# Suspension:

**Equation:**

The suspension spring stiffness and damping coefficient are computed as follows:

where, is the sprung mass, is the natural frequency, and is the damping ratio of the suspension.

The suspension force can be applied at an offset based on geometry of the suspension. The force application point is computed as follows:

where, is the Z-component of vehicle COM, is the Z-component of the relative transform between each wheel and the vehicle frame , is the wheel radius, and is the force offset governed by the suspension geometry. Finally, the suspension distance at any given time can be computed as follows:

where, is the acceleration due to gravity and is the suspension equilibrium point.

**Parameters:**

* Natural Frequency () = 7.5 rad/s
* Damping Ratio () = 0.3
* Force Offset () = 0.03 m

# Anti-Roll Bar:

**Equation:**

The anti-roll bar applies a force on left and right wheels as long as they are grounded at the contact point and receive a normal reaction from ground. This force is directly proportional to the stiffness of the anti-roll bar, .

where, and are left and right wheel travels in the Z-axis.

**Parameters:**

* Anti-Roll Bar Stiffness () = 5000 N/m

# Brakes:

**Test Specifications:**

* Braking distance @ 60 mph (26.8224 m/s) = 119 ft (36.2712 m) [[Source](https://www.napletonellwoodcity.com/research/chrysler-pacifica-vs-kia-sedona.htm#:~:text=Pacifica's%20braking%20system%20is%20appropriately,Call%20it%20a%20wash.)]

**Equation:**

[[Source](https://calculator.academy/braking-force-calculator/#:~:text=Alternatively%20known%20as%20Brake%20Power,measured%20in%20newtons%20%E2%80%9CN.%E2%80%9D)]

[[Source](https://www.buybrakes.com/help/what-is-brake-torque/#:~:text=Brake%20torque%20is%20a%20way,to%20come%20to%20a%20stop.)]

This braking torque is applied to all the wheels based on the type of brake input. For combi-brakes, this torque is applied to all the wheels, and for handbrake, it is applied to the rear wheels only.

**Parameters:**

* Mass () = 2262.065 kg
* Velocity () = 26.8224 m/s
* Braking Distance () = 36.2712 m
* Brake Disk Radius () = 0.5\*330 mm = 0.165 m

**Value:**

Braking Force = 22434.0886 N

Braking Torque = 3701.6246 Nm

# Engine

The engine is modeled based on its torque-speed characteristics. The engine RPM is updated smoothly based on its current value , the idling RPM , average wheel RPM , final drive ratio , current gear ratio and the vehicle velocity :

The total torque generated by the powertrain is computed based on the engine torque , gear ratio , final drive ratio , throttle input and acceleration profile :

Here, denotes evaluation of at , and is a non-linear smoothing operator which increases the vehicle acceleration based on the throttle input.

# Automatic Transmission

**Test Specifications:**

* Test data available in attached **Pacifica\_Transmission\_Map.xlsx** file. [[Source](https://www.pacificaforums.com/threads/trans-wont-shift-to-last-gear.4274/page-2)]

**Equation:**

The automatic transmission decides to upshift/downshift the gears based on the transmission map of a given vehicle. This keeps the engine RPM in a good operating range for a given speed.

***Note 1:*** *While shifting the gears, the total torque produced by the powertrain is set to zero to simulate the clutch disengagement.*

***Note 2:*** *The transmission is put in “Neutral” gear once the vehicle is in standstill condition and in “Parking” gear if handbrake is engaged in standstill condition. Switching between “Drive” and “Reverse” gears requires that the vehicle first be in “Neutral” gear to allow this transition.*

**Parameters:**

* Velocity () = velocity in miles per hour (MPH)
  + converts velocity from mph to inch per second
* Tire Circumference = 91.428 in
  + , where is radius of tire (18’’ tire dia)
* Final Drive Ratio () = 3.25
* Current Gear Ratio () = int{-1,0,1,2,3,4,5,6,7,8,9}

# Differential

The total torque from the drivetrain is divided to the wheels based on the drive configuration of the vehicle:

The torque transmitted to wheels is modeled by dividing the output torque to the left and right wheels based on the steering input.

where, the is the torque-drop at differential and indicates positive and negative steering angles, respectively. The value of is clamped between .

# Steering

The steering mechanism of the vehicle is actuated smoothly to attain the commanded steering angle , without exceeding the steering limits . The rate at which the vehicle steers is governed by its speed and steering sensitivity :

Here, is the speed-dependency factor of the steering mechanism.

Finally, the individual turning angles and for left and right wheels are computed based on the commanded steering angle and the Ackermann steering geometry:

# Air Drag and Downforce

The variable air drag acting on the vehicle is computed based on the vehicle’s operating condition:

where, is the vehicle velocity, is designated top-speed of the vehicle, is designated maximum reverse velocity of the vehicle, is the operating gear, and is the average wheel RPM.

The downforce acting on the vehicle is modeled proportional to the vehicle velocity:

where, is the down-force coefficient.