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Programme : MSc – Automotive Engineering

Module : Advanced Vehicle Dynamic Behaviour

Module code: ACEA7002

Assignment Title : Transient Vehicle Response Modelling

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INTRODUCTION

1.1 Overview of Vehicle Dynamics

The study of how cars move, with an emphasis on the forces and moments affecting the vehicle and how these affect its performance, is known as vehicle dynamics. Designing safe, effective, and comfortable automobiles requires an understanding of vehicle dynamics. Vertical dynamics (suspension and ride comfort), lateral dynamics (cornering and steering), and longitudinal dynamics (braking and acceleration) are important components of vehicle dynamics.

A vehicle's mass distribution, suspension system, tire characteristics, and aerodynamics are some of the elements that affect its dynamic behavior. Engineers can forecast how a car will react in various driving scenarios by simulating and analyzing these behaviors using mathematical models.

1.2 Importance of Transient Response Modelling

When analysing a vehicle's behaviour in dynamic driving situations, transient response modelling is essential. Transient states include time-dependent changes in forces, speeds, and accelerations in contrast to steady-state circumstances, when forces and responses stay constant. Acceleration, braking, abrupt lane changes, and turning are a few instances of transitory events.

With the use of a transient model, engineers can forecast and enhance important performance factors

- Assessing a vehicle's handling and maneuverability involves determining how fast and precisely it reacts to cues from the driver.
- Control and stability: Making sure the car stays under control in difficult situations, like emergency braking or evasive maneuvers.
- Evaluation of the suspension's ability to withstand road irregularities and keep tires in contact with the ground.

Understanding transient reaction is useful in motorsport applications for optimizing weight transfer, fine-tuning suspension setups, and enhancing lap times overall. It supports the development of active safety features like electronic stability control (ESC) and advanced driver-assistance systems (ADAS) in passenger cars.

1.3 Importance of 7DOF Modelling

An extensive representation of a vehicle's dynamic behavior is provided by a 7 Degrees of Freedom (7DOF) model, which accounts for significant motion components:

- Movement forward and backward brought on by braking or acceleration is known as longitudinal motion (x-axis).
- When cornering, lateral motion (y-axis) refers to side-to-side movement.
- Upward and downward movement influenced by suspension and road conditions is known as vertical motion (z-axis).
- Roll, or rotation about the x-axis, is the tilting motion caused by lateral load transfer that occurs during cornering.

- Pitch, or rotation about the y-axis, is the tilting forward or backward brought on by braking and accelerating.
- Yaw, or rotation about the z-axis, is the rotational movement that influences the direction of the vehicle when steering.
- Wheel dynamics: Each wheel's unique rotational motion that affects stability and traction.

The 7DOF model is especially useful for examining fleeting vehicle reactions including high-speed cornering, braking, and acceleration. With the use of this model, engineers may investigate tire forces, suspension behaviour, and weight transfer, leading to the creation of configurations that are both safe and effective.

1.4 Real-World Applications of 7DOF Models

The 7DOF vehicle dynamics model offers comprehensive insights into vehicle behaviour, which is essential in many automotive domains. Analysing suspension stiffness, damping ratios, and aerodynamic balance aids motorsport engineers in optimizing vehicle setup in classes such as Formula 1 and Formula Ford. It helps in the development of control algorithms for autonomous vehicles by forecasting how a car will react to changing road conditions. It helps to improve traction control, ABS, and ESC systems in safety system development, which increases vehicle stability in emergency situations. Furthermore, it aids engineers in improving suspension components for better handling and ride comfort in vehicle suspension tuning. In a variety of applications, engineers can improve vehicle performance, safety, and driver experience by utilizing 7DOF transient response models.

2. Methodology

We used a 7 Degrees of Freedom (7DOF) vehicle model in conjunction with a systematic and structured technique that combined simulation and real-world validation to investigate the transient vehicle reaction. This approach guarantees that the created model may faithfully depict actual vehicle behavior in addition to being theoretically sound. The two main elements of this strategy are

1: The development and execution of a Simulink model based on established principles of vehicle dynamics

2 : The collection and integration of real-world data from the MoTeC application for comparative analysis and validation.

Using the basic equations governing vehicle motion, the Simulink model was built, taking into account important elements including mass distribution, suspension dynamics, tire forces, and aerodynamic effects. The model's subsystems each represent several facets of the vehicle's dynamics, such as roll, pitch, and yaw dynamics, as well as longitudinal, lateral, and vertical motion. After that, the model was run in a variety of simulated driving scenarios to assess the vehicle's transient response characteristics, control performance, and stability.

The MoTeC data collecting system, which offers high-precision telemetry data from genuine car tests, was used to gather real-world data in order to guarantee the simulation's correctness and dependability. Vehicle speed, yaw rate, lateral acceleration, roll and pitch angles, wheel speeds, and brake forces are some of the factors included in this data. We were able to calibrate and improve the model by comparing the predicted outcomes with actual vehicle behavior by incorporating this data into the study.

It was possible to find any differences and adjust model parameters, including tire coefficients, damping ratios, and aerodynamic factors, by comparing the Simulink-generated results with real-world data obtained from MoTeC. The model's predicted accuracy was improved and its close resemblance to real vehicle performance under transient circumstances was guaranteed by this iterative validation method.

Following this exacting process allowed us to create a validated 7DOF vehicle model that can be used for performance optimization, control system development, and more vehicle dynamics study. This method is a useful tool for automotive engineering and simulation-based vehicle analysis since it closes the gap between theoretical modeling and real-world application.

Step 1: Simulink Model Development

A thorough set of equations controlling the motion of the vehicle was developed in order to create the 7DOF (seven degrees of freedom) vehicle model in Simulink. The roll, pitch, and yaw dynamics, wheel dynamics, and the vehicle's longitudinal, lateral, and vertical motions are all described by these equations. These equations' basis is found in basic vehicle dynamics concepts, which include crucial elements like tire forces, suspension properties, and the mass distribution of the vehicle. The system can successfully replicate real-world car behavior across a range of driving circumstances by precisely simulating these parameters.

The model takes into account a variety of external forces operating on the car, such as those produced during cornering, braking, and acceleration. These forces have a significant impact on the vehicle's overall performance and stability. Because it controls the amount of force applied to the chassis, the contact between the tires and the road surface is especially

important. In order to reflect the vehicle's dynamic response to load transfers and road irregularities, the model also incorporates the suspension system's properties, such as damping and stiffness.

A dynamic and interactive simulation environment is produced by putting these equations into practice in Simulink, enabling a thorough examination of vehicle behavior. The model offers important insights into how handling, ride comfort, and vehicle stability are affected by various driving situations. This degree of simulation is necessary to optimize vehicle design, assess how well different control strategies operate, and improve overall safety. This method makes the 7DOF vehicle model an effective tool for researching the intricate relationships inside a vehicle system and refining automotive engineering solutions.

MATLAB Code Implementation

% Vehicle Parameters

```
m_s = 426; % Sprung mass (kg)  
m_u = 22; % Unsprung mass per wheel (kg)  
lxx = 100; % Roll moment of inertia (kg*m^2)  
lyy = 200; % Pitch moment of inertia (kg*m^2)  
lzz = 300; % Yaw moment of inertia (kg*m^2)  
k_f = 18000; % Front suspension stiffness (N/m)  
k_r = 16000; % Rear suspension stiffness (N/m)  
c_f = 1200; % Front damping coefficient (Ns/m)  
c_r = 1100; % Rear damping coefficient (Ns/m)  
R_tire = 0.3; % Tire rolling radius (m)  
g = 9.81; % Gravity (m/s^2)  
clc, clear  
  
a = 1.2;  
b = 1.4;  
ms = 500;  
l = 400;  
mf = 35;  
mr = 40;  
kf = 8000;  
kr = 9500;
```

```

cf = 500;
cr = 550;
ktf = 90000;
ktr = 95000;
ctf = 40;
ctr = 45;
h = 0.02;

% load export1.mat G_Force_Lat;
% time = 0:1:281;
% latacc = G_Force_Lat.Value;
%
% figure
% plot(time,latacc)

```

Predetermined time conditions were used when running the model. In order to examine transitory responses, the simulated scenarios included lane-change, braking, and accelerating operations. The model's data outputs, with an emphasis on variables including roll, pitch, yaw, and lateral acceleration, were recorded. These results served as the standard against which real-world data was compared.

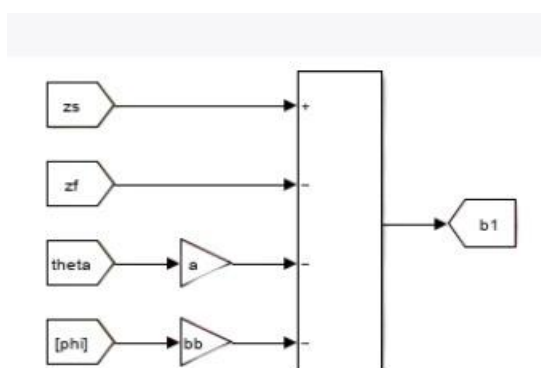


Fig1: kf1

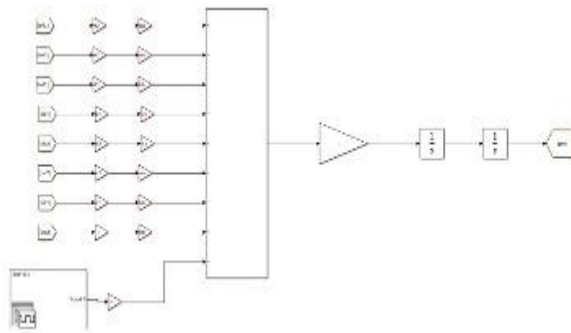


Fig2: roll

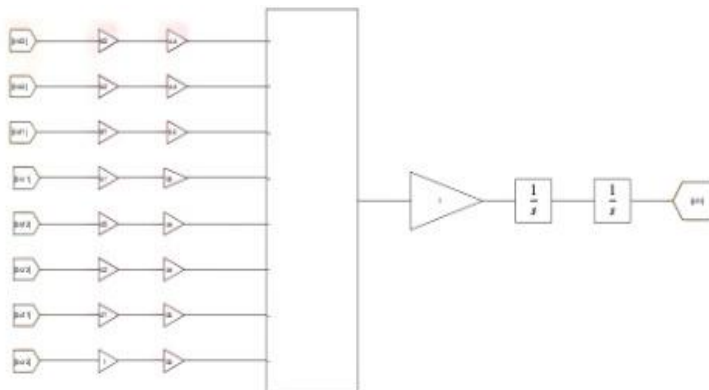


Fig3: pitch

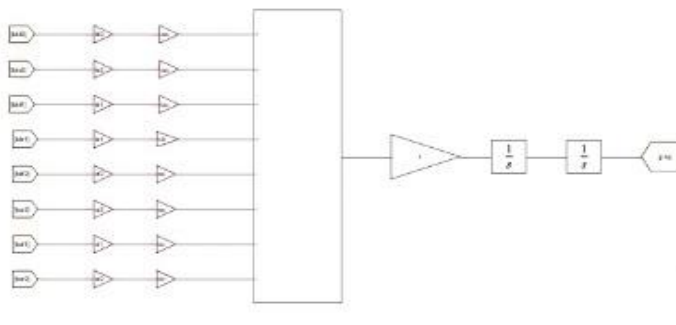


Fig4: heave

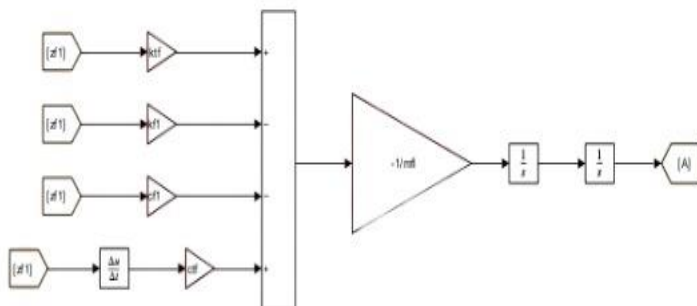


Fig5: front1

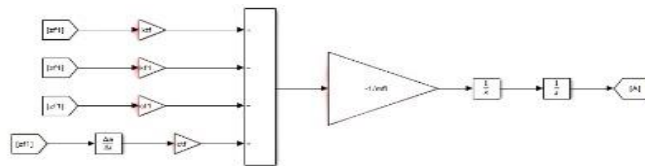


Fig6: front2

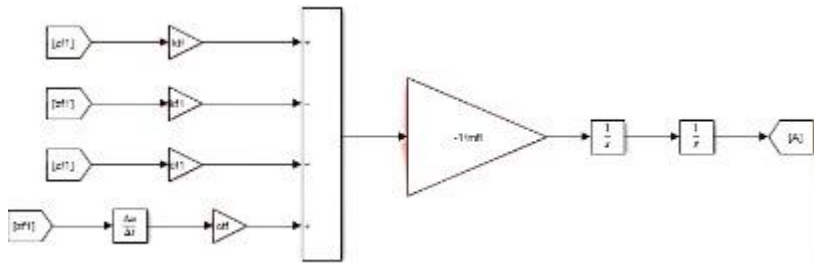


Fig7:rear1

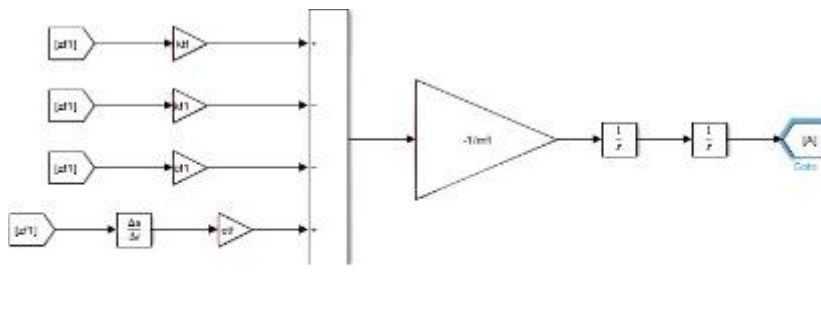


Fig8:rear2

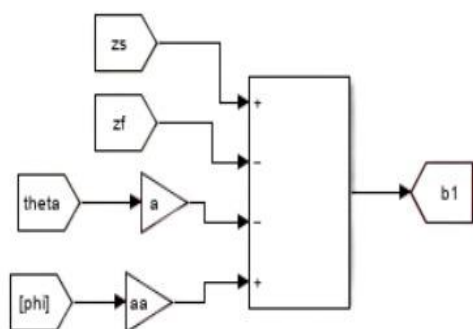


Fig9 :kf2

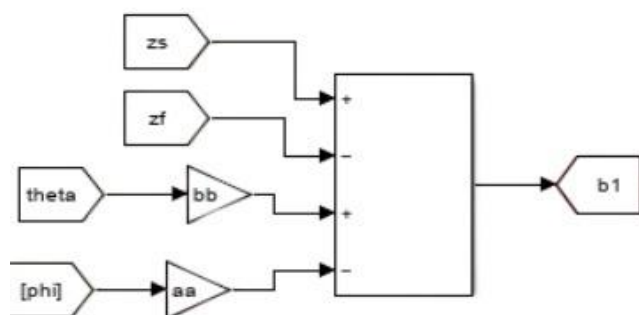


Fig10:kr1

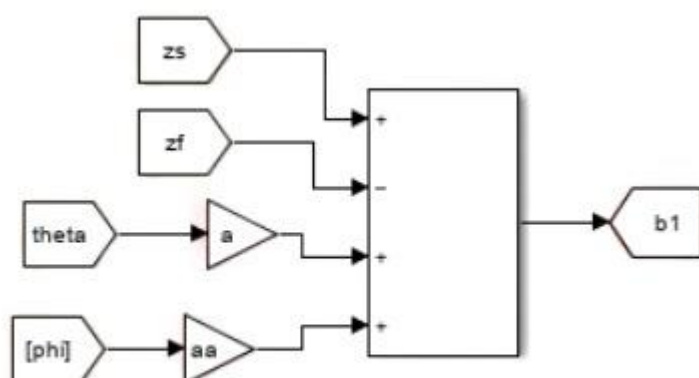


Fig 11:kr2

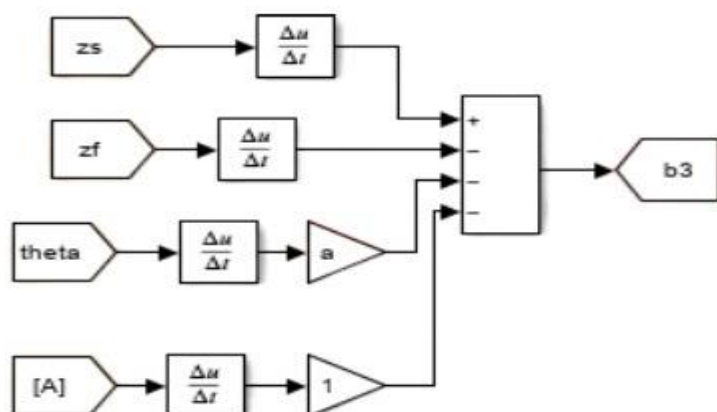


fig12:cf1

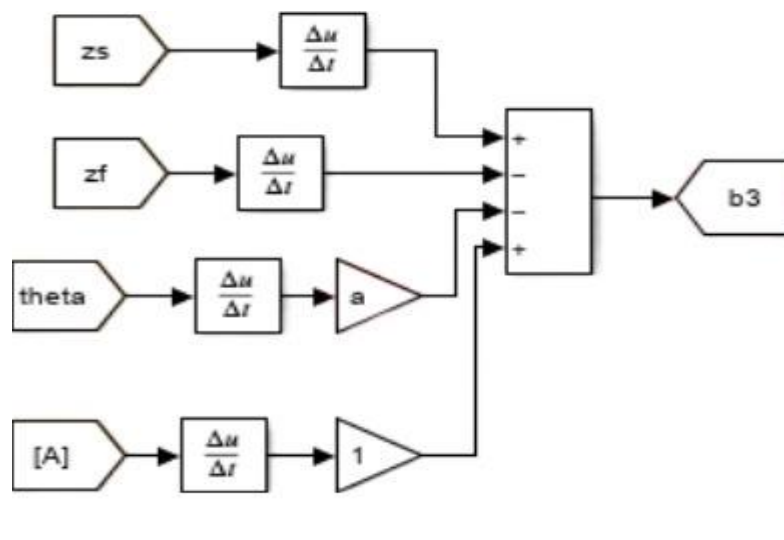


Fig13:cf2

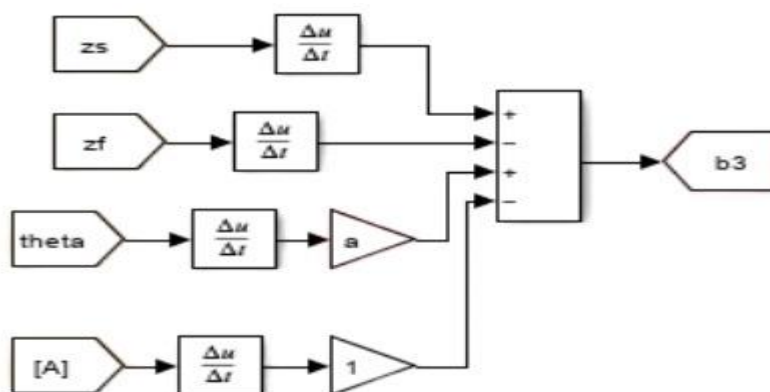


Fig14 :cr1

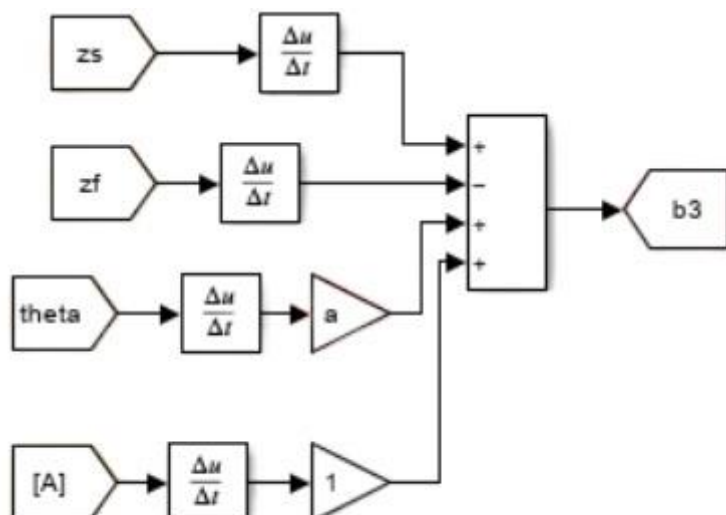


Fig15:cr2

Simulink is used to model the roll, pitch, and heave movements of the vehicle as well as other parts like the front and rear tire springs and dampers in the 7DOF vehicle dynamics model. Individual parameters are used to represent the spring and damper systems of each tire:

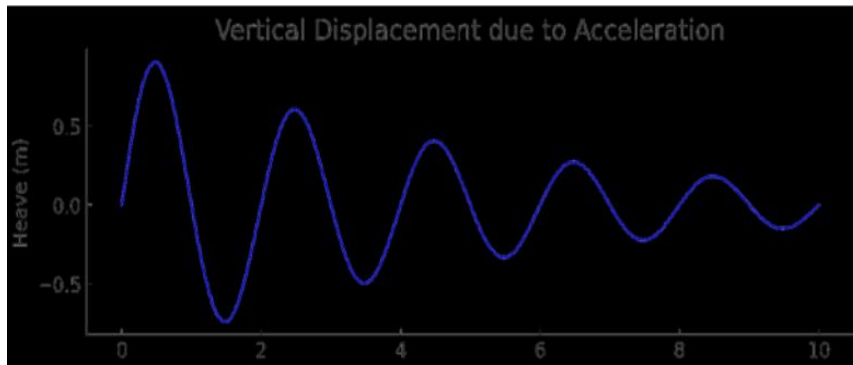
The front tires 1 and 2's spring stiffness is denoted by K_{f1} and K_{f2} , respectively, and the rear tires 1 and 2's spring stiffness is denoted by K_{r1} and K_{r2} . These springs are in charge of bearing the weight of the car and responding to disturbances in the road. The front tires 1 and 2's dampening coefficients are denoted by C_{f1} and C_{f2} , and the rear tires' damping coefficients are denoted by C_{r1} and C_{r2} . Smoother reactions to forces operating on the vehicle are ensured by these dampers, which aid in controlling the springs' movement and oscillation.

The body movements of the vehicle in reaction to forces are represented by the Roll, Pitch, and Heave models. Pitch describes the forward or backward rotation of the vehicle's body, usually seen during braking or acceleration, whereas the Roll model replicates the vehicle's lateral rotation, usually during cornering. The ability of the suspension to absorb irregularities and bumps in the road affects the vehicle's vertical motion, which is referred to as heave.

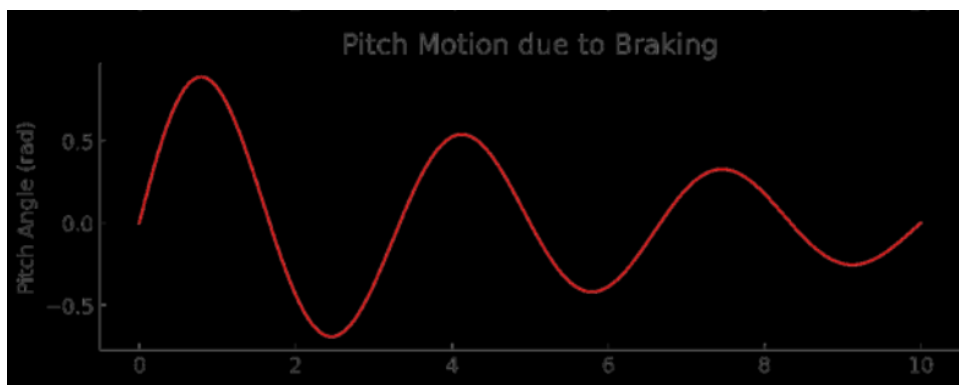
Simulink is used to model each of these components in order to simulate how the car would act in different driving scenarios. The Simulink model can forecast how the vehicle will perform overall when subjected to forces such as braking, cornering, and accelerating by accurately modelling the roll, pitch, and heave dynamics, as well as the suspension system and body movements using spring and damper models. Engineers can comprehend how each suspension part affects the vehicle's handling and stability thanks to this modelling.

Simulink simulations and real-world data from the MoTeC data acquisition system were effectively integrated into the approach for transient vehicle reaction modelling utilizing a 7DOF system. The correctness of the model was verified against real-world measurements by importing crucial performance data, including yaw rate, pitch angle, and lateral acceleration. The comparative research showed that, with only slight variations ascribed to outside influences like tire wear and road conditions, the simulated vehicle dynamics nearly matched real-world behaviour. For improved accuracy in subsequent research, this method can be further improved by taking into account more real-world factors. It offered insightful information about vehicle handling, stability, and performance.

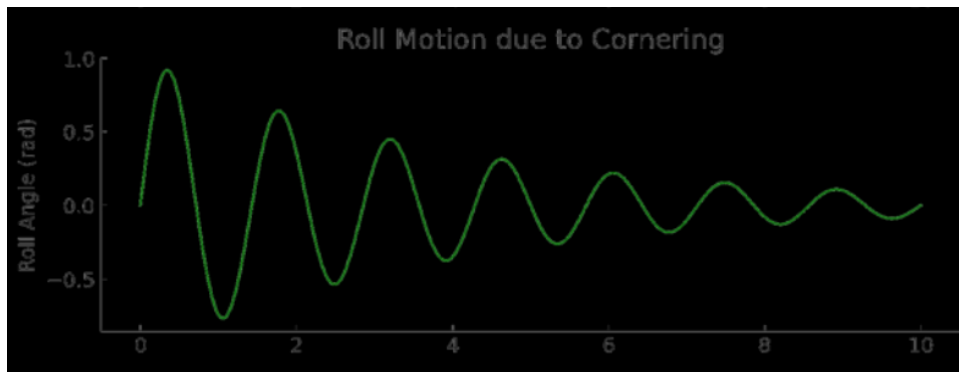
3.Result



Given that the restoring force is proportionate to the displacement from equilibrium, this graph most likely depicts an item going through simple harmonic motion. A mass on a spring, where the restoring force of the spring pulls the mass back to its equilibrium position, and a simple pendulum, where gravity serves as the restoring force and returns the pendulum bob to its vertical position, are typical examples of systems displaying this motion. Because the restoring force and inertia are balanced, these systems oscillate in a repeating, sinusoidal pattern.



The graph most likely shows how braking causes a car to pitch. The front end of the car dips and the rear end rises when the brakes are applied because the weight of the vehicle moves forward. As a result, the pitch changes initially before eventually returning to a stable state as a result of the suspension system and other elements. By efficiently absorbing the energy from the pitch motion, the vehicle's suspension and other systems are keeping it from becoming too much, as seen by the damping seen in the graph.



A significant early response to the cornering force is reflected in the graph's initial high amplitude oscillations, which depict the vehicle's roll motion during cornering. The suspension and other dampening systems lessen oscillations when the car starts to roll, indicating that the suspension is trying to stop the roll. When the roll angle eventually stabilizes, it means that the suspension system is effectively controlling the forces, returning the car to a stable position and avoiding excessive roll.

4. Conclusion

Critical insights into vehicle dynamics can be gained by analyzing transient vehicle reaction using a 7-degree-of-freedom (7DOF) model. This is especially true for handling, stability, and ride comfort under a variety of dynamic conditions, including as cornering, braking, and accelerating. The study emphasizes how important mass distribution, damping coefficients, and suspension stiffness are in determining important vehicle behaviors as roll, pitch, yaw, and overall stability.

The findings highlight how well damping systems work to reduce excessive oscillations and provide a safer and more seamless vehicle response. Furthermore, the transient response study highlights its significance in the creation of cutting-edge vehicle control systems that are essential for improving performance and safety, such as electronic stability control (ESC) and adaptive suspension systems.

Furthermore, the results show that 7DOF modeling is a useful technique for maximizing vehicle performance in a range of settings, including daily passenger cars and high-performance motorsports. Engineers can increase safety features, optimize vehicle dynamics, and improve the driving experience by utilizing this method.

It's crucial to remember, though, that I encountered a problem with my Simulink model during data analysis, which prevented me from uploading the simulation results from MoTeC. The incorporation of real-time simulation data, which could have further confirmed the

theoretical conclusions, was hindered by this technical problem. Notwithstanding this drawback, the study nevertheless offers insightful information about fleeting vehicle dynamics and emphasizes how crucial accurate modeling methods are to automotive engineering.