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Optimizing the Knuckle Corner Design of an Urban EV8 Vehicle Category Concept to Meet Turning Radius Requirements.

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Abstract

This research aims to achieve the smallest possible turning radius for the knuckle joint while also meeting the regulations set by the Shell Eco-Marathon (SEM) committee regarding the design angles and lengths. Calculations and testing are conducted using simulation methods to obtain suitable angles and lengths for the knuckle. This simulation method involves a series of analyses to obtain data such as static turning radius diagrams, followed by an analysis using the camber calculation formula. The shape, angle, length, and design of the knuckle are considered with regard to driving safety factors. The findings of this study indicate that for a six-meter turning radius, the outer wheel requires a steering angle of δ_0=10.868°, and the inner wheel requires a steering angle of δ_i=77.397°. After improvements, for a 5.5-meter turning radius, the outer wheel requires a steering angle of δ_0=15.960°, and the inner wheel requires a steering angle of δ_i=71.321°. It can be concluded that this design can optimize the performance of the knuckle steering system.

Keywords
Steearing Wheel, Knuckle, Turning Radius

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INTRODUCTION

Important aspects to consider in vehicle design include safety, driving comfort, and traction capability during use. Fuel efficiency also needs to be a focus in designing vehicles, especially for urban environments [1] Incomplete fuel combustion leads to vehicles producing toxic exhaust gases such as carbon monoxide (CO), nitrogen oxides (NOx), and other harmful fine particles that are detrimental to health and the climate. As a result, efforts are needed to reduce vehicle exhaust emissions to make them more environmentally friendly and safe for human health [2]. Shell Eco-Marathon (SEM) is a unique global program in which students participate by designing, building, and driving vehicles to measure energy efficiency [3]. Vehicles designed for SEM must be lightweight and sturdy to perform well in acceleration on straight tracks as well as maneuvering through winding tracks. The SEM program aims to encourage young innovators in developing sustainable and environmentally-friendly alternative energy solutions by testing the capabilities of their vehicles. Therefore, when designing SEM vehicles, it is important to consider factors of strength and stability to achieve the desired energy efficiency [4]. Figure 1 depicts a vehicle designed for the SEM competition with the goal of achieving maximum fuel efficiency. Fuel efficiency is measured in units of distance traveled per liter of fuel or distance traveled per kilowatt-hour for electric vehicle categories. To accomplish this goal, vehicle performance can be enhanced by considering the design of the steering system, vehicle weight, aerodynamic drag, wheel and bearing friction, and power efficiency. All these factors must be carefully considered in designing SEM vehicles to achieve optimal performance and, most importantly, energy efficiency. Therefore, in the SEM competition, participants must strive to design vehicles that can overcome all these factors and achieve maximum fuel efficiency [5].

Figure 1. Design of Category Urban Concept Vehicle for Shell Eco-Marathon (SEM)

The vehicle steering system functions to change the vehicle's motion in the direction chosen by the driver. The Ackerman condition describes an ideal steering system where the desired steering input from the driver matches the vehicle's steering output [6]. The function of the steering knuckle is to convert the linear motion of the tie rod into angular motion of the axle. The steering knuckle transfers the driving force from the tie rod to the stub axle, so it needs to be strong, rigid, and lightweight. In the case of a car, during steering, the steering knuckle experiences compressive and tensile loads, as well as torsional loads on the wheel [7]. The turning radius used during driving must be less than six meters. The turning radius is the distance that separates the outer wheel of the vehicle from the center of the circle. The outer wheel of the vehicle should be able to follow a six-meter arc with a 90-degree angle in all directions. The design should aim to prevent contact between the tire and the body or chassis [8].

The basic working principle of the steering system used in the EV8 vehicle is a 1:1 comparison between the desired input and the actual output. In short, when the driver wants to steer the vehicle according to their needs, the force is transmitted through the steering linkage. The development of the linkage involves the development of the tie bar, which then moves the knuckle, allowing the wheel to move. In this research, the steering knuckle is the component under investigation, particularly in terms of its design, including shape, knuckle tilt angle, and weight, as these factors impact energy efficiency in technology development. Therefore, design optimization should be applied to achieve minimum weight with maximum performance. The knuckle component is required to support the loads and torques generated by bumps, braking, and acceleration, as well as assist in directing the connecting tie rod. In the optimization of the knuckle component design, which affects the Ackerman turning radius, the weight of the knuckle component should be minimized, while design factors such as strength, rigidity, and durability should be adjusted according to the design targets. The results of this research are expected to identify more efficient designs to meet the requirements of the steering system while also considering energy efficiency in its usage.

METHOD

This research aims to analyze the Ackerman angle in the CV8 vehicle. The method used involves simulating the turning angles and verifying them through theoretical calculations. Afterwards, a comparison will be made between the test results of the turning radius distance of the EV8 vehicle to determine the differences in steering angles between the left and right wheels. Several aspects need to be considered in the steering design planning, such as the distance between the front and rear wheels (wheelbase), the distance between the front left and right wheels (wheel track), and determining the position of the knuckle either in front of or behind the axle shaft [9], this research was then carried out with the steps shown in Figure 2.

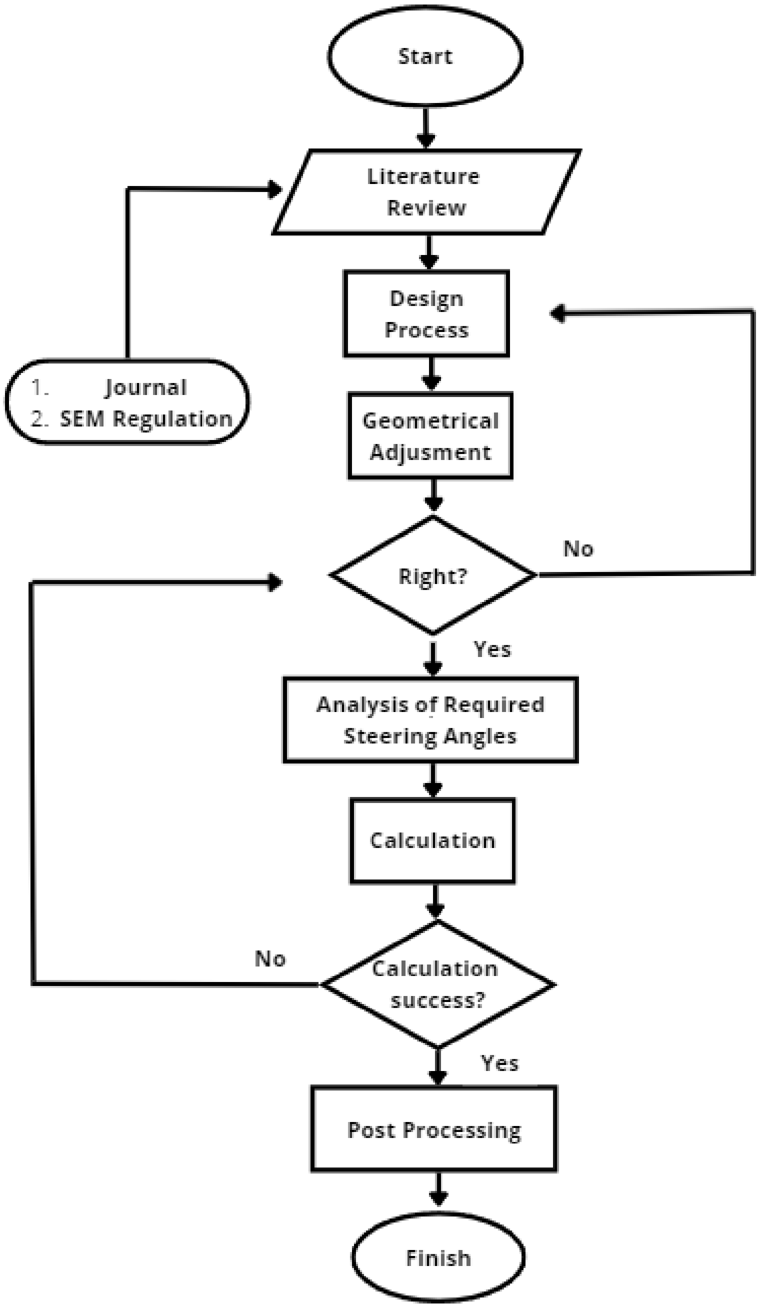


figure 2. Research flow diagram

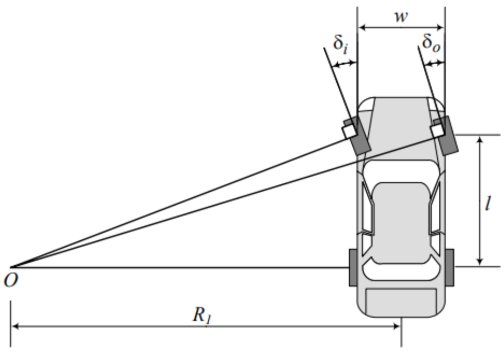


Figure 3. Front-Wheel Steering Vehicle and Inner and Outer Steering Angle.

In Figure 3, the radius of the circle that can be formed by the vehicle when making a full turn to the right or left is called the turning radius (R). R is calculated from the center of the axis to the intersection of each wheel. The steering angles of the front wheels, both right and left, will be different when turning. Equation (1) is used when the vehicle turns to the left or counterclockwise, describing the value of the steering angle. Equation (2) is used when the vehicle turns to the right or clockwise [10]. how does the wheel slip angle affect the stability and performance of the vehicle when turning [13].

$$\text{(1)}\quad \delta_{i_{Left}} = tan^{-1} + \left(\frac{L}{R_1+\frac{W}{2}}\right) \qquad \delta_{o_{Left}} = tan^{-1} + \left(\frac{L}{R_1+\frac{W}{2}}\right)$$

$$\text{(2)}\quad \delta_{i_{Right}} = tan^{-1} + \left(\frac{L}{R_1+\frac{W}{2}}\right) \qquad \delta_{o_{Right}} = tan^{-1} + \left(\frac{L}{R_1+\frac{W}{2}}\right)$$

Equation (1) describes the inner inclination angle (δ_i) and outer inclination angle (δ_o) on the left side of an object or structure. The inner inclination angle (δ_i) is calculated using the inverse tangent function of the sum of length (L) divided by the distance from the center (R_1) plus half of the width (W/2). The outer inclination angle (δ_o) is calculated in the same way as (δ_i) on the left side. Equation (2) describes the inner inclination angle (δ_i) and outer inclination angle (δ_o) on the right side of an object or structure. The inner inclination angle (δ_i) is calculated using the inverse tangent function of the sum of length (L) divided by the distance from the center (R_1) plus half of the width (W/2). The outer inclination angle (δ_o) is calculated in the same way as δ_i on the right side.

By using these equations, we can calculate the inner and outer inclination angles on the left and right sides of an object or structure based on the length (L), distance from the center (R_1) ,and width (W/2).

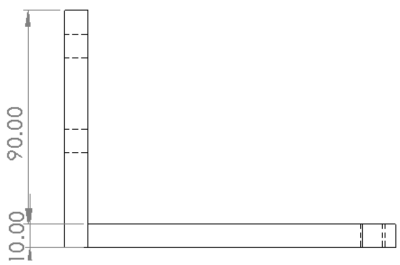
Modeling Simulation using SolidWorks 2020

This research began by preparing a testing tool using a modeling system created through engineering software, namely SolidWorks 2020, with the assistance of computerization. The modeling system involves creating components of the steering system that are then assembled using component assembly methods, including the design of the steering knuckle. This design takes into account parameters such as diameter, length, and ideal shape to compare the results from the software modeling with the reality obtained from the actual vehicle.

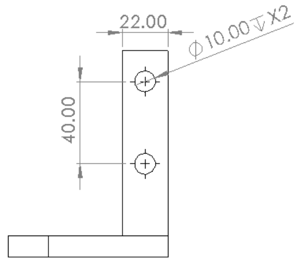
The output of this software consists of assembly drawings used to obtain the steering radius angle (Ackerman angle) using detailing and dimensional methods. After obtaining these results, a comparison is made with the manual calculation system as a reference. Thus, this research method integrates the use of modeling software with manual calculations to obtain more accurate results and ensure consistency between the modeling results and the actual vehicle [10].

Figure 4. Design Assembly of the Vehicle Steering System

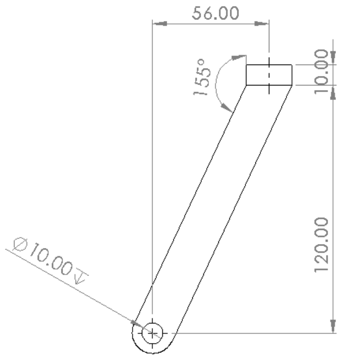
Figure 4 shows the overall design of the urban concept EV8 steering system created in the Solidworks 2020 program. It is used for the corrective angle design phase of the knuckle arm. The knuckle arm angle is initially determined through calculations for the design. The control of the urban concept vehicle will be influenced by the angle of the knuckle arm [11]. Typically, energy-efficient vehicle designs have four wheels, consisting of two front tires and two rear tires.



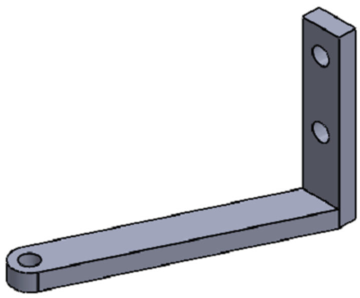
(a) Side View



(b) Front View



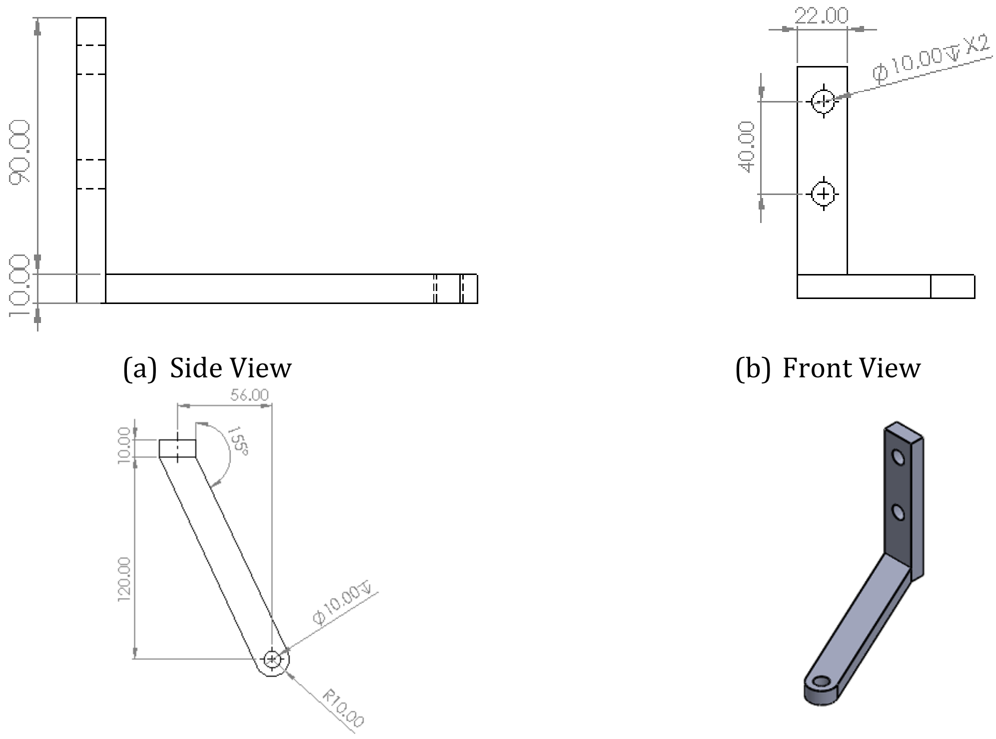
(c) Top View



(d) Isometri View

Figure 5. Technical Drawing of the Right Wheel Knuckle Design

The configuration process of the knuckle involves the use of Solidworks 2020 software for handling three-dimensional configurations. Two-dimensional designs are utilized in the knuckle manufacturing process and serve as working drawings to assist in determining the angles. This can be observed in Figure 5 for the design of the right wheel knuckle, which depicts the design drawing of the left wheel knuckle[12]. Technical regulations issued by the Shell Eco Marathon committee are necessary to determine which vehicle's turning radius will serve as the benchmark for knuckle arm design. Additionally, the six-meter turning radius is of utmost importance and will serve as a guide for the design, as it represents the minimum radius.



(a) Side View (b) Front View

(c) Top View (d) Isometri View

Figure 6. Design Working Drawing of the Left Wheel Knuckle.

Figures 5 and 6 are the consequences of the steering system design. Following the design of the steering system components, the steering system is constructed. The steering column continues the rotation of the wheels by moving the tie rod holder and steering column towards the knuckle arm to steer the wheels left or right in this steering system.

RESULTS AND DISCUSSION

Results

The calculations in SolidWorks 2020 can be used to simulate the Ackerman geometry steering angle. It starts by measuring the vehicle's wheelbase length, determining the front wheel ground clearance, and drawing the axis to the desired radius according to the Shell Eco Marathon competition guidelines. The tie rod is drawn to the pivot point from the center of rotation (O - Center Of Rotation) to the pivot point range as shown in Figure 7. The centrifugal force that results in slip angles on each tire has a significant impact on the vehicle's turning conditions. When the slip angle of the front tire and the slip angle of the rear tire are equal, a neutral turning condition can occur.

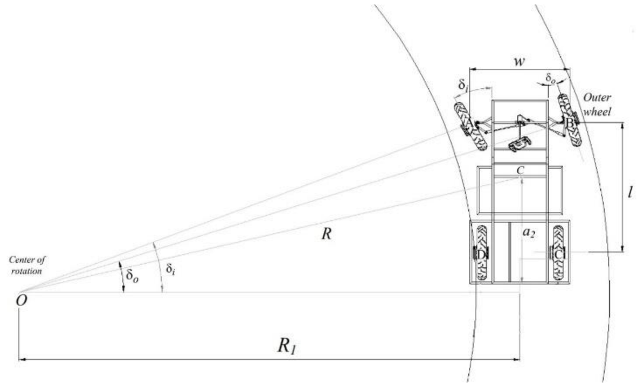


Figure 7. Analysis of Required Steering Angles for a Vehicle with Two Pivot Points

$$(3)\ \cot\delta_0 - \cot\delta_i = \frac{W}{L}$$

Where δ_i represents the steering angle of the inner wheel, and $\delta_0$represents the steering angle of the outer wheel. The inner and outer wheels are determined based on the center of rotation O (Center Of Rotation). The distance between the steering axes of the wheels, which can be steered, is called the wheeltrack and is denoted by W. As shown in Figure 7, the wheeltrack (W) represents the width of the vehicle, while the wheelbase (l) represents the length of the vehicle's kinematics. The radius of turn (R_1) indicates the turning radius of the vehicle's movement [10].

To determine the value of R_1, the following formula is used:

$$(4)\ R_1 = \frac{1}{2}W + \frac{l}{\tan\delta_i} = \frac{1}{2}W + \frac{l}{\tan\delta_o}$$

The initial calculation is performed with the aim of determining the wheel angle required to achieve a vehicle turning radius of six meters. This can be solved using the formula:

$$(1)\ \tan\delta_0 = \frac{l}{R_1 - \frac{W}{2}}$$

$$(2)\ \tan\delta_i = \frac{l}{R_1 - \frac{W}{2}}$$

The result obtained for a minimum turning radius of six meters is that the outer wheel requires a steering angle of $\delta_0 = 10.868°$ and the inner wheel requires a steering angle of $\delta_i = 77.397°$

A. Testing using Simulation Software

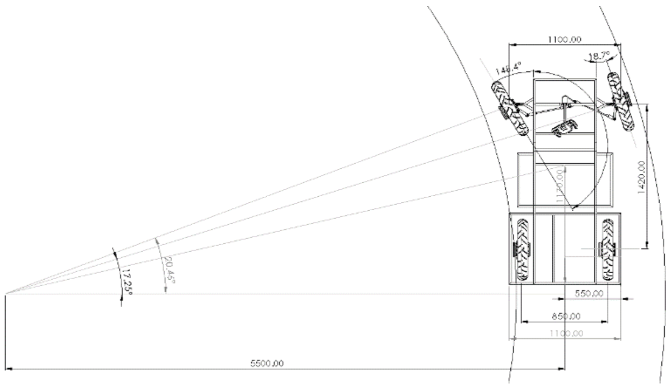


Figure 8. Analysis Result of Required Steering Angles for a Vehicle with Dual Pivot Axes.

As seen in Figure 8, the outer wheel angle δ_0 148.4°, and the inner wheel angle δ_i 18.7°. It can be concluded that the simulation results using SolidWorks 2020 software show that the steering angles between δ_0 and $\delta_i$may exceed the calculated requirements. Therefore, the designed system meets the criteria set by the Shell Eco Marathon regulations.

B. Theoretical Calculation Analysis

In order for all wheels to rotate freely on a curved road, the normal line to the center of each wheel must be maintained. Figure 6 illustrates a vehicle turning left. Therefore, the center of rotation O is located to the left, and the inner wheel is the left wheel that is closer to the center of rotation. The inner and outer steering angles δ_0 and $\delta_i$can be calculated using equations (5) and (6). From the calculation results, we can conclude that the minimum steering radius required for a 5.5-meter turning radius is $\delta_0 = 15.960°$ for the outer wheel and $\delta_i = 71.321°$for the inner wheel.

Data from theoretical calculation results are entered in table 1. which can be seen below.

Table 1. Calculation Results for EV8 Wheel Turning Radius

Turning Radius	**Inner Wheel Radius (δ_i)**	**Outer Wheel Radius (δ_0)**
6 meters	77.397°	10.868°
5.5 meters	71.321°	15.960°

Discussion

The author explains the background of the importance of Ackermann Geometry steering angle in the vehicle's turning condition. The author identifies relevant grand theories in this field and explains how their research findings will enrich our understanding of the topic. The author also describes the research objectives and research questions to be answered.

The simulation results of the Ackermann Geometry steering angle obtained through Solidworks 2020 program simulation have a significant influence on the vehicle's turning radius. The front and rear wheel slip angles play a role in creating neutral turning conditions in the vehicle. The Ackermann Geometry steering angle is based on geometric principles that recognize that the rear wheels of the vehicle turn with a larger radius than the front wheels. This is necessary for all wheels to follow the same turning path, which in turn improves the stability and performance of the vehicle during turning [14].

The front and rear wheel slip angles play an important role in creating neutral turning conditions in the vehicle. If the front and rear wheel slip angles are the same, the vehicle achieves neutral turning conditions where all wheels follow the same turning path. Therefore, a larger steering angle is required on the inner wheel to achieve a smaller turning radius. The required turning radius to achieve a specific turning radius in real conditions is highly influenced by the steering angle on the outer wheel and inner wheel. In this context, the simulation results show that by following the principles of Ackermann Geometry steering angle, specifically by adjusting the steering angle on the inner wheel to be larger, the vehicle's turning radius can be better controlled [15].

These simulation results provide a deeper understanding of how the arrangement of Ackermann Geometry steering angles affects the performance of the vehicle during turning. By considering these principles, better knowledge can be obtained in designing effective steering systems and improving vehicle maneuverability during turning.

CONCLUSION AND RECOMMENDATIONS

Conclusion

A 4-wheel vehicle with a turning radius below six meters requires careful consideration of several factors that can affect the vehicle's ability to turn with a very tight radius. The knuckle angle of the front wheels significantly affects the vehicle's capability to make tight turns. A larger knuckle angle results in a more pronounced turning point on the front wheels, thereby reducing the vehicle's turning radius. However, an excessively large knuckle angle can also reduce stability and comfort, so an optimal knuckle angle needs to be chosen to achieve the best maneuverability. The conclusions drawn from this research are as follows: First, The Ackermann Geometry steering angle has a significant impact on the vehicle's turning radius during turns. Simulation results using Solidworks 2020 program demonstrate that a larger steering angle is required on the inner wheel to achieve a smaller turning radius. Second, centrifugal forces that cause slip angles on each tire greatly affect the vehicle's condition during turns. When the slip angle of the front wheels and the slip angle of the rear wheels are equal, a neutral turning condition can be achieved. The last one, In real conditions, to achieve a specific turning radius, appropriate steering angles are required for the vehicle's wheels. Research findings indicate that for a six-meter turning radius, the outer wheel requires a steering angle of $\delta_0 = 10.868°$, and the inner wheel requires a steering angle of $\delta_i = 77.397°$. After improvements, for a 5.5-meter turning radius, the outer wheel requires a steering angle of $\delta_0 = 15.960°$, and the inner wheel requires a steering angle of $\delta_i = 71.321°$.

These research findings provide a deeper understanding of the relationship between the Ackermann Geometry steering angle, the vehicle's turning condition, and the required turning radius. This information can be used to design and adjust the steering system in vehicles to comply with regulations and meet the requirements of competitions like the Shell Eco Marathon. Furthermore, this research can serve as a basis for further studies in advancing vehicle steering technology.

Recommendations

Further research in the field should consider the following recommendations. Firstly, it is important to investigate the influence of Ackermann Geometry steering angles on the vehicle's performance during tight turns. This can provide valuable insights into optimizing steering angle settings for improved maneuverability. Additionally, exploring the impact of slip angles on the neutral turning condition and validating simulation results through practical testing would enhance the accuracy and applicability of the findings. Furthermore, studying the effects of steering angles on vehicle performance at different speeds and considering innovative solutions in steering system design can lead to advancements in efficiency and responsiveness. Applying the research findings to the development of electric and environmentally friendly vehicles can contribute to sustainable transportation. Lastly, analyzing the influence of steering angles on vehicle stability in emergency situations would provide valuable insights for safety enhancements. By pursuing research in these areas, we can further our understanding and improve the steering technology of vehicles, resulting in enhanced performance during turns.

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