DEPARTMENT OF MECHANICAL

ENGINEERING INDIAN INSTITUTE OF

TECHNOLOGY ROPAR RUPNAGAR-140001,

INDIA

Rear Axle Steering in Cars

B. Tech Capstone Project: CP-302

By
AYUSH SINGH (2021MEB1275)
DINESH SWAMI (2021MEB1285)
PRATIMA (2021MEB1308)
YASH RAI (2021MEB1338)

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY ROPAR
RUPNAGAR - 140001 (INDIA)

END-SEM REPORT

INDIAN INSTITUTE OF TECHNOLOGY ROPAR, RUPNAGAR

CANDIDATE'S DECLARATION

We hereby certify that the work which is presented in the report, entitled "Rear Wheel Steering in Cars" in part fulfillment of the requirement for the award of the Degree of Bachelor of Technology and submitted in the Department of Mechanical Engineering of Indian Institute of Technology Ropar is an authentic record of our own work carried out during a period from January, 2024 to May 2024 under the supervision of Prof. R.K. Maurya.

The matter presented in the report has not been submitted by us for the award of any other degree of this or any other University/Institute.

(**AYUSH SINGH, DINESH SWAMI, PRATIMA, YASH RAI)**

Signature of the Candidates

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

Date: May 9, 2024

(PROF. Rakesh Kumar Maurya)
Professor
Department of Mechanical Engineering
Indian Institute of Technology Ropar
Rupnagar-140001, India

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We want to say our sincere thanks to Indian Institute of Technology, Ropar for giving us an opportunity to explore the outside world and being a part of expanding our creative minds in developing an idea to solve an existing and crucial problem. We would also like to thank our friends, colleagues and others for their support and assistance whenever we needed it. Our appreciation also goes to our families and friends for their encouragement and support all throughout our project.

Abstract:

The steering system plays a vital role in a car by directing its path. Presently, cars typically steer using only their front wheels, but there's potential to enhance efficiency and comfort by enabling the rear wheels to also turn. We aim to illustrate diverse approaches to achieving this, exploring both mechanical systems and electronic components like sensors and actuators.

Through the implementation of sensors, such as Inertial Measurement Units (IMUs), Torque sensor, steering angle and wheel angle sensors, yaw rate sensor, lateral acceleration and velocity of the car we can gather detailed data on the car's movements. Our goal is to demonstrate that incorporating rear-wheel steering can result in the car executing sharper turns, navigating corners with improved precision, and ultimately delivering a more comfortable driving experience. Rigorous testing will be conducted to substantiate that this enhancement positively impacts the overall performance and safety of the vehicle.

Introduction:

As automotive technology evolves, innovative solutions are emerging to address everyday challenges faced by drivers. With an increasing number of cars on the roads, particularly in bustling regions like India, navigating through congested streets and heavy traffic has become increasingly challenging.

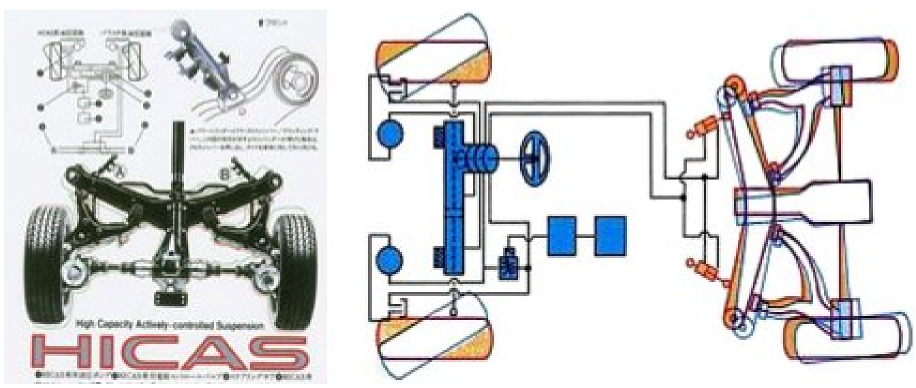
This issue is particularly problematic for novice drivers. To tackle these challenges head-on, we're focusing on enhancing the steering system. By incorporating advancements that leverage the movement of rear wheels, we aim to revolutionize how vehicles maneuver through tight spaces and execute sharp turns.

The integration of rear wheel steering is pivotal in reducing the turning radius of vehicles and facilitating quick lane changes. This technology holds immense promise in streamlining the driving experience, especially in urban settings where space is limited and traffic congestion is prevalent. Furthermore, rear wheel steering not only enhances maneuverability but also contributes to improving safety on the roads. By enabling drivers to navigate through tight spots with greater ease and precision, it reduces the likelihood of accidents and enhances overall road safety.

As we continue to innovate and refine this technology, we're poised to empower drivers, particularly newcomers, with greater confidence and control behind the wheel. The advancement of the steering system represents a significant step forward in addressing the evolving needs of drivers in today's increasingly congested and demanding driving environments.

History

Rear wheel steering, also known as active rear steering or four-wheel steering, has roots dating back to the 1930s with Mercedes-Benz's military offroader, the 170VL. However, it wasn't until 1985 with the Nissan Skyline GTS (R31) that rear wheel steering saw mass production application with the HICAS system. Unlike earlier systems, HICAS aimed at improving stability during high-speed cornering rather than just maneuverability. It functioned above 30 kph, steering the rear wheels in the same direction as the front. Despite limitations, it marked a significant step in automotive technology, paving the way for further advancements in handling and safety.

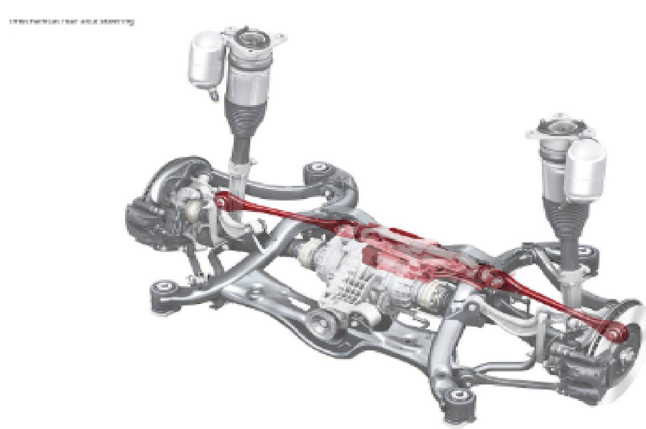


The first generation Nissan HICAS on R31 Skyline (left) and Mid4 concept car (right).

Current Technology

Currently the market is witnessing the introduction of RWS systems in high-end vehicles along with passenger cars alike. Audi A8 & Q7, BMW 5, 6, 7 and 8 series, Honda Accord, Mazda RX-7, MX-6, Renault Laguna, M´egane and Talisman, Nissan Skyline GT-R, Porsche 911, 918, Lamborghini Aventador, Centenario, Urus and Hurac´an Evo, Mercedes-AMG GT R, Ferrari GTC4 Lusso and F12tdf are amongst the vehicles currently on the market with RWS system as a standard or an optional extra on their vehicles. A few subsystems are explained briefly below.

Audi's RWS-



The system combines **dynamic steering at the front axle**, which uses an **infinitely variable strain wave gearing**, with a **separate rear axle steering system with an electric spindle drive and track rods**. As such, the steering angle at the front and rear axle can be adjusted independently of each other. It uses the **electro-mechanical power steering in the front and rear axle steering** The signal to turn is electrically transmitted to the steering linkage and **actuators in the rear** of the car via a **drive-by-wire system**. At low speeds, the back wheels turn up to five degrees in the opposite direction of the front wheels. That reduces the turning radius by about one meter (3.28 feet) and is particularly beneficial when maneuvering and parking.

Porsche's RWS-

Porsche's rear-axle steering system employs **two electromechanical actuators** positioned on either side of the axle, replacing traditional toe control arms. These actuators gather data on road speed and **steering angle, transmitting it to the Electronic Control Unit (ECU)**. The ECU then instructs electric motors to adjust the rear axle accordingly. At speeds below 80 km/h, the rear axle steers up to +/- 3 degrees in the opposite direction of the front axles, effectively reducing the wheelbase. Conversely, at speeds exceeding 80 km/h, both axles steer in the same direction, effectively extending the wheelbase. This configuration enhances the performance and driving stability, particularly during high-speed maneuvers like lane changes on the highway.

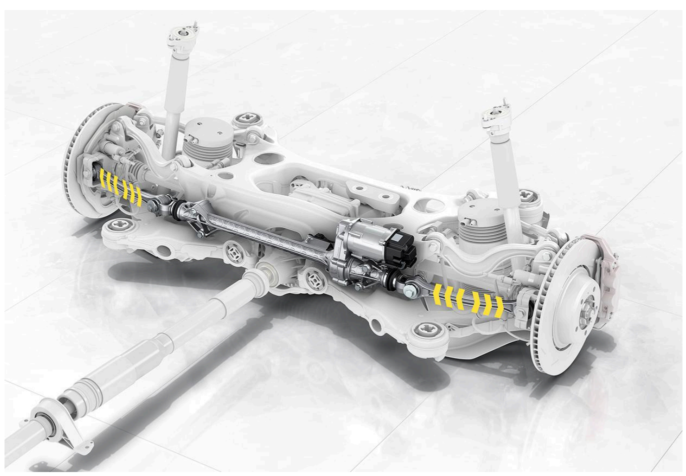


Fig. 2: Porsche Panamera Rear-Axel

Mercedes' RWS-

Introduces a groundbreaking 10-degree turn angle capability for the rear axle which reduces the turning radius up to 2 meters. This innovation is powered by an **electric motor that propels a rod connected to the rear axle via a drive belt**. Active telemetry, derived from radar, cameras, and ultrasonic sensors,

Fig 3: Mercedes' Active Rear axel steering

continuously informs the system, allowing it to adapt the steering angle to suit the prevailing circumstances. This dynamic adjustment seamlessly transitions between counter-direction and same-direction steering based on the vehicle's speed.

<u>Bosch's RWS-</u>

Bosch uses this technology to increase maneuverability and control over their large & heavy commercial vehicles, like trucks. Up to three or even more rear axle steering systems can be used in one heavy commercial vehicle. A hydraulic cylinder unit is combined with an electronic power unit.

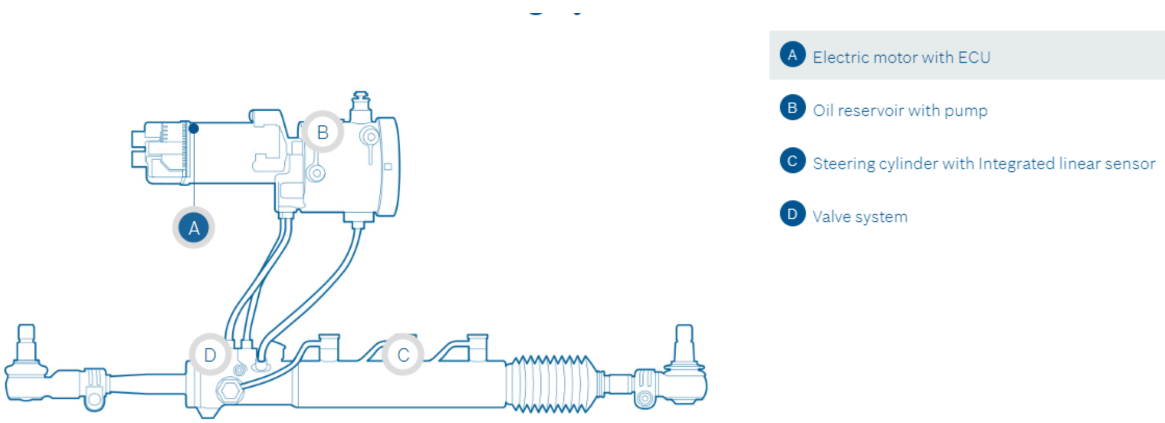


Fig. 4: Bosch hydraulic steering system

Objective:

The overall objective of this project is to design, develop, and demonstrate a cost-effective rear wheel steering system suitable for integration into low-end vehicles in India. By prioritizing affordability without compromising safety or performance, the aim is to enhance vehicle maneuverability and driving experience, ultimately contributing to improved road safety and accessibility for drivers in India.

The following is the enumeration of objectives

<u>1. Feasibility Assessment:</u> Evaluate the technical feasibility and economic viability of integrating rear wheel steering systems into low-end vehicles in the Indian market.
<u>2. Cost Analysis:</u> Conduct a detailed cost analysis to identify cost-effective components, materials, and manufacturing processes that can be utilized to achieve affordability without compromising safety and performance.
<u>3. Market Research:</u> Conduct market research to understand consumer preferences, demand trends, and potential market opportunities for low-end vehicles equipped with rear wheel steering in India.
<u>4. Prototype Development:</u> Design and develop a prototype rear wheel steering system suitable

for installation in low-end vehicles, emphasizing simplicity, reliability, and cost-effectiveness.
5. Performance Testing: Conduct comprehensive performance testing of the rear wheel steering prototype, including handling, stability, maneuverability, and durability assessments, to ensure it meets safety and regulatory standards.
6. Scalability and Manufacturing: Explore scalability and mass production capabilities of the rear wheel steering system, considering manufacturing processes, supply chain logistics, and production costs to achieve economies of scale.
7. Policy and Regulatory Implications: Investigate policy and regulatory implications related to rear wheel steering adoption in low-end vehicles, including compliance with automotive safety standards, licensing requirements, and insurance considerations.

Advantages

1. Reduced Turning Radius
2. Improved cornering
3. Enhanced handling at High speed
4. Parking Maneuverability
5. Increase Driver comfort
6. Adaptability to various driving conditions
7. Potential fuel efficiency gains

Literature Review

Vehicle Motion

Before diving into the details and mechanics of 4 wheel steering, we need to understand the basic Vehicle Motion Control. Vehicle motion refers to its translation along and rotation about all three axes (i.e., longitudinal, lateral, and vertical). Rotations of a vehicle around these three axes correspond to angular momentum of the car body in roll, yaw, and pitch. Roll refers to angular displacement about the longitudinal axis; yaw refers to angular displacement about the vertical axis; and pitch refers to angular momentum about the lateral axis.

While studying and designing the rear axle steering mechanism, two factors principally govern the vehicle's dynamics namely- Yaw motion & vehicle lateral motion
Yaw motion and lateral motion are essential aspects of vehicle dynamics, governing how a car moves and

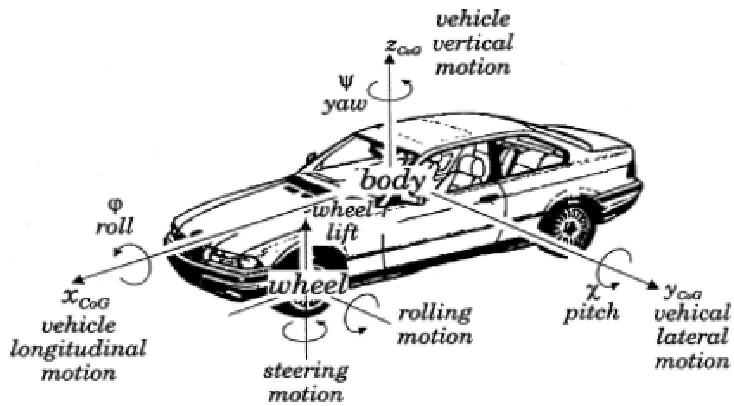


Fig.5: Forces on vehicle

behaves on the road.

Here are brief points explaining their influence:

1. **Yaw Motion:**
- Yaw motion refers to the rotation of a vehicle around its vertical axis, commonly known as its "yaw axis."
- It occurs when the car turns left or right, causing the front and rear of the vehicle to rotate in opposite directions.
- Yaw motion influences the stability and handling of the car during cornering, as well as its response to steering inputs.
- Control systems such as stability control and electronic stability control (ESC) help manage yaw motion by selectively applying brakes to individual wheels.

2. **Lateral Motion:**
- Lateral motion refers to the side-to-side movement of a vehicle perpendicular to its direction of travel.
- It occurs when the car changes lanes, drifts sideways during cornering, or experiences crosswinds.
- Lateral motion affects the vehicle's stability, traction, and cornering performance.
- Factors influencing lateral motion include tire grip, suspension geometry, and weight distribution.
- Technologies such as traction control and active suspension systems help manage lateral motion by adjusting wheel forces and damping rates to maintain stability.

Yaw and lateral movement serve as crucial inputs for rear axle steering systems.
Yaw rate, indicating the rate of rotation around the vertical axis, helps correct understeer or oversteer during turns.**A yaw-rate sensor** is a gyroscopic device that measures a vehicle's yaw rate, its angular velocity around its vertical axis. The angle between the vehicle's heading and velocity is called its slip angle, which is related to the yaw rate.
Yaw velocity can be measured by measuring the ground velocity at two geometrically separated points on the body, or by a gyroscope, or it can be synthesized from accelerometers.
Lateral movement data detects deviations from the intended path, enabling adjustments to maintain stability and control.
Lateral velocity is indirectly measured by integrating the lateral acceleration measured with an accelerometer.
Incorporating these inputs allows rear axle steering systems to dynamically optimize rear wheel steering angles, enhancing vehicle handling and maneuverability, especially in challenging driving conditions.

Steering system

Comprehending how front steering works is essential before implementing rear wheel steering to ensure compatibility, coordination, safety, and optimal performance of the integrated steering system.

- <u>Recirculating Ball steering</u>

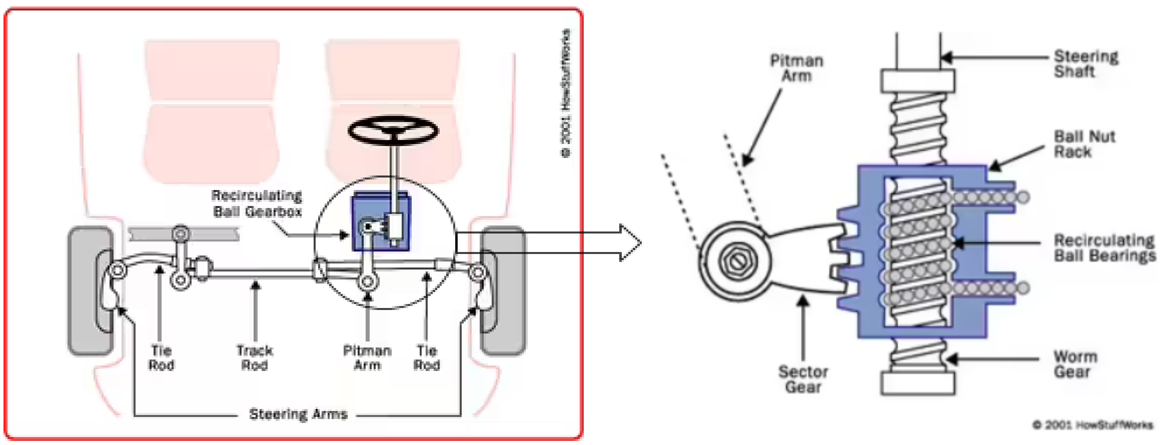


Fig. 6: Recirculating ball steering

Involves a worm gear and recirculating ball mechanism.
Common in older vehicles and some heavy-duty applications.

- <u>Rack and Pinion steering</u>

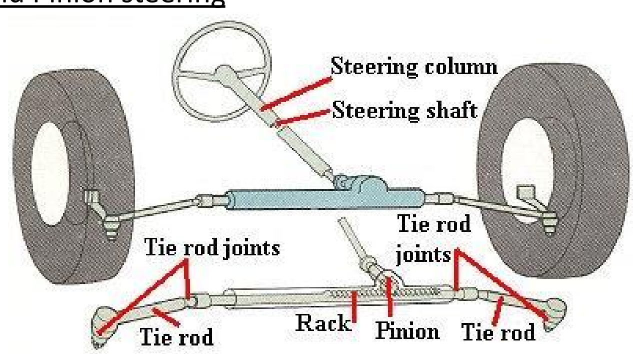


Fig. 7: Rack and pinion steering

Utilizes a gear set (rack and pinion) to convert rotational motion into linear motion.
Commonly used in modern cars for its simplicity, responsiveness, and compact design.

<u>Power steering</u>

Types of power steering

- <u>Hydraulic Power steering (HPS)</u>

Uses a hydraulic pump driven by the engine to provide power assistance. Hydraulic fluid is pressurized to assist in turning the steering mechanism. Traditional and widely used, but it can be less fuel-efficient compared to newer systems.

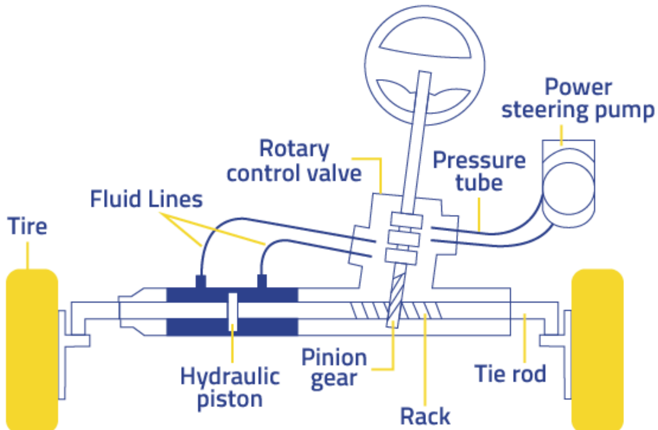


Fig. 8: Hydraulic power steering

- <u>Electric Power Steering (EPS)</u>
  Utilizes an electric motor to provide power assistance controlled by integration with the car's Electric Control Unit (ECU).
  Does not rely on engine power, improving fuel efficiency.
  More adaptable and can be easily integrated with other vehicle systems.

EPS systems apply steering assist force based only on driver input. The system uses input data from a multitude of vehicle sensors to determine how much steering assist force is required.

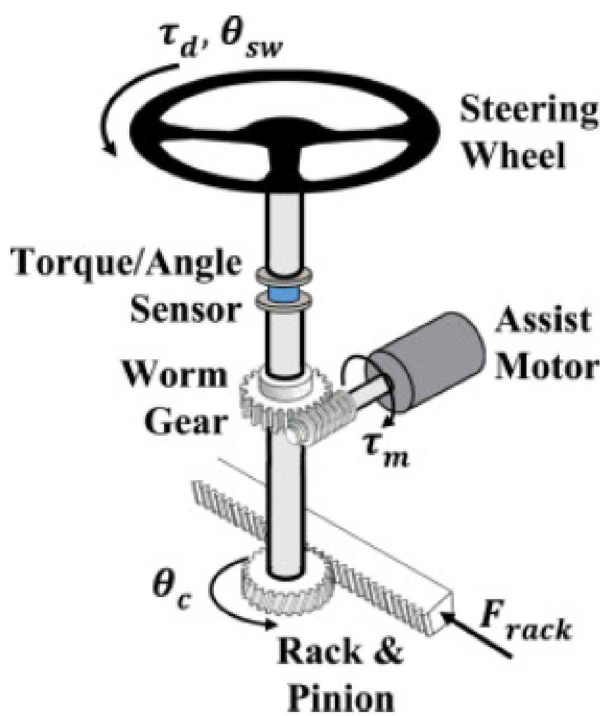


Fig 9: Electric powered steering

Some commonly used sensors are-

1. Steering Angle Sensor
2. Wheel angle sensor.

3. Steering Torque/Force Sensor

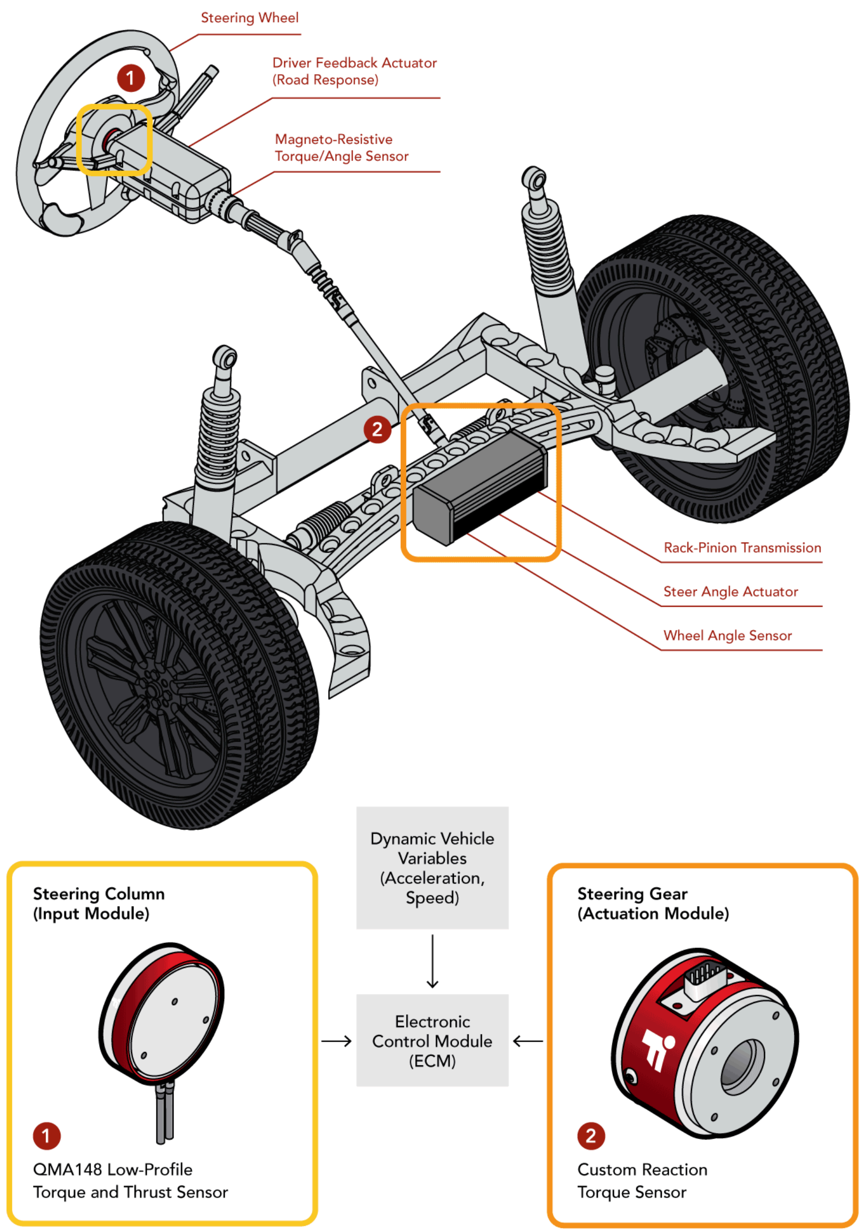


Fig. 10: Sensors used in steering

Electronic Control Unit (ECU)

An electronic control unit (ECU), also known as an electronic control module (ECM), is an embedded system in automotive electronics that controls one or more of the electrical systems or subsystems in a car or other motor vehicle.

The Electronic Control Unit (ECU) functions include:
1. Engine management
2. Sensor monitoring
3. Fault detection and diagnostics
4. Emissions control
5. Adaptive control
6. Transmission control
7. Vehicle safety and stability

Since the ECU works as the input, output and information relay center of a car's functionality, it can be used to collect the data from sensors dictating different parameters of the vehicle's dynamics. These inputs and signals can be used similarly the way 'steer by wire' is achieved. Using an Actuator which steers the rear axle from these signals and sensor data, precise and automatic movement can be achieved up to a desired steering angle . We will need to set a relationship between the rear axle steering and the velocity of the car, and the steering angle of the front axle (this will include all the sensor information listed above).
ECU will drive the actuator installed on the rear axle based on a programme & information received from the various sensors. Setting parameters like a velocity range for which the rear axle will turn in the opposite direction wrt to the front axle.

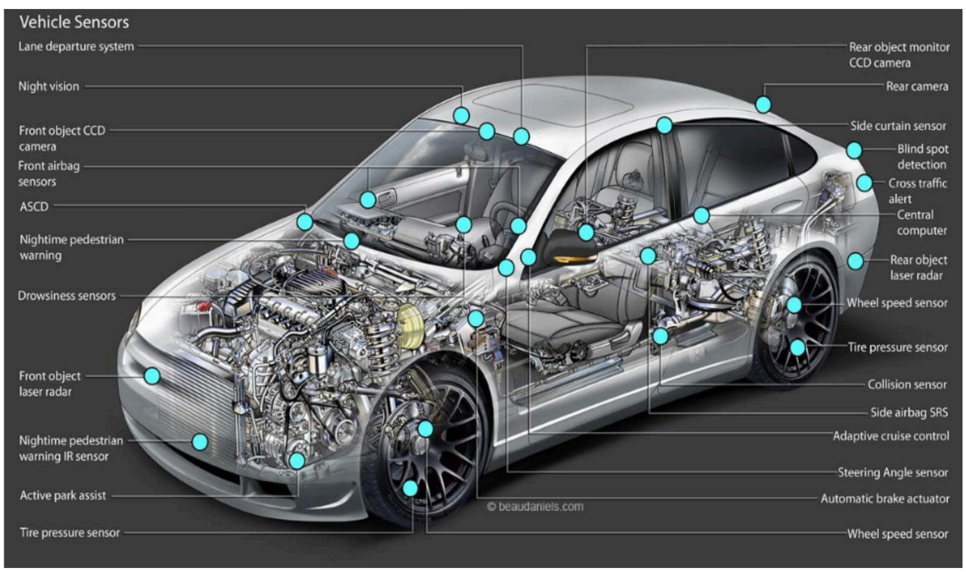


Fig. 11 Different sensors connected to ECU

Analytical Details

Methodology

To enhance maneuverability by minimizing the turning radius, it's essential to steer the rear axle in the opposite direction of the front wheels during turns. This is achieved by actively controlling the rear wheels with a **motorized rack and pinion system**. The motor's rotation is synchronized with the front wheel steering input, facilitated by a **torque sensor** embedded within the steering shaft. This sensor precisely detects both the **torque applied and the steering angle**, allowing the motor to adjust the rear wheel orientation accordingly.
This type of maneuvering is called Active Rear Axle Steering, most modern high end cars (listed above) use this type of system.

Fig. 12 Steering actuator

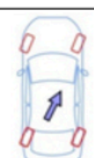
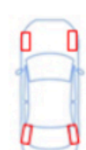
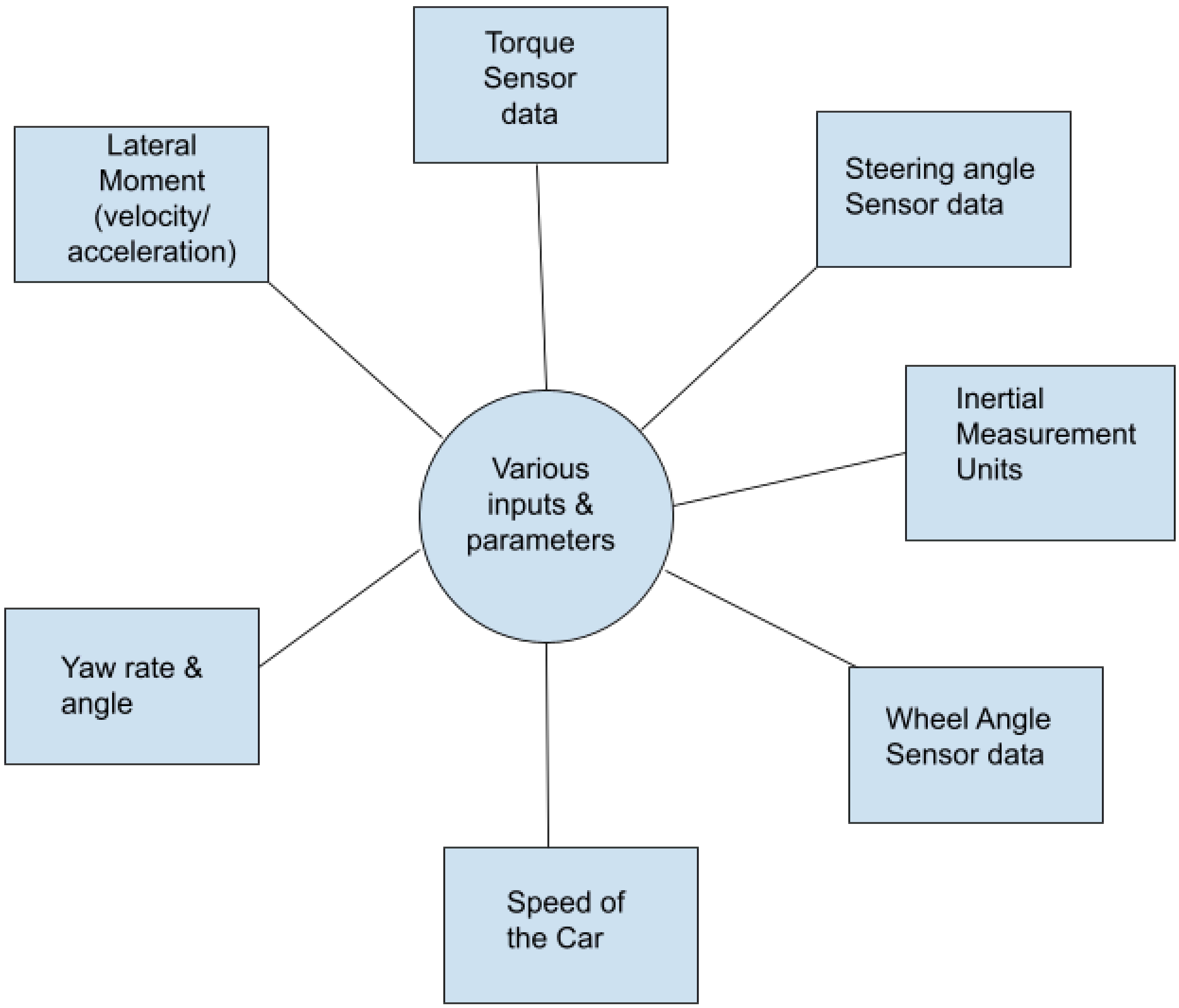
	Same Direction	Opposite Direction	Toe-in	Toe Angle 0
Steering Condition				
Effects of rear-wheel control	Limits yaw that is generated when steering, and increases vehicle stability	Improves cornering	Improves straight-line performance Uneven tire wear	Improves fuel efficiency Reduces tire wear

Fig. 13: Different rear wheel alignment

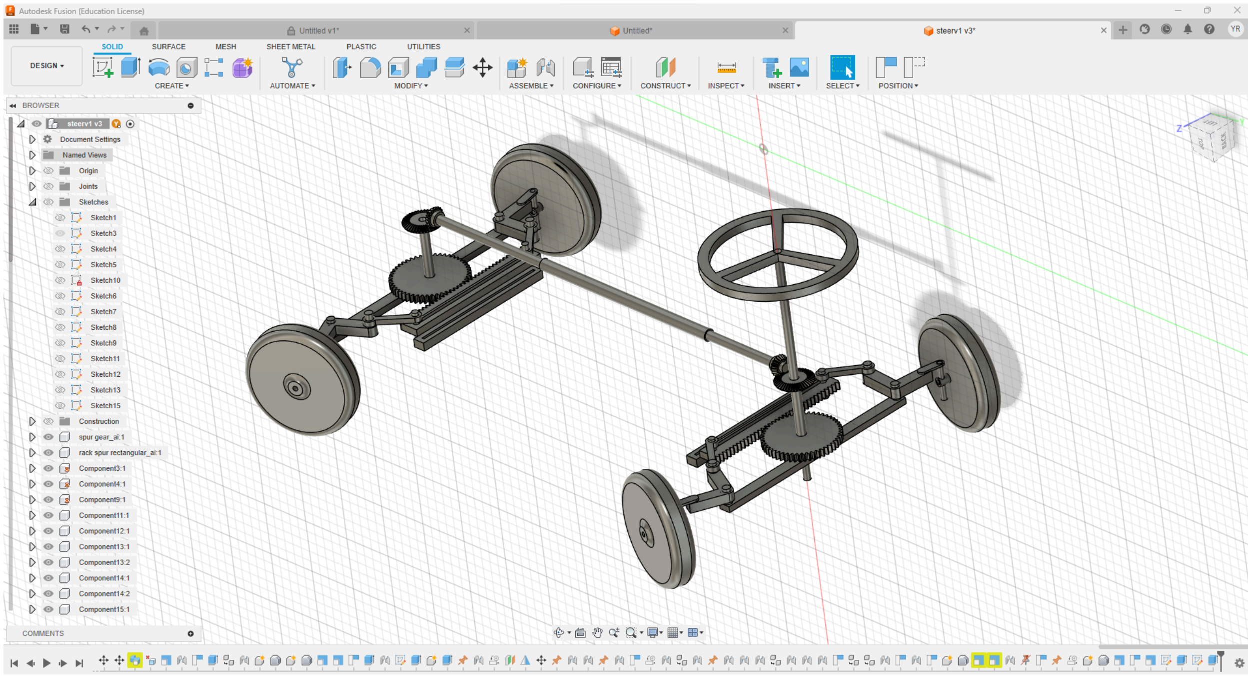
Inputs and parameters required to achieve precise automated actuation of the rear axle are summed up below in the flowchart-



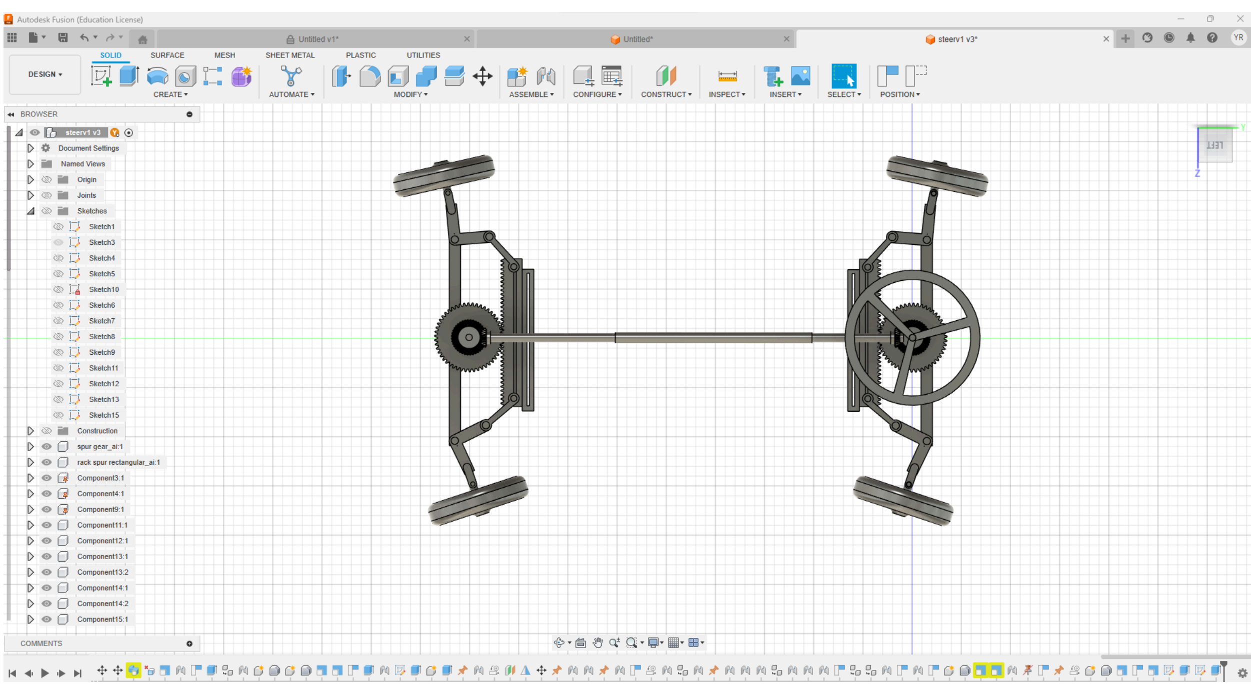
Naive Demonstration of the rear axle steering based purely on mechanical

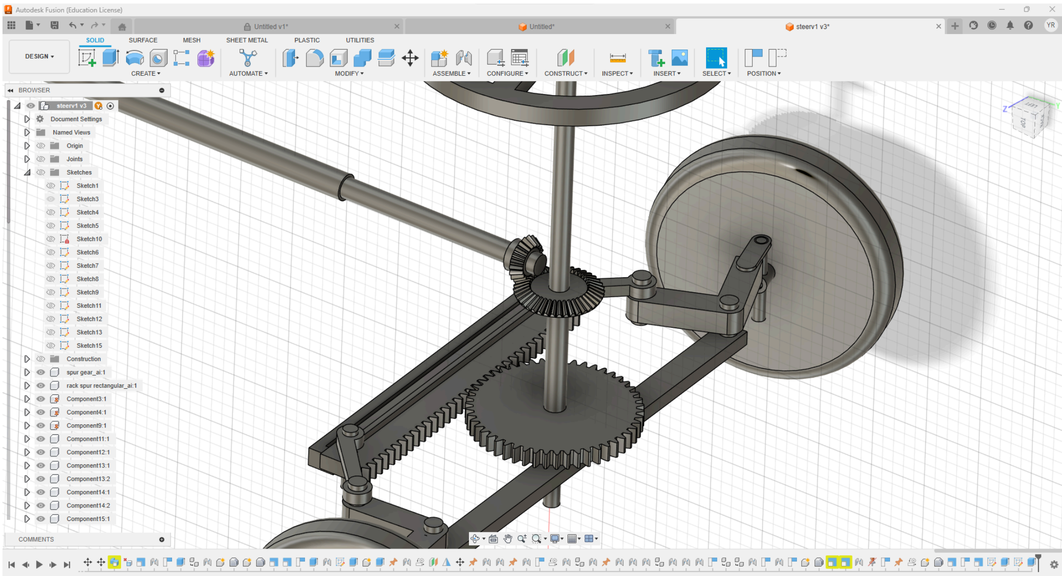
transmission of the steering action provided by a human-

Designed in FUSION 360, the CAD design attached below demonstrates actuation achieved by only mechanical means , where a shaft running along the length of the car transmits the steering action.



A rack and pinion assembly converts the rotating motion into translational motion to steer the front axle.





Joints and constraints applied to the assembly perform the low speed maneuvering where the rear axle turns in the opposite direction of the front axle.
With the help of a bevel gear assembly the steering action is transmitted to the rear axle, we keep the rear axle free to move by eliminating the tie rod mechanism.

Calculations

For front axle steering
In the below figure,
a = Length of front axle or distance
L = Distance b/w front and rear wheel or Wheelbase a, L are fixed for a vehicle
R = Turning radius
O= instantaneous center
ϴ = angle turned by inner wheels (the larger angle)
Φ = angle turned by outer wheels.
From the figure, after performing calculations the following expressions are obtained,
b = L.cot ϴ
R*2 = (L/2)*2 + (b+a/2)*2

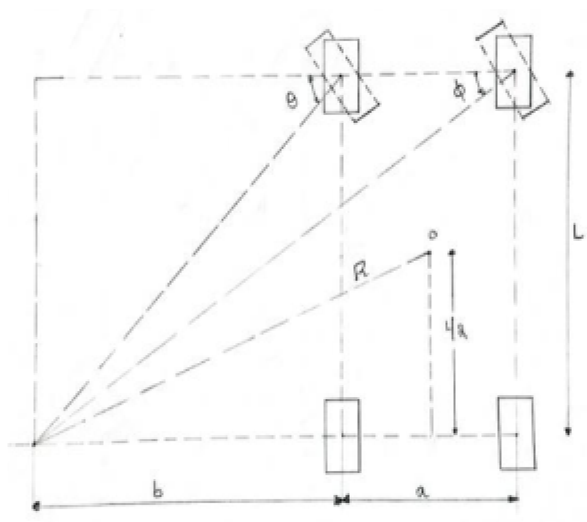


Fig. 14: Turning radius for only front wheel steering

By using the above expressions, we can calculate
the turning radius of the vehicle whose wheelbase (L), axle length (a) and turning angle (ϴ) are

known. It is found that almost every vehicle's maximum turning angle lies between 28 to 35 , hence we are considering 35 as the maximum angle of turning the wheel.

L=5180mm

a= 2850 mm

b= 7397 mm

Ɵ= 35 degree

R=9194 mm

For Rear axle steering

C1+ C2 =L

Tan(Ɵ1)= C1/b

Tan (Ɵ2)= C2/b =(L-C1) / b

Equating C1 from both the equations

b= L/(tan (Ɵ1)+ tan (Ɵ2))

and C1= b tan(Ɵ1)

R*2 = (b+a/2)*2 + (L/2 – C2) *2

Ɵ1=35 degree

Ɵ=10 degree

L= 5180 mm

a=2850 mm

C1= 4138 mm

c2=1042

b= 6405 mm

R=7495mm

Mass of the CAR: 2000kg

Centre of Gravity: 0.3m above axles

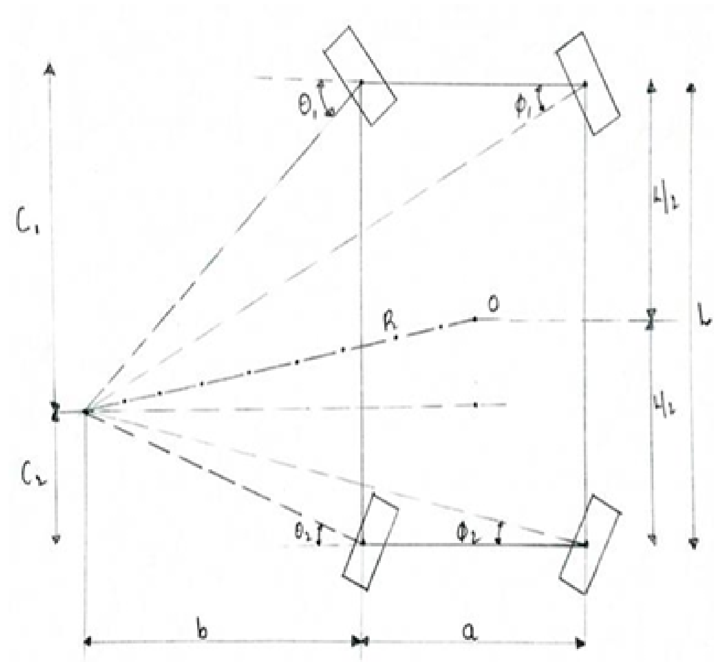


Fig. 15: Turning radius for rear wheel steering

From these calculations, we see that we can reduce the turning radius from 9194 mm to 7495 mm, reducing a total of **around 1700 mm(almost 2 meters).**

This means that the distance required to make a U turn has reduced by 3400 mm.

Simulation on MATLAB SIMULINK

The Simulink Vehicle Body Dynamics Blockset -

The Simulink Vehicle Body Dynamics Blockset is a set of tools and components within Simulink, a MATLAB-based simulation software, used for modeling and simulating the dynamic behavior of vehicle bodies. It provides a collection of blocks that represent various aspects of vehicle dynamics, such as suspension systems, tires, steering mechanisms, and chassis dynamics.

With this Blockset, we can design complex vehicle dynamics models, simulate the behavior of different vehicle configurations under various driving conditions, and analyze the performance of suspension systems, steering mechanisms, and other components.

By using this tool, we explored the interactions between different vehicle components, optimizing vehicle performance, and validating control algorithms before implementing them in real-world vehicles. Overall, the Simulink Vehicle Body Dynamics Blockset is a powerful tool for understanding and improving the dynamic behavior of vehicles.

Simulating rear wheel steering system using the Simulink Vehicle Body Dynamics Blockset

- To simulate a rear wheel steering system using the Simulink Vehicle Body Dynamics Blockset, we begin by modeling the vehicle dynamics. We use the appropriate blocks from the blockset to represent components such as the vehicle body, suspension systems, tires, steering mechanisms, and chassis dynamics.
    - For simplicity and study purposes we use only the Vehicle Body 3DOF block which implements a rigid two-axle vehicle body model to calculate longitudinal, lateral, and yaw motion. The block accounts for body mass and aerodynamic drag between the axles due to acceleration and steering.

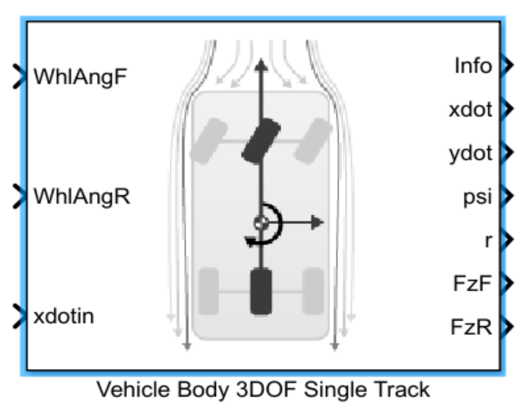


Fig. 16 vehicle body block from MATLAB

- Using the custom Simulink blocks to implement the rear wheel steering controller(WhlAngR), front wheel steering controller(WhlAngF) inputs along with the longitudinal velocity (xdotin) input.
- Next, we integrate the rear wheel steering system into our vehicle model. The Kinematic steering block is used which implements a steering model to determine the left and right wheel angles for Ackerman, rack-and-pinion, and parallel steering mechanisms. The block uses the vehicle coordinate system.

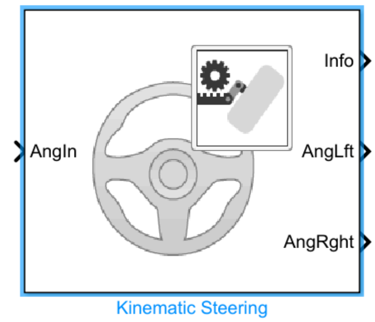
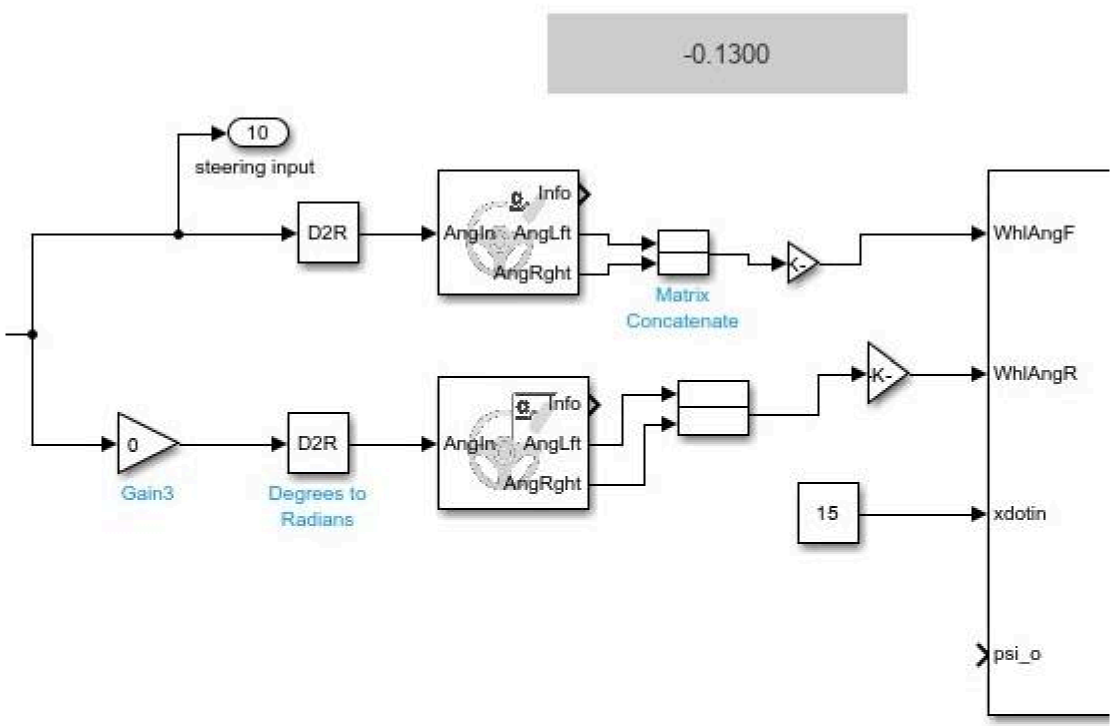
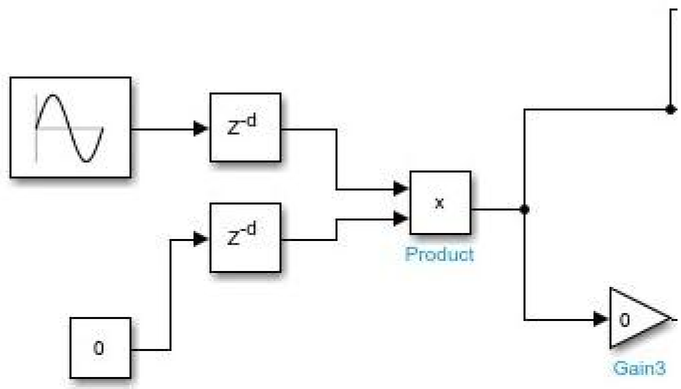


Fig 17 Kinematic steering block from MATLAB

- We define the inputs for the rear wheel steering, specifying the desired steering angles for the front axle steering and its relationship(ratio) with the rear wheel axle. In the image below. The Gain3 block represents this ratio and assigns this relationship to the input of front axle steering, this input then gets multiplied by the gain to act as the input for Rear Axle steering angle.



- We provide a sinusoidal wave input to simulate the input of car steering because it represents a periodic and smooth oscillation, similar to the way a driver might turn the steering wheel. The sinusoidal input goes through a delay block (Z-d block in figure) to ensure only a single wave to pass through, otherwise a '0' value of steering angle (indicating linear movement), this way we are simulating a single turning scenario like lane changing. We don't use this block while simulating the turning radius calculation scenario (turning radius of a vehicle defines the minimum dimension of available space required for that vehicle to make a semi-circular U-turn without skidding.)

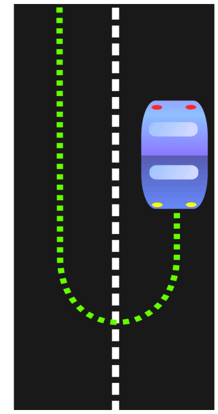


- After configuring the simulation settings, such as simulation time and solver options, we run the simulation to observe the behavior of the vehicle with the rear wheel steering system enabled. We analyze the simulation results by varying different parameters to evaluate the performance of the system under various driving conditions and inputs.
- Parameters and variables used in the simulation are-
    - Rear wheel Steering ratio with respect to the front wheel angle.
    - Different vehicle speeds.
    - Same direction and opposite direction steering with respect to the front wheel.
    - Coefficient of Friction.
- Finally, we iterate on the design, tuning, and validation of the rear wheel steering system based on the simulation results like-
    - Change in Turning radius with RWS ON.
    - Change in Yaw rate and its effect on the stability of the vehicle.
    - Tendency to Roll
    - Difference in stability under different friction conditions.
- All this involves adjusting controller parameters, refining the steering logic, or optimizing the vehicle dynamics for better performance.

★ Simulation Data, Graphs & Interpretations

1. <u>Turning Radius Maneuver</u>

Different Steering Ratios at different vehicle speeds:



1.1. <u>5km/hr</u>

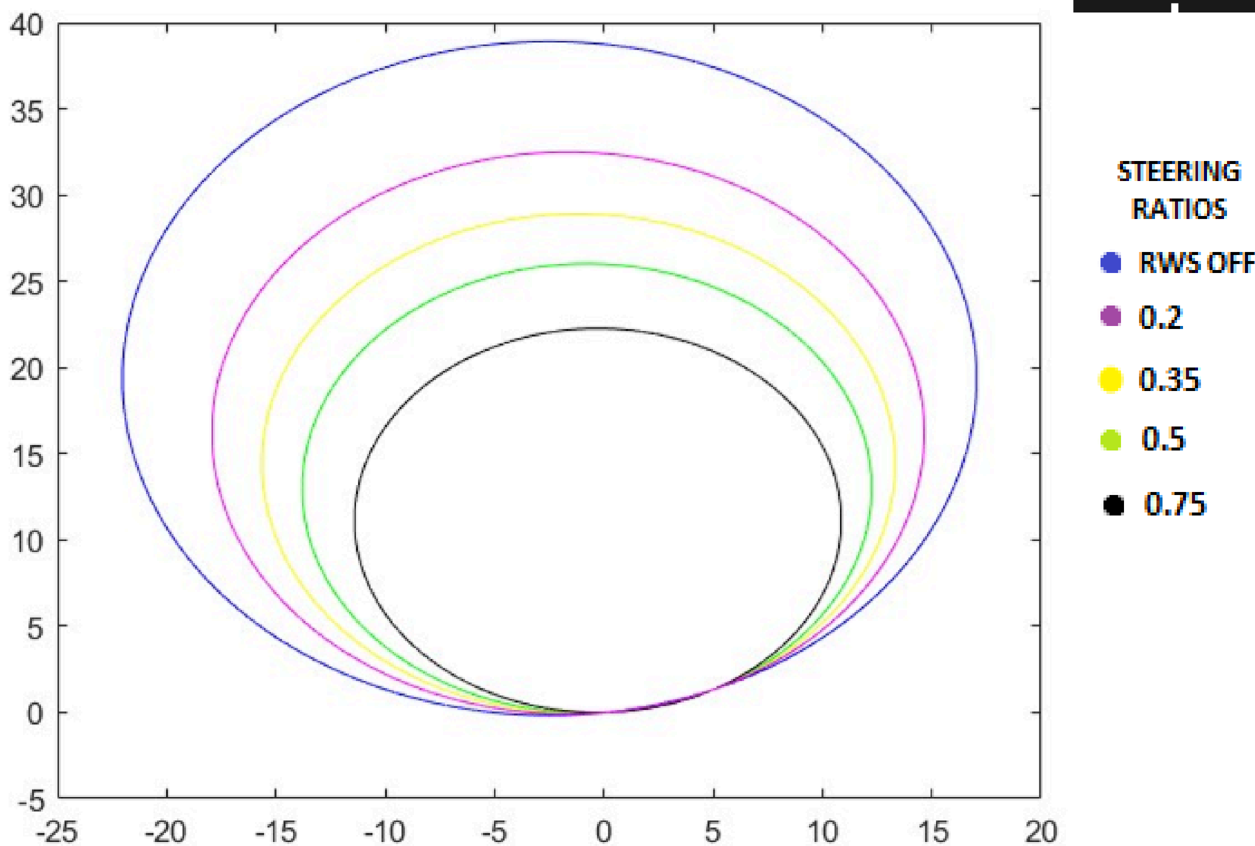


Fig18 <u>5kmph for different ratios</u>

- ➢ This illustration depicts turning radius circles and the required distance for a vehicle to execute a complete circle. If we aim to perform a U-turn without reversing, limiting the tire turning angle to a maximum of 15 degrees, we must allocate this amount of space.
- ➢ Both axes represent distances: t**he X-axis indicates the vehicle's movement in the horizontal (x) direction, while the Y-axis represents movement in the vertical (y) direction,** providing a visual representation of the vehicle's actual trajectory in physical space.

➢ We have used different RWS ratios and hence we get different path circles.

1.2. 10km/hr & 25km/hr

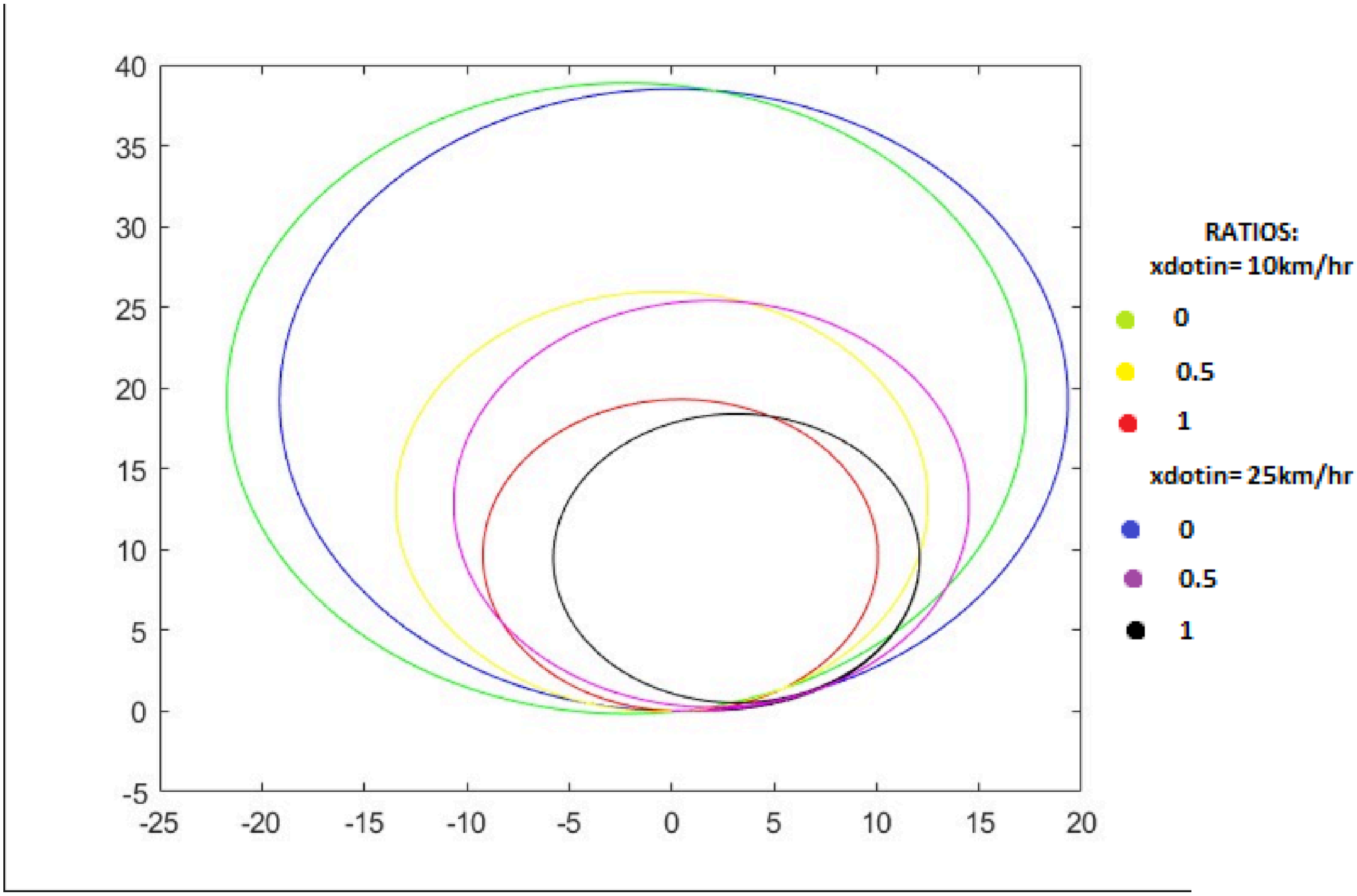


Fig19 for 25km/hr and 10 km/hr for ratio 0, 0.5, 1

This figure shows the comparison between RWS used at different speeds-

- 10km/h
- 25 km/h

for RWS ratio of **0, 0.5 and 1.**

❖ At lower speeds, the rear wheel steering (RWS) system exhibits remarkable stability when turning in the opposite direction. However, as speed increases, its stability diminishes. This characteristic makes it particularly effective for low-speed maneuvers such as parking, cornering, and executing U-turns.

Drawing inferences:

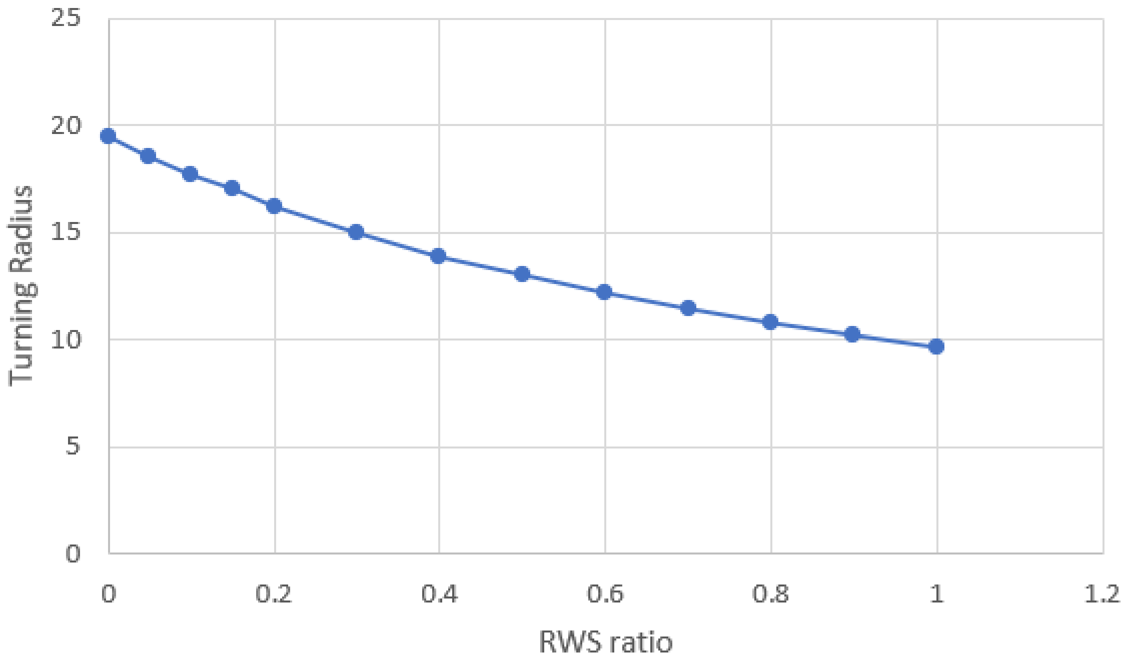
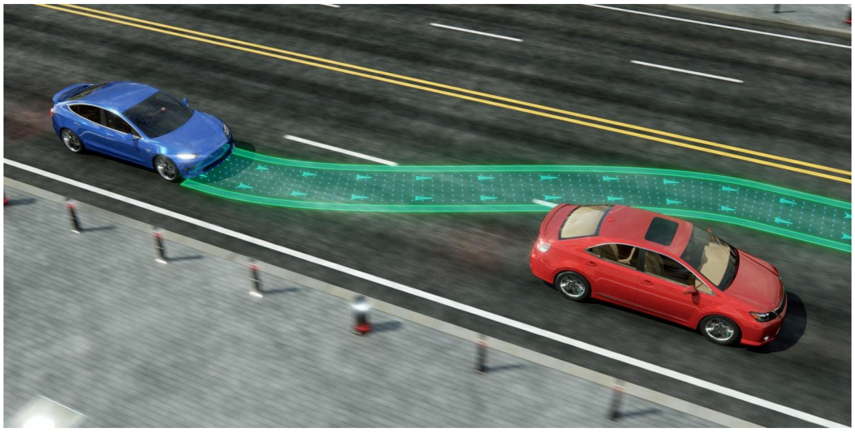


Fig20: turning radius vs RWS ratio at 5km/hr speed

❖ The depicted figure illustrates the correlation between the turning radius and the RWS (Rear Wheel Steering) ratio. A discernible trend emerges, showcasing a reduction in turning radius as the RWS ratio increases. Notably, turning radius nearly halves with an RWS ratio of 1 in comparison to when RWS is switched off. This relationship underscores the significant impact of RWS activation on maneuverability, offering insights into its potential to enhance vehicle agility and navigation in tight spaces.

2. Lane Changing Maneuver



At high speeds, when Rear Wheel Steering (RWS) is aligned with the front wheel steering, that is - the rear wheels turn in the same direction as that of the front wheels, it can significantly improve lane changing maneuvers. By coordinating the movement of all wheels, RWS enhances stability, reduces body roll, and minimizes the risk of oversteer or understeer situations during lane changes. This alignment optimizes vehicle control and responsiveness, ensuring safer and more confident maneuvering at high speeds. Lateral displacement at the time of lane changing at speed of 100 kmph, we give a sinusoidal steering input to the vehicle as a driver gives in real life while lane changing at highways.

The same quick responsiveness and control is demonstrated in the graphs plotted below

- **RWS OFF**

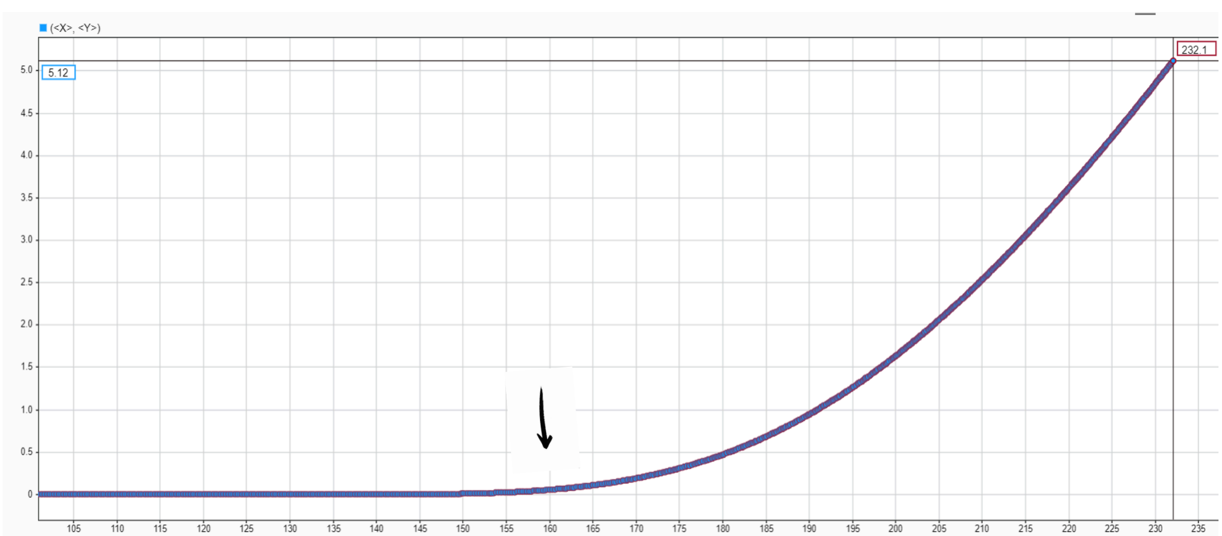


Fig 21: Shows lateral displacement while lane changing at 100km/hr.
Y axis: shows displacement(meter),
X axis: shows time(seconds)

- ➢ The car starts to turn at a distance of approximately 165 meters (depicted by arrow).
- ➢ The output varies from the sinusoidal input suggesting a delay in responsiveness and control over the car.

- **RWS ON**

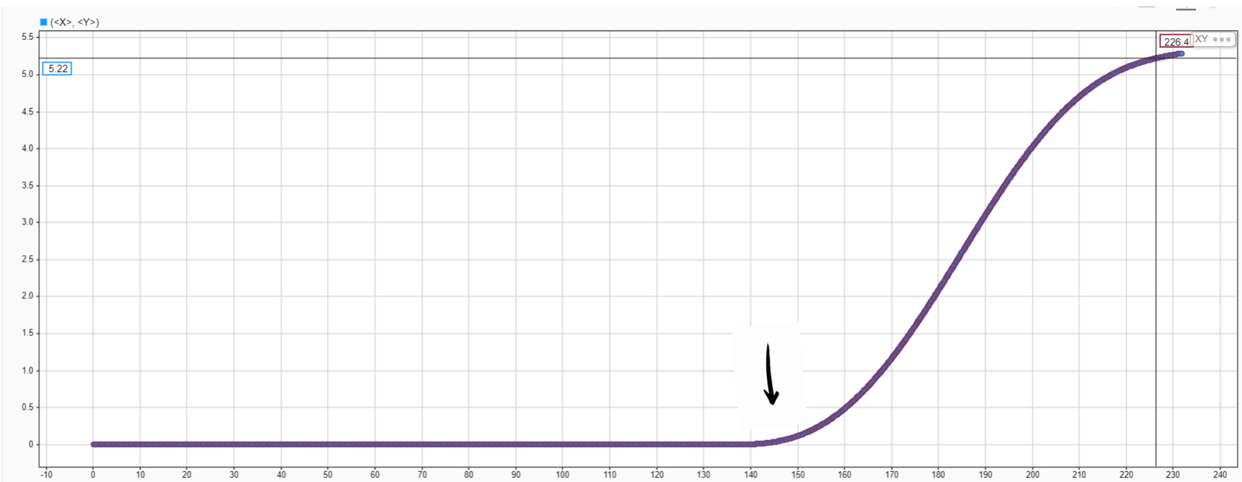


Fig 22 Shows lateral displacement at lane changing at 100km/hr.
Y axis: shows displacement(meter),
X axis:shows time(seconds) with RWS 0.93 ratio.

- ➢ The vehicle responds to the steering quicker than when RWS is OFF.
- ➢ The car starts to turn at a distance of approximately 145 meters (depicted by arrow), which is less than that when RWS OFF case.
- ➢ The path traced resembles that of the input sinusoidal wave, therefore a quicker response and better control can be seen.

Effect on roll motion of the Vehicle:

- ➢ When Rear Wheel Steering (RWS) aligns with the front wheel steering during lane changes, it effectively reduces the roll motion of the car. By coordinating the movement of all wheels, RWS helps stabilize the vehicle, minimizing lateral forces and reducing body roll. This alignment enhances the car's overall stability during lane changes, making the maneuver smoother and more controlled, especially at higher speeds.
- ➢ The same is depicted below in terms of Normal Forces on the wheels.
- ➢ A reduction in normal forces tells the instability and vulnerability to roll

➢ **Fig (a)** shows normal forces(N) on tires **RWS OFF** and **Fig (b)** shows normal forces(N) on tires with **RWS ON .**

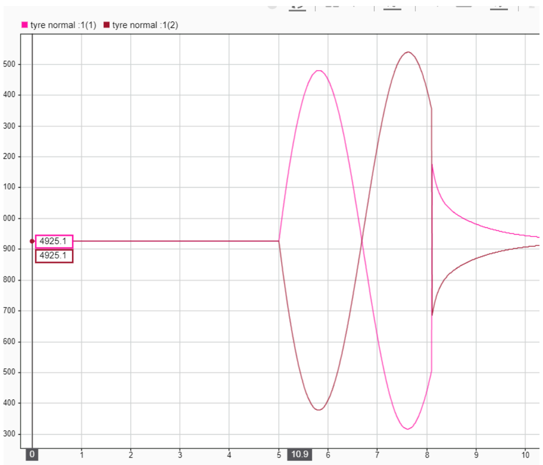


Fig 23 a: RWS OFF

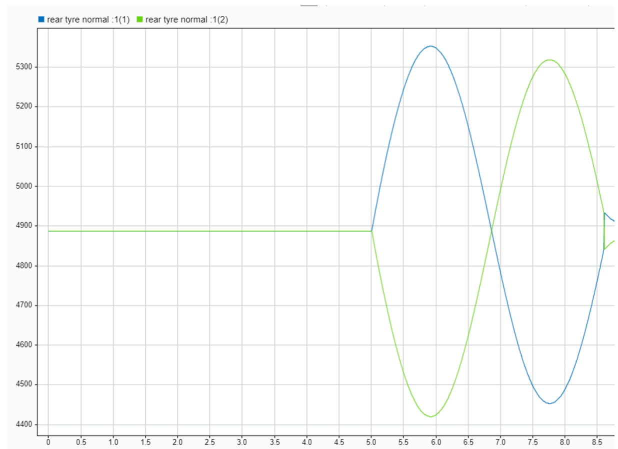


Fig 23 b :RWS ON

These figures show the normal forces on tires during lane changing. This is an important indicator of stability as this shows the rolling probability of the vehicle. If the normal forces become zero in any case this means that the tyre is lifted in air.
From these graphs we can see that in RWS off case normal forces fluctuated more compared to RWS in cases where there is less fluctuation showing a comfortable and safe lane changing.

Time Delay

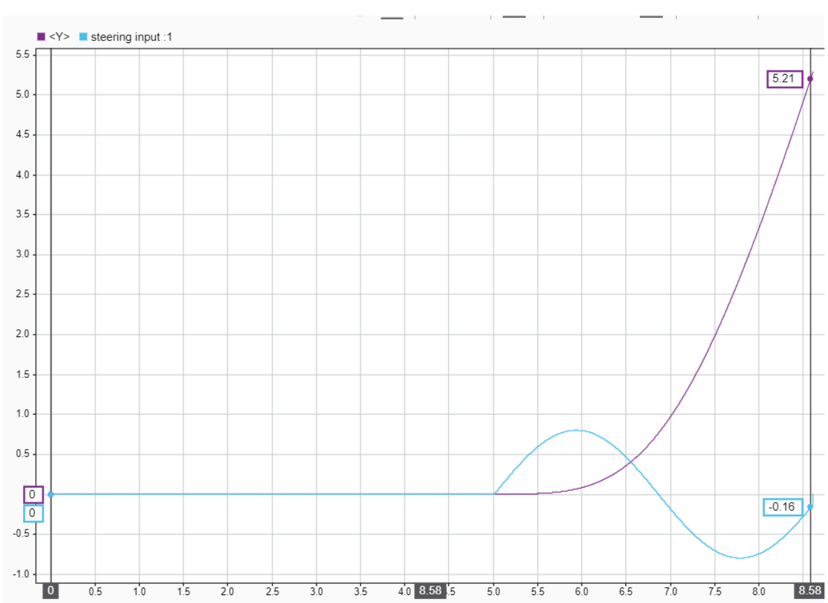


Fig 24: shows time relation between steering input and displacement of vehicle at high speed **RWS OFF.**
This figure shows that there is a delay between the steering input and the displacement of the vehicle, which can lead to losing control at high speed.
Blue: SINE input
Magenta: Path output

Fig 24 show time relation between steering input and displacement of vehicle at high speed with RWS

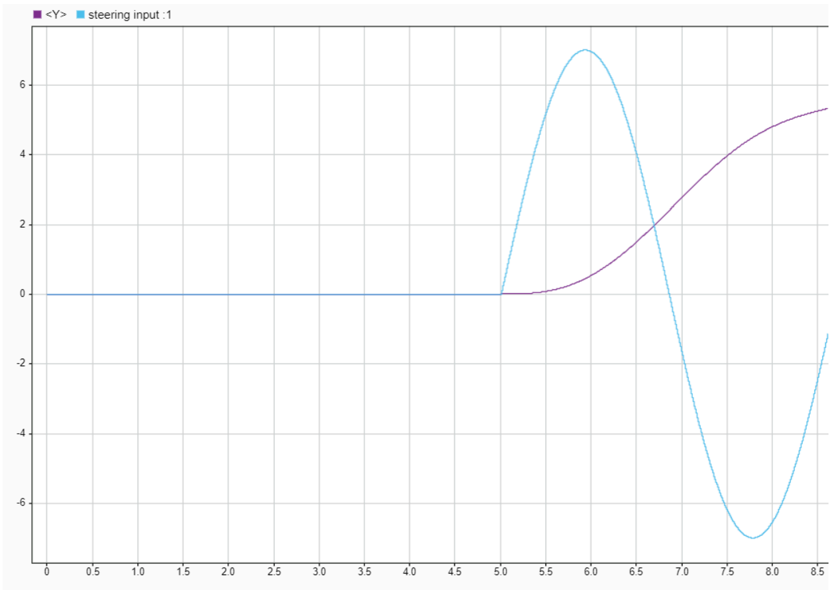


Fig 25: shows that the delay between steering input and displacement of vehicle (**RWS ON**) is reduced giving us a better control over vehicle which can also be seen with the profile of vehicle(magenta path) where we are getting the desired curve.

Blue: SINE input
Magenta: Path output

Effect on YAW rate:

Rear Wheel Steering (RWS) can have a significant impact on the yaw rate of a vehicle, especially at higher speeds. Here's how RWS affects yaw rate:

1. Enhanced Agility: When RWS is activated and aligned with the front wheel steering, it can increase the vehicle's agility by optimizing the coordination between the front and rear wheels. This coordinated movement allows for more precise control over the vehicle's yaw rate during maneuvers such as lane changes or high-speed cornering.
2. Improved Stability: RWS can also enhance stability by reducing the vehicle's tendency to oversteer or understeer. By adjusting the rear wheel angles in coordination with the front wheels, RWS helps maintain a balanced yaw rate, improving overall stability during dynamic maneuvers.
3. Reduced Lateral Forces: Properly tuned RWS systems can minimize excessive lateral forces acting on the vehicle, which can contribute to yaw rate instability. By optimizing the alignment of the rear wheels, RWS helps distribute lateral forces more evenly, promoting smoother handling and reduced yaw rate fluctuations.
4. Enhanced Control: RWS provides drivers with greater control over the vehicle's yaw rate, allowing for more precise and predictable handling characteristics, particularly during high-speed maneuvers. This improved control helps drivers maintain stability and confidence, even in challenging driving conditions.

The difference between yaw rates of the two cases i.e **RWS ON** & **RWS OFF** is depicted below:

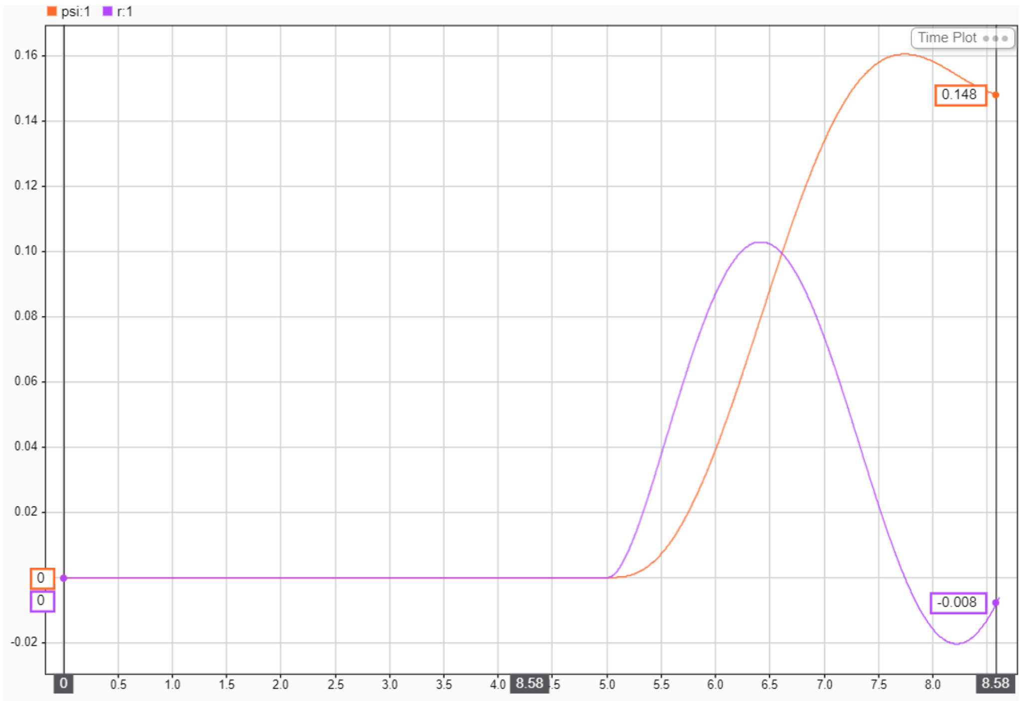


Fig26(a): RWS OFF:

Yaw moment and Yaw rate without RWS.

- YAW Rotation: peak value: 0.16 rads
- YAW Rate: peak value: 0.105 rads/s

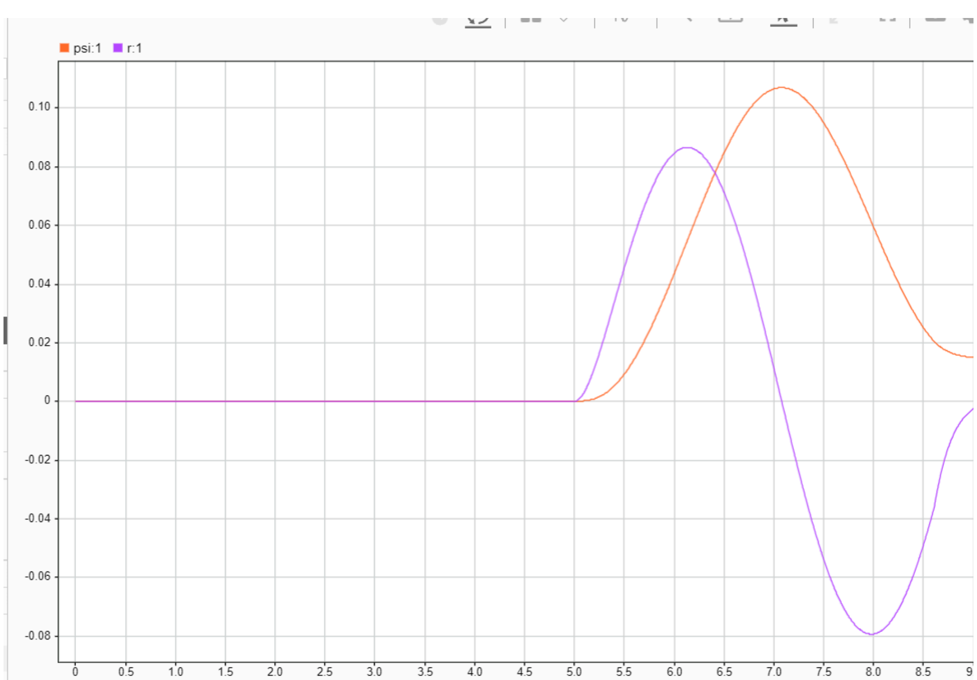


Fig 26(b): RWS ON:

Yaw moment and Yaw rate with RWS.

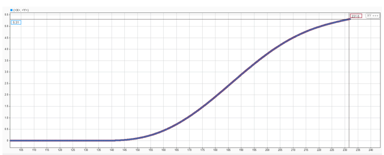
- YAW Rotation
- YAW Rate

The peaks of yaw rate and yaw rotation are significantly reduced to 0.09rads/s and 0.12rads, respectively.

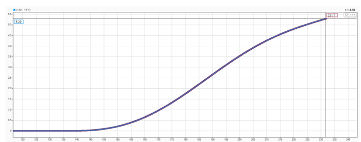
The data clearly indicates that Rear Wheel Steering (RWS) leads to lower yaw changes and consequently lower yaw rates, especially during high-speed driving. This reduction in yaw rate contributes to **improved stability**, as it minimizes the vehicle's tendency to sway or rotate around its vertical axis. Ultimately, RWS enhances driving stability at higher speeds, promoting safer and more confident handling on the road.

Variation of displacement curve(path of the vehicle) with coefficient of friction

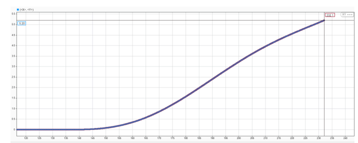
With RWS ON



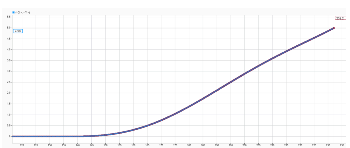
friction coefficient = 0.9



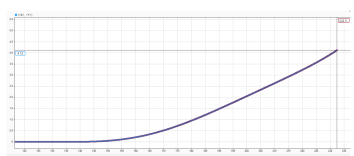
friction coefficient = 0.8



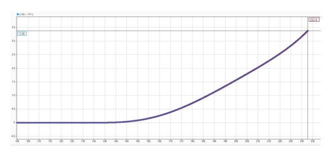
friction coefficient = 0.7



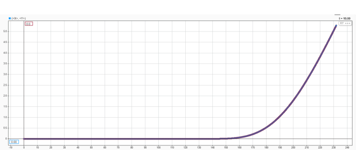
friction coefficient = 0.6



friction coefficient = 0.5

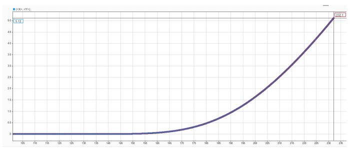


friction coefficient = 0.4

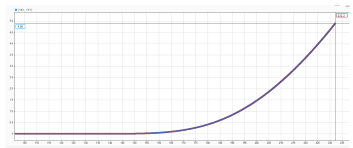


friction coefficient = 0.3

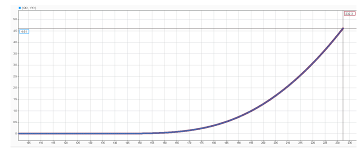
Without RWS



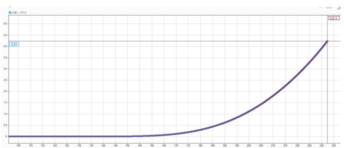
friction coefficient =0.9



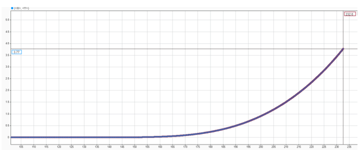
friction coefficient = 0.8



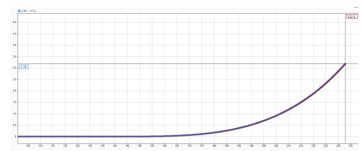
friction coefficient = 0.7



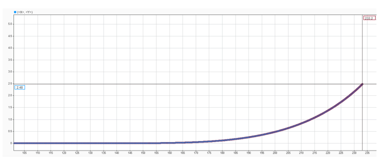
friction coefficient = 0.6



friction coefficient = 0.5

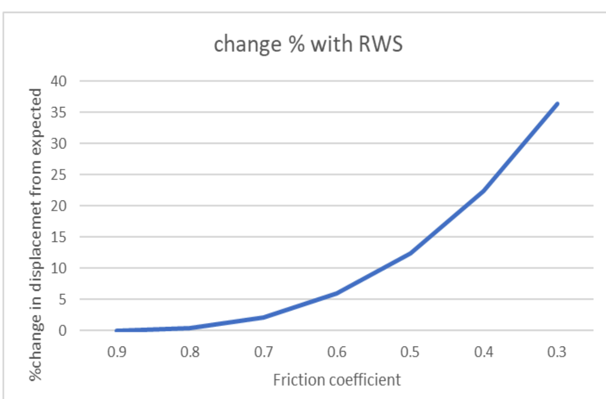


friction coefficient = 0.4



friction coefficient = 0.3

<u>Graph data of peaks of the above graphs (for friction coefficient =0.9)</u>



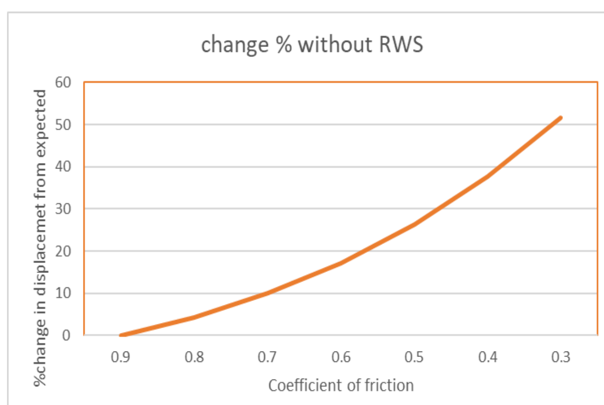


Fig 27(a) **RWS ON**

Fig 27(b) **RWS OFF**

Fig_(a): shows the % change in lateral displacement at different friction coefficient with **RWS ON** v/s displacement
Fig_(b) shows the % change in lateral displacement at different friction coefficients **without RWS** v/s displacement.

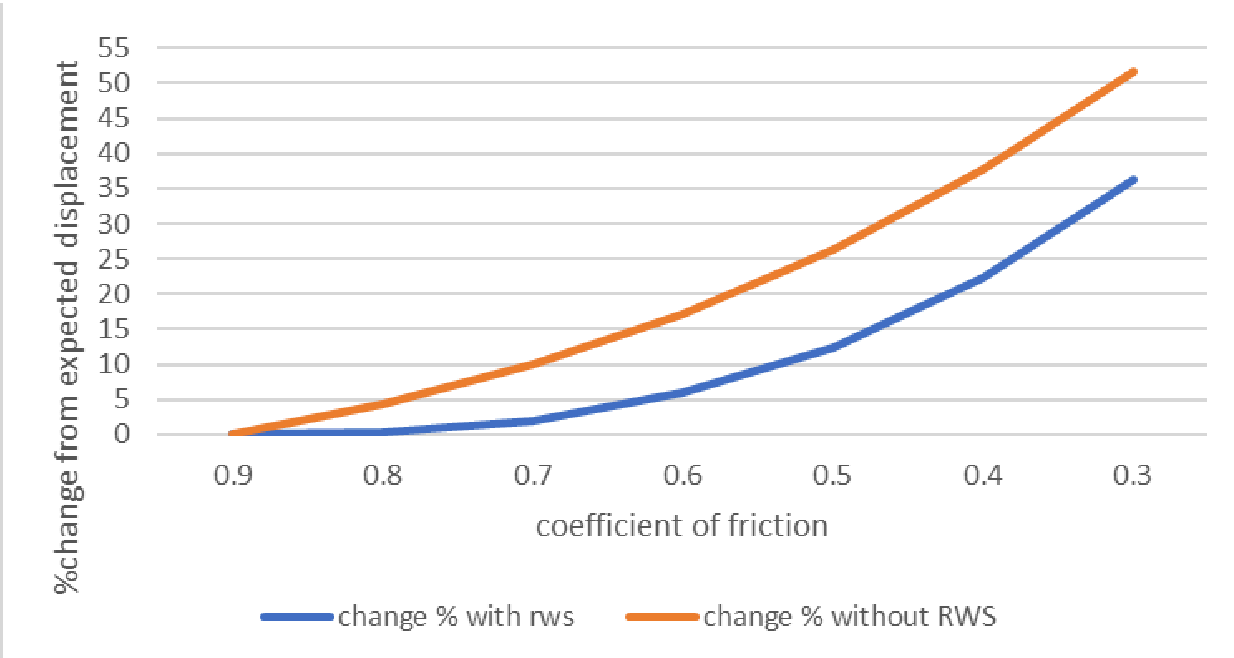
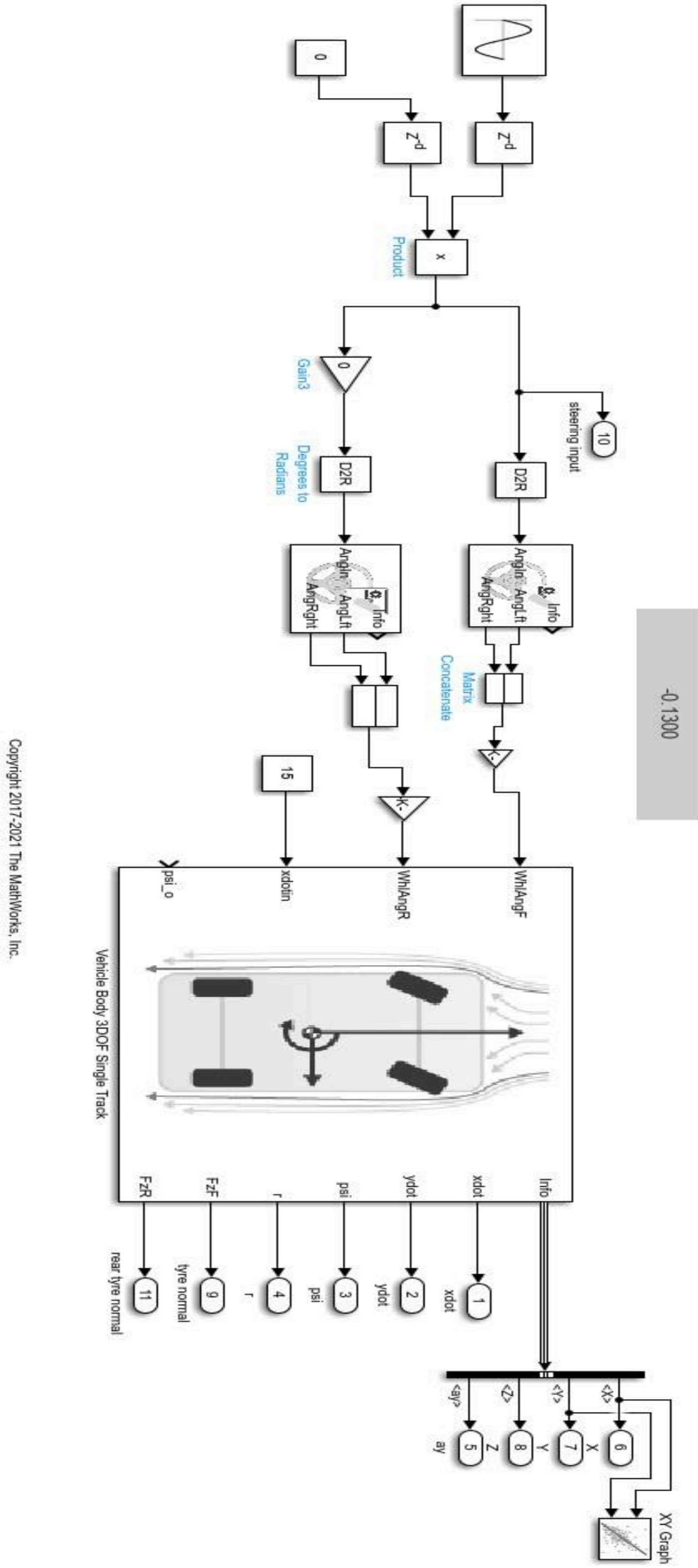


Fig 28 shows the combine output of Fig 27(a) and Fig 27(b)

From this graph, it's evident that as the coefficient of friction decreases, lateral displacement also decreases, suggesting a loss of control. However, what's noteworthy is that the percentage change observed with Rear Wheel Steering (RWS) is significantly less compared to the scenario without RWS. This indicates that even as the coefficient of friction decreases, the loss of control is much less pronounced when RWS is engaged. In essence, RWS mitigates the loss of control, offering better stability and control compared to driving without RWS, particularly in challenging road conditions with reduced friction.

NOTE: All dimensions & measurements specified in the calculations part i.e *pg.18 , pg19.*

Complete Blockset Diagram:



Conclusion:

1. Steering Direction: The direction of rear wheel steering, whether aligned with or opposite to the front wheels, has distinct effects on vehicle stability. When RWS operates in the opposite direction to the front wheels, stability is notably enhanced, particularly at lower speeds and during low-speed maneuvers such as parking and U-turns. This finding underscores the significance of aligning RWS with specific driving scenarios to optimize vehicle performance and driver confidence.

2. Rear Wheel Steering (RWS) Ratio Impact & Turning Radius: The RWS ratio plays a pivotal role in determining the vehicle's turning capabilities. Through simulations, we observed that increasing the RWS ratio leads to a substantial reduction in the turning radius. This reduction enables the vehicle to execute tighter turns, enhancing its maneuverability in various driving scenarios. Consequently, adjusting the RWS ratio offers a practical means of tailoring the vehicle's handling characteristics to meet specific performance requirements.

3. Effect of Vehicle Speed: Our simulations also underscored the influence of vehicle speed on the effectiveness of RWS. At higher speeds, RWS demonstrated a notable contribution to stability. By reducing the yaw rate and minimizing lateral displacement during dynamic maneuvers, RWS enhances the vehicle's overall control and responsiveness, particularly during lane changes and high-speed cornering. This highlights the importance of considering vehicle speed when evaluating the impact of RWS on driving dynamics.

4. Impact of Coefficient of Friction: Our simulations revealed the significant influence of the coefficient of friction on vehicle stability and control. RWS emerged as a valuable tool for mitigating the loss of control, especially in scenarios characterized by decreasing coefficients of friction. By reducing yaw rate and minimizing lateral displacement, RWS effectively enhances stability, ensuring safer and more predictable driving experiences across a range of road conditions.

5. Design Optimization and Validation: The iterative process of designing, tuning, and validating the RWS system based on simulation results is paramount for achieving optimal performance. Parameters such as turning radius, yaw rate, tendency to roll, and stability under varying friction conditions serve as key metrics for evaluating RWS effectiveness and fine-tuning system parameters. This iterative approach enables engineers to optimize RWS performance and ensure its reliability and efficacy in real-world driving scenarios.

In summary, our comprehensive analysis of RWS performance through simulations highlights its potential to significantly enhance vehicle maneuverability, stability, and control. By carefully considering parameters such as RWS ratio, vehicle speed, steering direction, and road conditions, RWS can be optimized to deliver superior driving experiences and safety outcomes.

Future Scope & Plan

1. Prototype Development & Further Simulations

- Build a prototype go-kart equipped with Rear Wheel Steering (RWS) technology, actuators, and sensors to demonstrate the feasibility and potential of this innovative vehicle design.
- Including more complicated SIMULINK block sets
  - - Modeling detailed RWS Systems
  - - Simulation of Vehicle Dynamics (multiple DOFs)
  - - Controller Design and Validation
  - - Integration with other multi axled vehicles

2. Conduct research on cost-effective algorithms and mechanisms for installing RWS technology on vehicles in India. Explore innovative solutions and adaptations tailored to the unique requirements and constraints of the Indian automotive market.

3. Investigate opportunities for integrating RWS technology into affordable vehicle models commonly used in India, such as compact cars and two-wheelers, to enhance their maneuverability and safety features.

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