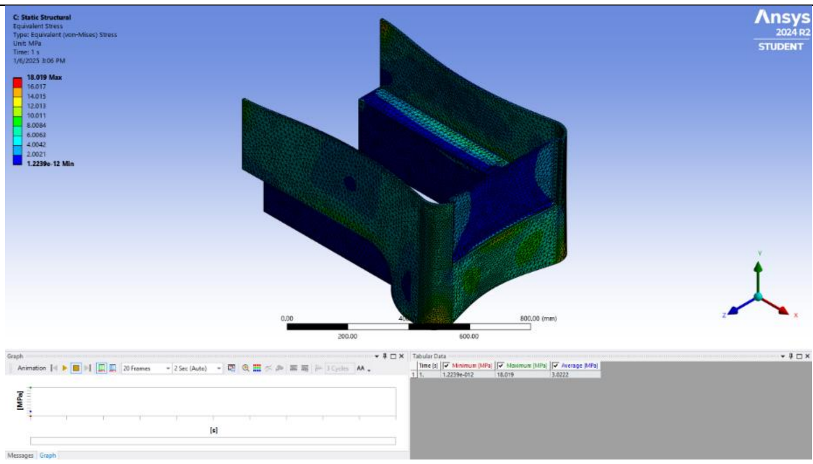
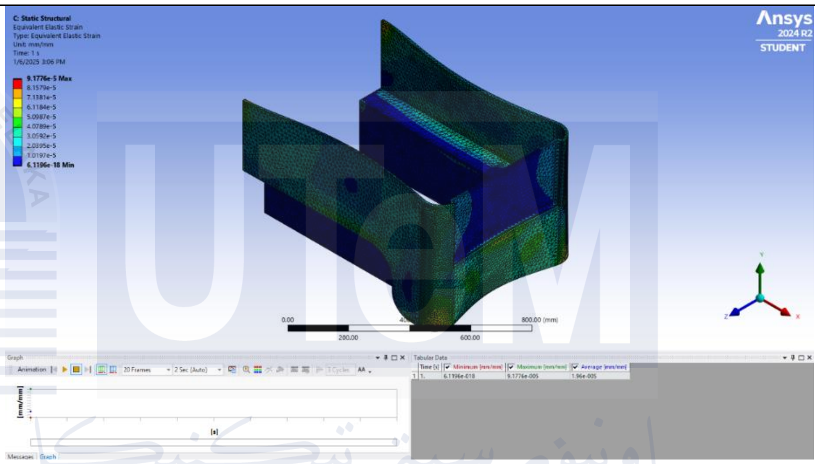
	Structural Steel	Composite, Epoxy/glass fiber, woven prepreg, biax.	Plastic, ABS (high-impact)
Source	Project Materials	Project Materials	Project Materials
Density	7.85e-06 kg/mm³	1.857e-06 kg/mm³	1.03e-06 kg/mm³
Structural			
Isotropic Elasticity			
Derive from	Young's Modulus and Poisson's Ratio	Young's Modulus and Poisson's Ratio	Young's Modulus and Poisson's Ratio
Young's Modulus	2e+05 MPa	26400 MPa	2090 MPa
Poisson's Ratio	0.3	0.1543	0.4089
Bulk Modulus	1.6667e+05 MPa	12728 MPa	3823.6 MPa
Shear Modulus	76923 MPa	11436 MPa	741.71 MPa
Isotropic Secant Coefficient of Thermal Expansion	1.2e-05 1/°C	1.688e-05 1/°C	0.000184 1/°C
Compressive Ultimate Strength	0 MPa		
Compressive Yield Strength	250 MPa		
Strain-Life Parameters			
S-N Curve			
Tensile Ultimate Strength	460 MPa	440.1 MPa	36.26 MPa
Tensile Yield Strength	250 MPa	440.1 MPa	27.44 MPa

1. Steel Metal

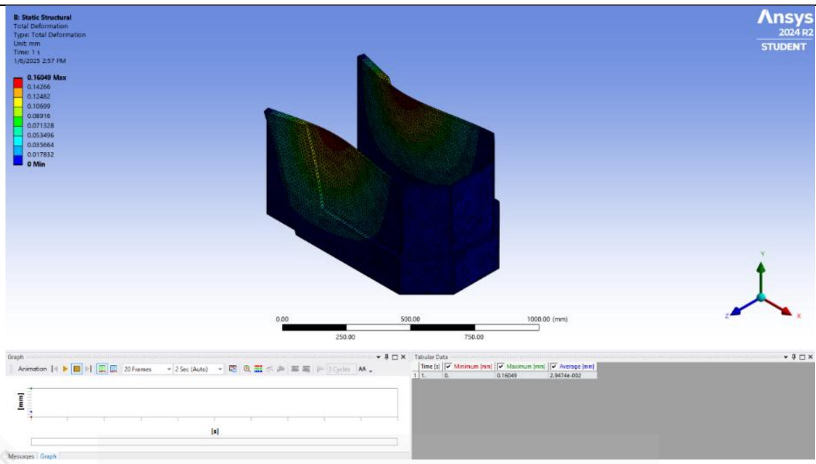
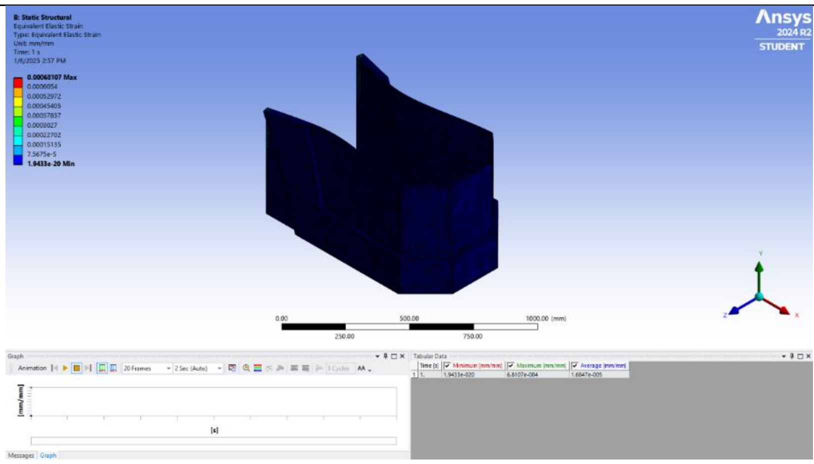
	Analysis	Data Figure
D1	Total Deformation	

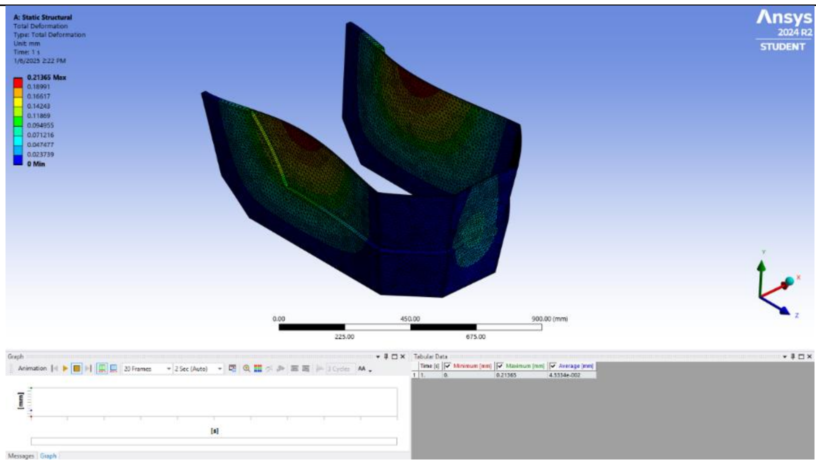
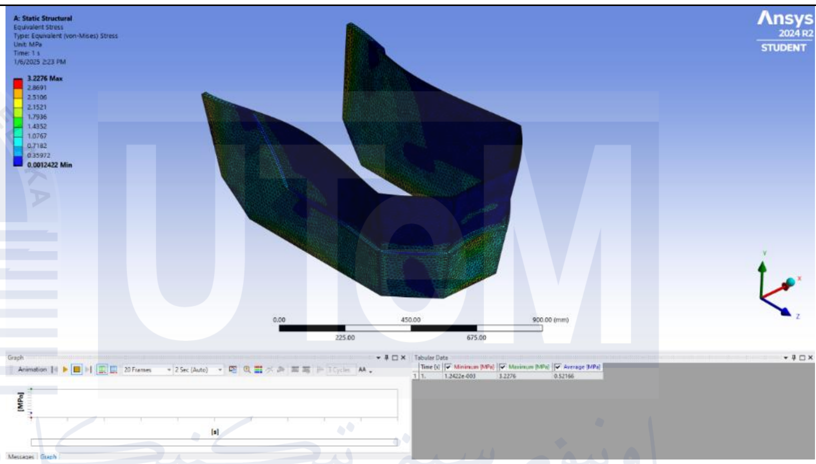
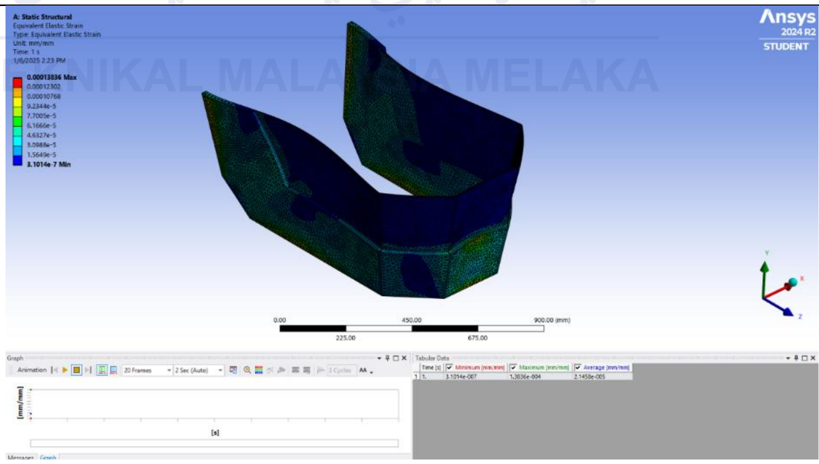
	Equivalent Stress	
	Elastic Stress	
D2	Total Deformation	

	Equivalent Stress	
	Elastic Stress	
D3	Total Deformation	

	Equivalent Stress	
	Elastic Stress	

2. Composites Fibreglass

	Analysis	Data Figure
D1	Total Deformation	
	Equivalent Stress	
	Elastic Stress	

D2	Total Deformation	
	Equivalent Stress	
	Elastic Stress	

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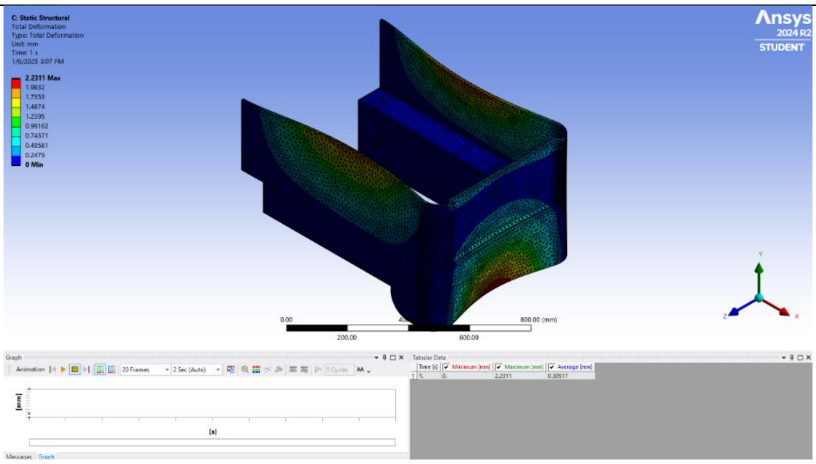
<tr><td rowspan="3">D3</td><td>Total Deformation</td><td>
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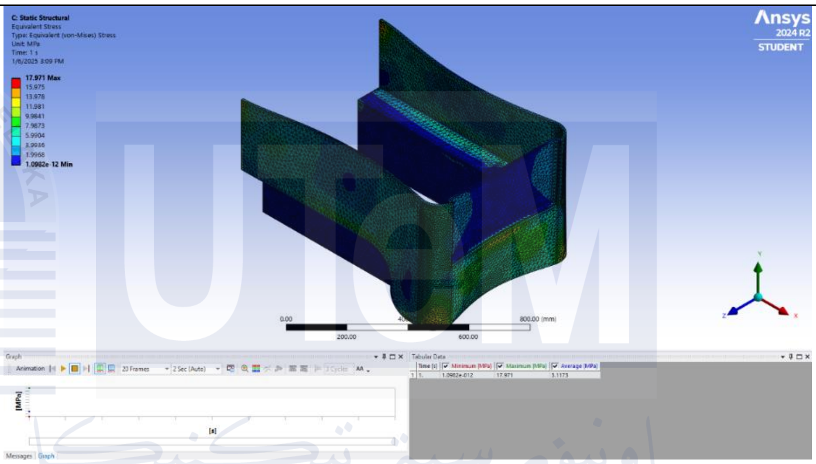
<tr><td>Equivalent Stress</td><td>
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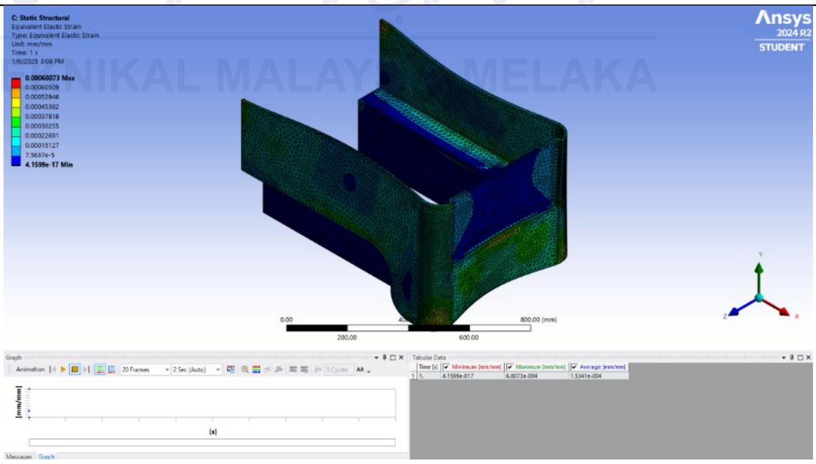
<tr><td>Elastic Stress</td><td>
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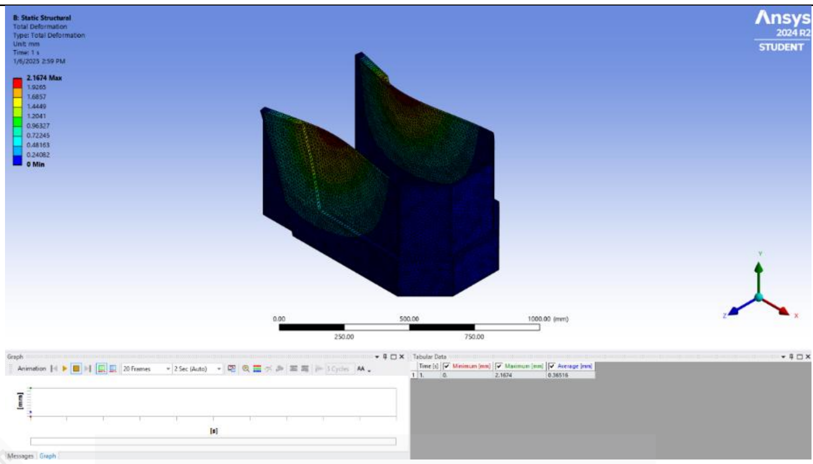
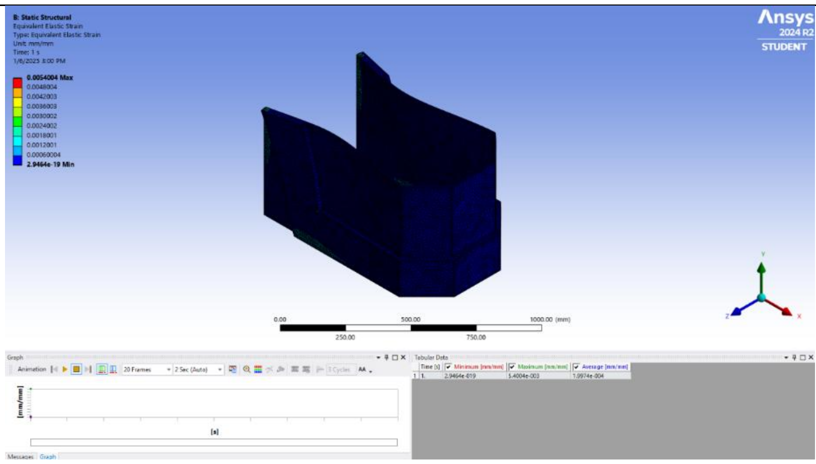
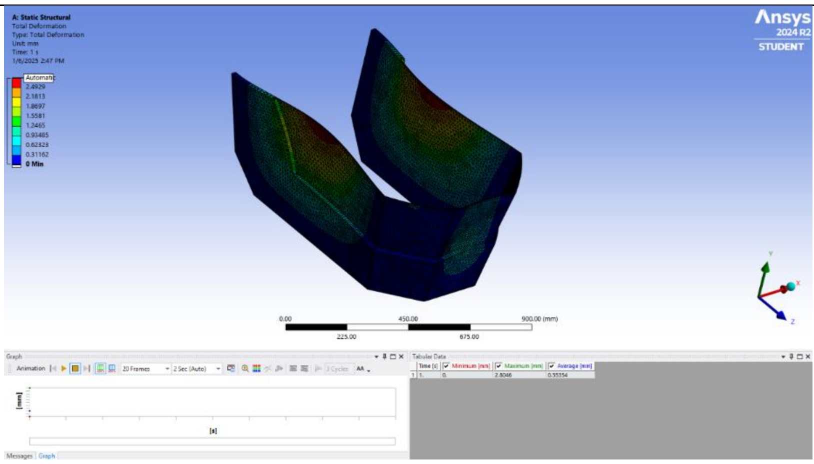
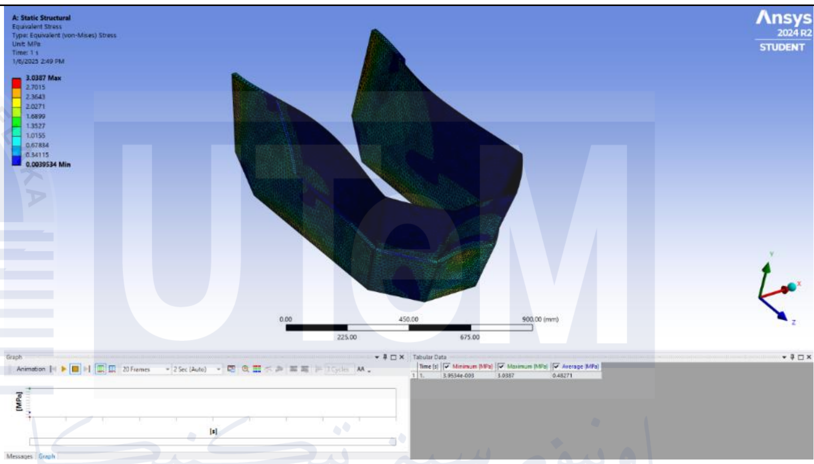
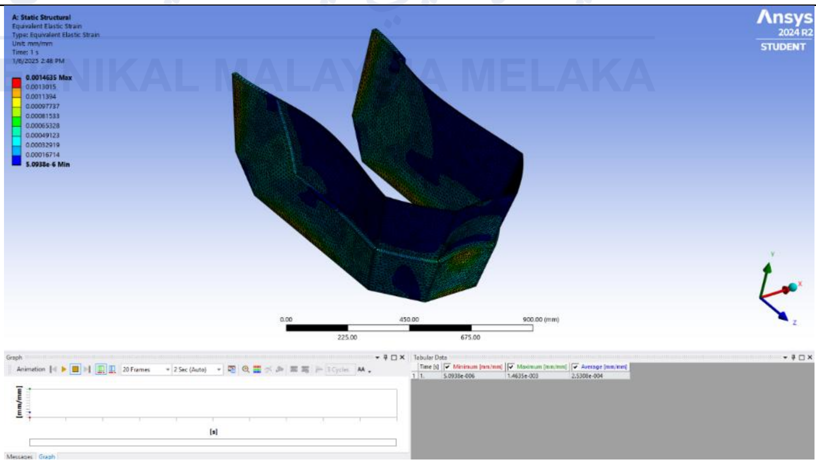
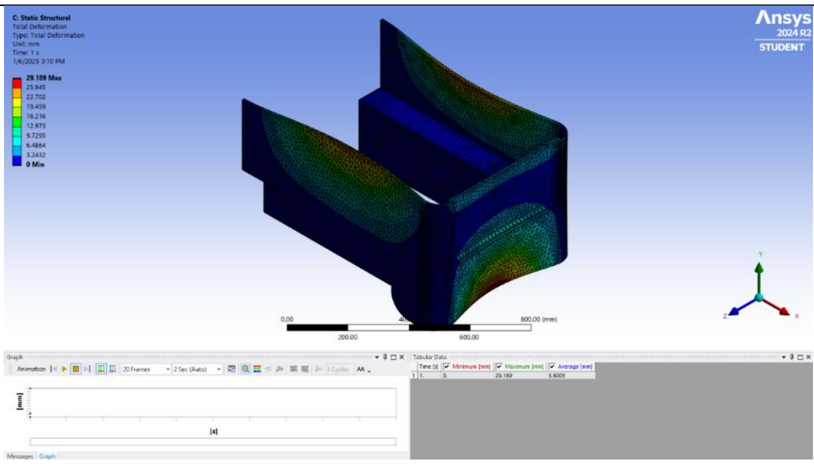
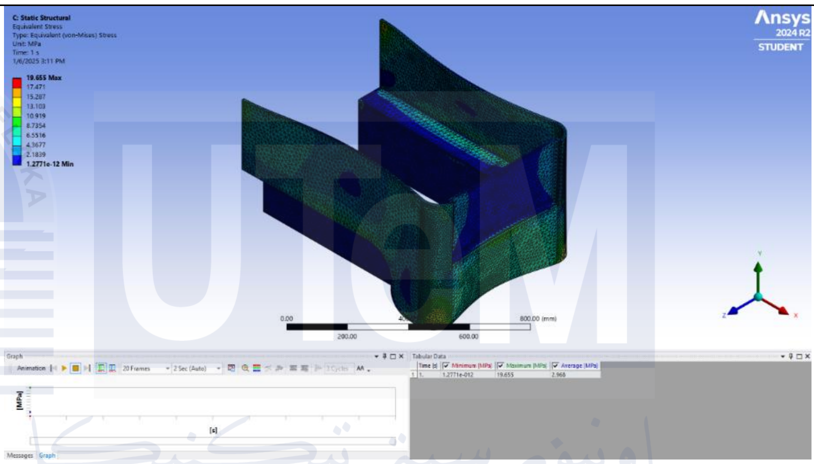
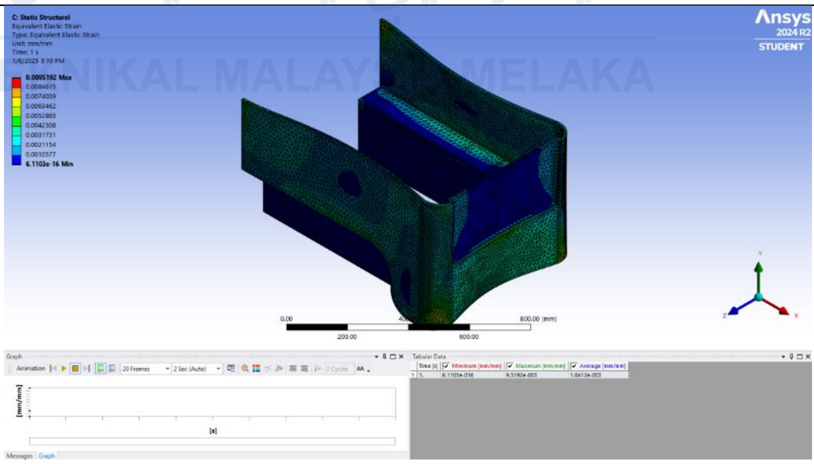
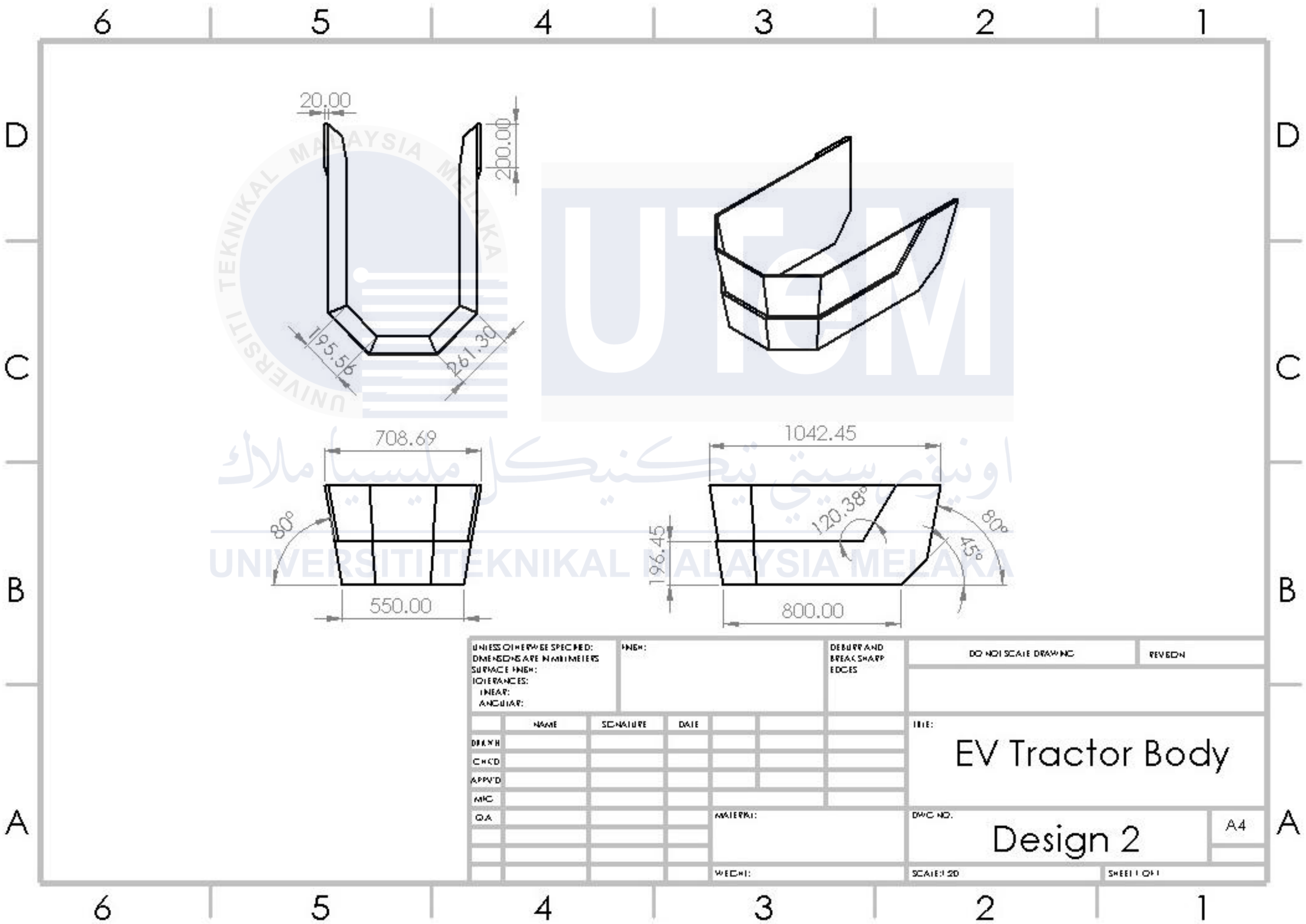
3. Plastic ABS (High-Impact)

	Analysis	Data Figure
D1	Total Deformation	
	Equivalent Stress	
	Elastic Stress	

D2	Total Deformation	
	Equivalent Stress	
	Elastic Stress	

D3	Total Deformation	
	Equivalent Stress	
	Elastic Stress	


20.00
200.00
195.56
261.30
708.69
80°
550.00
1042.45
120.38°
196.45
80°
45°
800.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
EV Tractor Body
DWG NO.
Design 2
A4
SCALE:1:20
SHEET 1 OF 1