DESIGN AND IMPLEMENT ENERGY-EFFICIENT STRUCTURE FOR ELECTRICAL VEHICLE

विद्युत वाहनों के लिए ऊर्जा – कुशल संरचना का डिजाइन और कार्यान्वयन

A
Thesis
Submitted for the Award of the Ph.D. degree of
PACIFIC ACADEMY OF HIGHER EDUCATION AND RESEARCH UNIVERSITY

By

SHINDE AMOL SHAHAJI

शिंदे अमोल शहाजी
Under the supervision of

Dr. RAJU KUMAR SWAMI
Associate Professor.
Pacific Academy of Higher
Education & Research University, Udaipur

Dr. SAMEER NANIVADEKAR
Associate Professor,
A.P. Shah Institute of Technology,
Thane, Maharashtra

FACULTY OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING
PACIFIC ACADEMY OF HIGHER EDUCATION AND RESEARCH UNIVERSITY, UDAIPUR

2024

DECLARATION

I, **SHINDE AMOL SHAHAJI S/O SHRI SHAHAJI NARAYAN SHINDE** resident of B/501, Shri Drushti CHS LTD., Kasarvadavali, Ram Mandir Road, Ghodbunder Road, Thane (W)- 400615, hereby declare that the research work incorporated in the present thesis entitled **“Design and Implement Energy-Efficient Structure For Electrical Vehicle” (**विद्युत वाहनों के लिए ऊर्जा – कुशल संरचना का डिजाइन और कार्यान्वयन) is my original work. This work (in part or in full) has not been submitted to any University for the award or a Degree or a Diploma. I have properly acknowledged the material collected from secondary sources wherever required.

I solely own the responsibility for the originality of the entire content.

Signature of the Candidate

Date:

FACULTY OF ENGINEERING

PACIFIC ACADEMY OF HIGHER EDUCATION AND RESEARCH UNIVERSITY, UDAIPUR

Dr. RAJU KUMAR SWAMI
Associate Professor

CERTIFICATE

It gives me immense pleasure in certifying that the **"Design and Implement Energy-Efficient Structure For Electrical Vehicle"** (विद्युत वाहनों के लिए ऊर्जा – कुशल संरचना का डिजाइन और कार्यान्वयन) and submitted by **SHINDE AMOL SHAHAJI** is based on the research work carried out under my guidance. He / she have completed the following requirements as per Ph.D. regulations of the University;

(i) Course work as per the University rules.

(ii) Residential requirements of the University.

(iii) Regularly presented Half Yearly Progress Report as prescribed by the University.

(iv) Published / accepted minimum of two research paper in a refereed research journal.

I recommend the submission of thesis as prescribed/notified by the University.

Date: **Name and Designation of Supervisor**

Dr. RAJU KUMAR SWAMI
Associate Professor,
Pacific Academy of Higher Education
& Research University, Udaipur

CERTIFICATE

It gives me immense pleasure in certifying that the thesis **“Design and Implement Energy-Efficient Structure For Electrical Vehicle”** (विद्युत वाहनों के लिए ऊर्जा – कुशल संरचना का डिजाइन और कार्यान्वयन) and submitted by **SHINDE AMOL SHAHAJI** is based on the research work carried out under my guidance. He / she have completed the following requirements as per Ph.D. regulations of the University;

(i) Course work as per the University rules.

(ii) Residential requirements of the University.

(iii) Regularly presented Half Yearly Progress Report as prescribed by the University.

(iv) Published / accepted minimum of two research paper in a refereed research journal.

I recommend the submission of thesis as prescribed/notified by the University.

Date: **Name and Designation of Co-Supervisor**

Dr. SAMEER NANIVADEKAR
Associate Professor,
A.P. Shah Institute of Technology,
Thane, Maharashtra

COPYRIGHT

I, **SHINDE AMOL SHAHAJI,** hereby declare that the Pacific Academy of Higher Education and Research University, Udaipur, Rajasthan, shall have the rights to preserve, use and disseminate this dissertation entitled **“Design and Implement Energy-Efficient Structure For Electrical Vehicle”** (विद्युत वाहनों के लिए ऊर्जा – कुशल संरचना का डिजाइन और कार्यान्वयन) in print or in electronic format for the academic research.

Date:

Signature of Candidate

Place:

ACKNOWLEDGEMENT

I heartily express my deep sense of gratitude indebtedness to my Supervisor **Dr. Raju Kumar Swami,** and my Co-Supervisor **Dr. Sameer Nanivadekar** for his free accessibility, friendly attitude, instance guidance and constant encouragement at every step of my research work. It is really a matter of pride and joy for me to work under his guidance.

I would like to express my sincere thanks to our Dean **Dr. Hemant Kothari** and **Mr. Ramesh Agrawal**, Pacific Academy of Higher Education and Research University, Udaipur for their encouragement and moral support at all times.

I would also like to express my deeply felt gratitude to **Shri. Chiragbhai Shah**, Chairman, and **Mrs. Pooja Shah**, Trustee, Parshvanth Charitable Trust's, A. P. Shah Institute of Technology, Thane. In addition, I am also thankful to our Principal **Dr. U. D. Kolekar** for their kind cooperation and constant encouragement during my research work.

I accord my sincere thanks to, **Mrs. Prajakta Nanivadekar, Mr. Pankaj Jadhav**, **Mr. Amarnath Landge**, **Mr. Bhushan Chavan**, **Mr. Sushrut Patankar**, for their constant encouragement and moral support.

I am really happy to be blessed by **Aajji, Aai** and **Aaba** while completing this work. It is impossible to express my gratitude and emotions in words to my wife **Devayani** for her help in completing this work.

The final one, my distinctive thanks to ***Nav Nimantran Thesis Printing & Binding, Udaipur*** Admin Team ***Mr. Hemant Sharma and Mrs. Kusum*** for their role in shaping this research, creative design work and bringing out this document meticulously, neatly and timely.

DATE: - **SHINDE AMOL SHAHAJI**

DEDICATED TO
MY FAMILY, FRIENDS
AND WELL-WISHERS

PREFACE

In an era where sustainability and energy efficiency are paramount, the transition towards more environmentally friendly modes of transportation is inevitable. The research undertaken in this thesis, titled "Design and Implement Energy-Efficient Structure for Electrical Vehicle," embodies a significant stride toward this transition. This study carves out a niche in the burgeoning field of electric vehicles (EVs) by focusing on the innovative design and optimization of energy-efficient structures for three-wheeled electric vehicles.

The inception of this research is rooted in the critical examination of the global transportation sector's impact on carbon emissions, with a keen eye on the burgeoning potential of electric vehicles to mitigate these environmental challenges. The thesis navigates through the historical evolution of EVs, elucidating the shift from conventional internal combustion engines to more sustainable electric alternatives. It intricately explores the design, implementation, and potential of three-wheeled electric vehicles, particularly focusing on the tadpole structure for its advantages in terms of aerodynamics, stability, and energy efficiency.

A multi-faceted approach was adopted in this study, encompassing an extensive literature review, methodological rigor in design and prototyping, and empirical analysis through simulation and real-world testing. This comprehensive exploration is underpinned by a dual objective: to innovate in the design of a tadpole-structured electric vehicle that champions energy efficiency and to empirically validate the performance enhancements through meticulous testing.

The significance of this research is manifold. It not only contributes to the academic and practical knowledge on electric vehicles but also provides a blueprint for future innovations in the design and implementation of energy-efficient structures. The findings underscore the feasibility of three-wheeled electric vehicles as a viable alternative to their four-wheeled counterparts, presenting a compelling case for their adoption in urban settings for a sustainable future.

This thesis is a testament to the collaborative spirit, dedication, and intellectual rigor that characterizes the quest for innovation and sustainability in transportation. It is hoped that the insights gleaned from this study will fuel further research in this vital field and inspire a new generation of engineers and environmental advocates to continue pushing the boundaries of what is possible in the realm of electric vehicles.

INDEX

LIST OF TABLE

LIST OF FIGURE

INTRODUCTION

Global temperatures are increasing due to global warming that is caused by CO_2 emissions [1]. It is predicted that global temperatures will increase between 1.1° Celsius to 5.4° Celsius by the year 2100. Hence to combat rising global temperatures it is necessary to reduce CO_2 emissions. Vehicular transportation is the largest contributor to CO_2 emissions in India. Traditional cars use fuels like petrol and diesel while emitting CO_2 emissions. Electric vehicles don't emit any substances [2]. They run on electric power and not directly on fossil fuels. However, the mileage offered by electric vehicles is not comparable to that of traditional vehicles [3].

Three-wheeled vehicles provide more mileage as compared to their four-wheel counterparts, as they are lighter and more aerodynamic [4]. Designing an energy-efficient and stable structure for three-wheeled electric vehicles would ensure considerable mileage along with long battery life. Additionally, three-wheeled vehicles allow the use of innovative structures such as Tadpole and Delta that maximize the speed and stability of such vehicles. By using such electric vehicles, global warming can be slowed down by reducing CO_2 emissions.[5]

Electric vehicles may be traced back to the early 19th century when inventors such as Robert Anderson and Thomas Davenport created rudimentary electric vehicles driven by batteries. These vehicles were the first step in the development of electric vehicles. However, in 1884, a British inventor named Thomas Parker produced the first functional electric vehicle. He designed an electric automobile that could run up to 100 miles on a single charge and built an electric car that he built in 1884.[6]

1.1 Historical Development of Electrical Vehicle

In the early part of the 20th century, electric vehicles began to gain favor as a mode of urban transportation, particularly for use as taxis and delivery trucks. On the other hand, electric vehicles fell out of favor and were mostly abandoned after the invention of the internal combustion engine and the widespread availability of inexpensive petrol.[7]

Concerns over air pollution and reliance on foreign oil led to a resurgence of interest in electric vehicles towards the end of the 20th century. The first electric vehicle to be manufactured on a large scale in the modern period was the General Motors EV1, which was introduced in 1996. Other car manufacturers quickly followed suit, beginning production of electric and hybrid vehicles similar to the Toyota Prius and the Honda Insight, amongst others.[8]

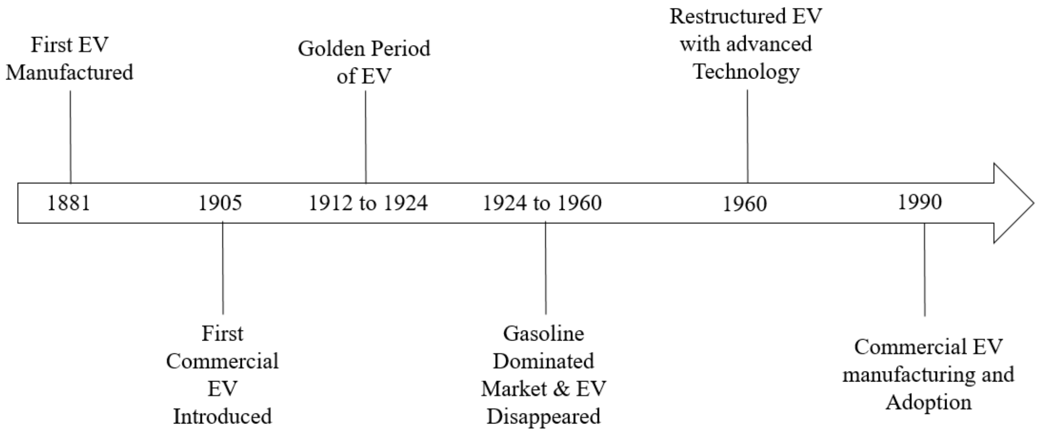


Fig. 1 : Historical Development of EV

Early on in the 21st century, improvements in battery technology and financial incentives offered by the government contributed to a rise in the demand for electric vehicles. Roadster, Model S, and Model X helped propel Tesla Motors to the forefront of the electric vehicle industry soon after the company's founding in 2003. Other major automakers, like as Nissan, BMW, and Chevrolet, have also started developing electric vehicles, and many nations have established policies, such as tax incentives and subsidies, to inspire the implementation of electric vehicles.[9]

To this day, electric vehicles continue to advance thanks to developments in battery technology, charging infrastructure, and technology that allows them to operate without human intervention. Electric vehicles are being increasingly recognized as a critical component of the evolution towards a transportation system that is both more sustainable and less harmful to the environment as people become increasingly concerned about issues such as climate change and air pollution.[10]

Three-wheeled automobiles have existed for an extended time, even predating the Patent Motor Wagen design. For example, in the 15th century, Leonardo da Vinci sketched a simple three-wheeled car driven by a spring-operated mechanism similar to a clock. In 1769, French engineer Nicolas Cugnot developed a sizable, tricycle-like automobile equipped with a steam-powered motor. As the twentieth century progressed Three-wheelers became popular as affordable and lightweight vehicles, but their popularity declined in the late 1920s with the increasing dominance of four-wheeled cars. However, things changed once more after WW II.[11]

In war-torn countries like England, France, Germany, and Japan, gasoline and other auto parts were hard to come by, but people still needed a way to get around. Most of the time, they couldn't afford or couldn't get full-sized four-wheel cars, and a motorbike was too small for their needs. Bond Cars Ltd. did well in England after the war by making small three-wheeled cars with motorbike engines that only had one cylinder. People on motorcycles who wanted to be protected from the weather liked these small cars. As an added plus, you didn't need an auto driver's license to drive one. In addition, they were very helpful because they could get more than 100 miles per gallon (42.5 km per liter) when fuel was expensive and sources were limited.[12]

There were three-wheelers made by Bond Cars until the 1970s. In the 1950s, BMW started selling a funky, egg-shaped microcar called the Isetta with three wheels. And once more, the three-wheeled form of this car was very popular in the UK, where you could drive one with a motorbike license. Japan's car companies, like Daihatsu, made three-wheelers that were often used as cabs, light trucks, and other service vehicles. For the second time, a lot of them were small and driven by cheap motorbike engines. The English have made the fiberglass microcar Reliant Robin on and off for more than 30 years. It is thought to be one of the most famous three-wheelers of all time.[13]

1.2 Definition of an Electrical Vehicles

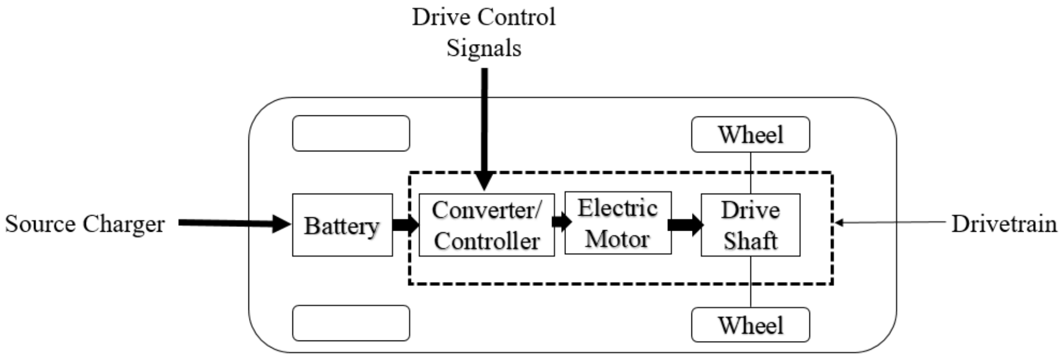


Fig. 2 : General Configuration of EV

An electric vehicle (EV) is a car that uses electricity as its primary source of propulsion, as opposed to a fossil fuel like petrol or diesel. Electric vehicles (EVs) run on either hydrogen fuel cells or rechargeable batteries, and they don't release any pollutants from their exhaust pipes. [14] These three categories best describe EVs:

1.2.1 Battery Electric Vehicles (BEVs)

The batteries in these automobiles may be recharged by connecting them to a standard wall socket or charging station.

1.2.2 Hybrid Electric Vehicles (HEVs)

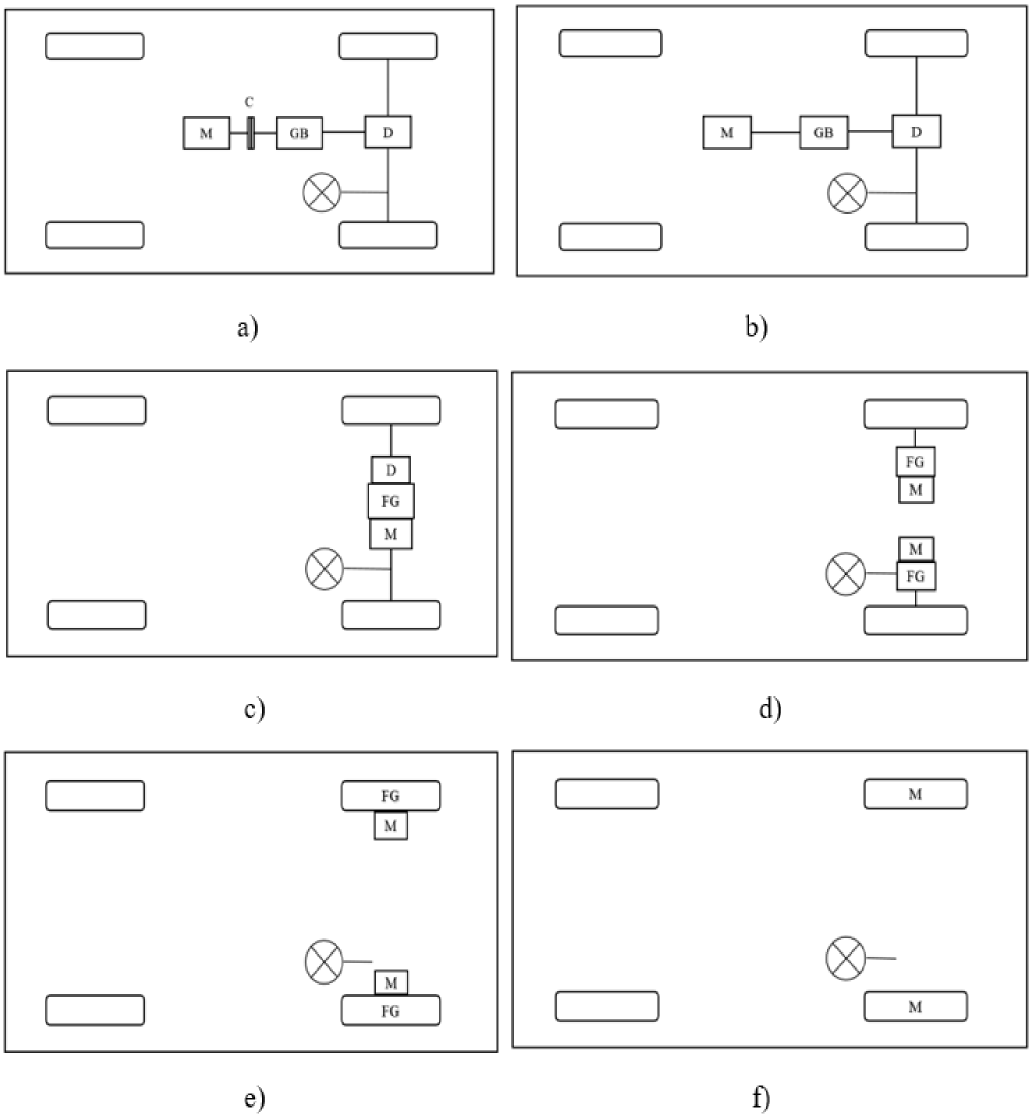
These automobiles are powered by both electricity and conventional fuels like petrol or diesel. The electric motor helps the petrol or diesel engine out and charges the batteries, but the petrol or diesel engine takes over when going faster or when the batteries are low.

1.2.3 Plug-In Hybrid Electric Vehicles (PHEVs)

Like HEVs, these automobiles are equipped with both an electric motor and a petrol or diesel engine. However, plug-in hybrid electric vehicles (PHEVs) have larger battery packs that may be recharged by connecting the car to a standard electrical outlet or charging station. PHEVs may travel short distances solely on electric power before switching to the petrol or diesel engine.[15] on electric power before switching to the petrol or diesel engine.[15]

1.3 Configurations of Electric Vehicles

In the past, most electric vehicles were based on existing ICEVs; the main difference was that ICEVs had internal combustion engines and fuel tanks that were replaced with electric motor drives and battery packs. This kind of electric vehicle's popularity has waned because of its cumbersome design, lack of maneuverability, and diminished performance. [16]



a) b) c) d) e) f)

Figure 3 : EV Configurations

Modern EVs use original body and frame designs. This meets EV structural standards and makes electric propulsion versatile. Due to features of electric propulsion and sources of energy, Figure 3 shows many EV setups.

Figure 3 (a) shows the first option, which doesn't use an IC engine but instead makes use of electric power. A clutch, an electric motor, a gearbox, and a differential. Clutches can be swapped out for automatic gears. The clutch lets you connect or disconnect the electric motor from the wheels. The gearbox has the right gear ratios for the load's speed-power (torque) formula. When the car turns, the differential (usually planetary gears) sends different speeds to the wheels on each side.

An electric motor that has steady power over a wide speed range can be used instead of the multispeed gearbox and the clutch. This set-up, shown in Figure 3(b), makes the mechanical transmission smaller and lighter, and it makes controlling the drive train easier by getting rid of the need to change gears.[17] With both hubs directed at both moving wheels, the electric motor, set gears, and differential can all be built into a single unit. Making the engine shown in Figure 3 (c) simpler and smaller. In Figure 3 (d), the mechanical differential has been replaced by two drive motors. Each person drives one side wheel at a different speed when the car turns.

A traction motor inside a wheel simplifies the drive train indicated in Figure 3 (e). Thin planetary gear sets can lower motor speed and increase torque. The thin planetary gear set has a high-speed reduction ratio and an integrated input/output shaft.[18] In-wheel (Hub Motor) drives can directly connect the out-rotor of a low-speed electric motor to the driving wheel by eliminating mechanical gearing shoed in Figure 3 (f). The electric motor controls wheel speed and vehicle speed. To start and accelerate the car, the electric motor needs more torque.

1.4 3-Wheeled & 4-Wheeled Vehicles

Table 1.1 : Comparison of Three-wheel and Four-wheel Vehicles

Three-wheeled	Four-wheeled
Less number of friction points	More number of friction points
More aerodynamic	Less aerodynamic
Can tip over at high cornering speeds	Can’t tip over at higher cornering speeds
Supports less number of passengers	Supports more number of passengers

1.4.1 3-Wheeled Vehicles

A three-wheeled car also called a tri-car, has either one front wheel for steering and two back wheels for power, two front wheels for steering and one rear wheel for power, or any other combination. The front-steering "tadpole" or "reverse trike" is becoming popular due to its handling.[19]

Three-wheeled cars are triangular. This implies the car either has two front wheels or two rear wheels, depending on where the travelers sit, the engine's location, and other key mechanical components. Steering and engine drive can be done anyway.

1. **Delta Structure:** Delta layout has one front wheel and two back wheels. Reliant Robin and Karl Benz followed this setup. The Mazda-Go, the first three-wheeled Mazda, had a pickup truck bed in the back. Delta is cost-effective. The engine drives the back wheels and steers the front in most cars. One-wheel steering is cheap and straightforward to build.[5]

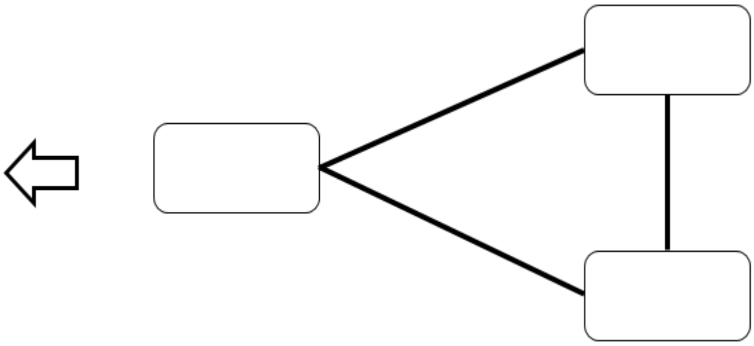


Fig. 4 : Delta Structure

2. **Tadpole Structure:** Tadpole trikes are backward trikes. This arrangement has two front wheels and one back, unlike the delta. Tadpole designs exhibit greater stability compared to delta designs due to the presence of a back-wheel drive and two front wheels for steering. The vehicle's teardrop form makes it aerodynamic. Air flows readily over the vehicle's bodywork. For its stability, aerodynamics, and fuel efficiency, auto designers are favoring tadpole design. Many hybrid and electric concept cars feature a three-wheel configuration. Three-wheelers may become increasingly common as cars become eco-friendlier.[20]

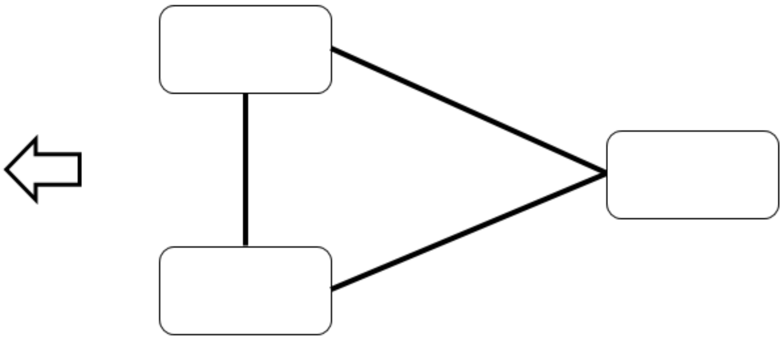


Fig. 5 : Tadpole Structure

1.4.2 Advantages of Tadpole over Delta structure

- **Turning:** two front wheels offer better stability and higher turning speeds.
- **Weight distribution:** Higher in the front providing improved steering and braking.
- **Center of gravity:** Lower and near the steering axis providing higher speeds.
- Simpler drive mechanism.
- Lighter in weight.
- Not prone to tip over while turning on high speeds.

1.5 Types of Tadpole structure Vehicle

1.5.1 Solar-Powered Tadpole

The tadpole-based three-wheeled electric vehicles offer better aerodynamics which reduces air drag and provides better mileage as compared to their four-wheeled counterparts. However, the tadpole design limits the size of the batteries that can be used to power the vehicle. Hence, Tahjib et al. [7] have proposed a tadpole-based electric vehicle that is powered via solar panels. Their design specifically focuses on battery charging circuits, suspension systems, and motor control circuits. They have also designed a data logging system to evaluate the performance of the proposed design. The designed vehicle is of type rear-wheel drive and uses a Brushless Direct Current (BLDC motor). The data logger is attached to the rear wheel to read the speed of the vehicle, current, voltage, and power received by the motor. The solar panel array was connected to a solar charge controller, which is in turn connected to a motor controller. The accelerator and the BLDC motor were connected to the motor controller. The suspension system is situated on the two front wheels, with the free length of the springs being 250 mm and the compressed length being 180 mm. The data coming in from the voltage and current sensors are passed through a signal conditioning process to remove noise. The filtered signal was then passed through an Analog-to-Digital (ADC) converter to produce digital signals. [21]

1.5.2 Hybrid Tadpole

Auto rickshaws are Delta-based three-wheeled vehicles which are commonly used in Asian countries like India and Pakistan to ferry passengers over short to medium distances. In contrast, Tadpole-based three-wheelers generally seat only one passenger. As they are designed to carry a single person they have better aerodynamics. At the cost of being lesser aerodynamic, more passengers can be added. However, designing a single-seater vehicle affects its large-scale adoption as people would rather have multi-passenger vehicles. Hence, to address this issue Reddy et al. [5] have proposed a hybrid two-seater Tadpole-based vehicle. The proposed design has a low center of gravity situated near the rear wheel and high ground clearance. They have also designed a unique powertrain for the proposed design. The vehicle consists of a mechanical drive design that requires the users to pedal to drive the vehicle. Additionally, an electric drive mechanism can also be attached to the rear wheel. Hence the proposed vehicle is a hybrid electric vehicle. They have designed a transmission system that is easy to manufacture and utilizes a single motor to drive the vehicle as well as charge the battery through regenerative braking. Considering only the roll cage, the weight of the vehicle is 16 Kg. Its simple design allows for quick and straightforward manufacturing.[22]

1.6 Current State of Electrical Vehicle Technology

Fig. 6 : Current Electric Vehicle Scenario in India (ecogears.in)

Battery technology, power electronics, and electric motor design are all seeing tremendous advancements, which is driving the quick evolution and improvement of the current level of electric vehicle (EV) technology. Electric vehicles are gaining popularity because they have cheaper running costs, have less impact on the environment, and are eligible for government incentives.[23] The following is a list of significant advances in EV technology:

At the moment, lithium-ion batteries are the most prevalent form of battery that is utilized in electric vehicles (EVs). Because of advancements in battery technology, batteries now offer a higher energy density, a greater range, and a shorter time to charge. There is ongoing research and development into other battery chemistries, such as lithium-sulfur and solid-state batteries, with the goals of further enhancing performance and lowering costs.[24]

The electric motors that are used in EVs are becoming more efficient and compact, which enables them to provide more power in a smaller size. EVs are expected to hit the market in the next few years. In addition, developments in the algorithmic control of motors have led to improvements in both performance and efficiency.

The availability of charging infrastructure is growing, as more public charging stations are being created and as prices for home charging systems continue to fall. The technology behind rapid charging is also advancing, which will cut the amount of time needed to charge an electric vehicle and make it more convenient to use.

Electric vehicles are currently undergoing the process of integrating with autonomous driving technology, which will allow for increased fuel efficiency and safety. Some manufacturers of electric vehicles (EVs) are already introducing features that allow for partially autonomous driving, such as adaptive cruise control and lane-keeping assistance.[25]

1.6.1 Lightweight Materials

In order to reduce the overall weight of electric vehicles (EVs) and boost their fuel efficiency, automobile manufacturers are turning to lightweight materials like carbon fiber and aluminium. This may result in an increase in performance and range, in addition to a reduction in the amount of energy required for operation.[26]

In general, the current level of electric vehicle technology is progressing at a quick pace, and there is a substantial amount of space for growth and improvement in the years to come.

1.7 Energy-Efficient Structures

The increased availability of charging infrastructure and the environmentally benign character of electric vehicles (EVs) are two factors that are contributing to the rise in the popularity of EVs. However, one of the most significant obstacles that stand in the way of the general adoption of electric vehicles is the restricted range of their batteries, which is partly controlled by how efficiently they use energy.[27]

In the context of electric vehicles (EVs), "energy-efficient structures" refers to designs and technical processes that cut down on the amount of energy needed to run the vehicle. This can be accomplished by reducing the overall weight of the vehicle, enhancing its aerodynamics, maximizing the performance of its powertrain, and minimizing the amount of energy that is lost as a result of friction and other reasons.

Creating structures for electric vehicles (EVs) that are both energy efficient and lightweight involves multidisciplinary knowledge in fields such as mechanical engineering, materials science, electrical engineering, and computer science. Research in this field focuses on discovering novel materials and manufacturing techniques, as well as improving the efficiency of already existing components like motors, batteries, and power electronics, in order to meet the growing demand for these technologies.[28]

Increasing the energy efficiency of electric cars (EVs) can assist to extend their driving range and lower their operating costs, which in turn makes EVs more competitive with conventional automobiles that use internal combustion engines. In addition, electric vehicles that are efficient in terms of energy use can contribute to the reduction of greenhouse gas emissions and the improvement of air quality, which makes them an important instrument for the mitigation of the effects of climate change.[29]

1.7.1 Parameters of Energy-Efficient Structure

- **Materials with a Low Specific Gravity:** Lightweight materials are one technique to increase the energy efficiency of an electric vehicle (EV). This is something that can be accomplished by the utilization of lightweight materials like carbon fiber, aluminium, or high-strength steel. These materials have the potential to help minimize the amount of energy necessary to accelerate, brake, and climb slopes.[30]
- **Aerodynamic Drag:** The reduction of aerodynamic drag is another method that may be used to increase energy efficiency through the use of aerodynamic design. This can be accomplished in a variety of ways, including streamlining

the design of the body, improving the underbody panels, and taking additional steps. If there is less drag, then there will be less need for energy to maintain a certain speed, which will result in an increase in the vehicle's range.[31]

- **Energy-efficient accessories:** Electric vehicle (EV) accessories such as air conditioning, heating, and lighting can use a large amount of energy. Energy-efficient accessories can help reduce this consumption. The utilization of designs that are more energy-efficient for these components can contribute to the total reduction of energy usage.

There are many alternative energy-efficient structures and technologies that may be utilised to improve the efficiency of electric vehicles, and manufacturers are always inventing new methods to increase the range of EVs while simultaneously reducing the amount of energy they require to operate.[32]

1.7.2 Benefits of Energy-Efficient Structures

In general, buildings that are efficient in their use of energy can confer a number of advantages on electric vehicles. These advantages might vary from enhanced range and performance to decreased running costs and less of an impact on the environment. As a consequence of this, manufacturers are consistently working on the development of innovative technologies and designs in order to enhance the effectiveness of EVs and make them more suitable for day-to-day use.[33], [34]

1.7.3 Challenges Involved in Designing an Energy-Efficient Structure

The task of developing a framework that is both energy-efficient and suitable for electric vehicles (EVs) can be difficult. The following are some of the most important problems that need to be solved:

Constructing that is both energy efficient and aesthetically pleasing frequently necessitates making compromises between various competing objectives. For instance, reducing weight can enhance energy efficiency, but this often comes at the expense of other considerations like as safety, durability, or cost.

The integration of several components is typically required for energy-efficient constructions. These components can include things like lightweight materials, aerodynamic designs, and efficient powertrains. To ensure that these parts can function efficiently together after they have been integrated, careful planning and engineering are required.

Due to the usage of specialized materials and manufacturing processes, energy-efficient structures sometimes have a higher production cost than conventional designs. This is because of the increased demand for these buildings. This may cause EVs to be more expensive for customers, which in turn may slow the adoption of EVs.Producing structures that are efficient with energy typically requires the use of specialized manufacturing methods and equipment. This can add complexity to the production process, which can in turn lead to a rise in prices.

Energy-efficient structures are held to the same stringent safety requirements as conventionally designed buildings. However, the vehicle's safety performance and crashworthiness can be negatively impacted by either reducing its weight or making changes to its aerodynamics.

In order to be considered energy efficient, a building must also have a long lifespan and be able to resist the rigors of regular use, such as vibration, impact, and being exposed to the elements. To ensure that anything will last for a long time, it is generally necessary to use specialized materials and production methods.[35]

1.8 Problem Statement

The Delta structure for three-wheeled vehicles could be replaced with more efficient structures like Tadpole. The tadpole structure is optimized to reduce weight and increase strength. Also, the crashworthiness of the vehicle will be optimized to increase driver safety. To reduce toppling, rollover, etc. the design of these vehicles can be optimized by varying parameters like wheel suspension and steering geometry. This tadpole vehicle is integrated with level-one autonomy for maximizing performance.

1.9 Aim

This project aims to design a tadpole structure for three-wheeled electric vehicles as an energy-efficient structure. The chassis of the vehicle is designed and optimized for parameters such as weight, strength, and crashworthiness. Also, parameters of suspension and steering geometries like wheel diameter, wheelbase, Track width, Camber, Caster, KPI, etc, would be optimized and tested to identify the most efficient combination. The best-performing structure and geometries will be chosen to manufacture a prototype. Pilot testing of the prototype will be performed to assess its performance.

1.10 Objectives of the Proposed Study

1. To design an electric vehicle with an innovative tadpole structure by considering parameters wheel diameter, wheelbase, track width, steering geometries, suspension geometries, weight, crashworthiness, etc.
2. To design a prototype of an electric vehicle and conduct pilot testing on city roads. Its characteristics such as air drag, cornering stability, energy efficiency, acceleration, braking performance, driver comfort, etc. will be evaluated.

1.11 Scope

The scope of this project is to design an electric vehicle with a Tadpole structure that can achieve maximum mileage and battery life while ensuring stability during cornering. The Tadpole structure will be optimized by testing the combinations of varying wheel diameter, vehicle weight, vehicle height, location of the center of gravity, tumbling speed, etc. A 3D model of the proposed design will be prepared. Various types of roads will also be simulated with varying friction co-efficient.

The most efficient combination of suspension and steering mechanism will be identified by evaluating various parameters for front-wheel and rear-wheel. Testing of the proposed design on a simulated cement road will be performed. The optimal structure design and steering-suspension geometries will be used to manufacture a prototype. Pilot testing of the prototype will be performed on the streets and parameters such as drag coefficient, maximum speed, maximum acceleration, braking efficiency, and driver comfort will be observed.

1.12 Hypothesis

H0: Optimization of wheel diameter, wheelbase, track width, vehicle height, vehicle weight, and location of the center of gravity will affect the performance of the vehicle.

H1: Variation of suspension and steering parameters affects the performance of the electric vehicle.

REVIEW OF LITERATURE

2.1 Three-Wheeled Vehicle

Three-wheeled motorized rickshaws (3W-MR) are a popular means of transport for people in developing countries such as India and Pakistan. Such 3W-MRs are also used to deliver small quantities of goods over short distances. However, despite being a popular means of transportation, not much analysis has been performed on the injury severity of 3W-MRs. To address this issue Ijaz et al. has analyzed the crash data (from 2017 to 2019) collected for Rawalpindi city, Pakistan, using three machine learning models. Decision Tree (DT), Decision Jungle (DJ), and Random Forest (RT) algorithms were trained using the previously mentioned dataset that documented data from 2743 crashes causing 258 casualties. The three models were trained to predict the severity of injury for a 3W-MR crash. Employing 10-fold cross-validation, the DJ algorithm achieved the highest accuracy of 83.7 %. Spearman correlation analysis was performed to identify factors that could increase the severity of such crashes, such as lighting conditions, weather conditions, etc.[36]

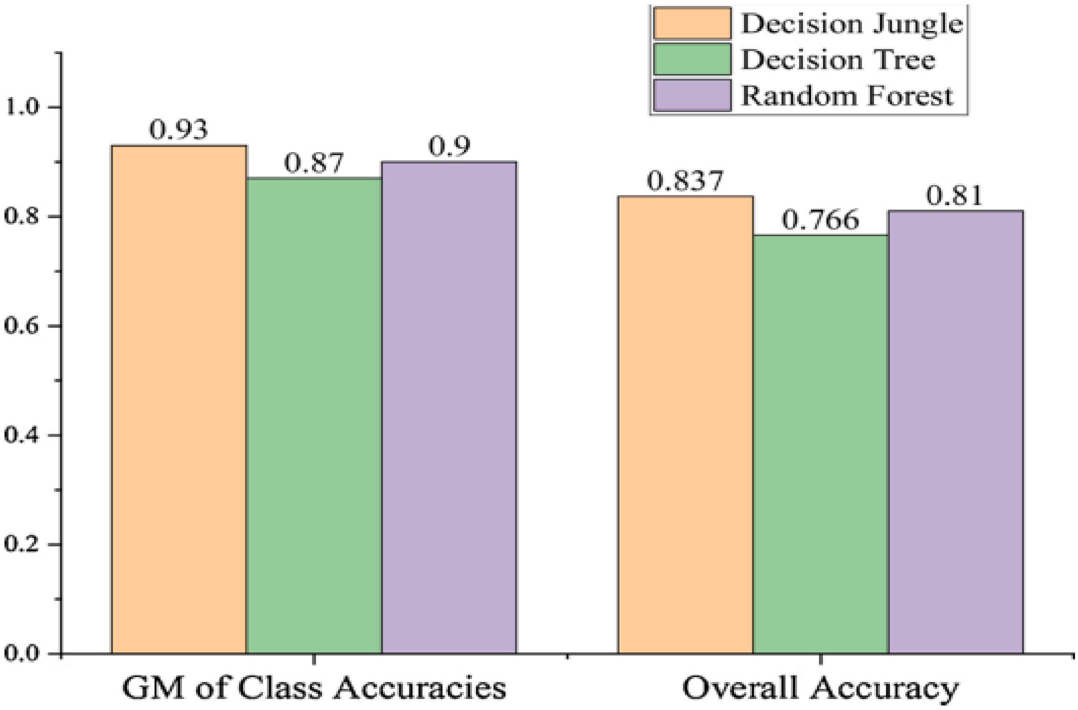


Fig. 7 : Performance of the three trained models by Ijaz et al. [36]. Decision jungle obtained highest average accuracy of 81%

2.2 Concept of tadpole structure

The production of three-wheeled chassis is rare as compared to the four-wheeled chassis. Palanivendhan et al. [8] proposed the chassis design for three-wheeled vehicles. A tadpole-shaped structure was used with two front wheels and one rear wheel. Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) were used in the design and evaluation of the chassis. The vehicle won't lean while steering unlike two-wheeled vehicles and its steering is based on rack and pinion. The maximum speed that is supported by the chassis is 80 kmph. To avoid topping over, the vehicle had a low center of gravity hence the ground clearance was kept low. A rear-engine enabled rear-drive mechanism was used. The chassis would be manufactured with Mild Steel providing it strength while keeping its weight low. Due to space being available above the engine in the rear, the vehicle can have a battery-powered electric motor placed in the rear.[37]

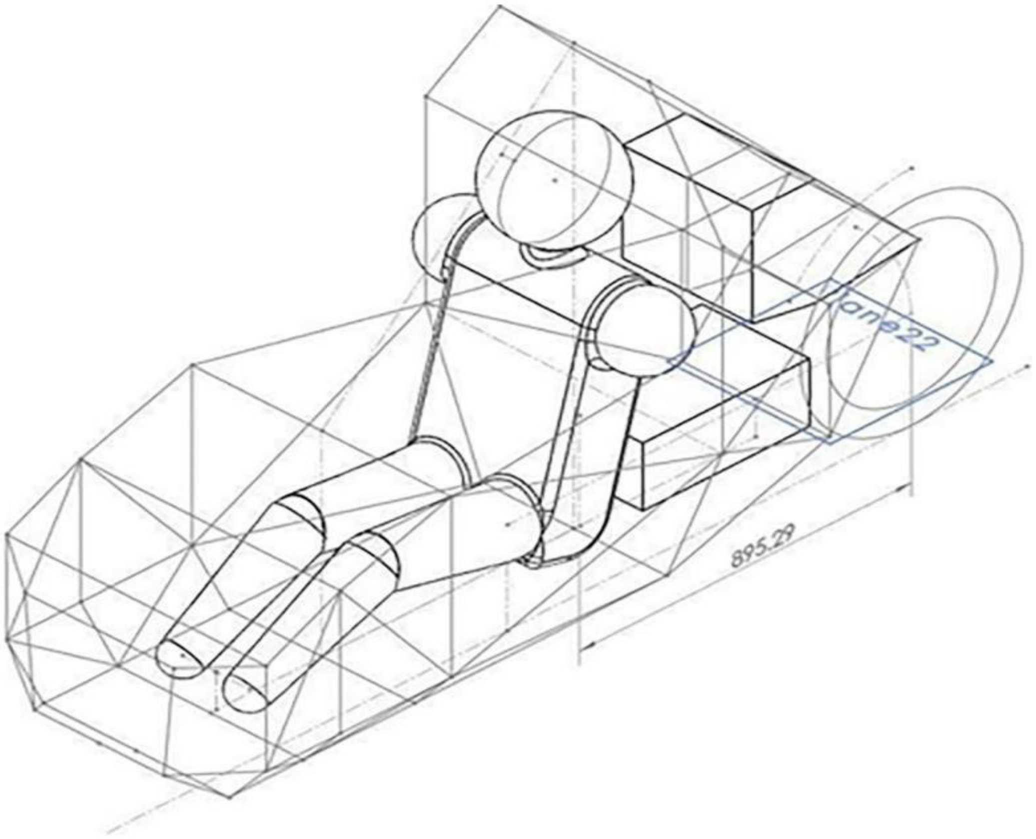


Fig. 8 : Conceptual Design of Structure

To reduce the number of accidents caused by two-wheelers a three-wheeled vehicle can be used which has a slower top speed and improved stability due to the presence of three wheels. However, analysis of the effects of passenger loading on such vehicles needs to be performed to ensure the safety of the occupants. Sunday et al.[38] has analyzed the variation in the location of the center of gravity due to the varying number of passengers. An increase in the load of the vehicle beyond 5410 N reduces the stability factor of three-wheeled, unlike their four-wheel counterparts. As the vehicle is driven by a rear-engine large weight transfer occurs during braking. Static Stability Factor (SSF), and weight on the front and back wheel are inversely proportional to the number of occupants. The height of the center of gravity increases with each increase in the number of passengers.

2.3 Corner Module Design

Increasing urban traffic density and increasing urban population has led to narrower roads in cities and frequent traffic jams. Urban vehicles are a viable solution for urban transportation as these vehicles are narrow, require less space than conventional vehicles, and are generally powered by electric batteries. Three-wheeled vehicles are a popular choice for transportation in the cities. However these vehicles suffer from a limited amount of cargo space, and passenger space, as they are narrower than their four-wheeled counterparts. To address this issue, Waters et al.[39] have proposed the design of a corner module that can be attached to three-wheeled vehicles. Corner modules also increase the handling capabilities of the vehicle. They have proposed the use of an active camber mechanism that enhances the turning stability of the vehicle while also maintaining a small and compact design. Their proposed design cambers the front wheels to -15^0 during turning, which lowers the center of gravity by increasing the track width. Two actuators were used to correct the orientation of the wheels of the vehicles. The mechanical linkage between the front left and right wheels is disconnected to increase the cabin space with the motor being attached to the rear wheel. Regenerative braking could also be performed in combination with disc brakes integrated into the corner module.[2]

2.4 Tadpole Electric Vehicle

The battery life of these vehicles limits the distance that can be traveled using such vehicles. The heavier the vehicle, the more electric power is required to drive it. Hence, instead of the standard four-wheeled design, an innovative lightweight three-wheeled design can be used to increase the mileage of electric vehicles. However, these vehicles can only carry a single passenger generally. Hence they are ideal for traveling short distances. Nabil et al.[40] have proposed a tadpole-based three-wheeled vehicle that operates on a battery. Their design focuses on improving aerodynamics and reducing the vehicle's weight.

2.5 Components of Tadpole EV

1. **Chassis/Frame:** The vehicle has three wheels that all lean together with the vehicle's body. The single rear drive wheel has an electric BLDC motor to drive the vehicle. This configuration simplifies the rear chassis and drive train design. This meant that need to build the frame to match the required vehicle subsystems.

2. **Steering System:** The most conventional steering arrangement allows a driver to turn the front wheels of a vehicle using a hand–operated steering wheel positioned in front of the driver. The steering wheel is attached to a steering column, which is linked to rods, pivots, and gears that allow the driver to change the direction of the front wheels. Other arrangements are sometimes found on different types of vehicles; for example, a tiller or rear-wheel steering. Tracked vehicles such as bulldozers and tanks usually employ differential steering, where the tracks are made to move at different speeds or even in opposite directions, using clutches and brakes, to achieve a change of direction.[37]

3. **Front A-arms:** A-Arms are the main components of the suspension geometry and are made with the same material with which the frame is made. Short A-arms in length are compact but bigger A-arms will make a very wide vehicle. The control arms will attach to the frame using a deep-grove ball bearing and high tensile bolts.[41]

4. **Upright:** The upright is the part that connects the wheels with the control A-arms, it provides the wheels to be mounted onto them and on the other hand it is connected to the upper and lower control arms with the help of a ball joint called rod end bearings.Upright is an important part in a vehicle, as all the important alignment angles are given to the vehicle through the hub. The position of upper and lower mounting points for the rod end bearings on the

hub determines the value of Kingpin inclination which is very important as it directly affects the handling and performance of the vehicle. [41]

5. **Rear swing arm:** What is a swing arm or "swinging arm"? It was first called a swing fork or hinged fork. It is a mechanical device that connects the back wheel of a motorbike to the body of the bike and lets it turn vertically. It's the main part of the back suspension on most modern motorcycles and ATVs. It holds the rear axle in place and pivots to absorb shocks and the rider's movements when speeding up or slowing down.[42]

6. **Braking System:** One of the most important parts of any car is the brakes. Without them, you can't really drive. It's clear that a stop, which slows down a car, shouldn't be too weak. But it's also important that when you build a brake system, it's not too good at stopping. If the brakes were too strong, we would always be at risk of getting hurt when the bus or car suddenly applied the brakes. If the driver stops quickly or hard, the passenger could hit the front seat or something else in the car. So, a stop device that works too well is not needed.[43]

7. **Drive Train (Transmission):** An electric vehicle's transmission system has a gearbox that changes the ratios of rotation between the drive motor and the drive wheels, a differential that takes power from the gearbox to make up for differences in the speed of rotation of the drive wheels, and two wheel axles that send power from the differential to the drive wheels. The gearbox has a case that is attached to the body of the car. When an electric car goes on a bumpy road and makes a turn, the frame can move up and down and left and right in relation to the gearbox body. This makes the car less likely to bounce and less likely to tilt or roll due to rotational force, which makes driving more fun and stable.[44]

8. **Battery**: EVs use different kinds of batteries, but lithium-ion (Li-ion) batteries are the most popular because they have a high energy density, last longer, and have a low self-discharge rate. Nickel-Metal Hydride (NiMH) and Lead-Acid batteries are two other types, but they are not used as much in current EVs. [45]

2.6 Chassis

In this context, the term "chassis" specifically refers to the structural frame of the car, excluding the suspension and wheel assemblies. The fundamental prerequisites for the structural chassis are as follows:

- Adherence to pertinent formula regulations.
- Provision of a secure placement for all car components, including the engine, fuel tank, battery, etc.
- Furnishing adequate strength and rigidity to withstand the forces generated by the suspension and steering components during high-g force acceleration, braking, and cornering.
- The primary purpose of the structure is to ensure the safety of the driver in the event of a collision and to provide a stable attachment point for the safety harness.
- Additionally, it serves to reinforce the wings and other bodywork, particularly when exposed to significant aerodynamic forces.

The chassis structure is comparable to the skeletal system in humans, serving to maintain the proper positioning of important organs and providing support for tendons and muscles, enabling efficient movement and functionality. In the past five decades, there have primarily been two prominent types of chassis structure.[46]

The space-frame is a three-dimensional structure composed of tubular elements. Subsequently, non-structural bodywork is applied to cover it. The monocoque is composed of plates and shells that are assembled to create a sealed box or cylinder. The monocoque can therefore serve as a substitute for some parts of the bodywork. Contemporary monocoques are consistently constructed using carbon fibre composite materials. Another noteworthy form is stressed-skin structure, which combines elements of the preceding two forms. This term can serve as an alternate designation for a monocoque structure. However, in this context, it refers to a space-frame design in which certain components are substituted or augmented by a fixed structural covering attached to the tubes.[47]

2.6.1 Wheelbase and Track Width

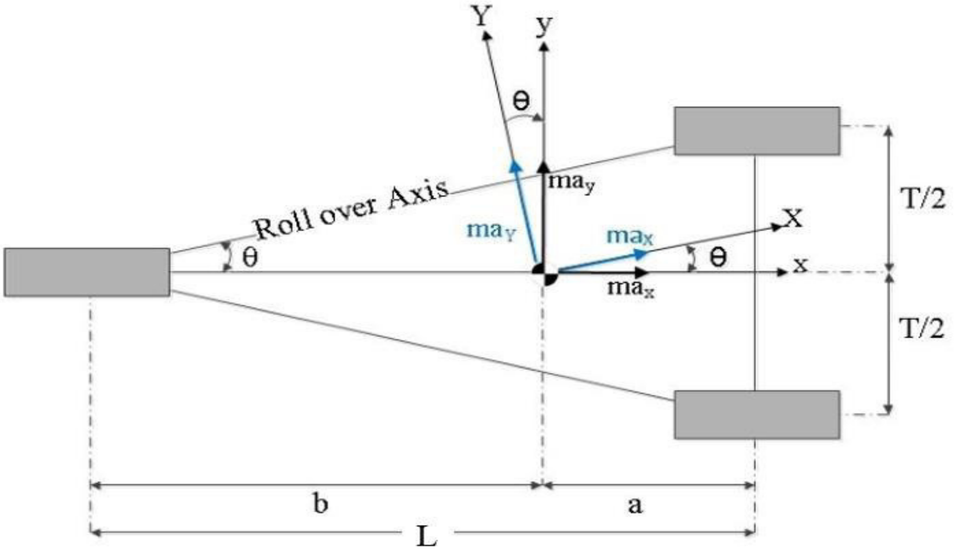


Fig.9 : Wheel Base and Track Width

Wheelbase and Track Width are crucial dimensions in vehicle design, affecting the vehicle's handling, stability, and aesthetics. Wheelbase is the distance between the centers of the front and rear wheels and is measured along the vehicle's length. It affects vehicle dynamics, such as ride comfort, handling, and stability. Longer wheelbases provide smoother rides, while shorter ones make a vehicle more maneuverable and stable. Different types of vehicles have varying wheelbase lengths based on their intended use, such as sports cars for agility and luxury sedans for smoother rides. Track width is the distance between the left and right wheels on the same axle, measured from the center of the tire tread on one wheel to the center of the tire tread on the opposite wheel. Its impact on vehicle dynamics is significant, with wider track widths enhancing stability, handling, and aesthetics. Sports cars and high-performance vehicles typically have wider track widths for improved handling and stability, while utility vehicles may have narrower tracks for better off-road maneuverability.[48]

2.6.2 Center of Gravity

Observe a 4-Wheeler from the rear, as depicted on the right side. When the car is turning left, a centrifugal force acts on the center of gravity, while the weight of the vehicle creates a downward gravitational force.

The centrifugal force exerts a tendency to cause the vehicle to roll towards the right, pivoting around an imaginary point located beneath the right tires. On the other hand, the gravitational force acts to prevent the vehicle from rolling over.

The combination of centrifugal and gravitational forces appears to collaborate in shifting the center of gravity towards this hypothetical point. If the height of the center of gravity exceeds that of the half-track, the resulting force will be directed towards the imaginary point and cause the vehicle to overturn in a curved trajectory. [37], [38]

The stability of a 4-Wheeler against rollover is determined by the ratio of its center of gravity (CG) height to its half-track. The center of gravity height for a sports car should be minimized in order to enhance rollover safety. Sport-utility 4X4s possess more height compared to family sedans. This elucidates the reason behind the increased occurrence of rollovers in these cars.

2.7 Steering System

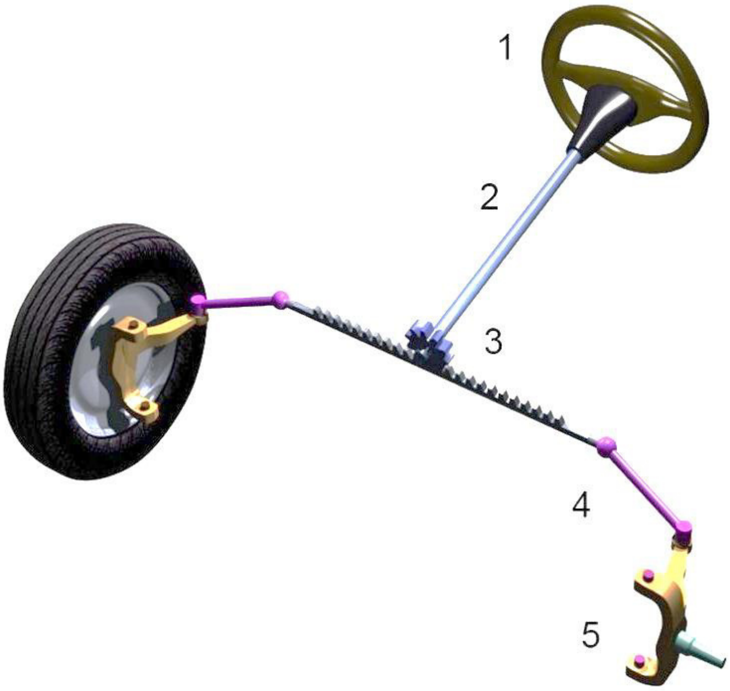


Fig. 10 : Steering System Components (1. Steering Wheel, 2. Column, 3. Rack & Pinion, 4. Tie Rod, 5. Upright)

Steering in vehicles is a fundamental mechanism that enables the driver to guide the vehicle in the desired direction. Steering geometry is a critical aspect of vehicle design that influences how a vehicle handles and responds to driver inputs. It involves several key parameters:[37]

- **Camber:** Camber refers to the angular displacement of the wheels in relation to the vertical axis as seen from the frontal perspective of the vehicle. Positive camber refers to a situation where the upper portion of the wheel is inclined perpendicular to the vehicle, and negative camber indicates a perpendicular deviation towards the vehicle. The impact of camber on cornering performance and tire wear is significant.
- **Caster**: The term "caster" refers to the angle formed by the pivot point of the steering system when seen from the side of the vehicle. The use of a positive caster, characterized by an inclined pivot point towards the rear of the vehicle, contributes to enhanced straight-line stability and improved cornering efficacy. The negative caster is hardly used.
- **Toe**: The term "toe" refers to the orientation of the wheels in relation to the central axis of the vehicle. Toe-in refers to a tight proximity between the fronts of the wheels compared to the rears, whilst toe-out denotes the reverse. The tire wear, straight-line stability, and cornering capabilities are influenced by the toe settings.
- **Ackermann Principle**: This principle relates to the geometry of the steering linkages in a way that allows the wheels to follow the correct arc during a turn. Ideally, the inside wheel turns at a sharper angle than the outside wheel, as it has a smaller radius to cover. This helps reduce tire scrubbing and improves handling.
- **Steering Ratio**: The aforementioned ratio represents the relationship between the rotational angle of the steering wheel and the rotational angle of the wheels. A greater ratio necessitates a greater amount of steering wheel rotation, resulting in enhanced precision control during high-speed maneuvers. A decreased ratio leads to a more rapid reaction.

- **Kingpin Inclination (KPI)**: This is the angle formed by a line drawn through the upper and lower ball joints of the wheel's steering axis, relative to vertical. KPI influences steering feel and the vehicle’s self-centering tendency.
- **Scrub Radius**: This is the distance between where the SAI intersects the ground and the center of the tire's contact patch. It affects steering feel and response, particularly during braking.
- **Wheel Offset**: This is the distance from the wheel's mounting surface to the centerline of the wheel. It affects the scrub radius and overall vehicle handling.
- **Bump Steer**: This is a condition where the wheels steer themselves as they move up and down. It's ideally minimized to keep the vehicle stable, especially over bumps or during hard cornering.
- **Roll Center**: This is the point around which the body of the vehicle rolls in cornering. The height of the roll center affects the vehicle’s body roll and overall stability in turns.

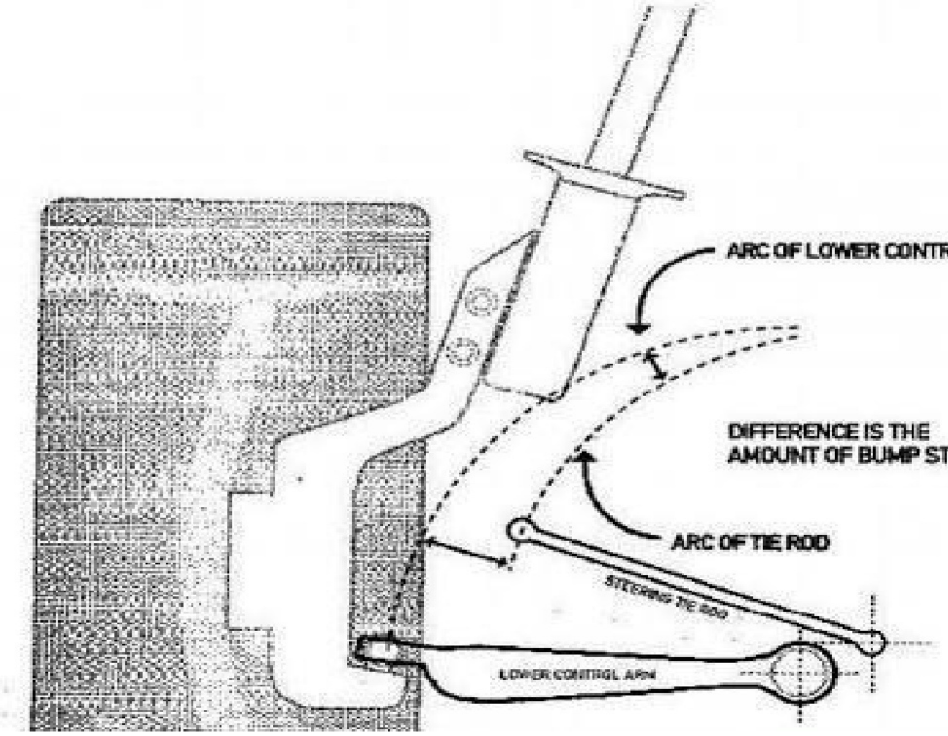


Fig. 11 : Bump Steer

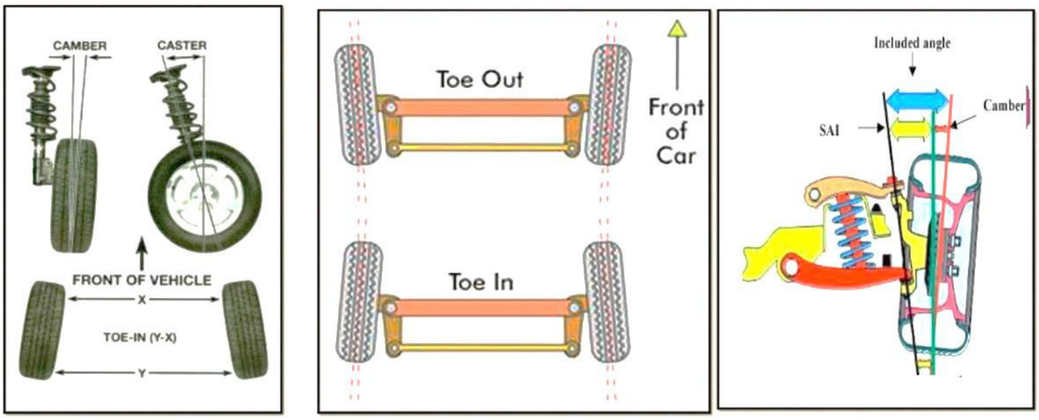


Fig. 12 : Steering Geometry (Camber, Caster, Toe, KPI)

2.7.1 Rollover Stability

In a 3-wheeler, the vehicle rolls from the unique wheel to the other symmetrical wheel. Despite a higher center of gravity, the 4-Wheeler's rollover distance is shorter for the same length and track as 4-Wheeler. CG height is proportionally larger, reducing rollover safety in curves.

A 3-Wheeler in a curve may also be susceptible to braking or accelerating forces. The lateral centrifugal force may enhance 3-Wheeler rollover possibilities. In the case of the single-front-wheel 3-Wheeler, above right, braking to the left will Increase 3-Wheeler's rollover risk. [49], [50]

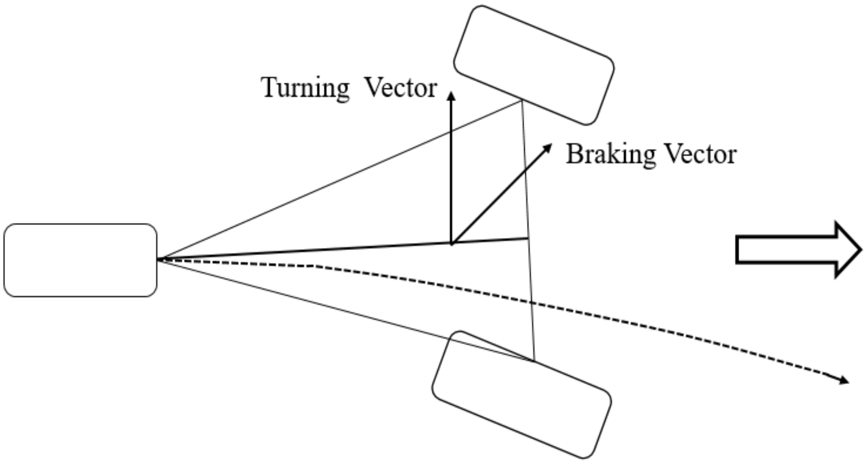


Fig. 13 : Turning of Tadpole Vehicle

2.7.2 Oversteer/ Understeer

Single-front-wheel configuration oversteers, single-rear-wheel layout understeers. Single rear wheel arrangement is popular by lay drivers because they like understeer.

Braking and accelerating turns are another factor. Braking turns destabilise single front-wheel vehicles, whereas accelerating turns destabilise single rear-wheel vehicles. Because braking forces can be bigger than acceleration forces (the adhesion limit of all three wheels determines maximum braking force, rather than two or one wheel in acceleration), the single rear wheel design has the benefit. Single rear wheel arrangement is preferred for high-performance consumer vehicles driven by non-professionals. Racers prefer oversteer than understeer. Oversteer allows a talented driver to undertake extreme moves that an understeering car cannot. By adjusting tyre size and pressure, a single-front-wheel vehicle can be constructed for a neutral steer with oversteer at the limit of adhesion. Design subtleties, driver preferences, and talents all matter. [51], [52]

2.8 Suspension Geometry

The geometry of a wheel suspension delineates the configuration and arrangement of pivot points and system lines. Therefore, the manner in which the forces within the tires are transmitted to the vehicle's mass via the upright and wishbones is determined by the geometry.[53]

Misconceptions regarding the kinematics of this force transmission may lead to the selection of an inappropriate geometry. This may result in geometry-related issues, but the engineer is frequently oblivious to the potential root cause. Certain issues, such as excessive roll or unwanted self-steering during bumps (bump steer), are consequently addressed with anti-roll bar settings, spring rates, and shock absorber rates that are typically inappropriate for the vehicle.[54]

The kingpin The angle of inclination between the steering axis of the upright and a vertical line is referred to as the Inclination and Caster KPI. It is essential for maneuverability in confined areas, where a minimal scrub radius R0 may be required. The direction of the scour radius—positive or negative—is determined by where the steering axis intersects the road. When the scour radius is zero, which occurs during centerpoint steering, the vehicle becomes less stable.

When a steering movement is executed, the KPI angle modifies the vertical position of the stub axle, thereby ensuring stability while proceeding in a straight line. Nevertheless, chassis roll results from the outer tire moving upwards in relation to the sprung mass while the inner wheel descends during cornering. This can result in weighty steering, particularly when substantial quantities of KPI and caster are implemented.[55]

When a wheel is steered around an inclined steering axis, it undergoes a camber change. This change is considered to be within acceptable parameters, provided that the caster angle and KPI angle both remain within the same order of magnitude. In order to ascertain the overall dynamic camber angle, it is necessary to add the camber change and static adjusted camber.[56]

2.9 Rear Swing Arm

A swing arm, alternatively referred to as a swing fork or pivoted fork, is a mechanical component of either one or two sides that facilitates vertical rotation by connecting the rear wheel of a motorcycle to its chassis. It is a pivotal element in the rear suspension of the majority of modern motorcycles and ATVs, supporting the rear axle firmly during rotation in order to mitigate suspension loads and rider-induced vibrations when accelerating or decelerating.[42], [57]

2.9.1 Types of Swing-Arm

Swing-arm motorcycle suspension links the back wheel to the motorbike chassis. Swing arms come in a variety of styles, including:[58]

- **Straight swing arms:** These are the most basic and widely used variety. It is made up of a single straight piece of metal that links the back wheel to the frame.
- **Single-sided swing arms**: These are intended to enable for easy wheel removal for maintenance or repair. It features a single-sided framework that links the wheel to the frame and is often equipped with a hub-center steering mechanism.
- **Dual-sided swing arm**: This form of swing-arm has two arms, one on each side of the wheel, that link the wheel to the frame. This style is more stable than the straight kind and is typically found on heavy-duty motorcycles.
- **Pro-link swing arms:** These are meant to improve suspension performance by utilizing a linkage system between the swing arm and the shock absorber. It enables more accurate suspension settings and enhanced handling.

- **The banana swing arm:** It has a curved form that resembles a banana. Several racing motorcycles employ it to boost aerodynamics and save weight.

Ultimately, the choice of swing-arm type is determined by the vehicle's unique requirements and the rider's preferences.

2.9.2 Wheel Hub

The selection of an appropriate wheel hub for a particular type of car is a challenging task. Luo et al. [48] has analyzed 6 types of generic cars along with 20 types of wheel hubs to identify the most appropriate choice of wheel hub for each type of car. Kansei attributes were identified, evaluation of a match was performed using the ranking method and semantic differential evaluation for the car types and wheel hubs was performed. The match between a wheel hub for each type of car depended on the similarities in the design of both the components. Automobile manufacturers can use this information to offer suitable combinations of wheel hubs with each new car.

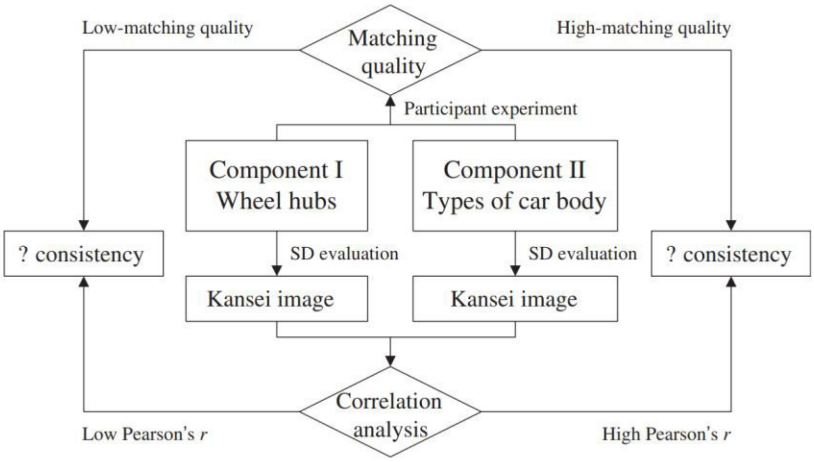


Fig. 14 : Workflow of the matching algorithm proposed by Luo et al. [48]

2.9.3 Motor

BLDC (Brushless DC) motors are alternatively referred to as electronically commutated motors (ECM motors) on account of their reliance on semiconductor switches to facilitate accurate stator winding switching. These synchronous motors are driven by a closed loop controller and are supplied with an AC electric current via an inverter or switching power supply that converts a DC supply into AC. [28], [59]

Ratio of power to engine capacity As a point of reference, the power-to-combustion engine displacement equivalency for electric motors in these vehicle categories is 20.1

cc = 1 kW. This may be utilized to access regulations pertaining to combustion engine equivalents (MS2413 2015). The classification of vehicles frequently employs motor power as a surrogate for, or in conjunction with, maximum speed. Although there is considerable variation in current regulations worldwide, the following are the prevailing speed–power correlations that pertain to these light-duty vehicles. An approximation of the following relationship exists between power and maximal speed: Higher velocities result in a square root of the motor power dictating the top speed, as the aerodynamic drag on a vehicle is proportional to the square of the vehicle's speed. Moreover, greater power is required for larger vehicles, including those with more axles, to achieve equivalent velocities as smaller vehicles.[28]**-**

BLDC motors operate on the same principle as conventional DC motors, namely the Lorentz force law, which states that a force is applied to any current-carrying conductor that is situated in a magnetic field. Due to the action of the reaction force, the magnet will be subjected to an opposing force of equal magnitude. While the permanent magnet rotates, the current-carrying conductor remains stationary in a BLDC motor.

When a supply source electrically switches the stator coils, the device transforms into an electromagnet and initiates the generation of a uniform field within the air gap. Despite the DC source of supply, the process of switching produces an AC voltage waveform that exhibits a trapezoidal shape. The rotor continues to rotate as a result of the interaction force between the electromagnet stator and permanent magnet rotor.[15]

2.10 Battery & Controller

Electric Vehicles (EVs) rely on a battery and controller for performance, efficiency, and usability. The battery, typically lithium-ion, offers a balance between energy density, weight, and recharge cycles. Its characteristics include energy density, durability, and charging time. Advancements in battery technology include solid-state batteries and fast charging batteries.

Controllers in EVs manage the electric motor's power, controlling speed and torque. They come in AC and DC types, with AC controllers providing precise control over motor speed and torque, and DC controllers being simpler and less expensive but less efficient. They have power ratings, efficiency, and support for regenerative braking.

Advancements include integration with vehicle systems for enhanced performance and diagnostics, and smart controllers that incorporate software algorithms for optimized energy use and predictive maintenance. The battery and controller must be integrated into the EV's powertrain, drawing power from the battery based on driver inputs and vehicle conditions. The efficiency and performance of an EV depend on the effective integration of the battery and controller, which is crucial for the vehicle's range, acceleration, top speed, and overall driving experience.[60]

The battery and controller are fundamental to the performance and capabilities of an EV, and ongoing research and development focus on improving efficiency, reducing costs, and enhancing the driving experience.

2.11 Vehicle Dynamics

Vehicle dynamics is the study of how a vehicle responds to various conditions while being driven, focusing on the forces and interactions between the vehicle, the driver, and the road. Key aspects of vehicle dynamics include ride and handling, suspension system, steering dynamics, braking performance, traction and tire dynamics, aerodynamics, weight distribution and center of gravity, powertrain and drivetrain dynamics, vehicle roll, pitch, and yaw, and dynamic load transfer.[47]

Ride and handling involve the vehicle's response to steering, braking, acceleration, and the road surface. Suspension systems absorb shocks from the road surface and maintain tire contact, affecting ride comfort, handling, and overall stability. Steering dynamics involve studying steering mechanisms, steering response, and alignment, affecting directional control and stability. Braking performance involves understanding how a vehicle decelerates and stops, while tire dynamics involve understanding grip, friction, and forces acting on tires, influencing acceleration, braking, and cornering.[61]

Aerodynamics studies how air flows around the vehicle, affecting fuel efficiency, top speed, and stability. Weight distribution and center of gravity impact stability, handling, and cornering ability. Powertrain and drivetrain dynamics involve the transmission of power from the engine to the wheels, and vehicle roll, pitch, and yaw describe rotational movements around the axes. Dynamic load transfer affects grip and stability. Understanding vehicle dynamics is crucial for designing safer, more efficient vehicles, enhancing driving pleasure, and ensuring passenger comfort.[20]

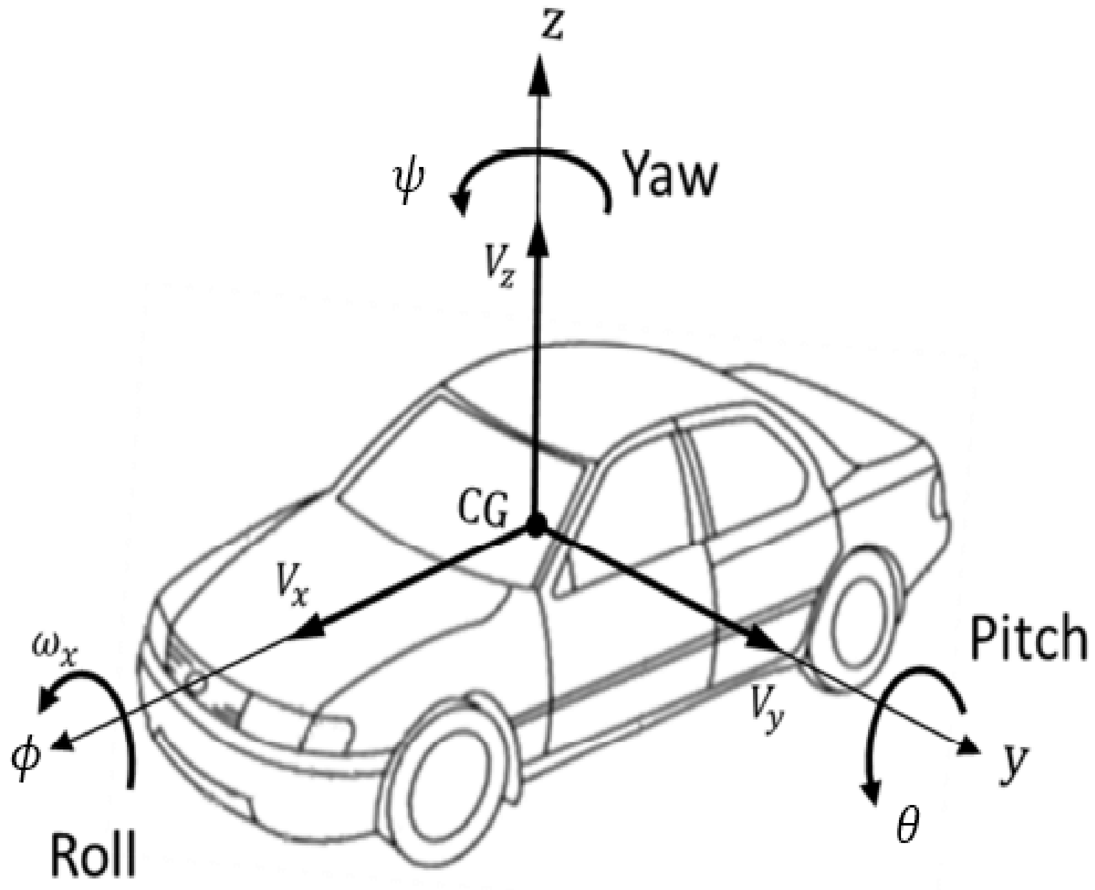


Fig. 15 : Vehicle Dynamics [47], [62]

Each of the three fundamental components entails a type of velocity change or acceleration. This is lateral acceleration during cornering, whereas deceleration can be characterized as negative acceleration. According to Newton's first law of motion, an item in motion will continue to move at the same speed and in the same direction until an external force is applied to it.[62], [63]

Therefore, for the purpose of acceleration or altering direction, the automobile must experience an external force, with the primary origin of this force being at the interface between the tires and the road, often referred to as the tire contact patch. It is evident that external aerodynamic forces are also present and will be addressed subsequently. Therefore, it can be inferred that the capacity of an automobile to increase its speed, decelerate, and alter its trajectory is contingent upon the frictional force generated between the rubber tire and the surface of the road. The force in question is often known as traction or grip, and its optimization is a crucial design factor for a competitive automobile. [64] The classical friction, also known as Coulomb friction, exhibits a straightforward linear correlation between the initial normal force applied and a constant coefficient of friction, denoted as μ.

$$\text{Friction force} = \text{normal load x } \mu$$

Upon closer examination of tire mechanics, it becomes evident that the contact patch between a tire and the road does not adhere to this straightforward principle. Figure 16 illustrates the correlation between the vertical load on the wheel and the maximum lateral grip of a standard racing tire. It also compares this connection to the basic Coulomb friction with a value of 1 (shown by the dotted line).

As the vertical force on the wheel is augmented, the grip also rises, although at a gradually decelerating pace. It is often referred to as tire sensitivity. The understanding of the normal force at each tire contact patch, namely the vertical wheel loads, has significant importance in several facets of racing vehicle design. The purpose of their use is in the assessment of loads within the chassis, braking components, suspension members, transmission, and other relevant areas. Additionally, they serve the purpose of fine-tuning the basic handling and balance of the vehicle. This study aims to examine the static wheel loads and their subsequent variations under the influence of three key racing elements: braking, acceleration, and turning. Initially, it is important to ascertain the precise location of the car's center of mass, often known as the center of gravity. The center of mass refers to the specific location where the whole of the mass may be regarded as being concentrated. Understanding the precise placement of an automobile is crucial for designers, since it directly influences the distribution of weight between the front and back wheels. The vertical distance between the center of mass and the ground has a significant impact on the car's rolling behavior during turns, as well as the weight distribution between the wheels during braking, accelerating, and cornering.[65]

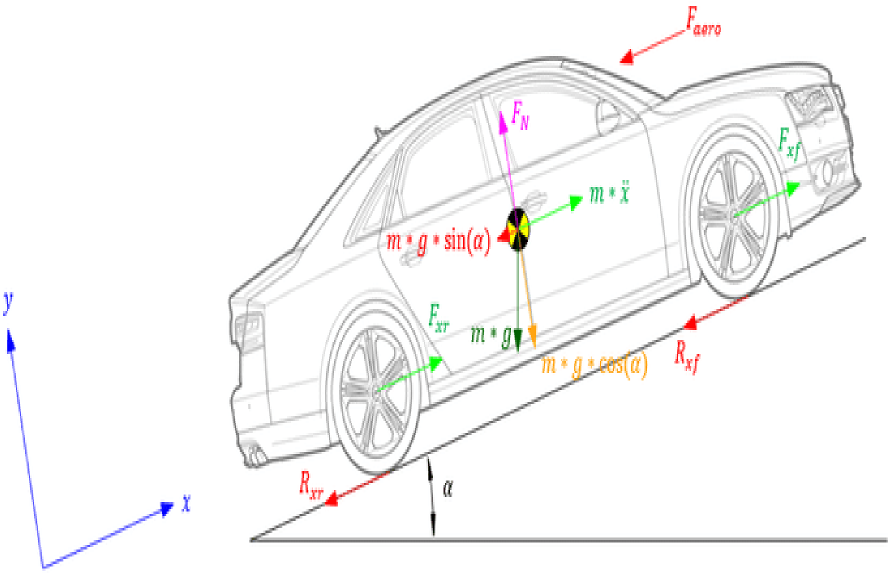


Fig. 16 : Vehicle Forces on Inclination

2.12 Regulations for South Asia for Small Electric Vehicles

2.12.1 Maximum weight and Speed Regulations

These policy suggestions are applicable to all low-speed electric vehicles with 2, 3, and 4 wheels, as long as their gross vehicle weights do not exceed 400kg. In the context of the policy principles outlined in this document, the described vehicles are classified as "submicron" 4-wheeled electric vehicles. It is important to note that these vehicles are not meant to be directly similar to conventional automobiles and are much smaller in size. Therefore, although this research will mostly focus on motorcycles and three-wheeled vehicles, it is worth noting that certain nations may also apply the same standards to low-speed electric four-wheeled vehicles. The speed class permits the following maximum weights:[66]

Table 2.1 : Vehicle Class and Maximum Speed and Vehicle Weights [66]

Class/Category	Top Speed (Kmph)	2-Wheelers	3-Wheelers	4-Wheelers
Pedestrian	Less than 10	40	100	NA
Slow	10-25	40	100	200
Low Speed	25-50	60	200	350
Intermediate	50-100	200	300	400
High Speed	Greater than 100	400	400	400

Here as per regulations, we will select maximum weight for tadpole structure is 300 Kg (3- Wheeler) considering the intermediate speed range.

2.12.2 Maximum Overall Dimension Regulations

The overall dimensions of the three-wheeler shall be within the following limits and the maximum area behind the passenger seat backrest for luggage space is, dimensions l x b in mm i.e. 1400 X 480. [67]

Table 2.2 : Overall Dimensions Limits for 3 – Wheelers

Specification	Dimension (mm)	Dimension (inches)
Length	4000	158
Width	2000	78
Height	2500	98

2.12.3 Motor Selection Regulations

Table 2.3 : Motor Power (W) as Per the Vehicle Speed

Top Speed (Kmph)	2-Wheelers	3-Wheelers	4-Wheelers
Less than 10	NA	NA	NA
10-25	250	300	350
25-50	1000	1500	4000
50-100	5000	5000	15000
Greater than 100	No Limit	No Limit	No Limit

It is important to acknowledge that electric motors have the capability to run at power levels that exceed their rated output for brief durations, often ranging from 30 to 60 seconds. In some goods, a motor with a nominal rating of 250W has the capability to generate power exceeding 500W for a duration of up to one minute. The use of "burst" acceleration or overtaking is often seen and is subject to limitations imposed by the vehicle's controller. Therefore, it is customary to categorize the vehicle according to its "maximum continuous" motor power. [66]

2.13 Canadian Motor Vehicle Rule

According to Standard 505 of the 2003 Canadian Motor Vehicle Safety Regulations, it is stipulated that the height of a motor tricycle's center of mass must not surpass 1.5 times the distance between the center of mass and the closest roll axis. Based on the stipulations mentioned in this rule, it is permissible for the height of the center of gravity to be 1.5 times the distance between the center of gravity and the rollover line. The resultant force has the potential to act in alignment with the imaginary point and curve of the vehicle. This legislation is too broad since it permits the presence of some unsafe vehicles on public roadways.

This new law establishes a framework for defining and regulating motorbikes with two or three wheels. In addition, goodwill producers may persist in substituting single rear wheels with two rear wheels on motorbikes used by goodwill persons who ride cautiously and at a leisurely pace, without exceeding certain limits. According to Article 505 of the recently implemented Canadian standard, it is stipulated that the total weight of a motor tricycle or three-wheeled vehicle, as determined by measuring the weight at the tire-ground interfaces, should fall within the range of 25% to 70% of the vehicle's loaded weight. [47]

2.14 SAE Driver Ergonomics

The SAE 30th percentile male model is a standardized anthropometric representation used in automotive design and ergonomics to represent the physical characteristics of a male, larger than 30% of the male population but smaller than 70%. It is crucial for designing vehicle interiors and control layouts to ensure comfort, safety, and accessibility for a significant portion of the male population. Key characteristics include height and weight, body proportions, optimal seating position, visibility, reach and accessibility, ergonomic comfort, and safety considerations. This model is part of a spectrum of models that cater to diverse body sizes and shapes.[61]

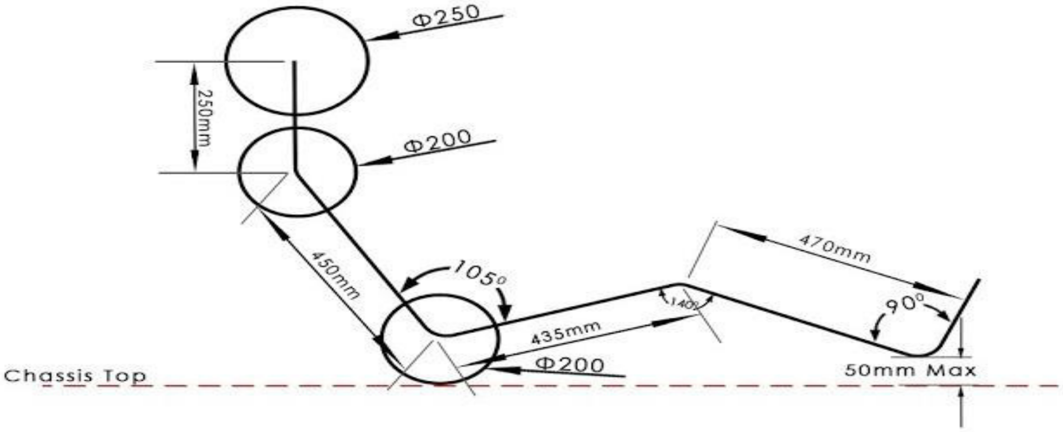


Figure 17 : SAE 30TH Percentile Male Model Driver Ergonomics

2.15 Design Approach

2.15.1 System Light Weight Design

System lightweight design is the process of putting together multiple parts or functions into a single part or system to make an assembly lighter. The strategies for making things lighter, such as material lightweight design and lightweight structure design are parts of lightweight system design.[68] The reduction in energy usage in cars is now being driven by the use of lightweight design. The performance of parts for automotive applications may be enhanced by using design techniques for lightweight components, strategies that use materials with desirable particular qualities, and the utilization of hybrid materials.

Material Light Weight Design: This way of designing takes advantage of what the material has to offer. Different materials reach different levels of strength and/or stiffness based on their density and other properties. Material: Lightweight design can be done by using a single material with a high specific property or by combining different materials to take advantage of the best of each. This is called a composite or hybrid.[69]

1. **Structure Light Weight Design:** It is a way to think about making and designing parts by optimizing their topology, shape, and parameters. The goal is to change the shape and form to reduce the weight. The stiffness and structure of an assembly can lead to a light system, so structure lightweight design is a subset of system lightweight design or strength goes up or stays the same.[70]

2.15.2 Generative Design

Generative design is a method that uses algorithms and computer power to create and optimize designs depending on specified goals, restrictions, and inputs. This process involves the creation and optimization of designs. This strategy enables designers and engineers to investigate a vast variety of potential design options and determine the approaches that will produce the greatest results depending on the outcomes that are wanted.[71]

The generative design process generally consists of the following four basic steps:

- **Describing the design's objectives and limitations**: This involves stating the design goals, such as reducing weight or improving performance, as well as any production restrictions or functional requirements that need to be taken into consideration.
- **Generating design options:** Generative design software can generate a wide range of design options based on the defined goals and constraints by utilising computational algorithms and techniques such as artificial intelligence and machine learning. These techniques allow the software to learn from previous designs.[72]
- **Assessing and improving the designs:** When the designs have been developed, they are compared to the predetermined goals and limitations, and the solutions that appear to have the most potential are chosen for future development. [42]

The chosen design is further refined and enhanced by the application of standard design methodologies, and the ultimate product is produced using either traditional or additive manufacturing methods. Generative design has several major advantages, including the capacity to create designs with intricate geometries and designs that are ideal in terms of various factors, such as cost, weight, and strength. Additionally, it can reduce the need for manual data entry and repetitive processes throughout the design stage.[73]

Generative design is utilized in several industries such as aerospace, automotive, and architecture for their product development procedures. It is particularly advantageous in applications where factors like as weight reduction, performance enhancement, and customization improvement are the main priorities. Generative design is a design technique that use algorithms and computational capabilities to create and enhance designs based on preset constraints and objectives. This approach allows designers to explore a diverse range of possible design alternatives and choose the most optimal design solutions by making selections based on the anticipated outcomes. Additive manufacturing and generative design are two technologies that can enhance the design and production of components and final things. Both technologies are mutually beneficial and can be used in conjunction. Generative design enables the generation of designs that are tuned to fully utilize the unique capabilities of 3D printing. This is achieved by exploiting the design autonomy and adaptability provided by additive manufacturing.

Generative design can be employed to create lightweight structures that are optimized for certain load conditions. Consequently, this leads to the creation of components that possess superior durability and efficiency compared to those manufactured by traditional processes. Subsequently, additive manufacturing can be employed to fabricate intricate geometries with exceptional precision and accuracy, facilitating the production of components that would be challenging or unfeasible to manufacture using conventional manufacturing techniques. Additive manufacturing, often known as 3D printing, emerged as a novel manufacturing method in the 1990s.The number 18 is enclosed in square brackets. The integration of additive manufacturing with generative design has the capacity to revolutionize the process of designing and constructing parts and products, enabling us to attain higher levels of efficiency, utility, and innovation.[42]

2.16 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a methodology that enables the estimation of environmental factors and prospective consequences across the entire life cycle of a product, from inception to disposal. The evaluation scope of this assessment encompasses the entire life cycle of the product or its sub-assemblies, beginning with the extraction, processing, manufacturing, transport, use, re-use, and maintenance of the raw materials. It concludes with the product's end-of-life, which can be achieved through recycling back into circulation or disposal in a landfill devoid of any recycling infrastructure . LCA provides a methodical framework for assessing products and processes through the monitoring of primary inputs and outputs, including energy, materials, and emissions. This approach identifies and quantifies the material utilized, as well as the corresponding energy and emissions. [74]

2.17 Autonomous Tadpole Electric Vehicle (ATEV)

One subset of autonomous vehicles developed with Indian roads in mind is the Autonomous Tadpole Electric Vehicle (ATEV). It combines the advantages of an electric vehicle (EV) with those of autonomous driving technology to provide a mode of transportation that is at once practical, secure, and friendly to the environment.[75]

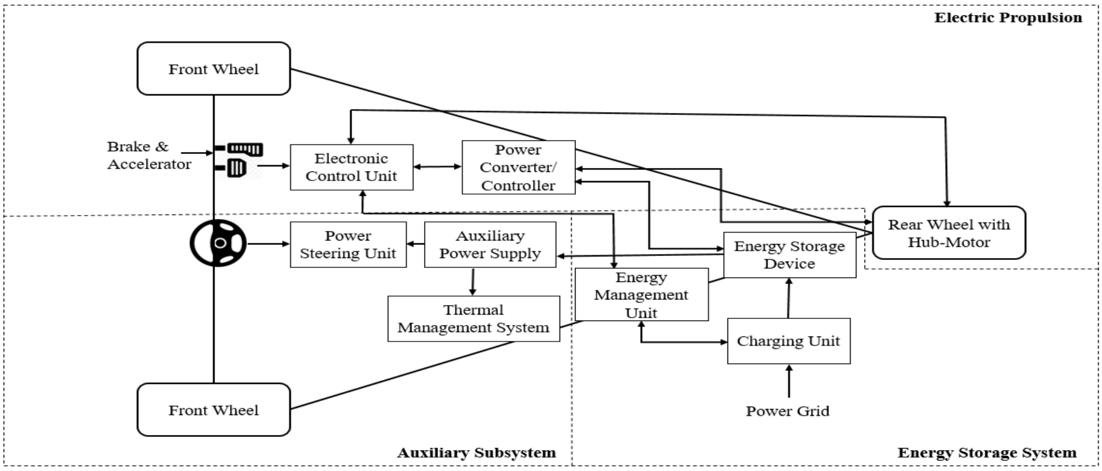


Fig. 18 : ATEV Architecture

Three wheels (two in the front and one in the back) provide stability and manoeuvrability for ATEVs. The improved stability and manoeuvrability of this design make it possible for the vehicle to make its way through tight spaces and heavy traffic with ease. ATEVs are propelled by electric motors that draw power from rechargeable batteries. Electric propulsion has several benefits over traditional internal combustion engines, including fewer exhaust pollutants, less noise pollution, and cheaper running expenses.[25]

ATEVs have the ability to operate without human intervention thanks to their sophisticated sensor systems. These systems include cameras, LiDAR (Light Detection and Ranging), radar, and ultrasonic sensors. With the help of these detectors, the car is able to avoid collisions with people and other vehicles. Autonomous vehicles are made possible by data analysis and decision-making capabilities made possible by high-tech algorithms and systems.[75]

2.18 Indian Road Conditions

2.18.1 Overview of Indian Road Network

India has one of the world's biggest road networks, covering over 5.8 million km. National highways, state highways, district roads, and country roads are all included. However, road quality and conditions vary greatly across the country. The landscape of Indian roadways is diverse, ranging from smooth motorways to badly maintained country roads, mountainous regions, and congested metropolitan centres.[76]

2.18.2 Challenges and Unique Characteristics

Autonomous Tadpole Electric Vehicles (ATEVs) face a number of obstacles on Indian roads that must be considered for their safe and effective functioning. Among these difficulties are:[25]

- **Congestion:** There is typically a great deal of traffic congestion in Indian cities, particularly around rush hour. Autonomous cars have difficulty navigating through congested areas and avoiding accidents caused by irresponsible drivers.
- **Deplorable Road Network:** Despite recent progress, many roads in India are still poorly maintained, with issues such as potholes, uneven pavement, and a lack of clear signage. ATEVs' capacity to navigate and remain stable may be affected by these elements.
- **Irregular Driving Habits:** Drivers in India often engage in a wide variety of irregular driving styles, such as making unexpected lane changes, using non-standard signaling, and ignoring traffic laws. ATEVs need to be prepared to deal with these kinds of situations and to communicate with other cars. Particularly in rural and semi-urban regions, walkers, bikers, and cattle are common sights on Indian highways.
- **Pedestrian and Livestock Presence:** For ATEVs to be able to recognize and react to such shifting factors, sophisticated perceptual systems are required.
- **Challenging Weather Conditions:** India has a wide range of climates, from heavy monsoons and scorching summers to cold, foggy winters in certain areas. ATEVs need to be built to perform dependably in such extreme climates.
- **Narrow and Congested Streets:** Many Indian towns have streets that are both small and crowded, making it difficult for automobiles to move about. All-terrain vehicles (ATEVs) need to be able to navigate these roads without endangering the lives of pedestrians or other motorists.

2.19 EV Performance Characteristics

The performance characteristics of electric vehicles (EVs) are distinct from those of traditional internal combustion engine (ICE) vehicles. These characteristics are influenced by various factors, such as the electric motor, battery technology, vehicle design, and control systems. Key performance characteristics include:

- **Acceleration and Torque:** EVs are known for their instant torque and rapid acceleration. Electric motors can deliver maximum torque from a standstill, unlike ICE vehicles, which need to rev up to reach peak torque. This results in faster and smoother acceleration, making EVs highly responsive.[75]
- **Top Speed:** While EVs excel in acceleration, their top speed is often lower compared to high-performance ICE vehicles, mainly due to limitations in electric motor speed and a focus on range efficiency. However, many modern EVs still offer top speeds that are more than sufficient for everyday driving and highway use.
- **Range:** Range pertains to the extent of a vehicle's capability to traverse on a solitary charge. The factors that significantly influence it include traveling conditions, battery capacity, efficiency, vehicle weight, and aerodynamics. As a result of recent developments in battery technology, the range of electric vehicles has been substantially increased, with many models now offering ranges comparable to those of internal combustion engine vehicles.
- **Regenerative Braking:** Regenerative braking in EVs captures kinetic energy during braking and converts it back to electrical energy, which is then stored in the battery. This not only improves overall efficiency but also extends the driving range and reduces wear on the mechanical braking system.
- **Energy Efficiency:** In general, EVs have a higher energy efficiency than ICE vehicles. A greater proportion of electrical energy is converted from the grid to power at the axles. EVs use energy more efficiently during both acceleration and cruising.
- **Noise and Vibration:** EVs operate much more quietly than ICE vehicles, as electric motors generate less noise and vibration. The lack of engine noise is a distinct characteristic of EVs, contributing to a quieter and smoother driving experience.
- **Maintenance and Reliability:** EVs have fewer moving parts compared to ICE vehicles, which typically results in lower maintenance requirements and potentially higher reliability. The absence of components like the engine,

transmission, fuel injection systems, and exhaust systems reduces the need for regular maintenance.

- **Environmental Impact:** Electric vehicles (EVs) generate no exhaust emissions, rendering them more ecologically sustainable in comparison to internal combustion engine (ICE) vehicles. The overall environmental impact of EVs also includes factors like electricity generation and battery production.
- **Charging Time:** Charging times for EVs vary based on the battery's capacity and the charging infrastructure (from standard outlets to fast-charging stations). While it takes longer to recharge an EV compared to refueling an ICE vehicle, the ability to charge at home or work adds convenience.
- **Driving Dynamics:** The placement of batteries in EVs usually results in a low center of gravity, which can enhance handling and stability. The weight distribution and chassis design are crucial in determining an EV's driving dynamics.

2.20 Research Gaps

The Delta three-wheeled structure is very commonplace. However, the Tadpole structure has not been used in mainstream three-wheeled vehicles. The Tadpole structure is more stable, can achieve higher cornering speed, and has less likelihood of toppling over. A lot of designs for three-wheeled vehicles are proposed but manufacturing and pilot testing of such designs is rare. Electric vehicle implementation of the Tadpole structure has not been made. Autonomous three-wheeled vehicles have not been proposed.

METHODOLOGY

3.1 Introduction

In the contemporary era of technological advancements, the automotive industry is undergoing a pivotal transition, gravitating towards sustainable and eco-friendly transportation solutions. This transition is primarily driven by the escalating concerns over environmental degradation, fossil fuel depletion, and the consequential need for renewable energy sources. Electric vehicles (EVs), emerging as a cornerstone in this paradigm shift, represent not just an alternative to internal combustion engine vehicles but also a step towards a more sustainable future. The focus of this research is to contribute to this evolving landscape by designing an energy-efficient electric vehicle (EV) with a particular emphasis on the tadpole structure, which is a novel and promising approach in the realm of EV design.[77]

3.2 Importance of Designing Energy-Efficient Electric Vehicles

The significance of developing energy-efficient EVs cannot be overstated. The global urgency to reduce greenhouse gas emissions and mitigate climate change is compelling industries to rethink and innovate. Energy-efficient EVs stand out as a crucial solution in this regard. They offer the potential to significantly reduce the carbon footprint associated with transportation, a sector that is one of the largest contributors to global CO2 emissions. By enhancing energy efficiency, these vehicles not only promise a reduced environmental impact but also offer improved performance, longer range, and lower operating costs, making them more appealing to consumers and more viable as a long-term sustainable transportation solution.[78]

3.3 Rationale Behind Focusing on the Tadpole Structure

The tadpole structure, characterized by two wheels at the front and one at the rear, presents a unique design opportunity in the realm of EVs. This research is motivated by the potential advantages of the tadpole configuration, such as improved aerodynamics, enhanced stability, and reduced material usage, which collectively contribute to greater energy efficiency. The choice of this structure is also driven by its novelty and the relatively unexplored nature in the field of EV design, offering a fertile ground for innovation and discovery. The tadpole design potentially allows for a more balanced weight distribution and a lower center of gravity, which are crucial for the safety and performance of EVs.[79]

3.4 Outline of the Methodology

The term "methodology" refers to a system of methods, principles, and rules used in a particular discipline or field of study. It encompasses the theoretical underpinnings of the methods and techniques used to conduct research or carry out a project. In essence, methodology provides a blueprint or guideline for how to approach and solve specific problems or answer questions within that discipline.

In this research generalized methodology is used as follows shown in Figure 19. Detailed descriptions and processes used are elaborated in the lateral part of this chapter.

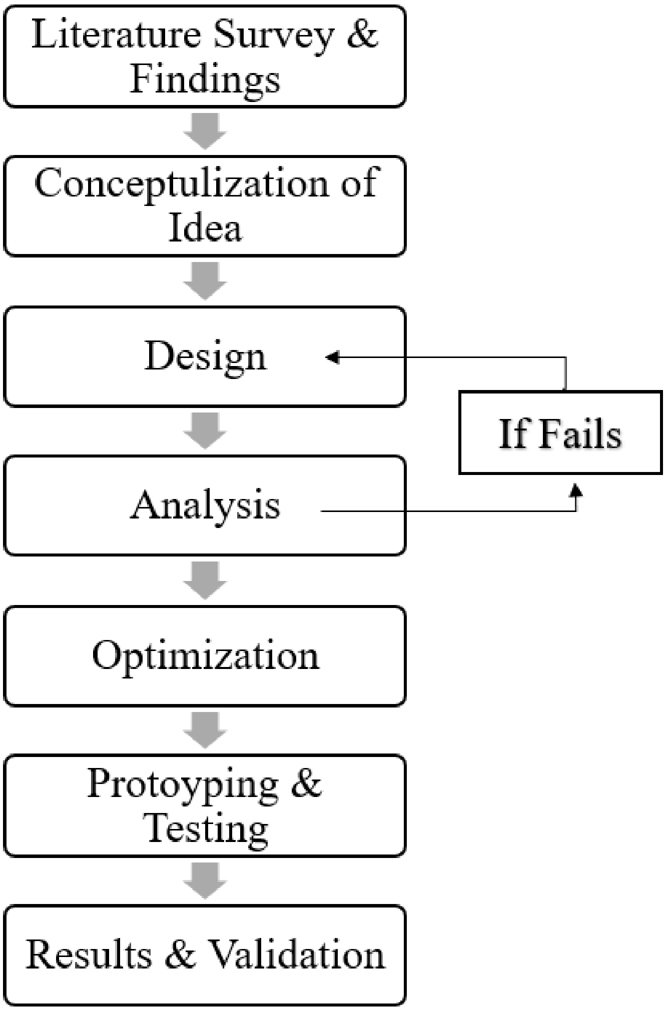


Fig. 19 : Flow Chart of General Methodology Used for Research

This methodology chapter is structured to provide a comprehensive overview of the research process undertaken to design the tadpole-structured EV. It begins with a detailed literature review, establishing the theoretical foundation for the research. This is followed by the initial conceptualization phase, where key requirements for an energy-efficient EV are identified and elaborated upon. The chapter then delves into the design development process, detailing the approach for establishing design parameters, material selection, and the iterative design process. Subsequent chapters cover the simulation and analysis phase, integrating autonomous technology, prototyping, and testing. Finally, the chapter discusses the data collection and empirical analysis, addressing design constraints, and outlines the challenges and limitations encountered during the research. This structured approach ensures a meticulous and holistic development of the energy-efficient tadpole-structured EV.

3.5 Research Design and Approach

3.5.1 Research Design

The methodology adopted for this research is a mixed-methods approach, combining both qualitative and quantitative elements. This multifaceted strategy is crucial for a comprehensive understanding and development of an energy-efficient electric vehicle (EV) with a tadpole structure. The qualitative aspect involves a thorough literature review and conceptual development, providing a deeper understanding of the theoretical underpinnings and design considerations. The quantitative component encompasses the empirical testing and data analysis, offering measurable and statistically significant insights into the performance and efficiency of the design.

3.5.2 Justification for Research Design Choice

The choice of a mixed-methods approach is predicated on the multifaceted nature of vehicle design, which necessitates a balance between theoretical knowledge and empirical validation. Qualitative methods enable a nuanced understanding of complex design concepts and industry trends, while quantitative methods provide hard data for validating hypotheses and design choices. This combination ensures that the research is grounded in solid theoretical foundations while also being rigorously tested and validated through empirical means.

3.6 Literature Review

The literature review forms the backbone of the research, setting the stage for the entire project. It serves to contextualize the research within the current state of knowledge, identify gaps in the existing literature, and guide the subsequent phases of the research. Sources for the literature review include academic journals, industry reports, white papers, and publications from leading automotive and environmental organizations. These sources are meticulously chosen to ensure a comprehensive understanding of the latest advancements and challenges in EV technology, especially focusing on energy efficiency and tadpole structures. The literature is selected based on relevance to the research topic, credibility of the source, and the recency of the publication. Priority is given to peer-reviewed articles and publications from recognized experts in the field.

3.7 Initial Conceptualization

The initial conceptualization phase is where the foundational ideas for the EV design are formulated. This stage involves:

3.7.1 Defining Design Parameters

Key parameters such as vehicle size, weight distribution, aerodynamic profile, and powertrain configuration are established. These parameters are influenced by factors like intended vehicle use, target market, and regulatory standards.

3.7.2 Initial Conceptualization

In this stage from the literature and current industrial scenarios, the primary requirements for an energy-efficient structure for EVs are identified. Also, the parameters affecting performance and majorly affecting the design are considered. Also, Analyzed existing data and regulations to establish performance and efficiency benchmarks to conceptualize the tadpole structure.

3.7.3 Design Approach: Creating an Energy-Efficient EV Structure

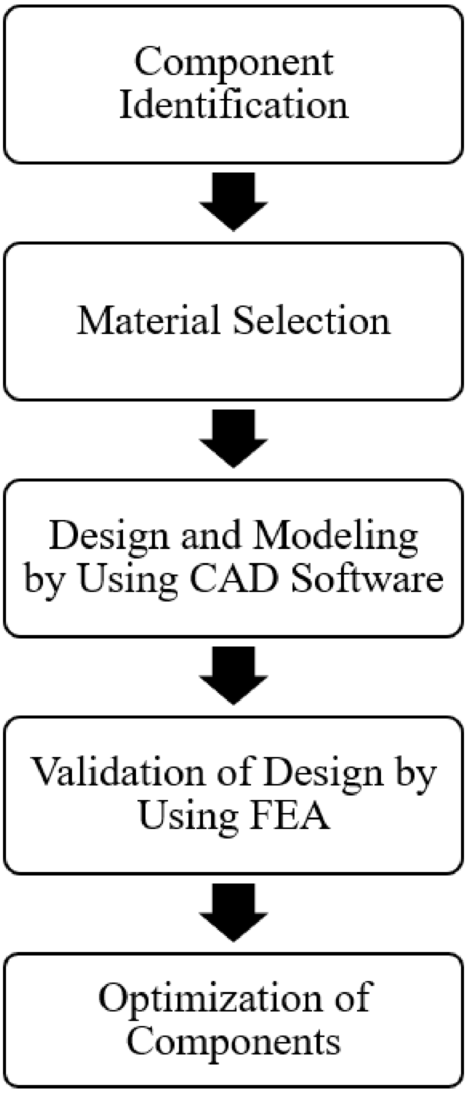


Fig. 20 : Design Approach

3.8 Material Selection

Material selection is a critical decision in this phase, impacting the vehicle's weight, durability, and cost. Factors considered include strength-to-weight ratio, environmental impact, cost, and availability. Materials like lightweight alloys, composites, and recyclable materials are evaluated for their suitability.

3.8.1 Material Selection Criteria

Criteria for material selection are established based on the vehicle's performance requirements, manufacturing capabilities, and sustainability goals. Trade-offs between different materials are carefully evaluated to find the optimal balance.

3.9 Design Development

The design development phase is an iterative process involving constant refinement of the vehicle design. This phase includes:

3.9.1 Establishing Design Parameters

Detailed specifications for each component of the vehicle are developed. This includes the chassis design, motor type, battery capacity, and suspension system. Simulation tools are used to predict the performance and identify potential areas for improvement.

3.9.2 Iterative Design Process

The design undergoes several iterations, each influenced by feedback from simulations, prototype testing, and expert reviews. This iterative process ensures that the final design is not only theoretically sound but also practically viable.

This comprehensive research design and approach ensure that the development of the energy-efficient EV is robust, well-founded, and aligns with both current technological capabilities and future advancements in the field. The mixed-methods approach provides the flexibility and depth needed to explore the complex and evolving landscape of electric vehicle technology.[80]

3.10 Research Design and Approach

The research adopts a mixed-methods approach, integrating qualitative and quantitative elements.

- Qualitative aspect: In-depth literature review and conceptual development.
- Quantitative component: Empirical testing and data analysis.

The research design and approach encompass various methodologies to comprehensively assess and optimize the performance of the electric vehicle. Weight, Camber, and Tire Width Analysis: The research heavily focuses on understanding how the weight of the vehicle, camber (wheel alignment), and tire width impact the vehicle's range and efficiency. This involves both Taguchi and regression analyses to determine the most influential factors and their optimal levels.

3.11 Simulation and Analysis

In the realm of modern vehicle design, especially for electric vehicles (EVs) with specific structures like the tadpole, simulation and analysis play a pivotal role. They provide a means to test, refine, and validate various aspects of the vehicle design before physical prototyping. This section delves into the simulation tools and software utilized, the process and objectives of Finite Element Analysis (FEA), Vehicle Dynamics Simulation, and Suspension and Stability Analysis.[81], [82]

3.11.1 Simulation Tools and Software Used

For this research, a suite of advanced simulation tools and software was employed, each selected for its specific capabilities in analyzing different aspects of the EV design:

- **FEA Software**: Industry-standard FEA software such as ANSYS was used for structural analysis. These tool is renowned for their robustness in handling complex material behaviors and geometries.
- **Vehicle Dynamics Simulation Software**: Tools like MATLAB Simulink and ADAMS CAR provided dynamic simulation capabilities. They are instrumental in modeling and simulating the behavior of the vehicle under various driving conditions.
- **Suspension Analysis Software**: Software such as Lotus Suspension Analysis (Shark) was used for detailed suspension modeling and analysis.

3.11.2 Process of Finite Element Analysis

The primary objective of FEA in this research was to assess the structural integrity, durability, and safety of the EV chassis and components, particularly focusing on the unique demands of the tadpole structure. FEA aimed to predict how the design would respond to various physical stresses and strains, thus ensuring its reliability and safety.

The FEA setup involved creating detailed 3D models of the EV’s chassis and critical components. These models were constructed based on the design parameters established in the conceptualization phase. Material properties, including elasticity, density, and thermal characteristics, were input based on the selected materials.[83]

3.11.3 Expected Outcomes

- Identification of stress concentration areas.
- Analysis of deformation under load conditions.
- Fatigue analysis to predict the lifespan of components.
- Safety factor calculations to ensure compliance with industry standards.

3.11.4 Vehicle Dynamics Simulation

- **Parameters Considered:** Several key parameters were considered in the vehicle dynamics simulation:
- **Weight Distribution**: Critical for understanding the impact of the vehicle’s center of gravity on handling and stability.
- **Aerodynamic Drag**: Including drag and lift, which directly affect energy efficiency and high-speed stability.
- **Suspension Settings**: Such as spring rates, damping coefficients, and camber angles, which influence ride quality and handling.
- **Tire Characteristics**: Including tire grip and wear patterns, which affect the vehicle’s traction and cornering abilities.

3.11.5 Relevance to the Study

Understanding these parameters was crucial for designing an EV that balances efficiency, safety, and performance. For instance, optimizing aerodynamics could significantly reduce energy consumption, while precise suspension tuning could enhance passenger comfort and handling stability.

3.11.6 Suspension and Stability Analysis

Suspension and stability analysis utilized both computational tools and physical testing methods. The computational analysis involved simulating various suspension configurations to determine the optimal setup. The tools provided insights into parameters like roll stiffness, damping ratios, and spring rates. Physical testing methods included skid pad tests and slalom courses to validate the simulation results and further refine the suspension design.[84]

Suspension and stability are crucial for any vehicle, but they are particularly vital in the context of a tadpole-structured EV. The unique configuration of this structure demands a bespoke approach to suspension design to ensure vehicle stability, especially during cornering and under different load conditions. Properly designed suspension systems not only contribute to the vehicle's overall performance but also play a significant role in ensuring passenger comfort and safety.[85]

The simulation and analysis phase of this research was integral in shaping the final EV design. By employing advanced tools and methodologies for Finite Element

Analysis, Vehicle Dynamics Simulation, and Suspension and Stability Analysis, the research was able to iteratively refine and validate the design, ensuring that the final product was not only innovative in its approach but also robust, safe, and efficient. These simulations bridged the gap between theoretical design and practical application, allowing for a comprehensive understanding and optimization of the tadpole-structured EV.[86]

3.12 Prototyping and Testing

Prototyping and testing constitute a critical phase in the development of an energy-efficient electric vehicle (EV) with a tadpole structure. This stage transitions the theoretical and simulated designs into a tangible form, allowing for real-world testing and evaluation. This process not only tests the feasibility of the design but also ensures that the final product meets all performance, safety, and efficiency standards.

3.12.1 Process of Physical Prototyping

- **Design Considerations:** The prototyping phase commenced with a thorough review of the design specifications derived from the conceptualization and simulation stages. Key considerations included:
- **Ergonomics and Aesthetics**: Ensuring the prototype is user-friendly and visually appealing.
- **Functional Requirements**: Adherence to the performance parameters established during the design phase.

3.12.2 Manufacturing Techniques

Advanced manufacturing techniques were employed to construct the prototype:

- **CNC Machining**: For precise fabrication of metal components.
- **3D Printing**: For complex shapes and rapid prototyping of certain parts.
- **Composite Molding**: For producing lightweight and strong body panels.

3.13 Description of Various Tests

Below tests assess the vehicle's handling dynamics and performance which can be tested for various parameters.

- **Slalom Testing**: Evaluating the vehicle’s maneuverability and responsiveness.
- **Brake Test**: Included stopping distance and high-speed braking tests.
- **Aerodynamic Drag Test**: Evaluated the vehicle's efficiency at higher speeds.

- **Yaw Rate Testing**: Assessed the vehicle’s response to steering inputs.
- **Pitch Testing**: Evaluated the vehicle's response to acceleration and braking.
- **Rollover Testing**: Assessed the vehicle's susceptibility to rollover under various conditions.
- **Center of Gravity Testing**: Determined the vehicle's stability and handling characteristics.
- **Lateral Force Testing**: Evaluated the vehicle's handling characteristics under lateral loads.
- **Acceleration and Speed Test**: Measured the vehicle's acceleration capability and top speed.
- **Range Test**: Assessed the vehicle's fuel efficiency and overall range.

3.14 Methodology of Testing

Each test was designed to replicate real-world conditions as closely as possible. Scenarios were set up based on typical usage patterns, legal standards, and safety considerations.

3.14.1 Data Collection and Analysis

Data collection employed a combination of onboard sensors, high-speed cameras, GPS tracking, and telemetry systems to gather comprehensive performance data.

Data analysis involved both quantitative and qualitative methods. Quantitative data from sensors and telemetry provided objective performance metrics, while qualitative observations helped in understanding real-world dynamics and user experience.

Feedback from each testing phase was meticulously analyzed and used to refine the prototype. Key areas of focus included:

- **Design Modifications**: Alterations in design were made based on test outcomes. For instance, aerodynamic features might be tweaked to reduce drag, or suspension settings adjusted to improve handling.
- **Material Reevaluation**: In some cases, testing may reveal the need for different materials or construction techniques.
- **Performance Enhancement**: Based on test data, improvements in various systems like braking, steering, and motor efficiency were implemented.

Testing also provided insights into potential user experience enhancements and maintenance requirements, ensuring the final product is not only safe and efficient but also user-friendly and practical for everyday use.

The prototyping and testing phase was pivotal in bridging the gap between theoretical design and practical application. Through rigorous testing and iterative improvements, this phase ensured that the final EV design was optimized for performance, safety, and efficiency, validating the vehicle's readiness for real-world application. This process exemplifies the importance of empirical validation in the development of innovative automotive technologies, particularly in the context of EVs with unconventional structures like the tadpole design.

3.14.2 Data Collection and Empirical Analysis

In the journey of developing an energy-efficient electric vehicle (EV) with a tadpole structure, empirical data collection and analysis play a crucial role. This phase involves gathering real-world data on various parameters, analyzing them, and incorporating the findings into the vehicle’s design. This section elaborates on the methods of collecting road condition data, studying real-world driving patterns, and gathering suspension system data, along with the respective analysis techniques and their impacts on design decisions.

3.14.3 Road Condition Data

Road condition data was sourced from various channels to ensure a comprehensive understanding of the different environments the EV would encounter. These sources included:

- **Transportation Departments**: For official records of road types and conditions.
- **Geographic Information Systems (GIS)**: For detailed mapping and terrain data.
- **Field Surveys**: Conducted to gather first-hand information on road conditions.

3.14.4 Data Collection Methods

Data was collected using a combination of methods:

- **Automated Data Collection**: Utilizing GPS and GIS technology to gather large-scale data on road types, gradients, and surface conditions.

- **Manual Surveys**: Conducting physical inspections and assessments of road conditions in targeted areas.
- **Public Databases**: Accessing publicly available data on road conditions, traffic patterns, and historical weather impacts.

3.15 Analysis Techniques

Analysis of road condition data involved:

- **Statistical Analysis**: To identify common road features and conditions.
- **Simulation Modeling**: Using the collected data to simulate different road conditions in vehicle testing simulations.
- **Geospatial Analysis**: To map and understand the geographical distribution of various road types and conditions.

3.15.1 Performance Analysis

Included Taguchi and regression analyses to understand the impact of weight, camber, and tire width on the vehicle's range. Each of these stages plays a critical role in ensuring the final vehicle meets performance, safety, and quality standards. The comprehensive testing regime demonstrates the thoroughness in evaluating and optimizing the vehicle’s design and functionality.

3.16 Additional Considerations

The research also considers aspects like ergonomic and aesthetic design, functional requirements, and compliance with legal standards and safety considerations.

The methodology outlined in the thesis is comprehensive and designed to ensure the development of a robust, efficient, and practical EV with a tadpole structure. The mixed-methods approach, encompassing both theoretical research and practical application, provides a solid foundation for innovative automotive technology development.

In the context of vehicle design and optimization, the Multi-Criteria Decision Making (MCDM) method plays a crucial role. This approach is particularly useful when selecting the optimal solutions for design elements, taking into account a range of factors such as weight, stiffness, and aesthetics. MCDM assists decision-makers in identifying the most suitable option by considering multiple perspectives and preferences.

Here's a more detailed look into how MCDM can be applied in vehicle technology:

1. **Weight Considerations**: In vehicle design, weight is a critical factor, especially for electric vehicles. Lighter vehicles generally have better efficiency and performance. Using MCDM, you can weigh the importance of reducing vehicle weight against other design aspects like structural strength or cost.
2. **Stiffness and Structural Integrity**: The stiffness of components like the chassis, suspension, and body panels is vital for the vehicle's handling, safety, and durability. MCDM helps in balancing stiffness with other factors like material cost and weight.
3. **Aesthetic Appeal**: While technical specifications are crucial, the visual appeal of a vehicle also plays a significant role in consumer acceptance. MCDM can aid in finding a balance between aesthetic appeal and functional design elements.
4. **Application Across Sectors**: MCDM isn't limited to vehicle design. It's widely used in various fields, including engineering, management, economics, and environmental research. This versatility makes it a powerful tool in decision-making where multiple criteria must be considered.

In vehicle technology, particularly for electric and hybrid vehicles, the application of MCDM ensures that the final design is not just focused on a single aspect like range or speed, but is a well-rounded product considering multiple facets of vehicle performance and design. This holistic approach is crucial for creating vehicles that are not only efficient and functional but also meet the broader needs and preferences of consumers and the market.

DESIGN AND OPTIMIZATION

Major Components which affecting on the performance of tadpole structured electric vehicle are Chassis/Frame, Upright with A- Arms and rear swing arm. Design and optimization of this component is essential to optimize the performance of vehicle based on weight criteria.

4.1 Chassis/ Frame Design

4.1.1 Design Considerations

The chassis design, which was among the most critical elements to be completed, was tasked with integrating every vehicle component into a singular, functional vehicle. The procedure by which the chassis was designed was as follows:

- Weldable sections were incorporated into the chassis to facilitate the attachment of components using fasteners.
- Analysis was conducted to verify the structural integrity of the chassis. FEM analysis was performed on the chassis to determine its frequency and strength response. Members were added or member thickness was adjusted until the chassis achieved adequate strength.
- The chassis underwent manufacturing preparations. Individual tube components were identified and their profiles were specified in a manner that facilitated assembly and manufacturing.
- Placing the obtained suspension points on the chassis.
- Designing the driver compartment for the suitable driver and to satisfy the ergonomics requirements.
- Assuring the proper node-to-node triangulation.

4.1.2 Material Selection

The material selected for the chassis is AISI 4130 steel. It is a versatile alloy steel with very good strength, fatigue strength and weldability. For properties material is tested in the laboratory OM Meta Lab Services PVT. LTD.

Table 4.1: Material Properties of AISI 4130

Property	Observed Value
OD (mm)	25.40
ID (mm)	23.42
% Elongation	19.12

Property	Observed Value
Thickness (mm)	1.01
Density (Kg/m^3)	7850
Poisson Ratio	0.29
Modulus of Elasticity (Gpa)	205
Tensile Strength (N/mm^2)	679.67
Yield Strength (N/mm^2)	594.31

In the construction of this automobile, a decision was made to utilize 25.4 mm tubing in various thicknesses between 1 mm and 1.2 mm for the tube members. Where necessary, sheet steel was incorporated into the design. The 25.4 mm tube diameter provided an extensive selection of tube thickness options and satisfied the chassis's strength requirements. Maintains a low-to-the-ground profile and a straightforward design, but fails to adequately safeguard its occupants in the event of a rollover, an occurrence that is more frequent in urban vehicles compared to conventional cars. As a consequence, a roll cage was incorporated into the design of the chassis. However, in order to facilitate the incorporation of future structural body designs onto the vehicle, the roll hoop was intentionally engineered to be detachable. In order to accomplish the goal of a removable roll hoop, two distinct chassis components—the primary body and the roll hoop—were fabricated and could be bolted together as needed. With the completion of the primary chassis components, the sheet metal mounting tabs were affixed to the chassis components. Every tab was specifically engineered to be produced using a waterjet or laser cutting technique, followed by jigging into the chassis for welding. With the exception of the 3 mm and finer tabs, which were intended to be bent, all other sizes were constructed to be welded to the chassis. This method permits the fabrication of tabs with small tolerances at the frame and mount locations through the incorporation of tab-specific alignment features, such as a profile of the tube member. With the aid of these characteristics, the tabs on the chassis could be readily located.

4.1.3 Wheelbase and track

It is challenging to precisely determine the optimal wheelbase, which is the distance between the centerlines of the axles on a vehicle. On winding circuits, short-wheelbase vehicles are typically more agile and adept at tight turns, whereas long-wheelbase vehicles maintain greater stability on rapid straightaways. Hillclimb and sprint cars, which are typically required to traverse narrower roads with tighter hairpins, have developed wheelbases ranging from 2000 to 2500 mm. It is simpler to specify the optimum track, which is the distance between the centers of the axles of a vehicle. It can be seen that weight transfer decreases as track T increases. Moreover, a broad track decreases cornering roll. Frequently, the regulations are expressed in terms of the vehicle's utmost overall width, which results in the wider rear wheels having a slightly narrower track than the front wheels. The tight and winding circuits require a vehicle that is both lightweight and exceptionally agile. Studies have shown that compact automobiles with a track of 1200 mm and a wheelbase between 1500 and 1700 mm perform the best. Considering all parameters like city road conditions wheelbase and track have been optimized as 1800 mm and 1200 mm respectively keeping 60 % ratio for optimum performance of the vehicle.

4.1.4 Position of centre of mass of a vehicle

During the preliminary design phase, it is essential to make an estimate of the center of mass for each primary component as it is integrated into the system. Subsequent modifications may be implemented to the ultimate positional correlation between the constituent elements and the wheels, with the aim of achieving the desired allocation of weight between the front and back. In order to graphically represent the process, Figure 1.4 showcases a restricted set of components together with the distances between their separate centers of mass and a shared point. In this case, the front contact patch, represented as x, is the shared element.[53]

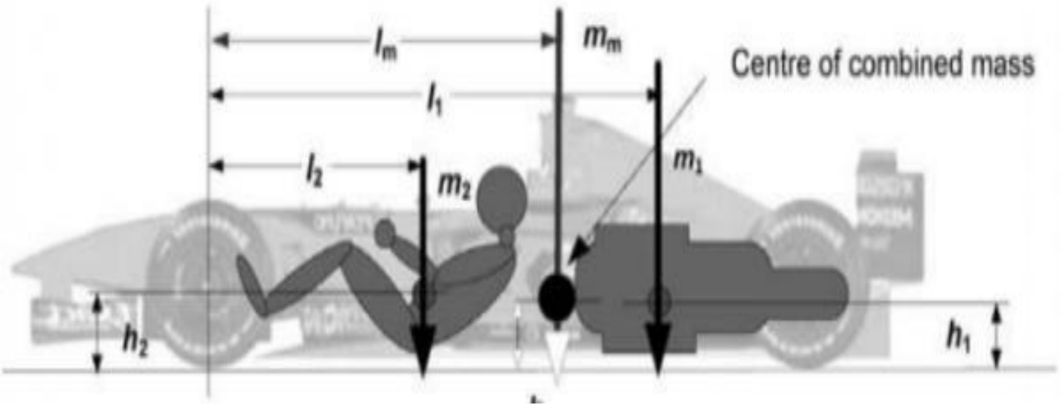


Figure 21 : Position of the Center of mass [53]

Either an estimation or measurement is performed on the magnitude (m) and location (l, h) of the center of mass of each individual component. Determining the location of the combined mass (mm) in relation to the common point (lm) and hm is the objective.

Simply summing the masses of the constituent components yields the total mass. For a set of n number components in total, this is mathematically represented as:

$$m_m = \sum(m_1 + m_2 + \cdots \dots \dots m_n) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(4.1)}$$

The location of the combined center of mass is:

$$l_m = \frac{\sum(l_1 m_1 + l_2 m_2 + \cdots l_n m_n)}{m_m} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(4.2)}$$

$$h_m = \frac{\sum(h_1 m_1 + h_2 m_2 + \cdots h_n m_n)}{m_m} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(4.3)}$$

By ensuring that the combined mass of the components exerts the same moment about the front contact patch as the sum of the masses of the individual components, the procedure described above is straightforward.

Table 4.2: Center of Mass of Vehicle

Component	**Mass**		**Horizontal Distance from front axle**	**Horizontal moment**	**Vertical distance from ground**	**Vertical moment**
	(kg)		**(mm)**	**(kg-mm)**	**(mm)**	**(kg-mm)**
Car						
Front-wheel assembly	21		0	0	200	4200
Pedal box	2		0	0	200	400
Steering gear	5.5		100	550	300	1650
Controls	3		300	900	800	2400
Frame + floor	23		800	18400	700	16100
Body Works	30		800	24000	700	21000
Fire extinguisher	3		1000	3000	600	1800
Motor	9		1780	16020	200	1800
Battery Pack	30		1200	36000	700	21000
Battery 12 V	2		1200	2400	700	1400
Controller &	10		1200	12000	700	7000

Component	**Mass**		**Horizontal Distance from front axle**	**Horizontal moment**	**Vertical distance from ground**	**Vertical moment**
	(kg)		**(mm)**	**(kg-mm)**	**(mm)**	**(kg-mm)**
Ele. Panel						
Rear Swing	5		1780	8900	200	1000
Electrical	7		1200	8400	700	4900
Mescellinoius				0		0
Total car	**150.5**		**812**	**122170**	**530**	**79750**
Driver						
Drivers Weight	80	Distance between front axle to pedal face	700			
Feet	2.8	40	740	2052	250	693.3333
Calves	7.7	200	900	6912	430	3302.4
Thighs	17.3	560	1260	21773	600	10368
Torso	36.9	800	1500	55360	650	23989.33
Forearms	3.2	530	1230	3936	700	2240
Upper arms	5.3	800	1500	8000	840	4480
Hands	1.3	330	1030	1318	820	1049.6
Head	5.5	830	1530	8486	1110	6156.8
Total driver	**80**	**4090**	**9690**	**107837.87**	**653**	**52279.47**
Grand total	230.5		**998**	230008	**573**	132029.5
Rear load	129					
Front load				101		
Ratio F/R			**43.9%**	**56.1%**		

4.1.5 Individual Static Wheel Loads and Front to Rear Weight Balance

The static case pertains to the loads experienced by the vehicle in the absence of accelerations caused by deceleration, cornering, or acceleration. The vehicle ought to be evaluated while it is completely loaded with the driver. The following burdens would be assessed in the pits if the vehicle were to be positioned on a level surface. Thus far, the bulk of components has been denoted in kilograms. The terms 'load' and 'weight', nevertheless, refer to force, which is naturally expressed in Newtons. We will therefore henceforth consider the forces, denoted as W, acting on the vehicle.[87]

Where, Force (N) = mass (kg) x acceleration (m/s^2).

where, for vertical loads, the acceleration = g = 9.81 m/s^2.

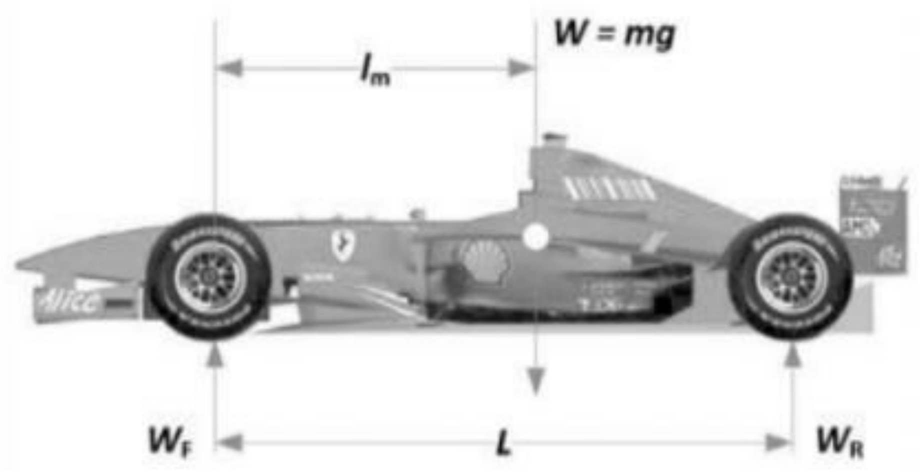


Figure 22 : Static Wheel Loads

To ascertain the load on the rear axle, WR, we need only measure the moments about the front axle and the horizontal position of the center of mass.

Weight distribution on the rear axle,

$$W_R = W\ X\ \frac{l_m}{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 4.4$$

From vertical equilibrium:
Weight distribution on the front axle,

$$W_F = W - \ W_R \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 4.5$$

Figure 22. represents a free-body diagram. In order for the car to remain in a state of static equilibrium while floating weightlessly in space, the three forces at play, W, WF, and WR, must balance each other. Specifically, the downward force of gravity, W, must be equal and opposite to the combined forces exerted by the wheels, WR and WF. The upward display of wheel forces is attributed to this reason. They denote the exertion of the road's forces on the car.

The designer has the ability to manipulate the distribution of weight between the front and rear of the vehicle by strategically relocating specific components, such as the battery or electronic elements. Modifying the location of the front and/or rear axles in relation to the battery and motor's major mass leads to a notable difference. What is the ideal ratio of weight distribution between the front and back of a vehicle? From a practical perspective, it might be contended that a 50:50 ratio is the most favorable. Nevertheless, as we will soon observe, having a greater amount of weight over the wheels that provide propulsion offers a distinct benefit when it comes to accelerating from a stationary position. Cars often strive for a front/rear ratio of approximately 45:55 and tackle the handling problem by utilizing bigger rear tires.[47]

4.1.6 Un-sprung mass lateral force

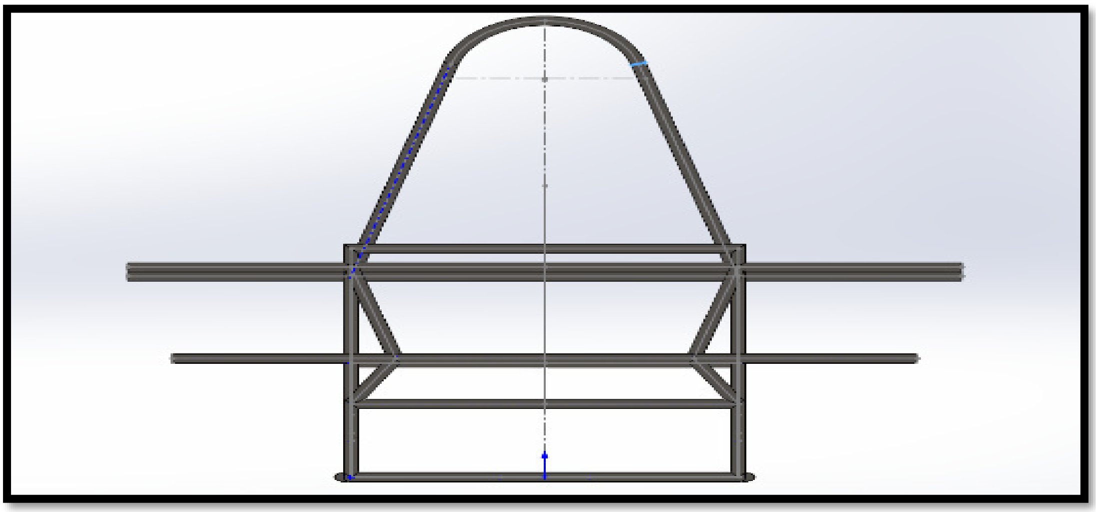
Lateral load transfer calculations are often performed in lateral g increments. At a lateral acceleration of 1.5 g, the masses of all the vehicles (in kg) are multiplied by the lateral acceleration, Ay, of 1.5 x 9.81 to get lateral forces (N). Normal lateral acceleration for cars is between 0.7 to 0.9. If this value goes above 1.0 it will be good design. So, for our design considering it as 1.25 and calculating lateral forces. Table below shows the individual wheel loads and lateral forces on each wheel.[88]

Table 4.3: Individual Wheel Loads

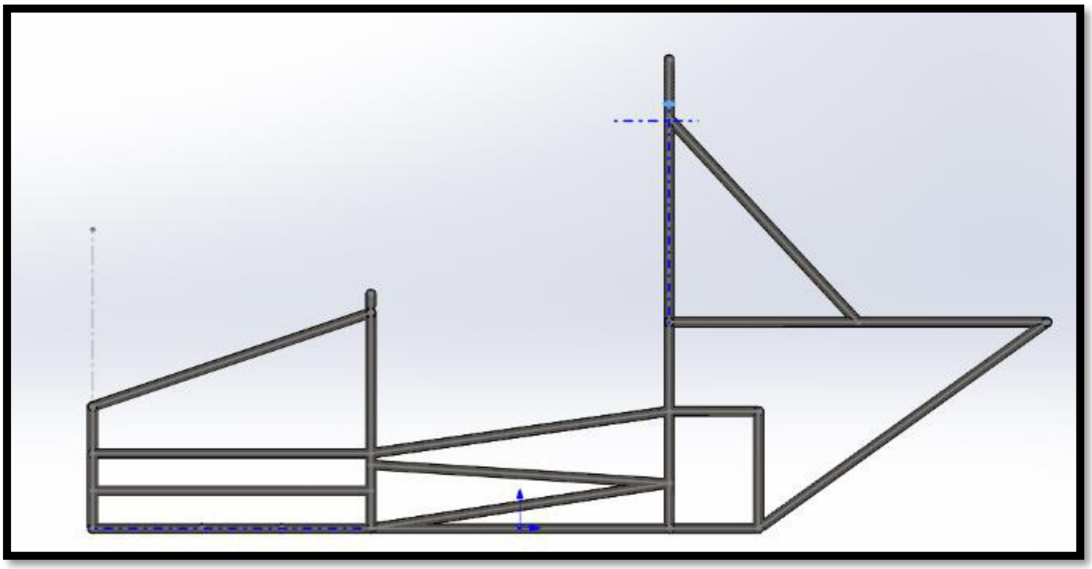
Lateral g, A_y	**1.25**	
Data	Front	Rear
Wheel radius, r (mm)	200	200
Wheel track, T (mm)	1200	700
Height roll centre, h_{rc} (mm)	200	200
Ride rate, K_R (N/mm)	30	30
Unsprung Mass, M_u (kg)	20	12
Wheelbase, L (mm)	1800	
Sprung mass, M_S (kg)	230	
Height sprung mass, h_{ms} (mm)	200	
Dist, front axle to M_S, l_{ms}(mm)	800	
Wheel loads		
Static loads, R (N)	724.9	560.3
From unsprung mass (N)	40.9	42.0
From sprung mass thro. Links (N)	261.1	358.1
Roll rates (Nm/deg)	377.0	128.3
Roll distribution %	74.6	25.4
From sprung mass thro. springs (N)	0.0	0.0
Total load transfer	302.0	400.2
Inner wheel loads	422.8	160.1
Outer wheel loads	1026.9	960.4

4.1.7 Dimension Parameters & CAD Model

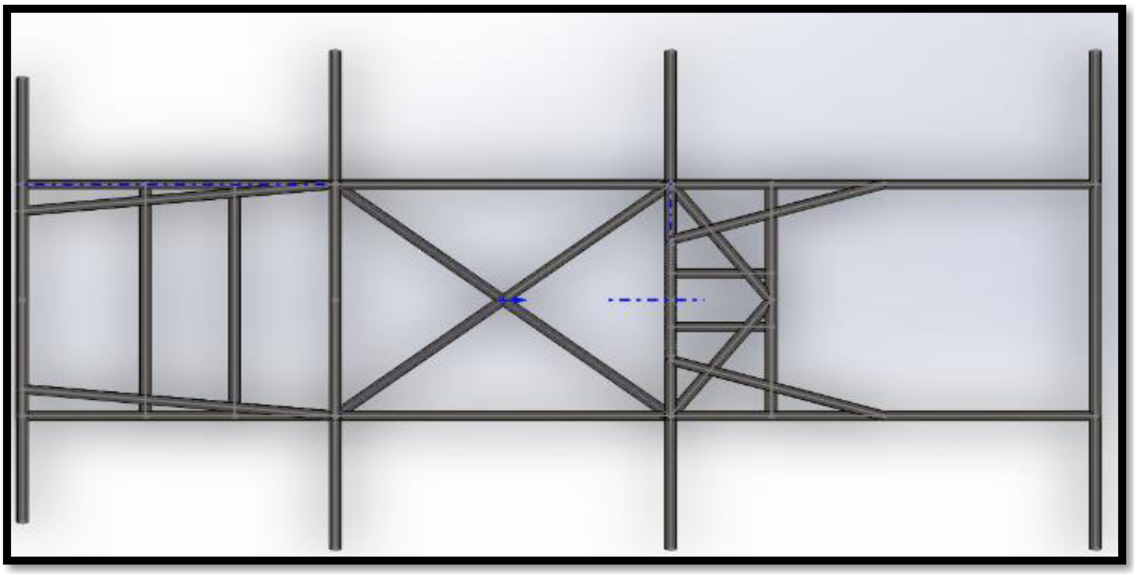
By using solid works and designed parameters chassis generated as CAD model. After several iteration chassis shown in the fig. is selected and further analysed.



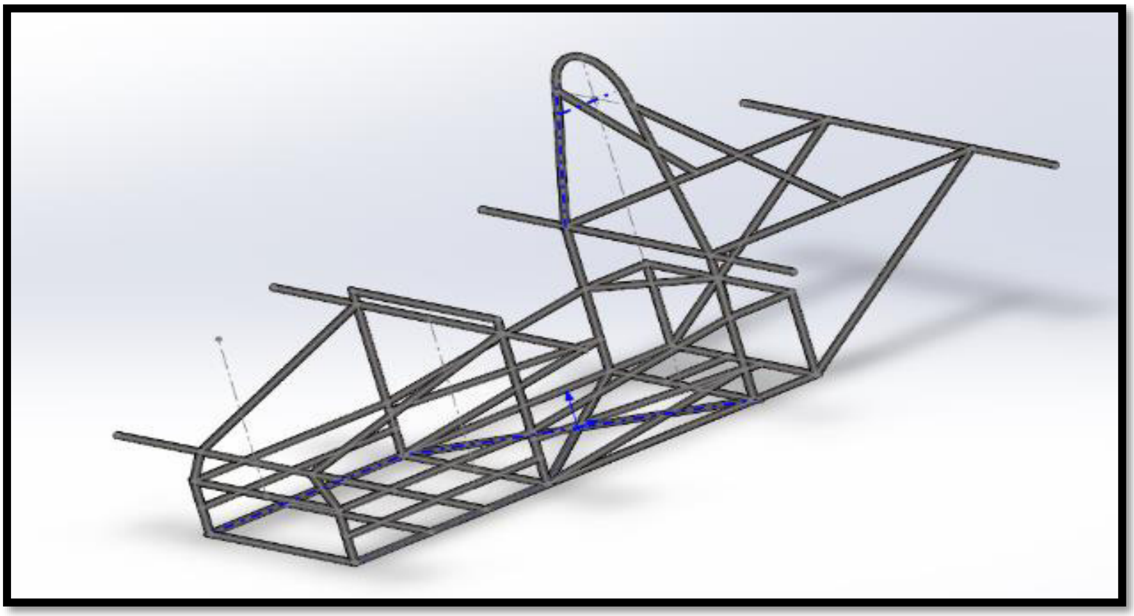
(a)



(b)



(C)



(D)

Fig. 23 : a) Side view of chassis b) Front view of chassis c) Top view of chassis d) Isometric view of chassis

From the CAD model below are the observed parameters of the vehicle chassis and design considerations.

Table 4.4: Estimated vehicle chassis parameters

Description	Value	Units
Total Mass (Approx.)	180	Kg
Mass of Chassis	23	Kg
CG Height	417	mm
Front Wheel To CG Distance	743	mm
Rear Wheel To CG Distance	1057	mm
Wheelbase	1800	mm
Cornering Stiffness, Front Wheel	2500	N/mm
Cornering Stiffness, Rear Wheel	4000	N/mm
Nominal Track Width	1200	mm
Ground Clearance	160	mm

In the structural investigation, boundary conditions and equivalent loads were applied to the chassis, when necessary. Accelerations have more significance compared to the specified quantity of forces for the chassis, therefore being classified as overarching design requirements. The application of forces may be effectively determined by applying a load that is 20 times the acceleration due to gravity in the desired direction. If certain conditions are not met, such as the lack of a tube structure between the driver and a component, it is recommended to utilize a 40g load. Only 20-gram loads were used in this experiment for two particular reasons. The first rationale is derived from the overarching recommendation presented in reference [47], whilst the subsequent rationale is that the suggested acceleration attains a magnitude that has the potential to induce harm, a threshold that has been determined to be appropriate for the chassis to endure, as described in reference [47]. The research assumed that the weight of both the driver and passenger was equivalent to the requirement set by the Fédération Internationale de l'Automobile (FIA). This regulation specifies that the harness we have selected is intended to accommodate a weight of 80 kg. The evaluation will consider the tube members as beam elements, whilst the sheet metal linked with them will be analyzed as solid elements. The use of this simplified analytic approach is well-suited for tube member chassis, resulting in a significant reduction in the computing complexity of the research [4]. In order to improve the accuracy of the model, mesh refinement was conducted on components that exhibited significant strain rates. It was essential to enhance the element density of the tube members connected to solid elements, since the transmission of forces was limited to the nodes. All connections that were welded were categorized as bonded. The bolt of the roll hoop was designed to establish a connection by applying a preload of 25 Nm and implementing a lock mechanism that effectively prevents any ingress between the surfaces being attached. The primary determinant influencing the time of the model's execution was the absence of penetration, necessitating around 20 minutes to accomplish for every permutation of boundary conditions. The research may use specific material characteristics, since the producer of the tubes performed several tests on the tubes utilized in the construction of the chassis. Similar to previous finite element analysis, the findings presented in this study provide an estimation of the potential outcomes in real-world scenarios.

4.1.8 Calculations for Load

As per south Asia guidelines for small electric vehicles, the speed is limited by the weight of the car and driver. So while designing the car considering the weight of car is to be 200 kg and the weight of the driver to be 80 kg. Hence by using the formula for maximum force ($\mathrm{F_{max}}$) applied on the car with driver.[53]

$$\mathrm{F_{max}} = \text{mass} \times \frac{\text{velocity}}{\text{time}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.6)}$$

where time (t) is the time of contact between the car and impact load which is 0.5 s, Velocity is 15 m/s (Approx. 55 KMPH) and mass is 280kg. (considering maximum)
Therefore,

$$\mathrm{F_{max}} = 280 \times \frac{15}{0.5} = 8400\,N$$

For being safe side considering,

$$\mathrm{F_{max}} = 10000\,N$$

This is the force used for front, rear and side impact analysis of chassis.

4.1.9 Impact Analysis

1. Front Impact Analysis

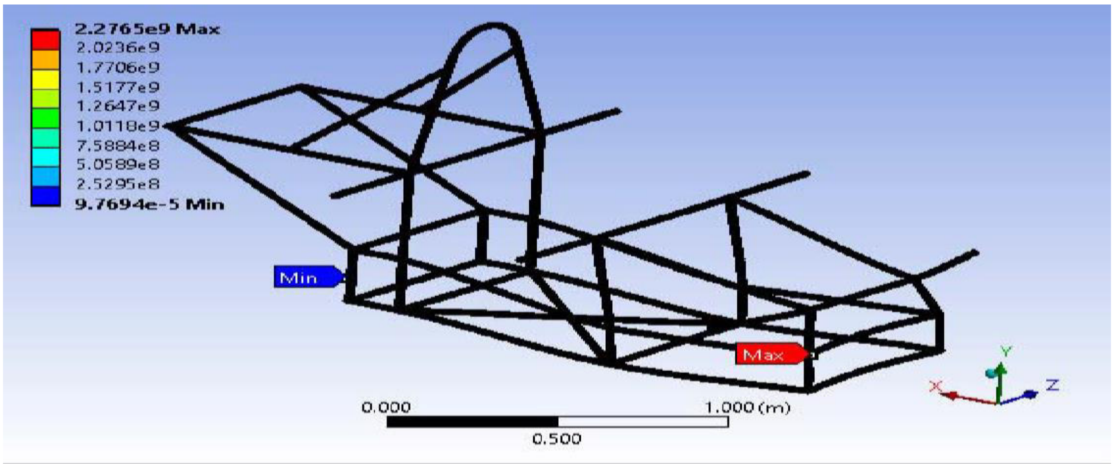
An off-axis frontal impact occurs when a vehicle collides with a huge object, such as a wall or building, while traveling at a high speed. The event is represented as a 20g acceleration, accompanied by a minor off-axis force component. The following boundary conditions were applied for a total vehicle mass of 280 kg:

Forces – $F_X = -10\ KN$, $F_y = 0\ KN$, $F_Z = 0\ KN$

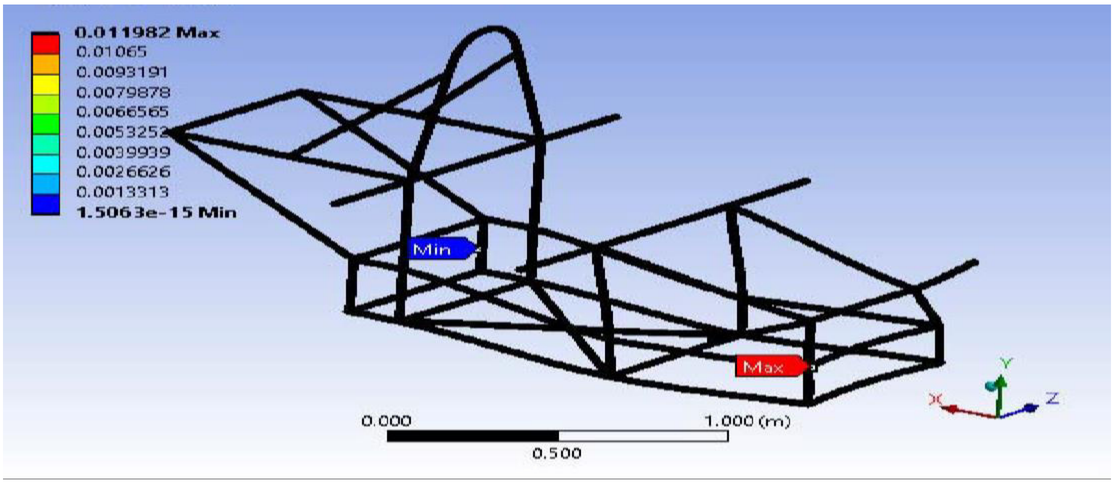
Located in the foremost part of the vehicle's structure, these tube members are the first to come into contact after an impact, excluding the bumper members that protect the wheels.

Fixtures – The primary roll hoop's bottom nodes allow for unfettered rotation while maintaining a fixed displacement.

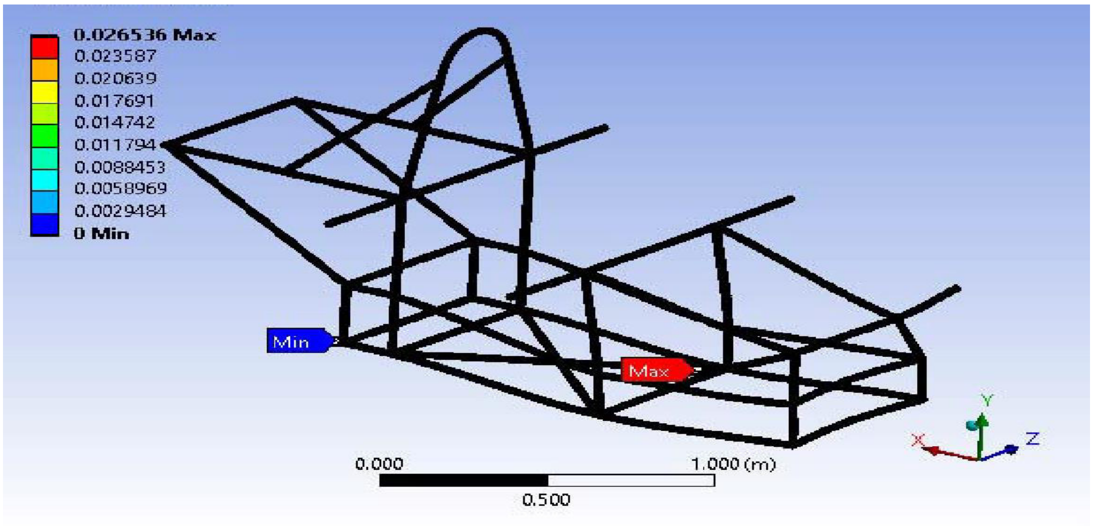
Acceptance Criteria – Absence of stress failures that pose a risk. Figure a) displays the stresses of the beam members, Figure b) illustrates the strain, and Figure c) presents the deflection.



a)



b)



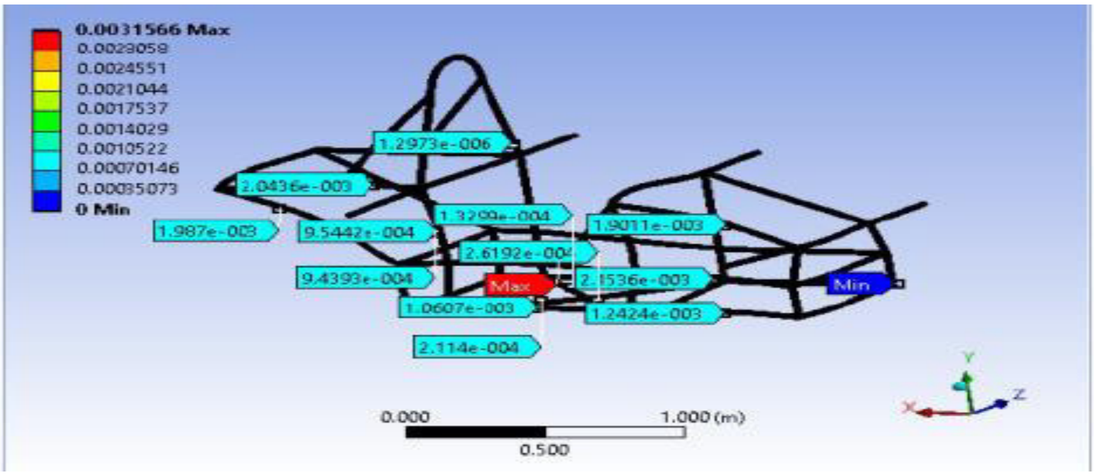
c)

Fig. 24 : a), b) and c) Showing Front Impact Analysis

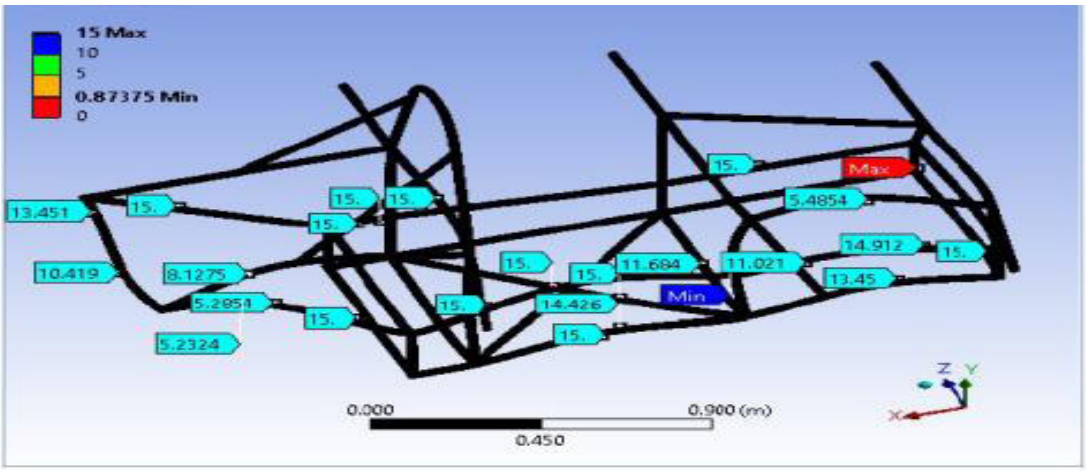
The stress plot clearly shows that the frame fails in two elements of the bumper members when subjected to loading, while the remaining chassis members remain below the yield stress of the material. The failure of the bumper material is not a cause for concern, as its primary function is to prevent pedestrians from entering the wheel wells, rather than providing structural reinforcement. The chassis components that secure the driver are well below the yield stress and will provide enough protection for them. If the front members fail, it is likely that the other members will experience greater deformation and stress. Nevertheless, due to the minimal stress levels, the members should have the capacity to withstand the additional strain. The deformation plot exhibits conventional deflection patterns, characterized by a relatively low magnitude. The chassis exhibits a propensity to deform upwards in the absence of any vertical force. The probable cause for this is the heightened stiffness in the lower layer of the chassis compared to the upper layer, as evidenced by the implementation of diagonal cross members.

Table 4.5 : Front Impact Analysis Results

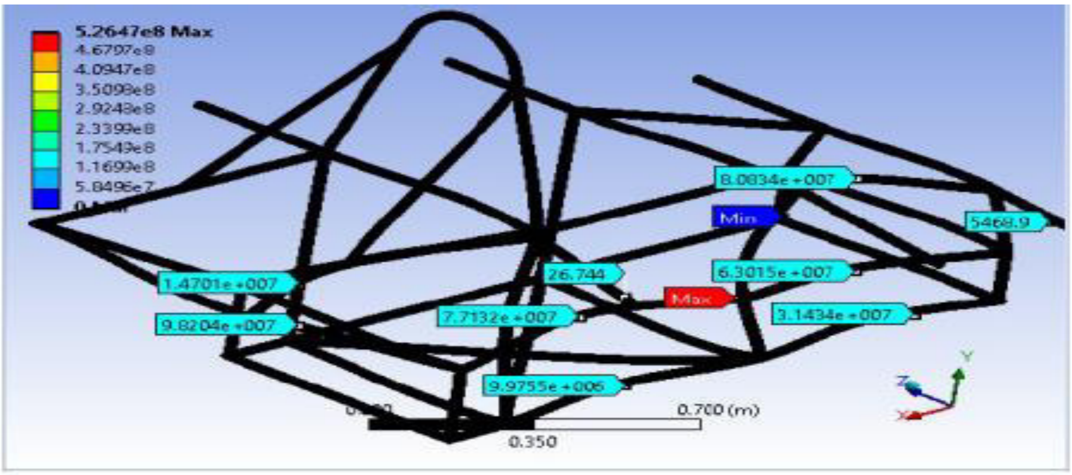
Parameters	Maximum Values
Stress	2.276×10^9 N/m^2
Strain	11.982
Deflection	26.53 mm
Factor of Safety (F.O.S.)	**8.3**



d)



e)

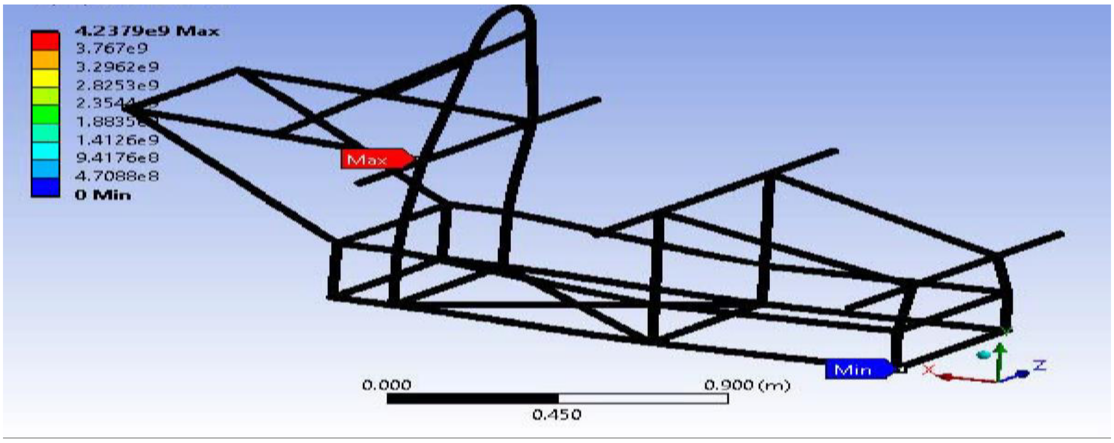


f)

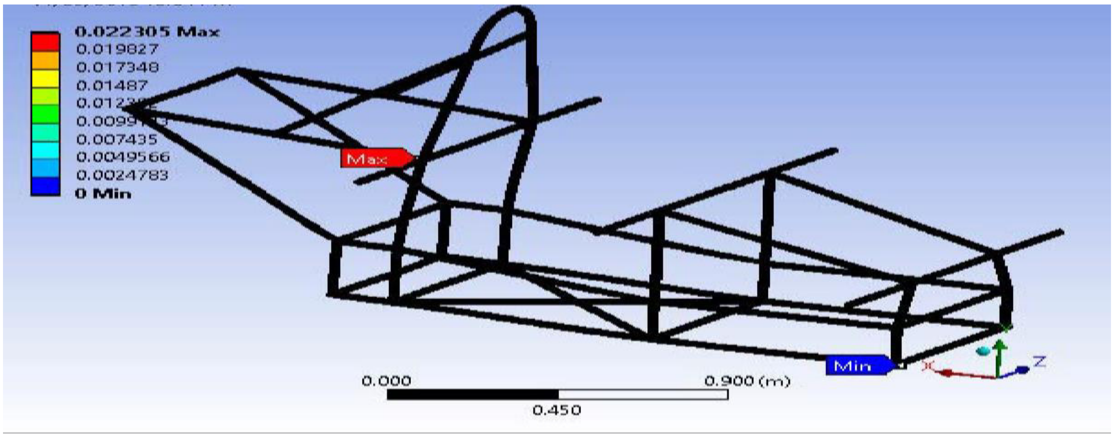
Fig. 25 : d), e) and f) Showing Side Impact Analysis

Table 4.6 : Side Impact Analysis Results

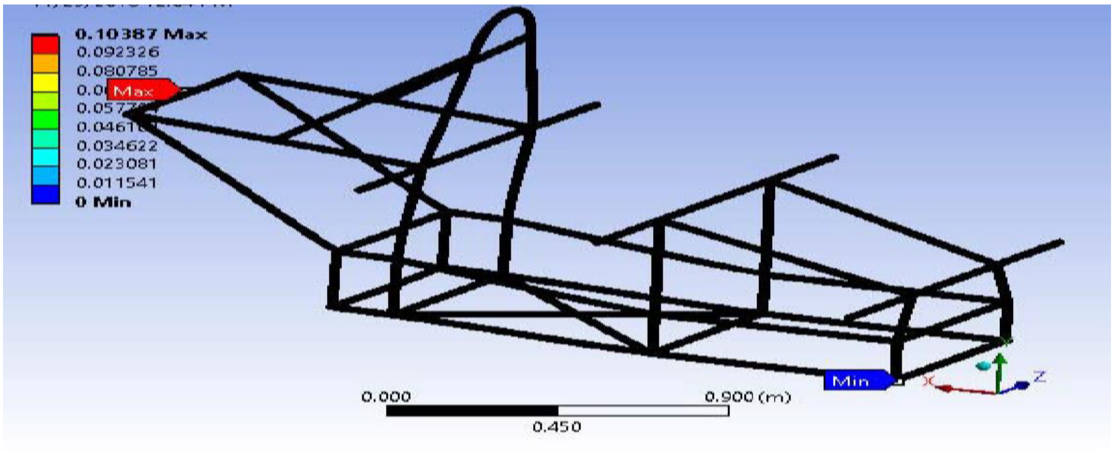
Parameters	Maximum Values
Stress	5.26 X 10^8 N/m^2
Strain	2.86
Deflection	3.156 mm
Factor of Safety (F.O.S.)	**9.67**



(g)



(h)



(i)

Fig. 26 : g), h) and i) Showing Rear Impact Analysis

Table 4.7 : Rear Impact Analysis Results

Parameters	Maximum Values
Stress	4.24 X 10^9 N/m^2
Strain	22.3
Deflection	103.87 mm
Factor of Safety (F.O.S.)	**6.13**

(Note: Pipes on which Upper spring points are mounted are of 1inch x 1.6mm while all other pipes are of thickness 1inch x 1mm for strength enhancement purpose.)

Table 4.8 : Iteration of Chassis

Parameter	Iteration-I	Iteration-II	Iteration-III	Iteration-IV	Iteration-V
FOS (Min.)	10.23	8.3	7.9	6.9	6.13
Weight (Kg)	30.2	27.9	24.8	23	20

Fifth iteration from the results gives better strength as FOS is more than 6 and weight of the chassis reduced by 10.2 Kg. So, for further consideration iteration five will be selected in the design.

4.2 Rear Wheel Assembly Design

4.2.1 Selection of Motor

As per the guidelines of south Asia small EV manufacturing for intermediate speed vehicle selecting motor of 1500 Watt. On the basis of weight, selected the motor with minimal power consumption, to contribute in weight reduction of vehicle. As the power consumption of motor increases price also increases. So, opted minimum range of motor to keep our vehicle under minimum budget. Allowable power for the motor up to 5000 Watt. So, to have our peak current minimum, we opted for optimized motor i.e., of 1500 Watt. [66]

Table 4.9 : Peak Current Calculation

Parameter	Case -I	Case -II
Peak Power (Watt)	1500	2000
Voltage (V)	48	48
Peak Current (A) (I= $\frac{P}{V}$)	31.2	41.6

Hence, based on our prototype requirement, selected 1500-Watt motor. As minimum and if selecting for higher range of motor, current requirement will also increase leading to sudden load on battery. Because of which the battery will drain faster than the required consumption.

Table 4.10 : Specifications of selected motor

Specification	Value
Rated Voltage	48 Volt
Rated Power	1500 Watt
Rated Speed	600 – 900 RPM
Rated Torque	15 – 45 N-m
Maximum Speed	45- 60 KMPH
Weight	9 Kg
Rated Current	20 – 40 A
Continuous Discharge Current	10 -15 A
Load Consideration	250– 900 Kg

A. Design Consideration:

It depends upon the weight constraints of the vehicle that is 280 Kg with drive. Also, the torque is 10 N-m for 280 Kg.

B. Torque Calculation Given:

Power (P) = 1.5 KW

Rim dia. = 14 inch = 355.6 mm

R = 0.178 m = 178 mm

μ = 0.017 = 0.02

Tractive Force:

$$F_t = \mu m g \quad \text{(4.7)}$$

Starting Torque:

$$T = F_t \, X \, R \quad \text{(4.8)}$$

$$a_{max} = \frac{(Total\ Max\ Torque - Required\ Torque)}{m\ X\ R} \quad \text{(4.9)}$$

where,

μ = coefficient of friction

g = gravitational force

m = mass

R = radius of wheel

a_{max} = maximum acceleration

Table 4.11 : Calculation of Maximum Acceleration

Parameter	**Case I (m= 280 Kg)**	**Case II (for m=260 kg)**	**Case III (for m=240 kg)**
F_t	54.936	51.02 N	47.088 N
T	9.778 N-m	9.081 N-m	8.381 N-m
T_{max}	45 N-m	45 N-m	45 N-m
a_{max}	0.706 m/s^2	0.776 m/s^2	*0.857* m/s^2

4.2.2 Swing Arm

A. Material Selection

Lightweight structural materials allow automobiles to carry improved emission control, safety, and integrated electrical systems without adding weight. Hybrid, plug-in, and electric cars need lightweight materials. Lightweight materials may reduce the weight of power systems like batteries and electric motors, enhancing efficiency and all-electric range. Lightweight materials might reduce battery size and cost while maintaining plug-in car all-electric range. [90]

Lightweight materials' cost, recycling, integration with cars, and fuel efficiency advantages depend on research and development. The most commonly used materials for lightweight structures in automotive industries and their properties of it are given below.

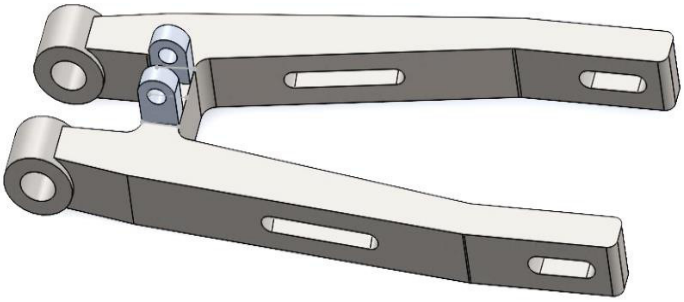
Table 4.12: Material Properties

Material	Tensile Strength (MPa)	Approximate Cost Per Kg. (Rs.)
High strength steel	500	125
Advanced high-strength steel	700	175
Glass fiber composites	3500	200
Titanium	1400	5500
Aluminum and Al matrix composites	240	200
Carbon fiber composites	3500	8000
Magnesium	440	90
7076 T6 Aluminium Alloy	570	600

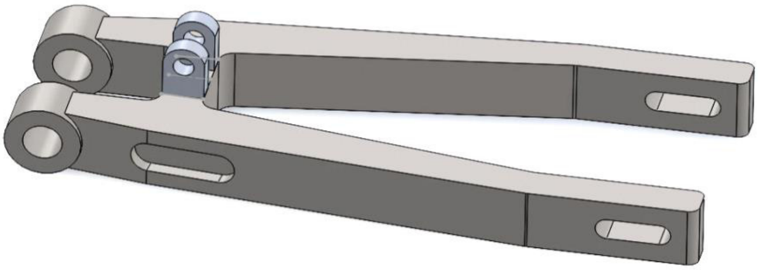
It is crucial to consider the particular needs and restrictions of the system being optimized while thinking about design factors. This comprises elements including price, size, and performance objectives. By considering the cost-effectiveness and strength of the material used for the automobile and ease in manufacturing 7076 T6 Aluminium alloy material is selected for the swing-arm of a tadpole structured electric vehicle.

B. Generative Design Approach

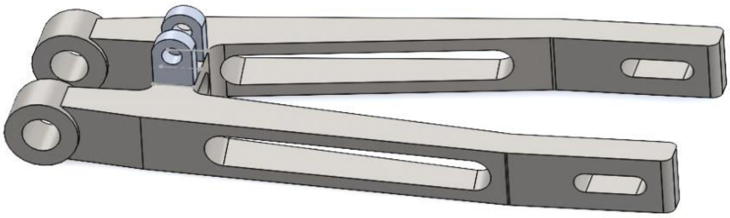
By using Solid works software CAD model of the swing arm is prepared and assigned given properties to the model.



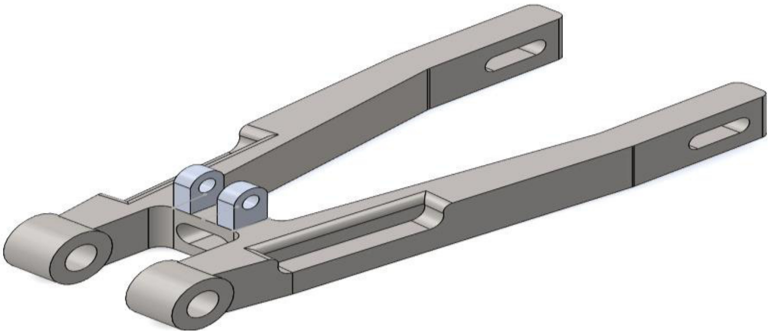
a) Iteration 1



b) Iteration 2



c) Iteration 3



d) Iteration 4

Fig. 27 : Weight and Shape Optimization Iterations

The initial Weight of the Swing Arm was 11.70 Kg. After application of the generative design concept and getting different iterations as follows with varying mass.

Table 4.13: Weight Reduction and it's percentage

Iterations No.	Mass (Kg)	Mass Reduction %
Iteration 1	11.08	2.3%
Iteration 2	11.41	1.00%
Iteration 3	8.75	25.22%
Iteration 4	10.80	7.7%

C. Load Applied for Analysis

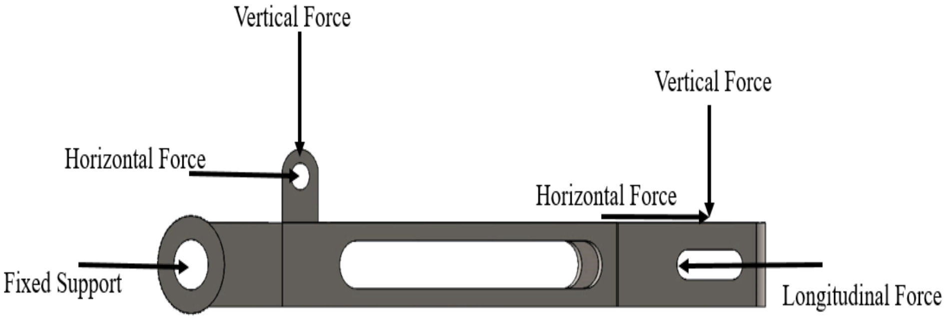
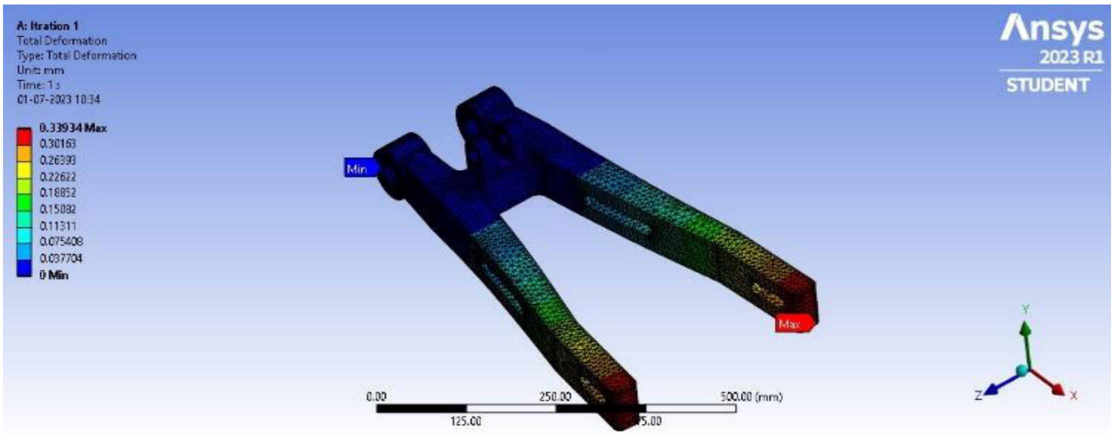
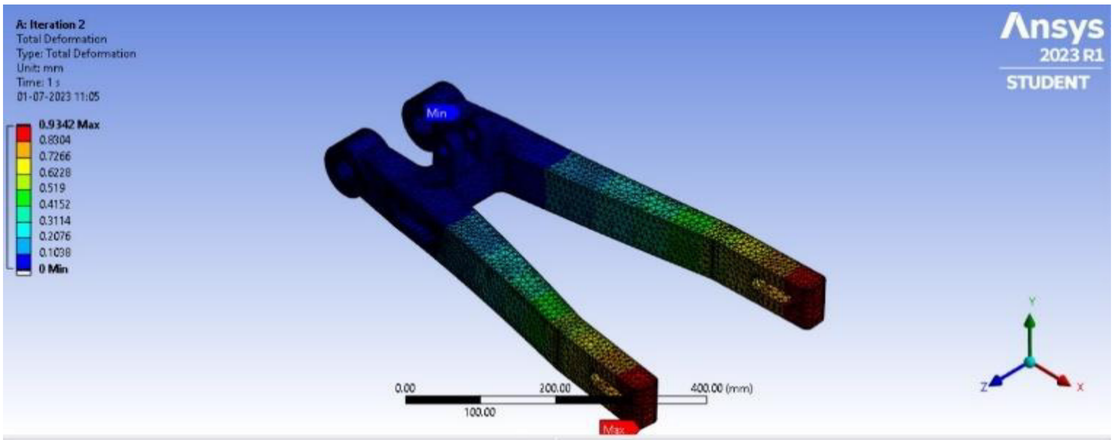


Fig. 28 : Loading Conditions for Rear Swing Arm

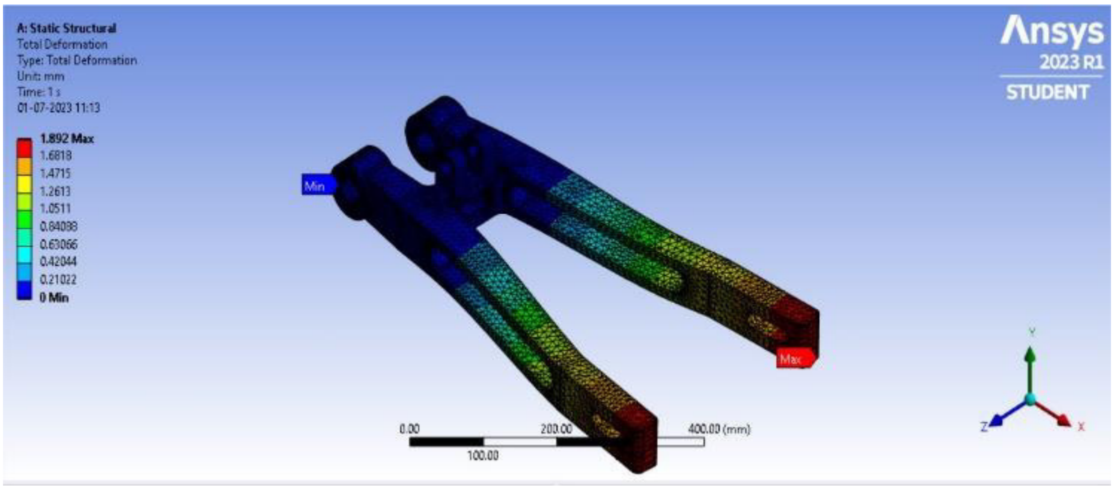
In Ansys software loads are applied as shown in Fig. 4. For analysis purpose at the eye end fixed support is considered and vertical forces of 325 N and horizontal force of 1925 N is applied on the swing arm by considering bump due to tire and forces due to suspension. Also, longitudinal force due to acceleration and braking is applied 2000 N.



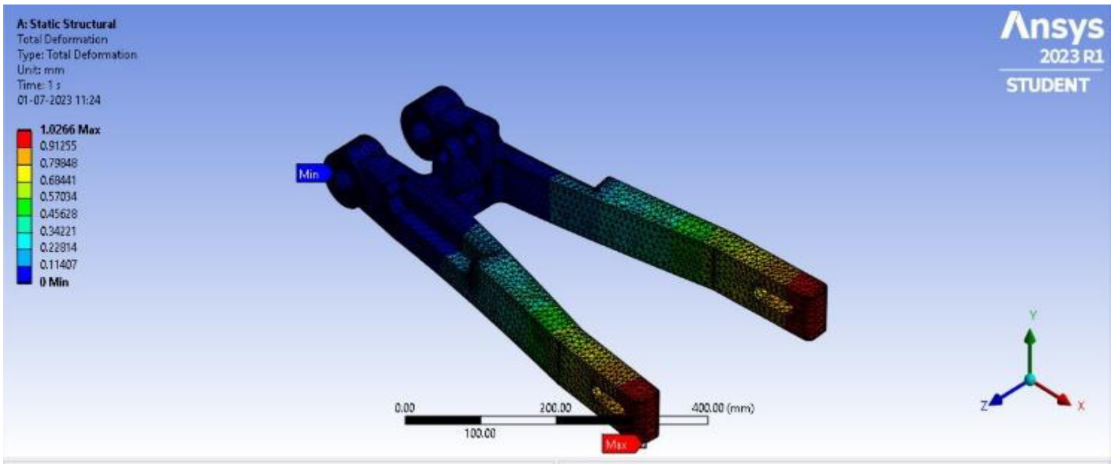
a) Iteration 1



b) Iteration 2



c) Iteration 3



d) Iteration 4

Fig. 29 : Iterations of Rear Swing Arm Analysis by using Ansys Software

Here we are assigning the ranking for the geometry parameters as follows as per the manufacturability and aesthetics of swing arm.

Table 4.14 : Ranking for geometry parameter

Description	Ranking
Low	1
Below Average	2
Average	3
Good	4
Excellent	5

Dividing parameters into beneficial and non-beneficial categories as per their effect on the swing arm as maximum or minimum. So considering Geometry and stiffness as beneficial parameters as they should be maximum and mass, stresses induced, and deformation as non-beneficial parameters as they should be minimum. Values were observed for different parameters after Ansys and applying generative design concept for each iteration as follows.

Table 4.15: Observed Values of different Parameters

	Beneficial		**Non-Beneficial**			
Iteration	**Geometry**	**Stiffness**	**Mass (Kg)**	**Stress (MPa)**	**Deformation (mm)**	
1	4	5893.79	11.08	35.582	0.33934	
2	5	2140.87	11.41	25.502	0.9342	
3	2	1057.08	8.75	53.634	1.892	
4	1	1948.18	10.8	23.002	1.0266	
Max	**5**	**5893.79**	**8.75**	**23.002**	**0.33934**	**Min**

For decision-making by using multi-criteria here considering the maximum value of beneficial criteria and minimum value of non-beneficial criteria. After dividing these values to actual values will get the multiplication factor as follows.

Table 4.16: Multiplication Factors for Parameters

	Beneficial		**Non-Beneficial**		
Iteration	**Geometry**	**Stiffness**	**Mass**	**Stress**	**Deformation**
1	0.8	1	0.7897111913	0.6464504525	1
2	1	0.3632416493	0.7668711656	0.9019684731	0.363241276
3	0.4	0.1793548803	1	0.4288697468	0.1793551797
4	0.2	0.3305479157	0.8101851852	1	0.3305474381

After getting multiplication factors will assign the weightage to each criterion as per importance in tadpole structured electric vehicle and get the total weightage for deciding the optimized iteration of swing arm for tadpole EV.

Table 4.17 : Total Weightage of Parameters and Ranking

	Beneficial		Non-Beneficial			Total	
Weightage	20	25	20	20	15	100	
Iteration	**Geometry**	**Stiffness**	**Mass**	**Stress**	**Total Displacement**	**Total**	**Ranking**
1	16	25	15.79422383	12.92900905	15	84.7232	1
2	20	9.081041232	15.33742331	18.03936946	5.448619139	67.9064	2
3	8	4.483872008	20	8.577394936	2.690327696	43.7515	4
4	4	8.263697892	16.2037037	20	4.958211572	53.4256	3

4.2.3 Rear Wheel Swing arm assembly

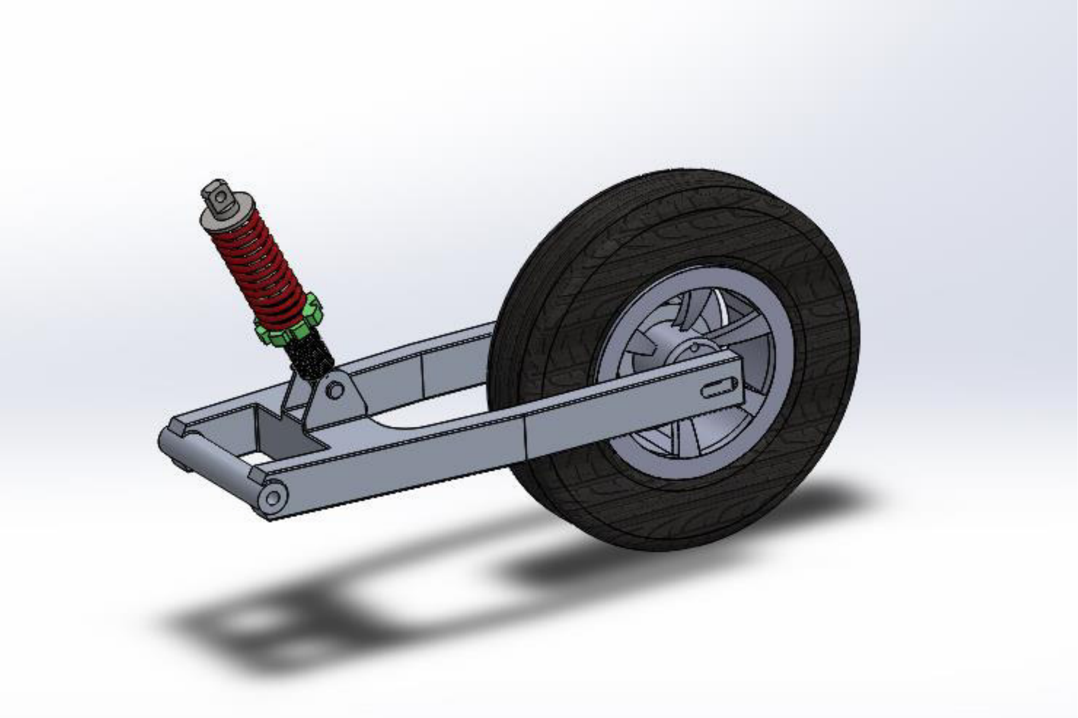


Fig. 30 : Rear wheel Assembly including Mono-shock Suspension

4.3 Design of front wheel assembly and Suspension system

Table 4.18 : Initial Design considerations for Front Wheel Assembly

Parameter	Value
Ground clearance	178 mm
C.G. from ground	400 mm
Wheel base	1800 mm
Track Width	1200 mm
Tire Rate	818154 N/m
Camber	0^o
Castor	0^0
Kingpin Inclination	3^o
Toe Angle	0^0

1. Estimation of maximum weight with driver

Weight on each front Axle/tire

$$W1 = 55 \text{ Kg}$$

$$W2 = 55 \text{ Kg}$$

$$W_f = 110 \text{ Kg}$$

Weight on rear Axle/tire:

$$W3 = W_r = 170 \text{ Kg}$$

Total weight (W) = 280 Kg

2. Design Calculations

Table 4.19: Design Considerations & Parameters

Parameter	Value
C.G. height(z)	406 mm
Roll center height (h)	238 mm
Distance between C.G. and roll center (H): (z-h)	366 mm
Turning radius (R)	2.5 m
Wheel base	1780
Track width	1320

Parameter	Value
Wheel travel	50 mm jounce 50 mm rebound
Roadway bank angle ($\boldsymbol{\alpha}$)	5^0
Velocity (V)	5 m/s

Considered roll rates:

$$K\Phi_{Front} = 7400\frac{Nm}{Rad}$$

$$K\Phi_{Rear} = 10606\frac{Nm}{Rad}$$

Analytical C.G. position:

$b = \frac{(W1 + W2)}{(W) \times L}$………………………………………….. (4.10)

= 0.6461 m

$a = 1 - b$ ……..……………………………………... (4.11)

= 0.926 m

Horizontal lateral acceleration:

$A_\alpha = \frac{V^2}{R\,x\,g}$…………………………………………… (4.12)

= -1.01 g^{-1}s

Lateral acceleration in car system:

$A_\gamma = A_\alpha.\mathrm{Cos}(\alpha) - \mathrm{Sin}(\alpha)$………………………….. (4.13)

= -1.01 g^{-1}s

Effective weight of car due to banking:

$W_e = W\,X\,A_\gamma$ ………………………………………. (4.14)

= 317 kg

Effective weight on front and rear wheels:

$W_{ef} = \frac{W_e b}{L}$……………………………………… (4.15)

= 130.634 Kg

$W_{er} = \frac{W_e a}{L}$ ………………………………………… (4.16)

= 186.88 Kg

Roll angle:

$\frac{\Phi}{A_Y} = \frac{(-W\ .\ H)}{(K\Phi_{Front}+K\Phi_{Rear})}$ ……………………………… (4.17)

Φ = -1.14^0

Front and Rear lateral load transfer due to lateral acceleration:

$W_{Front} = A_Y.\frac{W}{t}\ \frac{H\ .K\Phi_{Front}}{K\Phi_{Front}+K\Phi_{Rear}} + \frac{b}{L}.Z$ …………... (4.18)

$$W_{Front} = -33.56 \text{ Kg}$$

$$W_{Rear} = -48.08 \text{ Kg}$$

The magnitude of $A_\alpha.\text{Cos}(\alpha)$ is greater than magnitude of $\text{Sin}(\alpha)$ thus, the outside wheel load increases.

Therefore, Front & Rear outside load:

$W_{fo} = \frac{W_{ef}}{2} + 48.08$ …………………………… (4.19)

= 98.79 Kg

Similarly,

W_{ro} = 141.66 Kg

Change in static load measurement on ground:

$\Delta W_{front} = W_{fo} - W_{Front}$ …………………….. (4.20)

= 38.79 kg

Similarly,

$$\Delta W_{rear} = \mathbf{55.47}\ \textbf{Kg}$$

Specific ride rate:

$K_{Rf} = \frac{\Delta W_{front}}{Wheel\ Travel}$ ……………………………… (4.21)

= 7489.29 N/m

Similarly,

K_{Rr} **= 10700.2 N/m**

Front and Rear tide frequency:

$W_{frf} = \frac{1}{2\pi}(\frac{K_{Rf}}{W_{Front}})^{\frac{1}{2}}$ …………………………… (4.22)

$$= \mathbf{1.25\ Hz}$$

Similarly,

$$W_{frr} = \mathbf{1.23\ Hz}$$

Therefore, $W_{frf} > W_{frr}$

Wheel Center rate:

$$K_{wfront} = \frac{K_t . K_{Rf}}{K_t - K_{Rf}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.23)}$$

$$= 7558.479 \text{ N/m}$$

$$K_{wrear} = 10842 \text{ N/m}$$

Spring Rate:

$$K_{wfront} = K_{sf} . (IR)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.24)}$$

Assuming Installation Ratio (IR) for front suspension to be 0.75.

Therefore, front spring rate,

$$K_{sf} = \mathbf{13437.3\ N/m}$$

Similarly,

Assuming Installation Ratio (IR) for rear suspension will be 0.5.

Therefore, rear spring rate,

$$K_{sf} = \mathbf{43368 \times 2\ N/m}$$

$$= \mathbf{86736\ N/m}$$

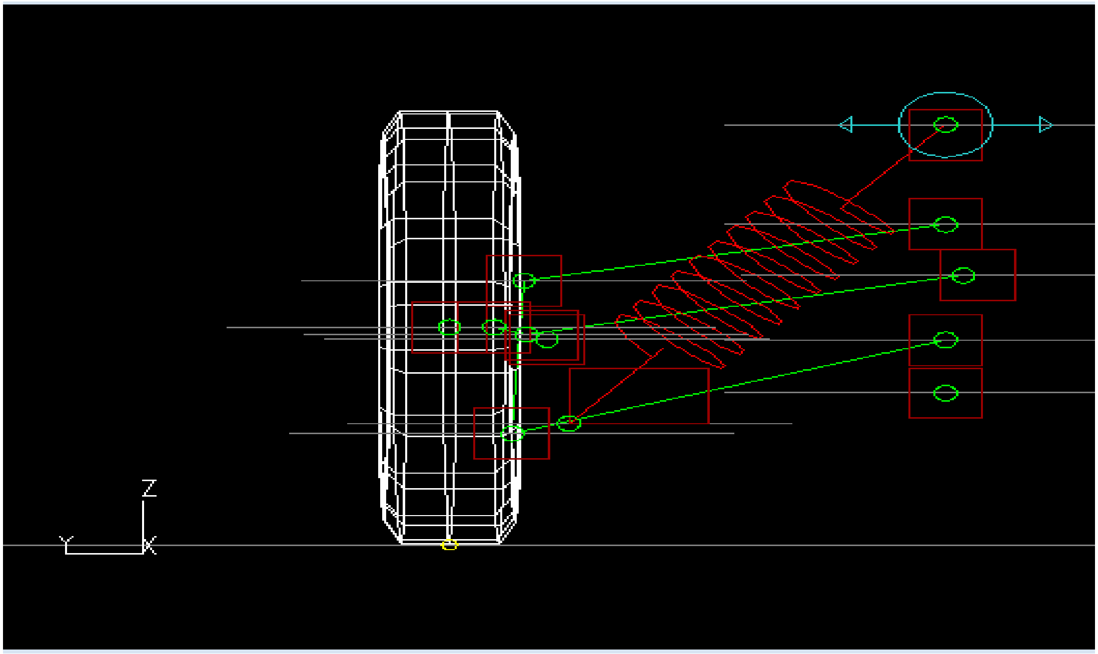


Fig. 31 : Lotus Suspension Analysis

Table 4.20 : Calculated Suspension Parameters

Suspension Parameter	Front	Rear
Type	Double Wishbone	Swing arm
Tire Rate	818.15N/mm	818.15N/mm
Spring Rate	13.4N/mm	86.7N/mm
Installation Ratio	0.75	0.5
Roll angle	1.14^{o}	1.14^{o}
Camber change	1.6875°	0o
Toe angle change	2.16^{0}	00
Castor angle change	0.1870°	00
Kingpin inclination change	0.5319^{0}	00
Halftrack change	1.02 mm	-
Wheelbase change	2.38 mm	-
Un-sprung Mass	20 kg	10 kg

3. Upright

For upright and spindle material selected is **Al 6061 T6** grade because of high tensile strength and light weight characteristics.

Table 4.21: Material Properties of Al 6061 T6

Parameter	Value
Density	2700 Kg/m^{3}
Youngs Modulus	6.89×10^{10} Pa
Poisson's Ratio	0.33
Yield Strength	2.76×10^{8} Pa
Ultimate Tensile Strength	3.1×10^{8} Pa

A. Load Applied on Upright:

Brake caliper mounting = 1000 N

Steering tie rod joint = 1000 N

Factor of safety: 15

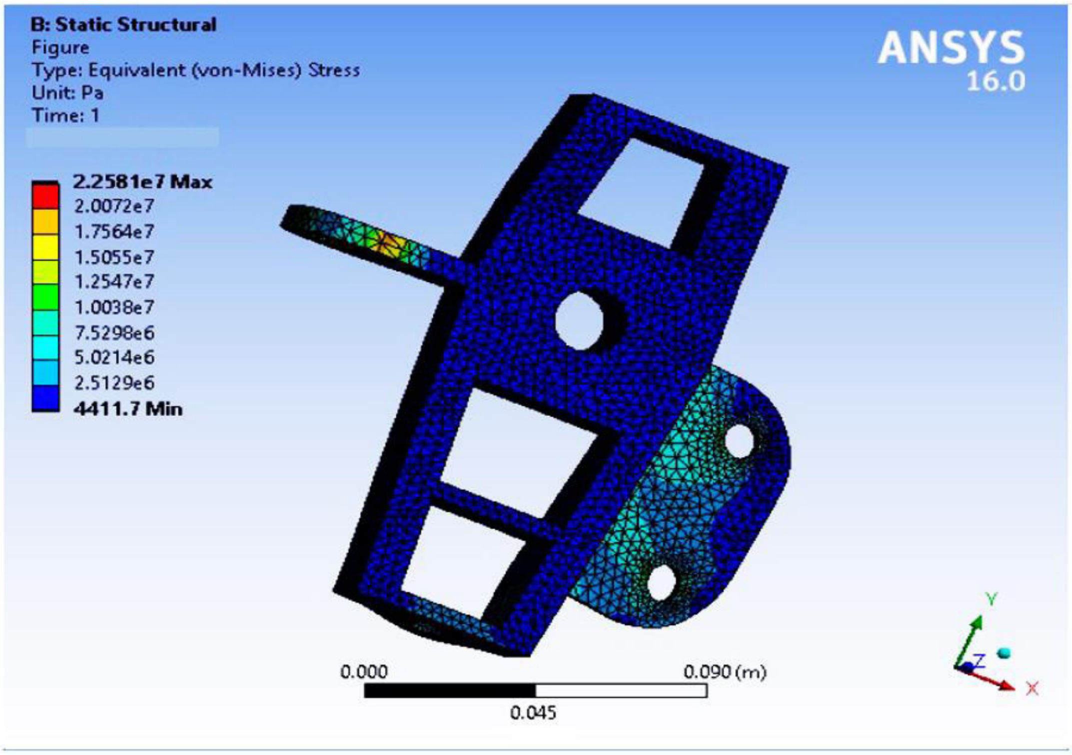


Fig. 32 : Stresses Induced in Upright

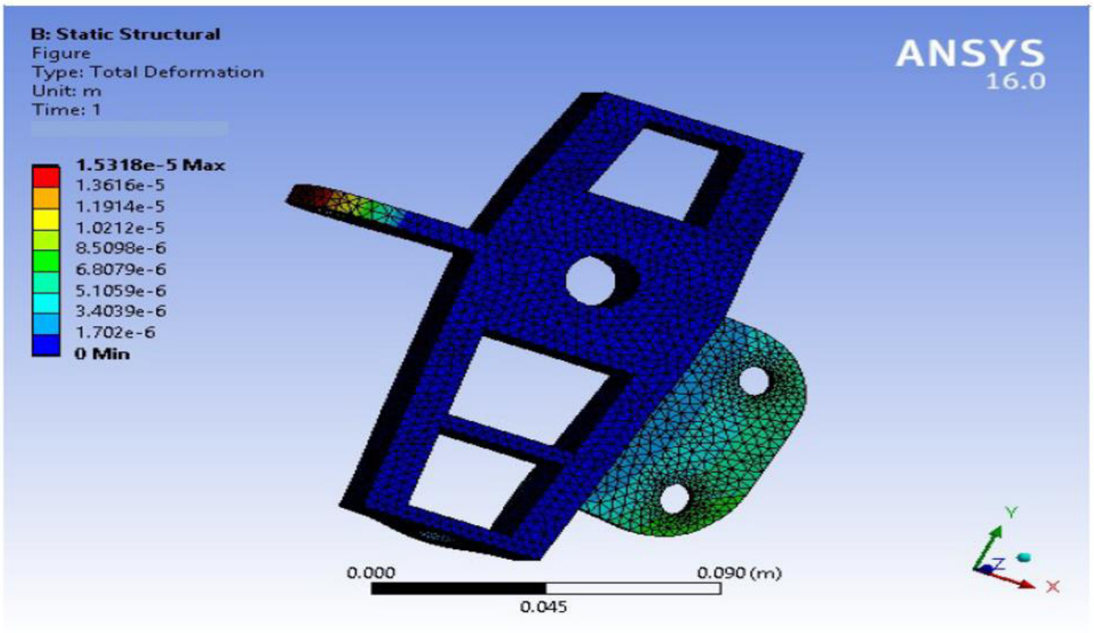


Fig. 33 : Deformation in Upright

1. A-Arms

Material: AISI 4130

Loading condition: 3g

F.O.S: 15

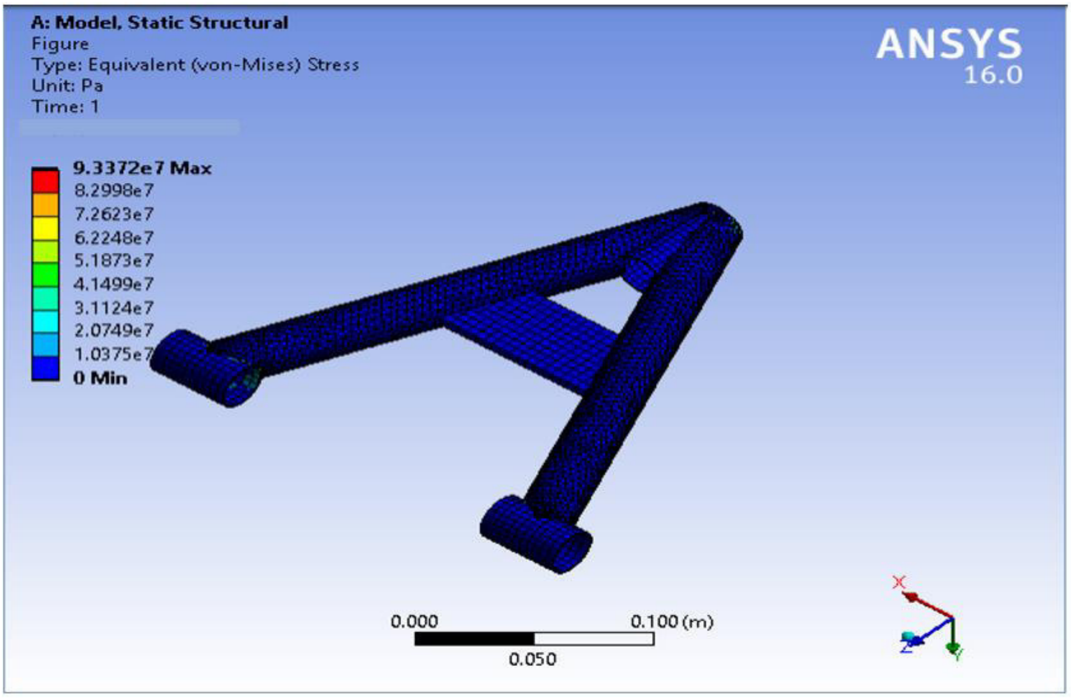


Fig. 34 : Stresses Induced in Lower A- Arm

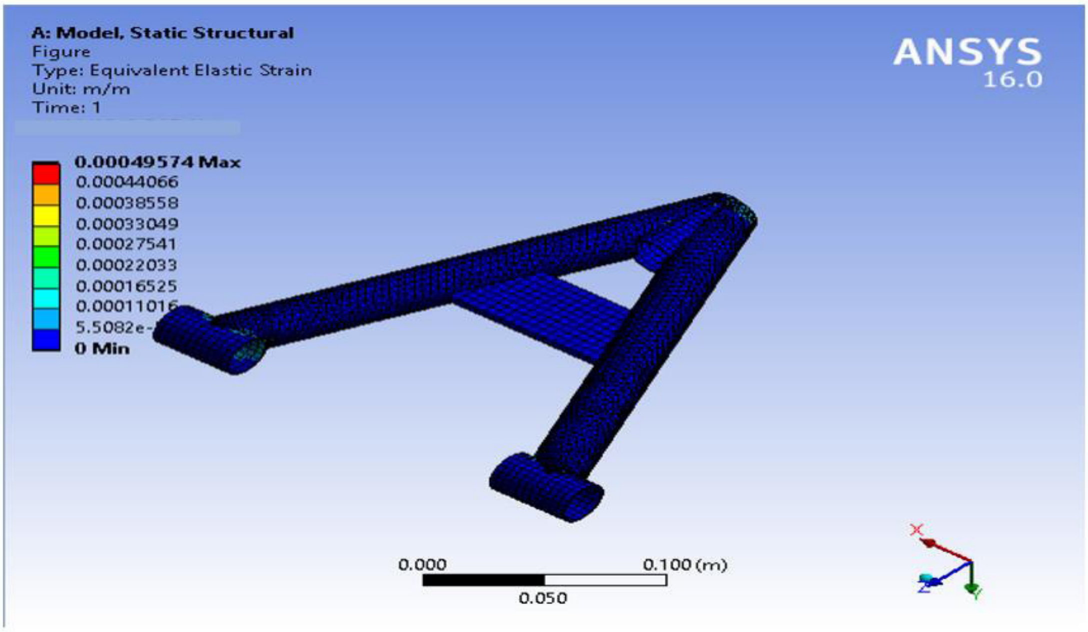


Fig. 35 : Deformation in Lower A- Arm

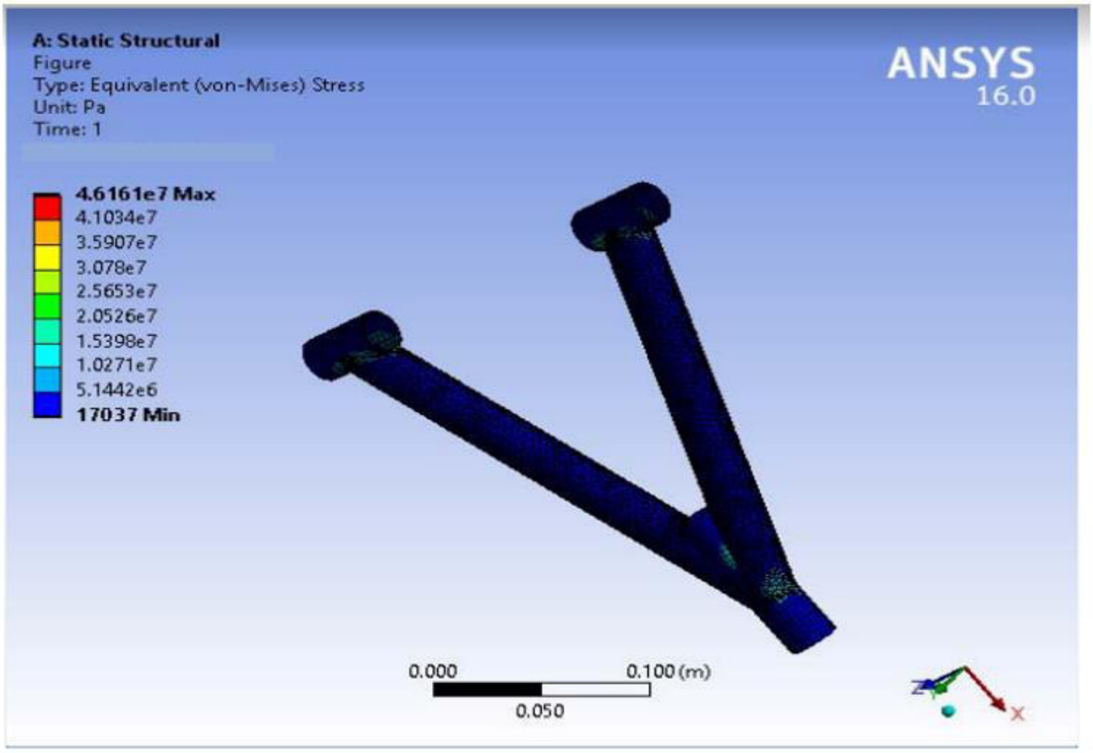


Fig. 36 : Stresses Induced in Upper A- Arm

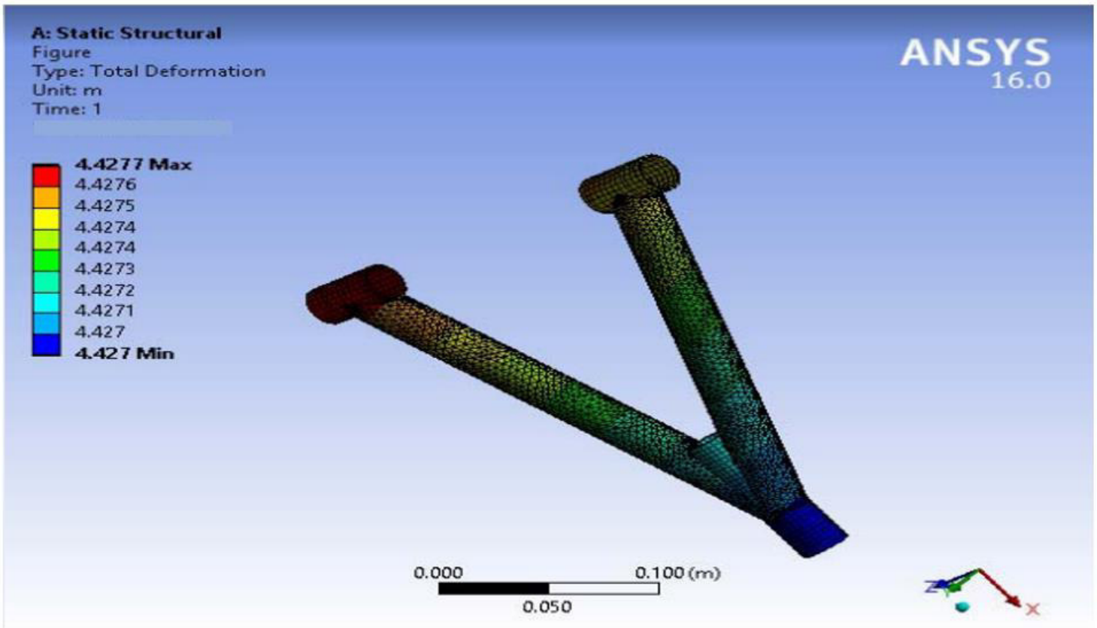


Fig. 37 : Deformation in Upper A- Arm

2. Front Wheel Assembly

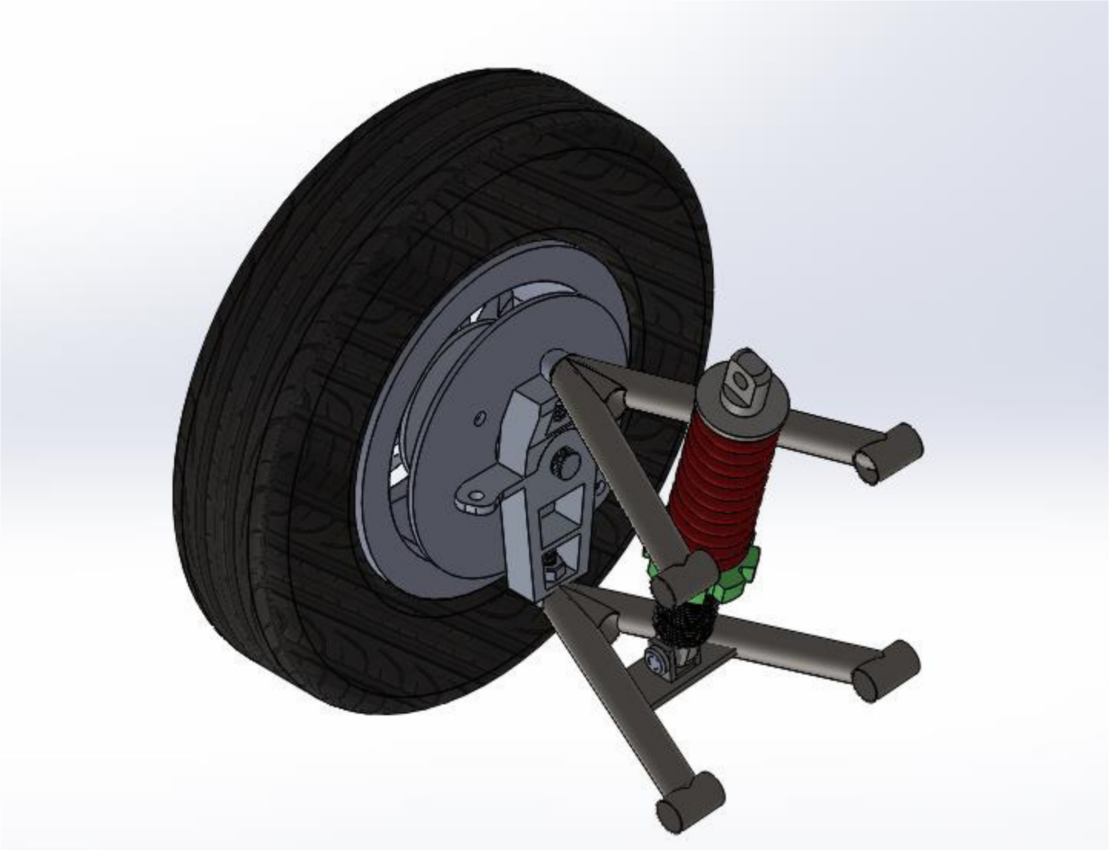


Fig. 38 : Front Wheel Assembly

4.4 Steering System

1. Requirements of steering system:

The steering system must meet the following specifications.

During the maneuvering of the vehicle on a small and curving route, it is imperative for the steering system to possess the capability of executing sharp turns with both ease and fluidity. During a turn, the driver needs to counteract the self-aligning torque by firmly gripping the steering wheel to ensure a seamless recovery of the vehicle. Upon completing the turn, the wheels realign themselves to the straight-ahead position as a result of the self-aligning torque, which occurs when the driver releases the force applied to the steering wheel. The objective is to ensure that there is no loss of steering wheel control and no transfer of kickback caused by road surface roughness and imperfections.

2. Purpose:

The primary function of the steering system is to enable the driver to manipulate the trajectory of the vehicle by rotating the front wheels. The steering wheel serves the purpose of controlling the steering operation. The steering column serves to connect the steering wheel and the pinion. Steering gears are responsible for converting the torque applied to the steering wheel, transmitting it through the steering linkage, and causing the car to turn. A steering linkage refers to the interconnected rods and arms that transfer the motion from the steering gear to the front wheels, enabling them to turn left or right.

3. Ackermann geometry:

- **Turning Radius and Angle:**

$$R=\frac{L}{sin\o}+\frac{T-C}{2} \text{ ………………………….. } (4.24)$$

$$Sin\O = 0.67$$

$$\O = 42.067^0$$

$$cot\Theta - \cot\O = \frac{L}{T} \text{ …………………… } (4.25)$$

$$\Theta = 22.24^0$$

$$\text{Total angle} = 64.3^0$$

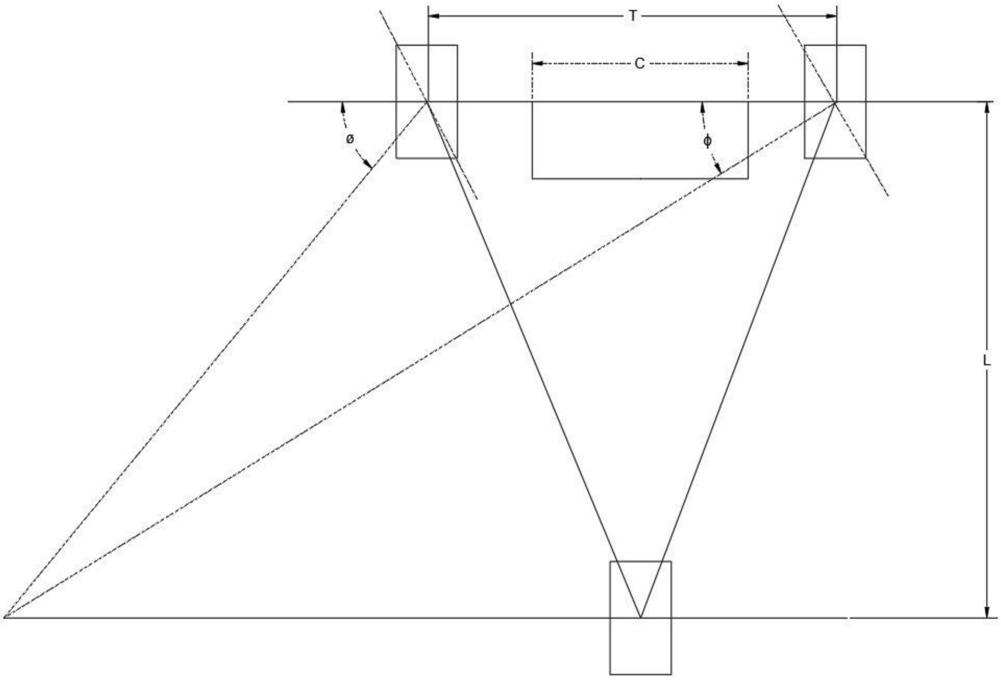


Fig. 39 : Ackermann geometry for Tadpole Structure

$$\text{Steering ratio} = \frac{360}{64.3}$$

$$= 6:1$$

Ackerman percentage = 56.31

Turning radius = 3545.86 mm

Kingpin Inclination = 3.03^0

Radius of steering wheel (r) = 127 mm

= 0.127 m

Torque required (T_s) = f × d × r ……………………(4.26)

= 15×2×0.127

= 3.81N-m

Total rack travel=70 mm turn

=1.5 turn

Hence, rack travel for one rotation of pinion (X_O) = 46.667 mm

$$X_0 = 2\pi r \text{……………………………………………… (4.26)}$$

r = 7.422mm

$$\text{Moment ratio} = \frac{Input}{Output} \text{………………………………….. (4.27)}$$

$$= \frac{R}{r}$$

Moment ratio = 21.74 : 1

Output load = f × 2 × Moment ratio…………………. (4.28)

Output load = 652.2N

Table 4.22 : Double wishbone, damper to lower wishbone Incremental Geometry Values

Rack Travel (mm)	Toe Angle RHS (deg)	Toe Angle LHS (deg)	Camber Angle RHS (deg)	Camber Angle LHS (deg)	Ackermann (%)	Turning Circle Radius (mm)
-30.00	-26.03	21.00	0.53	0.23	56.31	3545.86
-25.00	-21.30	17.38	0.39	0.17	63.91	4389.12
-20.00	-16.88	13.76	0.29	0.14	79.98	5622.44
-15.00	-12.68	10.14	0.22	0.11	116.69	7648.59
-10.00	-8.64	6.49	0.16	0.09	223.78	11708.59
-5.00	-4.74	2.81	0.13	0.09	806.64	24726.5

Rack Travel (mm)	Toe Angle RHS (deg)	Toe Angle LHS (deg)	Camber Angle RHS (deg)	Camber Angle LHS (deg)	Ackermann (%)	Turning Circle Radius (mm)
0.00	-0.93	-0.93	0.10	0.10	510.57	94070.7
5.00	2.81	-4.74	0.09	0.13	806.64	24726.5
10.00	6.49	-8.64	0.09	0.16	223.78	11708.59
15.00	10.14	-12.68	0.11	0.22	116.69	7648.59
20.00	13.76	-16.88	0.14	0.29	79.98	5622.44
25.00	17.38	-21.3	0.17	0.39	63.91	4389.12
30.00	21	-26.03	0.23	0.53	56.31	3545.86

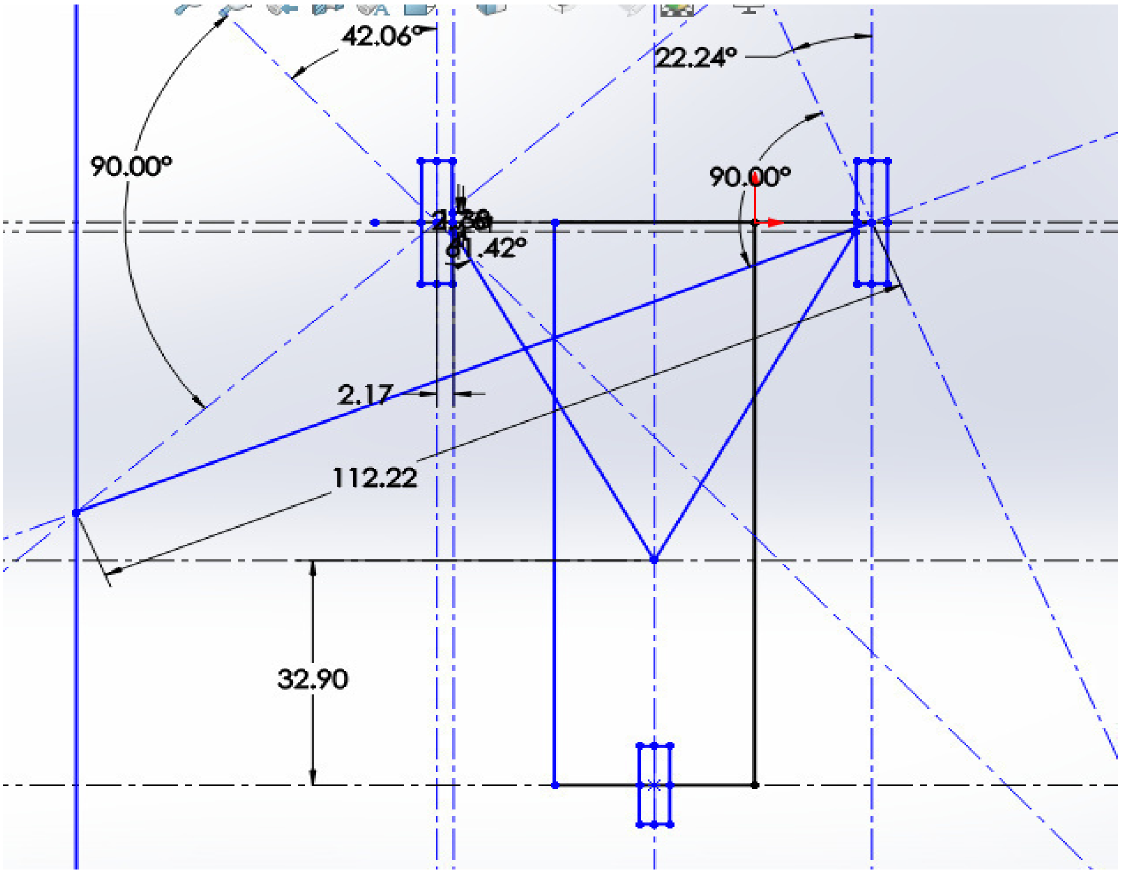


Fig. 40 : Steering Parameters Analysis

4. Result:

Table 4.23: Steering System Parameters

PARAMETERS	VALUE
Wheelbase	1875 mm
Track width	1333.5mm
Inner lock angle	42.06 degree
Outer lock angle	22.24 degree
Camber	0 degree
Castor	0 degree
Kingpin inclination	3.03 degree
Scrub radius	43mm
Toe angle	0 degree
Turning radius	3545.5mm
Rack Travel	140mm end to end
Steering ratio	6:1
Ackermann %	56.31 percentage
Rack Length	11.02 inch

4.5 Battery Selection

1. Battery Type: Lithium-ion battery pack

Chemistry of Cell: $LiFePO_4$.

Chosen the Lithium-ion battery pack due to its lower weight. Research is currently centered around the light weight design strategy. In order to maintain the weight of our car, the lithium-ion battery is a superior choice compared to other existing alternatives. The Battery Management System (BMS) is included with the lithium-ion battery pack. Therefore, it is more secure than a lead-acid battery pack.

Table 4.24 : Selected Battery Pack Specification

Parameter	Value
Nominal Voltage	48 V
Battery Capacity	80 Ah
Low Voltage Cut-Off	41.6 V

Parameter	Value
High- Voltage Cut- Off	57.6 V
Operating Temperature	55^0 C
IP Rating	64
C Rating	0.5 C

2. Selection Criteria:

Availability: The standard voltage sizes are multiples of 12 volts, such as 12V, 24V, 36V, 48V, and 60V.

Cost: As the quantity of cells in the battery pack rises, the total cost of the pack will also increase.

Weight: As capacity increases, the weight of battery pack also increases.

Motor Voltage: Motor, battery and controller voltage should match.

To optimize all above mentioned parameters battery voltage is selected as 48 V and capacity of 80 Ah for development of prototype with minimum cost, minimum weight within the available options of voltage ratings.

3. Power Consumption (P):

P = VOLTAGE * CAPACITY

= 48 * 80

= 3840 Watt.

4. Continuous Run Time of Battery Pack:

Capacity: C = 80 AH

Operating Voltage: V = 48 volt

Average current consumption by motor: I = 25 Amps

Total run time: $T = \frac{C}{I}$

$= \frac{80}{25}$

= 3.2 Hours

Theoretical Range: At Average speed of 50 kmph for 3.2 hours and 20% SOC at the end we can get range of 150 Km.

4.6 Braking System Design

1. Requirements of Braking System

The brakes on the front and rear should be capable of locking the wheels simultaneously. There must be a balance between the amount of clamping force generated and the pedal travel as they are inversely related. The braking torque generated at optimum pedal effort and travel should be much greater than the required braking torque. There should be a provision of two independent hydraulic systems to ensure braking even during failure of one of the systems. [43] The braking torque generated should not be such that the vehicle topples over and loses contact with the ground. In this research, vehicle has incorporated an all-wheel disc braking system is chosen due to its numerous benefits and the simplicity of its installation and maintenance.

The following criteria and parameters were considered during the design of the all-wheel disc brake system:

Table 4.25 : Braking Parameters and Values

PARAMETERS	VALUES
Front Disc diameter	228 mm
Rear Disc diaeter	228 mm
Front Caliper piston diameter	64 mm
Rear Caliper piston diameter	64 mm
Coefficient of friction (μ_r)	0.7
Coefficient of friction (μ_p)	0.6
Master Cylinder Bore Diameter	127 mm
Maximum Velocity	60 Km/h
Maximum Weight of vehicle considered	280 kg

A single pedal, which is aligned with two separate master cylinders, controls the hydraulic braking system. The implementation of two separate master cylinders functions as a safety measure, guaranteeing that in the case of a fault in one cylinder, the other cylinder remains operational. Another advantage of using dual master cylinders is the ability to precisely adjust the braking bias. The braking circuit used is rectangular in shape. This particular approach was used due to the tires' possession of a positive scrub radius. Therefore, the front braking system will be controlled by one cylinder, while the rear system will be controlled by the other cylinder.

2. Caliper Selection

All three calipers are of the floating type due to their compactness and ease of installation on automobiles. Furthermore, they possess a reduced number of potential areas for leakage in comparison to fixed piston variants.

3. Master Cylinder Selection

Each Master cylinder forms an individual hydraulic braking circuit. Similar master cylinders were chosen for rear and front as a bias bar was installed to distribute pressure proportionately to the front and rear. The brake circuit designed is of horizontal split type. One cylinder will control the front braking and the other the rear system.

4. Pedal

The pedal was designed by keeping in mind that, It should be able bear the load of 2000N. Light weight and feel comfortable to the driver. In case of excessive pedal travel i.e. brake failure due to leakage etc.., a brake over travel switch is to be activated resulting in complete shutdown of the electrical systems. A pedal ratio of 6:1 is selected by considering master cylinder bore size, caliper piston diameter, pedal travel etc. A force of 2000N applied on the pedal pad with the inner circle for balance bar in the pedal as the fixed geometry. Aluminium is the material selected based on its density and yield stress.

5. Braking Calculations

Force/Pressure exerted on MC Bore - F_{mc}/P_{mc}

Force/Pressure developed on calipers – $\frac{F_c}{P_c}$

Clamping force on each wheel – $\frac{F_{CF}}{F_{CR}}$

Effective rotor radius - r_e

Max. Retardation – a

MC Bore area – A_{mc}

Caliper piston area – A_c

Mechanical leverage (m)= 6:1

Force acting on the master cylinder:

$$F_{mc} = m \; x \; F_p \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \; (4.28)$$

= 8776.2444 N

Area of master cylinder (piston/bore):

$$A_{mc} = \pi \frac{b^2}{4} \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \; (4.29)$$

= 2516 mm^2

Pressure generated:

$$P_c = \frac{F_{mc}}{A_{mc}}$$

= 3.48 N/mm^2

Area of caliper:

$$A_{cp} = \pi \frac{{d_{cp}}^2}{4} \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \; (4.30)$$

= 2542 mm^2

Force on caliper:

$$F_{cp} = P_c \; X \; A_{cp} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \; (4.31)$$

= 8776.244 N

By two caliper pistons:

$$F_c = 2F_{cp}$$

= 17552.48 N

Force on disc:

$$F_d = \; \mu \; x \; F_c$$

= 10531.488 N.

Braking Torque:

$$T_b = \; F_d \; x \; \frac{D_d}{2} \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \; (4.32)$$

= 1069.97 N-m

Braking Force:

$$F_b = \frac{2T_b}{D_w} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(4.33)$$

= 4680.661 N

On two tires = 9361.322 N

Stopping Distance:

Table 4.26 : Braking Parameters

Parameter	Case-I	Case-II
Distance (S)	5 m	2 m
Initial Velocity (u)	40 KMPH	40 KMPH
Acceleration (a)	-12.34 m/s^2	-30.85 m/s^2
Inertia Force (F)	3209 N	8023 N
Energy Generated	15146 J	16046 J

As **F_b > ma,** Therefore, braking is effective.

PROTOTYPE AND TESTING

5.1 Chassis Manufacturing for Tadpole Structured Electric Vehicle

This section delves into the manufacturing process of the chassis for a tadpole-structured electric vehicle, based on the design considerations and optimizations detailed in "Chapter 4". The primary focus is to fabricate a chassis that not only meets the design criteria of weight, strength, and crashworthiness but also aligns with the unique requirements of a tadpole configuration.

5.1.1 Design Considerations

The chosen material for the chassis is AISI 4130 steel, known for its excellent strength-to-weight ratio, fatigue strength, and weldability. The tubing used predominantly has an outer diameter (OD) of 25.4 mm with varying thicknesses from 1 mm to 1.2 mm, supplemented with sheet steel for additional support. This choice ensures a balance between structural integrity and weight efficiency.

5.1.2 Fabrication Techniques

- **Tube Cutting and Bending:** The AISI 4130 steel tubes, selected for their optimal strength and weight characteristics, are cut to specific lengths. Cutting is done with a high-precision laser cutting machine to ensure accuracy and intersection curvature as a crucial factor for the assembly process. The tubes are then shaped using the bending technique whenever required. This process is vital for achieving the necessary chassis geometry while maintaining the material's structural integrity. The bending process is closely monitored to ensure consistency with the design angles and dimensions.
- **Welding and Assembly:** The chassis assembly involves welding the cut and bent tubes. This process employs the TIG welding technique to ensure strong and durable joints. Welding is executed under strict quality control to prevent any defects that might compromise the chassis's strength. Post-welding, the chassis is inspected for alignment. This step is critical to ensure that the chassis conforms to the specified geometrical design. Any misalignments are corrected to ensure that the chassis provides the desired structural integrity and vehicle handling characteristics.

5.1.3 Integration of the Roll Hoop

The chassis incorporates a specially designed roll hoop to enhance safety during rollover scenarios. This feature is particularly important in a tadpole vehicle structure, where the dynamics can differ significantly from traditional vehicles. The roll hoop is integrated into the chassis using bolt connections. This design choice allows for the roll hoop to be removable, facilitating future modifications or replacements as needed. The bolting mechanism is chosen for its strength and ease of assembly and disassembly.

5.1.4 Surface Treatment and Finishing

The chassis undergoes thorough surface cleaning to remove any contaminants, followed by a surface treatment process to enhance paint adhesion and corrosion resistance. A layer of primer is applied, followed by high-quality paint to protect against environmental factors.

5.1.5 Component Integration

Specific mounting points for the suspension, motor, battery pack, and other critical components are marked and prepared on the chassis. The suspension system, steering mechanism, and drivetrain components are assembled and aligned with the chassis.

Fig. 41 : Integrated Chassis

5.2 Rear Swing Arm Manufacturing and Assembly

The rear swing arm plays a critical role in the overall dynamics of a tadpole-structured electric vehicle, as detailed in "Chapter 4". It must be manufactured with precision to ensure proper alignment, strength, and functionality. This section outlines the process of manufacturing and assembly of rear sing arm.

5.2.1 Material Selection

7076 T6 Aluminium alloy selected for its high strength-to-weight ratio, this material is ideal for creating a lightweight yet durable swing arm. The choice of material is crucial for maintaining the balance between performance and efficiency.

5.2.2 Fabrication Techniques

The aluminum alloy is cut and shaped to match the design specifications. Precision-cutting tools are used to ensure accurate dimensions and profiles. The cut materials are machined to create the necessary mounts, pivot points, and attachment areas. This process includes CNC milling, and drilling for such a complex geometry. To enhance corrosion resistance and durability, the swing arm undergoes anodizing and powder coating. This also provides an aesthetic finish to the component.

5.2.3 Integration of Bushings and Bearings

Bushings are inserted at the pivot points to ensure smooth movement and to reduce wear. They are typically made of nylon materials that offer low friction and high durability. Bearings are fitted to the pivot points to handle radial and axial loads. Precision is key in this step to ensure smooth operation and alignment.

5.2.4 Mounting of the Suspension Components

The swingarm is designed with specific attachment points for the suspension components, like the shock absorber. After the suspension components are mounted, an alignment check is performed to ensure that everything is correctly positioned according to the design specifications. The swingarm is mounted to the rear section of the chassis. All bolts and fasteners are tightened to the specified torque settings to ensure secure attachment and to prevent loosening during operation.

Fig. 42 : Rear Wheel Assembly

5.3 Upright Manufacturing Using CNC Machining

The manufacturing of uprights for a tadpole-structured electric vehicle, as outlined in "Chapter 4", requires precision and accuracy. CNC (Computer Numerical Control) machining is a critical process in this context, offering high precision, repeatability, and efficiency. This section describes the manufacturing process of the uprights using CNC machining techniques.

5.3.1 Material Selection

Typically, materials like Al 6061 T6 grade aluminum are used for uprights due to their high tensile strength and lightweight properties. This material is particularly suited for CNC machining.

5.3.2 CNC Machining Process

The CAD model is translated into a CNC program using CAM (Computer-Aided Manufacturing) software. This program directs the CNC machine on how to move, cut, and shape the material. The CNC machine performs various operations such as drilling, milling, and tapping to create the complex geometries of the upright. This includes the creation of bearing housings, brake caliper mounts, and attachment points for suspension components.

5.3.3 Surface Treatment and Finishing

After machining, the uprights may undergo surface finishing processes like sandblasting or polishing to improve their appearance and surface quality. To enhance corrosion resistance and durability, the uprights are coated with protective materials.

5.3.4 Integration and Assembly

The uprights are integrated with other suspension components like wheel hubs, bearings, and suspension arms, and steering rods.

5.4 Integration of Vehicle Components: Suspension, Steering, Motor, Battery, and Electrical Connections

The integration of various components like the suspension, steering, motor, battery, and electrical connections is a critical phase in the assembly of a tadpole-structured electric vehicle, as outlined in "Chapter 4". This process involves careful coordination and precision to ensure optimal vehicle performance, safety, and reliability.

5.4.1 Mounting of Suspension Components

- **Front Suspension - Double Wishbone Setup:** The double wishbone suspension, known for its superior handling and control, is installed at the front. Each component, including the upper and lower arms, springs, and shock absorbers, is carefully positioned and secured to the chassis. Precision is key in aligning the wishbones to maintain the correct geometry, which is essential for effective shock absorption and maintaining tire contact with the road. The shock absorbers and springs are mounted within the wishbone structure. This setup is critical for absorbing impacts and providing a smooth ride.
- **Rear Suspension - Swing Arm Assembly:** The rear swing arm, pivotal for the vehicle's stability and handling, is mounted to the rear of the chassis. This component acts as the main linkage between the chassis and the rear wheel. The rear shock absorber is attached to the swing arm. The positioning and securing of the shock absorber are crucial for effective damping and response to road irregularities.

In both the front and rear suspension setups, every bolt and fastener is tightened to specified torque settings. This precision ensures the suspension system remains intact and functions correctly under various driving conditions.

5.4.2 Steering System Assembly

The assembly of the steering system is a critical component in the construction of a tadpole-structured electric vehicle, ensuring precise maneuverability and handling. This section outlines the integration process of the steering mechanism, focusing on the steering rack and pinion, linkages and tie rods, and wheel alignment.

Steering Mechanism Integration

- **Steering Rack and Pinion:** The steering rack is mounted onto the vehicle's chassis. This mounting must be robust and secure to withstand the forces exerted during steering. The pinion, which is attached to the steering column, is carefully aligned and connected to the steering rack. Precise alignment is crucial to ensure that the steering input from the driver is accurately transmitted to the steering mechanism. Once the rack and pinion are connected, the assembly is checked for smooth operation. Any resistance or irregularity in movement necessitates an adjustment to ensure steering response.
- **Linkage and Tie Rods:** Steering linkages are installed to connect the steering rack to the tie rods. This setup converts the linear motion of the rack into the angular motion required to turn the wheels. The tie rods are attached to the ends of the steering rack. These rods are critical for transmitting the steering forces to the wheels. The tie rods are adjusted to achieve the correct toe settings, which are essential for optimal tire wear and vehicle handling.
- **Wheel Alignment:** Proper wheel alignment is conducted to ensure the vehicle’s wheels are set to the angles specified in the design. This includes camber, caster, and toe adjustments. Correct wheel alignment is essential for predictable vehicle handling and stability. It also ensures even tire wear and optimal driving performance.

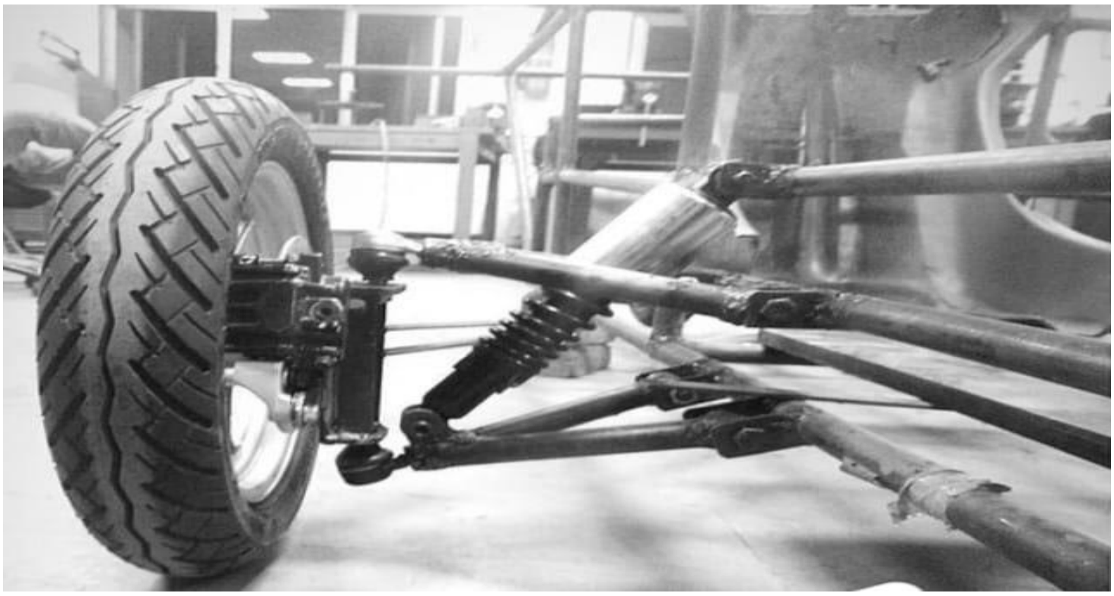


Figure 43 : Front Wheel Assembly

5.4.3 Motor and Drive Train Installation

The installation of the motor and drive train is a pivotal aspect of assembling a tadpole-structured electric vehicle, playing a crucial role in the vehicle's power delivery and overall performance. This process demands meticulous attention to detail in both the positioning and alignment of the motor and its integration with the drive train.

The electric motor is strategically positioned within the chassis. This location is carefully chosen to maintain the vehicle's center of gravity and to ensure optimal weight distribution, which is essential for the vehicle's handling and stability. The motor is securely mounted onto the chassis using robust mounting brackets and fasteners. These mounts are designed to handle the torque produced by the motor and to minimize vibrations. Precise alignment of the motor is critical. Misalignment can lead to inefficient power transmission and increased wear on the drive train components. The alignment is checked and adjusted to ensure that the motor shaft is parallel and co-axial with the drive train components.

5.4.4 Battery System Integration

The battery pack is installed in a position that maintains the vehicle's center of gravity and does not interfere with handling. This often involves a secure, vibration-resistant mounting system. Electrical Connections: The battery is connected to the electric motor and the vehicle's electrical system. This includes high-voltage connections and the integration of the Battery Management System (BMS).[91]

The battery pack is positioned to maintain the vehicle's center of gravity. Its location is strategically chosen to ensure it does not adversely affect the vehicle's handling and stability. This is particularly important in a tadpole configuration where weight distribution can significantly influence driving dynamics. The battery pack is secured using a mounting system designed to withstand vibrations and shocks that are typical in vehicle operation. This system often includes reinforced brackets and vibration-resistant materials to ensure the battery remains stable in various driving conditions. The mounting design also considers ease of access for maintenance, ensuring that the battery pack can be easily inspected, serviced, or replaced as needed.

5.4.5 Electrical Connections

The battery pack is connected to the electric motor through high-voltage cabling. This connection must be robust and well-insulated to handle the high power levels safely. The battery also powers the vehicle's electrical system, including lighting, instrumentation, and control units. These connections are carefully routed and secured to prevent any electrical interference or hazards.

The Battery Management System is a crucial component that monitors and manages the battery's health, state of charge, and temperature. Integrating the BMS involves connecting it to the battery cells and calibrating it to ensure it accurately assesses and reports the battery's status. Post-integration, comprehensive safety checks are performed. These include testing for short circuits, and insulation resistance, and ensuring all electrical connections are secure and properly insulated.

5.4.6 Electrical System and Wiring

The installation of the electrical system and wiring is a fundamental aspect of assembling a tadpole-structured electric vehicle. It involves the meticulous installation of the wiring harness and the connection of various electrical components. This process is crucial for the reliable operation of the vehicle's electrical and electronic systems.

- **Wiring Harness Installation:** The wiring harness, comprising a network of wires and connectors, is carefully laid out and routed throughout the vehicle.

The routing is planned to avoid areas of high heat, moving parts, and sharp edges that could damage the wiring. The harness is securely fastened using clips and ties to prevent it from moving or chafing, which could lead to electrical shorts or disconnections. Special attention is given to ensure that the wiring does not interfere with the vehicle's mechanical components. The harness is protected against environmental factors such as moisture and dust. This is often achieved using conduit or protective sleeving, especially in areas exposed to the external environment.

- **Connection to Electrical Components:** The wiring harness is connected to the vehicle's lighting system, including headlights, taillights, turn signals, and brake lights. These connections are crucial for safety and legal compliance. Various sensors and control units are connected to the harness. These include the vehicle speed sensor, battery management system, motor controller, and any other sensors required for the vehicle's operation. The dashboard and instrumentation, which provide the driver with vital information such as speed, battery charge level, and warning indicators, are connected to the harness. This ensures the driver has access to accurate and up-to-date vehicle information. Additional electrical components such as the audio system, air conditioning controls, and interior lighting are also connected to the wiring harness. These connections are made to ensure functionality and user comfort.

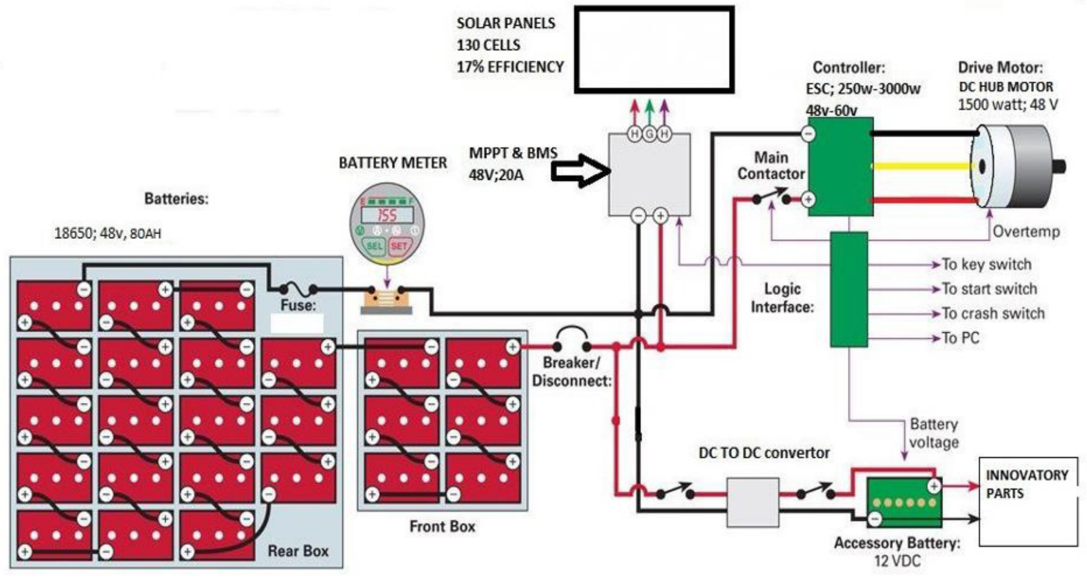


Fig. 44 : Wire Diagram of Tadpole Structured EV

5.4.7 Braking System Integration

The manufacturing process of the braking system components for a tadpole electric vehicle involves meticulous design and fabrication techniques, especially considering the unique demands of electric vehicles. Let's delve into the details of the manufacturing processes for the calipers, discs, brake pads, and hydraulic lines:

- **Calipers and Discs:** Calipers often made from high-strength materials like aluminum alloys, which offer a good balance between strength, weight, and heat dissipation. Discs are typically constructed from cast iron or reinforced carbon-carbon composites, especially for high-performance vehicles, due to their excellent heat dissipation properties.
- **Machining Process**: Precision machining is employed to ensure the calipers and discs meet exact dimensions and tolerances. This includes CNC (Computer Numerical Control) machining for accurate and consistent results. Surface treatments or coatings might be applied to the discs for added durability and performance under high-temperature conditions.
- **Brake Pads:** Made from a composite of materials including metals, ceramics, and organic fibers. The exact composition is tailored to provide the desired balance of friction, wear resistance, and heat dissipation. The materials are mixed, pressed into the shape of the brake pad, and then heat-cured in an oven to create a dense, durable material. Surface treatments or coatings can be added to optimize performance and reduce noise and dust.
- **Hydraulic Lines:** Hydraulic lines are made from materials like reinforced rubber or stainless steel. The choice depends on factors like flexibility, strength, and resistance to high-pressure conditions. For rubber lines, the rubber is extruded into the desired shape and then reinforced with materials like Kevlar or steel wire for added strength. Metal lines are typically bent and shaped using precision tools to fit the specific layout of the vehicle's braking system.
- **Installation of the Braking System:** The installation of the braking system in a tadpole electric vehicle is a critical process that involves several key steps to ensure the system's effectiveness and safety. Calipers are attached to the wheel hubs using bolts. The mounting must be secure and precise to ensure proper

alignment with the brake discs. In tadpole vehicles, front wheel assemblies usually bear more braking force, so the front calipers and discs are particularly robust. Brake discs are mounted onto the wheel assembly. Precision is crucial to ensure that the discs are perfectly aligned to avoid wobbling or uneven wear.

- **Brake Pads and Fluid:** Brake pads are inserted into the calipers. It's essential that they are correctly positioned for effective braking and to prevent noise or premature wear. The hydraulic system is filled with brake fluid. This process must be performed carefully to avoid air entrapment in the system, as air bubbles can significantly reduce braking efficiency. The system is then 'bled' to remove any trapped air. This is done by forcing brake fluid through the system until only fluid, with no air bubbles, emerges from the bleed valves. Hydraulic lines are routed from the master cylinder to each of the brake calipers. The routing must ensure there are no kinks or sharp bends that could impede fluid flow. The lines are securely connected to the master cylinder, which actuates the brakes when the brake pedal is pressed.

Fig. 45 : Braking System Master Cylinder

- **Adjustment and Balancing:** The braking force is adjusted to ensure a proper balance between the front and rear brakes. This balance is crucial, especially in a tadpole configuration, to prevent instability or uneven braking during operation. Modern electric vehicles often include electronic systems for enhanced braking functions, such as regenerative braking. These systems require the integration of ECUs and sensors with the mechanical braking system.

The system is calibrated to ensure that the electronic and mechanical components work seamlessly together. This includes adjusting sensor readings and actuator responses. Proper installation is crucial for the safety, efficiency, and longevity of the braking system in a tadpole electric vehicle.

5.5 Bill of Material and Cost Sheet

Table 5.1: Bill of Material and Cost

Sr. NO.	Component	Description	Quantity	Total Cost (Rs.)
1	Chassis Pipes	AISI 4130 (1mm Thickness)	110 ft	14,200
2	MPPT	Brand UNGE	1	8,913
3	Motor (Hub)	1.5 kW	1	16,000
4	Motor Controller	1.5 KW	1	4,000
6	Battery	Li-FePo4	1	1,10,000
7	Miscallaneous (Electronics)			20,000
8	Rack and Pinion Set	6:1 Steering Ratio	1	4,000
9	Steering Wheel	10 inch	1	1,000
10	Body Material	Acrylic	1	4,000
		Aluminium	1	2,000
11	Suspension Struts		3	2,000
12	Upright	Custom Made	2	6,000
13	Brake Assembly		3	7,000
14	Swing Arm		1	2,000
15	Miscallaneous (Mechanical)			7,000
			Total	**2,08,113**

5.6 Prototype Testing

5.6.1 Brake Test

A. Stopping Distance Test: The Stopping Distance Test is a fundamental part of vehicle brake testing, providing essential data on the effectiveness and safety of the braking system. This test is critical for evaluating how quickly a vehicle can come to a complete stop under various conditions. Here's an in-depth look at how the Stopping Distance Test is conducted. [92] The primary goal of the Stopping Distance Test is to measure the distance a vehicle travels from the time the brakes are applied until it comes to a complete stop. This data is crucial for assessing the effectiveness of the braking system and ensuring it meets safety standards.

- **Test Setup:**

1. **Test Track Selection**: A flat, straight, and level track is chosen to ensure consistent and accurate results. The surface condition (dry, wet, gravel, etc.) is noted as it significantly impacts stopping distances.

Fig. 46 : Track Selected for Braking & Acceleration Test

2. **Vehicle Preparation**: The vehicle is inspected to ensure it's in a standard driving condition with no modifications that could affect braking performance. Tires are checked for proper inflation and tread condition. The brake system is inspected for proper functionality.
3. **Instrumentation**: The vehicle is equipped with sensors to accurately measure speed and stopping distance. A high-speed camera may be used for additional data collection and analysis.

- **Test Procedure:**

1. **Speed Variations**: The vehicle is accelerated to various predetermined speeds (e.g., 30, 50, 60 Kmph). Different speeds are tested to assess braking performance under various driving conditions.
2. **Brake Application**: At each test speed, the brakes are applied firmly and consistently to simulate an emergency stop. The force applied to the brake pedal should be the same for each test to ensure consistency.
3. **Measurement**: The distance from the point where the brakes are applied to where the vehicle comes to a complete stop is recorded. The test is repeated multiple times at each speed to ensure reliability and accuracy of the data.

- **Data Analysis:** The data collected is analyzed to determine the average stopping distance at each speed. The results are compared to standard safety benchmarks and regulations.

B. High-Speed Braking Test: Tests the stability and control of the vehicle when brakes are applied at high speeds. Essential for assessing the risk of skidding or loss of control. The High-Speed Braking Test is a crucial part of vehicle safety assessments, particularly aimed at evaluating the stability and control of a vehicle under high-speed braking conditions. This test is vital for determining how effectively a vehicle can maintain control and prevent skidding when the brakes are applied at high speeds. The primary aim is to assess a vehicle's braking performance, stability, and control at high speeds. This test helps identify any potential risks of skidding or losing control during sudden or emergency braking scenarios.[93]

- **Test Procedure:**

The vehicle is accelerated to a high speed, typically above highway cruising speeds, to simulate emergency braking situations on fast roads or highways. At the predetermined speed, brakes are applied firmly to simulate a sudden stop. The force and method of brake application are kept consistent in each test iteration for reliable results. The vehicle's response, including any tendency to skid or lose control, is closely monitored. The stopping distance and time are recorded, along with any deviation from a straight-line stop. The test is repeated several times to account for variability and to ensure data reliability. Data on stopping distance, vehicle stability, and any control loss incidents are analyzed. The vehicle’s behavior under braking is evaluated, with particular attention to any skidding, fishtailing, or loss of directional control.

Table 5.2 : Brake Test Performance of Vehicle

Test Run No.	Initial Speed (kmph)	Stopping Distance (m)	Time to Stop (seconds)	Skid Marks (yes/no)	Vehicle Control (Stable/Unstable)	Brake System Response	Additional Notes
1	30	1.5	3.2	No	Stable	Good	-
2	30	1.3	3.4	No	Stable	Good	-
3	50	4.0	4.8	No	Stable	Good	-
4	50	3.5	4.6	Yes	Stable	Good	-
5	60	4.5	6.1	Yes	Unstable	Poor	Skidding occurred
6	60	4.7	6.0	No	Unstable	Average	Slight vibration in the pedal

5.6.2 Aerodynamic Drag Test

Performing an aerodynamic drag test on a vehicle is crucial for assessing its efficiency and performance, especially at higher speeds where drag significantly impacts fuel economy and acceleration. Here's a detailed overview of how to conduct an aerodynamic drag test. [94]

- **Preparation and Setup:** Ensure the vehicle is in standard driving condition. All tires should be properly inflated, and the vehicle's surface should be clean and free from any modifications that could affect aerodynamics.
- **Open Road Testing (Coastdown Testing):** Open Road Testing, also known as Coastdown Testing, is a practical method to evaluate a vehicle's aerodynamic drag and overall resistance. [95]
- **Test Procedure:** The vehicle is accelerated to a specific speed, which is usually representative of common driving conditions (e.g., highway speeds). Ensure that the vehicle reaches and maintains this speed steadily before beginning the coastdown phase. Once the predetermined speed is reached, the motor power is disengaged, and the vehicle is allowed to coast down naturally.

The transition from powered to coasting should be smooth to avoid influencing the test results. During the coastdown, record the time taken for the vehicle to slow down to a lower specified speed. Use precise instruments (like GPS speedometers) to record speed over time accurately. Conduct the test several times under similar conditions to ensure data reliability. Variations in wind, road grade, and other environmental factors can affect the results, so multiple runs help average out these variables.

- **Data Analysis for Drag Coefficient:** The primary goal is to calculate the vehicle's drag coefficient (Cd), a measure of its aerodynamic efficiency. Use the formula Drag force (D) can be derived from the deceleration rates observed during the coastdown.

$$C_d = \frac{2D}{\rho v^2 A}$$

Where,

D - Drag force

ρ - Air density

v – Velocity

A - Frontal area of the vehicle

Table 5.3 : Results of Aerodynamic Drag Coefficient

Test Run No.	Initial Speed (kmph)	Final Speed (kmph)	Coasting Time (seconds)	Calculated Drag Coefficient (Cd)	Observations
1	40	20	12.5	0.32	Stable descent, no turbulence noticed
2	45	25	13.0	0.33	Minor turbulence at rear end
3	50	30	11.8	0.31	Smooth coastdown, consistent with previous run
4	55	35	12.1	0.32	Slight vibration observed in chassis
5	60	40	10.5	0.30	Very stable, efficient airflow

5.6.3 Yaw Rate Testing

To measure the vehicle's response to steering inputs, particularly its ability to rotate around its vertical axis (yaw).[48], [96]

- **Test Setup:** A flat, dry surface is ideal, often marked with cones to define a test path. Equipped with sensors to measure yaw rate, steering angle, and lateral acceleration. Experienced drivers are required to maintain consistency in maneuver execution.
- **Test Procedure:** The Slalom Test involves driving through a series of cones placed in a straight line at regular intervals, requiring quick left and right steering inputs. Sudden Lane Change Test simulates an emergency lane change maneuver at various speeds. Yaw rate sensors measure the rate of turn, and data is analyzed to assess the vehicle’s stability and response time.

Table 5.4 : Yaw Rate for Different Test Types

Test Run No.	Manoeuvre Type	Initial Speed (Kmph)	Max Yaw Rate (degrees/sec)	Time to Steady Yaw (sec)	Observations
1	Slalom	20	15.2	2.8	Stable, responsive handling
2	Slalom	30	18.5	3.1	Minor understeer noticed
3	Sudden Lane Change	40	25.3	1.9	Oversteer at high speed
4	Sudden Lane Change	50	28.7	2.2	Brief loss of control
5	Fishhook	25	20.1	2.6	Stable with good recovery
6	Fishhook	30	23.6	2.9	Controlled oversteer

5.6.4 Pitch Testing

To evaluate the vehicle's response to acceleration and braking, causing its front or rear to rise or dip (pitch). A straight track section where the vehicle can accelerate and brake safely. Sensors to measure pitch angle, acceleration, and deceleration forces.[97]

- **Test Procedure:**

1. Acceleration Test: From a standstill, the vehicle is accelerated rapidly to a specific speed.
2. Braking Test: At a constant high speed, brakes are applied firmly to bring the vehicle to a stop.
3. Data Analysis: Observing the pitch angle during these maneuvers helps understand weight distribution and suspension effectiveness.

Table 5.5 : Pitch Angles for Different Speed

Test Run No.	Test Type	Initial Speed (kmph)	Max Pitch Angle (degrees)	Time to Level Out (sec)	Observations
1	Acceleration	0	4.5	1.8	Smooth acceleration
2	Acceleration	0	4.7	2.0	Slight delay in leveling out
3	Braking	20	-5.2	2.3	Stable deceleration
4	Braking	20	-5.5	2.5	Noticeable front dip
5	Braking	40	-6.8	2.8	Pronounced nose dive
6	Braking	40	-7.0	3.0	Minor skidding observed

5.6.5 Rollover Testing

To assess the vehicle's susceptibility to rollover under various driving conditions.

- **Test Setup:** A closed track with a designated area to perform maneuvers. Rollover tests pose higher risks, requiring comprehensive safety measures.
- **Test Procedure:**

1. Fishhook Maneuver: A rapid steering input to induce potential rollover conditions.
2. J-Turn Test: A high-speed turn followed by sudden deceleration.
3. Tilt Table Test: For non-dynamic testing, a tilt table tilts the vehicle to determine the rollover threshold angle.

- **Data Analysis and Safety:** In-depth analysis of the collected data to assess the vehicle's dynamic behavior. Ensuring the vehicle meets regulatory standards and safety requirements.

Table 5.6 : Rollover Threshold Degrees at Different Speed and Test Type

Test Run No.	Test Type	Speed (kmph)	Manoeuvre	Rollover Threshold (degrees)	Observations
1	Fishhook	30	Left	28	Stable, no rollover
2	Fishhook	30	Right	27	Minor tire lift
3	J-Turn	40	Left	32	Approaching rollover threshold
4	J-Turn	40	Right	31	Controlled, no rollover
5	Slalom	35	Mixed	29	Stable through manoeuvre
6	Slalom	45	Mixed	35	Noticeable tilt, risky

5.6.6 Testing the Center of Gravity (CG)

Testing the Center of Gravity (CG) of a vehicle is crucial for understanding its stability and handling characteristics. The CG is the point where the vehicle's mass is considered to be concentrated, and its position significantly influences how the vehicle behaves, especially in terms of rollover risk, cornering, and braking. Here's an overview of how CG testing is typically conducted:

- **Preparation and Setup:** Ensure the vehicle is in a standard condition, with all fluids at normal levels and no additional load. Tires should be properly inflated and in good condition. A flat, level surface is essential for accurate CG testing. An indoor facility is often preferred to eliminate wind or other environmental factors. Scales or load cells are used to measure the weight distribution of the vehicle. Additional equipment may include height gauges and plumb lines for precise measurements.[98]

- **Testing Procedure:** Place scales under each wheel of the vehicle to measure individual wheel loads. The total weight of the vehicle is recorded. To determine the height of the CG Tilt Table Method is used. The vehicle is tilted until it tips over. The angle of tilt at the moment of tipping, combined with vehicle dimensions, is used to calculate the height of the CG. The longitudinal CG location can be determined by measuring front and rear axle weights. The lateral CG location is found by tilting the vehicle sideways or using calculations based on vehicle dynamics in cornering.
- **Data Analysis:** Use collected data and vehicle dimensions to calculate the CG location in three dimensions (X, Y, Z axes). Software tools and mathematical formulas are often employed for precise calculations.

Table 5.7 : CG Position Results by Using Tilt Table Method

Test Run No.	Method Used	CG Height (mm)	Longitudinal CG Location (% from front)	Lateral CG Location (% from left)	Observations
1	Tilt Table	508	55	50	CG centered, stable
4	Tilt Table	559	57	49	Higher CG, more rearward

5.6.7 Lateral Force Testing

Lateral force testing is a crucial aspect of evaluating a vehicle's handling characteristics, particularly its response to side forces during maneuvers like cornering or when subjected to side winds. This test is essential for assessing vehicle stability, tire performance, and the effectiveness of suspension systems under lateral load conditions. Here’s an overview of how lateral force testing is typically conducted. [99]

- **Preparation and Setup:** Ensure the vehicle is in standard driving condition, with appropriate tire pressure and alignment. Check that all systems, especially the suspension and steering, are functioning correctly. Equip the vehicle with sensors to measure lateral forces, tire slip angles, and vehicle dynamics (such as yaw rate and lateral acceleration). Data logging equipment is necessary to record the test results accurately.

- **Slalom Test Procedure**: A series of cones is set up in a straight line for the vehicle to weave through, applying lateral forces as it changes direction. The spacing of the cones and the speed of the vehicle can be varied to alter the test's intensity.
- **Data Analysis:** Analyze the lateral forces experienced by the vehicle and its stability in responding to these forces. Assess how the tires, suspension, and overall vehicle design cope with lateral loads. Evaluate the grip, slip angle, and response of tires under lateral forces. Determine the tire's contribution to overall vehicle stability and handling.

Table 5.8 : Lateral Force Observed and Vehicle Stability

Test Run No.	Test Type	Speed (kmph)	Max Lateral Force (N)	Lateral Grip Level	Vehicle Stability	Observations
3	Slalom	45	1700	High	Stable	Responsive steering
4	Slalom	55	2200	Medium	Unstable	Oversteer at higher speeds

5.6.8 Acceleration and Speed Test

To measure the vehicle's acceleration capability from a standstill to a specific speed (commonly 0 to 60 Kmph) and determine its top speed capabilities. This test provides insights into the vehicle's powertrain efficiency, motor performance, and overall dynamics.

- **Procedure:** Use a straight, flat, and well-maintained track, free of obstacles and traffic, to ensure safety and consistency in testing. The track should be long enough to safely achieve the target speeds and allow for braking. Ensure the vehicle is in a standard condition, with all fluids at optimal levels and tires properly inflated. Remove any unnecessary weight that could affect performance. Set up precise timing equipment at predefined intervals along the track to measure acceleration times accurately. GPS-based data loggers used for high accuracy.

- **Test Execution:** From a standstill, accelerate the vehicle as quickly as possible to the target speed (e.g., 60 Kmph). Record the time taken to reach each significant speed interval (e.g., 0-30 Kmph, 0-60 Kmph). Continue to accelerate the vehicle beyond the initial target speed to determine its top speed. Ensure this is done under controlled conditions, considering the vehicle's safety limits. Perform several runs to ensure consistency and accuracy of the results. Account for variables such as wind direction, track conditions, and driver input.
- **Parameters Measured:**
  1. Acceleration Times: Specific times to accelerate from 0 to various speeds (e.g., 30 Kmph, 60 Kmph). These times are indicators of the vehicle's responsiveness and power output.
  2. Top Speed: The maximum speed the vehicle can achieve on the track. Important for assessing the vehicle's performance capabilities and motor power limit.

Table 5.9 : Acceleration Test Results

Test Run No.	0 to 20 kmph (sec)	0 to 40 kmph (sec)	Top Speed Achieved (kmph)
1	3.2	6.5	58
2	3.1	6.4	57
3	3.0	6.3	59
4	3.2	6.6	60
5	3.1	6.5	58
Average	**3.1**	**6.5**	**58**

5.6.9 Range Test

To evaluate the vehicle's fuel efficiency and overall range. This test aims to determine how economically a vehicle consumes fuel under various conditions and the maximum distance it can travel on a full tank or charge.[100]

- **Procedure:** Use standardized driving cycles like the EPA cycle, which simulate urban, highway, and mixed driving conditions. Alternatively, conduct tests under real-world driving conditions, including city traffic, highways, and varying speeds. Ensure the vehicle is in a typical operating state, with regular maintenance performed. The is battery fully charged. Equip the vehicle withenergy monitors, GPS and data logging systems to accurately track distance and driving conditions.

- **Test Execution:**

1. Urban Driving Cycle:
    - Simulate city driving with frequent stops, lower average speeds, and idling periods.
    - Measure the energy use over a predefined urban route.
2. Highway Driving Cycle:
    - Simulate highway driving with steady higher speeds and minimal stops.
    - Record the energy consumption over a set highway distance.
3. Mixed Driving Cycle:
    - Combine elements of both urban and highway driving.
    - Useful for assessing the vehicle's overall efficiency in typical usage scenarios.
4. Range Test:
    - For assessing the total range, continue driving the vehicle until the battery is depleted.
    - Record the total distance traveled under the test conditions.

Parameters Measured:

- Energy Consumption
    - The amount of kWh consumed per Km for electric vehicles.
    - Key for evaluating vehicle efficiency and comparing it to standards or other vehicles.
- Total Range:
    - The maximum distance the vehicle can travel on a a full battery charge.
    - Critical for understanding the practicality and usability of the vehicle in real-world conditions.

Table 5.10 : Different Mode and Range Results

Test Run No.	Driving Cycle Type	Energy Consumption (kWh/100 Km)	Total Range (km)	Observations
1	Efficiency Mode	1.8	185	Efficient in stop-go traffic
2	Cruise Mode	2.5	130	Balanced urban/highway drive
3	Normal Mode	2.2	150	Longer range at steady speed

5.7 Performance Analysis

In this section, we delve into the findings from the Taguchi and regression analyses conducted on the vehicle prototype developed. This study aimed to unravel the impact of three critical variables - weight, camber, and tire width - on the vehicle's range. Understanding the influence of these factors is crucial for optimizing vehicle design, particularly in the context of enhancing battery efficiency and overall performance.

The Taguchi method, a robust statistical tool, was employed to determine the effect of design parameters on performance characteristics. This technique is pivotal in engineering applications, particularly in optimizing product design and manufacturing processes. It simplifies the complex interplay of multiple variables into a comprehensible format, enabling designers to pinpoint influential factors and their optimal levels. In our study, the focus was on understanding which of the three variables - weight, camber, and tire width - most significantly affects the vehicle's range.

Complementing the Taguchi analysis, a regression analysis was also performed. Regression analysis, a fundamental statistical tool, helps in understanding the relationship between dependent and independent variables. In our case, it was utilized to develop a predictive model for the vehicle's range based on weight, camber, and tire width. Such models are instrumental in forecasting performance outcomes under various scenarios, thereby guiding design decisions.

Both analyses are central to this study as they provide a comprehensive understanding of how each variable influences the vehicle's range. The insights gained from these analyses are not only crucial for this specific model but also have broader implications in the field of automotive engineering. They contribute to the evolving knowledge base on vehicle efficiency and are pertinent in the context of escalating environmental concerns and the push for sustainable automotive technologies.

5.7.1 Design and Analysis of Experiments

Experimental design is a robust statistical technique used to ascertain the unknown characteristics of the operational parameters in a given experiment and to analyze and simulate the interplay between the components involved. The conventional experimental design methodologies are excessively intricate and not user-friendly. Moreover, an extensive array of experiments must be conducted as the quantity of operating parameters escalates. Hence, it is imperative to identify and examine the causes responsible for variances in a controlled laboratory setting. These investigations fall within the realm of offline quality enhancement. [101]

5.7.2 Signal to Noise Ratio

In order to assess the quality characteristics of a product or process parameters, the Taguchi approach employs the signal-to-noise ratio (S/N ratio). It is also known as a statistical performance indicator. The signal-to-noise ratio is defined as the ratio between the mean (signal) and the standard deviation (noise). Regardless of the category of quality characteristics, selecting process parameters with the greatest signal-to-noise ratio consistently yields the highest quality, while minimizing fluctuation. The Taguchi technique generally employs three standard signal-to-noise (S/N) ratios.

- Reduced size is preferable.
- Nominal is the superior choice.
- Greater size yields superior results.

LB is selected as the chosen approach for this investigation, with the aim of maximizing the effectiveness of the cooling tower. Here, n is the total number of measurements taken during the experiments, including the parameters being measured. A graph is created to display the average efficacy mean and S/N ratios for each parameter at various levels. According to the signal-to-noise ratio (S/N ratio), a bigger value is considered better (LB), as it corresponds to higher efficacy values. [101]

5.7.3 Selection of Orthogonal Array (OA)

The Taguchi method utilizes an orthogonal array for experimental analysis. The orthogonal array is employed to decrease the quantity of trials conducted to analyze quality criteria. The optimal OA is chosen based on the overall number of degrees of freedom needed. The degrees of freedom (DOF) can be determined by considering the number of components, the number of levels for each factor, and the number of interactions. The research work does not take into account the interaction effect between the process parameters. The degrees of freedom for a system with three levels is 2, which is calculated by subtracting 1 from the number of levels. The total degrees of freedom (DOF) needed for three elements with three levels each is 6, which can be calculated as 3 multiplied by the difference between 3 and 1, resulting in 6. In the Taguchi method, the total degrees of freedom (DOF) of the selected orthogonal array (OA) must be greater than or equal to the total DOF needed for the experiment. Therefore, the L9 OA with eight degrees of freedom is chosen for this study. [101]

Table 5.11: Parameters and their Values

Level	Weight (N)	Camber Angle (Degree)	Tire Width (mm)
1	2400	0	90
2	2600	1	100
3	2800	2	110

The combination of parameters for experimentation is acquired by utilizing the Taguchi L9 array and setting the level to 3 in the Minitab software. The table provided is labeled as Table 4.2.

Table 5.12 : Taguchi L9 array for Experimentation

Sr. No.	Weight (N)	Camber (Degree)	Tire Width (mm)
1	2400	0	90
2	2400	1	100

Sr. No.	Weight (N)	Camber (Degree)	Tire Width (mm)
3	2400	2	110
4	2600	0	100
5	2600	1	110
6	2600	2	90
7	2800	0	110
8	2800	1	90
9	2800	2	100

5.7.4 Analysis of Variance (ANOVA)

ANOVA is a highly prevalent strategy for identifying significant factors that influence a response and quantifying their impact. The primary cause of non-reproducibility in cooling tower performance is the lack of control over the test facility and the operating conditions of the cooling tower. The F-test in ANOVA refers to the ratio between the variance of the process parameter and the error variance. It assesses if the parameter has a substantial impact on the quality attributes. This procedure involves comparing the F-test statistic of the parameter with the critical value (F0.05) at a significance level of 5%. If the F-test value exceeds the critical value of F0.05, the process parameter is deemed to be statistically significant. It is evident that all factors are significant. The user's text is enclosed in tags.

5.7.5 Taguchi Analysis: Range versus Weight, Camber, Tire Width

The Taguchi analysis in this study offers critical insights into how weight, camber, and tire width influence the range of the vehicle. This methodical approach employs a systematic and efficient plan for experimentation, which is particularly advantageous in settings where multiple variables are at play.

The central premise of the Taguchi method is its focus on the concept of the signal-to-noise (S/N) ratio. This ratio is a measure of the robustness of the system's performance characteristic. In our context, it was used to assess which of the three variables - weight, camber, and tire width - most robustly impacts the vehicle's range. The analysis revealed that the weight had the most significant effect, followed by tire width and camber. This finding is crucial as it underscores the importance of weight in vehicle design, particularly in its role in influencing the range.

The Taguchi method's emphasis on 'larger-the-better' for the S/N ratio aligns perfectly with the goal of maximizing the vehicle's range. By ranking the variables based on their delta values, the method provides a clear hierarchy of their impact levels. The analysis thus guides designers and engineers in prioritizing their focus on weight reduction strategies, as it emerged as the top-ranked factor.

Moreover, the Taguchi method's ability to handle complex interactions between design parameters makes it an invaluable tool in automotive engineering. Its application in this study not only enhanced the understanding of individual variable impacts but also provided insights into their collective influence on the vehicle's range. This comprehensive understanding is essential for making informed design decisions that can lead to significant improvements in vehicle performance and efficiency.

5.7.6 Regression Analysis

The regression analysis conducted as part of this study serves as a cornerstone for developing a predictive model for the vehicle's range. This statistical approach is instrumental in quantifying the relationship between dependent and independent variables, which, in this case, are the range and the factors of weight, camber, and tire width, respectively.

The regression model derived from the analysis encapsulates the intricate relationship between the range and the three variables. It suggests a negative correlation, indicating that an increase in weight, camber, and tire width tends to decrease the range of the vehicle. This inverse relationship is particularly pronounced for weight, as highlighted by its coefficient and P-Value in the model. The model thus serves as a quantitative tool, enabling predictions about how changes in these variables can affect the vehicle's range. Such predictive capability is invaluable in the design phase, where various scenarios can be simulated to assess their impact on performance.

However, the model's moderate R-squared value and its lack of statistical significance at conventional levels indicate that it may not fully capture the complexity of the relationships between these variables and the vehicle's range. This suggests that other factors, not included in the model, might also have a significant impact. The moderate predictive power of the model implies that while it provides useful insights, it should be used with caution, and its predictions should be validated against real-world data.

The regression analysis contributes significantly to our understanding of how weight, camber, and tyre width interact to influence the vehicle's range. Although the model has limitations in its predictive power, it offers a foundational framework that can be built upon with further research. Incorporating additional variables and refining the model can lead to more accurate predictions, ultimately aiding in the design of more efficient and high-performing vehicles.[101]

Perimeter
2.21 km

Area
975,076 ft²

Fig. 47 : Track Selected for Testing

RESULT AND DISCUSSION

The results from the Taguchi and regression analyses provide valuable insights into the dynamics of vehicle design, particularly focusing on weight, camber, and tire width's impact on the vehicle's range. The primary revelation from the Taguchi analysis is the paramount importance of weight, which significantly outstrips the other variables in influencing the vehicle's range. This finding aligns with the broader understanding in automotive engineering that weight is a critical determinant of a vehicle’s efficiency and performance.

The secondary findings regarding camber and tire width, though less influential than weight, are still noteworthy. These factors, often considered secondary in traditional vehicle design, have been shown to have a measurable impact on the range. The nuanced understanding of these variables provided by the Taguchi method offers a more comprehensive view of the interplay of design elements, allowing for more informed decisions in the optimization of vehicle performance.

6.1 Weight

The Taguchi and regression analyses conducted, as detailed in the beginning of the chapter in my knowledge source, underscore the paramount importance of weight in influencing a vehicle's range. The primary revelation from these analyses is that weight significantly outstrips the other variables (camber and tire width) in its impact on the vehicle's range. This aligns with the broader understanding in automotive engineering that weight is a critical determinant of a vehicle’s efficiency and performance.

Reducing the weight of a vehicle can lead to improved efficiency, as it requires less energy to accelerate and maintain motion. In electric vehicles, this is particularly crucial as it directly translates to extended range capabilities – a key performance metric. Lighter vehicles require less battery power to move, allowing for longer distances to be traveled on a single charge. Additionally, lighter vehicles also benefit from improved handling and braking performance.

6.2 Camber

Although less influential than weight, camber still plays a notable role in the vehicle's range. Camber, the angle of the wheels in relation to the ground, affects the tire footprint – the area of the tire that makes contact with the road. Proper camber settings can ensure that the tires wear evenly and maintain optimal contact with the road, which can improve vehicle stability and handling. These factors, in turn, can influence the energy efficiency of the vehicle.

However, excessive camber can lead to increased tire wear and potentially higher rolling resistance, which might negatively impact the vehicle's range. Therefore, balancing camber settings is crucial to optimizing a vehicle's performance.

6.3 Tyre Width

Tire width, ranking third in terms of influence on vehicle range, still holds significance. Wider tires generally provide better traction and stability due to a larger contact area with the road. This can be beneficial for handling, especially in electric vehicles which may have a higher center of gravity due to battery placement.

However, wider tires can also lead to increased rolling resistance, which means the vehicle's motor has to work harder to move and maintain speed, thus consuming more energy. This can adversely affect the range of an electric vehicle. Therefore, selecting the right tire width is a balance between achieving desired handling characteristics and maintaining energy efficiency.

The combined analysis of weight, camber, and tire width provides valuable insights into optimizing vehicle design for maximum efficiency and range. While weight emerges as the most critical factor, camber and tire width also contribute significantly to overall vehicle performance, especially in the context of electric vehicles where range and efficiency are paramount.

Table 6.1 : Experimentation Results

Sr. No.	Weight (N)	Camber (Degree)	Tire Width (mm)	Range (Km)
1	2400	0	100	177
2	2400	1	90	180
3	2400	2	110	176
4	2600	0	100	140
5	2600	1	110	142
6	2600	2	90	145
7	2800	0	110	133

Sr. No.	Weight (N)	Camber (Degree)	Tire Width (mm)	Range (Km)
8	2800	1	90	130
9	2800	2	100	133

6.4 Response Table for Signal-to-Noise Ratios

This section includes the analysis of signal-to-noise ratios, adhering to the 'larger is better' principle. The level of influence of each factor (weight, camber, tire width) on the vehicle's range is quantified. The delta values indicate the total variation effect each factor has on the range.

Table 6.2 : Response Table for Signal-to-Noise Ratios

Level	Weight (N)	Camber (Degree)	Tyre width (mm)
1	43.29	42.69	43.08
2	42.45	43.02	42.43
3	42.43	42.46	42.66
Delta	0.85	0.56	0.64
Rank	1	3	2

This table presents the signal-to-noise (S/N) ratios for each of the three factors (weight, camber, and tire width) at three different levels. The S/N ratio is a key metric in quality engineering and is used to measure the robustness of a system against noise factors. In the context of vehicle range, a higher S/N ratio is desirable as it indicates a greater resistance to variability and hence a more consistent performance.

1. **Data Overview**
   - Weight (N): Shows values at three levels - 43.29, 42.45, and 42.43.
   - Camber (Degree): The values are 42.69, 43.02, and 42.46 at three levels.
   - Tire Width (mm): Recorded values are 43.08, 42.43, and 42.66.
2. **Delta Values**
   - Weight: Shows the highest delta value of 0.85.
   - Tire Width: Has a delta value of 0.64.
   - Camber: Shows the lowest delta value of 0.56.

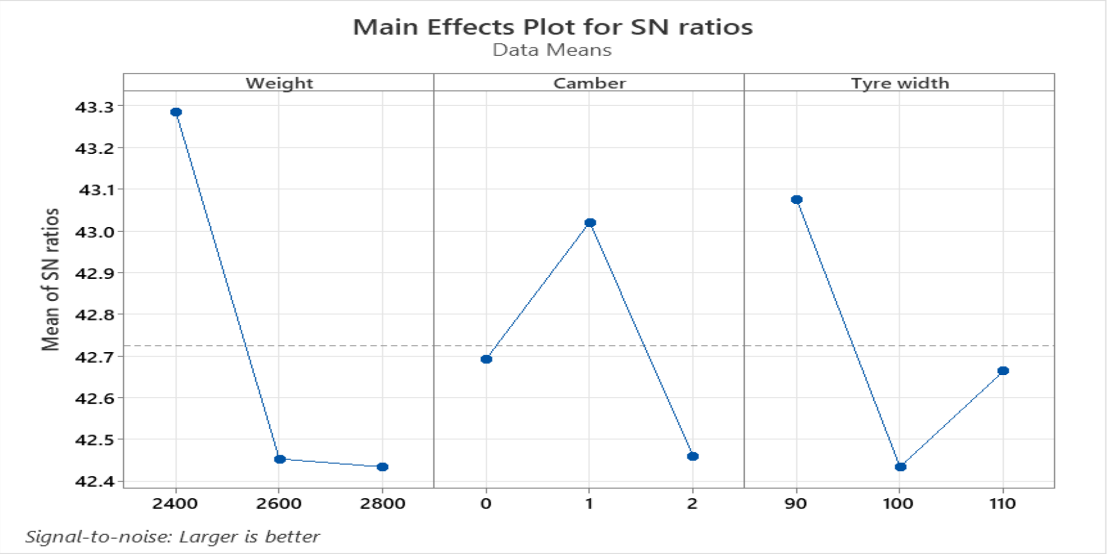


Fig. 48 : Main Effect plot for SN ratios

6.5 Analysis and Implications

1. **Dominance of Weight**: The highest delta value for weight (0.85) signifies its substantial impact on the vehicle's range. This implies that among the factors studied, weight is the most influential in affecting the range. A weight reduction could lead to a notable increase in the vehicle's range, making it a critical factor in design considerations for efficiency.
2. **Role of Tire Width and Camber**: Though less impactful than weight, tire width and camber still show notable delta values of 0.64 and 0.56, respectively. These factors, often considered secondary in traditional vehicle design, have a measurable impact on the range. The findings suggest that optimization of tire width and camber can also contribute to enhancing the vehicle's range, though their effect is relatively lesser compared to weight.
3. **'Larger is Better' Principle**: The adherence to this principle in the analysis reinforces the objective of maximizing the vehicle's range. The focus is on identifying factors that, when optimized, can lead to a larger vehicle range, which is a desirable outcome in electric and hybrid vehicle design.

The analysis of Signal-to-Noise Ratios and the resultant delta values in Table 6.1, as well as Fig. 6.1, underscore the importance of weight as a primary determinant of a vehicle’s range. Simultaneously, it highlights the significant, though lesser, roles of tire width and camber in influencing the vehicle’s range.

6.6 Response Table for Means

Here, we present the average effects of each factor at different levels. This table helps in identifying the optimal level of each factor for maximizing the vehicle's range.

Table 6.3: Response Table for Means

Level	Weight (N)	Camber	Tyre width
1	146.0	136.7	142.7
2	132.7	141.7	132.7
3	132.7	133.0	136.0
Delta	13.3	8.7	10.0
Rank	1	3	2

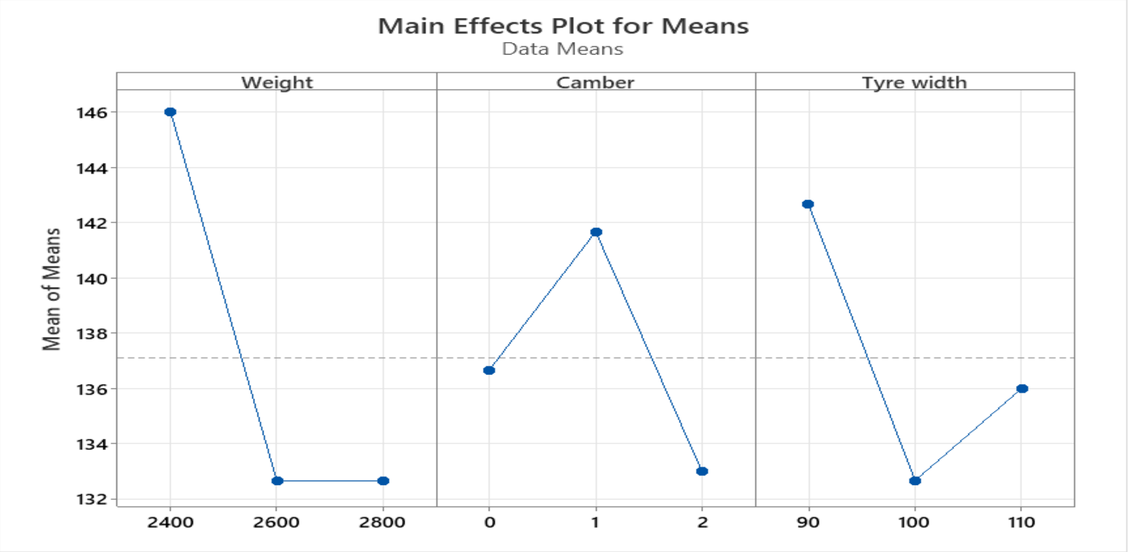


Fig. 49 : Main Effect Plot for Means

The "Response Table for Means" (Table 6.2) and its corresponding graphical representation (Fig. 6.2) in the provided document offer insights into how different levels of each factor (weight, camber, and tire width) influence the average effect on the vehicle's range. This table plays a crucial role in identifying the optimal level of each factor to maximize the vehicle's range.

1. **Impact of Weight on Range:** The weight of the vehicle continues to be the most influential factor affecting its range, as indicated by the highest delta value of 13.3. This reaffirms the earlier findings from the signal-to-noise ratio

analysis, underscoring the critical importance of weight in determining the vehicle's efficiency and range.

2. **Ranking of Factors:** The factors are ranked based on their delta values, signifying their relative impact on the vehicle's range. The rank order is consistent with the previous analysis, with weight being the most impactful, followed by tire width and camber.
3. **Optimal Levels for Maximizing Range:** By examining the average effects at different levels for each factor, one can deduce the optimal settings. For instance, a lower weight level would be more favorable for enhancing the vehicle's range.
4. **Broader Implications:** These findings have significant implications for vehicle design, particularly in the context of electric vehicles where range is a key performance metric. Designers and engineers can leverage this data to make informed decisions about material selection, vehicle dimensions, and other design aspects that directly influence weight.

The data from the "Response Table for Means" and the corresponding figure provide valuable guidance for optimizing the vehicle's design to maximize its range. The dominance of weight as a factor in vehicle range emphasizes the need for lightweight materials and efficient design in the automotive industry, particularly for electric and hybrid vehicles.

6.7 Regression Analysis: Range versus Weight, Camber, Tyre width

The regression analysis conducted in the study provides a detailed understanding of how weight, camber, and tire width affect the range of a vehicle.

6.7.1 Regression Equation

The formulation of a regression equation provides a quantitative model to predict the vehicle's range based on the three factors. This equation quantitatively models the vehicle's range based on three factors: weight, camber, and tire width.

$$Range = 258.9 - 0.0333\ X\ Weight - 1.83\ X\ Camber - 0.333\ X\ Tire\ Width$$

6.7.2 Coefficients

Table 6.4: Parametric Constant and Coefficients

Term	Coefficient	Secondary Coefficient	T-Value	P-Value	VIF
Constant	258.9	51.4	5.03	0.004	
Weight	-0.0333	0.0156	-2.13	0.086	1.00
Camber	-1.83	3.13	-0.59	0.583	1.00
Tire width	-0.333	0.313	-1.07	0.335	1.00

The coefficient for weight is -0.0333, indicating an inverse relationship between weight and the vehicle's range. This suggests that as the weight increases, the range decreases. The coefficient for camber is -1.83, also indicating an inverse relationship, though its effect is less pronounced than weight. The coefficient for tire width is -0.333, suggesting a similar inverse relationship.

6.7.3 Model Summary

- **Model Summary and ANOVA:** The summary of the regression model, including measures like R-squared and adjusted R-squared, gives insights into the model's explanatory power. The ANOVA table helps in determining the statistical significance of the model and each factor.

Table 6.5: Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
7.66014	54.65%	27.43%	0.00%

Analysis of Variance (ANOVA):

Table 6.6: ANOVA & Regression

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	353.50	117.83	2.01	0.231
Weight	1	266.67	266.67	4.54	0.086
Camber	1	20.17	20.17	0.34	0.583
Tire width	1	66.67	66.67	1.14	0.335
Error	5	293.39	58.68		
Total	8	646.89			

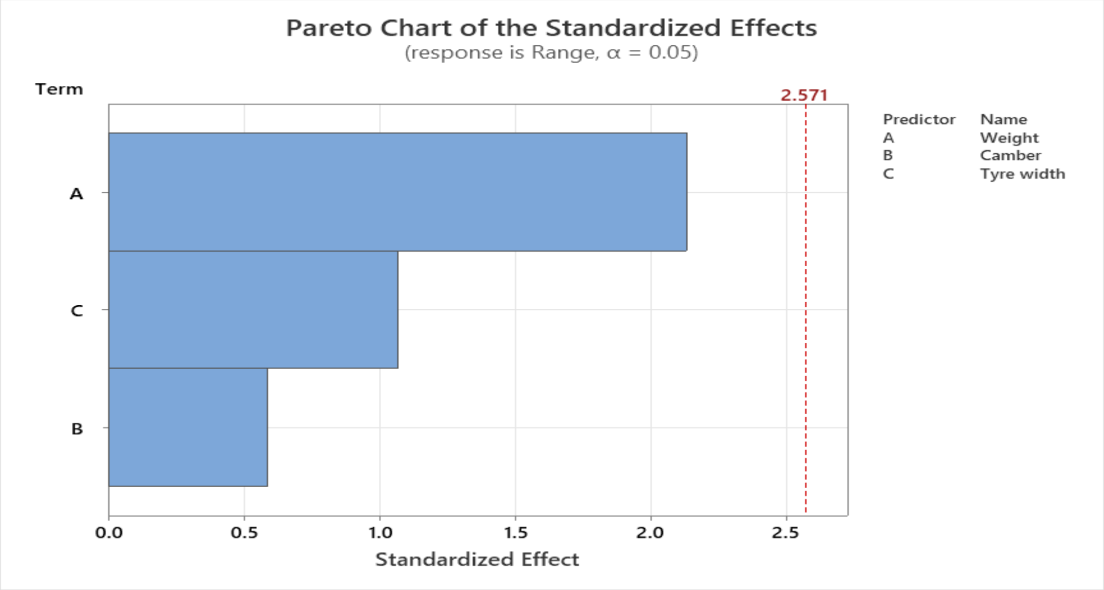


Fig. 50 : Pareto Chart of Standardized Effect

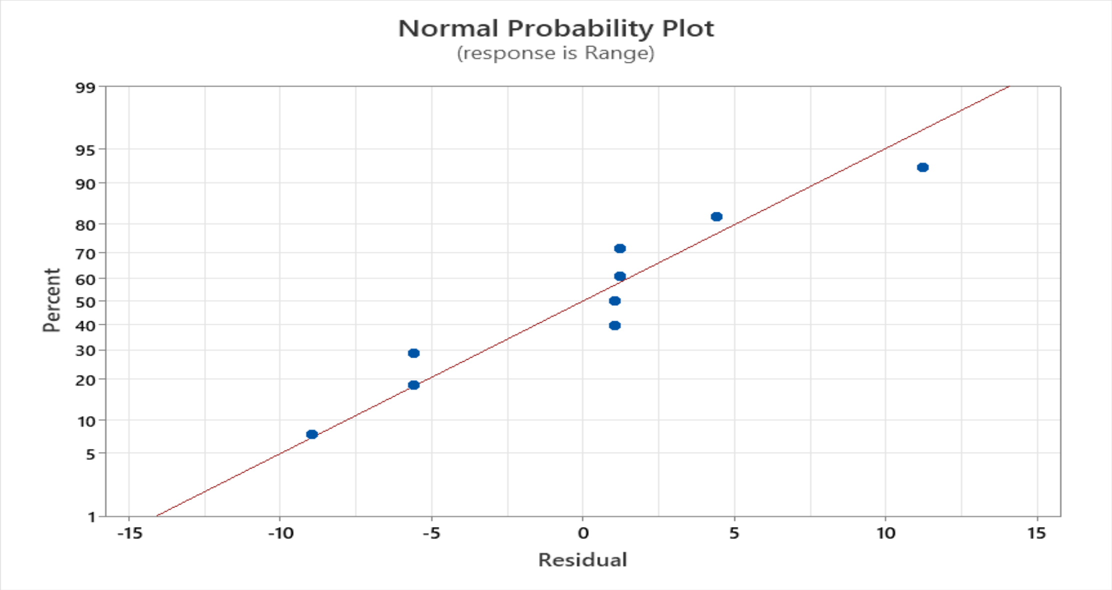


Fig. 51 : Normal Probability Plot

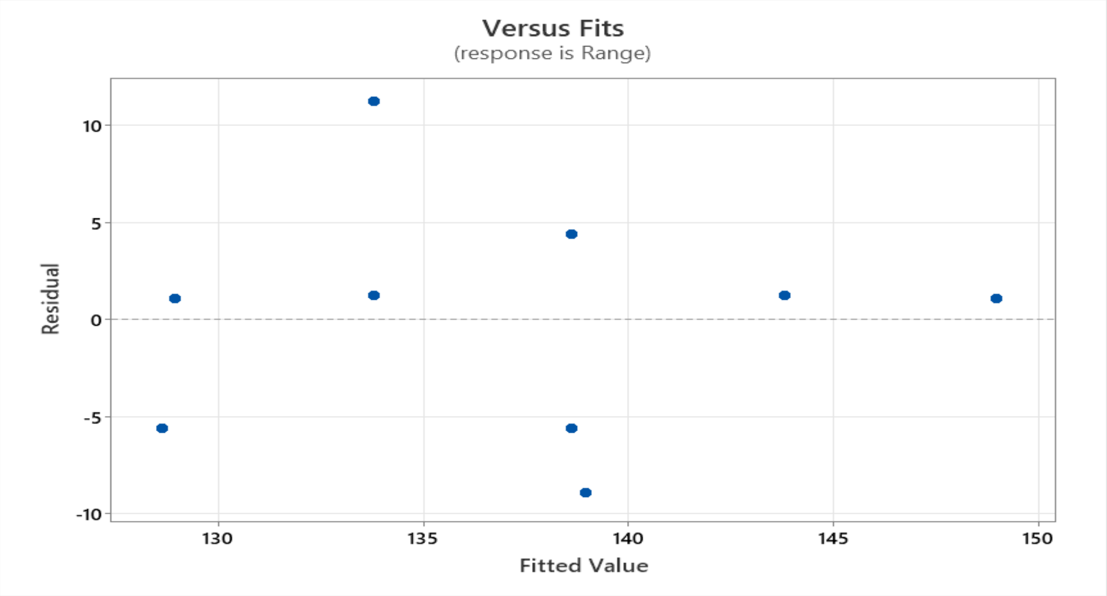


Fig. 52 : Residual Fits

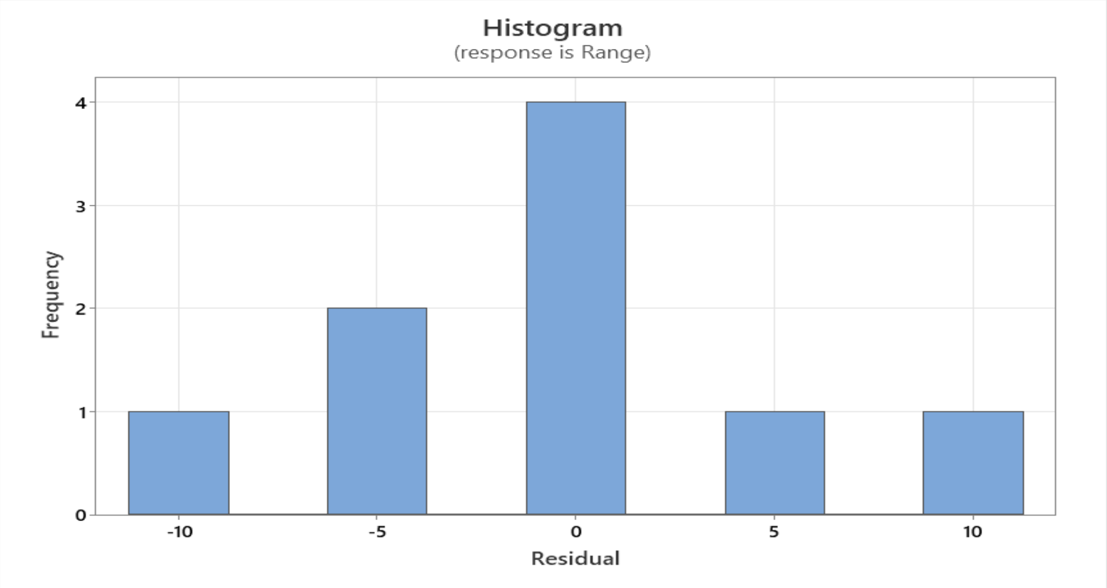


Fig. 53 : Histogram of Frequency

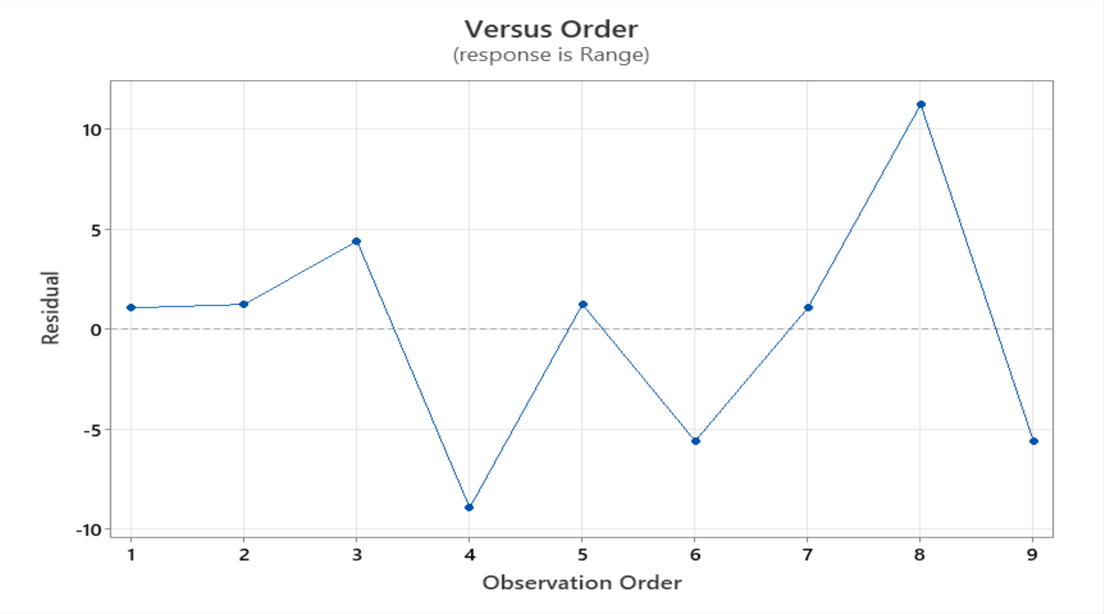


Fig. 54 : Observation Order

Model Summary and ANOVA:

The model summary includes R-squared and adjusted R-squared values which provide insights into the model's explanatory power. The R-squared value is 54.65%, and the adjusted R-squared value is 27.43%. These values indicate that while the model explains a significant portion of the variance in the vehicle's range, there might be other factors not included in the model that could affect the range.

The ANOVA (Analysis of Variance) shows the statistical significance of the model and each factor. The F-Value for weight is significant (4.54 with a P-Value of 0.086), indicating that weight is a significant predictor of vehicle range. However, the P-Values for camber and tire width are higher (0.583 and 0.335 respectively), suggesting less statistical significance.

Various figures (Fig. 6.3 to 6.7) such as the Pareto Chart of Standardized Effect, Normal Probability Plot, Residual Fits, Histogram of Frequency, and Observation Order. These graphical representations provide a visual understanding of the model's performance and the distribution of residuals.

The regression analysis confirms the inverse relationship between the range and the tested variables, especially weight. The model's moderate explanatory power indicates the potential for other factors to influence the vehicle's range, suggesting the need for further research. This analysis is crucial not only for academic purposes but also has practical implications in guiding design improvements and innovations in the automotive industry.

6.8 Main Effects and Interaction Plots for Range

This section would typically include graphical representations of the main effects and interaction effects. Main effects plots illustrate how each factor individually affects the range, while interaction plots show how the effect of one factor depends on the level of another factor.

6.8.1 Main Effects Plot for Range

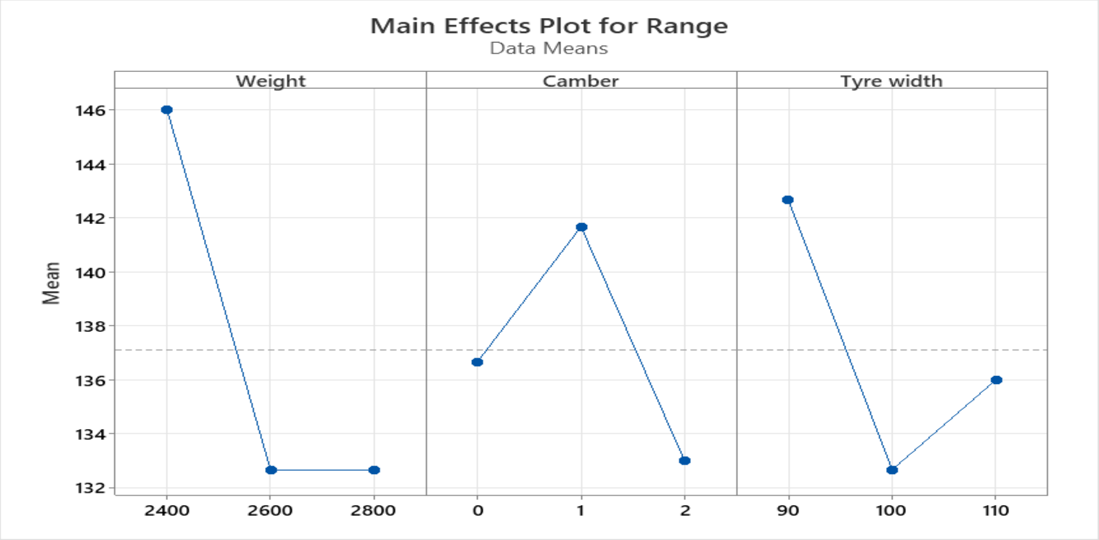


Fig. 55 : Main Effects Plot for Range

6.8.2 Interaction Plot for Range

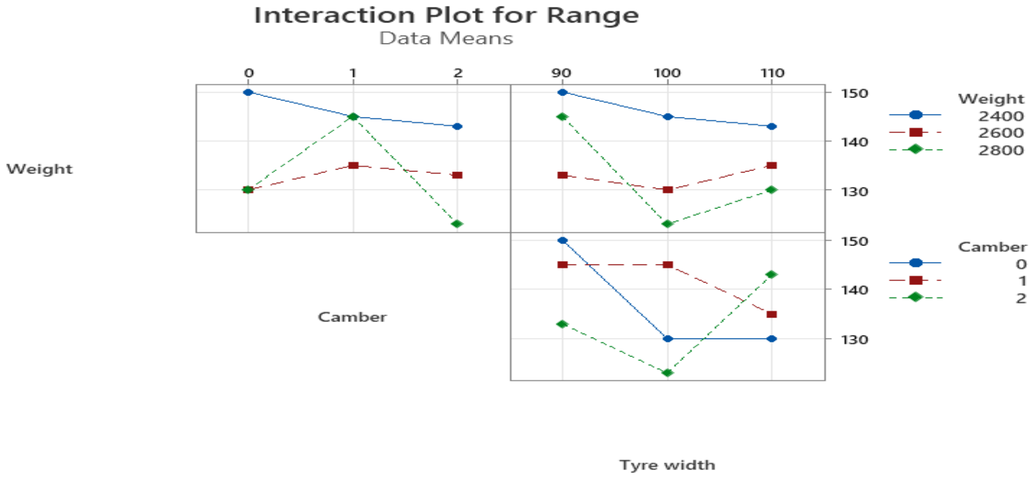


Fig. 56 : Interaction Plot for Range

This section aims to visually represent the impact of individual factors (weight, camber, and tire width) on the vehicle's range and how the effect of one factor may depend on the level of another. The observations and interpretations of these plots are crucial as they illustrate the dominance of weight in affecting the vehicle's range. These graphical representations complement the data presented in the response tables and emphasize weight's significant role in vehicle design, particularly in its influence on range. The section highlights the importance of considering these factors in the optimization of vehicle performance, providing valuable insights for automotive design and engineering.

The regression analysis, while revealing a statistically less robust model, still offers valuable insights. It confirms the inverse relationship between the range and the tested variables, especially weight. The model's moderate explanatory power (R-squared value) indicates that other unaccounted factors might be at play in determining the vehicle's range. This finding opens up new avenues for further research, suggesting that a more inclusive model incorporating additional variables could provide a more accurate and comprehensive understanding of the factors affecting vehicle range.

The discussion highlights the complexity of vehicle design and the intricate balance required between various design elements to optimize performance. The insights from these analyses are not just limited to academic interest but have practical implications in guiding design improvements and innovations in the automotive industry.

6.9 Overall Results

Table No. 6.7 : Overall Results

Parameters	Design Value	Experimental Value
Wheelbase	1800 mm	1875 mm
Track width	1200 mm	1333.5 mm
C.G. Height from Ground	417 mm	425 mm
C.G. From Front Axle	743 mm	748 mm
Ground Clearance	160 mm	158 mm
Camber	0 degree	2 degree
Castor	0 degree	1 degree
Kingpin inclination	3 degree	3.03 degree

Parameters	Design Value	Experimental Value
Scrub radius	43 mm	48 mm
Toe angle	0 degree	0 degree
Turning radius	3545.5 mm	4604.2 mm
Maximum Speed	60 kmph	58 kmph
Maximum Range	180 km	185 km

The design value was 1800 mm, while the experimental value turned out to be slightly longer at 1875 mm. The track was designed at 1200 mm, and the experimental measurement was 1333.5 mm, indicating a wider stance than planned. The Center of Gravity (C.G.) height from the ground initially set at 417 mm, the experimental value was slightly higher at 425 mm. C.G. distance from the front axle was closely matched, with the design at 743 mm and the experimental result at 748 mm. The vehicle was designed with a clearance of 160 mm but was marginally lower at 158 mm in the experimental setup. While the design camber was specified 0 degrees, the experimental camber value optimized by experimentation was adjusted to 2 degrees. Like the camber, castor also saw a change from the designed 0 degree to 1 degree in the experimental results. Kingpin Inclination (KPI) was almost accurately achieved with a design value of 3 degrees and an experimental value of 3.03 degrees. The design value of scrub radius was 43 mm, but the experimental value increased to 48 mm. Both the design and experimental values were maintained at 0 degrees. There was a significant increase from the designed 3545.5 mm of turning radius to an experimental value of 4604.2 mm. The designed speed was 60 kmph, which slightly decreased to 58 kmph in the experimental tests. Both the designed and experimental values were consistent at 180 km.

CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

The research successfully integrated various components into a cohesive design, emphasizing the importance of material selection and structural analysis. The chosen materials, such as AISI 4130 steel for the chassis and 7076 T6 Aluminium alloy for the swing arm, provided a balance between strength, weight, and manufacturability. The study extensively analysed vehicle dynamics, focusing on parameters like wheelbase, track width, centre of gravity, and suspension system. The design aimed to optimize these parameters for better stability, handling, and efficiency.

A pivotal finding was the significant impact of vehicle weight on range. Reducing weight was identified as a key strategy for enhancing efficiency, particularly in tadpole electric vehicles, where it directly translates to extended range capabilities. While less influential than weight, camber and tire width were found to have measurable impacts on vehicle range. Proper balancing of these factors is crucial for optimizing performance, as they affect tire wear, rolling resistance, and vehicle stability.

From the main effect plot and experimental test results we have optimized parameters which has maximum range are as follows.

Table 7.1 : Optimized Parameters

Weight (N)	Camber (Degrees)	Tire Width (mm)
2400	1	90

In this study weight parameter dominates the efficiency of the vehicle in the form of range as compared to camber and tire width. Camber and Tire width have little influence on range but these wheel alignment parameters also affect the range of the vehicle.

The research included prototype development and testing, which validated the theoretical models and simulations. The experimental results closely aligned with the design values, affirming the efficacy of the design process and methodologies employed. The study utilized regression analysis to quantify the relationships between range and factors like weight, camber, and tire width. This model provides a tool for predicting vehicle performance and guiding future design improvements. The thesis also discussed the development of advanced steering and braking systems, tailored to the specific needs of the vehicle. These systems were designed to enhance maneuverability, safety, and overall driving experience.

The final vehicle design achieved a balance between performance, efficiency, and safety. The vehicle's maximum range and speed were consistent with the design objectives, demonstrating the success of the optimization strategies employed. This thesis presents a comprehensive approach to the design and optimization of tadpole electric vehicles, emphasizing the importance of weight management, dynamic performance, and component integration. The methodologies and findings from this research contribute valuable insights to the field of automotive engineering, particularly in the development of efficient and high-performing tadpole electric vehicles.

7.2 Future Scope

Development of a More Comprehensive Model: The regression analysis has identified an inverse relationship between vehicle range and variables like weight, camber, and tire width. However, it also suggests that the model's moderate explanatory power could be enhanced by incorporating additional variables. Future research can focus on developing a more inclusive and comprehensive model that accounts for a broader range of factors impacting vehicle range. This approach would offer a more nuanced understanding of the dynamics influencing vehicle efficiency and performance.

Exploration of Unaccounted Factors: The current findings indicate that there are other unaccounted factors that might significantly influence a vehicle's range. Future studies could delve into identifying and analyzing these factors. This exploration could include elements like aerodynamic design, material science advancements, battery technology improvements, and the impact of different driving conditions on vehicle performance.

Balancing Design Elements for Optimal Performance: The study underlines the complexity of vehicle design and the need for a balanced approach to various design elements. Future work could focus on optimizing this balance, particularly in the context of tadpole electric vehicles. This could involve experimental designs that test different configurations of vehicle components to find the most efficient combination.

Practical Applications and Design Innovations: The insights gained from this study are not limited to theoretical understanding but have significant practical implications. Future scope includes applying these insights to guide design improvements and innovations in the automotive industry. This could lead to the development of new vehicle models that are more efficient, sustainable, and better suited to meet the evolving demands of consumers and environmental standards.

Integration with Emerging Technologies: There's a growing intersection between vehicle technology and other emerging fields like artificial intelligence, IoT (Internet of Things), and renewable energy sources. Future research could explore how these technologies can be integrated into vehicle design and operation to enhance performance, safety, and user experience.

Sustainability and Environmental Impact Studies: As the automotive industry increasingly moves towards sustainability, future studies could focus on the environmental impact of different design choices. This could include life cycle assessments of vehicle components, exploration of alternative materials, and the development of more eco-friendly manufacturing processes.

These future directions are aligned with the ongoing trends in automotive technology and the need for continuous innovation to meet both markets demands and environmental goals.

REFERENCES

REFERENCES

- F. Cavas-Martínez, F. Chaari, F. Gherardini, and Y. W. Kwon, “Lecture Notes in Mechanical Engineering Series Editors.” [Online]. Available: http://www.springer.com/series/11693
- A. Waters, “A Novel Universal Corner Module for Urban Electric Vehicles: Design, Prototype, and Experiment.”
- J. Lowry and James. Larminie, Electric vehicle technology explained. Wiley, 2012.
- V. Chinubhai Shah and K. Arturas Supervisor, “Designing and Investigating of Electric Tricycle,” 2018.
- A. Ewert, S. Schmid, M. Brost, H. Davies, and L. Vinckx, “Small Electric Vehicles An International View on Light Three-and Four-Wheelers.”
- “Electric and Plug-in Hybrid Vehicle Roadmap,” 2050. [Online]. Available: www.iea.org/roadmaps
- P. R. Shukla, S. Dhar, M. Pathak, and K. Bhaskar, “Electric Vehicle Scenarios and a Roadmap for India Working Group III contribution to the IPCC 6th Assessment Report (AR6) View project Linking sectoral and economy-wide models View project,” 2014, doi: 10.13140/2.1.4544.0325.
- “Electric vehicles Setting a course for 2030.”
- P. R. Shukla, S. Dhar, M. Pathak, and K. Bhaskar, “PROMOTING LOW CARBON TRANSPORT IN INDIA Electric Vehicle Scenarios and a Roadmap for India,” 2014.
- K. Sreeram, P. K. Preetha, and P. Poornachandran, “Electric Vehicle Scenario in India: Roadmap,Challenges and Opportunities,” in Proceedings of 2019 3rd IEEE International Conference on Electrical, Computer and Communication Technologies, ICECCT 2019, Institute of Electrical and Electronics Engineers Inc., Feb. 2019. doi: 10.1109/ICECCT.2019.8869479.
- K. V. Singh, H. O. Bansal, and D. Singh, “A comprehensive review on hybrid electric vehicles: architectures and components,” Journal of Modern Transportation, vol. 27, no. 2. Springer Berlin Heidelberg, pp. 77–107, Jun. 01, 2019. doi: 10.1007/s40534-019-0184-3.

- S. Rokadiya and A. Bandivadekar, “Hybrid and electric vehicles in India: Current scenario and market incentives,” 2016. [Online]. Available: http://www.theicct.org/sites/default/
- I. Husain, “Electric and Hybrid Vehicles: Design Fundamentals.”
- M. Ehsani, Y. Gao, S. E. Gay, and A. Emadi, “Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design.”
- Z. Q. Zhu and D. Howe, “Electrical machines and drives for electric, hybrid, and fuel cell vehicles,” Proceedings of the IEEE, vol. 95, no. 4, pp. 746–765, 2007, doi: 10.1109/JPROC.2006.892482.
- U. Polliecn, ! Ca, D. E. Caiauj, D. Sánchez-Repila, and J. E. W. Poxon, “hybrid electric vehicles: current concepts and future market trends.”
- M. Trzesniowski, Complete vehicle. Springer Fachmedien Wiesbaden, 2023. doi: 10.1007/978-3-658-39667-1.
- D. Deb, A. Dixit, and L. Chandra, “Smart Innovation, Systems and Technologies 161 Renewable Energy and Climate Change.” [Online]. Available: http://www.springer.com/series/8767
- M. V. Reddy, B. R. Kumar, P. P. Kumar, Y. V. Vardhan, and A. Ravindra, “Design, analysis and fabrication of effie-cycle: A hybrid tadpole vehicle,” in AIP Conference Proceedings, American Institute of Physics Inc., Feb. 2021. doi: 10.1063/5.0036599.
- A. Zandieh, “Dynamics of a Three-Wheel Vehicle with Tadpole Design.”
- A. Ranpariya, A. Thattil, S. Vachhani, D. Raval, P. Sharma, and U. G. Students, “Design of the Tadpole Type Three-Wheel Vehicle with Dynamic Conditions,” International Research Journal of Engineering and Technology, vol. 9001, 2008, [Online]. Available: www.irjet.net
- A. Tahjib, H. Tanzin, S. M. I. Rahman, B. S. Islam, and H. Azim, “Development of a Solar Powered Electric Vehicle based on Tadpole Design,” in International Conference on Robotics, Electrical and Signal Processing Techniques, 2021, pp. 206–210. doi: 10.1109/ICREST51555.2021.9331052.

- S. Rokadiya and A. Bandivadekar, “Hybrid and electric vehicles in India: Current scenario and market incentives,” 2016. [Online]. Available: http://www.theicct.org/sites/default/

- N. M. Sarode and M. T. Sarode, “Current Scenario of Electric Mobility in India and its Challenges.” [Online]. Available: www.ijert.org
- S. A. Bagloee, M. Tavana, M. Asadi, and T. Oliver, “Autonomous vehicles: challenges, opportunities, and future implications for transportation policies,” Journal of Modern Transportation, vol. 24, no. 4, pp. 284–303, Dec. 2016, doi: 10.1007/s40534-016-0117-3.
- F. Czerwinski, “Current trends in automotive lightweighting strategies and materials,” Materials, vol. 14, no. 21, Nov. 2021, doi: 10.3390/ma14216631.
- G. Tri Chandrasa, H. Suryoatmojo, and B. Tambunan, “Design and Performance a lightweight Electric Reverse Trike with Multiple Energy Storage.” [Online]. Available: https://ssrn.com/abstract=4627866
- X. Jiang, L. Chen, X. Xu, Y. Cai, Y. Li, and W. Wang, “Analysis and optimization of energy efficiency for an electric vehicle with four independent drive in-wheel motors,” Advances in Mechanical Engineering, vol. 10, no. 3, Mar. 2018, doi: 10.1177/1687814018765549.
- J. Filipe Dias Duque Marques Loureiro, A. Bento Moutinho Luís Alberto Gonçalves de Sousa, P. Jorge Coelho Ramalho Oliveira Supervisor, and L. Alberto Gonçalves de Sousa, “Energy Consumption Estimation in Lap Time Simulation Mechanical Engineering Examination Committee,” 2018.
- W. Zhang and J. Xu, “Advanced lightweight materials for Automobiles: A review,” Materials and Design, vol. 221. Elsevier Ltd, Sep. 01, 2022. doi: 10.1016/j.matdes.2022.110994.
- R. Pütz and T. Serné, Race Car Handling Optimization: Magic Numbers to Better Understand a Race Car. Springer Fachmedien Wiesbaden, 2022. doi: 10.1007/978-3-658-35200-4.
- “vehicle electrification january 2023.”
- Sae, “Materials Innovations Guide for Medical Components and Equipment EBOOK Guide to Battery, Electrification, and Mobility Advances.”
- “Automotive transmissions fundamentals selection design and aplication”.
- A. Suvac, L. Cucu, M. Stoica, and M. Savaniu, “Development and optimization of a three-wheeled electric vehicle frame using structural materials,” in Journal of Physics: Conference Series, Institute of Physics Publishing, Sep. 2019. doi: 10.1088/1742-6596/1297/1/012021.

- A. Suvac, L. Cucu, M. Stoica, and M. Savaniu, “Development and optimization of a three-wheeled electric vehicle frame using structural materials,” in Journal of Physics: Conference Series, Institute of Physics Publishing, Sep. 2019. doi: 10.1088/1742-6596/1297/1/012021.
- D. A. Sumarsono, M. K. Jati, and M. A. Muiz, “Modelling of Tilting and Steering Control System for a Tadpole Three-Wheeled Vehicle,” in Journal of Physics: Conference Series, Institute of Physics Publishing, Apr. 2020. doi: 10.1088/1742-6596/1519/1/012008.
- B. Sunday, U. Thomas, I. S. Ityokumbul, and A. Nasir, “effect of number of passengers [loading] on centre of gravity of a three wheeled vehicle [keke-napep] cg of Four Wheeled Vehicle CG of Three wheeled Vehicle Effects of Loading on CG Static Stability Factor,” vol. 15, no. 3, pp. 628–637, 2019, [Online]. Available: www.azojete.com.ng
- A. J. Waters and A. Khajepour, “optimization of novel corner module for urban electric vehicle,” 2017. [Online]. Available: http://www.asme.org/about-asme/terms-of-use
- T. Nabil et al., “Design and Fabrication of Prototype Battery Electric Three Wheeled Vehicles,” 2019.
- O. Ellerstrand and T. E. Kilicasan, “Optimization of Front Suspension Uprights on a Three-wheeled Electric Vehicle Ecoist,” 2017. [Online]. Available: http://www.mek.lth.se/
- S. P. Vijaya Ram, “mass optimization using generative design for rear accessory assembly in a two-wheeler,” International Journal of Mechanical Engineering, vol. 6, no. 3, 2021.
- “Brake Design and Safety Second Edition.” [Online]. Available: www.sae.org/BOOKSTORE
- Karin. Jonasson and Media-tr.), Analysing hybrid drive system topologies. Dept. of Industrial Electrical Engineering and Automation, Univ, 2002.
- L. Shui, F. Chen, A. Garg, X. Peng, N. Bao, and J. Zhang, “Design optimization of battery pack enclosure for electric vehicle,” Structural and Multidisciplinary Optimization, vol. 58, no. 1, pp. 331–347, Jul. 2018, doi: 10.1007/s00158-018-1901-y.
- “The Automotive Chassis.”

- B. Heissing and M. Ersoy, Chassis handbook : fundamentals, driving dynamics, components, mechatronics, perspectives. Vieweg + Teubner, 2011.
- S. Luo, "Human Vehicle Dynamics Coupling of Miniature Electric Vehicle Roll Stability: Effects of Driver Weight, Wheel Base and Track Width," in Journal of Physics: Conference Series, IOP Publishing Ltd, Aug. 2021. doi: 10.1088/1742-6596/2002/1/012018.
- S. A. Sree Ram, P. Raja, and K. Sreedaran, "Optimization of rollover stability for a three-wheeler vehicle," Adv Manuf, vol. 5, no. 3, pp. 279–288, Sep. 2017, doi: 10.1007/s40436-017-0191-8.
- H. Yim and K. Lee, "Preliminary Modular Design for Electric Personal Mobility with Design-Engineering Collaboration."
- M. Ataei, A. Khajepour, and S. Jeon, "Rollover stabilities of three-wheeled vehicles including road configuration effects," Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, vol. 231, no. 7, pp. 859–871, Jun. 2017, doi: 10.1177/0954407017695007.
- E. C. Tsirogiannis, G. E. Stavroulakis, and S. S. Makridis, "Electric car chassis for Shell Eco Marathon competition: Design, modelling and finite element analysis," World Electric Vehicle Journal, vol. 10, no. 1, Mar. 2019, doi: 10.3390/wevj10010008.
- D. Seward, Race car design.
- P. Kale and P. Ardak, "Design, Fabrication of Human-Powered Vehicle," in Lecture Notes in Mechanical Engineering, Springer Science and Business Media Deutschland GmbH, 2021, pp. 593–598. doi: 10.1007/978-981-15-7779-6_54.
- M. Lilavois et al., "Human Powered Vehicle Concept Design."
- Abhijit M. Mane, Akshay S. Chorge, Akshay Muragode, and Pranesh Bamankar, "Design and fabrication of universal," International Engineering Research Journal (IERJ), no. Special Issue, pp. 102–104, 2017.
- S. E. Manios, N. D. Lagaros, and E. Nassiopoulos, "Nested topology optimization methodology for designing two-wheel chassis," Front Built Environ, vol. 5, Jan. 2019, doi: 10.3389/fbuil.2019.00034.

- N. Rohithkumar, R. Tatapudi, D. Danyharsha, D. Yadav, S. Kumar, and M. Engineering, “Optimization of Swingarm Design using Generative Design,” JETIR, 2021. [Online]. Available: www.jetir.orgf599
- R. Maryniuk, “Development of a Modular Urban Electric Vehicle,” 2017.
- J. Peng, H. He, and N. Feng, “Simulation research on an electric vehicle chassis system based on a collaborative control system,” Energies (Basel), vol. 6, no. 1, pp. 312–328, 2013, doi: 10.3390/en6010312.
- “Fundamentals of Vehicle Dynamics”.
- A. Tarhan, “yaw dynamics control of three wheeled hybrid vehicle by torque vectoring üç tekerli hibrit aracin tork aktarimi ile doğrultu kontrolü.”
- J. Sangama, K. Belgavi, and M. Dijin Mathew, “DESIGN AND FABRICATION OF TADPOLE MODEL SOLAR POWERED TRICYCLE FOR PHYSICALLY CHALLENGED.”
- B. Lenzo, “Vehicle Dynamics,” CISM International Centre for Mechanical Sciences, Courses and Lectures, vol. 603. Springer Science and Business Media Deutschland GmbH, pp. v–vi, Nov. 01, 2022. doi: 10.1007/978-3-030-75884-4.
- B. Sunday, U. Thomas, I. S. Ityokumbul, and A. Nasir, “effect of number of passengers [loading] on centre of gravity of a three wheeled vehicle [keke-napep] cg of four wheeled vehicle cg of Three wheeled Vehicle Effects of Loading on CG Static Stability Factor,” vol. 15, no. 3, pp. 628–637, 2019, [Online]. Available: www.azojete.com.ng
- “Policy Guidelines for Electric 2-& 3-wheelers for Southeast Asia,” 2020. [Online]. Available: https://www.un.org/Depts/ Cartographic/english /htmain.htm.
- M. Palanivendhan, S. Devanand, J. Chandradass, J. Philip, and S. Sajith Reddy, “Design and analysis of 3-wheeler chassis,” in Materials Today: Proceedings, Elsevier Ltd, 2021, pp. 6958–6968. doi: 10.1016/j.matpr.2021.01.417.
- F. Xiong, X. Zou, Z. Zhang, and X. Shi, “A systematic approach for multi-objective lightweight and stiffness optimization of a car body,” Structural and Multidisciplinary Optimization, vol. 62, no. 6, pp. 3229–3248, Dec. 2020, doi: 10.1007/s00158-020-02674-5.

- D. Zindani, -Saikat Ranjan Maity, and -Sumit Bhowmik, “Excogitating Material Rankings Using Novel Aggregation Multiplicative Rule (AMR): A Case for Material Selection Problems,” Arab J Sci Eng, vol. 45, pp. 5631–5646, 2020, doi: 10.1007/513369-020-04495-6.
- S. Nandhakumar, S. Seenivasan, A. M. Saalih, and M. Saifudheen, “Weight optimization and structural analysis of an electric bus chassis frame,” in Materials Today: Proceedings, Elsevier Ltd, 2020, pp. 1824–1827. doi: 10.1016/j.matpr.2020.07.404.
- M. Musa Nisar, S. Zia, M. Fenoon, and O. Alquabeh, “Generative Design of a Mechanical Pedal Mass optimization using generative design View project,” Article in International Journal of Engineering and Management Sciences, 2021, doi: 10.21791/IJEMS.2021.1.5.
- S. Khan and M. J. Awan, “A generative design technique for exploring shape variations,” Advanced Engineering Informatics, vol. 38, pp. 712–724, Oct. 2018, doi: 10.1016/j.aei.2018.10.005.
- T. Briard, F. Segonds, and N. Zamariola, “G-DfAM: a methodological proposal of generative design for additive manufacturing in the automotive industry,” International Journal on Interactive Design and Manufacturing, vol. 14, no. 3, pp. 875–886, Sep. 2020, doi: 10.1007/s12008-020-00669-6.
- A. T. Mayyas, A. Qattawi, A. R. Mayyas, and M. A. Omar, “Life cycle assessment-based selection for a sustainable lightweight body-in-white design,” Energy, vol. 39, no. 1, pp. 412–425, 2012, doi: 10.1016/j.energy.2011.12.033.
- C. Chatzikomis, A. Sorniotti, P. Gruber, M. Zanchetta, D. Willans, and B. Balcombe, “Comparison of Path Tracking and Torque-Vectoring Controllers for Autonomous Electric Vehicles,” IEEE Transactions on Intelligent Vehicles, vol. 3, no. 4, pp. 559–570, Dec. 2018, doi: 10.1109/TIV.2018.2874529.
- “Creating harmonized standards solutions. Moving the on-and off-road vehicle industry forward. Issue Highlights,” 2010. [Online]. Available: www.sae.org
- “Status quo analysis of various segments of electric mobility and low carbon passenger road transport in India | Foreword by NITI Aayog.”

- S. Mande, Institute of Electrical and Electronics Engineers, International Conference on Technologies for Sustainable Development 1 2015.02.04-06 Mumbai, and ICTSD 1 2015.02.04-06 Mumbai, 2015 International Conference on Technologies for Sustainable Development (ICTSD) 4-6 Feb. 2015, Mumbai, India.
- D. A. Sumarsono, M. K. Jati, and M. A. Muiz, "Modelling of Tilting and Steering Control System for a Tadpole Three-Wheeled Vehicle," in Journal of Physics: Conference Series, Institute of Physics Publishing, Apr. 2020. doi: 10.1088/1742-6596/1519/1/012008.
- P. Upadhyay, S. Kumar Sharma, G. Kumar, P. Bansal, and P. Sharma, "Optimization of chassis for a solar powered vehicle," in IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, Feb. 2020. doi: 10.1088/1757-899X/748/1/012021.
- V. Fegade, G. Jadhav, and M. Ramachandran, "Design, Modelling and Analysis of Tilted Human Powered Vehicle," in IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, Jul. 2018. doi: 10.1088/1757-899X/377/1/012215.
- V. Gulati, E. Vikas Gulati, E. Sameer Mehta, A. Kashyap, and K. Pawar, "Design and FEA of a recumbent trike." [Online]. Available: https://www.researchgate.net/publication/291440380
- J. Prakash Srivastava et al., "Design and Fabrication of Human-Electric Hybrid Power Tri-Cycle," in IOP Conference Series: Materials Science and Engineering, IOP Publishing Ltd, Nov. 2019. doi: 10.1088/1757-899X/653/1/012004.
- P. Upadhyay, M. Deep, A. Dwivedi, A. Agarwal, P. Bansal, and P. Sharma, "Design and analysis of double wishbone suspension system," in IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, Feb. 2020. doi: 10.1088/1757-899X/748/1/012020.
- B. Siegler, A. Deakin, and D. Crolla, "Lap Time Simulation: Comparison of Steady State, Quasi-Static and Transient Racing Car Cornering Strategies."
- Y. Ye, Y. Sun, S. Dongfang, D. Shi, and M. Hecht, "Optimizing wheel profiles and suspensions for railway vehicles operating on specific lines to

reduce wheel wear: a case study," Multibody Syst Dyn, vol. 51, no. 1, pp. 91–122, Jan. 2021, doi: 10.1007/s11044-020-09722-4.

- T. Wilhelm, V. Dorsch, and F. Gauterin, "Mass data measurement, approximation and influence on vehicle stability for ultra-light human-powered vehicles," Applied Sciences (Switzerland), vol. 11, no. 12, Jun. 2021, doi: 10.3390/app11125485.
- O. Ellerstrand and T. E. Kilicasan, "Optimization of Front Suspension Uprights on a Three-wheeled Electric Vehicle Ecoist," 2017. [Online]. Available: http://www.mek.lth.se/
- S. Wang and D. Wang, "Crashworthiness-based multi-objective integrated optimization of electric vehicle chassis frame," Archives of Civil and Mechanical Engineering, vol. 21, no. 3, Aug. 2021, doi: 10.1007/s43452-021-00242-2.
- S. Rosenthal, F. Maaß, M. Kamaliev, M. Hahn, S. Gies, and A. E. Tekkaya, "Lightweight in Automotive Components by Forming Technology," Automotive Innovation, vol. 3, no. 3, pp. 195–209, Sep. 2020, doi: 10.1007/s42154-020-00103-3.
- B. El Elnaghi et al., "Design and Fabrication of Prototype Battery Electric Three Wheeled Vehicles," 2019. [Online]. Available: https://www.researchgate.net/publication/335021388
- B. Conard, M. Reynolds, and R. Marlee, "Testing of a Human Powered Vehicle." [Online]. Available: https://ideaexchange.uakron.edu/honors_research_projectshttps://ideaexchange.uakron.edu/honors_research_projects/866
- "Testing and Evaluation of a New Multitrack Electric Bicycle—A Comparative Study".
- P. Patodi, V. Saxena, and Y. Rathore, "international journal of research in aeronautical and mechanical engineering review on tadpole design-issues & challenges," international journal of research in aeronautical and mechanical engineering, vol. 2, no. 3, pp. 122–128, 2014.
- T. Varmora, M. Kumar, and S. K. Rajendra, "Design and Optimization of Hybrid Electric Vehicle," in Smart Innovation, Systems and Technologies,

Springer Science and Business Media Deutschland GmbH, 2020, pp. 199–209. doi: 10.1007/978-981-32-9578-0_18.

- S. A. Sree Ram, P. Raja, and K. Sreedaran, “Optimization of rollover stability for a three-wheeler vehicle,” Adv Manuf, vol. 5, no. 3, pp. 279–288, Sep. 2017, doi: 10.1007/s40436-017-0191-8.
- K. Srinivas et al., “design, analysis & virtual test run of three wheeler advanced hybrid electric vehicle (efficycle),” 2223. [Online]. Available: www.irjmets.com
- I. Journal, “IRJET-A design To Control the Center Of Gravity and Friction of A Tricycle,” International Research Journal of Engineering and Technology, 2018, [Online]. Available: www.irjet.net
- A. Kumar, B. P. Chaturvedi, M. Lal, K. Sri, and N. Singh, “Energy Systems in Electrical Engineering Planning of Hybrid Renewable Energy Systems, Electric Vehicles and Microgrid Modeling, Control and Optimization.” [Online]. Available: https://link.springer.com/bookseries/13509
- P. Serafini, E. Guazzelli, F. G. Rammerstorfer, W. A. Wall, and B. Schrefler, “CISM International Centre for Mechanical Sciences Courses and Lectures Volume 603 Managing Editor Series Editors.” [Online]. Available: https://link.springer.com/bookseries/76
- A. S. Shinde, B. R. Chavan, and S. M. Patankar, “Results: Investigation for Effect of Parameters on Corrugated Wire Mesh Laminates Strength,” International Advanced Research Journal in Science, Engineering and Technology, vol. 8, 2021, doi: 10.17148/IARJSET.2021.8656.

PUBLICATIONS

Gmail AMOL SHINDE <amolshinde01991@gmail.com>

[EPREC-2024] Information on accepted paper ID: 125

2 messages

Microsoft CMT <email@msr-cmt.org> 11 April 2024 at 13:31
Reply-To: Om Hari Gupta <omhari.ee@nitjsr.ac.in>
To: AMOL S SHINDE <amolshinde01991@gmail.com>

Dear Prof./Dr./Ms./Mr. AMOL S SHINDE,

Your paper titled: "Advances and Innovations in Small Electric Vehicles Structural Design: A Review", Paper ID-125 was recently accepted in the Springer Conference "5th Electric Power and Renewable Energy Conference (EPREC-2024)".

To ensure that your paper gets submitted to SPRINGER (subject to registration and presentation by the registered author in EPREC-2024) for publication in the Scopus-indexed "Lecture Notes in Electrical Engineering (LNEE)", kindly act accordingly as per the following instructions:

1. Please incorporate the suggestions and comments of reviewers while preparing the final camera-ready paper (in an ms-word/latex format as per the Springer-LNEE template). The reviews can be found in your CMT account at https://cmt3.research.microsoft.com/EPREC2024.
The final camera-ready paper should be prepared in the SPRINGER-LNEE template only, which can be downloaded from https://www.springer.com/gp/authors-editors/conference-proceedings/conference-proceedings-guidelines. Authors are also reminded that LNEE has a very strong anti-plagiarism policy for conference papers (less than 20% similarity index).

2. Please prepare a response/reply sheet consisting of a point-wise response to the reviewers' comments and mention where the changes have been incorporated in the camera-ready paper. Please download the template using the link below:
https://docs.google.com/document/d/1tkfmQqtn9O4wY0v-cTLRCXat-KjJlUil/edit?usp=sharing&ouid=102575237024591738362&rtpof=true&sd=true

3. Before submitting the Camera Ready paper using your CMT account associated with this email (use url https://cmt3.research.microsoft.com/EPREC2024 for accessing your CMT account), kindly prepare following documents/files to be uploaded:
a) Camera Ready Paper - in Word (doc/docx) or Latex (zip) - File name: "Camera Ready-Editable"
b) Camera Ready Paper - in pdf (pdf) - File name: "Camera Ready-pdf"
c) Reply Sheet - in Word (doc/docx) or pdf (pdf) - File name: "Reply"

These files must be uploaded to CMT portal by May 14, 2024.

4. Further, you must also complete the registration process using Google Form (https://forms.gle/yRgkmpBhH8RwmvqV7) by May 14, 2024 – details are available at https://www.eprec.co.in/information-for-authors/registration-details
-------While registering, the authors can also provide the mode of presentation of paper (online or offline).---------

5. You have to submit the copyright form – the information will be communicated on or before 14-04-2024

****
The conference organizers reserve the right not to include the paper in the conference proceedings if it is not compliant with EPREC-2024 formatting instructions or similarity index.

Thank you for considering EPREC-2024 to present the results of your research. For any queries, please feel free to contact us at eprec_eed@nitjsr.ac.in.

Please refer to the website "https://www.eprec.co.in" for further updates about the conference.

We look forward to meeting you at EPREC- 2024.

Best regards,
Technical Program Committee,
EPREC- 2024 <eprec_eed@nitjsr.ac.in>
https://www.eprec.co.in/

AMOL SHINDE <amolshinde01991@gmail.com> 11 April 2024 at 20:43
To: Sameer Nanivadekar Sir <sameermanas@gmail.com>

[Quoted text hidden]

Journal of Research Administration
Society of Research Administrators International

OPTIMIZATION OF SWING ARM FOR TADPOLE STRUCTURED ELECTRIC VEHICLE

Amol Shinde[1], Raju Kumar Swami [2], Sameer Nanivadekar [3]

[1] Research Scholar, Mechanical Engineering Department, Pacific Academy of Higher Education and Research University, Udaipur-313003, India;

[2] Associate Professor, Electrical Engineering Department, Pacific Academy of Higher Education and Research University, Udaipur-313003, India;

[3] Associate Professor, Department of Information Technology, A. P. Shah Institute of Technology, Thane-400615, India

Abstract:

The automotive industry is facing a challenge to develop compact, fuel-efficient, and secure automobiles. Three-wheelers are becoming increasingly popular due to their low fuel consumption, ease of driving, and parking in densely crowded urban areas. This paper used a tadpole-shaped electric three-wheeled vehicle structure to optimize and select a lightweight structure. The swing arm is a single or double-sided mechanical device that connects a motorcycle's rear wheel to its body, enabling it to rotate vertically. It is a key component of the most contemporary rear assembly. System lightweight design is the process of putting together multiple parts or functions into a single part or system to make an assembly lighter. The material lightweight design takes advantage of what the material has to offer, while the structure lightweight design is a subset of the system lightweight design. Additive Manufacturing and Generative Design (DfX) were developed to meet the demands of highly competitive markets in terms of manufacturing costs, quality, and speed to market. In this paper, the generative design approach is used to optimize the weight of the swing arm for a tadpole structure electric vehicle.

Key words: Tadpole Structure, Electric Vehicle, Generative Design, Swing-arm.

1 Introduction

The increased urban population and accompanying rise in the number of cars has presented the automotive industry with a new challenge: the development of compact, fuel-efficient, and secure automobiles.[1] A fresh crop of compact automobiles follows this trend. There has been a recent uptick in interest in these vehicles because of their low fuel consumption, ease of driving, and parking in densely crowded urban areas.[2] In numerous nations, including India, Thailand, Peru, China, and even Italy, three-wheeled vehicles are already integrated into the public transit system.[3] Low fuel costs and zero pollutants are two major benefits of electric three-wheelers. Along with their widespread acceptance, three-wheelers have significance: they are particularly stable while performing complex maneuvers. A variety of solutions to increase their reliability have been presented.[4]

The swing arm connects the motorcycle's rear wheel to the frame and is critical to the bike's rear suspension system. The motorcycle's handling, stability, and performance may all benefit from a well-tuned swing arm. The swing arm may be improved in a number of ways.[5] The stability, traction, and handling of a motorbike are all affected by its wheelbase, which in turn is affected by the length of the swing arm. The stability gains from a longer swing arm may not be worth the potential loss of control. The opposite is true as well; a shorter swing arm might increase maneuverability but may compromise stability. The trick is to strike a balance between length and steadiness.[6] [7] The swing arm's weight, strength, and pliability may all be affected by the material it's made out of. The total weight of a motorbike may be reduced by using lightweight materials like aluminum or carbon fiber, while the use of high-strength materials like titanium or steel can increase its durability and strength.[8]

Suspension geometry, and hence handling and traction, is affected by the motorcycle's swing arm's form and angle. The degree of squat and anti-squat may be modified by adjusting the swing arm angle, which in turn helps enhance the vehicle's responsiveness and control under acceleration and braking.[9] In a vehicle, the suspension linkage is what attaches the swing arm to the chassis and the shock absorber. Improving the responsiveness and adjustability of the suspension through linkage optimization can boost the motorcycle's performance and handling.[10] Swing arm optimization is a multi-faceted procedure that must take into account the function of the motorbike, the preferences of the rider, and the limitations of the design. It entails weighing the benefits and drawbacks of different performance qualities and is often carried out with the use of computer simulations and physical testing.[11]

An electric vehicle needs to optimize the weight of each component to increase its range and handling of the vehicle. The single-wheel drive will give the solution for urban traffic and a more stable structure with zero pollution. This paper used a tadpole-shaped electric three-wheeled vehicle structure for study analysis. Weight distribution, suspension geometry, and tire choice are a few examples of the requirements for optimization; each of these elements must be carefully chosen and fine-tuned to achieve the best performance. In addition, it's crucial to evaluate these optimization strategies in real-world settings and do computer simulations to confirm their efficacy.

2 Tadpole Design

A tadpole design for an electric vehicle consists of two wheels in the front and one wheel in the back. A reverse trike layout is another name for this style of vehicle. Because the vehicle's weight is shared by all three wheels, it is more stable in this configuration. At higher speeds, in particular, this can improve the vehicle's stability and make it simpler to handle. In addition, having two wheels up front helps enhance the vehicle's handling and agility, particularly in confined locations.[10] Suspension systems that can accommodate the tadpole layout's weight distribution and handling characteristics may be trickier to develop.

A vehicle's design will ultimately be decided by a number of criteria, such as the market segment the vehicle is aimed at, the specifications the vehicle must meet, and the preferences of the maker and the buyer.[11] The vehicle's teardrop form makes it aerodynamic. Air flows readily over the vehicle's bodywork. For its stability, aerodynamics, and fuel efficiency, auto designers are favoring tadpole design. Many hybrid and electric concept cars feature a three-wheel configuration. Three-wheelers may become increasingly common as cars become more eco-friendly.

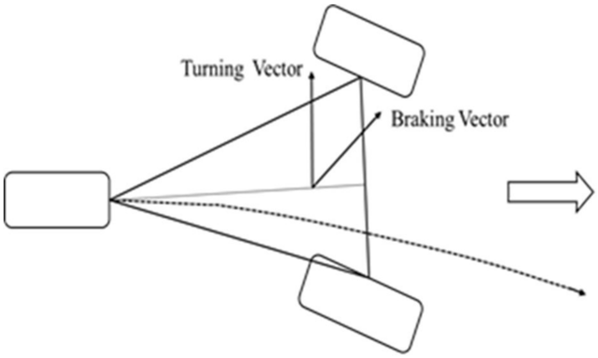


Fig.1 Tadpole Architecture

3 Swing Arm

A swing arm, also known as a swing fork or pivoted fork, is a single or double-sided mechanical device that connects a motorcycle's rear wheel to its body, enabling it to rotate vertically. The key component of most contemporary motorcycles and ATVs' rear suspension, it holds the rear axle solidly while rotating to absorb bumps and suspension loads caused by the rider, accelerating, and braking.[9]

3.1 Types of Swing-Arm

Swing-arm motorcycle suspension links the back wheel to the motorbike chassis. Swing arms come in a variety of styles, including:[10]

- Straight swing arms- are the most basic and widely used variety. It is made up of a single straight piece of metal that links the back wheel to the frame.
- Single-sided swing arms- are intended to enable for easy wheel removal for maintenance or repair. It features a single-sided framework that links the wheel to the frame and is often equipped with a hub-center steering mechanism.
- Dual-sided swing arm- This form of swing-arm has two arms, one on each side of the wheel, that link the wheel to the frame. This style is more stable than the straight kind and is typically found on heavy-duty motorcycles.
- Pro-link swing arms- are meant to improve suspension performance by utilizing a linkage system between the swing arm and the shock absorber. It enables more accurate suspension settings and enhanced handling.
- The banana swing arm- has a curved form that resembles a banana. Several racing motorcycles employ it to boost aerodynamics and save weight.

Ultimately, the choice of swing-arm type is determined by the vehicle's unique requirements and the rider's preferences.

4 System Light Weight Design

System lightweight design is the process of putting together multiple parts or functions into a single part or system to make an assembly lighter. The strategies for making things lighter, such as material lightweight design and lightweight structure design are parts of lightweight system design.[12]

4.1 Material Light Weight Design

This way of designing takes advantage of what the material has to offer. Different materials reach different levels of strength and/or stiffness based on their density and other properties. Material: Lightweight design can be done by using a single material with a high specific property or by combining different materials to take advantage of the best of each. This is called a composite or hybrid.[13]

4.2 Structure Light Weight Design

It is a way to think about making and designing parts by optimizing their topology, shape, and parameters. The goal is to change the shape and form to reduce the weight. The stiffness and structure of an assembly can lead to a light system, so structure lightweight design is a subset of system lightweight design or strength goes up or stays the same.[13]

5 Generative Design

Generative design is a method that uses algorithms and computer power to create and optimize designs depending on specified goals, restrictions, and inputs. This process involves the creation and optimization of designs. This strategy enables designers and engineers to investigate a vast variety of potential design options and determine the approaches that will produce the greatest results depending on the outcomes that are wanted.[14]

The generative design process generally consists of the following four basic steps:

- Describing the design's objectives and limitations: This involves stating the design goals, such as reducing weight or improving performance, as well as any production restrictions or functional requirements that need to be taken into consideration.[15]
- Generating design options: Generative design software can generate a wide range of design options based on the defined goals and constraints by utilizing computational algorithms and techniques such as artificial intelligence and machine learning. These techniques allow the software to learn from previous designs.[16]
- Assessing and improving the designs: When the designs have been developed, they are compared to the predetermined goals and limitations, and the solutions that appear to have the most potential are chosen for future development.[17]

The selected design is then further improved and optimized via the use of traditional design procedures, and the final product is manufactured by either conventional or additive manufacturing techniques.

The process of generative design has a number of advantages, the most notable of which is the capability to generate designs with complicated geometries as well as designs that are optimal with regard to a broad variety of considerations, such as cost, weight, and strength. Also, it can cut down on the amount of manual input and iteration that is required during the design phase.[17]

The fields of aerospace, automotive, and architecture are just a few of the many that make use of generative design in their product development processes. It is especially helpful in applications where aspects such as reducing weight, increasing performance, and improving customization are primary considerations.

5.1 Generative Design (GD) Methodology

A design approach known as generative design is one that makes use of algorithms and computing power to generate and optimize designs in accordance with a set of predetermined limitations and goals. This method enables designers to investigate a wide variety of potential design options and select the most effective design solutions by basing their decisions on the results that are intended. Additive manufacturing and generative design are two technologies that may be used to improve the design and production of components and finished goods. Both technologies are complementary to one another and can be utilized together. The generative design allows for the creation of designs that are optimized to make full use of the one-of-a-kind capabilities of 3D printing. This is accomplished by capitalizing on the design freedom and flexibility offered by additive manufacturing.[18]

For instance, generative design may be used to produce lightweight structures that are optimized for certain load circumstances. This results in components that are both more durable and more efficient than parts that are built using conventional methods. Additive manufacturing can then be used to produce these complex geometries with a high degree of precision and accuracy, which enables the creation of parts that would be difficult or impossible to produce using traditional manufacturing methods. Additive manufacturing is a relatively new manufacturing technique that was developed in the 1990s.[18] Ultimately, the combination of additive manufacturing with generative design has the potential to transform the way in which we design and build parts and products, making it possible to achieve better levels of efficiency, usefulness, and creativity

6 Material Selection

Lightweight structural materials allow automobiles to carry improved emission control, safety, and integrated electrical systems without adding weight. Hybrid, plug-in, and electric cars need lightweight materials. Lightweight materials may reduce the weight of power systems like batteries and electric motors, enhancing efficiency and all-electric range. Lightweight materials might reduce battery size and cost while maintaining plug-in car all-electric range.[12]

Lightweight materials' cost, recycling, integration with cars, and fuel efficiency advantages depend on research and development. The most commonly used materials for lightweight structures in automotive industries and their properties of it are given below.

Table 1 Material Properties

Material	Material Strength (MPa)	Cost Per Kg. (Rs.)
High Strength Steel	*500*	*125*
Advanced high-strength steel	*700*	*175*
Glass fiber composites	*3500*	*200*
Titanium	*1400*	*5500*

Aluminum and Al matrix composites	*240*	*200*
Carbon fiber composites	*3500*	*8000*
Magnesium	*440*	*90*
7076 T6 Aluminium Alloy	*570*	*600*

It is crucial to consider the particular needs and restrictions of the system being optimized while thinking about design factors. This comprises elements including price, size, and performance objectives.

By considering the cost-effectiveness and strength of the material used for the automobile and ease in manufacturing 7076 T6 Aluminium alloy material is selected for the swing-arm of a tadpole structured electric vehicle.

7 Methodology

Optimization techniques including material selection, structural design, and suspension tuning are all geared toward enhancing the strength, longevity, and performance of the swing arm under varied driving circumstances. With tadpole-shaped electric cars that mainly rely on the swing arm suspension system, these optimization approaches are essential for attaining the best handling and stability.

7.1 Selection of the Swing Arm for Tadpole Structure

As there are different types of swing in the market for different purposes such as for Sport and Commercial bikes. But we are designing for the tadpole structure as it consists of 3 wheels in this type of structure. So, to support the rear wheel of the structure we would select the double-sided swing arm for the Tadpole structure. As it supports all the types of force acting on the structure of the design.

7.2 Load Consideration

There are different loading conditions such as static conditions and dynamic conditions. In static conditions, the equal forces are acting on both beams of the swing arm, and in the dynamic condition we would consider the corning condition where there will be unequal loading on both sides of the beam of the chassis.

7.3 CAD Model of the swing-arm

Designing of the swing arm in the Cad model by considering load conditions for the modeling of the swing arm. From the modeling of the swing arm, we would get the dimension of the model and properties of the swing arm. And also would put the material to it.

7.4 Generative Design Software

The process of generative design involves using Altair Inspire Software to produce several CAD solutions that satisfy predefined constraints and we would be getting many design iterations which would be optimized models.[19]

7.5 Design Constraint for GD

We considered the 3 design constraints for the GD which would be the load acting on the swing, the stiffness & Weight reduction of the swing arm. This weight reduction will be based on getting the max stiffness.

7.6 Iteration for GD

There will be five iterations generated by the GD in the bases of weight reduction percentage from 70 to 90%.

7.7 Analysis of the Model

The analysis will be done in the ansys software which will be static structural. The results will be on the basis of total deformation, and maximum principal stress.

7.8 Selection Process

Selection will be based on different criteria such as weight, stiffness and aesthetics. The selection method that would be considered will be of MCDM which is called Multi Decision Criteria Decision Making method. In this we would be using the best and worst method in the MCDM for the selection of optimized solutions of our design.[20] When making a choice between many options, it might be helpful to take into account as many factors as possible. This is where "Multi-Criteria Decision Making" (or "MCDM") comes in handy. In multi-criteria decision making (MCDM), the decision maker takes into account a number of elements, or criteria, in order to make a final choice. MCDM assists decision makers in determining the best-suited option by taking into consideration multiple views and preferences. MCDM is widely utilized in many sectors, including engineering, management, economics, and environmental research.[16]

7.9 Final Design

The final iteration would be finalized based on the optimum value of all the selection parameters that would be considered. That would be the final design of the optimization of the swing arm.[21]

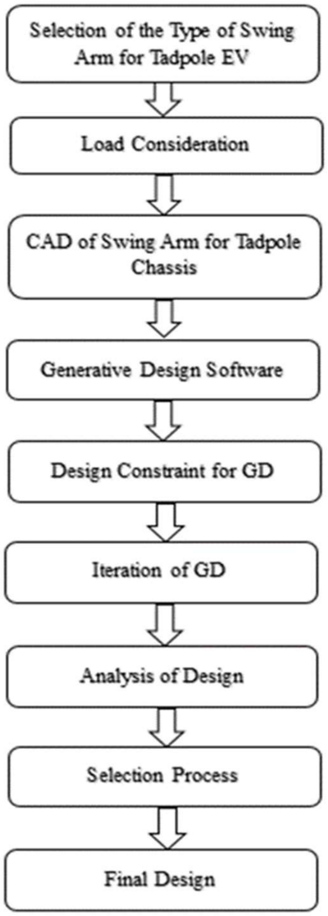


Fig.2 Flow Chart of Swing Arm Generative Design for Tadepole Structured EV

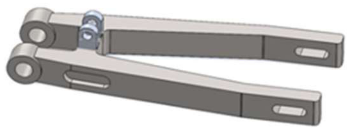
9 Analysis and Results

By using Solidworks software CAD model of the swing arm is prepared and assigned given properties to the model.

9.1 Generative Design Iteration

a) Iteration 1

b) Iteration 2



c) Iteration 3

d) Iteration 4

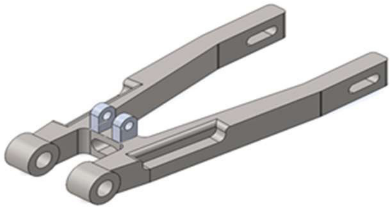


Fig.3 Weight and Shape Optimization Iterations

The initial Weight of the Swing Arm was 11.70 Kg. After application of the generative design concept and getting different iterations as follows with varying mass.

Table 2 Weight Reduction by Optimization

Iterations No.	**Mass (Kg)**	**Mass Reduction %**
Iteration 1	*11.08*	*2.3%*
Iteration 2	*11.41*	*1.00%*
Iteration 3	*8.75*	*25.22%*
Iteration 4	*10.80*	*7.7%*

9.2 Load Applied for Analysis

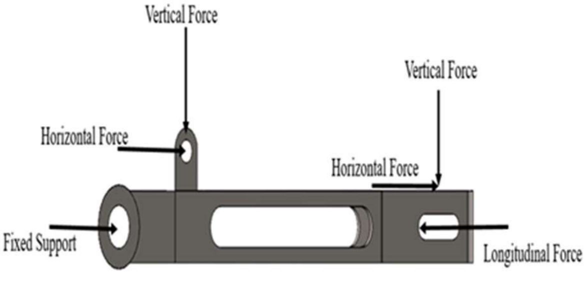
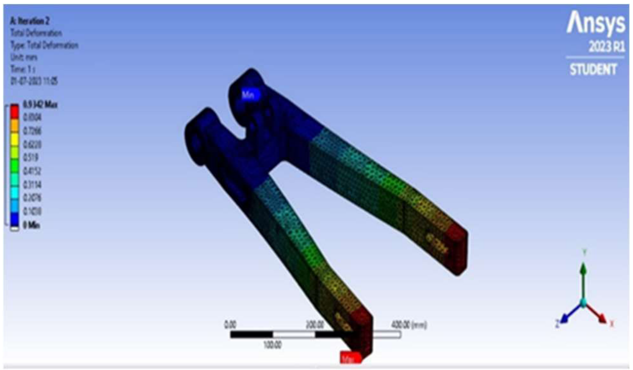


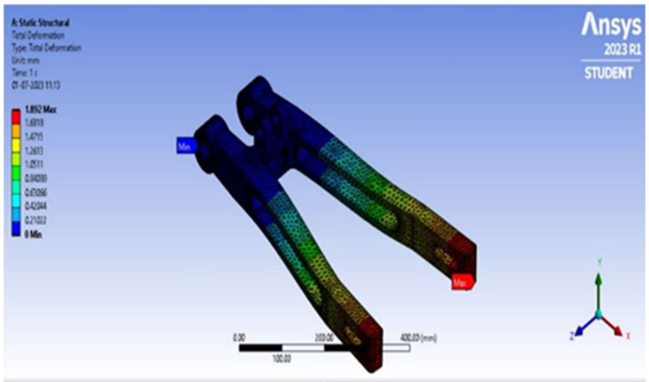
Fig.4 Loading Conditions

In Ansys software loads are applied as shown in Fig. 4. For analysis purpose at the eye end fixed support is considered and vertical forces of 325 N and horizontal force of 1925 N is applied on the swing arm by considering bump due to tire and forces due to suspension. Also, the longitudinal force due to acceleration and braking is applied at 2000 N.

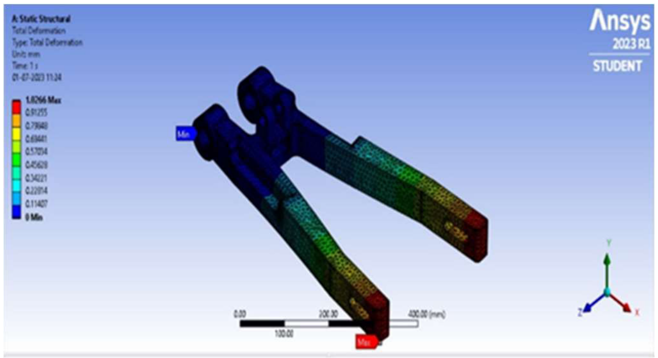
a) Iteration 1



b) Iteration 2



c) Iteration 3



d) Iteration 4

Fig.5 Analysis of Iterations by using ANSYS Software

Now here we are assigning the ranking for the geometry parameters as follows as per the manufacturability and aesthetics of the swing arm.

Table 3 Ranking for Geometry Parameter

Description	Ranking
Low	*1*
Below Average	*2*
Average	*3*
Good	*4*
Excellent	*5*

Dividing parameters into beneficial and non-beneficial categories as per their effect on the swing arm as maximum or minimum. So considering Geometry and stiffness as beneficial parameters as they should be maximum and mass, stresses induced, and deformation as non-beneficial parameters as they should be minimum.

Values were observed for different parameters after ANSYS and applying generative design concept for each iteration as follows.

Table 4 Observation Values of Different Parameters

	Beneficial		Non Beneficial			
Iteration	**Geometry**	**Stiffness**	**Mass (Kg)**	**Stress (MPa)**	**Deformation (mm)**	
1	*4*	*5893.79*	*11.08*	*35.582*	*0.33934*	
2	*5*	*2140.87*	*11.41*	*25.502*	*0.9342*	
3	*2*	*1057.08*	*8.75*	*53.634*	*1.892*	
4	*1*	*1948.18*	*10.8*	*23.002*	*1.0266*	
Max	***5***	***5893.79***	***8.75***	***23.002***	***0.33934***	***Min***

For decision-making by using multi-criteria here considering the maximum value of beneficial criteria and minimum value of non-beneficial criteria. After dividing these values to actual values will get the multiplication factor as follows.

Table 5 Multiplication Factors for Parameters

	Beneficial		Non Beneficial		
Iteration	Geometry	Stiffness	Mass	Stress	Deformation
1	*0.8*	*1*	*0.78971*	*0.64645*	*1*
2	*1*	*0.36324*	*0.76687*	*0.90196*	*0.363241*
3	*0.4*	*0.17935*	*1*	*0.42886*	*0.179355*
4	*0.2*	*0.33054*	*0.81018*	*1*	*0.330547*

After getting multiplication factors will assign the weightage to each criterion as per importance in tadpole structured electric vehicle and get the total weightage for deciding the optimized iteration of swing arm for tadpole EV.

Table 6 Total Weightage and Ranking of Parameters

	Beneficial		Non Beneficial			Total	
Weightage	20	25	20	20	15	100	
Iteration	Geometry	Stiffness	Mass	Stress	Total Displacement	Total	Ranking
1	*16*	*25*	*15.79*	*12.92*	*15*	*84.72*	*1*
2	*20*	*9.08*	*15.33*	*18.03*	*5.44*	*67.90*	*2*
3	*8*	*4.48*	*20*	*8.57*	*2.69*	*43.75*	*4*
4	*4*	*8.26*	*16.20*	*20*	*4.95*	*53.42*	*3*

10 Conclusions

Generative design software involves producing several CAD solutions that satisfy predefined constraints. Multi-Criteria Decision Making (MCDM) is an important tool for making a choice between many options, as it takes into account a number of elements, or criteria, to make a final choice.

In this paper, by applying the generative design method and Multi-Criteria Decision Making (MCDM) process the weight of the swing arm for a tadpole structured electric vehicle is assed with its initial weight of 11.7 Kg.

From the results iteration number one has ranking one, So iteration no. 1 is the optimized result for the material 7076 T6 Aluminium alloy material of the swing arm in which weight is reduced by 0.7 kg, geometry is optimized and having ease in manufacturing and getting higher strength with allowable induced stress and deformation.

References

1 B Kosankar, Sharda, and Chetana Khandar. "A review of vehicular pollution in urban India and its effects on human health." Journal of Advanced Laboratory Research in Biology 5, no. 3, 2014.

2 D'Amato, Gennaro, and Cezmi Akdis. "Global warming, climate change, air pollution and allergies." Authorea Preprints, 2020.

3 Xu, Bingjie, Arshian Sharif, Muhammad Shahbaz, and Kangyin Dong. "Have electric vehicles effectively addressed CO2 emissions? Analysis of eight leading countries using quantile-on-quantile regression approach." Sustainable Production and Consumption 27, 2021.

4 Gnann, Till, Thomas S. Stephens, Zhenhong Lin, Patrick Plötz, Changzheng Liu, and Jens Brokate. "What drives the market for plug-in electric vehicles?-A review of international PEV market diffusion models." Renewable and Sustainable Energy Reviews 93, 2018.

5 Ijaz, Muhammad, Muhammad Zahid, and Arshad Jamal. "A comparative study of machine learning classifiers for injury severity prediction of crashes involving three-wheeled motorized rickshaw." Accident Analysis & Prevention 154, 2021.

6 Luo, Shi-Jian, Ye-Tao Fu, and Yu-Xiao Zhou. "Perceptual matching of shape design style between wheel hub and car type." International journal of industrial ergonomics 42, no. 1, 2012.

7 Tang, Chen, Ling He, and Amir Khajepour. "Design and analysis of an integrated suspension tilting mechanism for narrow urban vehicles." Mechanism and Machine Theory 120, 2018.

8 Mr. Ketan Patil, Mr. Gaurav Rajpurohit, Mr. Rohan Magade, Mr. Akshay Shirphule, “Design and Analysis of Single Sided Swing Arm for Modified Bike,” International Research Journal of Engineering and Technology (IRJET), Volume: 06 Issue: 05, May 2019.

9 Sariman, F & Cipto, Cipto & Rahangmetan, Klemens & Asmal, S., “Analysis of static characteristics of a motorcycle swing arm of a twin-shock suspension type using the finite element method,” IOP Conference Series: Earth and Environmental Science. 343, (2019).

10 Ashish Powar, Hrishikesh Joshi, Sanket Khuley and D.P. Yesane, “Analysis and Topological Optimization of Motorcycle Swing-Arm,” International Journal of Current Engineering and Technology, Special Issue-6, Oct 2016.
11 Palanivendhan, M., S. Devanand, J. Chandradass, Jennifer Philip, and S. Sajith Reddy. "Design and analysis of 3-wheeler chassis." Materials Today: Proceedings 45, 2021.
12 Stephan Rosenthal, Fabian Maaß, Mike Kamaliev, Marlon Hahn, Soeren Gies, and A. Erman Tekkaya, “Lightweight in Automotive Components by Forming Technology,” Springer: Automotive Innovation (2020) 3:195–209.
13 Wen Zhang and Jun Xu, “Advanced lightweight materials for Automobiles: A review,” Elsevier: Materials & Design 221 (2022).
14 Shahroz Khana, and Muhammad Junaid Awana, “A Generative Design Technique for Exploring Shape Variations,” unpublished.
15 M. Fenoon, O. Alquabeh, M.M.Nisar, and S. Zia, “Generative Design of a Mechanical Pedal,” International Journal of Engineering and Management Sciences (IJEMS) Vol. 6. (2021).
16 Ersin Toptas, “Innovative approach to the design of mechanical parts,” Journal of Mechatronics And Artificial Intelligence In Engineering.June 2020, Volume 1, Issue 1.
17 Nitheesh.B.K, Sathya Vijaya Ram. P, Neranjen.S, Naveenkanna.M, Jithin.K.V, and Rajesh, P.K., “Mass Optimization Using Generative Design for Rear Accessory Assembly in a Two-Wheeler,” International Journal of Mechanical Engineering, Vol. 6 No. 3 (December, 2021).
18 Tristan Briard, Frédéric Segonds, and Nicolo Zamariola, “G-DfAM: a methodological proposal of generative design for additive manufacturing in the automotive industry,” Springer: International Journal on Interactive Design and Manufacturing (IJIDeM) (2020) 14:875–886.
19 Alastair R. Ruddle, Anthony J. M. Martin, "Adapting automotive EMC to meet the needs of the 21st century", IEEE Electromagnetic Compatibility Magazine, vol.8, no.3, pp.75-85, 2019.
20 C. Wachter et al., "Electric three-wheelers as an alternative to combustion-engined autorickshaws in Dar es Salaam - Generation of a standard drive cycle, Power Train modelling and simulation of the energy demand of light electric vehicles," 2020 Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER), Monte-Carlo, Monaco, 2020.
21 V. D. Diwakar, S. R. Nedumthaly and R. Prakash, "Objective based modelling and simulation within a context of an electric vehicle development program," 2013 World Electric Vehicle Symposium and Exhibition (EVS27), Barcelona, Spain, 2013.

5. INTERNATIONAL HARRAN CONGRESS ON SCIENTIFIC RESEARCH

December 8-10, 2023 Şanlıurfa, TÜRKİYE

Proceeding Book

EDITORS

Assoc. Prof. Dr. Hasan BÜYÜKASLAN
Assist. Prof. Dr. Veysel DELEN

ISBN: 978-1-955094-76-4

www.ubakkongre.com/harran

5. INTERNATIONAL HARRAN CONGRESS ON SCIENTIFIC RESEARCH

December 8-10, 2023 Şanlıurfa, TÜRKİYE

EDITORS

Assoc. Prof. Dr. Hasan BÜYÜKASLAN
Assist. Prof. Dr. Veysel DELEN

20.12.2023
by Liberty Academic Publishers
New York, USA

ISBN: 978-1-955094-76-4

https://www.ubakkongre.com/harran

Date: 08.12.2023 Ankara Time: 10:00-12:00 Session-1 / Hall-6		Head of Session: MUHAMMAD FAISAL
MUHAMMAD FAISAL	*Allama Iqbal Open University*	PROBLEM STATEMENT NO. 1 EXECUTION OF THE STANDARDS OF AUTHORITATIVE METHODOLOGY IN THE ARRANGEMENT OF COMPUTERIZED PUBLIC ADMINISTRATIONS WITH EU EXPERIENCE
MUHAMMAD FAISAL	*Allama Iqbal Open University*	VITAL VISION FOR WORKING ON THE PRESENTATION AND MONETARY SITUATION AS THE LIKELY CHIEF EXECUTIVE OFFICER OF THE PUBLIC AREA ORGANIZATION: A REVIEW BY DR FAISAL
Malik Muhammad Akhtar	*Balochistan University*	FLOOD DISASTER AND ITS SOCIO-ECONOMIC IMPACT ON PAKISTAN
Praveen Kakada	*Vellore Institute of Technology*	THRIVING IN CHANGE: THE EVOLUTION OF LEADERSHIP AMID AUTOMATION
Nanda Pardhey	*School of Law*	GREEN TECHNOLOGICAL INNOVATION FOR SUSTAINABLE DEVELOPMENT AND CONVERGENCE PATENT
Saida Safibullayevna Beknazarova	*Tashkent University*	MACHINE LEARNING ALGORITHMS ARE USED TO DETECT AND TRACK TRAINEES ON VIDEO IMAGES
Amol Shinde Rajukumar Swami Sameer Nanivadekar	*Pacific Academy of Higher Education and Research University*	OPTIMIZING HANDLING DYNAMICS OF TADPOLE ELECTRIC VEHİCLE BY EXPLORING CAMBER VARIATIONS WITH CASTER AND KING-PIN INCLINATION
Ghizlane Rahil Imane Rahil Mustapha Oujaoura Walid Bouarifi	*Processing National school of applied sciences SAFI*	HUMAN MOTION ANALYSIS USING COMPUTER VISION AND DEEP LEARNING
Ane Rahil Ghizlane Rahil Mustapha Oujaoura Walid Bouarifi	*Processing National school of applied sciences SAFI*	MACHINE LEARNING APPROACH FOR AUDIO VIOLENCE DETECTION IN SURVEILLANCE CAMERAS

OPTIMIZING HANDLING DYNAMICS OF TADPOLE ELECTRIC VEHICLE BY EXPLORİNG CAMBER VARIATIONS WITH CASTER AND KING-PIN INCLINATION

Amol Shinde
Research Scholar, Mechanical Engineering Department, Pacific Academy of Higher Education and Research University

Associate Professor Rajukumar Swami
Electrical Engineering Department, Pacific Academy of Higher Education and Research University

Associate Professor Sameer Nanivadekar
Department of Information Technology, A. P. Shah Institute of Technology

Abstract

The objective of this study is to examine the enhancement of handling dynamics in tadpole electric vehicles by optimizing three key wheel alignment parameters: camber, caster, and king-pin inclination (KPI). The objective of this study is to investigate the impact of parameter adjustments on the handling characteristics of a vehicle, specifically focusing on stability, cornering ability, and steering responsiveness. By employing a comprehensive approach that incorporates theoretical analysis, simulated modeling, and empirical data, this study investigates the separate and combined effects of camber, caster, and KPI alterations. Preliminary results indicate that individual parameters have discernible effects on handling dynamics. Specifically, camber has an impact on tire contact and performance during cornering, caster impacts steering effort and stability at high speeds, and KPI contributes to steering input and the self-centering action. The findings of the study indicate that although individual tweaks might lead to notable enhancements, the most effective handling configuration is typically attained by integrating all three elements in a harmonious manner. This research study makes a valuable contribution to the domain of automotive engineering by offering a comprehensive analysis of the intricate relationship between camber, caster, and KPI. Moreover, it provides practical recommendations for optimizing vehicle handling performance through strategic alignment modifications.

Keywords: Tadpole, Electric Vehicle, Vehicle Handling, Dynamics, Wheel Alignment.

Introduction

The landscape of the automotive industry has been undergoing a revolutionary transformation, fueled largely by the advent and increasing adoption of electric vehicles (EVs). Within this emerging field, tadpole electric vehicles represent a fascinating and innovative subcategory. Characterized by their distinct configuration of two wheels at the front and one at the rear, tadpole EVs distinguish themselves not only in aesthetics but also in their engineering and handling dynamics. This unique design presents a blend of challenges and opportunities in vehicle dynamics, setting tadpole EVs apart from traditional vehicle layouts.(Shinde et al., 2023)

The distinctiveness of tadpole EVs lies in their lightweight structure and low center of gravity, which can potentially offer enhanced maneuverability and energy efficiency. However, these advantages also come with inherent challenges in stability and handling, especially at higher speeds or during sharp cornering. The importance of this vehicle category is increasingly recognized in the context of urban mobility, eco-friendly transportation, and the growing trend towards more compact and efficient vehicle designs.

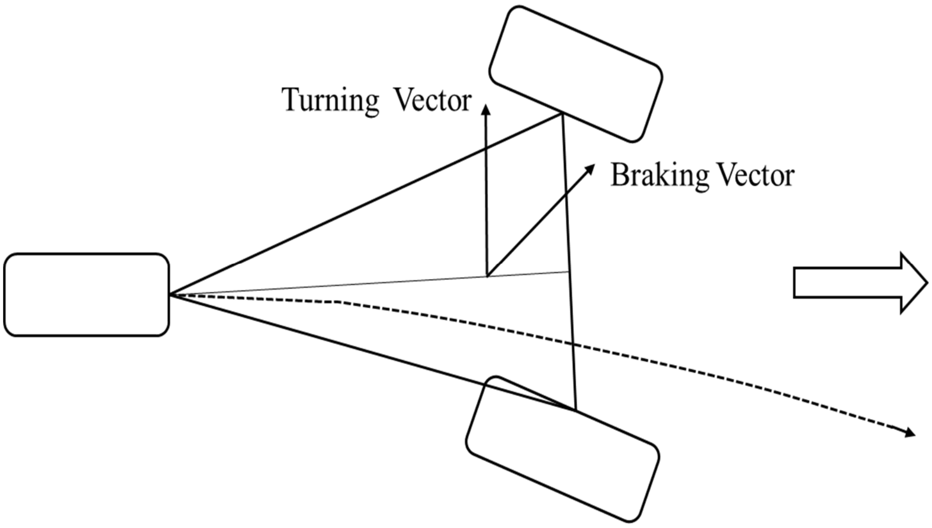


Fig.1 Tadpole EV Structure (Shinde et al., 2023)

Objective

The primary objective of this study is to delve into the enhancement of handling dynamics in tadpole electric vehicles, a crucial aspect that influences safety, performance, and driver experience. The study focuses on optimizing three pivotal wheel alignment parameters: camber, caster, and king-pin inclination (KPI). These parameters are instrumental in defining a vehicle's stability, cornering ability, and steering responsiveness. By analyzing and optimizing these alignment parameters, the study aims to improve the overall handling characteristics of tadpole EVs, making them not only more efficient but also safer and more enjoyable to drive.

Importance of Study

Handling dynamics are a cornerstone of automotive design and performance, particularly in electric vehicles where weight distribution and propulsion dynamics differ markedly from traditional internal combustion engine vehicles. In tadpole EVs, the unconventional wheel arrangement adds another layer of complexity to these dynamics.

Wheel alignment, encompassing camber, caster, and KPI, plays a pivotal role in how a vehicle interacts with the road. Camber, the angle of the wheels relative to the vertical axis, influences tire contact and grip during cornering. Caster, the angle created by the steering pivot point, affects stability and steering effort, especially at higher speeds. Lastly, KPI involves the steering pivot's inclination, which contributes to the vehicle's steering characteristics and the self-centering action of the wheels.

In electric vehicles, and tadpole configurations in particular, optimizing these parameters is crucial for ensuring that the vehicle remains stable and responsive under various driving conditions. This study is significant as it not only enhances our understanding of tadpole EV handling dynamics but also provides practical insights for the automotive industry to improve the design and performance of these novel vehicles. In doing so, it contributes to the broader goal of advancing sustainable and efficient transportation solutions in the modern automotive era.

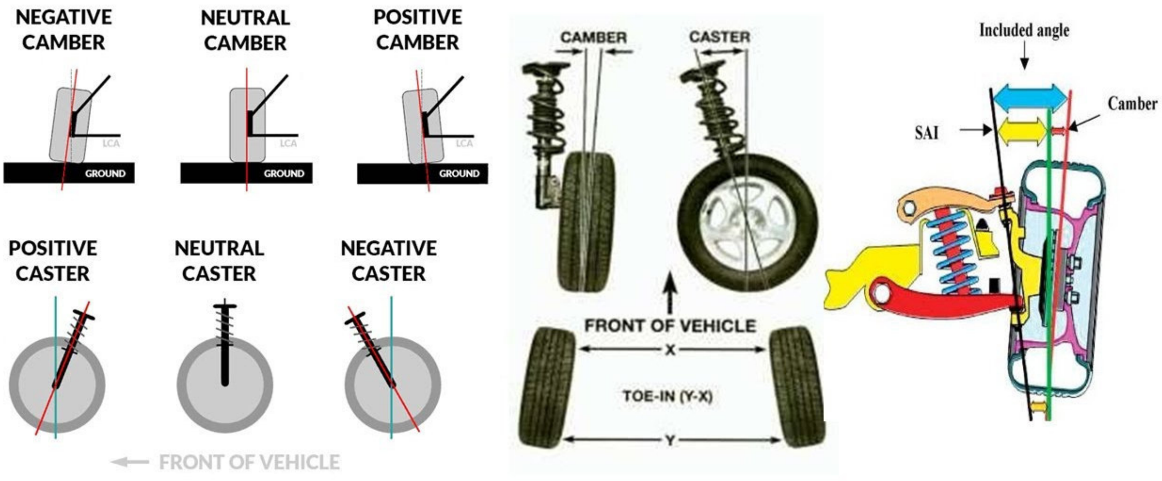


Fig. 2 Wheel Geometry

Literature Review

Wheel alignment, a critical aspect of automotive engineering, plays a vital role in determining a vehicle's handling characteristics. The literature on wheel alignment predominantly focuses on three key parameters: camber, caster, and king-pin inclination (KPI).

- **Camber:** Camber, defined as the angle between the vertical axis of the wheels and the vertical axis of the vehicle as viewed from the front or rear, is crucial for maintaining optimal tire contact with the road, especially during cornering. Studies have shown that negative camber, where the top of the wheel tilts inward, enhances grip during cornering but can lead to uneven tire wear and reduced stability in a straight line. Positive camber has the opposite effect. Research by (Cheng et al., 2011) highlights the delicate balance required in setting the camber for maximizing cornering performance while minimizing tire wear and preserving straight-line stability.
- **Caster:** Caster, the angle created by the steering system's pivot point in relation to the vertical axis of the wheel, influences high-speed stability and cornering effectiveness. A higher caster angle usually results in greater stability at high speeds and a more pronounced self-centering effect of the steering, as discussed in (Tazul Islam et al., 2018) analysis. However, this can also increase steering effort, a factor that must be carefully managed in electric vehicles.
- **King-Pin Inclination (KPI):** KPI is the angle formed by the line drawn through the upper and lower pivot points of the steering and the vertical axis from the center of the wheel. KPI contributes to the vehicle's steering characteristics and impacts the effort required to steer the vehicle.

A study by Rodriguez et al. (2021) showed that KPI adjustments could lead to significant improvements in steering responsiveness and the self-centering action, which is particularly crucial for EVs with front-heavy designs.(Ellerstrand & Kilicasan, 2017)

Research on the handling dynamics of tadpole electric vehicles is relatively nascent compared to traditional vehicle layouts. Tadpole EVs, with their distinct weight distribution and wheel arrangement, present unique challenges and opportunities in terms of handling dynamics. A notable study by (Waters, n.d.) focused on the stability challenges posed by the tadpole design, particularly under braking and cornering scenarios. Their findings suggest a need for tailored alignment settings to mitigate these issues. The research by (Pütz & Serné, 2022) explored the impact of wheel alignment on energy efficiency in tadpole EVs. They found that optimal alignment settings could lead to significant improvements in battery range and overall vehicle performance.

Despite these insights, there remain gaps in the literature, particularly regarding the combined effects of camber, caster, and KPI on tadpole EVs. Most studies have focused on these parameters in isolation or in conventional vehicle layouts. There is a scarcity of comprehensive research that integrates all three parameters in the context of the unique dynamics of tadpole electric vehicles. This study aims to bridge this gap by providing a holistic analysis of how camber, caster, and KPI adjustments can collectively enhance the handling performance of tadpole EVs.

Methodology

Theoretical Analysis

The theoretical framework of this study is grounded in classical mechanics and automotive engineering principles. It employs a multi-faceted approach to understand the interplay between camber, caster, and king-pin inclination (KPI) and their collective impact on handling dynamics in tadpole electric vehicles.

The analysis begins with the fundamental principles of vehicle dynamics, focusing on how forces and moments act on a vehicle during various maneuvers. This includes examining the effects of lateral and longitudinal forces during cornering, acceleration, and braking.

The study delves into the specific dynamics associated with each wheel alignment parameter. For camber, the focus is on its influence on tire contact patch and lateral grip. In the case of caster, the analysis covers its impact on steering effort, wheel returnability, and high-speed stability. For KPI, the emphasis is on understanding its role in steering geometry, particularly in steering effort and the self-centering action of the wheels.(Tian et al., 2023)

The theoretical analysis also includes an integrative approach, examining how changes in one alignment parameter may influence or counteract the effects of others, and how these interactions affect overall vehicle behavior.(Tri Chandrasa et al., n.d.)

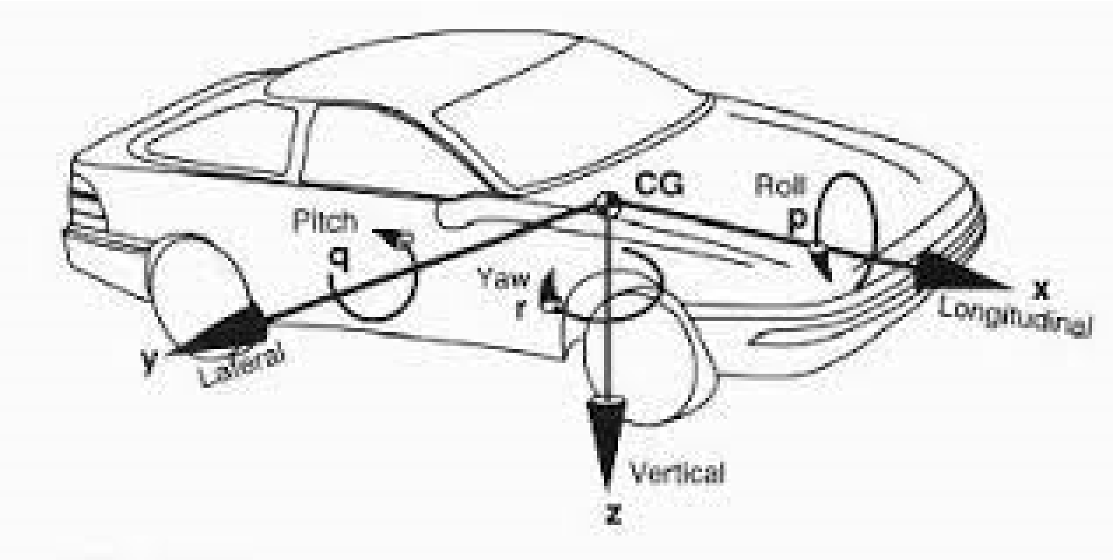


Fig.3 Vehicle Dynamics(Seward, n.d.)

Simulated Modeling

The study employs advanced simulation models to predict and analyze the behavior of tadpole electric vehicles under various alignment configurations.

The primary tool used is ANSYS, a state-of-the-art vehicle dynamics simulation software that allows for detailed modeling of vehicle kinematics and dynamics.

The simulation models incorporate realistic vehicle parameters including weight distribution, tire characteristics, suspension geometry, and powertrain dynamics. These parameters are calibrated based on the specifications of a typical tadpole electric vehicle.(Cachumba-Suquillo et al., 2023)

Various scenarios are simulated, including straight-line acceleration and braking, cornering at different speeds, and maneuvering under emergency conditions. Each scenario is run multiple times with different settings of camber, caster, and KPI to gauge their individual and combined effects.(Woo et al., 2023)

Empirical Data Collection

The empirical part of the study complements the theoretical and simulated analyses with real-world data. A prototype tadpole electric vehicle is used, equipped with adjustable suspension components to vary camber, caster, and KPI settings. Key data such as lateral acceleration, steering angle, tire forces, and vehicle speed are captured using onboard sensors and data acquisition systems. The vehicle undergoes a series of controlled tests, including slalom courses to assess cornering performance, straight-line tests for stability analysis, and skid pad tests to evaluate lateral grip and steering response. The collected data is analyzed to draw correlations between wheel alignment settings and vehicle handling characteristics. This empirical evidence is used to validate the findings from the theoretical and simulated analyses.(Maryniuk, 2017)

By combining theoretical analysis, simulated modeling, and empirical data collection, this study aims to provide a comprehensive understanding of how camber, caster, and KPI affect the handling dynamics of tadpole electric vehicles.(*Experimental Study on Wheel Alignment of TATA Motors Heavy Commercial Vehicle*, n.d.)

Results and Discussion

Impact of Individual Parameters

- **Camber Adjustments:** The study's findings indicate that camber adjustments have a pronounced impact on cornering performance in tadpole electric vehicles. Negative camber settings improved cornering ability by increasing the tire contact patch during lateral loads. However, excessive negative camber led to reduced stability in straight-line driving and uneven tire wear.

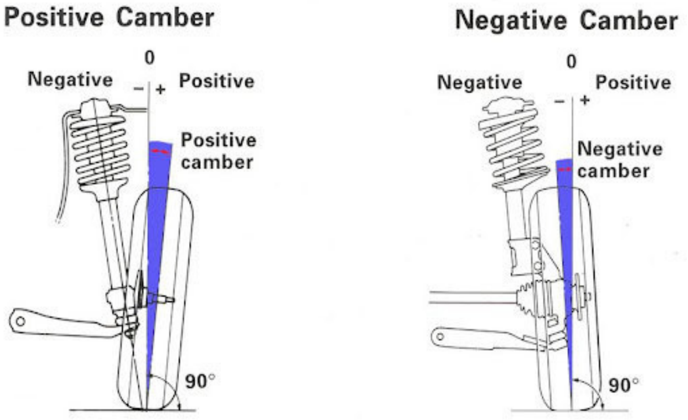


Fig.4 Camber Adjustment

- **Caster Adjustments:** Caster alterations predominantly influenced the vehicle's high-speed stability and steering feel. Increased caster angles enhanced straight-line stability and provided a more pronounced self-centering effect, beneficial for high-speed maneuvers. However, this also resulted in an increase in steering effort, which might be undesirable in urban driving scenarios.

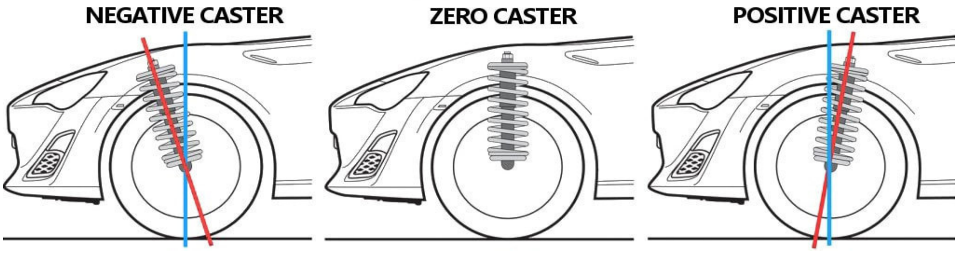


Fig. 5 Caster Adjustment

- **King-Pin Inclination (KPI):** Adjustments to the KPI angle had a notable impact on steering responsiveness and effort. A greater KPI angle resulted in reduced steering effort and enhanced the self-centering action of the steering. However, it also introduced a slight increase in tire wear and reduced feedback from the road.

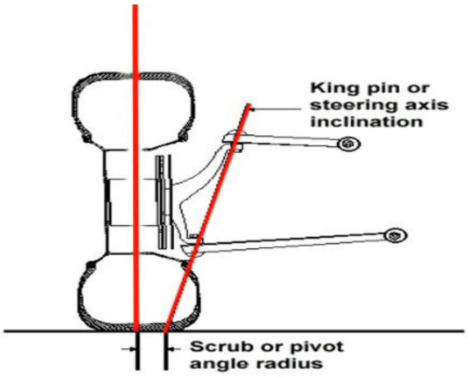


Fig.6 Kingpin Inclination (KPI)

Combined Effects

The study also revealed the interdependencies between camber, caster, and KPI adjustments. The interaction between camber and caster was critical in achieving a balance between cornering performance and straight-line stability. A combination of slight negative camber with increased caster provided an optimal blend for both performance and comfort. The synergy between KPI and caster played a significant role in steering dynamics. A higher KPI, combined with moderate caster settings, resulted in improved steering responsiveness without significantly increasing steering effort. The overall handling profile of the vehicle was most effectively enhanced when all three parameters were optimized in conjunction, rather than individually adjusted. This integrated approach allowed for compensating the drawbacks of one adjustment with the benefits of another.

Practical Implications

Based on these findings, the study provides several practical recommendations for optimizing vehicle handling in tadpole electric vehicles:

A slight negative camber setting is recommended to enhance cornering capabilities while minimizing adverse effects on straight-line stability and tire wear. A moderately high caster angle should be employed to ensure stability at high speeds and effective steering response, especially important in EVs that might have heavier front-end due to battery placement. The KPI angle should be adjusted to reduce steering effort while maintaining adequate road feedback and minimizing tire wear.

The most effective handling configuration should consider the collective adjustments of camber, caster, and KPI. This approach allows for a harmonious balance, ensuring that the vehicle is well-equipped for a variety of driving conditions while maintaining efficiency and safety.

Conclusion

This study embarked on an in-depth exploration of the effects of wheel alignment parameters - camber, caster, and king-pin inclination (KPI) - on the handling dynamics of tadpole electric vehicles. It was found that a slight negative camber improves cornering performance by increasing tire contact during lateral loads. However, excessive negative camber can compromise straight-line stability and increase tire wear. Higher caster angles enhance high-speed stability and the self-centering effect of the steering, albeit at the cost of increased steering effort.

Adjusting KPI influences steering effort and responsiveness. Increased KPI angles reduce steering effort but may lead to increased tire wear.

The study underscored the importance of an integrated approach to wheel alignment, demonstrating that the most effective handling dynamics in tadpole electric vehicles are achieved through a balanced adjustment of camber, caster, and KPI.

References

Cachumba-Suquillo, S. J., Alfaro-Ponce, M., Torres-Cedillo, S. G., Cortés-Pérez, J., & Jimenez-Martinez, M. (2023). Vehicle Dynamics in Electric Cars Development Using MSC Adams and Artificial Neural Network. *World Electric Vehicle Journal*, *14*(10). https://doi.org/10.3390/wevj14100293

Cheng, G., Wang, W., Zhao, G., Guan, Y., & Wang, Z. (2011). Influence of camber angle on rolling radial tire under braking state. *Procedia Engineering*, *15*, 4310–4315. https://doi.org/10.1016/j.proeng.2011.08.809

Ellerstrand, O., & Kilicasan, T. E. (2017). *Optimization of Front Suspension Uprights on a Three-wheeled Electric Vehicle Ecoist*. http://www.mek.lth.se/

Experimental Study on Wheel Alignment of TATA Motors Heavy Commercial Vehicle. (n.d.). www.ijlera.com

Maryniuk, R. (2017). *Development of a Modular Urban Electric Vehicle*.

Pütz, R., & Serné, T. (2022). Race Car Handling Optimization: Magic Numbers to Better Understand a Race Car. In *Race Car Handling Optimization: Magic Numbers to Better Understand a Race Car*. Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-35200-4

Seward, D. (n.d.). *Race car design*.

Shinde, A., Kumar Swami, R., & Nanivadekar, S. (2023). *OPTIMIZATION OF SWING ARM FOR TADPOLE STRUCTURED ELECTRIC VEHICLE* (Vol. 5, Issue 2).

Tazul Islam, M., Kumer Das, R., Abu Mowazzem Hossain, M., & Tazul Isalm, M. (2018). *42-P-7: Experimental Study on Wheel Alignment System of Light Vehicles Experimental Study on Wheel Alignment System of Light Vehicles*. https://www.researchgate.net/publication/344868389

Tian, Y., Chen, X., Liu, Y., Sun, G., Zhou, Z., Liu, C., & Huo, B. (2023). Effects of poling camber angle on the biomechanics of cross-country sit-skiing. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-48359-z

Tri Chandrasa, G., Suryoatmojo, H., & Tambunan, B. (n.d.). *Design and Performance a lightweight Electric Reverse Trike with Multiple Energy Storage*. https://ssrn.com/abstract=4627866

Waters, A. (n.d.). *A Novel Universal Corner Module for Urban Electric Vehicles: Design, Prototype, and Experiment*.

Woo, S., Heo, C., Jeong, M.-O., & Lee, J.-M. (2023). Integral Analysis of a Vehicle and Electric Power Steering Logic for Improving Steering Feel Performance. *Applied Sciences*, *13*(20), 11598. https://doi.org/10.3390/app132011598

CERTIFICATES

UBAK
ULUSLARARASI KONGRE VE
KONFERANSLAR PLATFORMU

CERTIFICATE

OF PARTICIPATION

THIS CERTIFICATE IS PROUDLY PRESENTED TO

Amol Shinde

attended the 5th International Harran Congress on Scientific Research
held on December 8-10, 2023 / Şanlıurfa, Türkiye
with an oral presentation entitled

OPTIMIZING HANDLING DYNAMICS OF TADPOLE ELECTRIC VEHİCLE BY EXPLORING CAMBER VARIATIONS WITH CASTER AND KING-PIN INCLINATION

Dr. Hüseyin Eriş
ORGANIZING BOARD

DEPARTMENT OF PG STUDIES AND DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING

(Pacific Academy of Higher Education and Research University, Udaipur)

INTERNATIONAL VIRTUAL CONFERENCE
on
EMERGING ERA OF APPLICATIONS OF COMPUTER

Certificate Awarded to

This is to certify that *Prof. Amol Shinde*

of *Research Scholar, Pacific Academy of Higher Education and Research University, Udaipur, India*

has Presented Paper entitled *The Role of Computer Technology in Mechanical Engineering Department*

in this International Virtual Conference on 15th-16th January 2022 held at Pacific Academy of Higher Education and Research University, Udaipur.

Prof. Hemant Kothari
Conference Chairman
PAHER University, Udaipur

Dr. Dilendra Hiran
Conference Co-Chairman
PAHER University, Udaipur

Dr. Tanveer Ahmed Kazi
Conference Director
PAHER University, Udaipur

Dr. Prashant Sharma
Conference Organizing Secretary
PAHER University, Udaipur

INSTITUTE OF ECONOMIC DEVELOPMENT AND SOCIAL RESEARCH

Certificate
of participation

This certificate is proudly presented to

Amol Shinde

in oral and technical presentation,
recognition and appreciation of research contributions to

MAS 16TH
INTERNATIONAL EUROPEAN CONFERENCE
ON MATHEMATICS, ENGINEERING, NATURAL & MEDICAL SCIENCES
February 22-23, 2022 / Mardin, Turkey

with the paper entitled

REVIEW: DEVELOPMENT OF LAP TIME SIMULATION SOFTWARE TO DRIVE EV

Dr. Almaz Ahmetov
Head of the Scientific Board

Techno-Societal 2022

Inaugural Speaker

Hon. Raghunath Shevgaonkar
(Former Director, IIT Delhi)

Plenary Speakers

Dr. Agus Budiyono
(Indonesia Center of Technology Empowerment, Indonesia)

Dr. J. M. Chandra Kishen
(Professor, IISc Bangalore, India)

Keynote Speakers

Ashok Ranade
(Project Advisor, Training and Support Services for New High Tech Global Startups, Canada)

Dr. Dhananjay Tambe
(Associate Professor, University of South Alabama, USA)

Botir Usmonov
(Rector of the Tashkent Institute of Chemical Technology, Tashkent Region, Uzbekistan)

Amit Utkarsh Sinha
(CEO & Founder at BasePair Inc, New York, USA)

Ajay Kumar Mishra
(Professor, Durban University of Technology, South Africa)

Dr. Venkata Reddy Poluru
(Associate Professor, AMITY University, Dubai)

Tithankar Banarjee
(Founder & Director, Oztron Energy, Greater Perth Area Australia)

Dr. Neha Biyani
(Research and Development Project Manager at Lantern Pharma, Georgia, USA)

Rajaram Desai
(Senior Project Manager CTARA, IIT Bombay India)

Dr. Gaurav Bartarya
(Assistant Professor, IIT Bhubaneswar)

Dr. Vijay Kumar Pal
(Assistant Professor, IIT Jammu)

Dr. Kashfull Orra
(Assistant Professor, IIITDM Kancheepuram)

SVERI

4th International Conference
on
"Advanced Technologies for Societal Applications"

Certificate

This is to certify that ***SHINDE AMOL SHAHAJI*** of ***Research Scholar, PAHER, Udaipur*** has presented a research paper entitled ***REVIEW OF STRUCTURES FOR ELECTRIC VEHICLES*** (Paper ID-4110) in the International Conference on "Advanced Technologies for Societal Applications: Techno-Societal 2022", held at Shri Vithal Education & Research Institute (SVERI), Pandharpur, India during 9th - 10th December 2022.

		B Ronge
Dr. R. R. Gidde **Coordinator**	Dr. P. M. Pawar **Co-convener**	Dr. B. P. Ronge **Convener**

SHRI VITHAL EDUCATION & RESEARCH INSTITUTE, PANDHARPUR

P.B. No. 54, Gopalpur-Ranjani Road, Gopalpur, Pandharpur Maharashtra 413304
website: www.sveri.ac.in

INTELLECTUAL
PROPERTY **INDIA**
PATENTS | DESIGNS | TRADE MARKS
GEOGRAPHICAL INDICATIONS

सत्यमेव जयते

ORIGINAL
क्रम सं/ Serial No. : 144170

पेटेंट कार्यालय, भारत सरकार The Patent Office, Government Of India

डिजाइन के पंजीकरण का प्रमाण पत्र | Certificate of Registration of Design

डिजाइन सं. / Design No. : 390192-001

तारीख / Date : 13/07/2023

पारस्परिकता तारीख / Reciprocity Date* :

देश / Country :

प्रमाणित किया जाता है कि संलग्न प्रति में वर्णित डिजाइन जो *TRAILING ARM OF TADPOLE ELECTRIC VEHICLE* से संबंधित है, का पंजीकरण, श्रेणी 12-16 में 1.Shriganesh Yadav 2. Amol Shahji Shinde 3.Dr.Sameer Nanivadekar 4.Dr. Raju Kumar Swami 5.Bhushan Chavan 6.Atharva Linge के नाम में उपर्युक्त संख्या और तारीख में कर लिया गया है।

Certified that the design of which a copy is annexed hereto has been registered as of the number and date given above in class 12-16 in respect of the application of such design to *TRAILING ARM OF TADPOLE ELECTRIC VEHICLE* in the name of 1.Shriganesh Yadav 2. Amol Shahji Shinde 3.Dr.Sameer Nanivadekar 4.Dr. Raju Kumar Swami 5.Bhushan Chavan 6.Atharva Linge.

डिजाइन अधिनियम, 2000 तथा डिजाइन नियम, 2001 के अध्यधीन प्रावधानों के अनुसरण में।

In pursuance of and subject to the provisions of the Designs Act, 2000 and the Designs Rules, 2001.

जारी करने की तिथि : 21/09/2023
Date of Issue :

महानियंत्रक पेटेंट, डिजाइन और व्यापार चिह्न
Controller General of Patents, Designs and Trade Marks

*पारस्परिकता तारीख (यदि कोई हो) जिसकी अनुमति दी गई है तथा देश का नाम। डिजाइन का स्वत्वाधिकार पंजीकरण की तारीख से दस वर्षों के लिए होगा जिसका विस्तार, अधिनियम एवं नियम के निबंधनों के अधीन, पाँच वर्षों की अतिरिक्त अवधि के लिए किया जा सकेगा। इस प्रमाण पत्र का उपयोग विधिक कार्यवाहियों अथवा विदेश में पंजीकरण प्राप्त करने के लिए नहीं हो सकता है।

The reciprocity date (if any) which has been allowed and the name of the country. Copyright in the design will subsist for ten years from the date of Registration, and may under the terms of the Act and Rules, be extended for a further period of five years. This Certificate is not for use in legal proceedings or for obtaining registration abroad.

INTELLECTUAL PROPERTY INDIA
PATENTS | DESIGNS | TRADE MARKS
GEOGRAPHICAL INDICATIONS

सत्यमेव जयते

ORIGINAL
क्रम सं/ Serial No. : 150563

पेटेंट कार्यालय, भारत सरकार The Patent Office, Government Of India

डिजाइन के पंजीकरण का प्रमाण पत्र | Certificate of Registration of Design

डिजाइन सं. / Design No. : 392602-001
तारीख / Date : 12/08/2023
पारस्परिकता तारीख / Reciprocity Date* :
देश / Country :

प्रमाणित किया जाता है कि संलग्न प्रति में वर्णित डिजाइन जो *UPRIGHT OF TADPOLE ELECTRIC VEHICLE CAP* से संबंधित है, का पंजीकरण, श्रेणी 12-16 में 1.Shriganesh Yadav 2. Amol Shahaji Shinde 3.Dr. Sameer Suresh Nanivadekar 4.Dr. Rajukumar Swami 5.Bhushan Ravindra Chavan 6.Sushrut Madhav Patankar के नाम में उपर्युक्त संख्या और तारीख में कर लिया गया है।

Certified that the design of which a copy is annexed hereto has been registered as of the number and date given above in class 12-16 in respect of the application of such design to *UPRIGHT OF TADPOLE ELECTRIC VEHICLE CAP* in the name of 1.Shriganesh Yadav 2. Amol Shahaji Shinde 3.Dr. Sameer Suresh Nanivadekar 4.Dr. Rajukumar Swami 5.Bhushan Ravindra Chavan 6.Sushrut Madhav Patankar.

डिजाइन अधिनियम, 2000 तथा डिजाइन नियम, 2001 के अध्यधीन प्रावधानों के अनुसरण में।
In pursuance of and subject to the provisions of the Designs Act, 2000 and the Designs Rules, 2001.

जारी करने की तिथि :
Date of Issue : 21/12/2023

महानियंत्रक पेटेंट, डिजाइन और व्यापार चिह्न
Controller General of Patents, Designs and Trade Marks

*पारस्परिकता तारीख (यदि कोई हो) जिसकी अनुमति दी गई है तथा देश का नाम। डिजाइन का स्वत्वाधिकार पंजीकरण की तारीख से दस वर्षों के लिए होगा जिसका विस्तार, अधिनियम एवं नियम के निबंधनों के अधीन, पाँच वर्षों की अतिरिक्त अवधि के लिए किया जा सकेगा। इस प्रमाण पत्र का उपयोग विधिक कार्यवाहियों अथवा विदेश में पंजीकरण प्राप्त करने के लिए नहीं हो सकता है।

The reciprocity date (if any) which has been allowed and the name of the country. Copyright in the design will subsist for ten years from the date of Registration, and may under the terms of the Act and Rules, be extended for a further period of five years. This Certificate is not for use in legal proceedings or for obtaining registration abroad.

PLAGIARISM
REPORT

DESIGN AND IMPLEMENT ENERGY-EFFICIENT STRUCTURE FOR ELECTRICAL VEHICLE

by Shinde Amol Shahaji

Submission date: 25-Apr-2024 10:48AM (UTC+0530)
Submission ID: 2361202265
File name: shinde_amol.pdf (6.08M)
Word count: 37563
Character count: 227853

DESIGN AND IMPLEMENT ENERGY-EFFICIENT STRUCTURE FOR ELECTRICAL VEHICLE

ORIGINALITY REPORT

7%	6%	2%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	dokumen.pub Internet Source	1%
2	hdl.handle.net Internet Source	1%
3	www.ijariit.com Internet Source	1%
4	www.iapatt.org Internet Source	<1%
5	auto.howstuffworks.com Internet Source	<1%
6	Ralph Pütz, Ton Serné. "Race Car Handling Optimization", Springer Science and Business Media LLC, 2022 Publication	<1%
7	Mariajayaprakash, A., and T. Senthilvelan. "Failure detection and optimization of sugar mill boiler using FMEA and Taguchi method", Engineering Failure Analysis, 2013. Publication	<1%

8	link.springer.com Internet Source	<1%
9	"Recent Trends in Mechanical Engineering", Springer Science and Business Media LLC, 2020 Publication	<1%
10	Submitted to Coventry University Student Paper	<1%
11	Bikram Pratim Bhuyan. "chapter 12 Artificial Intelligence-Based Approaches in Vehicular Power Energy Application", IGI Global, 2023 Publication	<1%
12	www.journal4research.org Internet Source	<1%
13	www.definitions.net Internet Source	<1%
14	Submitted to Swinburne University of Technology Student Paper	<1%
15	www.degruyter.com Internet Source	<1%
16	Submitted to University of Leeds Student Paper	<1%
17	www.researchandmarkets.com Internet Source	<1%

18	pnrsolution.org Internet Source	<1 %
19	Khurram Shahzad, Izzat Iqbal Cheema. "Low-carbon technologies in automotive industry and decarbonizing transport", Journal of Power Sources, 2024 Publication	<1 %
20	Submitted to Higher Education Commission Pakistan Student Paper	<1 %
21	S. Manoharan, P. Palpandian, B. Mahalakshmi, V. Govindarai. "A Review of Indian Scenario on Energy Conservation in Ceiling Fans Powered by BLDC Motors", 2021 Innovations in Power and Advanced Computing Technologies (i-PACT), 2021 Publication	<1 %
22	Submitted to Jawaharlal Nehru Technological University Student Paper	<1 %
23	d-nb.info Internet Source	<1 %
24	instituto.perfil.com Internet Source	<1 %
25	Submitted to De Montfort University Student Paper	<1 %

26	Submitted to University of Huddersfield Student Paper	<1 %
27	unsworks.unsw.edu.au Internet Source	<1 %
28	Submitted to UOW Malaysia KDU University College Sdn. Bhd Student Paper	<1 %
29	arxiv.org Internet Source	<1 %
30	Submitted to iGroup Student Paper	<1 %
31	Submitted to Brunel University Student Paper	<1 %
32	Submitted to University of North Texas Student Paper	<1 %
33	"Advances in Energy Technology", Springer Science and Business Media LLC, 2022 Publication	<1 %
34	Deep Patel, Vivek Jasani, Dhaval Shah, Absar Lakdawala. "Design and FE analysis of chassis for solar powered vehicle", Materials Today: Proceedings, 2022 Publication	<1 %
35	Kareeb Hasan, Neil Tom, Mehmet Rasit Yuce. "Navigating Battery Choices in IoT: An	<1 %

	Extensive Survey of Technologies and Their Applications", Batteries, 2023 Publication	
36	Stephan Rosenthal, Fabian Maaß, Mike Kamaliev, Marlon Hahn, Soeren Gies, A. Erman Tekkaya. "Lightweight in Automotive Components by Forming Technology", Automotive Innovation, 2020 Publication	<1 %
37	fastercapital.com Internet Source	<1 %
38	theijbmt.com Internet Source	<1 %
39	www.cdc.gov Internet Source	<1 %
40	www.icai.org Internet Source	<1 %
41	www.slideshare.net Internet Source	<1 %
42	A. M. Pinar, O. Uluer, V. Kırmacı. "Statistical Assessment of Counter-Flow Vortex Tube Performance for Different Nozzle Numbers, Cold Mass Fractions, and Inlet Pressures Via Taguchi Method", Experimental Heat Transfer, 2009 Publication	<1 %

43	Antonio Gagliano, Stefano Cascone. "Eco-friendly green roof solutions: Investigating volcanic ash as a viable alternative to traditional substrates", Construction and Building Materials, 2024 Publication	<1 %
44	Submitted to Athlone Institute of Technology Student Paper	<1 %
45	Submitted to Bedford College Student Paper	<1 %
46	Submitted to University of Utah Student Paper	<1 %
47	webthesis.biblio.polito.it Internet Source	<1 %
48	Submitted to Universiti Malaysia Sarawak Student Paper	<1 %
49	Submitted to University of Bolton Student Paper	<1 %
50	docplayer.net Internet Source	<1 %
51	mafiadoc.com Internet Source	<1 %
52	Submitted to Liverpool John Moores University Student Paper	<1 %

53	Submitted to Monash University Student Paper	<1 %
54	Submitted to 7034 Student Paper	<1 %
55	Submitted to Massey University Student Paper	<1 %
56	Submitted to Monash University Sunway Campus Malaysia Sdn Bhd Student Paper	<1 %
57	Submitted to Sabanci Universitesi Student Paper	<1 %
58	Submitted to Southern Illinois University Student Paper	<1 %
59	Submitted to University of Hertfordshire Student Paper	<1 %
60	pure.tue.nl Internet Source	<1 %
61	repository.tudelft.nl Internet Source	<1 %
62	www.europarl.europa.eu Internet Source	<1 %

Exclude quotes	On	Exclude matches	< 14 words

Exclude bibliography On