ME5670
VEHICLE DYNAMICS & MODELING

BRAKING (ANTI-LOCK BRAKING SYSTEM AND REGENERATIVE BRAKING)

TEAM

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BRAKING SYSTEMS AND THEIR TYPES

- In an automobile vehicle, a braking system is an arrangement of various linkages and components (brake lines or mechanical linkages, brake drum or brake disc , master cylinder or fulcrums etc) that are arranged in such a fashion that it converts the vehicle's kinetic energy into the heat energy which in turn stops or de accelerate the vehicle.

- The conversion of kinetic energy into heat energy is a function of frictional force generated by the frictional contact between brake shoes and moving drum or disc of a braking system.

- Braking Systems are generally classified into different types according to the source of brake torque:
  - Mechanical braking system
  - Hydraulic braking system
  - Air or pneumatic braking system
  - Vacuum braking system
  - Magnetic braking system
  - Electric braking system

ANTI-LOCKING BRAKING SYSTEM (ABS)

ABS antilock braking systems are closed-loop control devices implemented in ground vehicles that prevent wheel lock-up during braking. They are used in modern cars to prevent the wheels from locking after brakes are applied. The existing ABS controls have the ability to regulate the level of pressure to optimally maintain the wheel slip within the vehicle stability range. The dynamics of the controller needed for ABS system depends on various factors. The vehicle model and the ABS model exhibits strong nonlinear characteristics.

The controller is the one of the most important part and is responsible for maintaining the optimal value of wheel slip ratio. Here the wheel slip ratio is represented in terms of vehicle speed and wheel rotation.

ABS MECHANISM

An ABS system consists of the following parts

1.Wheel Speed Sensors
2.Brake Callipers
3.Hydraulic Motor
4.Pressure Release Valves
5.Control Module

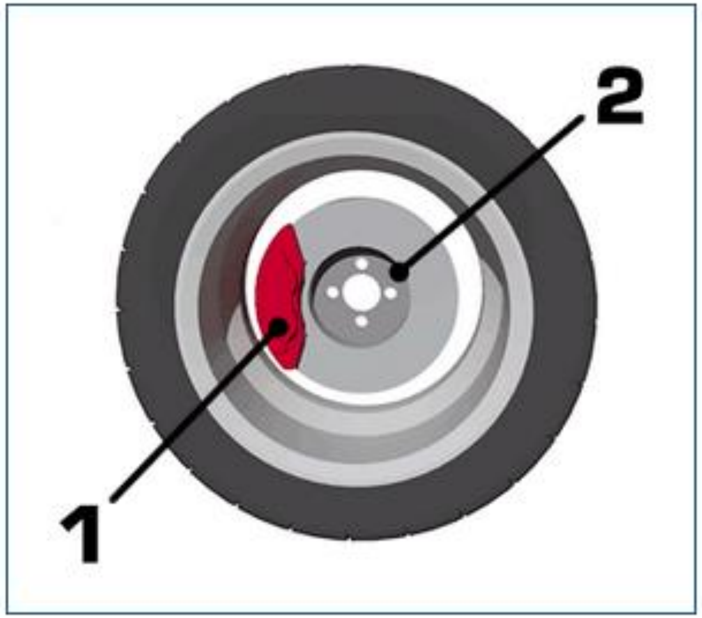
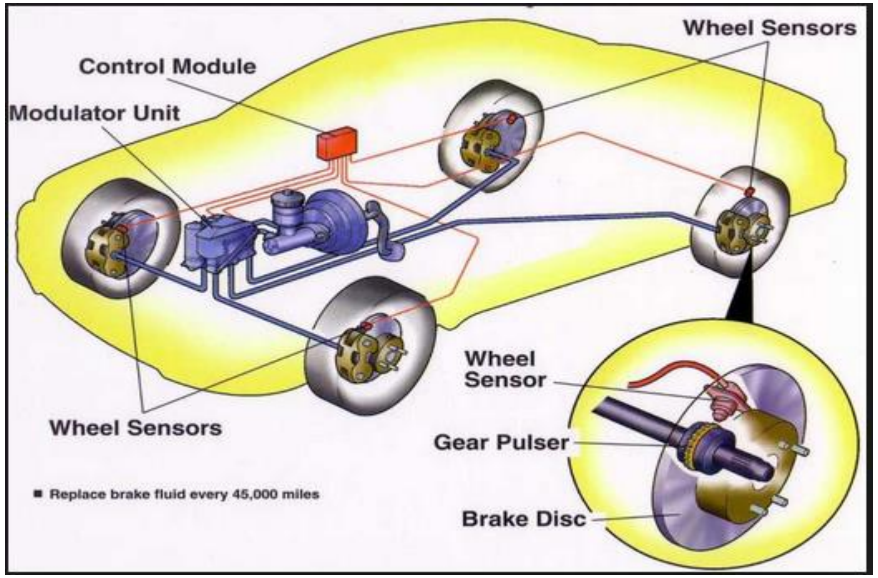
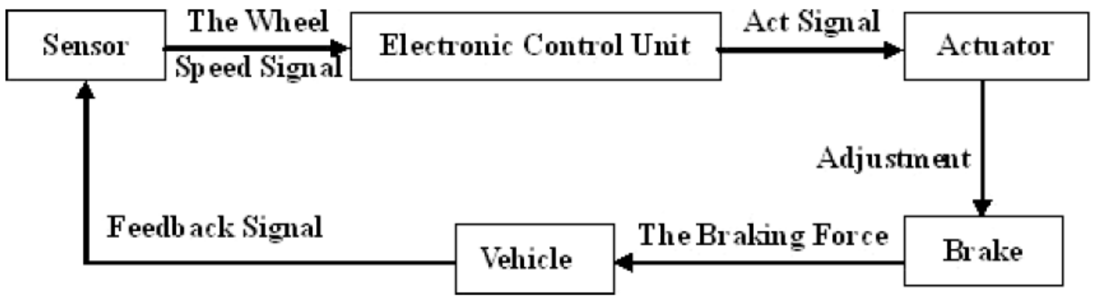


Diagram 1: Brake caliper (1) and wheel speed sensor (2)

ABS MECHANISM

When the driver hits the brakes this pressurises a hydraulic system which causes the brake pads to squeeze against the discs which causes the car to slow down. If the ABS system detects that one wheel is slowing down more rapidly than the rest (i.e. basically a wheel-lock situation) it automatically reduces the brake pressure on this wheel by opening a pressure release valve in the hydraulic system. ABS also has the ability to build the pressure back up via the hydraulic motor. The system reacts remarkably quickly, and compared wheel speeds many times a second. ABS systems can act on just the front wheels (which do most of the braking work), or all four depending on what car you're driving.





REGENERATIVE BRAKING

- Regenerative braking is an energy recovery mechanism which slows a vehicle or object by converting its kinetic energy into a form which can be either used immediately or stored until needed.

- In this mechanism, the electric motor uses the vehicle's momentum to recover energy that would be otherwise lost to the brake discs as heat. This contrasts with conventional braking systems, where the excess kinetic energy is converted to unwanted and wasted heat by friction in the brakes, or with dynamic brakes, where energy is recovered by using electric motors as generators but is immediately dissipated as heat in resistors.

- In addition to improving the overall efficiency of the vehicle, regeneration can greatly extend the life of the braking system as its parts do not wear as quickly.

REGENERATIVE BRAKING

- Regenerative braking systems have been used extensively in motorsports and such systems are being developed for the general vehicles.
- Increasingly stringent regulations on fuel efficiency and emissions are one driving factor as manufacturers aim to reduce energy loss in a variety of ways.
- Automatic electronic braking (AEB)systems are also set to proliferate the market as OEM’s take advantage of increased electronic power and more sophisticated electronic controls.
- Such systems will also be vital for autonomous driving as brakes, along with other critical vehicle systems, must be controlled to an extremely high degree of accuracy.
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- Regenerative braking systems designed for today’s petrol and diesel-powered vehicles can have a substantial impact on fuel efficiency and therefore, help to reduce emissions.

VEHICLE MODEL

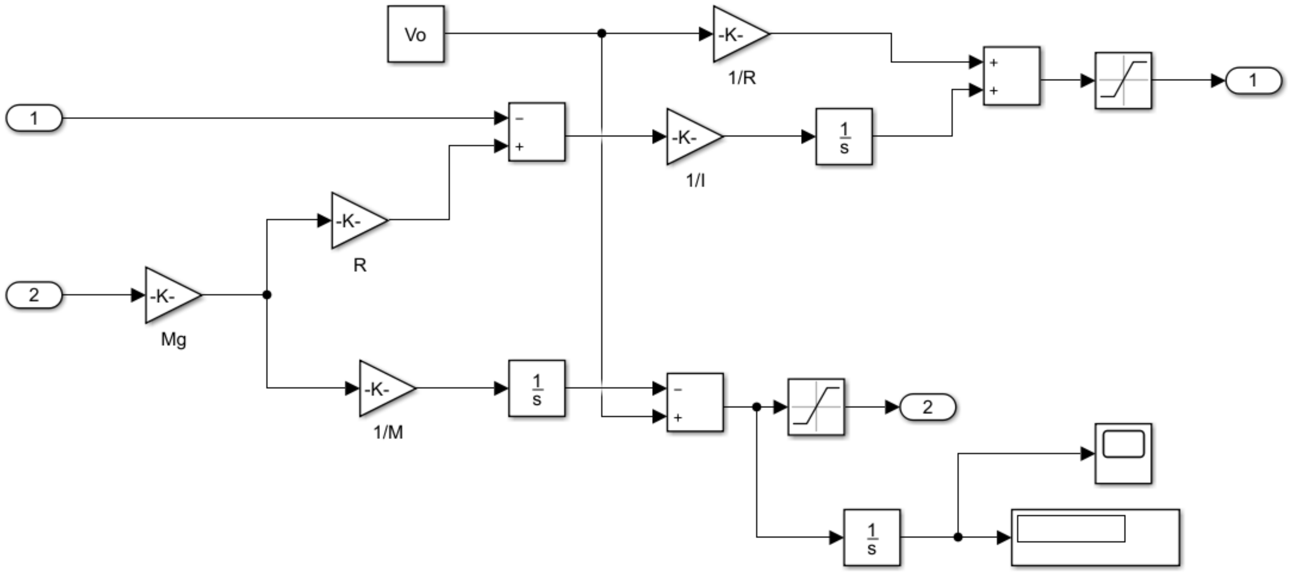
Mathematical equations

The motion equations of vehicles: $F = -M\dot{v}$,

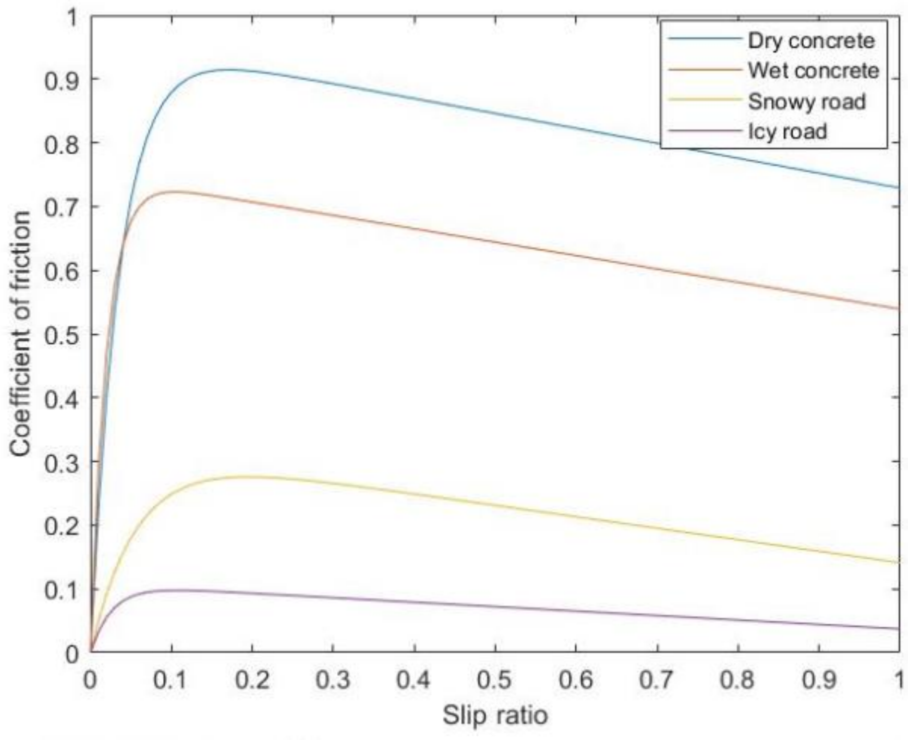
The motion equations of the wheels: $I\dot{\omega} = FR - T_b$,

The longitudinal friction of vehicles: $F = \mu N$,

Simulink Model



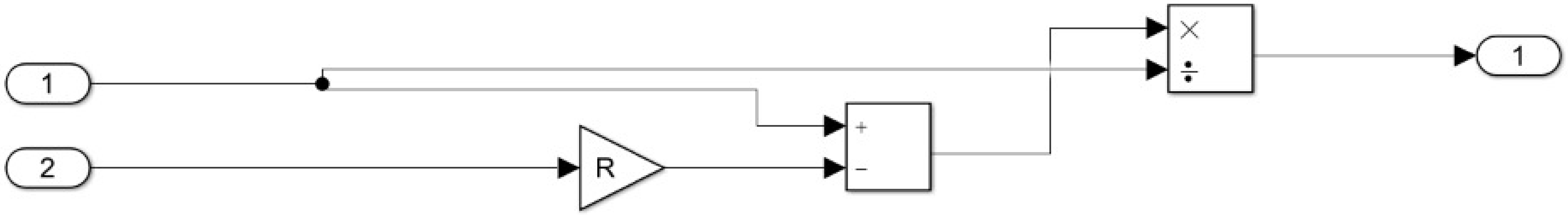
SLIP RATIO MODEL



For the slip ratio the model is as follows

$$S = \frac{v - \omega R}{v} \times 100\%.$$

Simulink Model



TIRE MODEL

The tire model is the functional relation between the tire adhesion during the braking process and other various parameters.

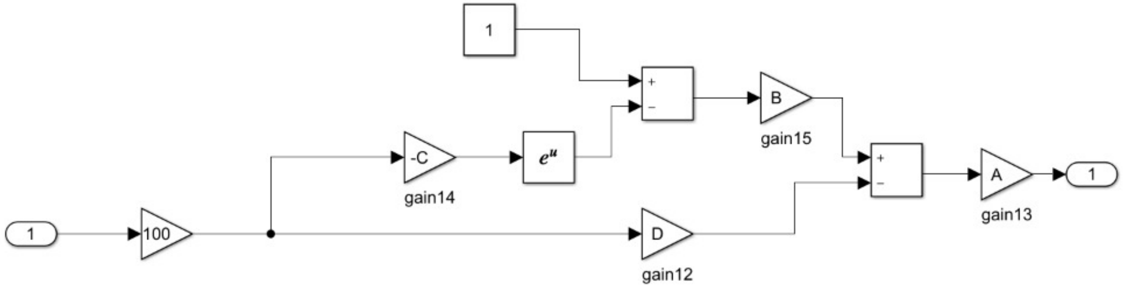
The friction coefficient can be expressed as an **empirical function**, where the wheel slip is a function argument:

$$\mu(s) = A \cdot (B \cdot (1 - e^{-C \cdot s}) - D \cdot s) \quad (12)$$

where:

s [-] – is the wheel slip
A, B, C, D [-] – are empirical coefficients

Simulink Model



BRAKE TORQUE MODEL

The braking system includes the transmission mechanism and the brake, both of which must be incorporated during the modeling. The modeling of the transmission mechanism mainly refers to the modeling of the hydraulic transmission, which mainly considers how the pressure regulator of the braking force changes with current from the electromagnetic valve.

The transmission function is as follows

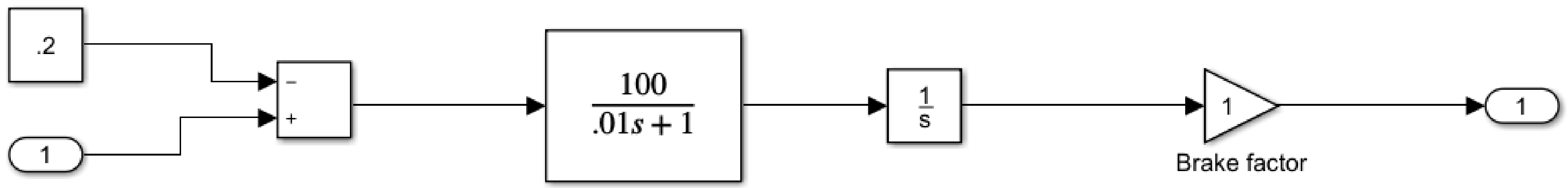
Here T is the parameter of inertia

$$G(S) = \frac{K}{S(TS+1)}.$$

The Brake equation is as follows

$$T_b = k_p p,$$

Simulink Model

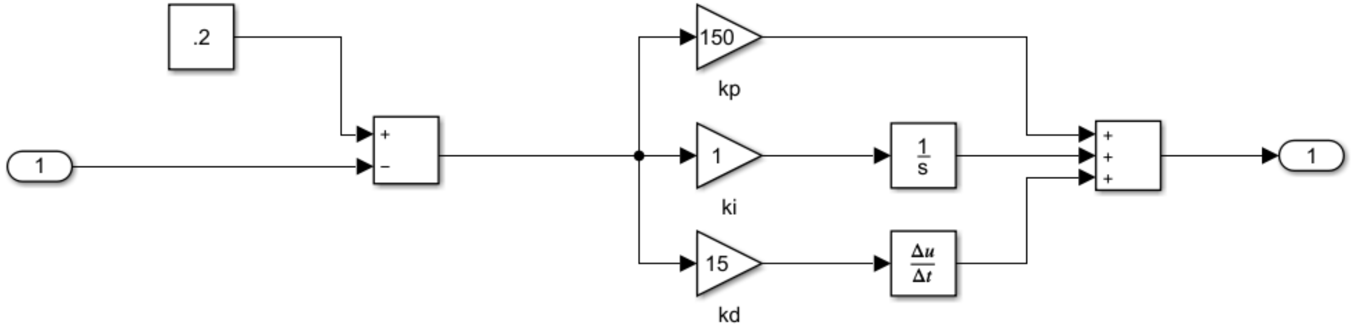


PID CONTROLLER

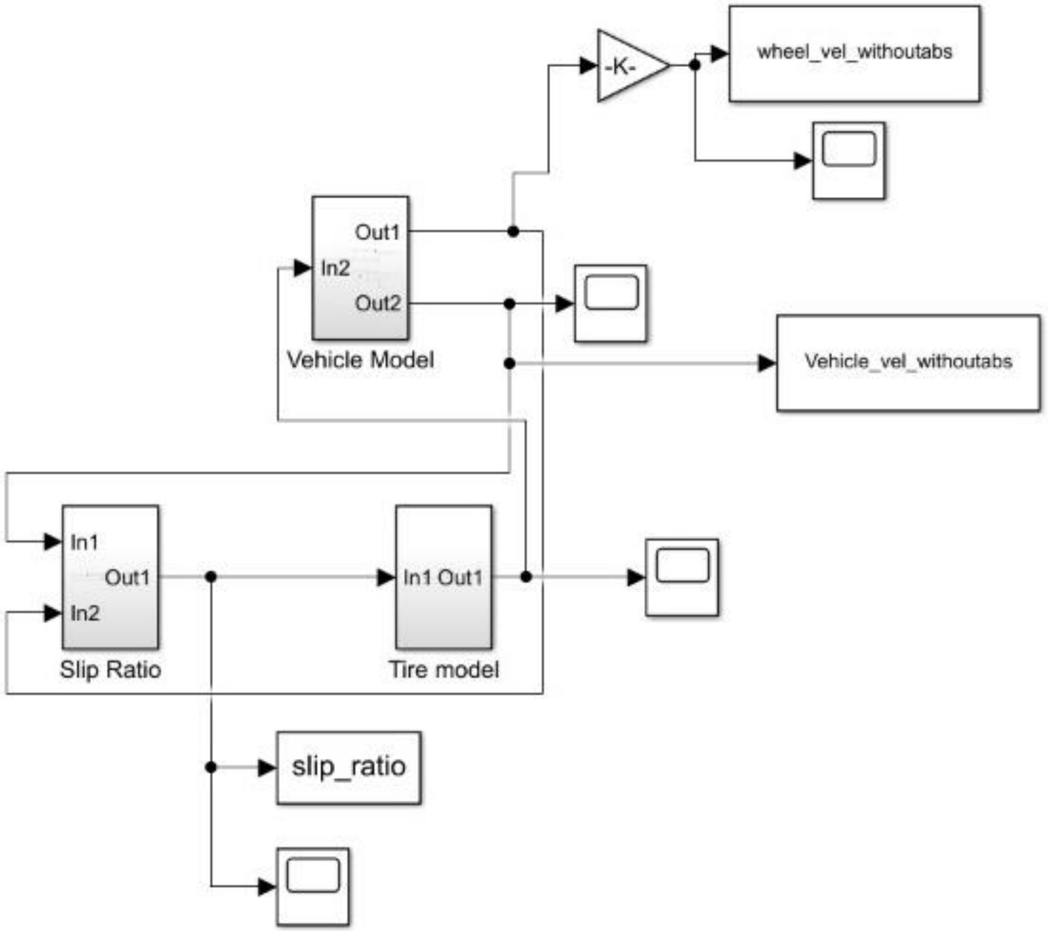
PID control is the control method of proportional, integral and derivative control technology. It is a control mode of technology that is mature and widely used in the continuous system.

Its biggest advantage is that it cannot understand the mathematical model of the controlled object and adjust the parameters based on experience. Also, it is easy implement and has good control effect. The classic PID controller was used for simulation analysis.

$$u(t) = K_\text{p} e(t) + K_\text{i} \int_0^t e(t')\, dt' + K_\text{d} \frac{de(t)}{dt},$$

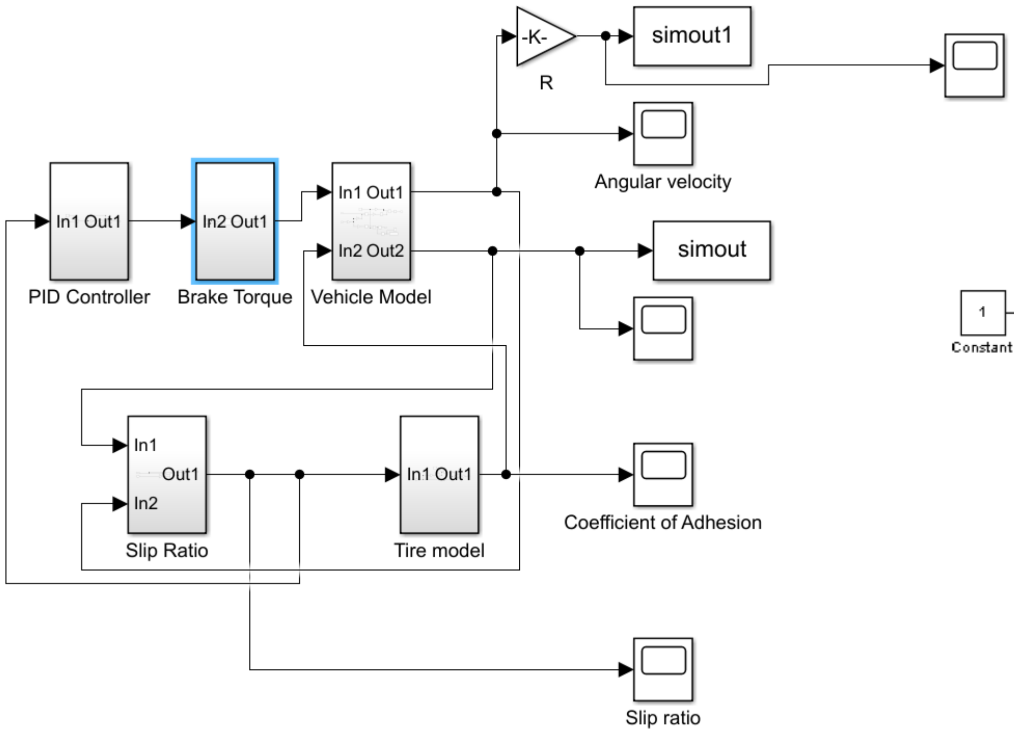


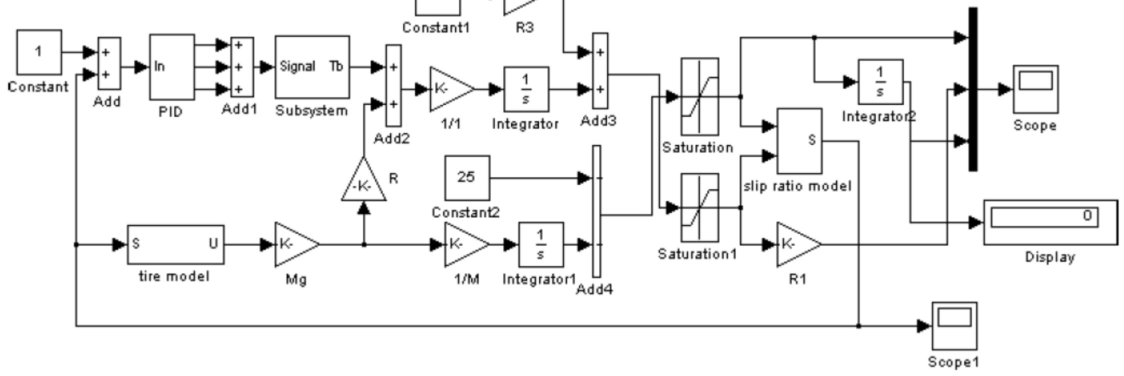
FINAL MODEL WITHOUT ABS



FINAL ABS MODEL

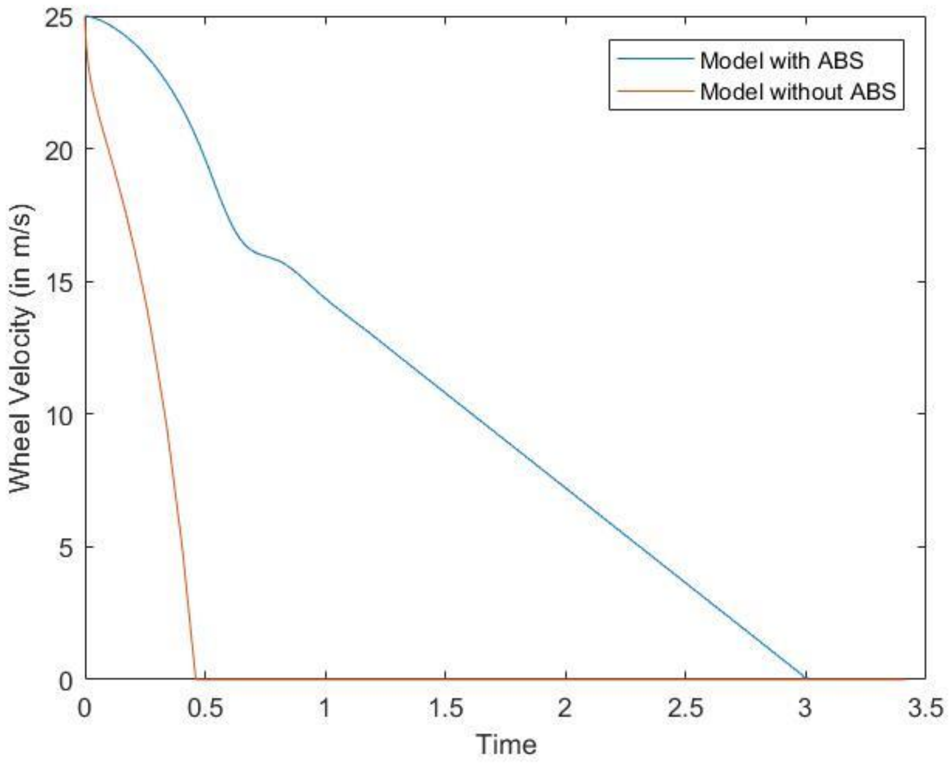
Full simulink is model is obtained by connecting all the above four modules



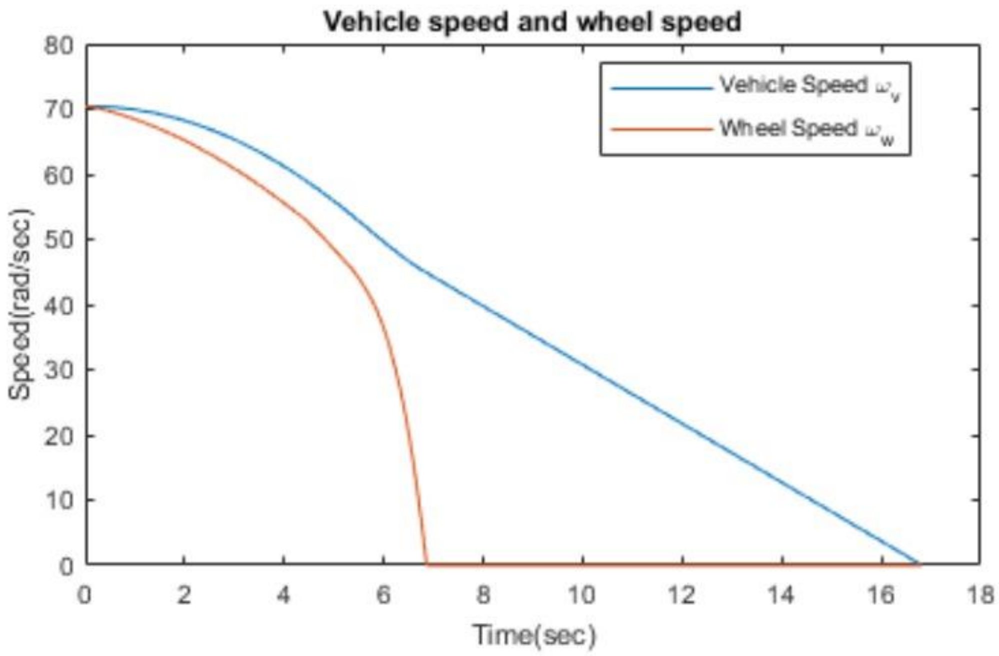


RESULTS AND VALIDATION

Wheel velocity comparison



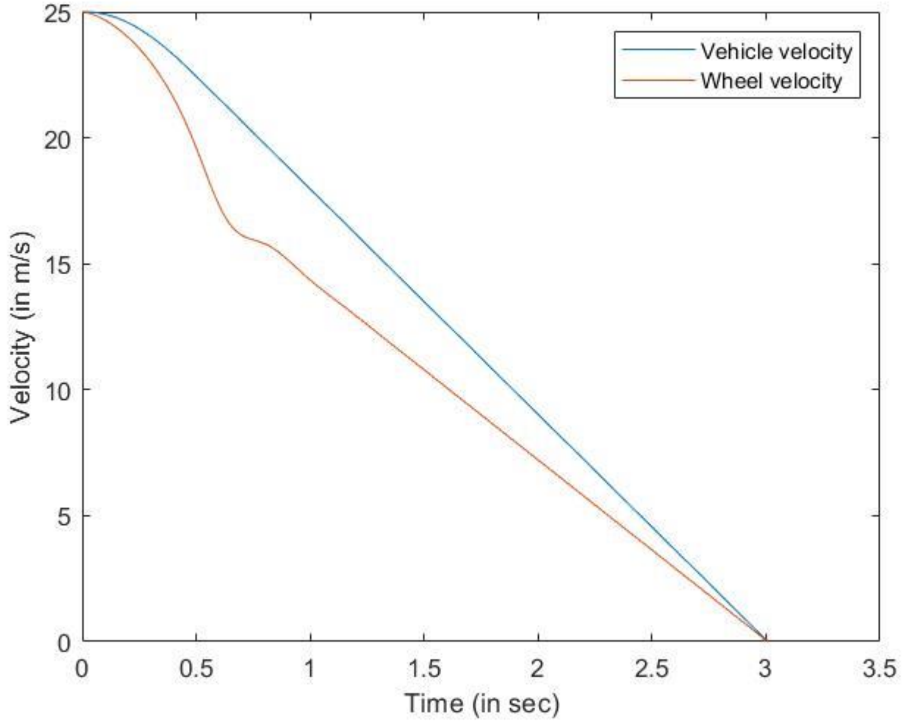
Graph obtained



Graph in the paper

RESULTS AND VALIDATION

Velocity comparison



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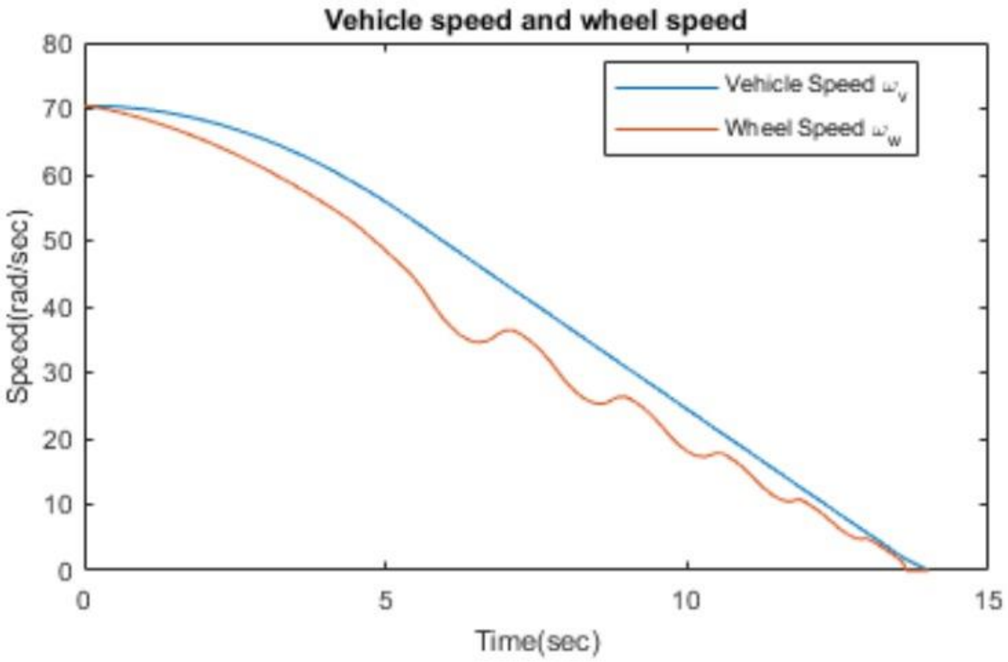
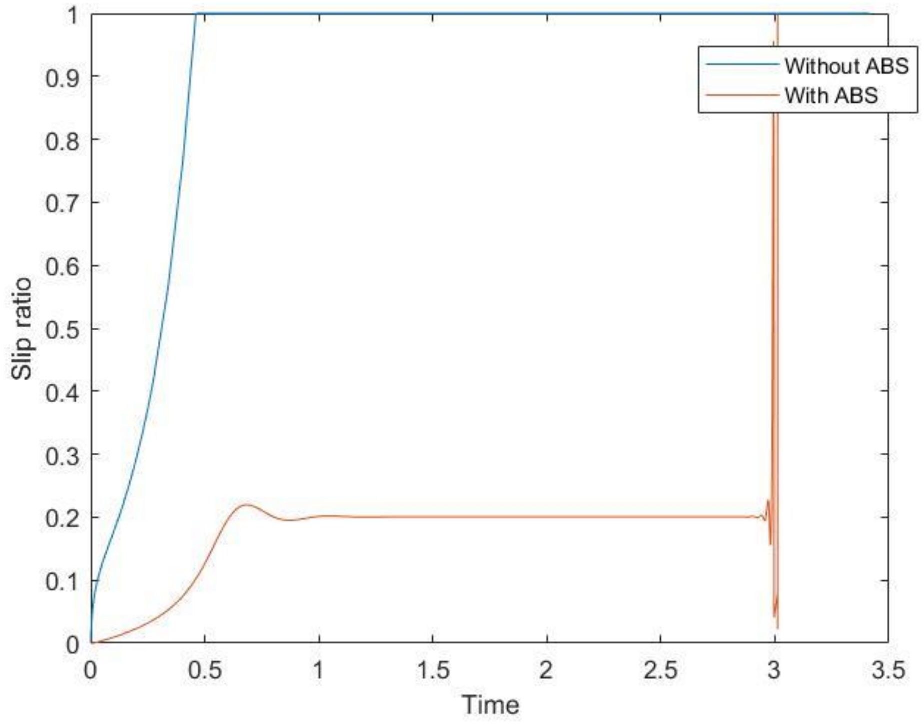


Graph in the paper

RESULTS AND VALIDATION

Slip ratio comparison



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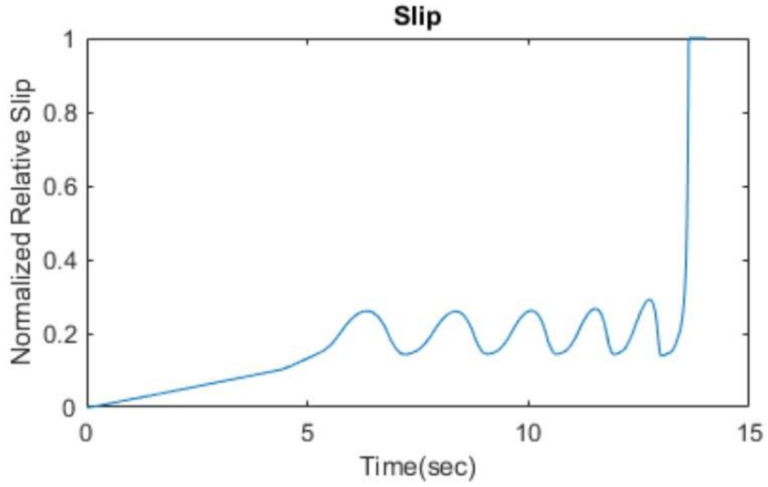

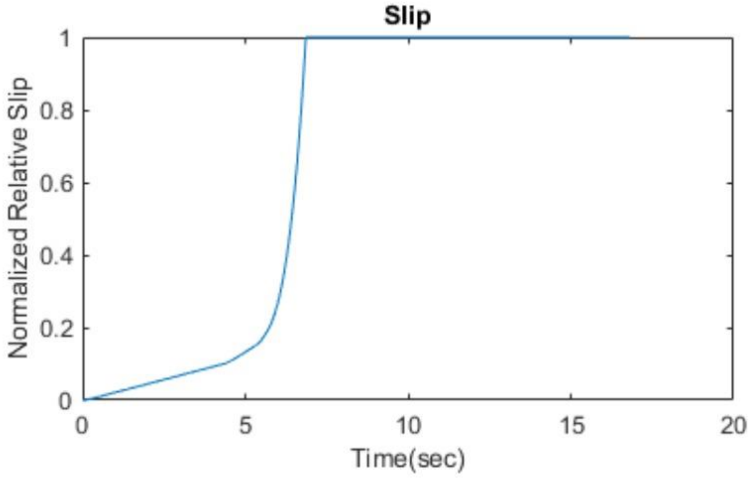

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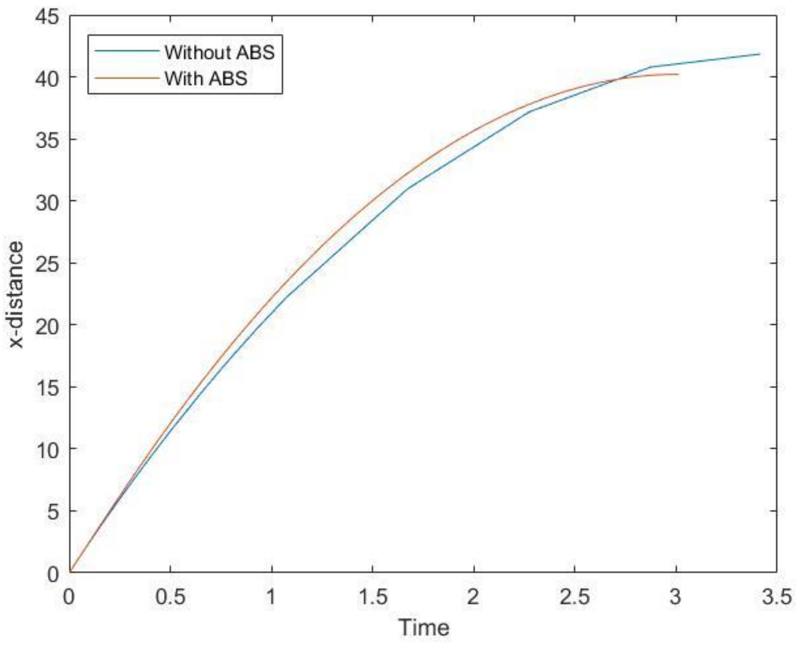
RESULTS AND VALIDATION

X - distance comparison

With abs stopping distance, 40.2040 m
Without abs stopping distance, 41.8359 m



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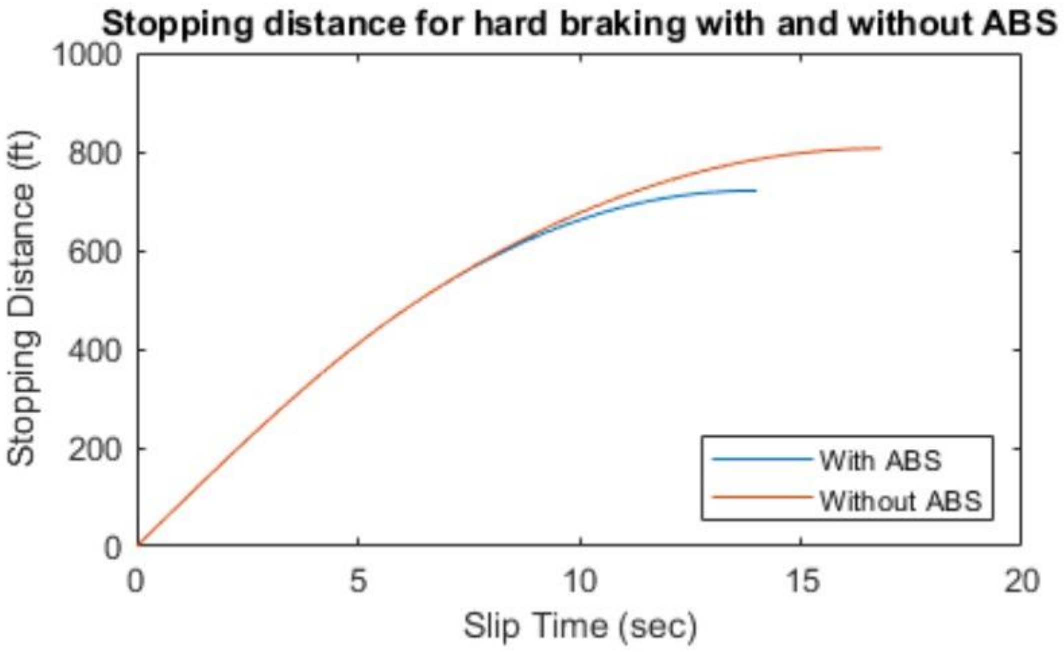
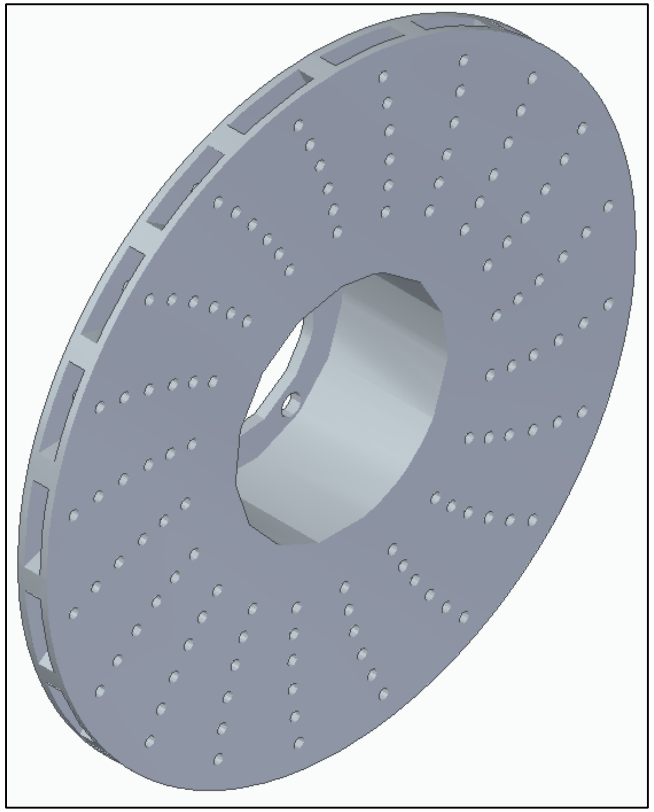
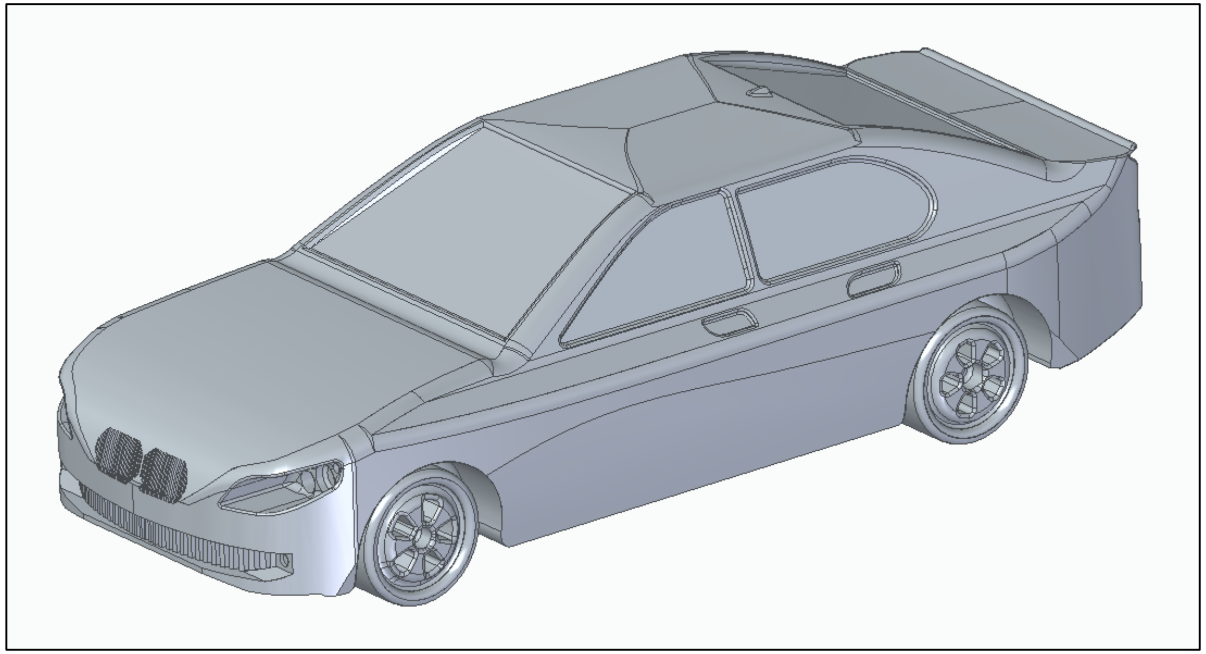


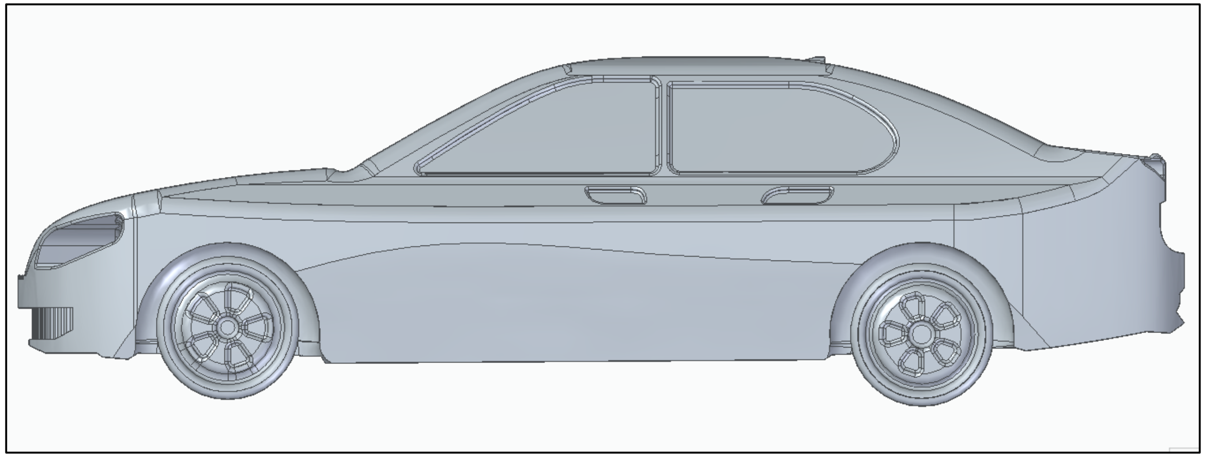
Graph in the paper

CAD MODEL

The CAD Models are designed in Solid Edge 2019







CONCLUSION

1. Regenerative braking and Antilock Braking System was studied and simulation of ABS was carried out

2. Since the objective of ABS is to prevent the locking of wheel and provide better stability to the vehicle, the results which we obtain seem to be in agreement with our desired results

3. We can see that the stopping distance for ABS is less than that for without ABS

From the Matlab code written, we can see that different road conditions have different stopping distance and also the vehicle parameters such as mass of the vehicle, radius of wheel and polar MOI of wheel also play an important part in calculating the stopping distance
For different velocities, tuning of PID controller needs to be done again because of the different slip ratio and subsequently the error conditions

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THANK YOU