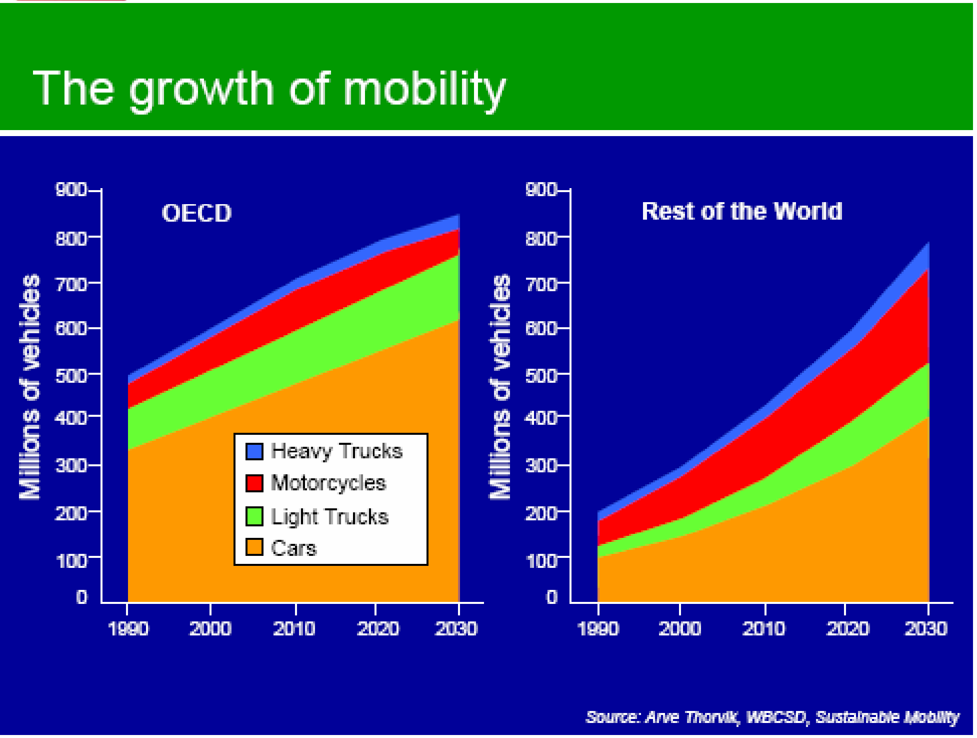
# Session-1

## Thursday,17-12-2009: 11.30 AM-1.00 PM

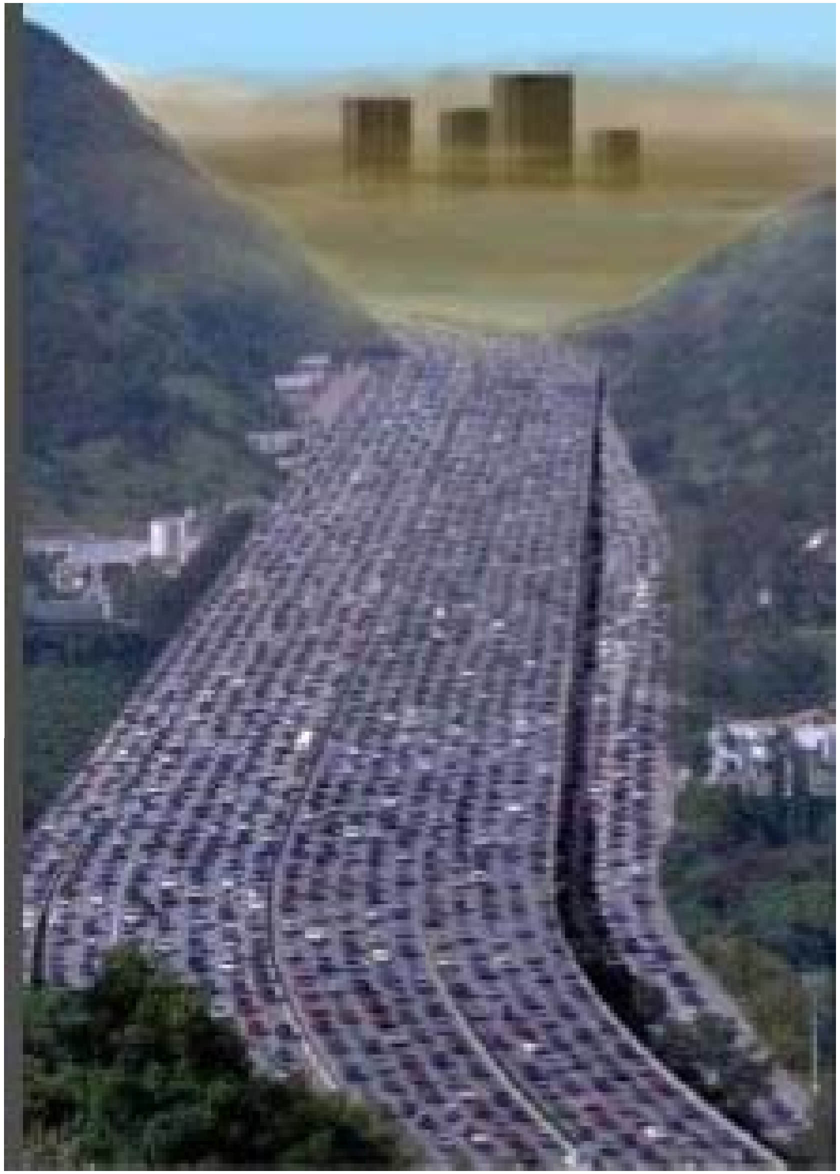
## Vehicle Dynamic Metrics and Fundamentals of Load Transfer

- Vehicle Dynamics
  - Metrics
  - Road Loads- Tractive Resistances
  - Tractive Forces
  - Basics of Weight Transfer,
    - Longitudinal Forces and Longitudinal Weight Transfer
    - Traction on Level Road and on Slopes
    - Lateral Forces
    - Lateral Weight Transfer
  - Forces between Road and Wheel

# Mobility







**Organisation for Economic Co-operation and Development** (OECD)

# Automotive Mission Plan India

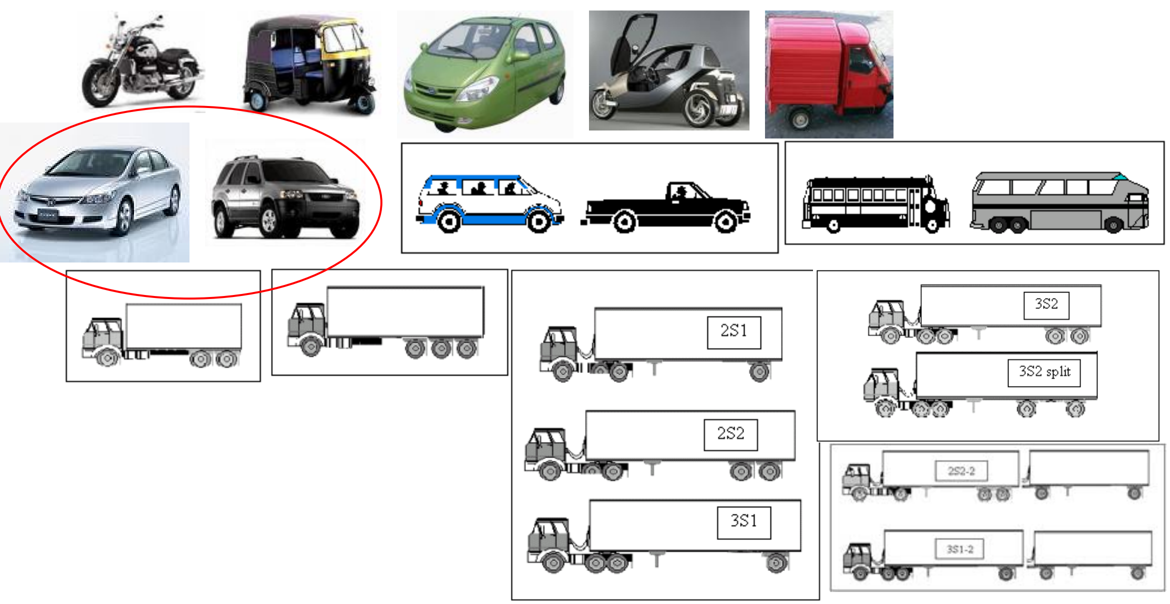
- By 2016, India will emerge as the destination of choice in Asia for the design and manufacture of automobiles and automotive components. The output of the India's automotive sector will be US$ 145 billion by 2016, contributing to 10% of India's GDP and providing employment to 25 million persons additionally

# Ground Vehicles

Ground Vehicles

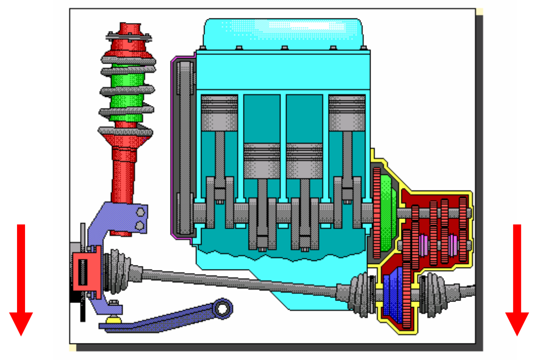
- Non Guided Ground Vehicles
  - Road Vehicles
  - Off Road Vehicles
- Guided Ground Vehicles

Road Vehicles



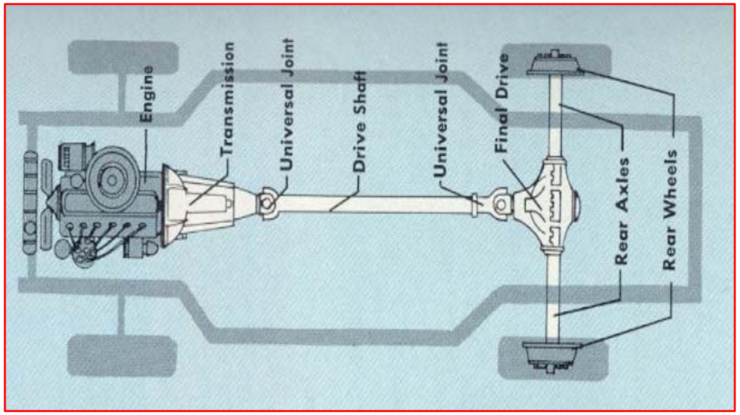

Off Road Vehicles

# Types of Automobile Drive Systems

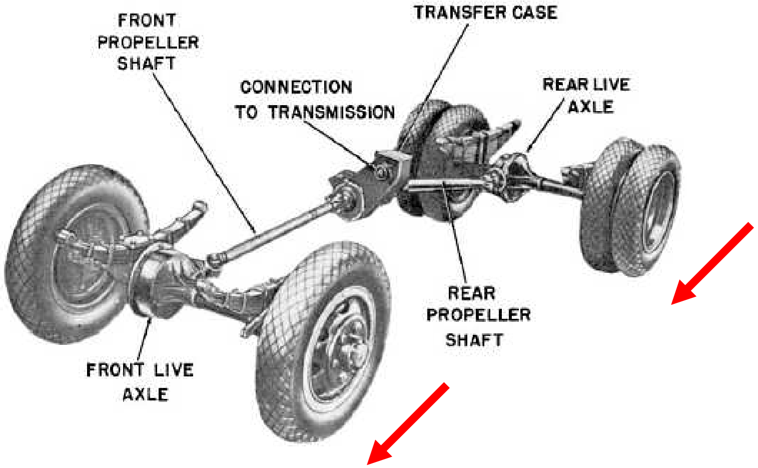



Front Wheel Drive Powertrain

Front Wheel Drive



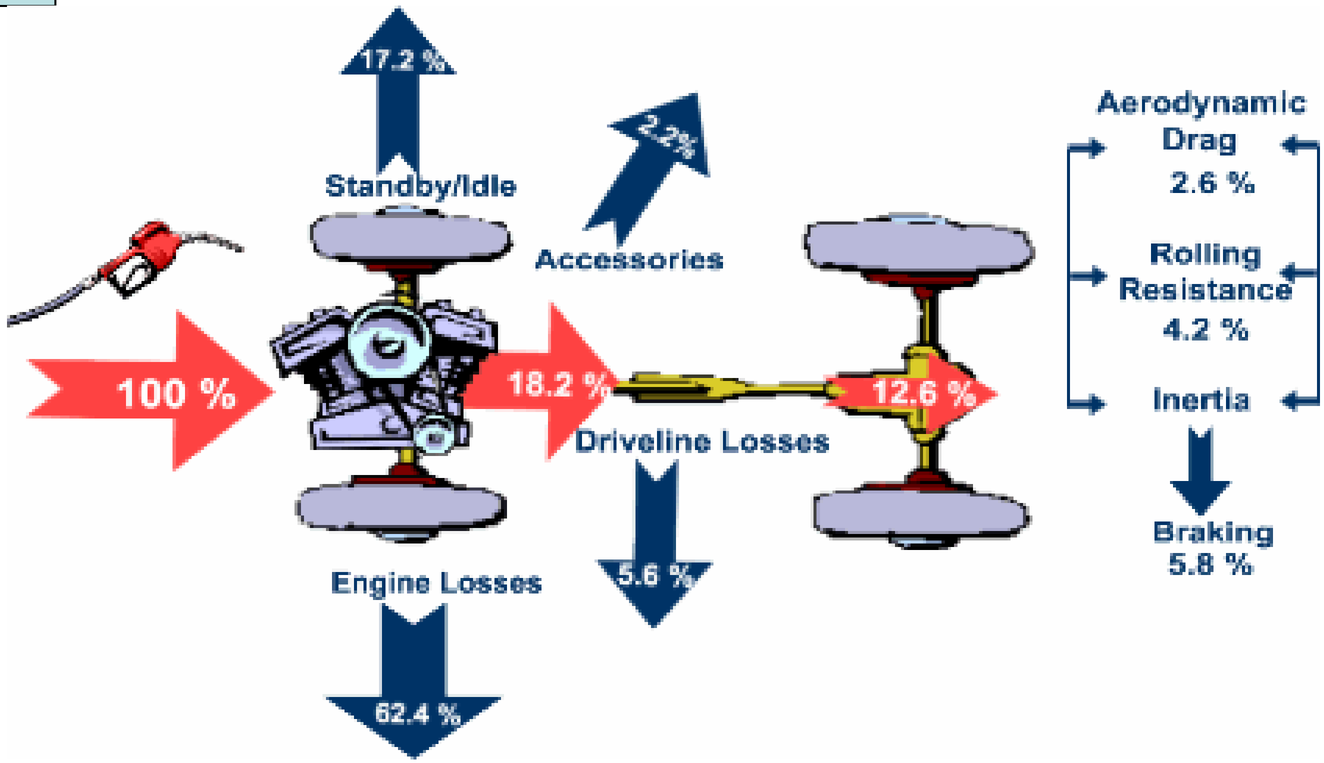

Rear Wheel Drive



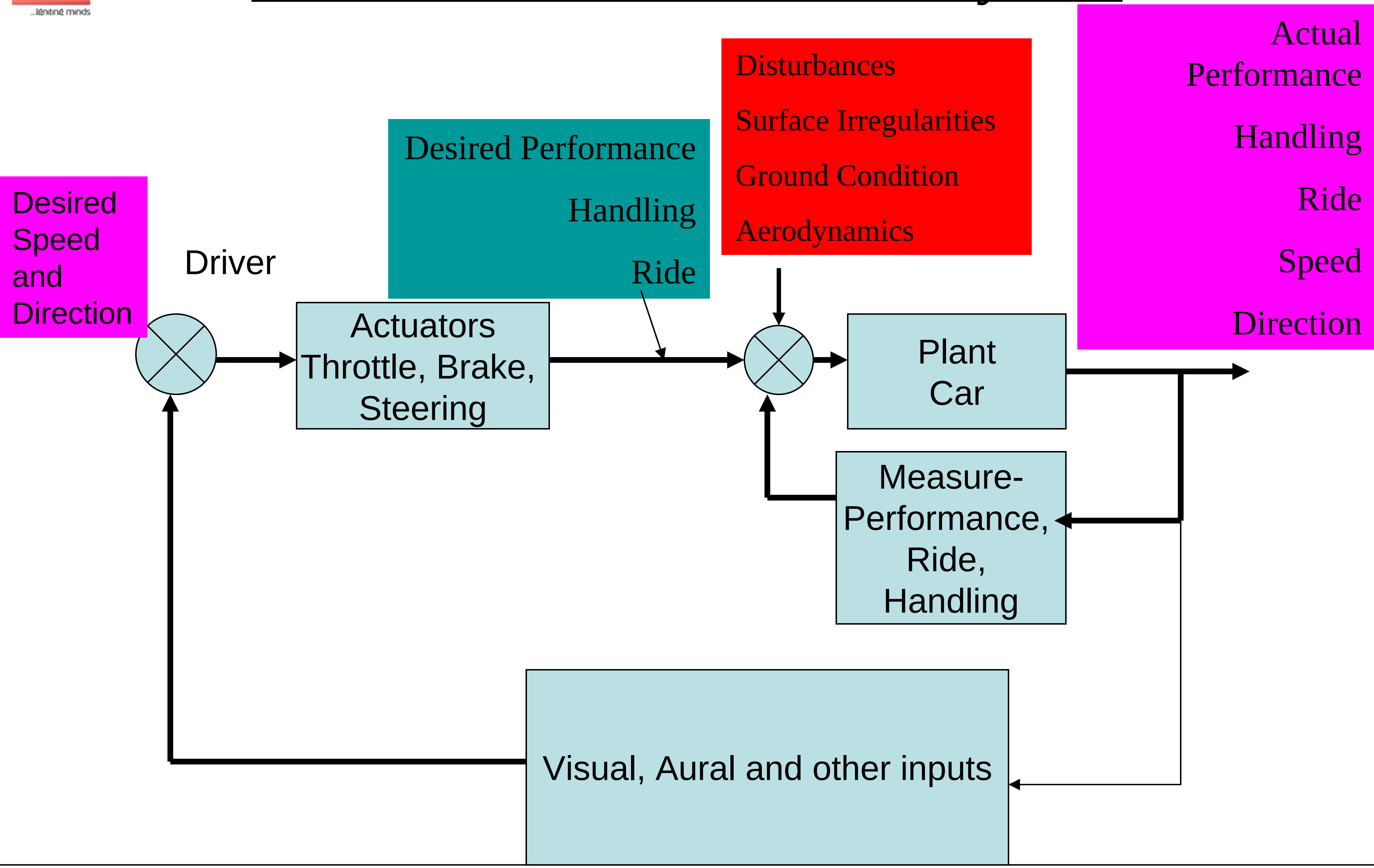

Four Wheel Drive

# Automotive Challenges

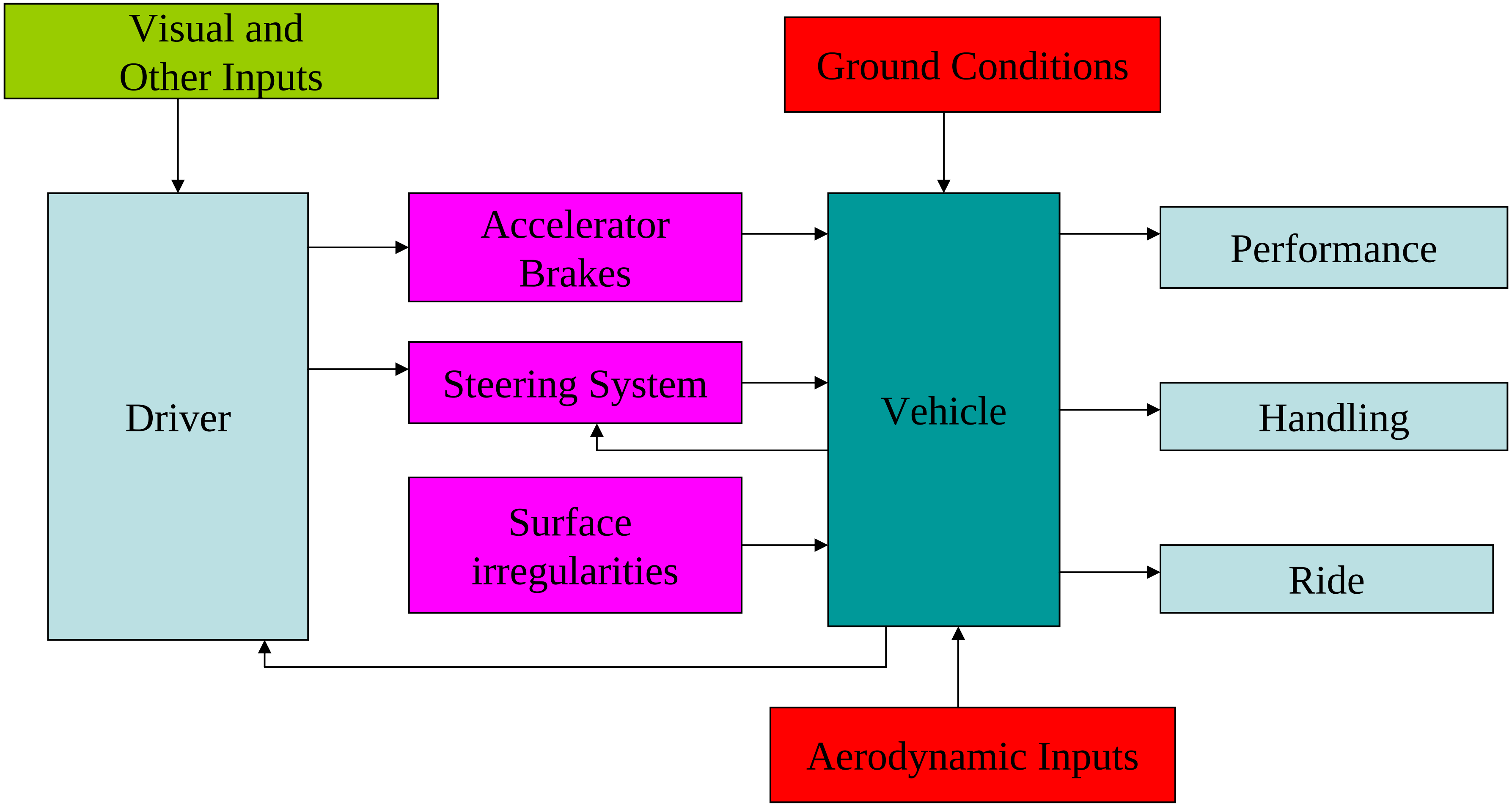
| | | |
|---|---|---|
| Current Challenges | Lowest Possible Emissions<br>Reduced Green House Gas Emissions<br>Occupant Safety | Power Train |
| | Stability and Comfort, Driving Experience | Running System (Metrics) |



# Ground Vehicle- A Control System



# Metrics (Characteristics) of Ground Vehicle



# Performance

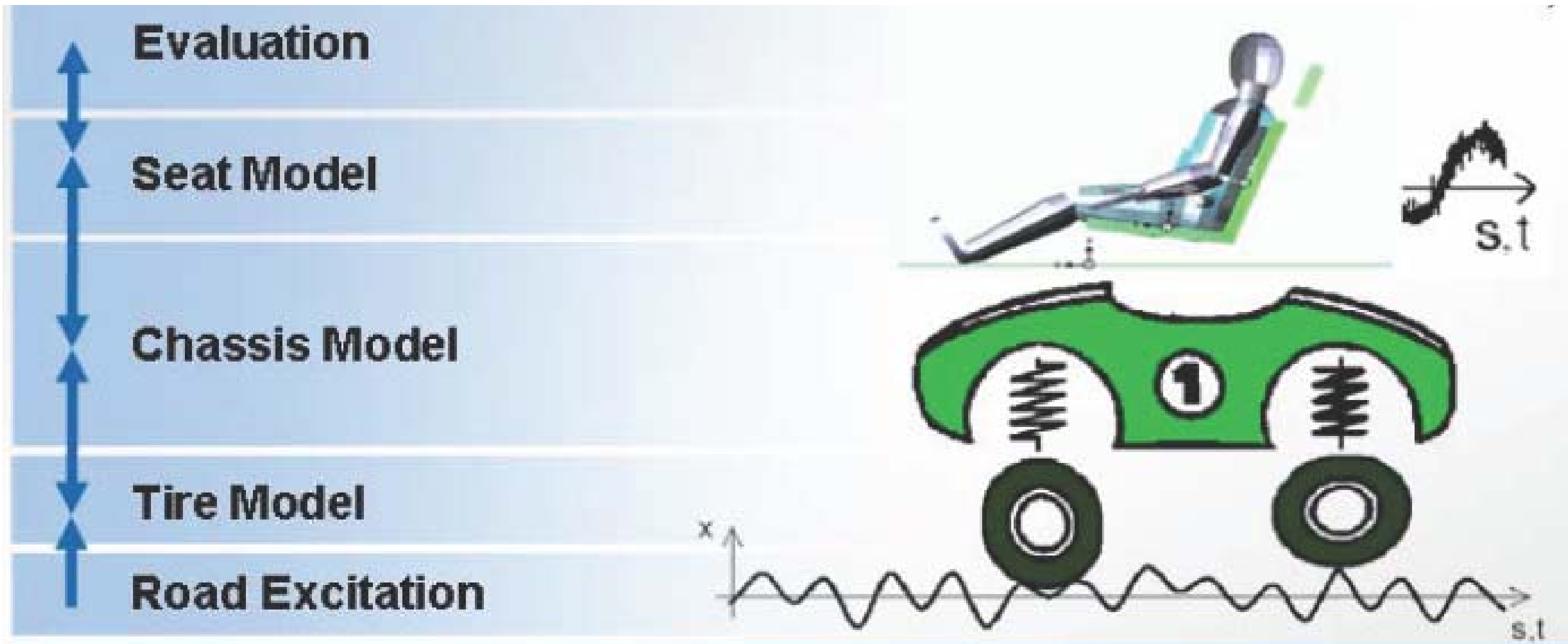
- Performance refers to motor vehicle ability to
  - Accelerate A1
    - Spinning SP (Acceleration 0.3g)
  - Decelerate, B1
    - Skidding Sk (wheel lockups)
  - Develop Drawbar Pull D1
  - Overcome Obstacles
    - Wheel slipping (insufficient friction)
    - Climbing hills (very high gradients)

# Handling

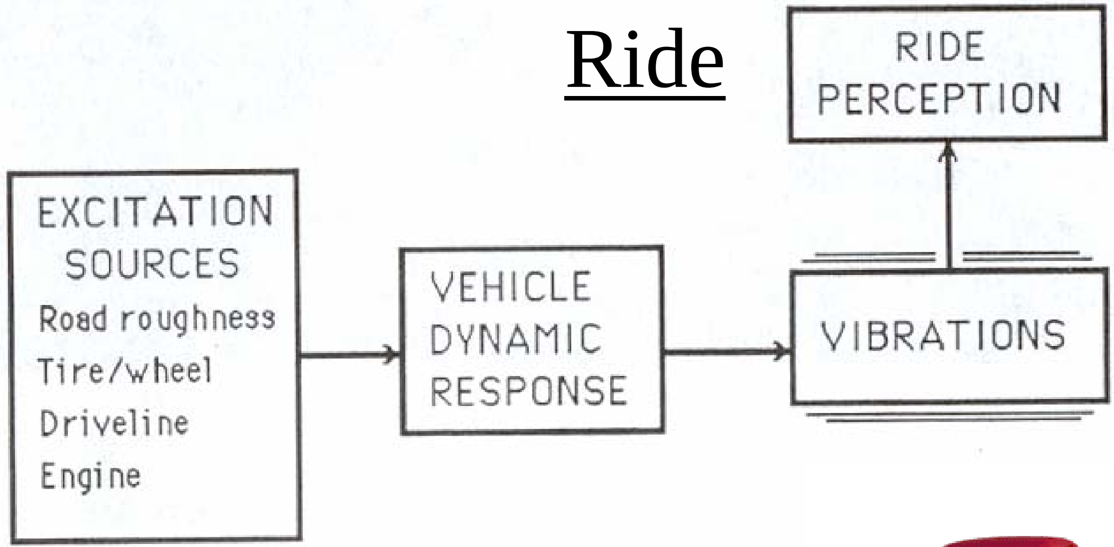
- Handling is concerned with the response of the vehicle to drivers' command and its ability to stabilize its motion against external disturbances-ease of maneuvering and stability
  - Understeering U1
  - Oversteering O1
- Sliding may happen during maneuvers
  - Sliding SL

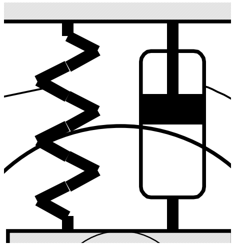
# Ride

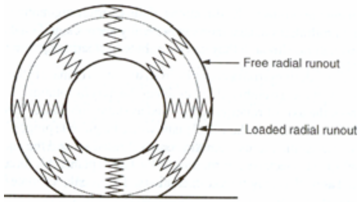
- Ride is related to the vibration of the vehicle excited by the surface irregularities and its effects on passengers comfort

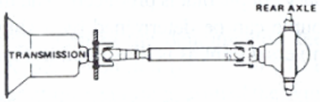


# Ride





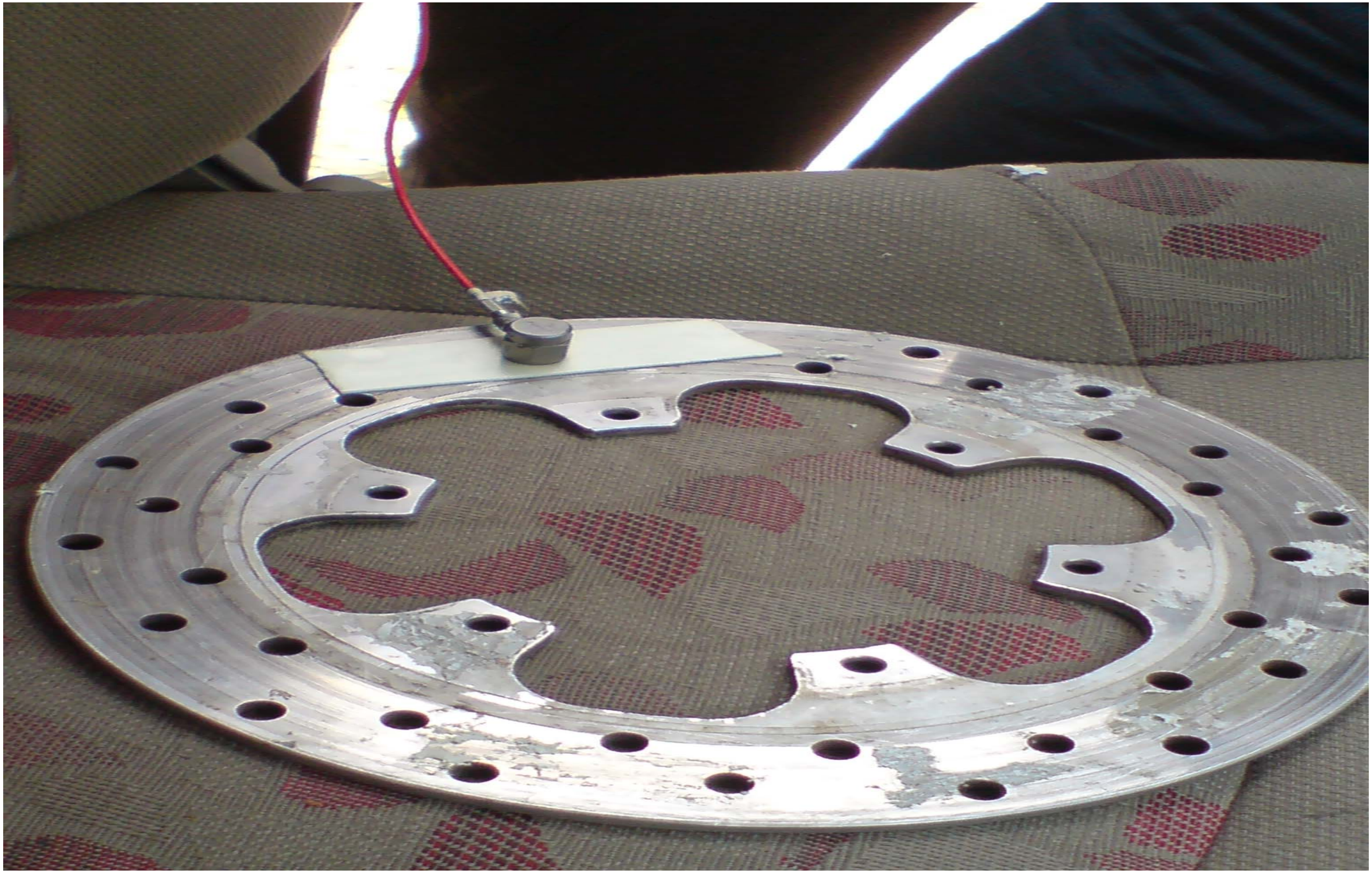




- Ride Comfort is a frequency weighted measure of vertical acceleration together with subjective assessments of harshness over various external road surface induced excitations.
- Ride is determined by spring stiffness, damper and bushing characteristics, component weights and natural frequencies

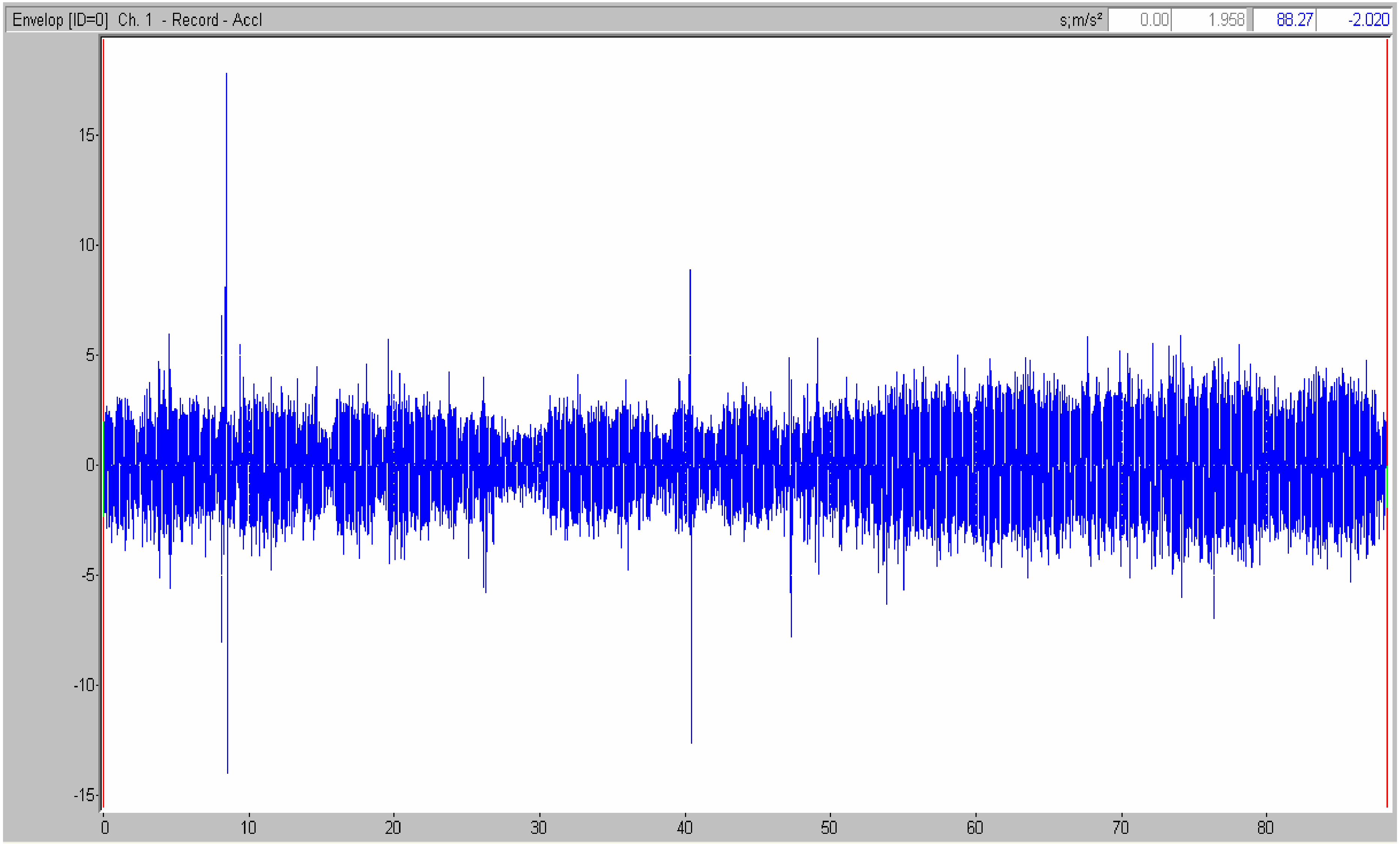
# Channel 1: 1695 – Rear left axle position

# Channel 3: 1697 – Rear left chassis position

# Channel 4: 1698 – Rear left seat position

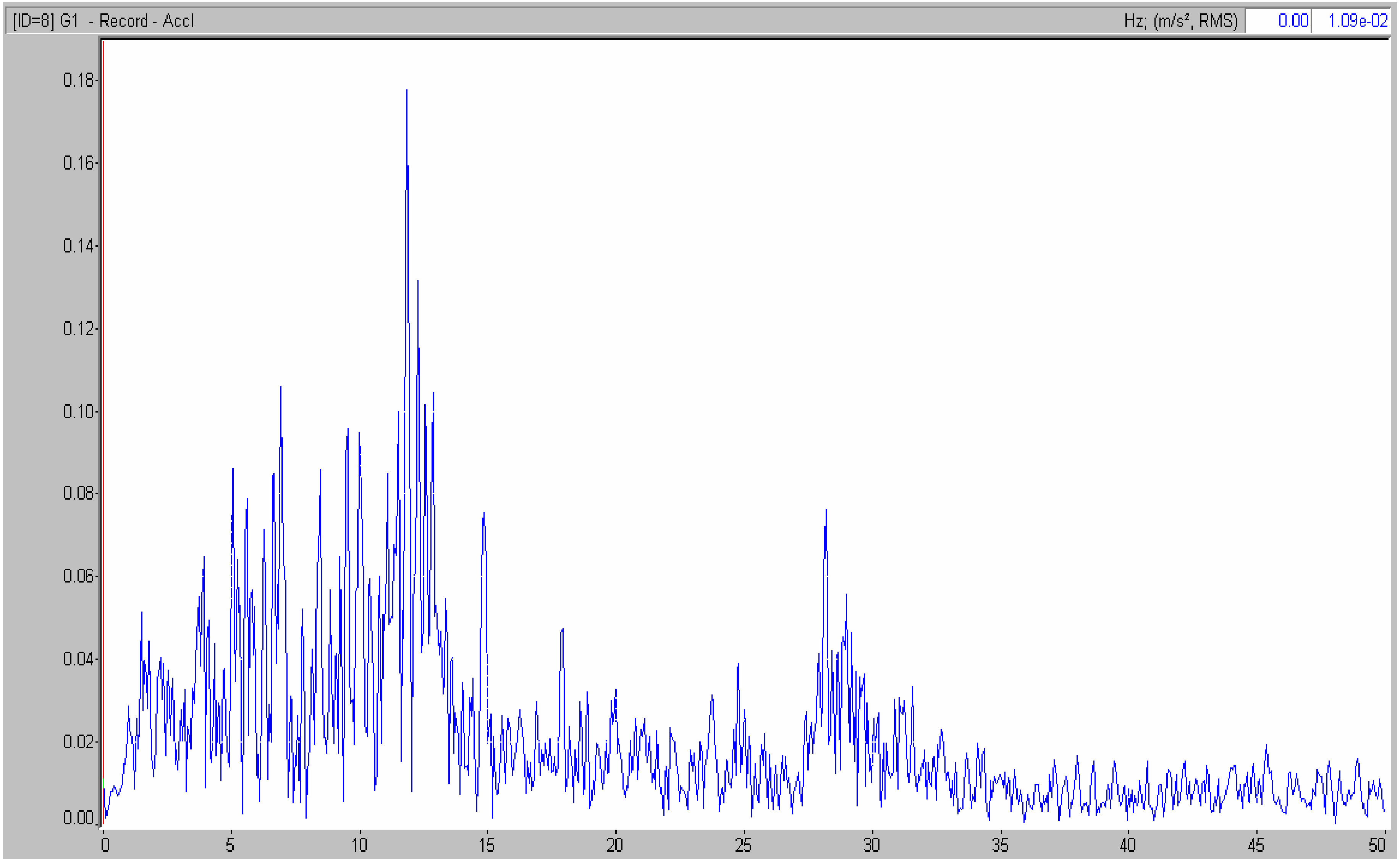


# Channel 1: 1695 (Rear Left Axle Position)



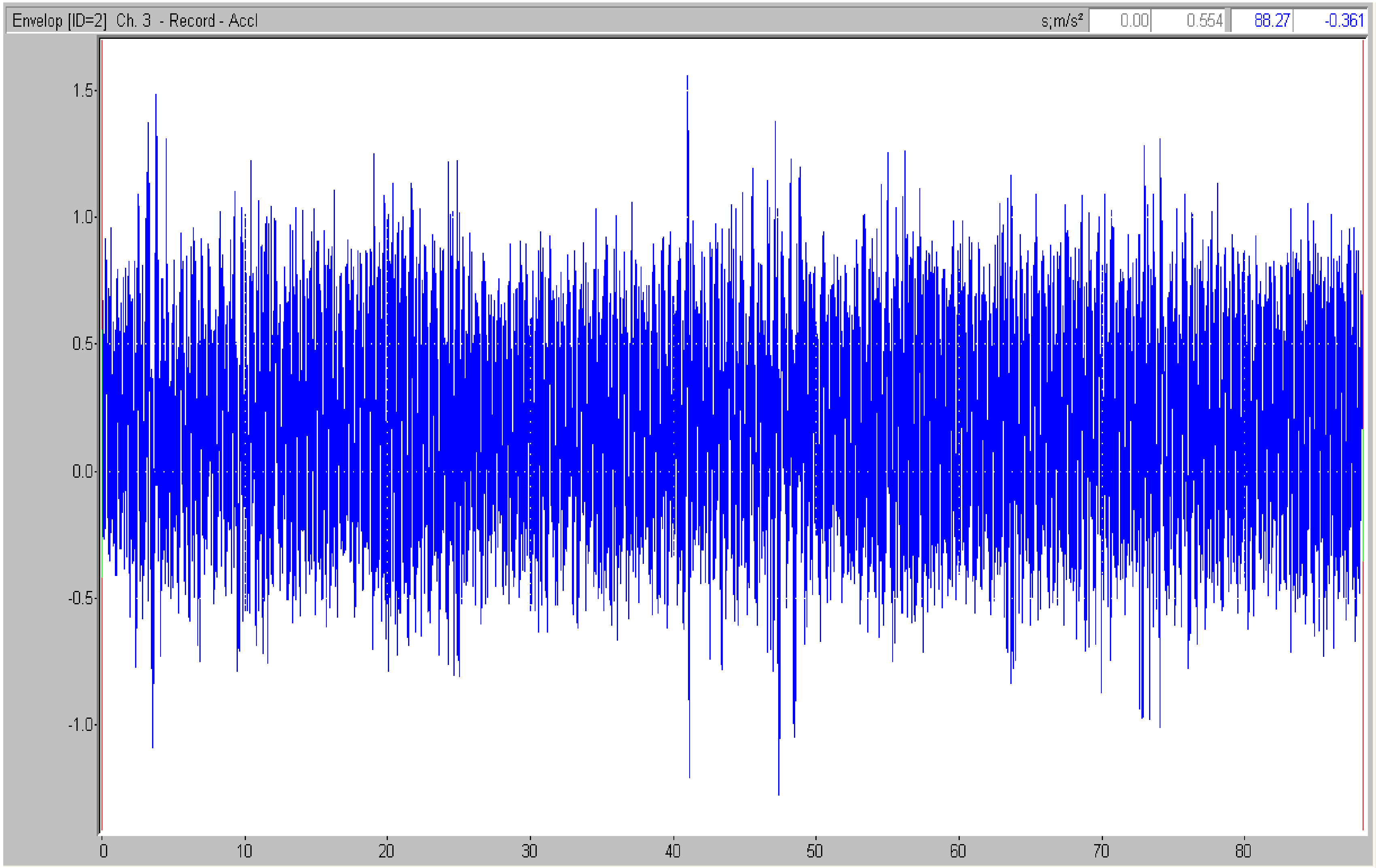

**Acceleration(m/s²) vs Time(s)**

# Channel 1: 1695 (Rear Left Axle Position)



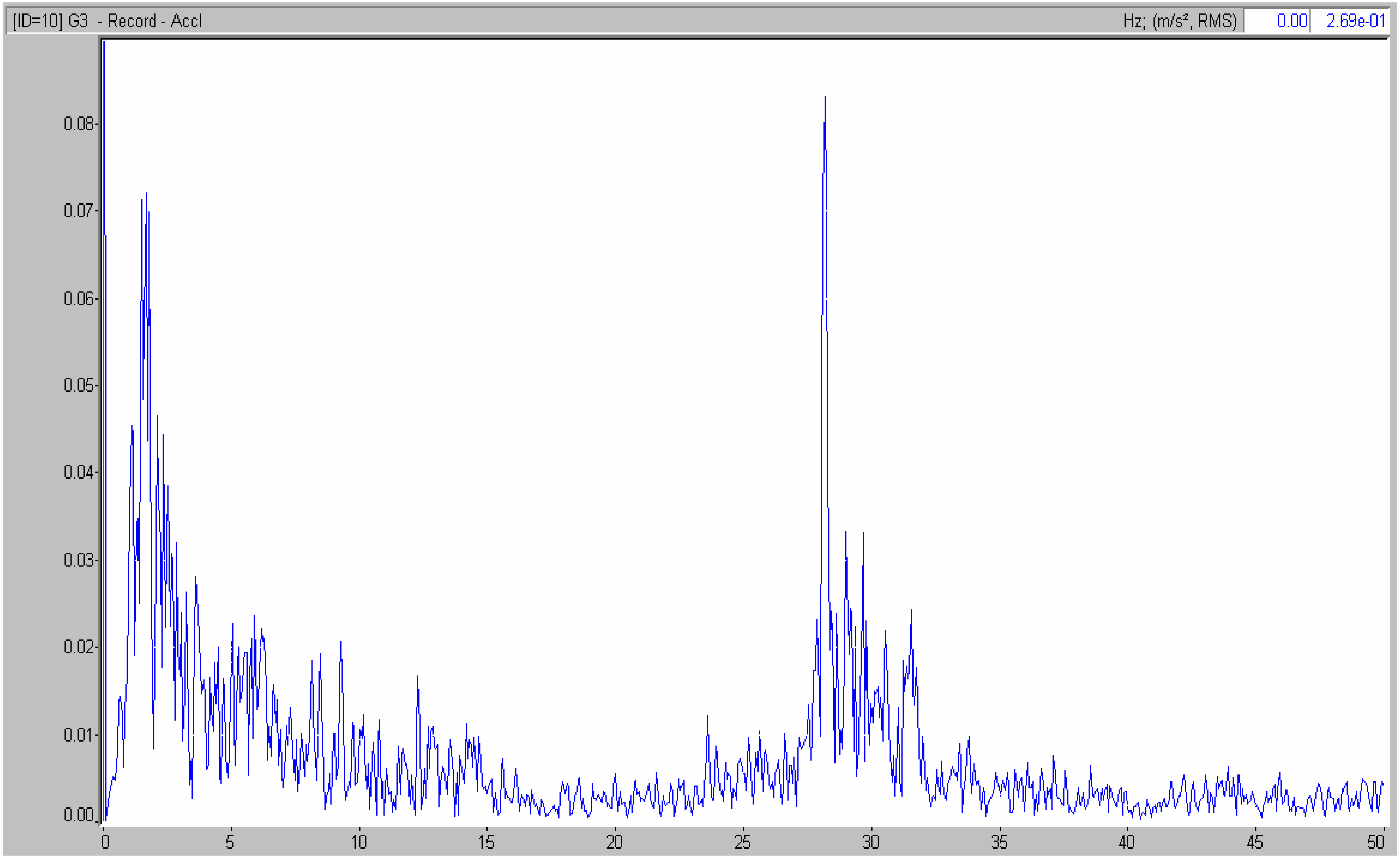

**Acceleration(m/s$^2$) vs Frequency(Hz)**

# Channel 3: 1697 (Rear Left Chassis Position)



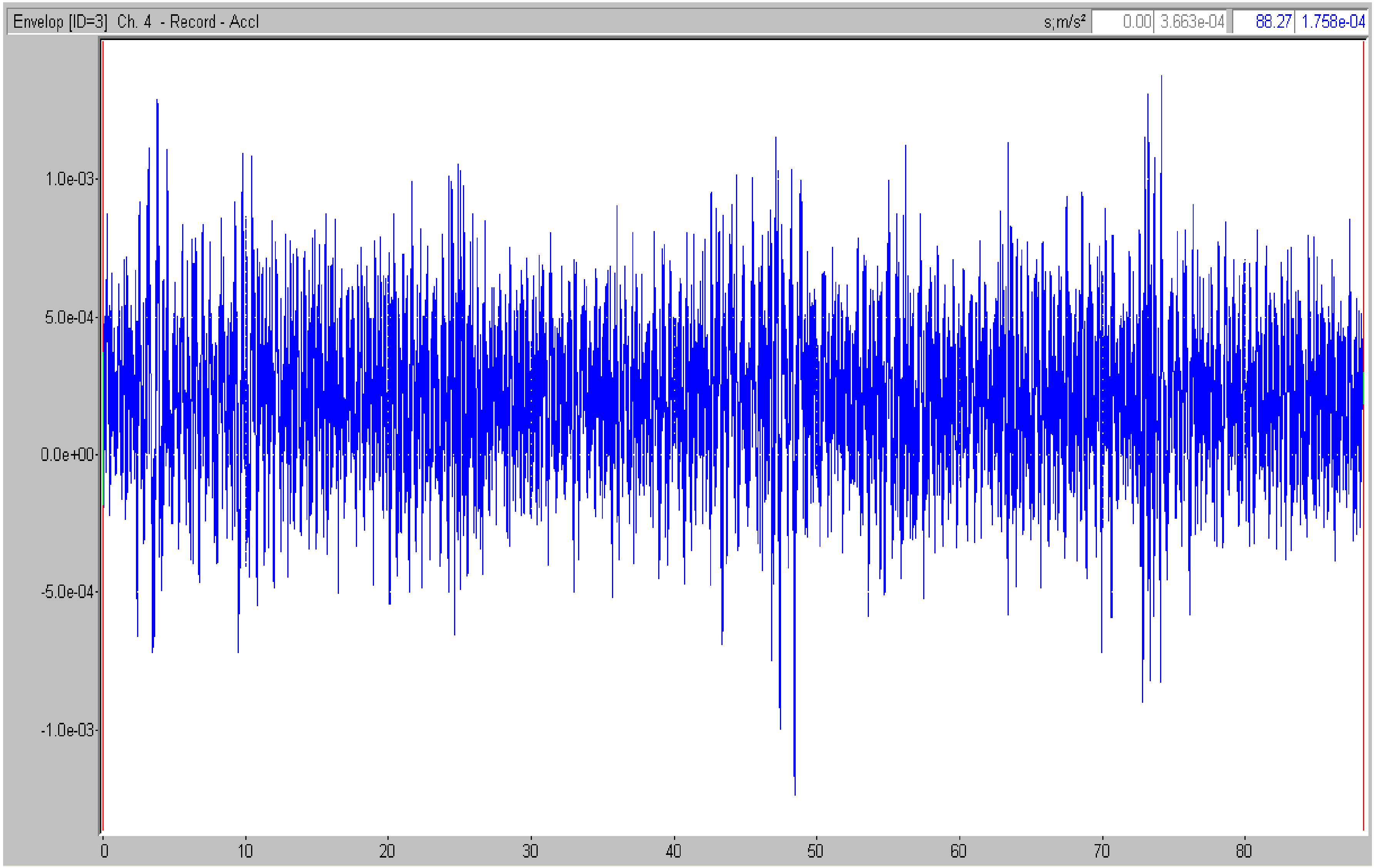

**Acceleration(m/s²) vs Time(s)**

# Channel 3: 1697 (Rear Left Chassis Position)



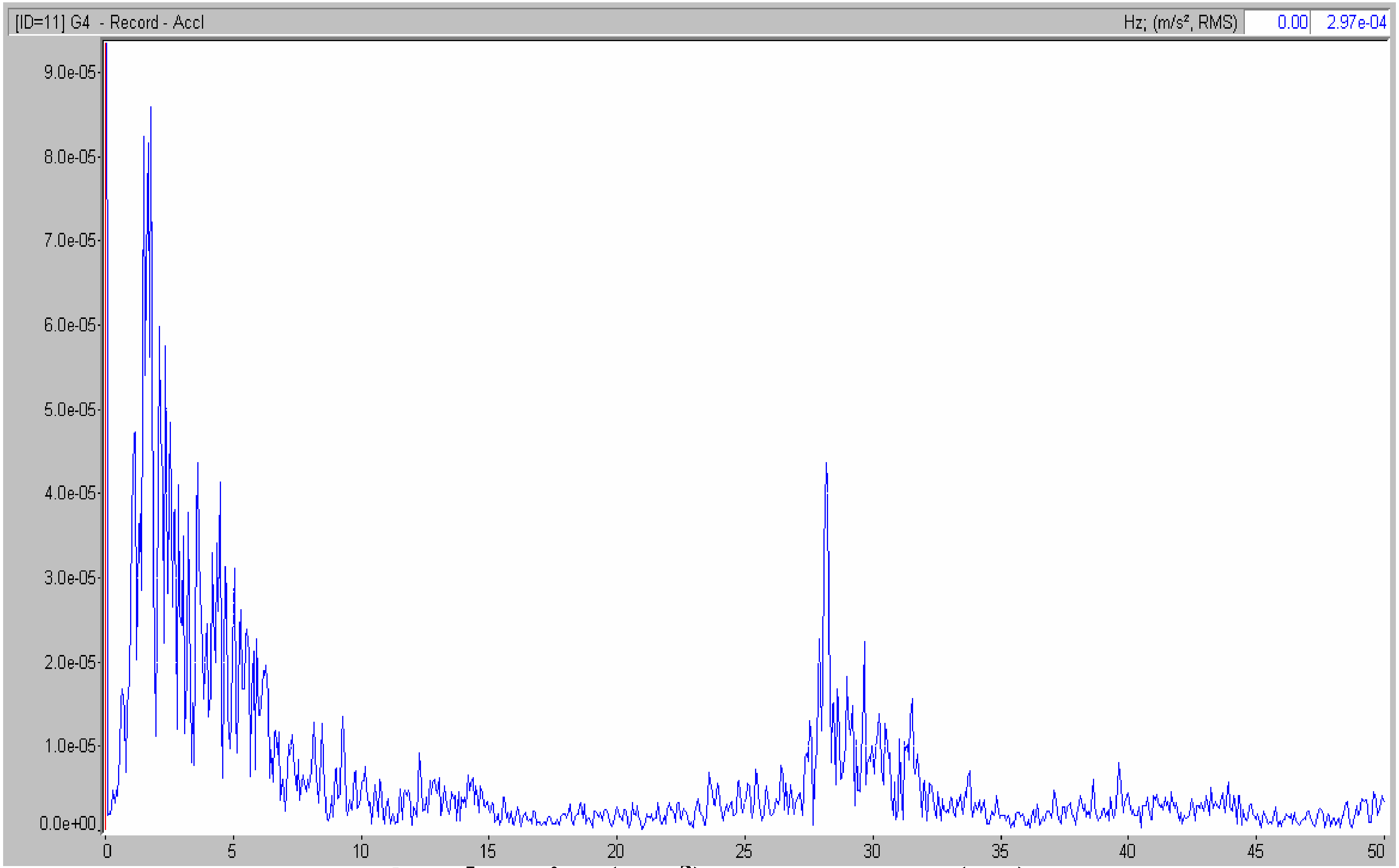

**Acceleration(m/s$^2$) vs Frequency(Hz)**

# Channel 4: 1698 (Rear Left Seat Position)



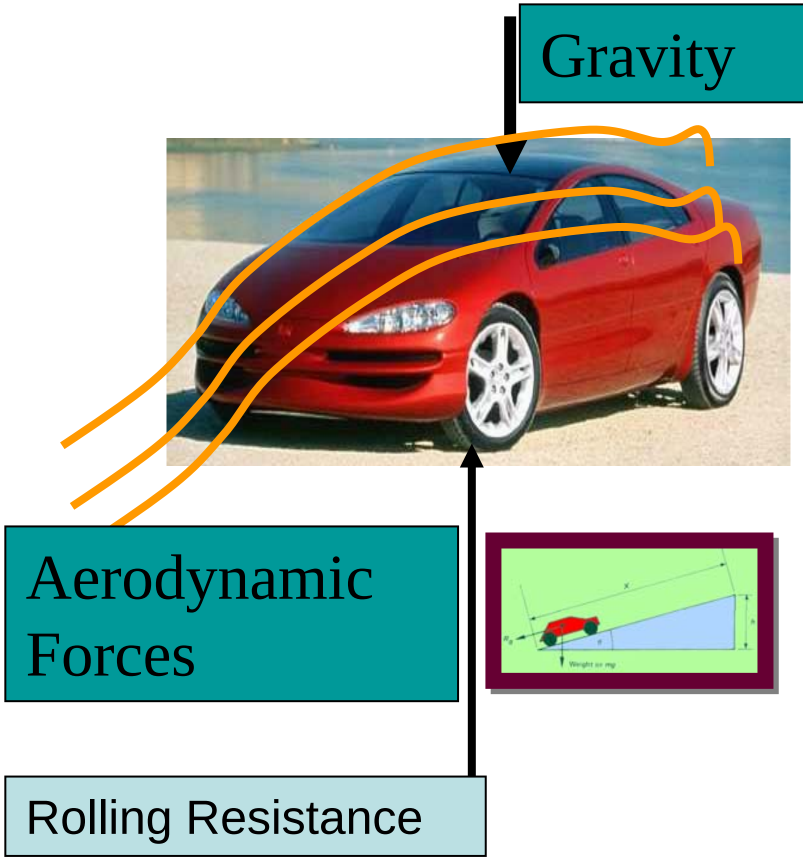

**Acceleration(m/s²) vs Time(s)**

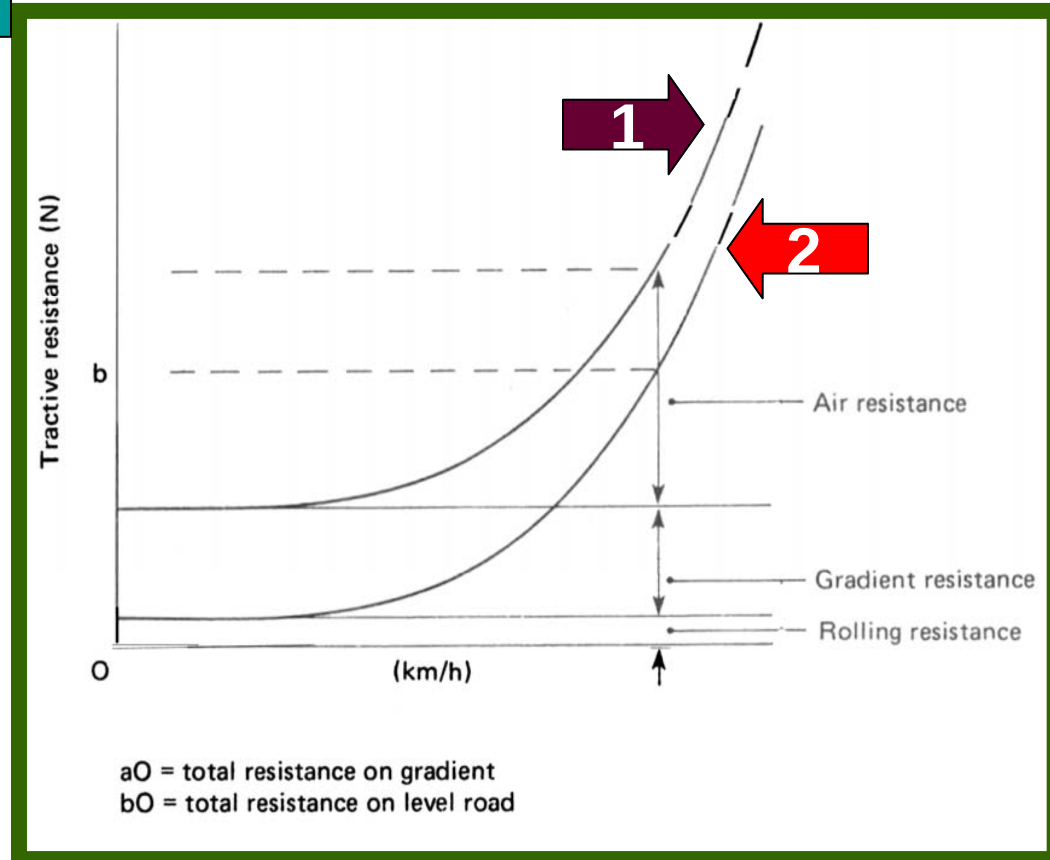
# Channel 4: 1698 (Rear Left Seat Position)




**Acceleration(m/s²) vs Frequency(Hz)**

# Road Loads-Tractive Resistance



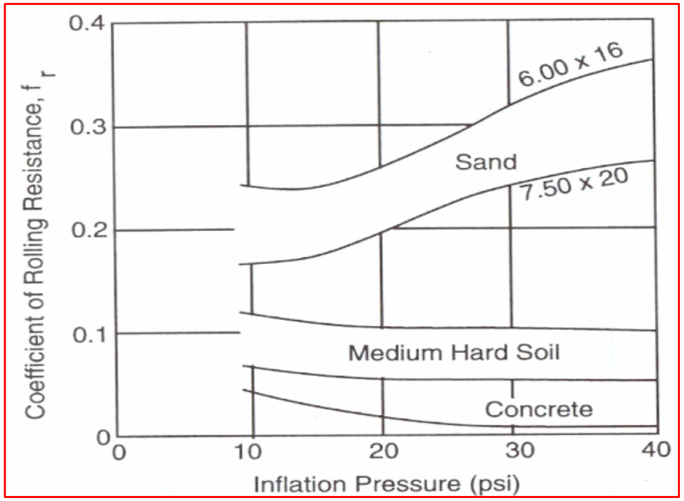

$$Tractive\ Resistance = (f_r W + 1/2\rho V^2 C_D A + W \sin\theta)$$

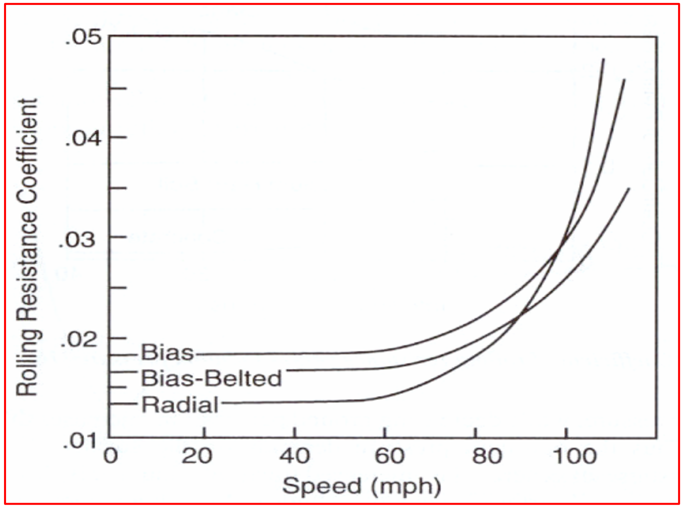
$$Tractive\ \ power = (f_r W + 1/2\rho V^2 C_D A + W \sin\theta)V$$

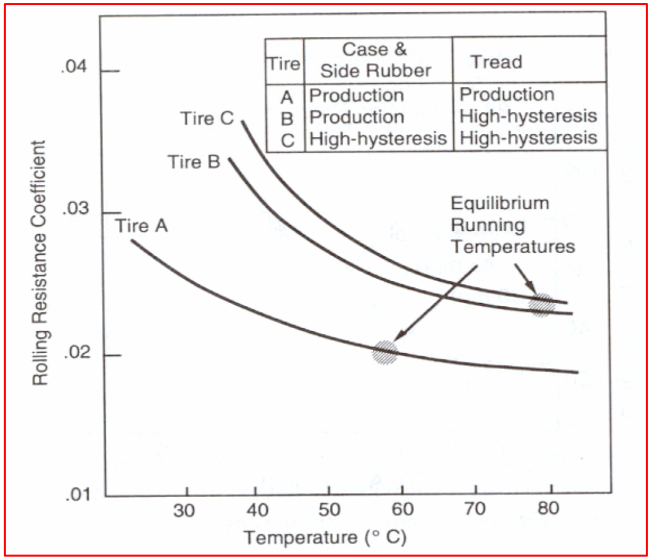
# Rolling Resistance ($f_r$)

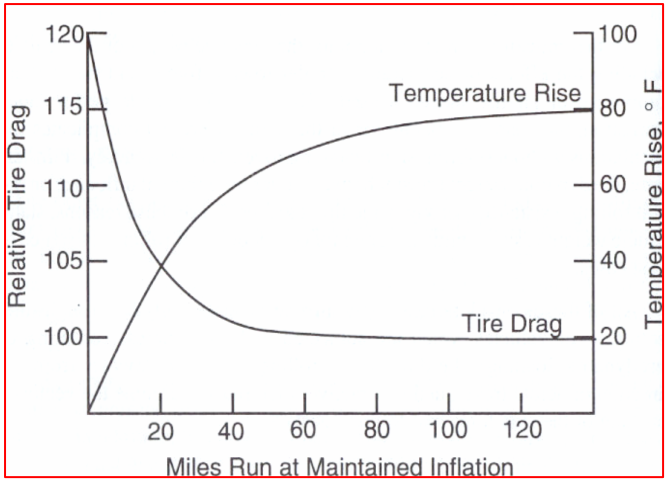
- It is due to hysteresis in tire material due to deflection of the carcass while rolling
  - Primary factor:
    - Hysteresis
  - Secondary factors:
    - Friction between the tire and the road caused by sliding
    - Air Circulation inside the tire
    - Fan effect of the rotating tire on the surroundings

# Factors Affecting Rolling Resistance ($f_r$)

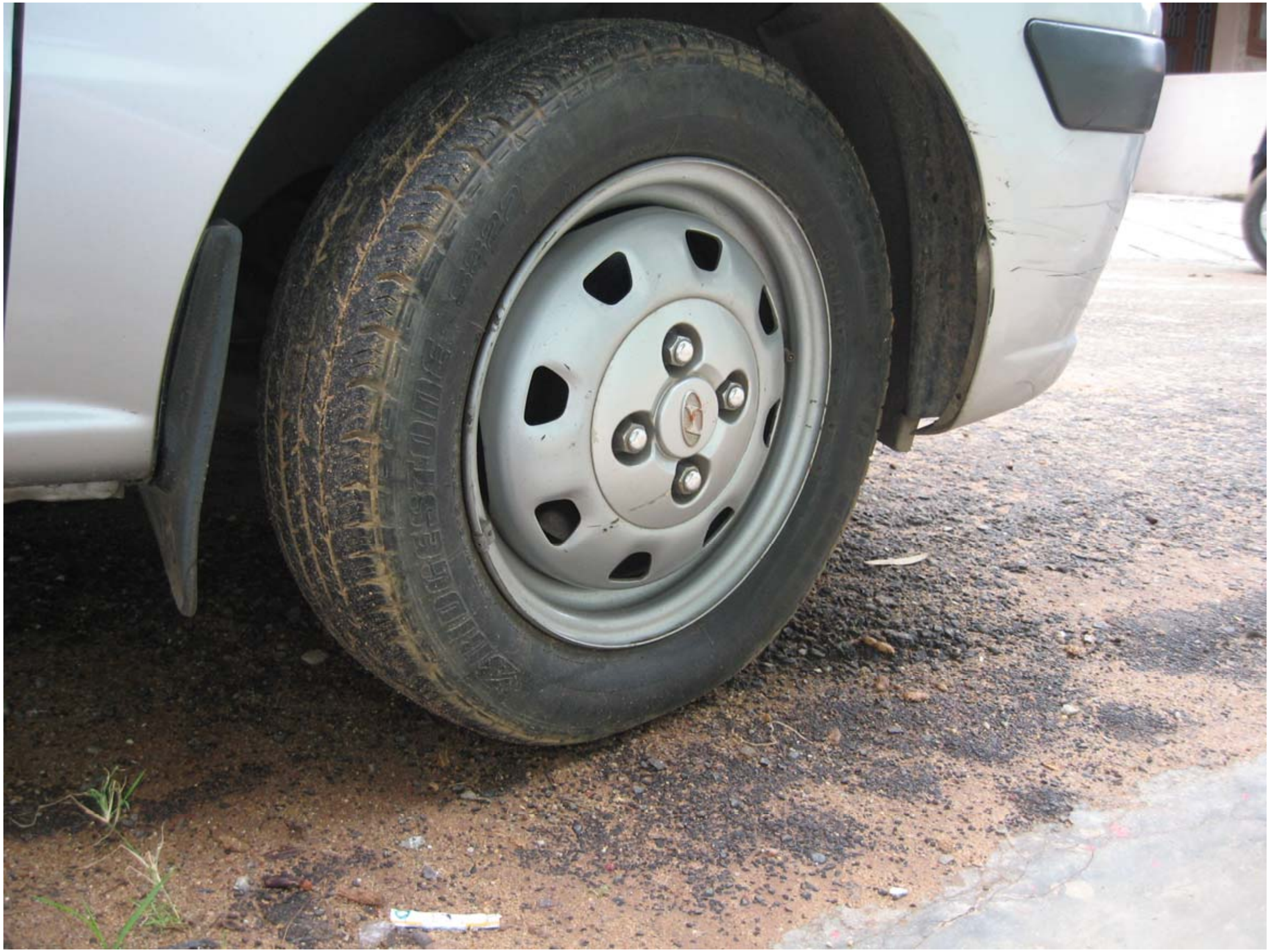


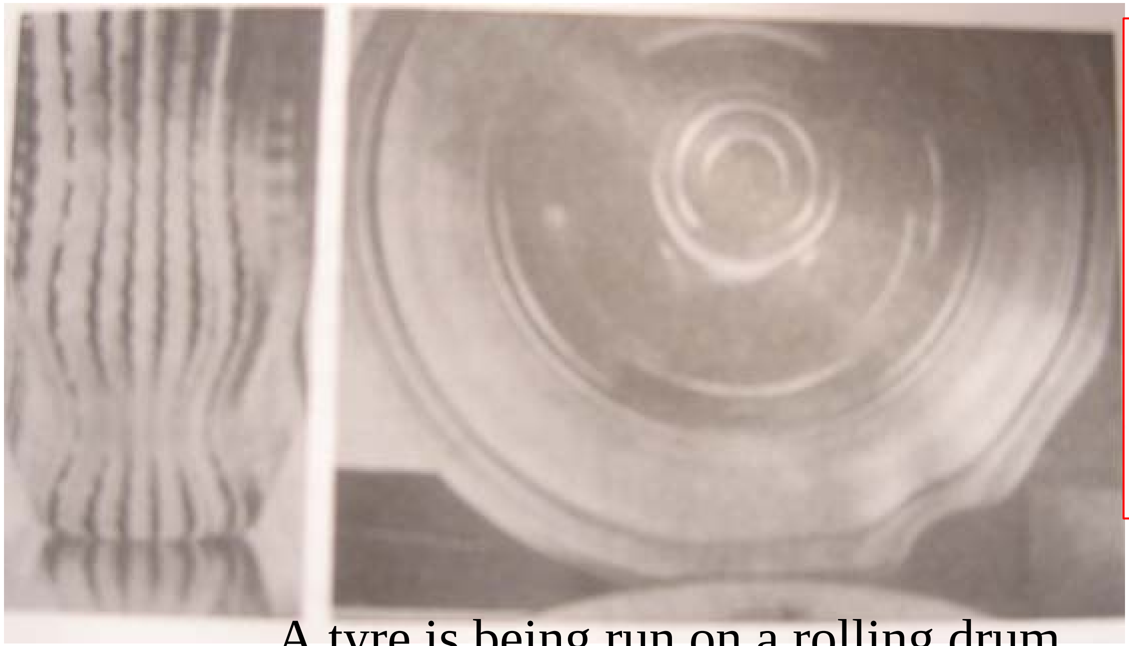



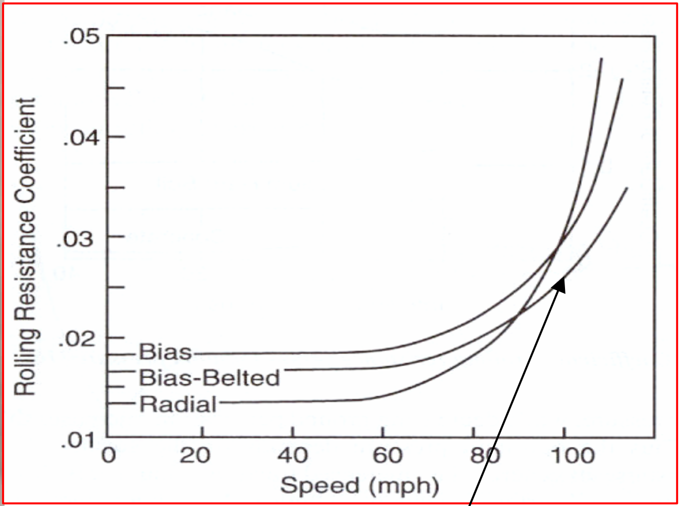
# Rolling Resistance



# Standing Waves



A tyre is being run on a rolling drum




Sharp Rolling Resistance is due to standing waves

When the tyre rotates at its critical speed, standing wave occurs

In such conditions rolling resistance increases, and energy gets dissipated into heat

A **standing wave**, also known as a **stationary wave**, is a wave that remains in a constant position. This phenomenon can occur because the medium is moving in the opposite direction to the wave, or it can arise in a stationary medium as a result of interference between two waves traveling in opposite directions.

# Rolling Resistance Coefficients ($f_r$)

$$f_r = \frac{R_x}{W} = C\frac{W}{D}\sqrt{\frac{h_t}{w}}$$

Where:

$R_x$ = Rolling resistance force

W = Weight on the wheel

C = Constant reflecting loss and elastic characteristic of the tire material

D = Outside diameter

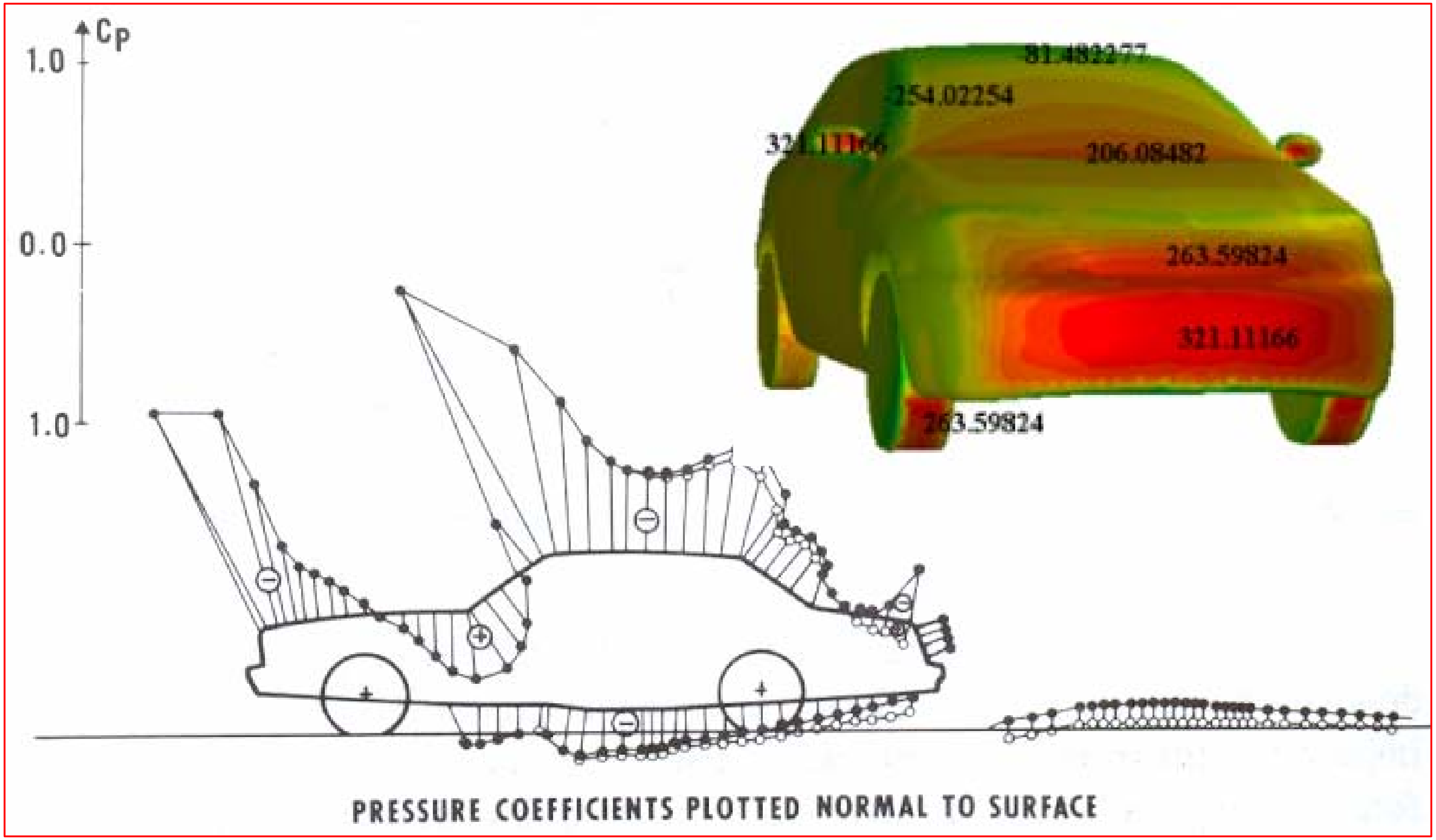
$h_t$ = Tire section height

w = Tire section width

| | Surface | | |
|---|---|---|---|
| Vehicle Type | Concrete | Medium Hard | Sand |
| Passenger cars | 0.015 | 0.08 | 0.30 |
| Heavy trucks | 0.012 | 0.06 | 0.25 |
| Tractors | 0.02 | 0.04 | 0.20 |

# Aerodynamic Loads

## Pressure Distribution On a Vehicle



# Aerodynamic Forces and Moments

Drag Force

$$D_A = 1/2\,\rho V^2 C_D A$$

Where:

$C_D$ = Aerodynamic drag coefficient
A = Frontal area of the vehicle
ρ = Air density

Lift Force

$$L_A = 1/2 V^2 C_L A$$

Where:

$L_A$ = Lift force
$C_L$ = Lift Coefficient
A = Frontal area

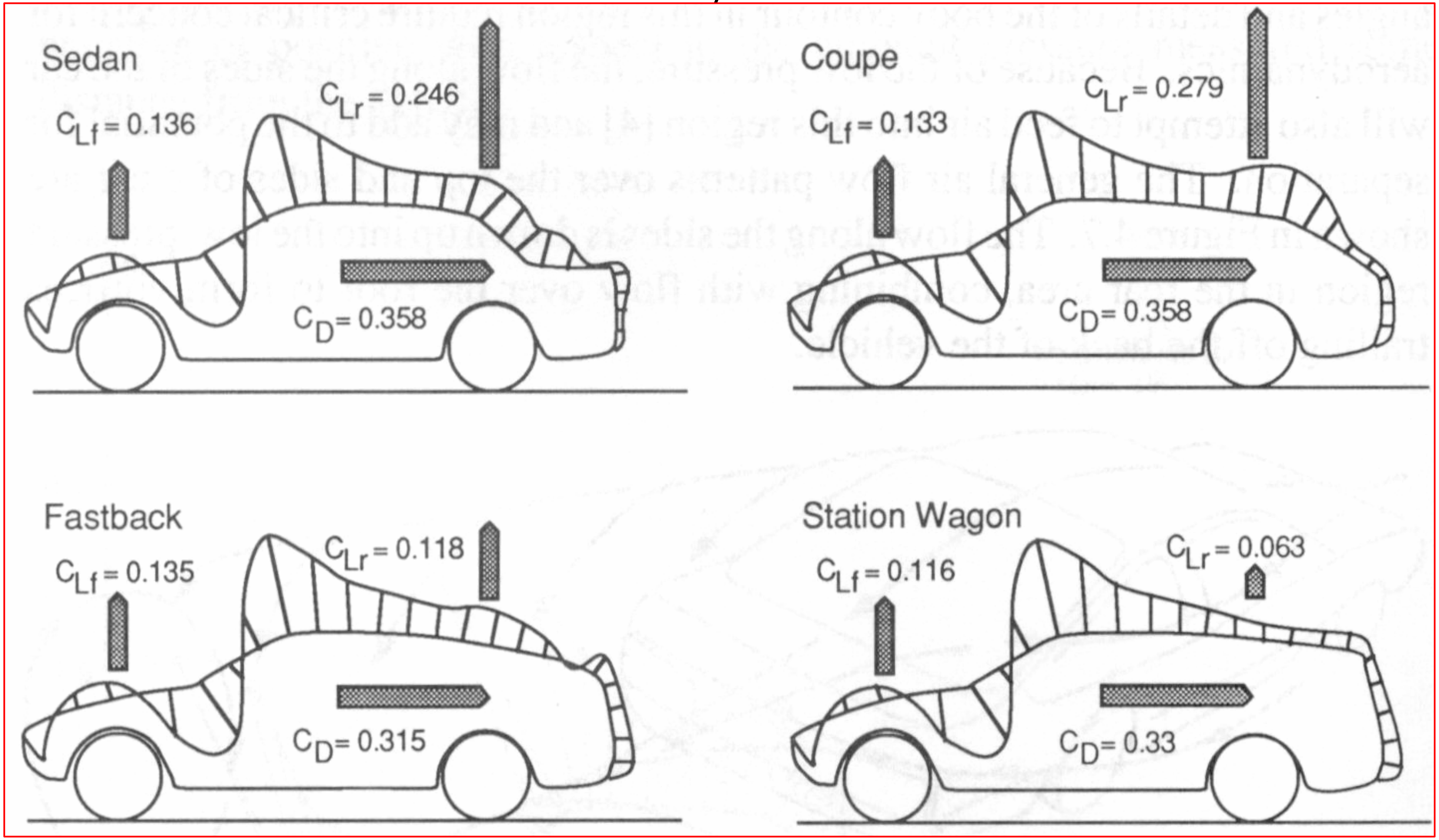
Side Force

$$S_A = 1/2\,\rho V^2 C_S A$$

Where:

$S_A$ = Side force
V = Total wind velocity
$C_S$ = Side force coefficient (function of the relative wind angle)
A = Frontal area

# Aerodynamic Lift and Drag with Different Vehicle Styles



## Pitching Moment

$$PM = 1/2\,\rho V^2 C_{PM}\,AL$$

Where:

PM = Pitching moment
$C_{PM}$ = Pitching moment coefficient
A = Frontal area
L = Wheelbase

## Yawing Moment

$$YM = 1/2\,\rho V^2 C_{YM}\,AL$$

Where:

YM = Yawing moment
$C_{YM}$ = Yawing moment coefficient
A = Frontal area
L = Wheelbase

## Rolling Moment

$$RM = 1/2\,\rho V^2 C_{RM}\,AL$$

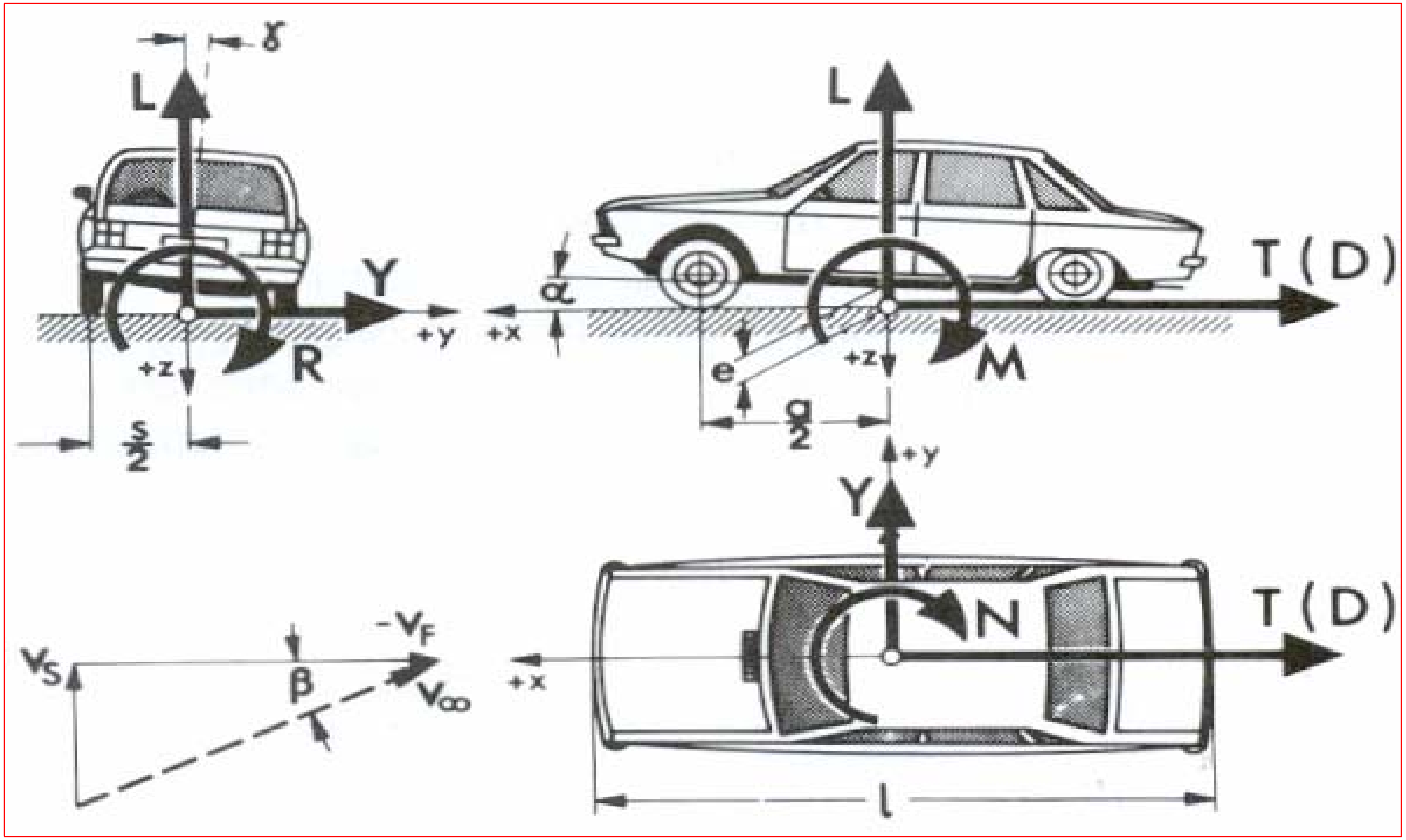
Where:

RM = Rolling moment
$C_{RM}$ = Rolling moment coefficient
A = Frontal area
L = Wheelbase

# Moments Due to Aerodynamic Forces

Rolling

Pitching

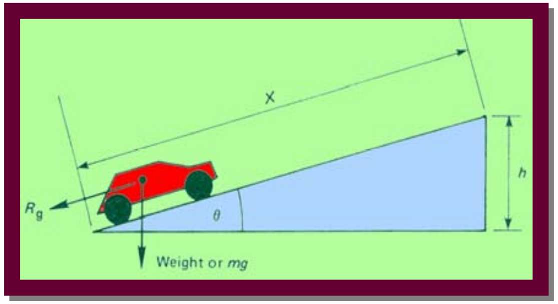



Yawing

**Side Coefficients**

# Gradient Resistance

"Heeresversuchsgelände Kummersdorf", south of Berlin




- The "slope hill" to test the gradeability of military vehicles. There are several slopes, beginning with around 10% grade ("1 : 10" or 5.7 degrees), the steepest slope is around 70% ("1 : 1,66" or 35 degrees)

- Gradeability
- It is the rise over run

$$G = \frac{T \times R \times 10200}{r \times GVW} - RR$$

**Where:**

10200 = Factor

T = Motor torque in newton metres

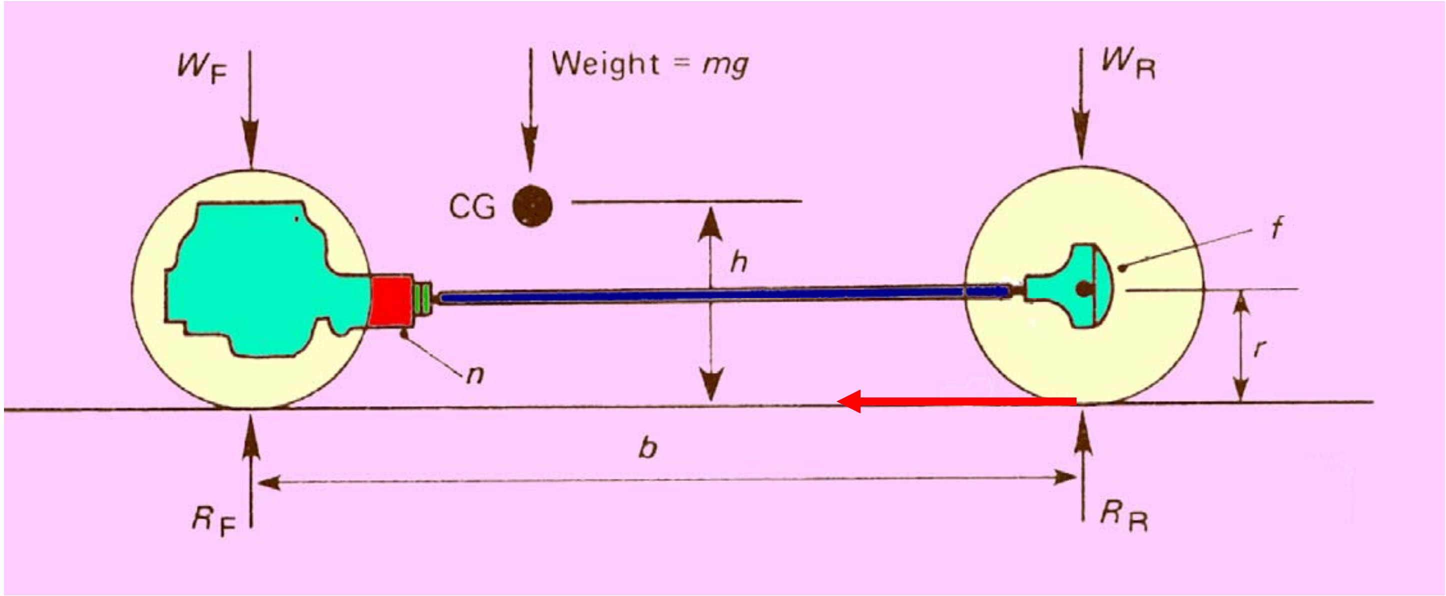
R = Overall gear reduction including both axle and transmission

r = Rolling radius of loaded driving type in millimetres

GVW = Gross vehicle weight in kilograms

RR = Rolling resistance expressed in percentage grade.

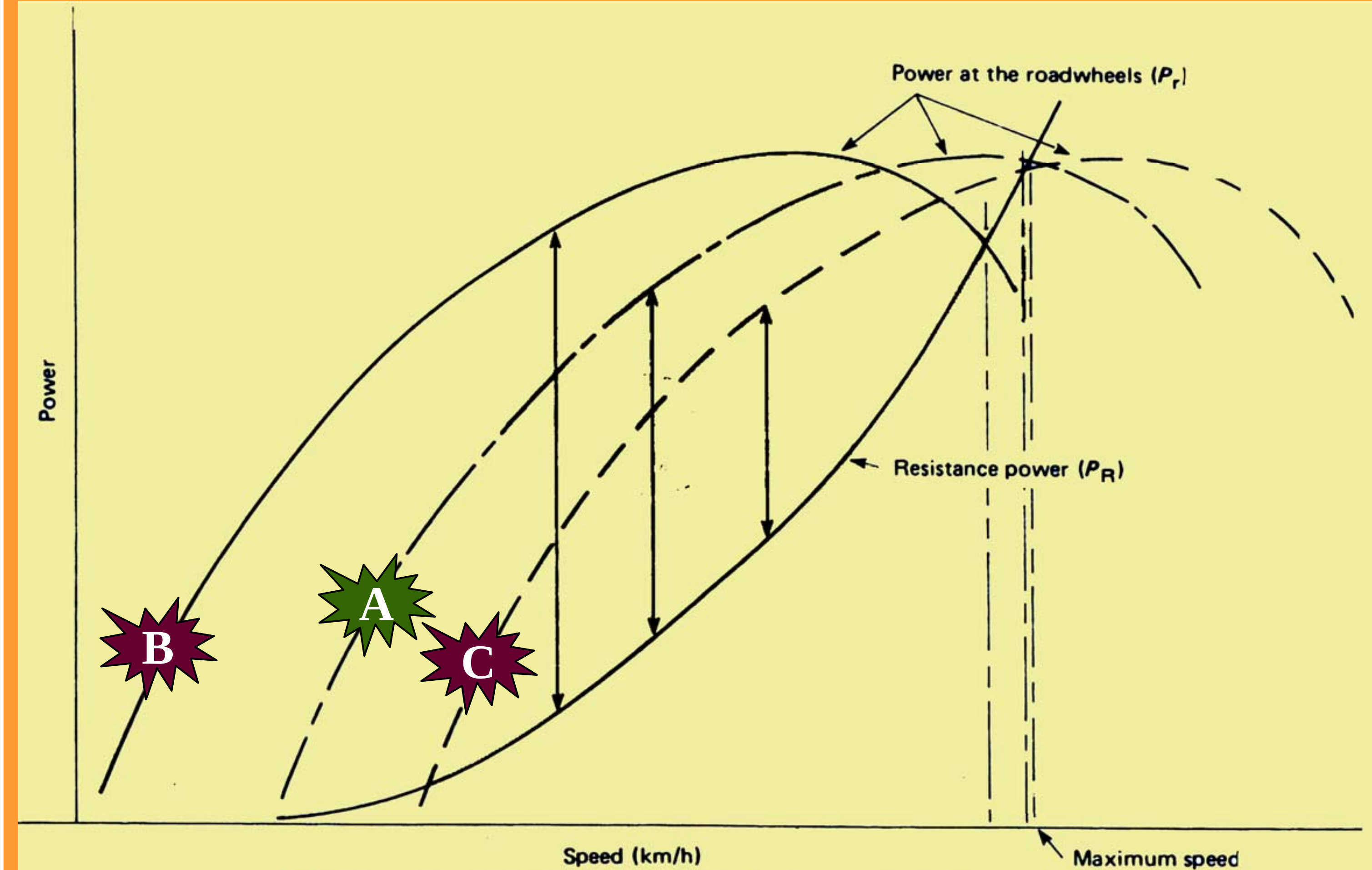
# Tractive Effort




$T_r = Tnfe$ and $TE = (Tnfe)/r$

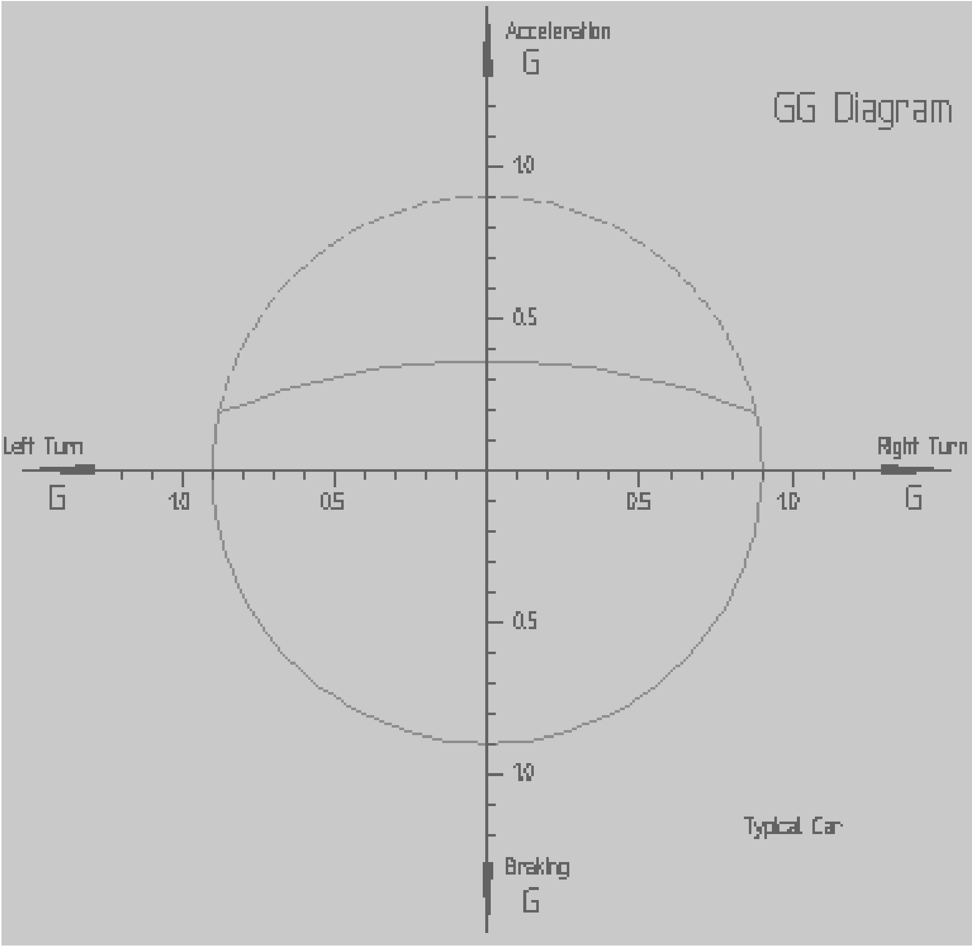
$$\text{rev/min of the roadwheels } N_r = \frac{\text{engine rev/min}}{\text{overall reduction ratio}} = \frac{N_r}{n\,f}$$

# Tractive Power and Tractive Resistance Power

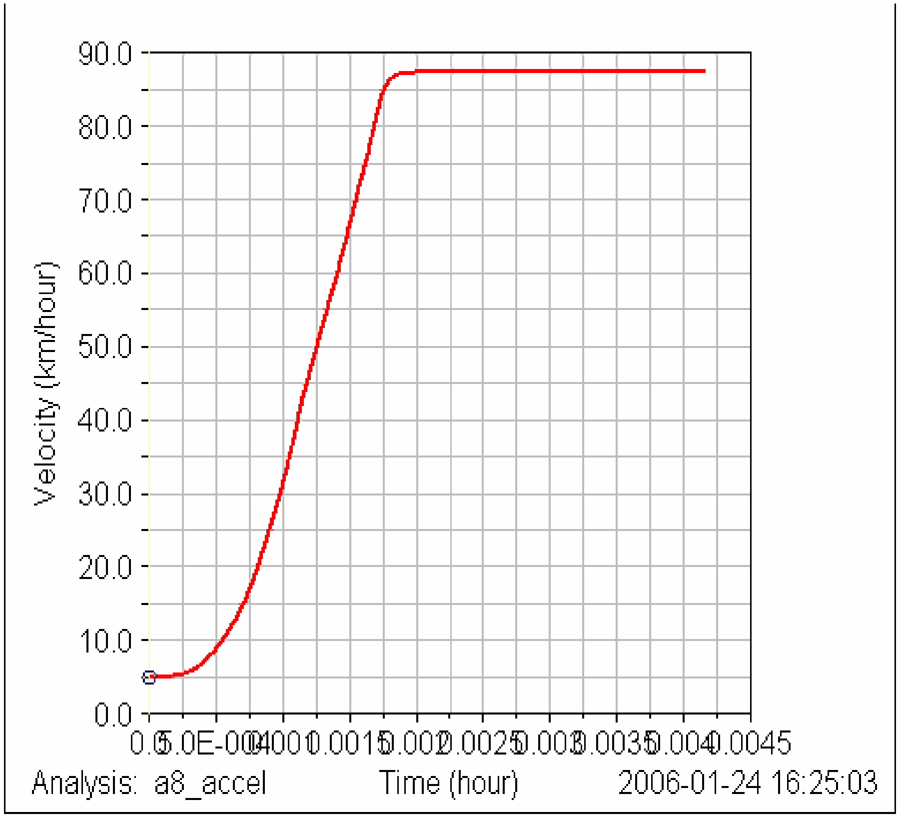


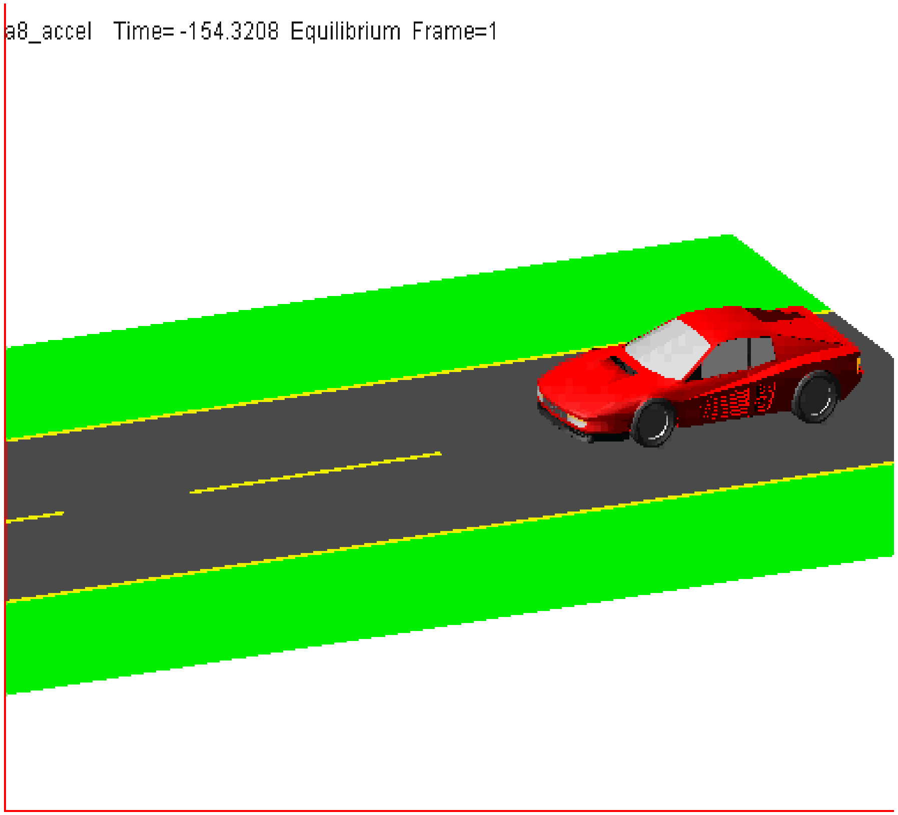

Performance curves for undergeared and overgeared vehicles.
– - – optimum gear setting, —— undergeared, – – – overgeared.

# Traction Limits



# Acceleration with Road μ = 0.8



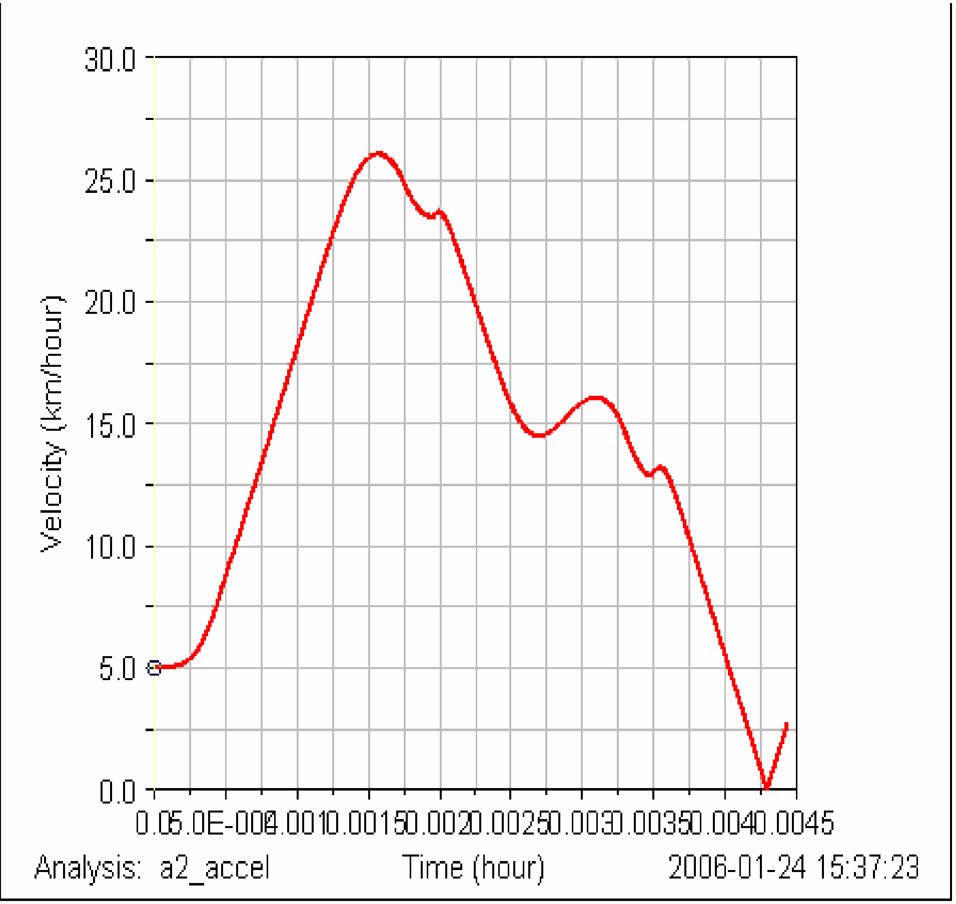



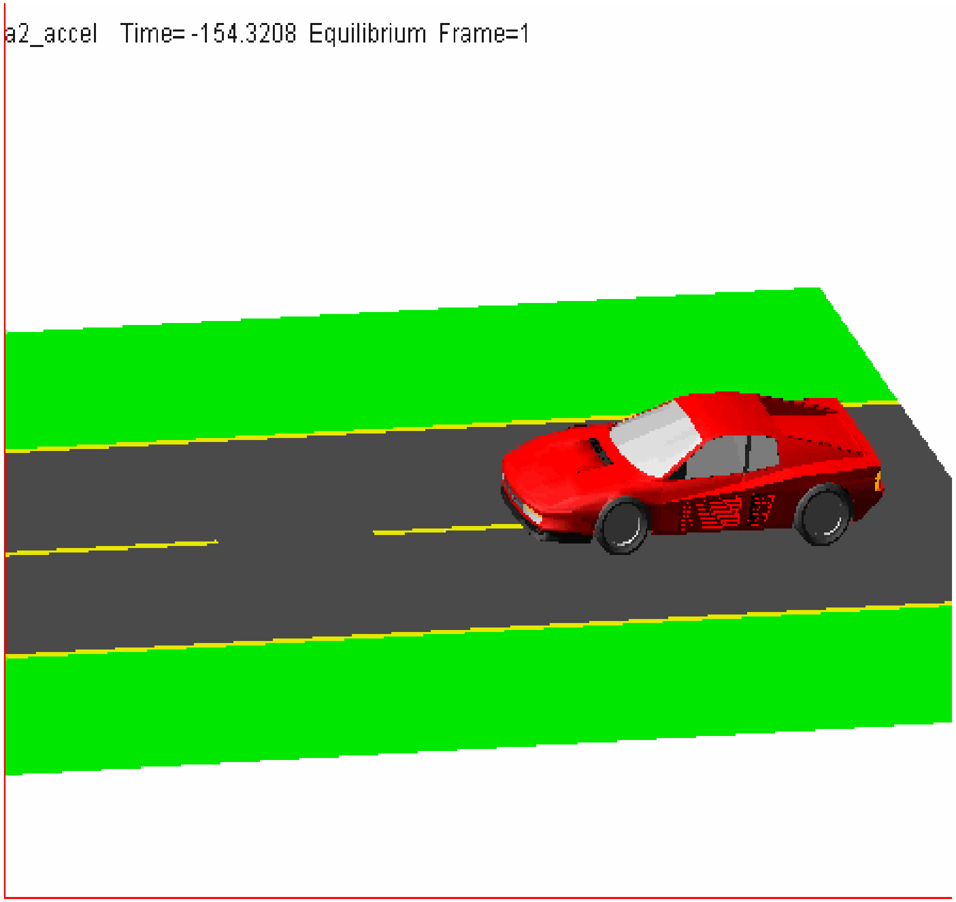
# Traction Loss

- If traction is less than the torque applied a tire will start spinning.
- We say: **"The tire lost traction"** even though traction (resistance) did not vanish completely - it was just not enough traction to handle the torque.
- Decreasing torque (backing off the gas) will help "regaining" traction.
- If you need a high amount of torque to move your vehicle (uphill etc) you can create more traction by deflating your tires (creating a larger footprint).

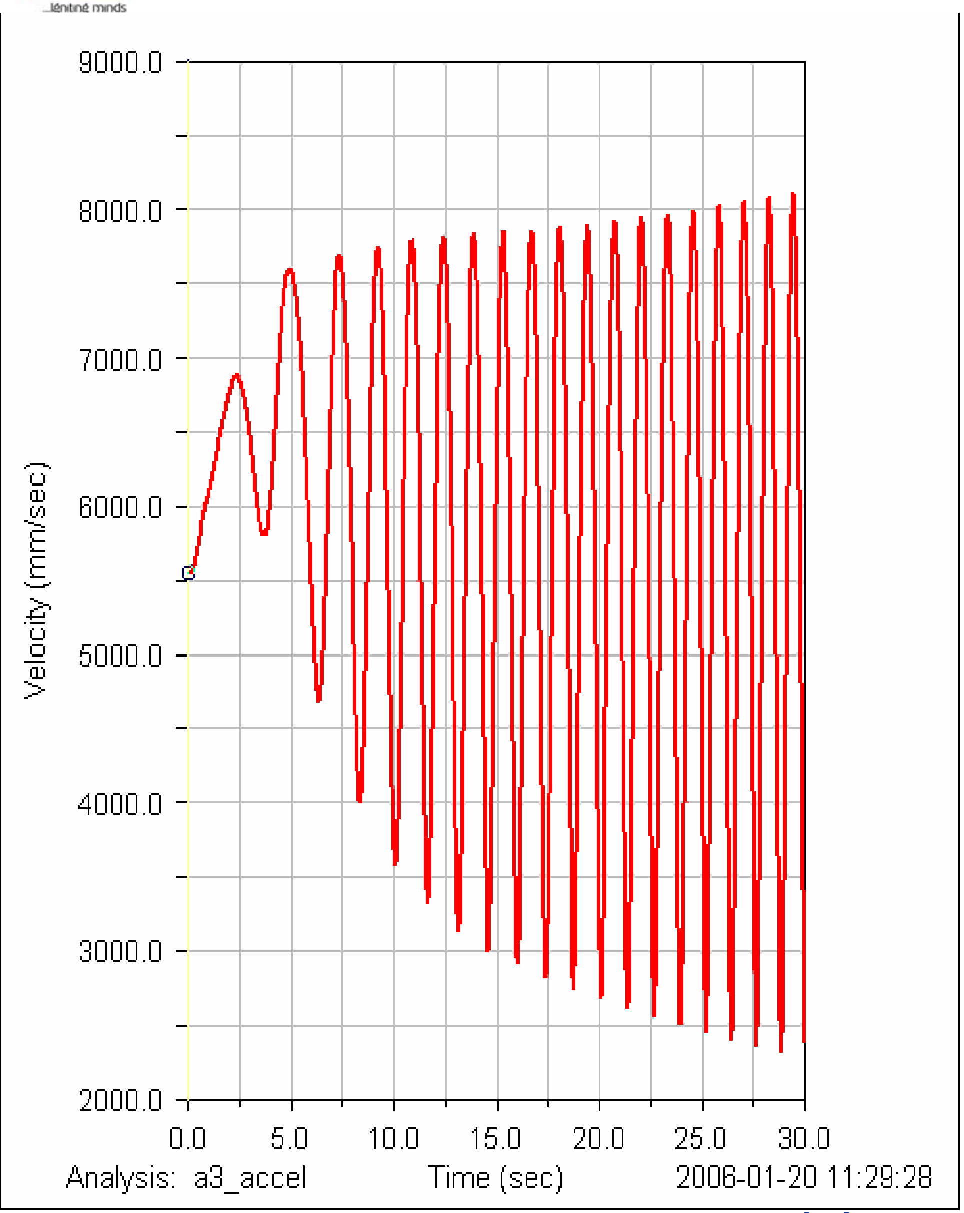
Traction = Reaction Balancing

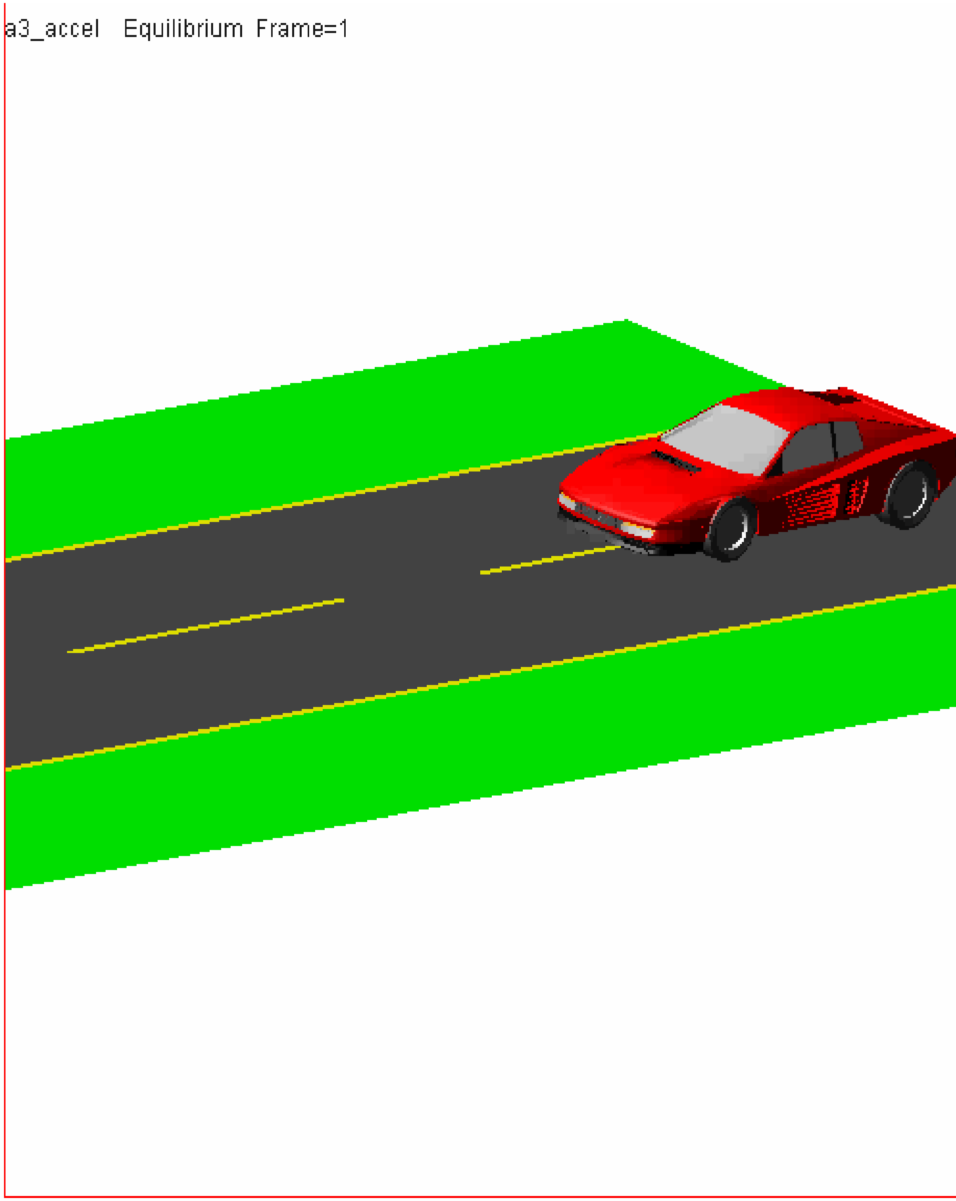
# With Road μ = 0.2



# With Road μ = 0.05



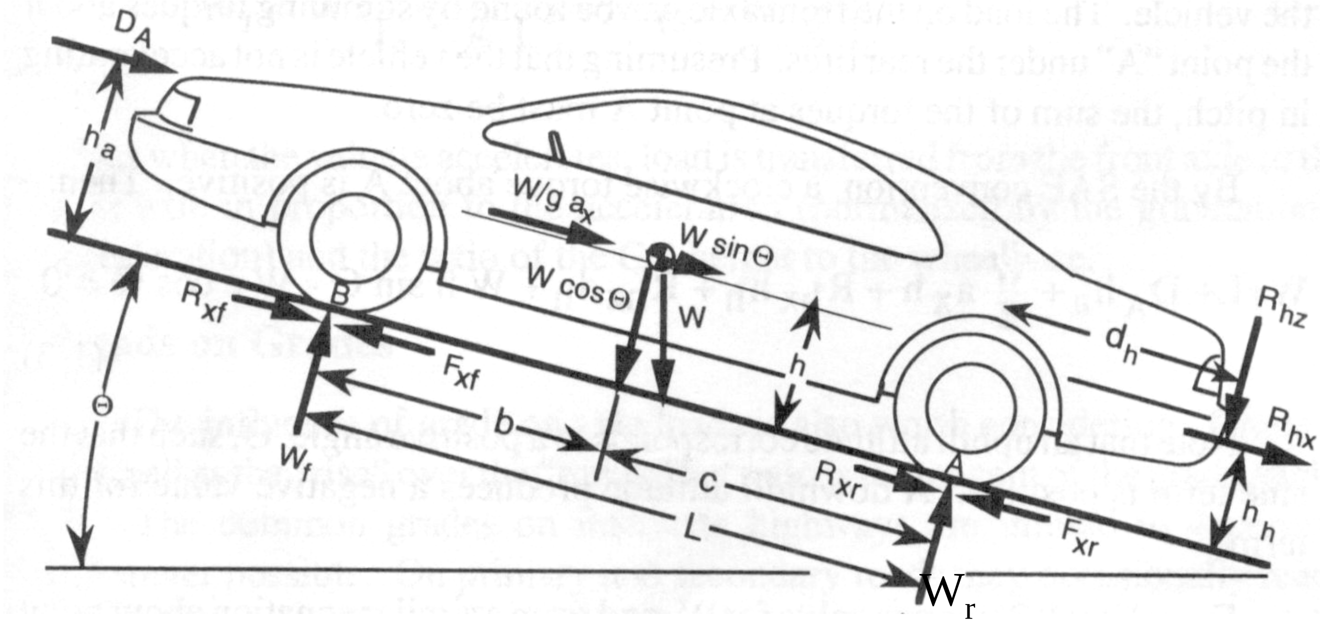



# Traction

- **If** one or more components of traction (**friction, footprint, weight**) **decreases** (less friction [mud etc], smaller footprint, less weight) **traction will decrease!**

- **If** one or more components of traction (**friction, footprint, weight**) **increase in value** (more friction [concrete etc], bigger footprint, more weight) **traction will increase!**

# Forces Acting on a Vehicle




**W**: weight of the vehicle acting at its CG

**W/ga$_x$** : Inertial force,if the vehicle is accelerating

**W$_f$, W$_r$**: :Dynamic weights carried on the front and rear wheels.

**F$_{xf}$, F$_{xr}$** : Tractive forces

**R$_{xf}$ ,R$_{xr}$** : Rolling resistance at the tyre contact patch

**D$_A$**: Aerodynamic force acting on the body of the vehicle

**R$_{hz}$, R$_{hx}$**: Vertical and longitudinal forces acting at the hitch point when the vehicle is towing a trailer

**L**: Wheel base length

**h**: Height of the Centre of Gravity from the ground

**b**: Distance of the Centre of gravity aft of the front axle

**c**: Distance of the Centre of Gravity fore of rear axle

$\theta : Grade$

# Newton's 2[nd] Law

- **Translational Sytems**

$$\Sigma F_X = M.a_X$$

where: $F_X$ = Forces in the X-direction

$M$ = Mass of the body

$a_X$ = Acceleration in the X-direction

- **Rotational System**

$$\Sigma T_X = I_{XX} \,.\, \alpha_X$$

where: $T_X$ = Torques about the X-axis

$I_{XX}$ = Moment of inertia about the X-axis

$\alpha_X$ = Acceleration about the X-axis

# Loads on Axles

## Dynamic Axle Loads:

- $W_f = (W\,c\,\cos\theta - R_{hx}\,h_h - R_{hz}\,d_h - (W/g)\,a_x\,h - D_A\,h_a - W\,h\,\sin\theta)/L$

- $W_r = (W\,b\,\cos\theta + R_{hx}\,h_h + R_{hz}\,(d_h + L) + (W/g)\,a_x\,h + D_A\,h_a + W\,h\,\sin\theta)/L$

## Static Loads on Level Ground:

- $W_{fs} = W.(c/L)$
- $W_{rs} = W.(b/L)$

The sine is zero and the cosine is one, and the variables $R_{hz}$, $R_{hx}$, $a_x$ and $D_A$ are zero.

**In cars usually load on the front axle is greater than the rear axle**

# Loads on Axles

## Load on the Axles during Low Speed Acceleration

$$W_f = W\left(\frac{c}{L} - \frac{a_x}{g}\frac{h}{L}\right) = W_{fs} - W\frac{a_x}{g}\frac{h}{L}$$

$$W_r = W\left(\frac{b}{L} + \frac{a_x}{g}\frac{h}{L}\right) = W_{rs} + W\frac{a_x}{g}\frac{h}{L}$$

When the vehicle is accelerating on level ground at a low speed, $D_A$ is zero and assuming no trailer hitch forces)

**When the vehicle accelerates, load transfer takes place from the front axle to the rear axle**

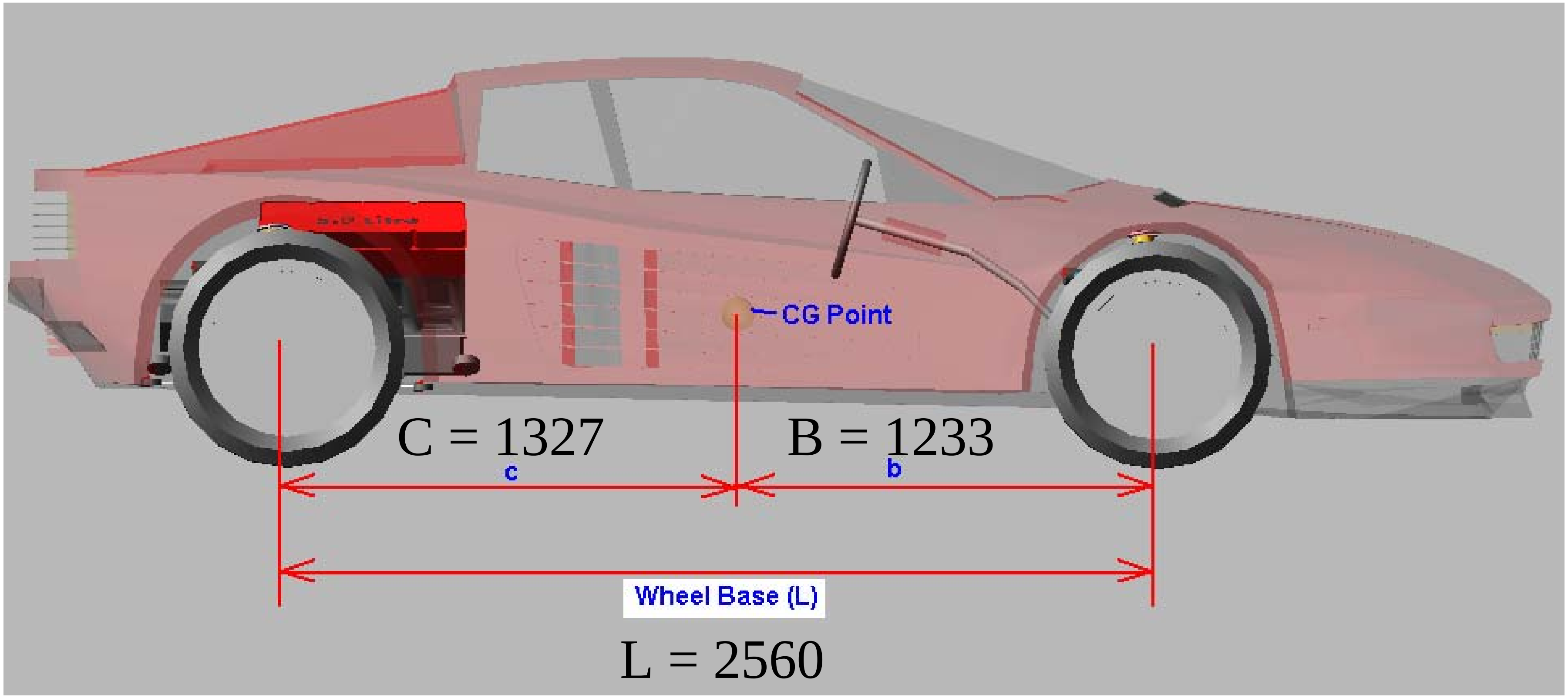
## Load on the Axles due to Grades

$$W_f = W\left(\frac{c}{L} - \frac{h}{L}\theta\right) = W_{fs} - W\frac{h}{L}\theta$$

$$W_r = W\left(\frac{b}{L} + \frac{h}{L}\theta\right) = W_{rs} + W\frac{h}{L}\theta$$

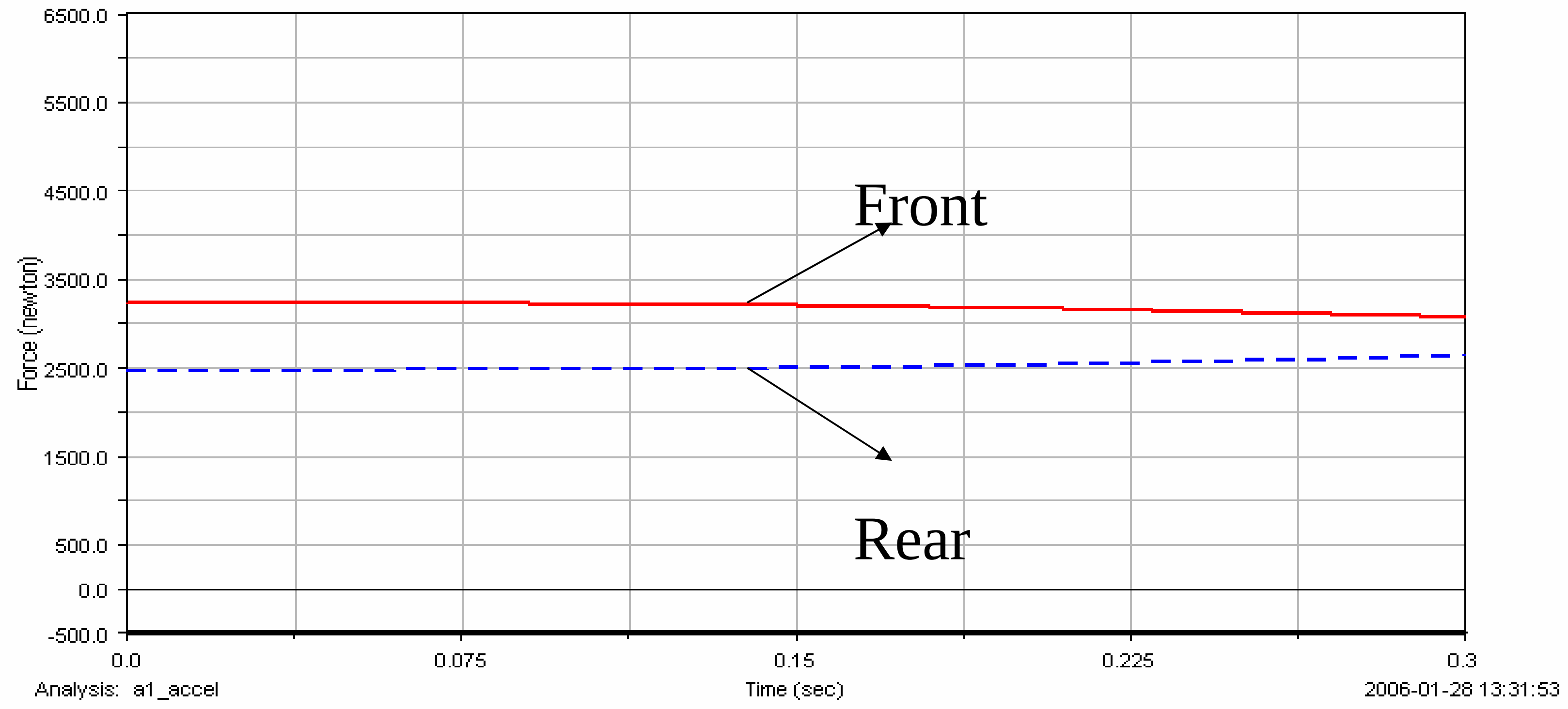
The common grades on highways are limited to 4 percent (2.3deg) On primary and secondary roads they occasionally reach 10 to 12 percent (6.8 deg).

**Positive grade causes load to be transferred from the front to the rear axle**



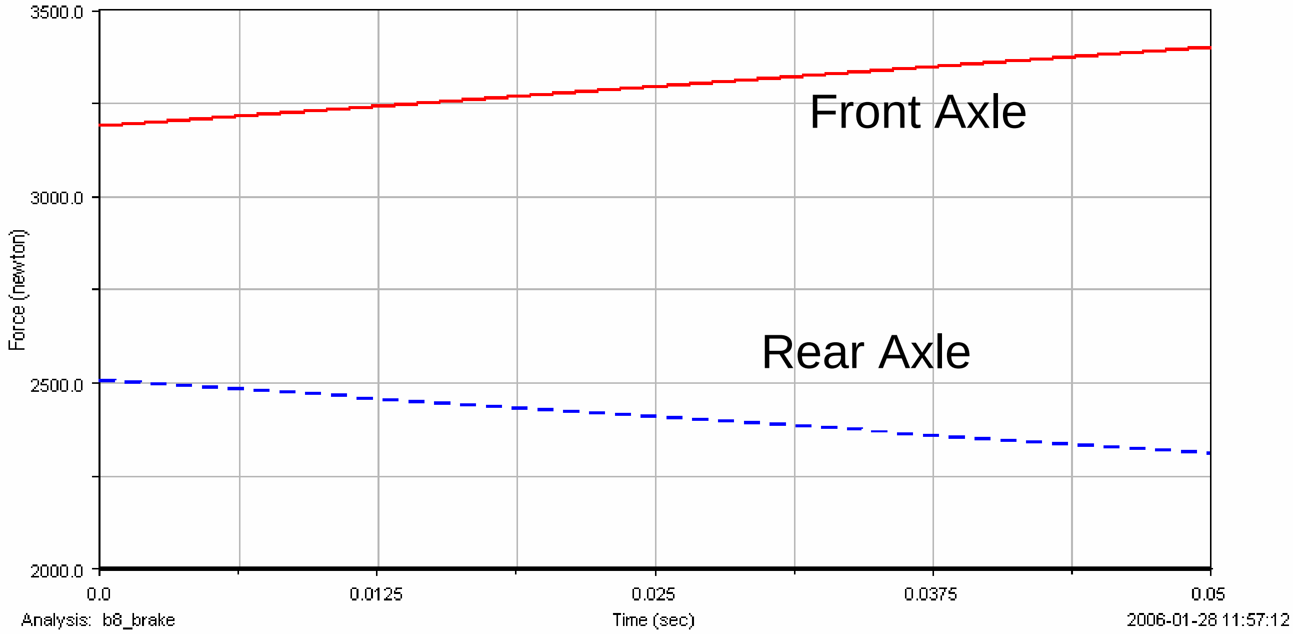
CG Point
C = 1327
c
B = 1233
b
Wheel Base (L)
L = 2560

# Load Transfer Due To Acceleration



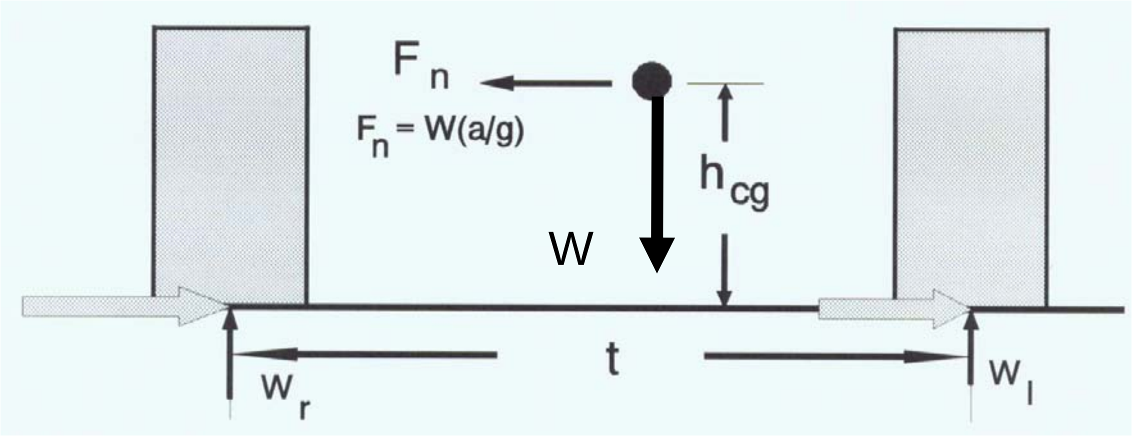

**Hard/Quick Acceleration Force or Weight Movement**

# Load Transfer Due to Deceleration




# Lateral Weight Transfer

- **Weight Transfer is directly a function of**
  - Lateral Acceleration, a/g ⟵
  - Weight, W
  - Height of the Center of Gravity, hcg
  - Wheel Track width, t



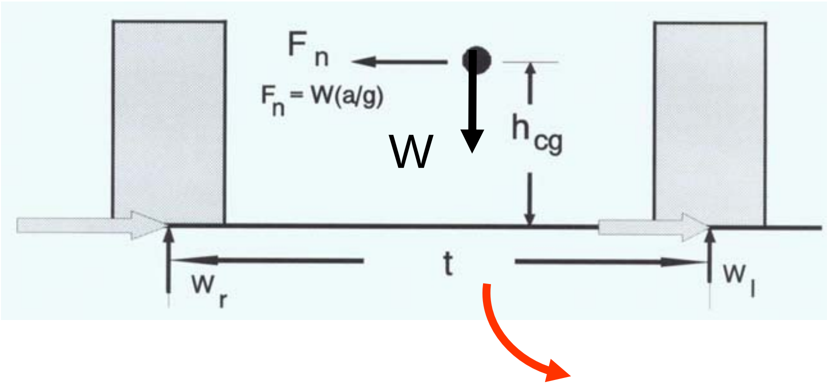
# Lateral Weight Transfer

- On a flat roadway the lateral weight transfer ($W_l$) is equal to

$$W_{lat_{TOTAL}} = W \frac{a}{g} \frac{h_{cg}}{t}$$

$$W_R = W \frac{a}{g} \frac{h_{cg}}{t} + W \frac{l_L}{t}$$

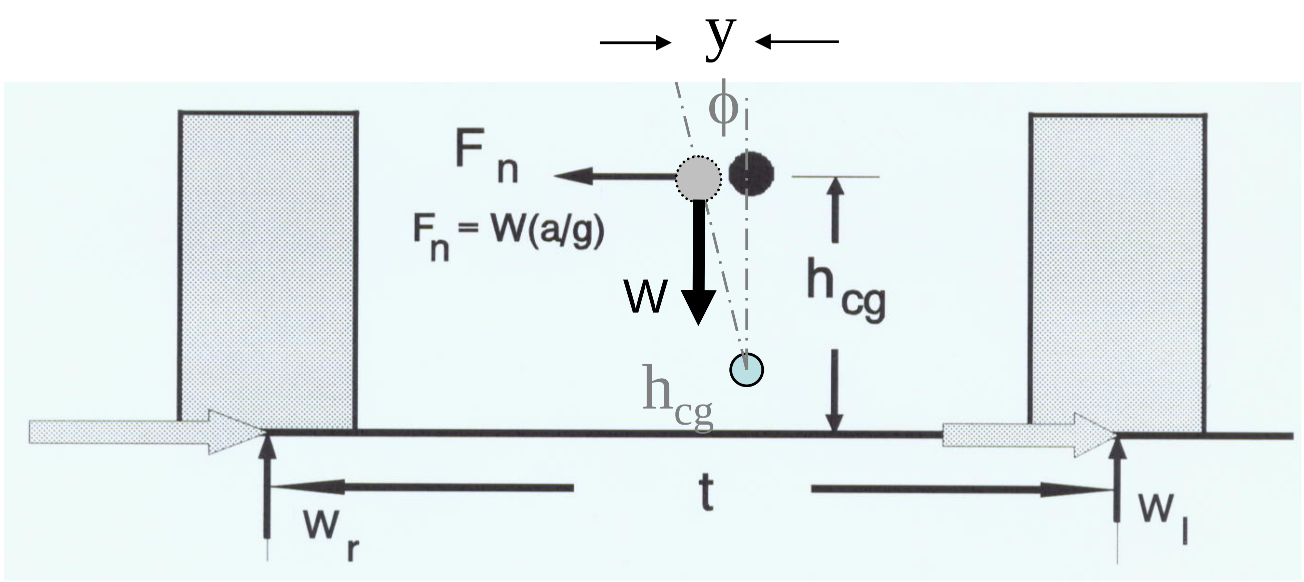
$l_L$=Lateral dist from CG to left tire




- The weight on the right side ($W_R$) in the turn is comprised of a static component and a component due to the lateral acceleration a/g.

# Lateral Weight Transfer

- Rollover potential

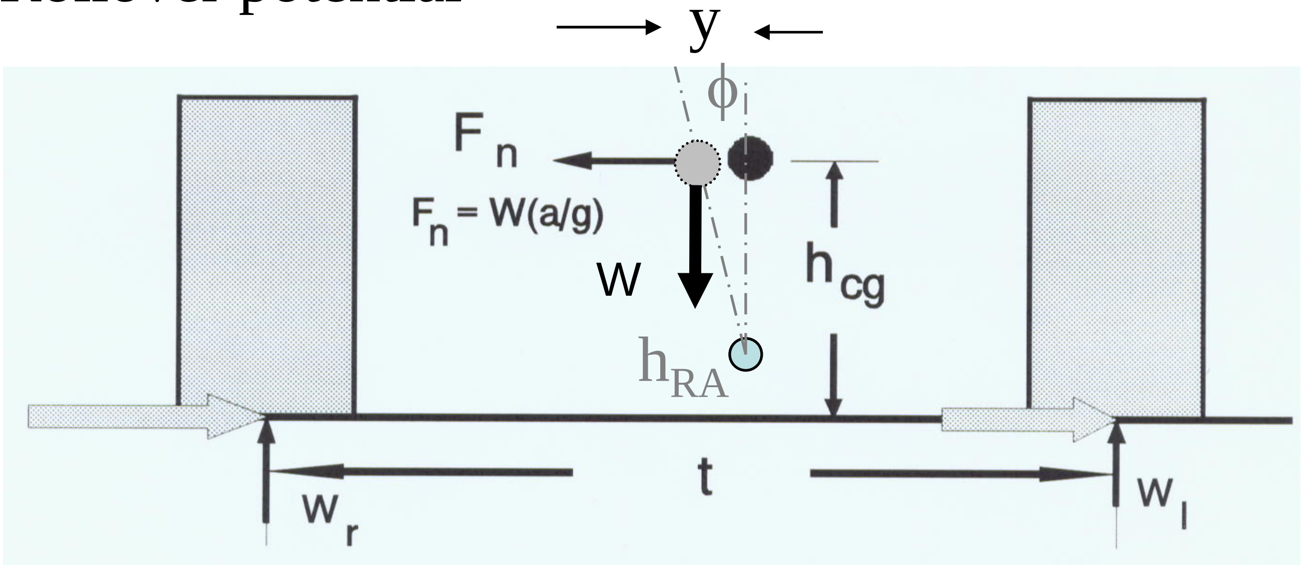



The weight on the inside tires in the turn is comprised of a static component minus a component due to the lateral acceleration a/g. When the weight transfer equals the static weight, rollover is possible.

$$\Sigma M_r = W(\frac{t}{2} - y) - F_N h_{cg} - W_l t = 0$$

# Lateral Weight Transfer

- Rollover potential




If the roll angle of the sprung mass is included in the analysis of a vehicle with a 50/50 L to R weight distribution.

$$if\ W_l = 0\ then\ \Sigma M_r = W\left(\frac{t}{2} - y\right) - F_N\, h_{cg} = 0 \qquad y = (h_{cg} - h_{RA}) Sin\phi$$

$$W\left(\frac{t}{2} - \left(h_{cg} - h_{RA}\right) Sin\phi\right) = W\,\frac{a}{g}\,\frac{h_{cg}}{t} \qquad (7)$$

# Lateral Weight Transfer

Roll Over potential

The weight on the inside wheels is defined as

$$W\left(\frac{1}{2}-\frac{\left(h_{cg}-h_{RA}\right)Sin\phi}{t}\right)=W\,\frac{a}{g}\,\frac{h_{cg}}{t}$$

Dividing through by W

$$\frac{1}{2}\ \text{-}\ \frac{\left(h_{cg}-h_{RA}\right)Sin\phi}{t}=\frac{a}{g}\,\frac{h_{cg}}{t}$$

With further transposing

$$\frac{t}{2h_{cg}}+Sin\phi\left\{\left(\frac{h_{RA}}{h_{cg}}\right)-1\right\}=\frac{a}{g} \qquad (8)$$

# Lateral Weight Transfer

- Potential rollover is possible when $W_l=0$

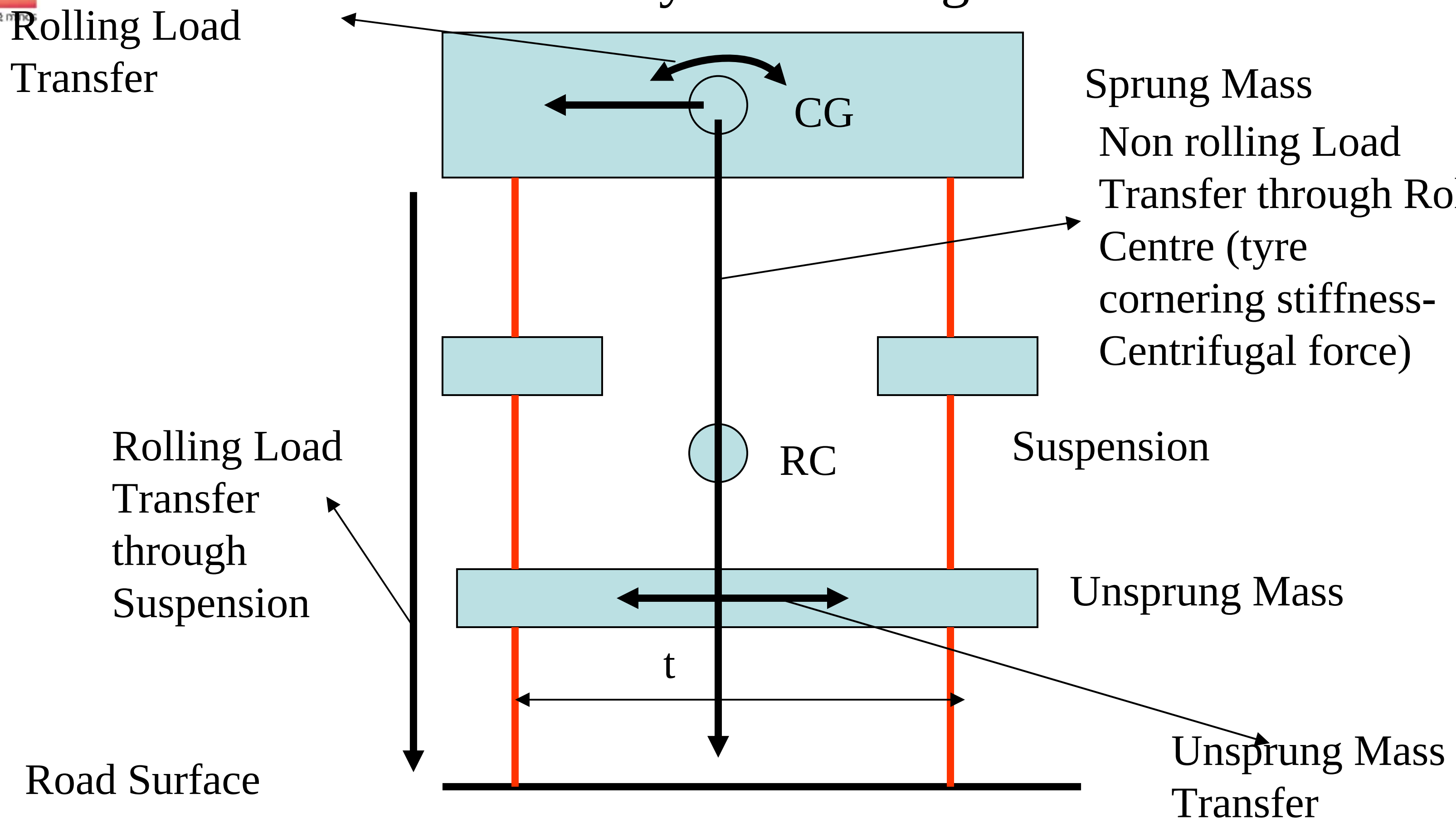
$$\frac{a}{g}=\frac{t}{2h_{cg}}+Sin\phi\left\{\left(\frac{h_{RA}}{h_{cg}}\right)-1\right\} \qquad (8)$$

- It should be noted that roll angle of the sprung mass has limited effect on the steady-state rollover potential.
- Static Stability Factor: SSF : $a/g = t/2h_{cg}$


Cars will roll at:
1.2 - 1.3 G
Sport Utility Vehicles:
about 1 G
Pick-up or Jeep:
about 0.8 G
A fully loaded semi:
only needs about 0.4 G

# Lateral Weight Transfer

## Mechanism of Dynamic Weight Transfer

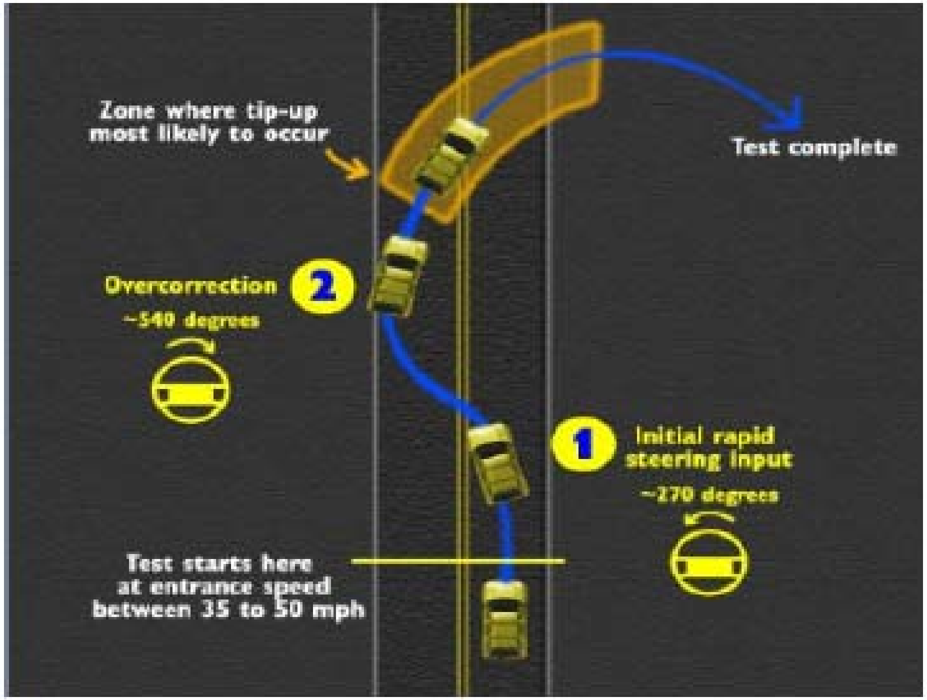


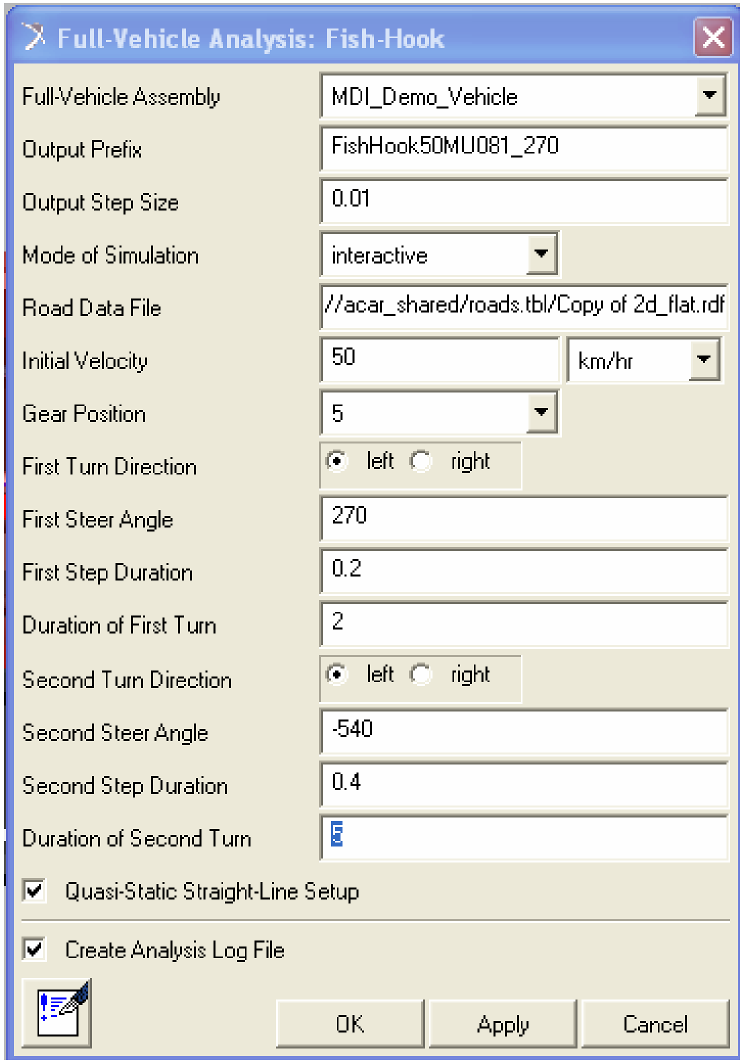

**Lateral Load Transfer= Sprung Mass Rolling Mass Transfer+ Sprung Mass Non Rolling Load Transfer+ Unsprung Mass Load Transfer**

$$W_{T_F} + W_{T_R} = \left(W_{T_{F_s}} + W_{T_{F_{nr}}} + W_{T_{F_{us}}}\right) + \left(W_{T_{R_s}} + W_{T_{R_{nr}}} + W_{T_{R_{us}}}\right)$$

$$W_{LAT_{TOTAL}} = W_{T_F} + W_{T_R} = W_{lat} = W\,\frac{a}{g}\,\frac{h_{cg}}{t}$$

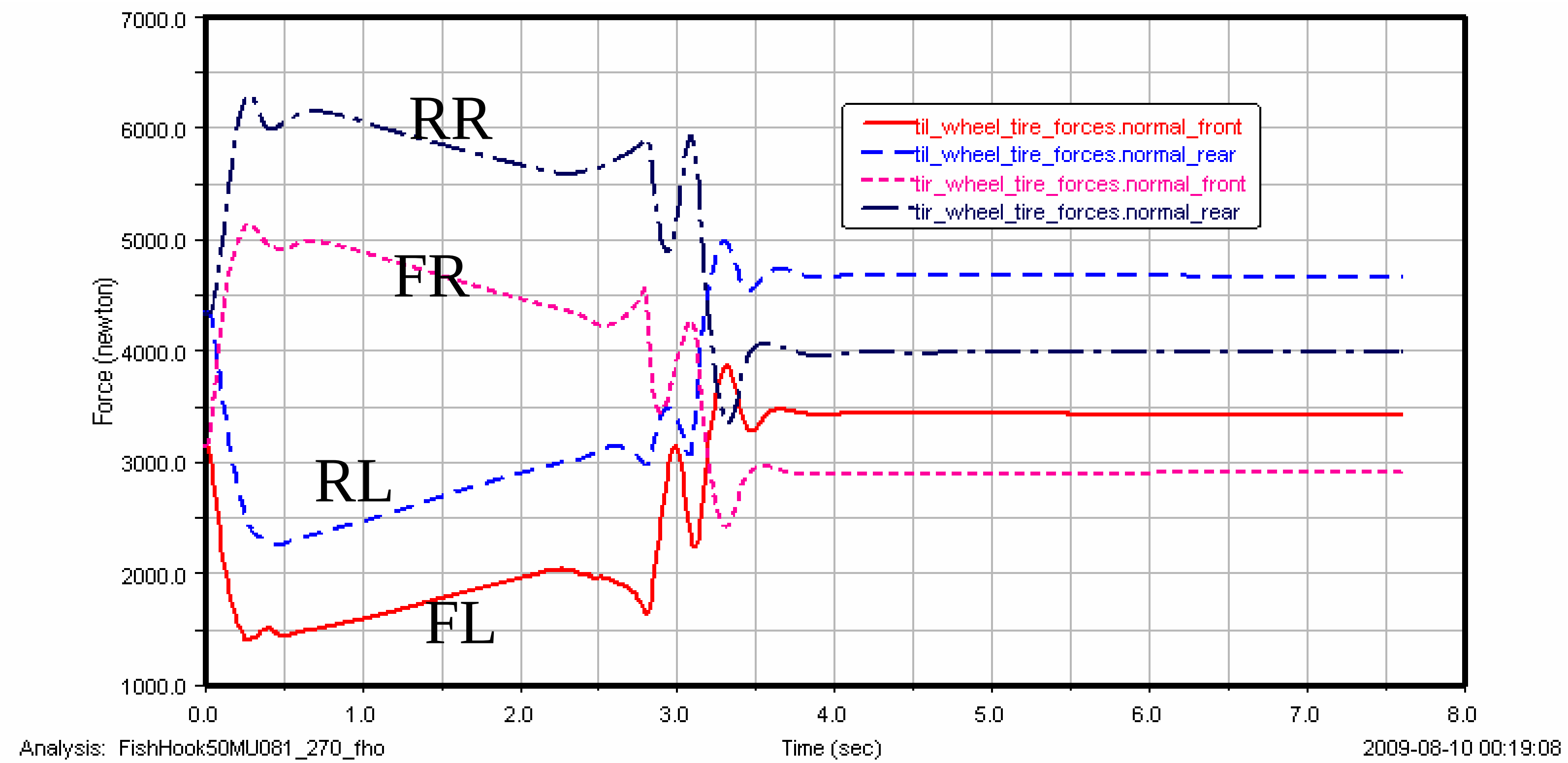
# Lateral Load Transfer Simulations



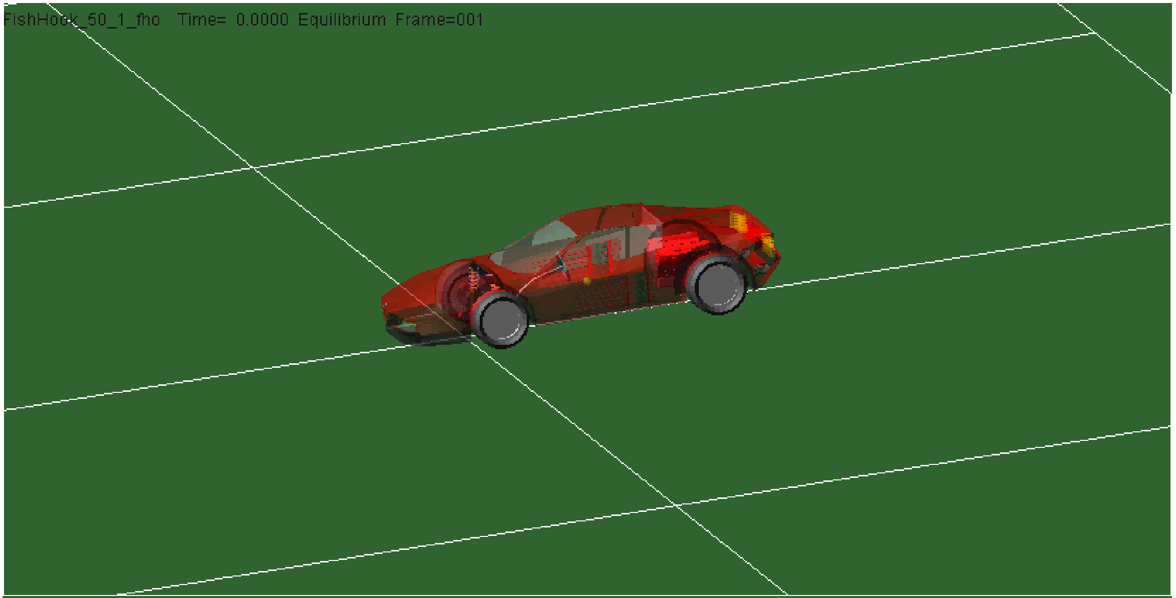



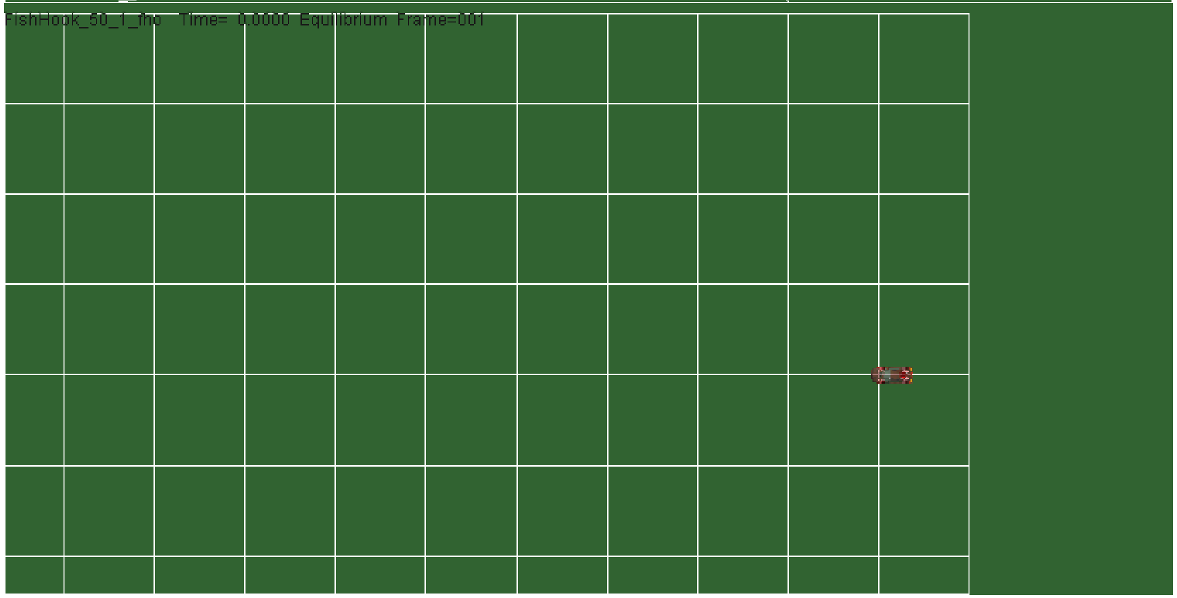
# Lateral Load Transfer Simulations

Normal Weight



# Fish Hook Maneuver



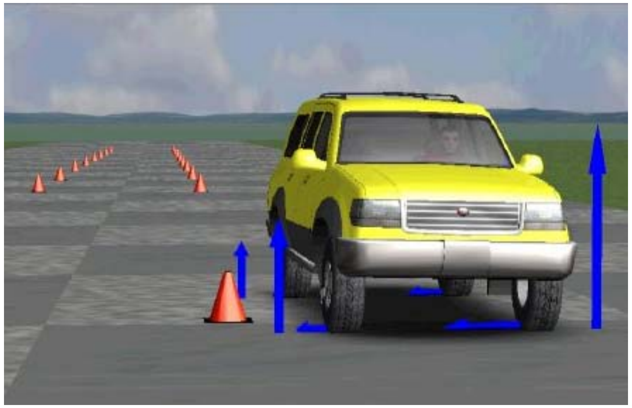



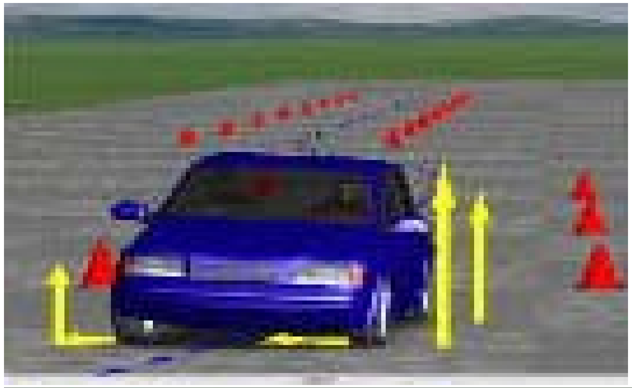
# Forces between Road and Wheel

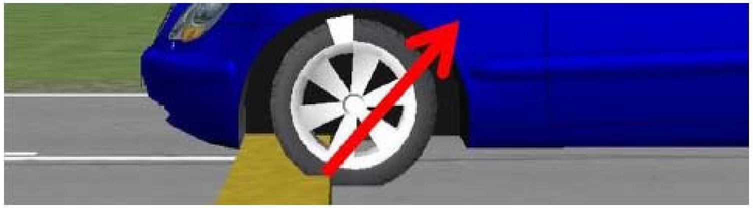
- Forces-F
  - Horizontal forward forces at the contact of the tires with the road -Traction Forces
  - Vertical forces at the contact of the tires with the road -Reactions
  - Side forces at the tire contact with the road – While taking a turn
- Study of response of vehicle to the forces that act at the four palm sized patches (at the tire and road contact)

# Forces between Road and Wheel

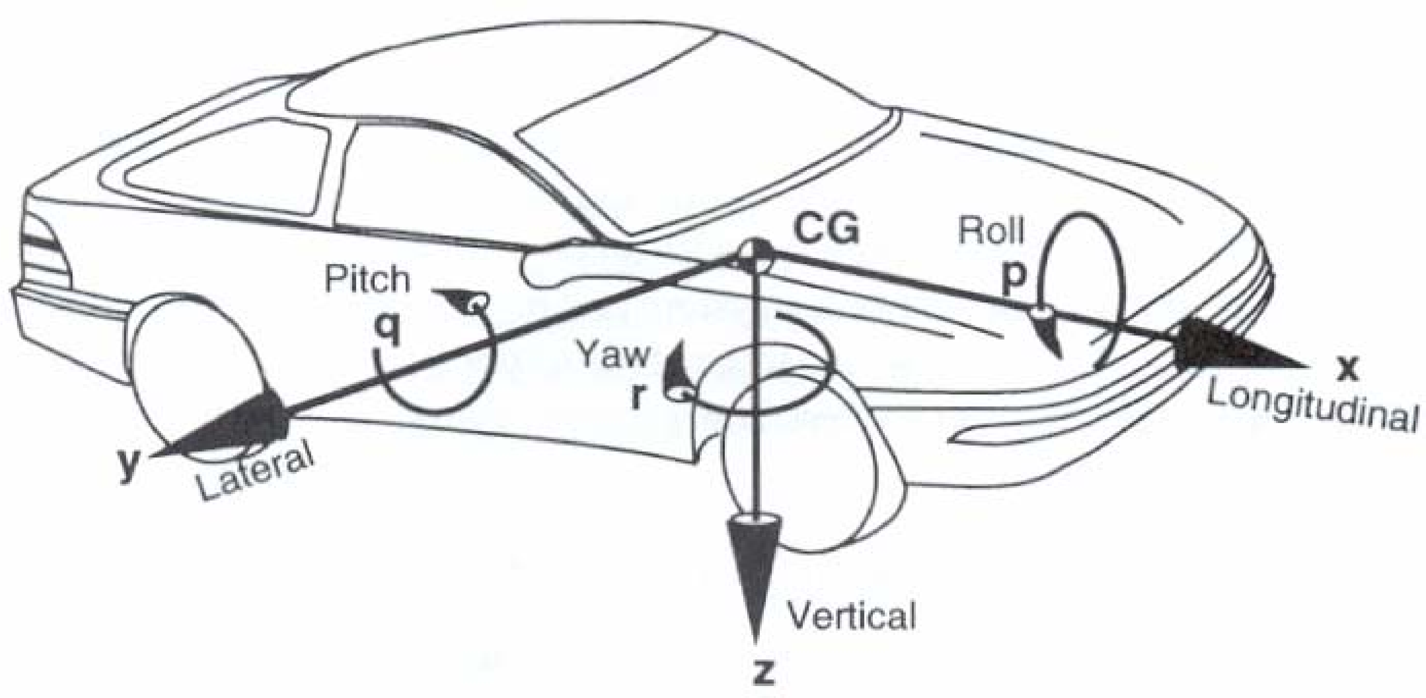
# Lateral and Vertical Forces





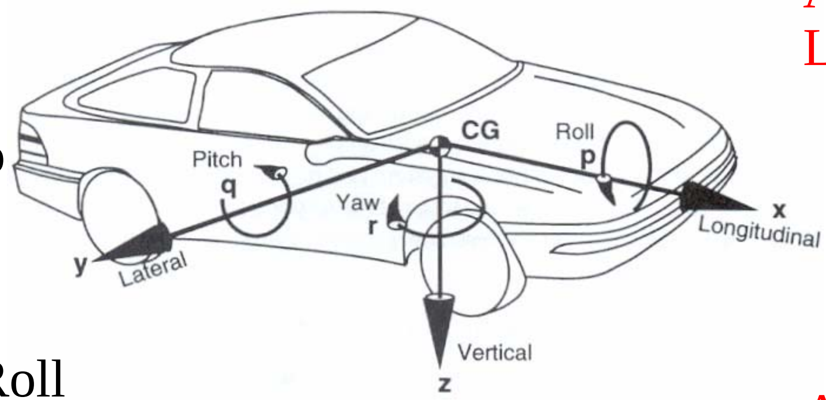


# SAE-Vehicle Co-ordinate System



# Vehicle Movements of Interest

- Along Y-Axis
  - Side force due to Cornering
  - Side force responsible for Roll
- About Y Axis
  - Pitching Caused by Diving (braking) and Squatting (Acceleration)
- Handling




- Along X-axis-Longitudinal
  - Acceleration of the Vehicle
  - Braking Performance
- About X-axis
  - Rolling caused by side forces
- Along Z-Axis-Vertical
  - Bouncing (Ride)
- About Z-Axis
  - Yaw caused by side forces

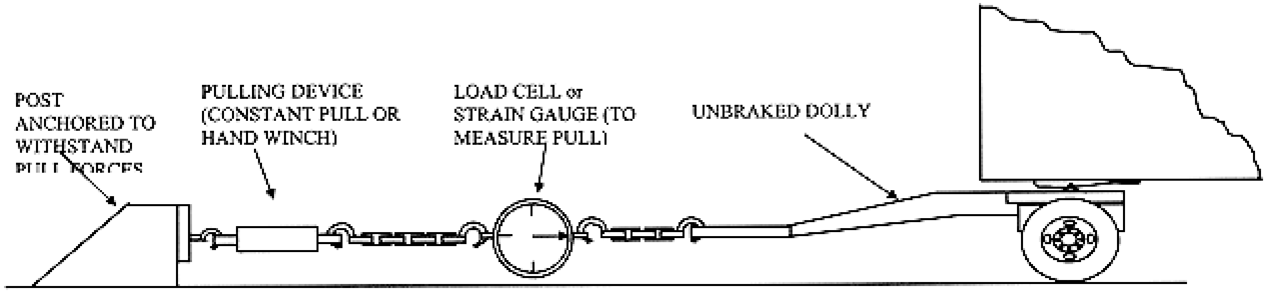
# Draw Bar Pull

The torque on the driving axle creates a force between the tyres and the road which is used to propel the vehicle. This gross force is termed the tractive effort and the net force, that is, gross force minus rolling resistance is the drawbar pull.

$$DP = \frac{T \times R \times 1000}{r} - RR$$

**Where:**

DP = Drawbar pull in newtons
T = Motor torque in newton metres
R = Overall gear reduction including both axle and transmission
r = Rolling radius of loaded driving tyre in millimetres
RR = Road rolling resistance in newtons
GVW = Gross vehicle weight of motive vehicle in kilograms




CLOSE UP VIEW OF EQUIPMENT SETUP