



Longitudinal and lateral dynamics

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Content of lecture

- **Basic terms and descriptions;**
- **Forces affecting a vehicle;**
- **Longitudinal and lateral dynamics of vehicles;**
- **Active Safety Systems which control forces of vehicles**
- **Electronic Stability-Program**



Basic terms and descriptions



Basic terms and descriptions

Force

What is a Force?

A force is a **Push** or a **Pull** that one body exerts on another.



Basic terms and descriptions

Net Force

The sum of the forces is called the net force._





Basic terms and descriptions

Net Force

Two forces acting in different directions. When the forces are equal and acting in different directions they balance each other out.

Separate Forces $\longleftrightarrow$ = 0 Net Force





Basic terms and descriptions

Weight

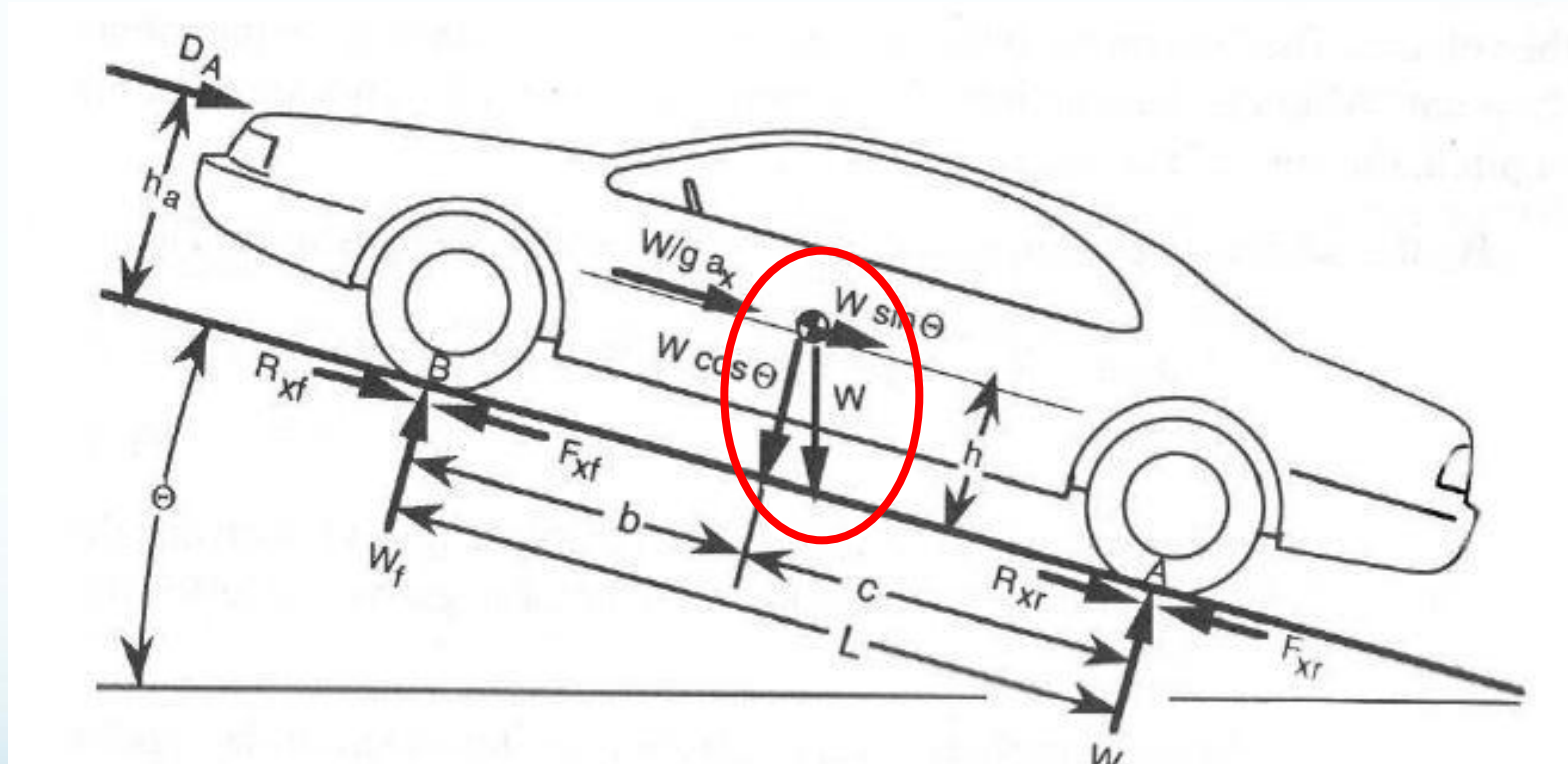
The weight of an object is defined as the force of gravity on the object and may be calculated as the mass times the acceleration of gravity, $w = mg$.

$$W = mg$$

Weight of object = mass of object x acceleration of gravity

At the Earth's surface, where $g=9.8 \text{ m/s}^2$

Weight





Speed

Speed is equal to distance travelled divided by the time taken.

If s is the length of the path traveled until time t , the speed equals the time derivative of distance s :

$$v = \frac{ds}{dt}.$$



Basic terms and descriptions

Speed units

Conversions between common units of speed

	m/s	km/h	mph	knot	ft/s
1 m/s =	1	3.6	2.236 936	1.943 844	3.280 840
1 km/h =	0.277 778	1	0.621 371	0.539 957	0.911 344
1 mph =	0.447 04	1.609 344	1	0.868 976	1.466 667
1 knot =	0.514 444	1.852	1.150 779	1	1.687 810
1 ft/s =	0.3048	1.097 28	0.681 818	0.592 484	1



Basic terms and descriptions

Kinetic Energy

Kinetic energy is a term that describes the energy a vehicle has due to its mass and speed.

Kinetic energy is energy of motion.

Kinetic energy = $\frac{1}{2}$ (mass) x (velocity)²

$$E = \frac{1}{2} m \cdot v^2$$
A diagram showing a yellow rectangular box with a blue border. Inside the box, the text "Mass m" is written in blue. To the right of the box, a blue arrow points to the right, with the text "Velocity v" written above it in blue. The entire diagram is enclosed in a red rectangular border.



Basic terms and descriptions

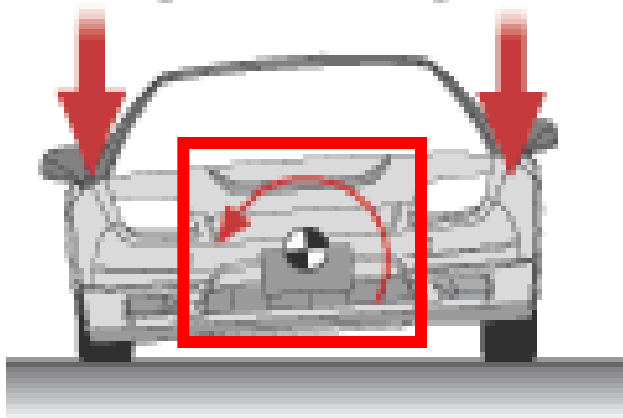
INERTIA

Inertia is the resistance to change the direction or velocity of a body in motion.

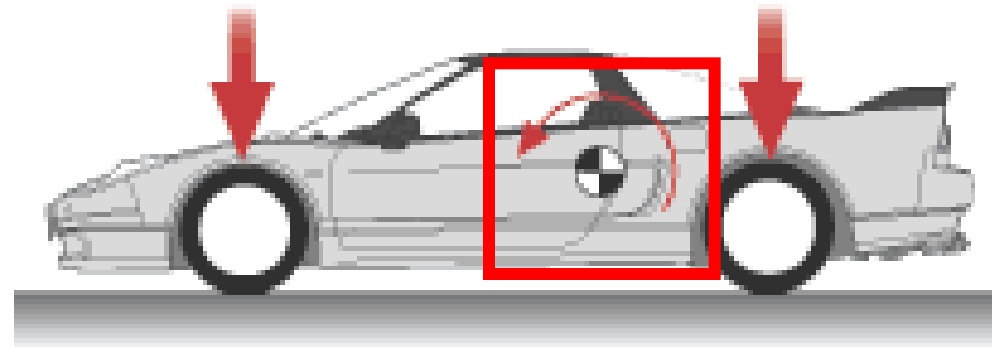
Inertia moments

Examples of inertia moments

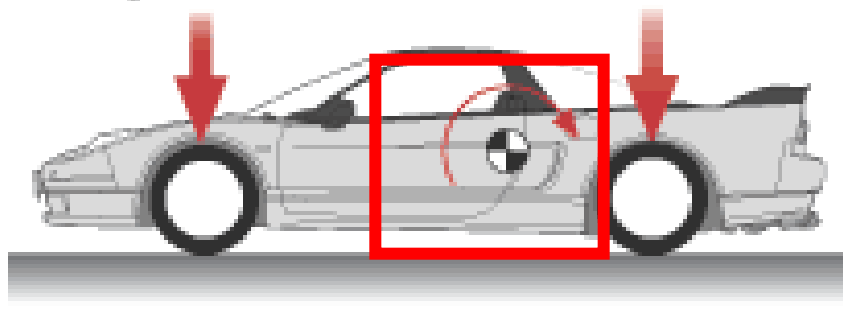
During cornering



During braking



During acceleration





Basic terms and descriptions

Moments of Inertia

- A. **Pitch** – the force felt in acceleration or braking movement around (Horizontal axis) of vehicle
- B. **Roll** – the force felt in cornering, side to side movement (Lateral axis) of the vehicle
- C. **Yaw** – the force felt in a spin movement around (Vertical axis) of the vehicle

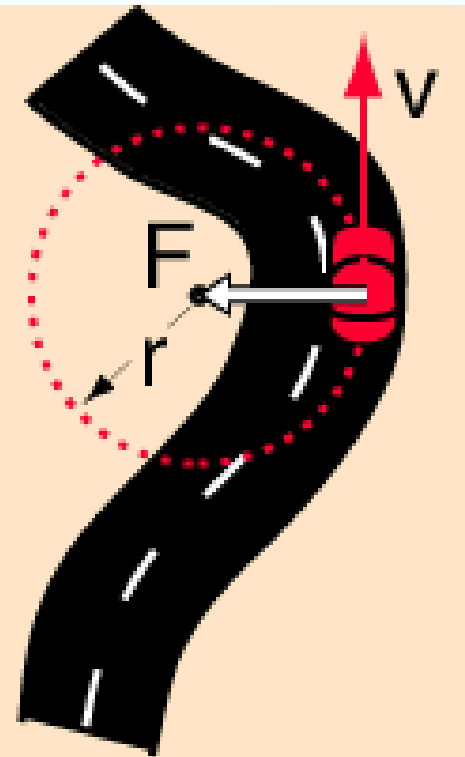


Centripetal Force

Any motion in a curved path represents accelerated motion, and requires a force directed toward the center of curvature of the path. This force is called the **centripetal force**.

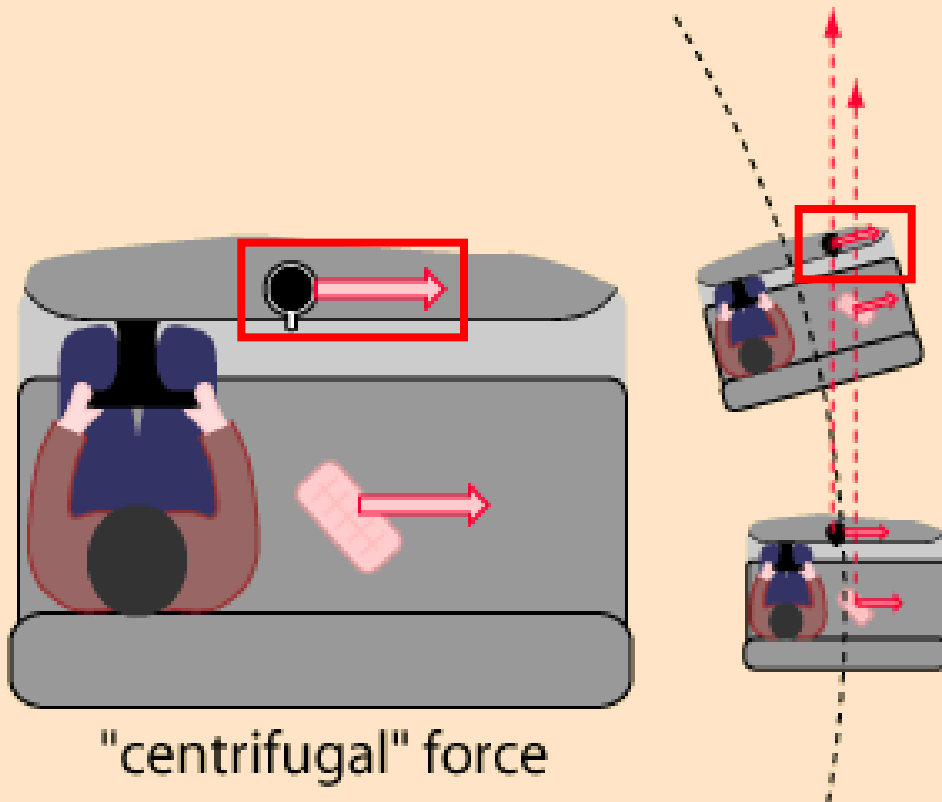
$$F_{\text{centripetal}} = m \frac{v^2}{r}$$

$\frac{v^2}{r}$ is the centripetal acceleration



Centrifugal Force

Centrifugal Force



When you move along a curved path, unattached objects tend to move toward the outside of the curve.



Basic terms and descriptions

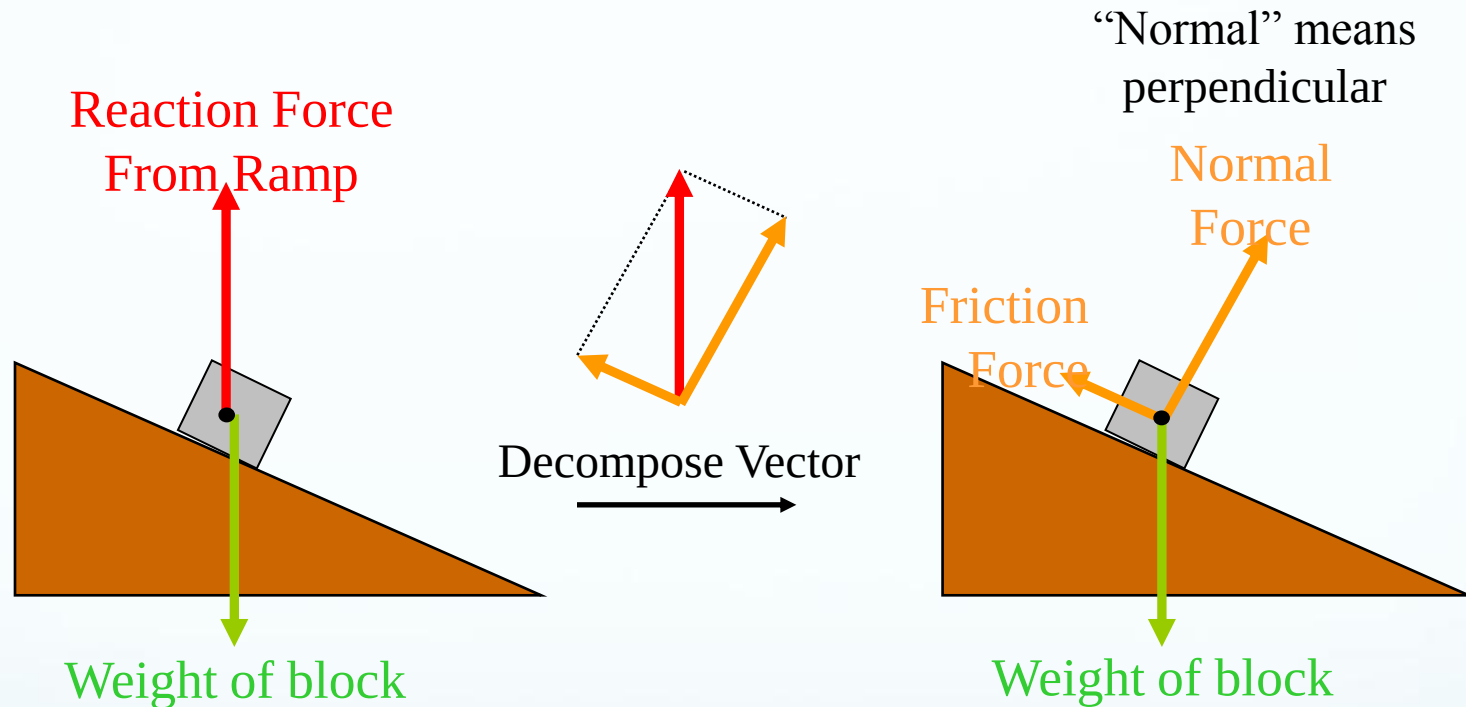
FRICITION

Friction is defined as the resistance to motion between two surfaces. There are four basic types of friction.

- A. Static – the holding force between two surfaces at rest;
- B. Sliding – the resistance to motion between two surfaces which are moving across each other;
- C. Rolling – the resistance to motion of a rolling object like a ball, cylinder or wheel;
- D. Internal – the resistance to motion within elastic objects (tires get warm from internal friction as they flex);



“Normal” Forces and Frictional Forces



Friction Force = Normal Force $\times$ (coefficient of friction)

$$F_{\text{friction}} = \mu \cdot F_{\text{normal}}$$

μ - frictional coefficient

Tyre Friction Coefficient

Average value of tire friction coefficient

<i>Road surface</i>	<i>Peak value</i>	<i>Sliding value</i>
Asphalt and concrete (dry)	0.80 – 0.90	0.75
Asphalt (wet)	0.50 – 0.70	0.45 – 0.60
Concrete (wet)	0.80	0.70
Gravel	0.60	0.55
Earth road (dry)	0.68	0.65
Earth road (wet)	0.55	0.40 – 0.50
Snow (hard-packed)	0.20	0.15
Ice	0.10	0.07



Traction

TRACTION

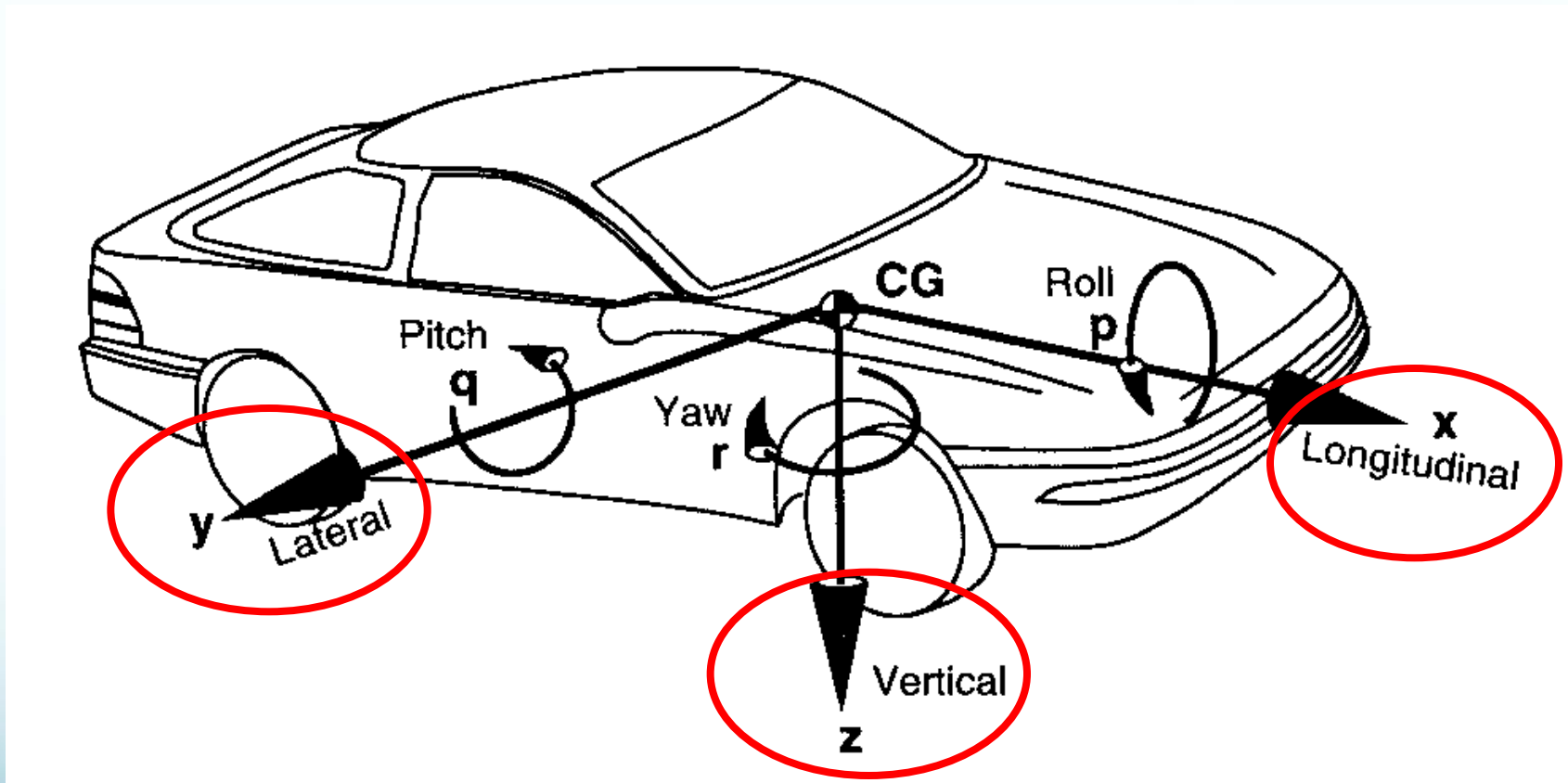
Traction is defined as the adhesive friction of the tire to the road surface. There are three traction forces:

- 1) Driving Traction – To accelerate the vehicle**
- 2) Braking Traction – To slow or stop the vehicle**
- 3) Cornering Traction – To turn the vehicle**

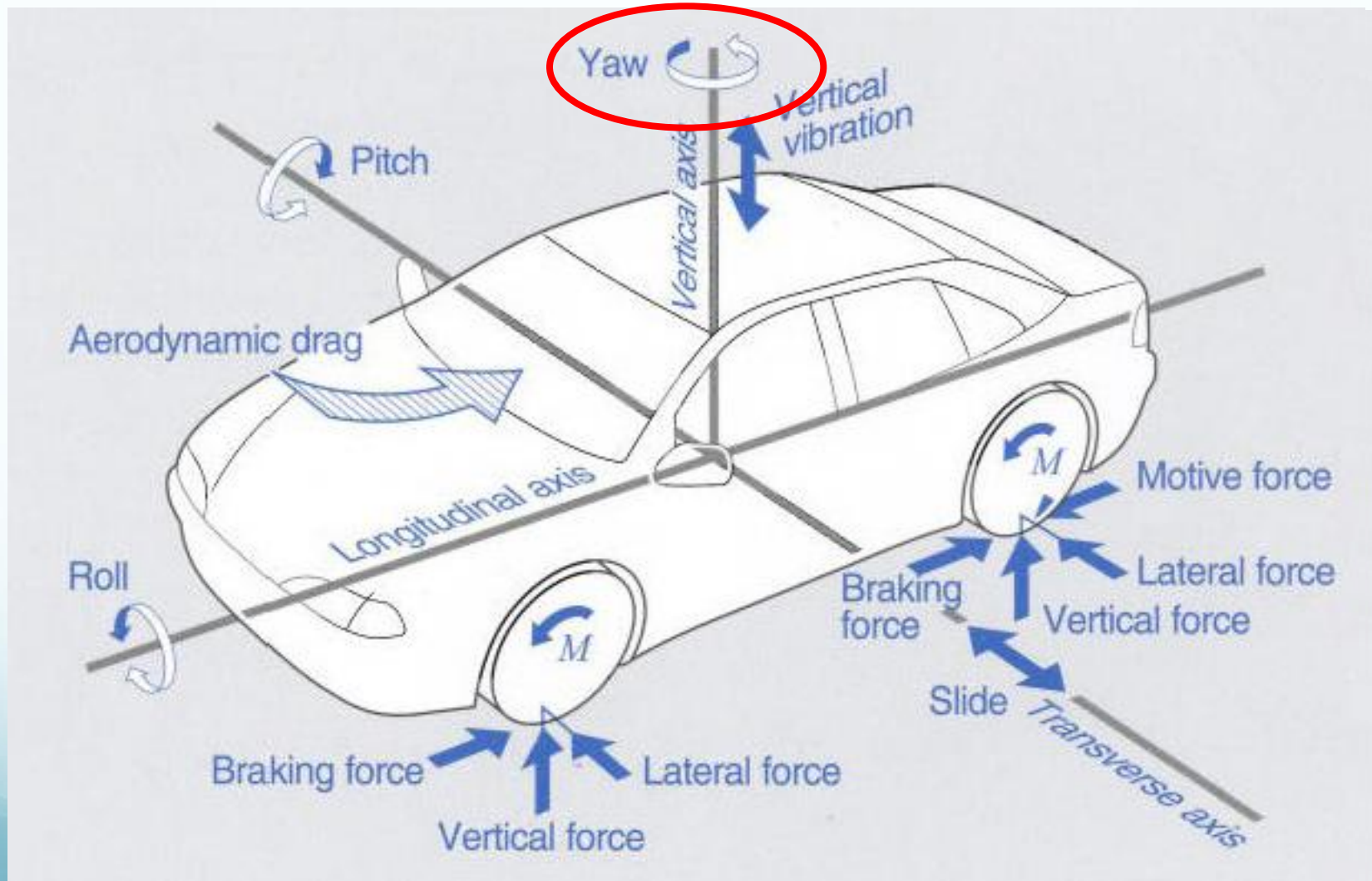


Longitudinal and lateral dynamics of vehicles

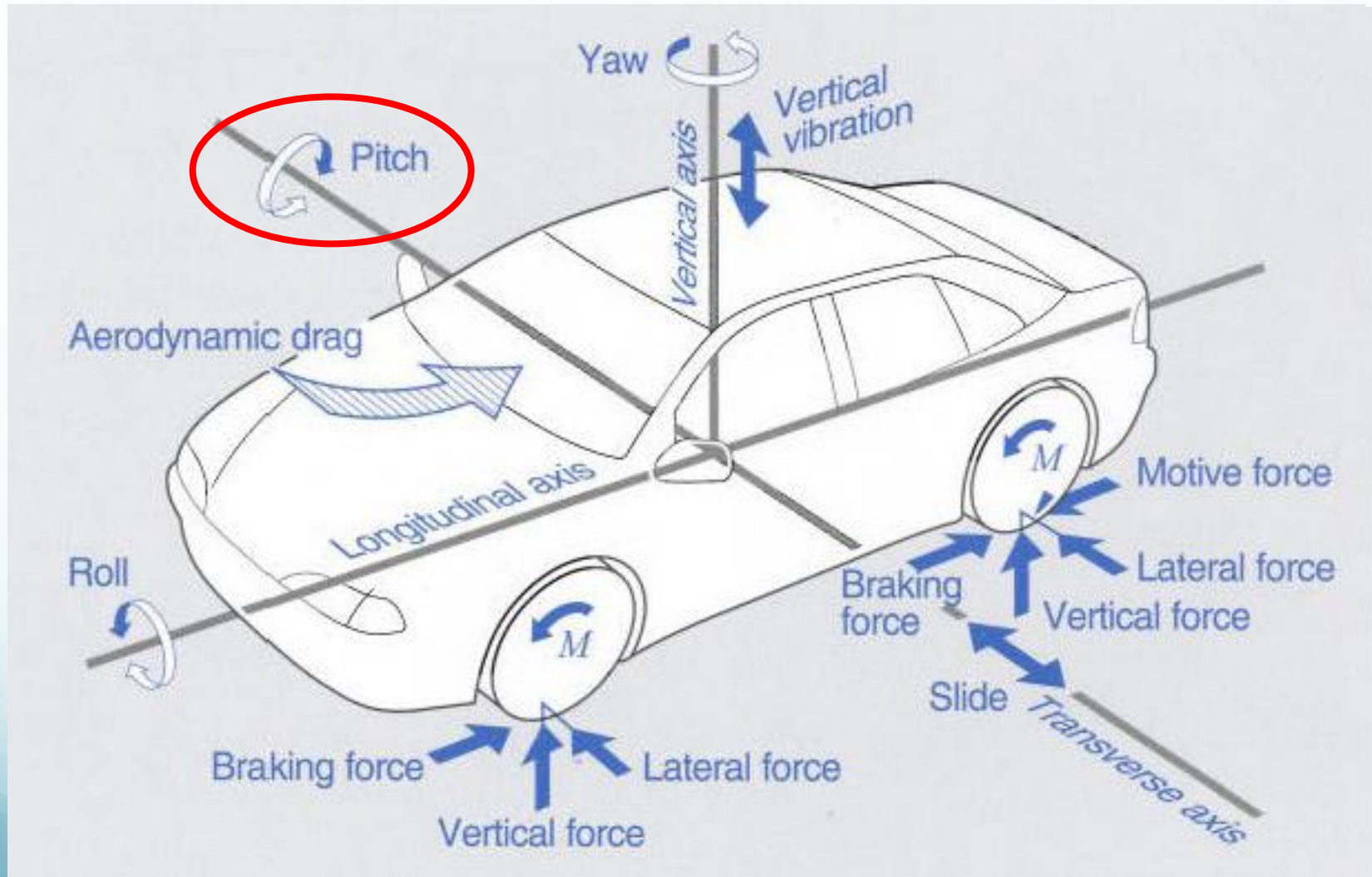
SAE vehicle axis system



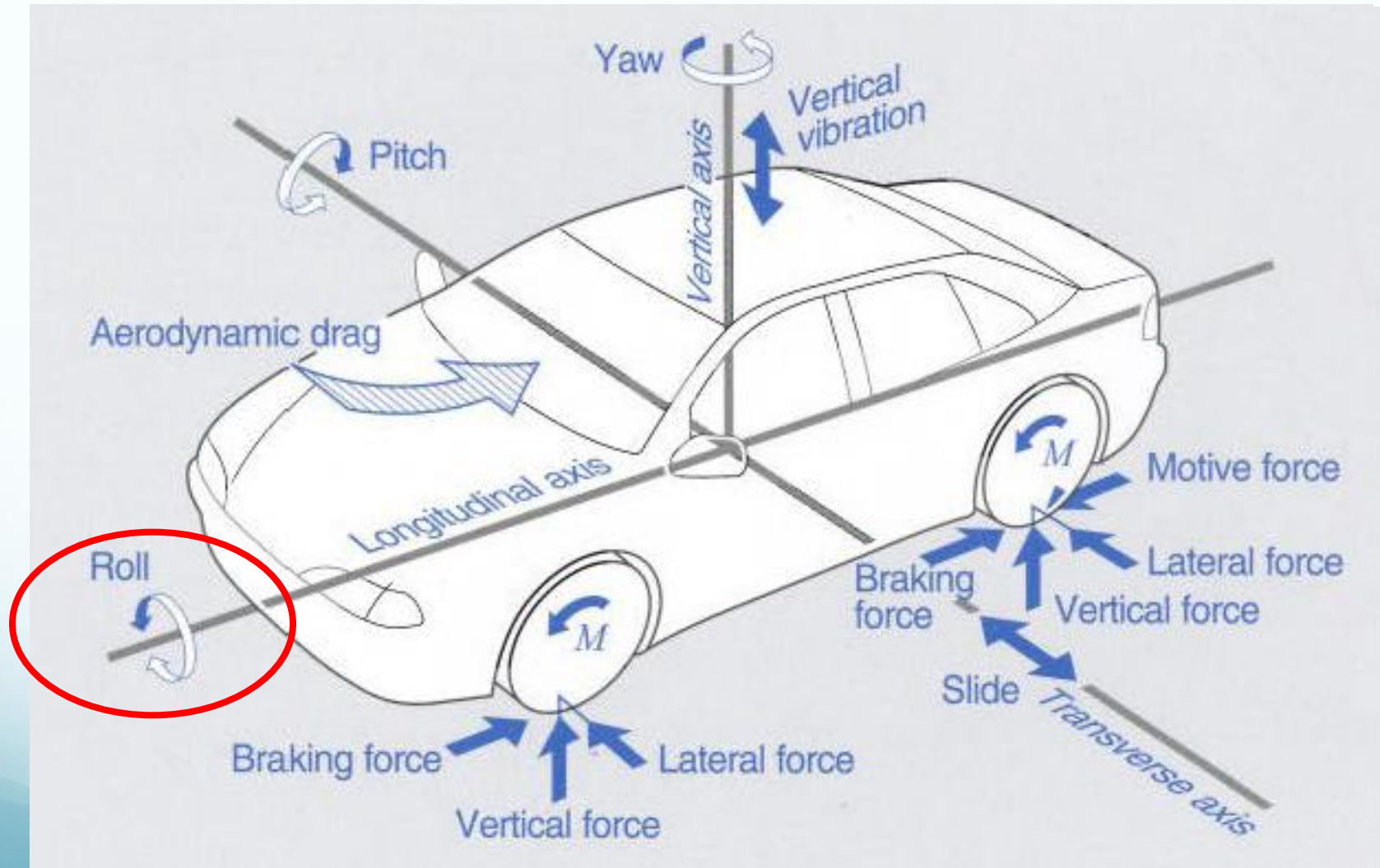
Moments affecting a vehicle



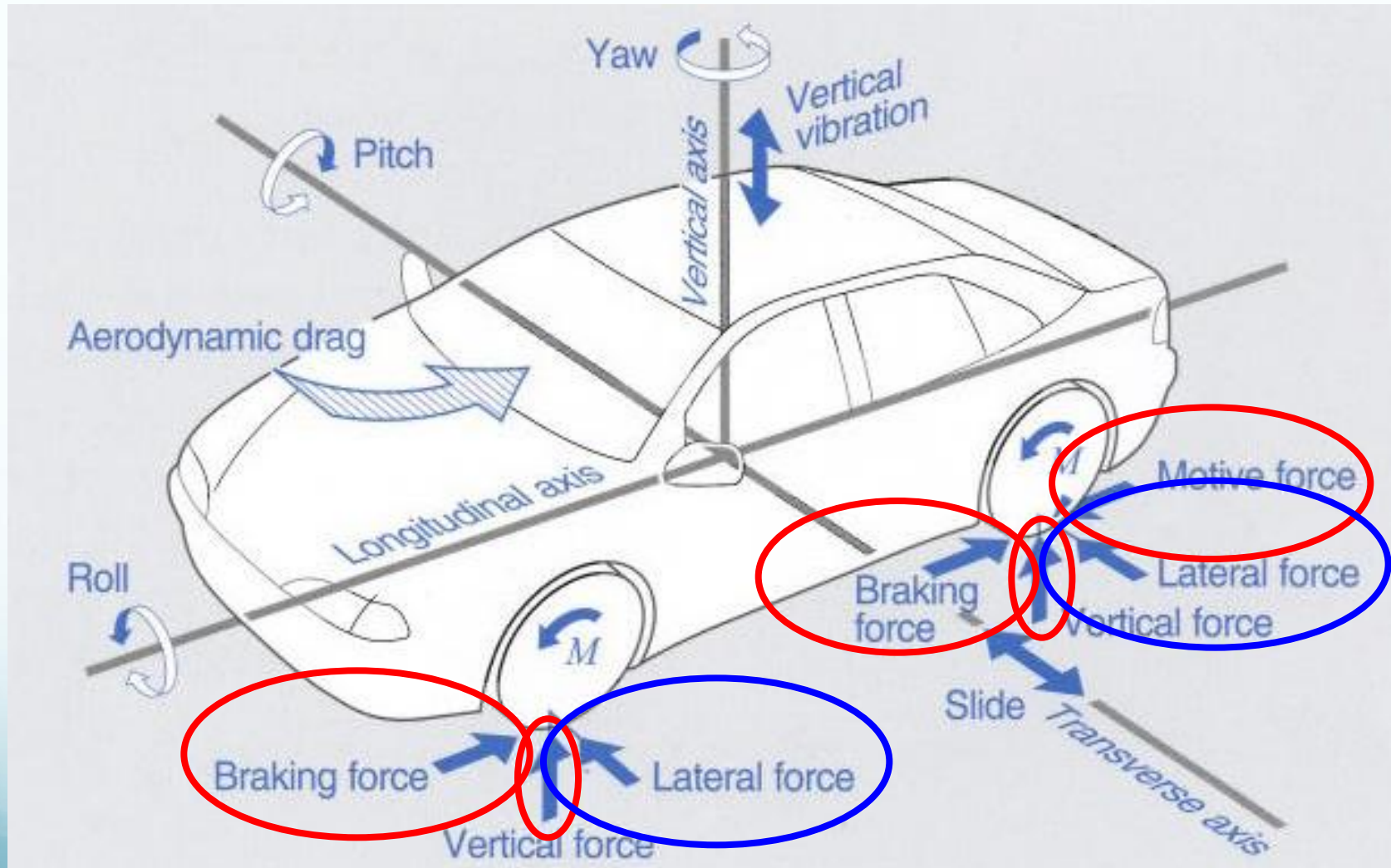
Moments affecting a vehicle



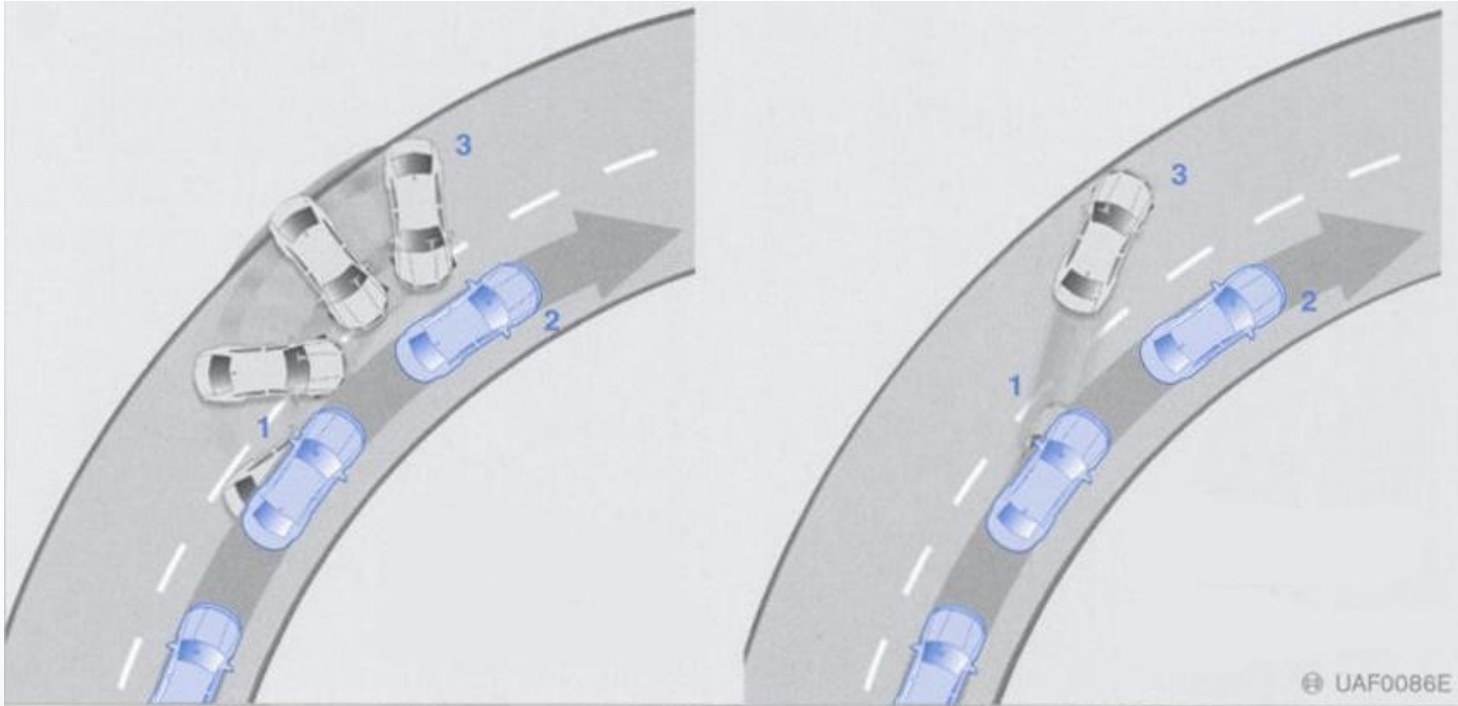
Moments affecting a vehicle



Forces affecting a vehicle



Forces affecting a vehicle



If the car starts to slide on any of the wheels, that means that the lateral, motive or braking force exceeds the force that wheel can handle and then slides in lateral and or longitudinal axis



Longitudinal and lateral dynamics

1. Resistance
 - a. Aerodynamic
 - b. Rolling
 - c. Up hill
2. Tractive Effort
3. Acceleration
4. Braking Force



Longitudinal dynamics. Resistance

Resistance is defined as the force impeding vehicle motion.

1. Aerodynamic resistance
2. Rolling resistance
3. Up hill resistance

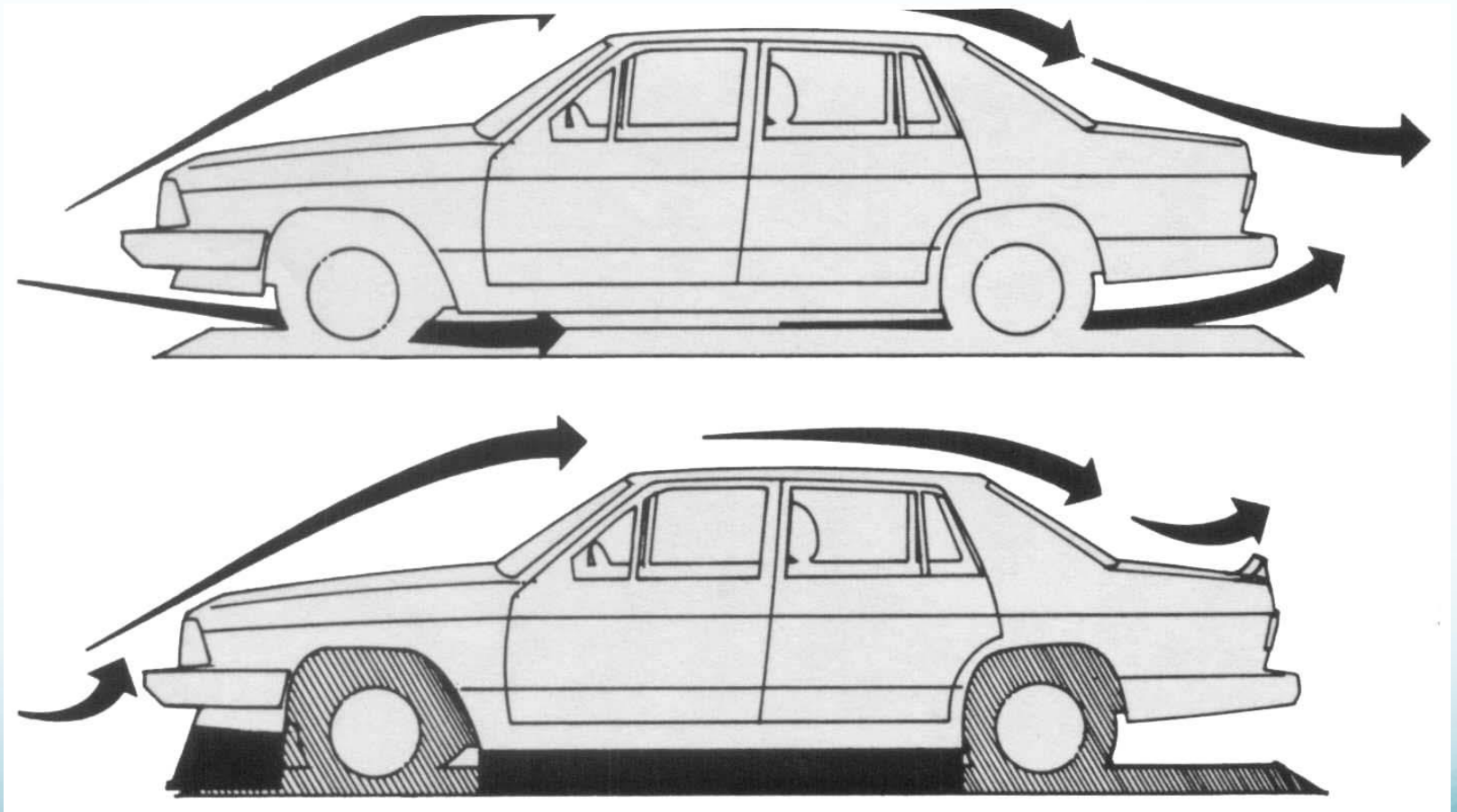


Aerodynamic Resistance R_a

Aerodynamic Resistance Composed of:

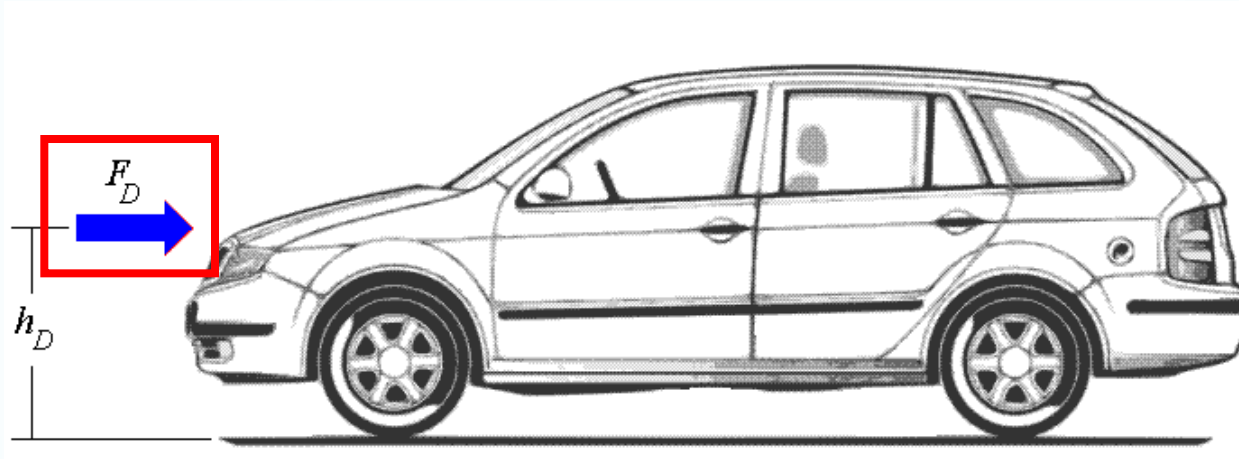
1. Turbulent air flow around vehicle body (85%)
2. Friction of air over vehicle body (12%)
3. Vehicle component resistance, from radiators and air vents (3%)

Aerodynamic Resistance R_a





Aerodynamic Resistance. Drag force.



The **drag force** is acting at height h_D above the ground.

$$F_D = 0.5\rho C_D A v^2;$$

Where ρ :
- Atmospheric air density (= 1.225 kg/m³)

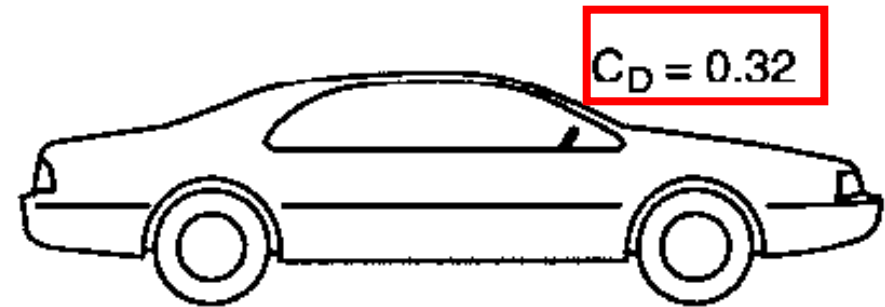
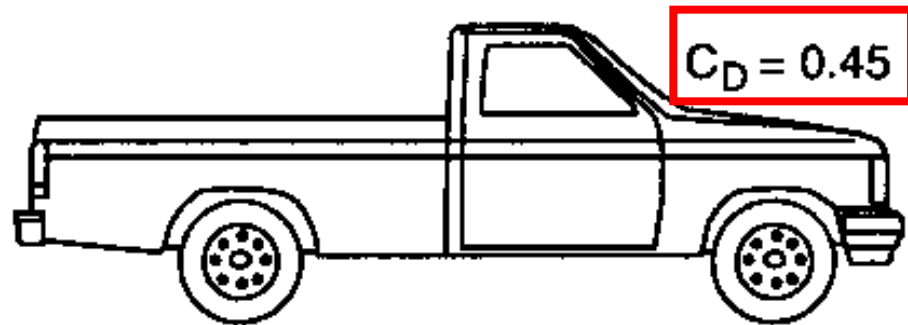
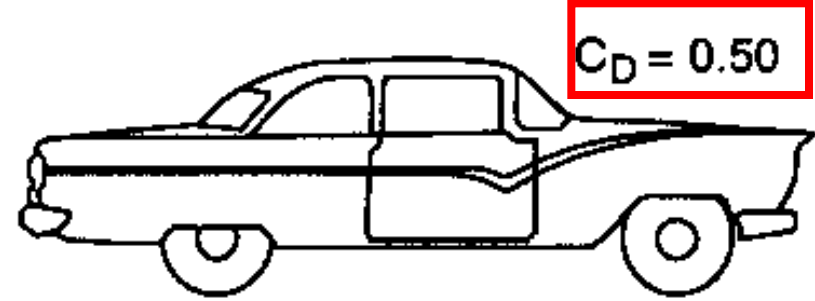
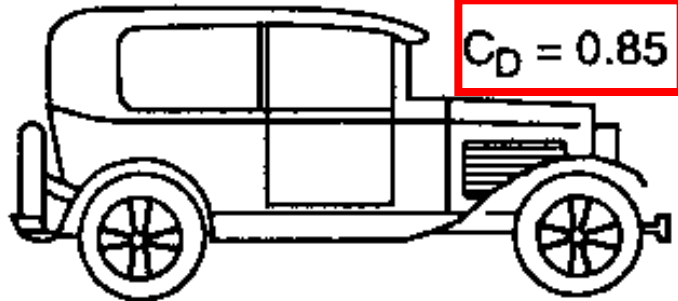
C_D - Drag factor

A - Area of vehicle frontal projection

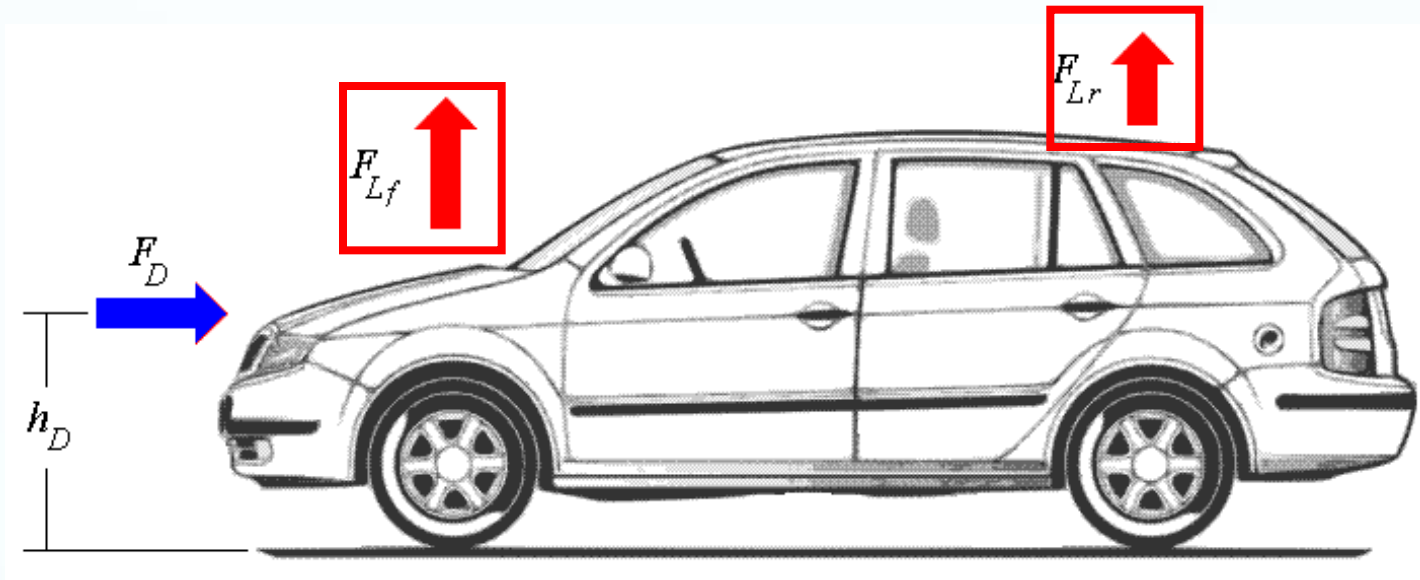
v - speed of vehicle



Aerodynamic Resistance. Drag factor.

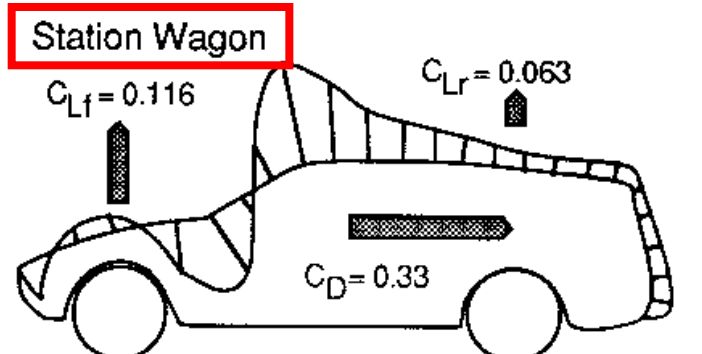
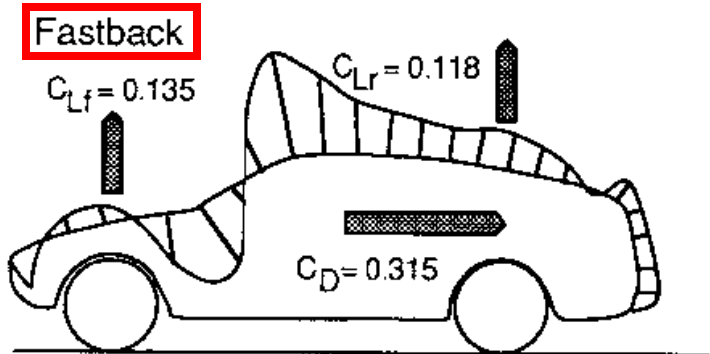
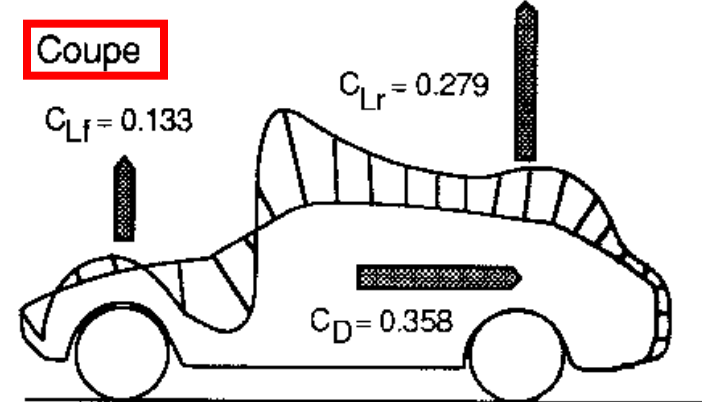
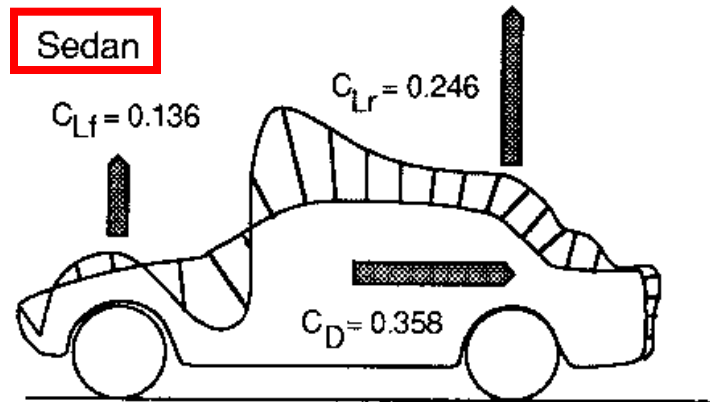


Aerodynamic Resistance. Lift force.



The **front lift force** ($F_{L_f} = 0.5\rho C_{L_f}Av^2$) and the **rear lift force** ($F_{L_r} = 0.5\rho C_{L_r}Av^2$).

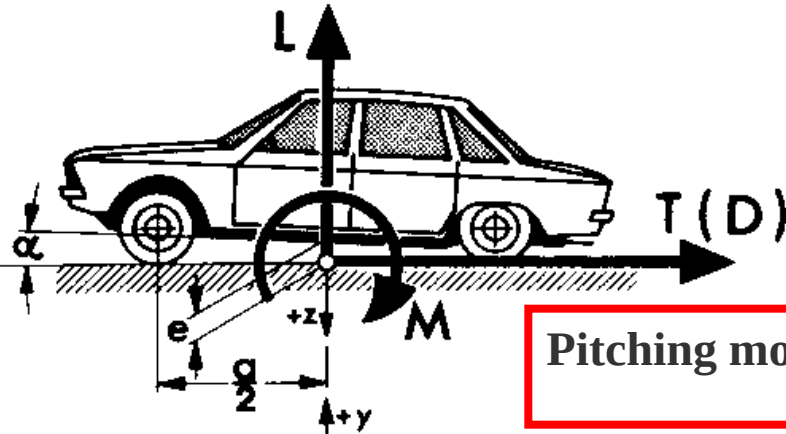
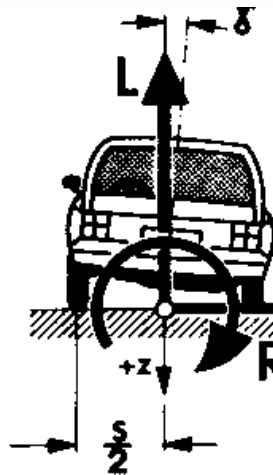
Aerodynamic Resistance.



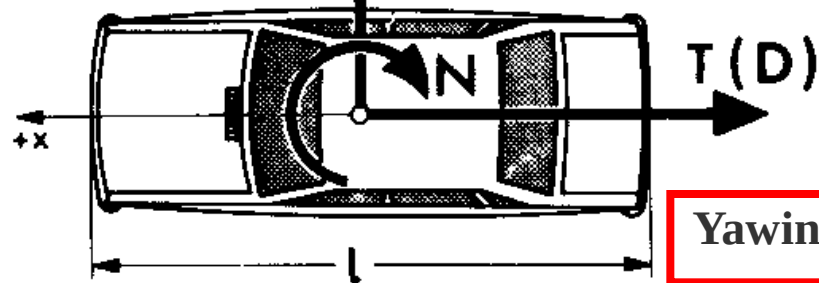
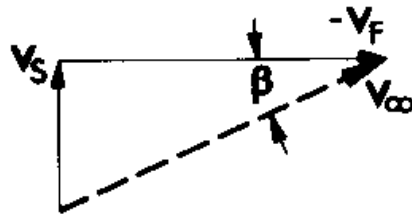
Aerodynamic lift and drag forces with different vehicle styles

Aerodynamic Resistance

Rolling
moment



Pitching moment



Yawing moment

The result of air stream interacting with the vehicle is forces and moments.



Rolling Resistance R_{rl}

Composed primarily of :

1. Resistance from tire deformation (~90%)
2. Tire penetration and surface compression (~ 4%)
3. Tire slippage and air circulation around wheel(~6%)

$$R_{rl} = f_{rl}W$$

Where: f_{rl} - roling resistance coeficient;
 W - weight of vehicle.



Up hill Resistance R_g

Composed of :

- Gravitational force acting on the vehicle:

$$R_g = W \sin \theta_g$$

For small angles, $\sin \theta_g \approx \tan \theta_g$

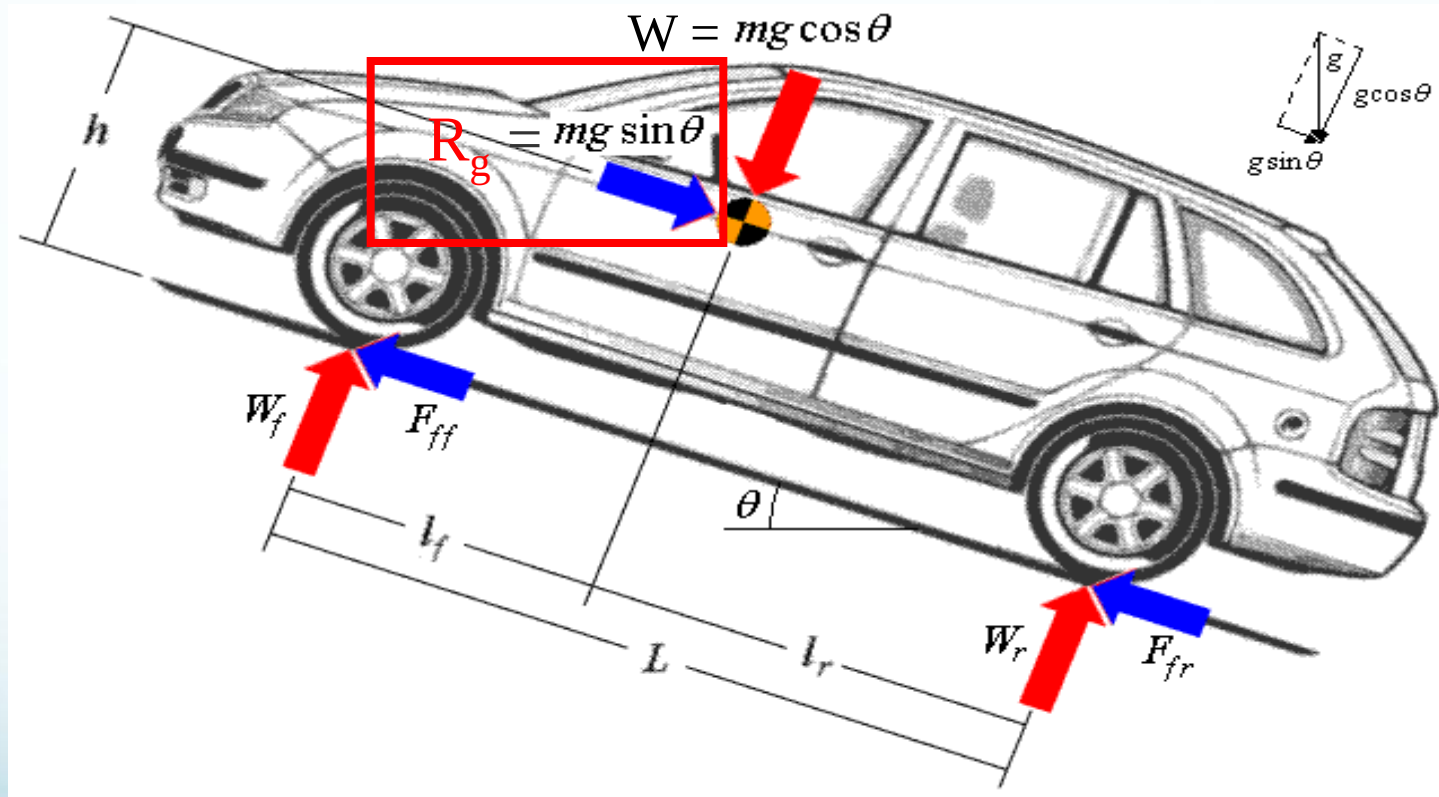
$$R_g = W \tan \theta_g$$

$$\tan \theta_g = G$$

$$R_g = WG$$



Up hill Resistance R_g





Up hill Resistance R_g

UP hill:

- 1- Increase the car motion resistance; $R_g = W \sin \theta$
(against the direction of motion)
- 2-Increase the load on rear axle and decrease the load on the front one.
- 3-Decrease the stopping distance when using the brakes



When you are driving uphill, the force of gravity is working against you.



Your traction could be reduced depending upon road conditions.



Down hill effect on the car

Down hill:

- 1- Increase the tractive force,
- 2- Increase the load on front axle and decrease the load on the rear one.
- 3- Increase the stopping distance when using the brakes

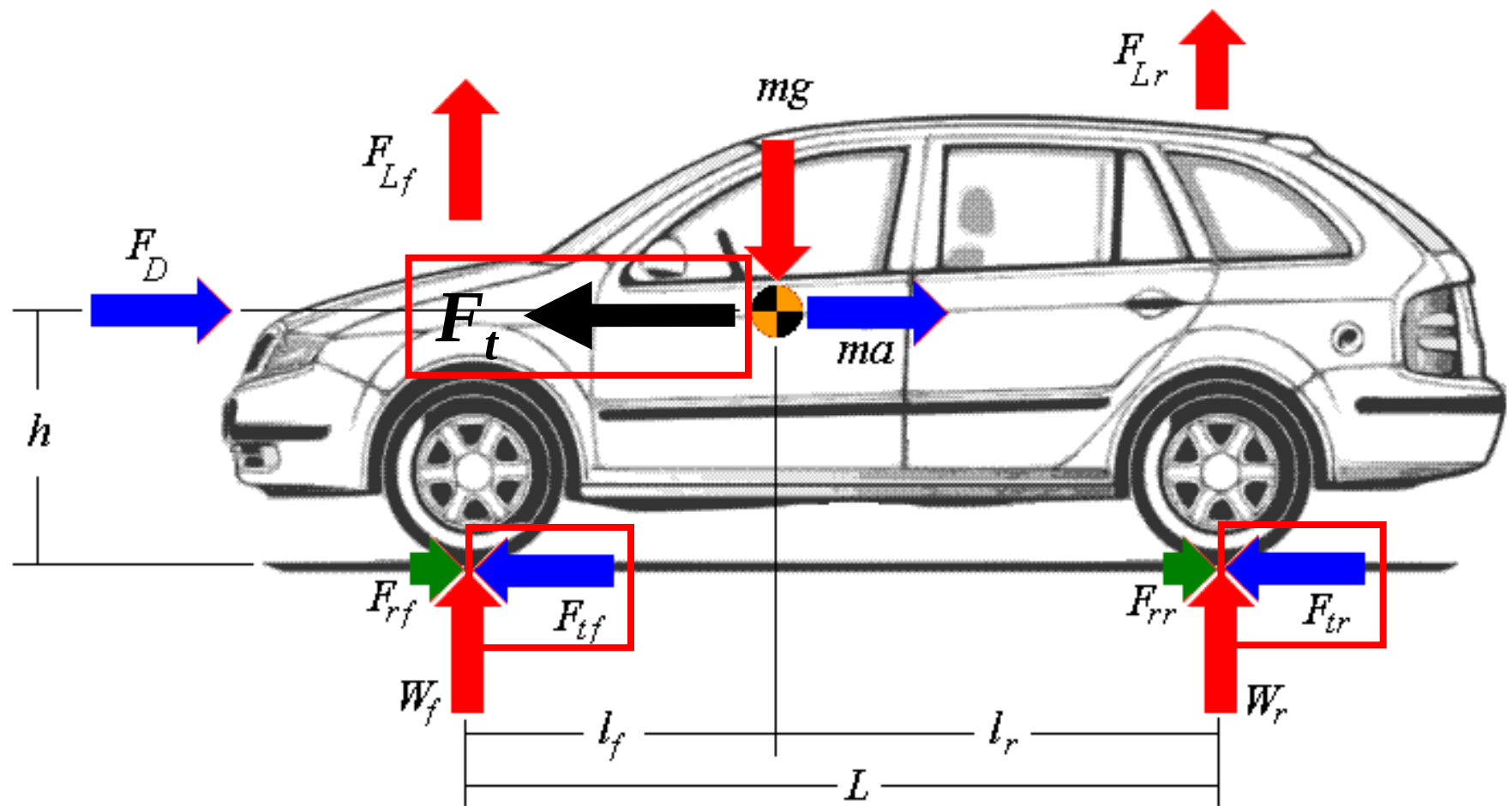


Traction

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- 1) Driving Traction – To accelerate the vehicle;**
- 2) Braking Traction – To slow or stop the vehicle;**
- 3) Cornering Traction – To turn the vehicle.**

Tractive force





Tractive force

The net power available for accelerating the vehicle will be:

$$P_t = T_t \omega_t = (\eta_t T_e)[(1 - i)\omega_e] = \eta_t(1 - i)P_e$$

The **engine power** (P_e) is the product of its torque (T_e) and angular velocity (ω_e):

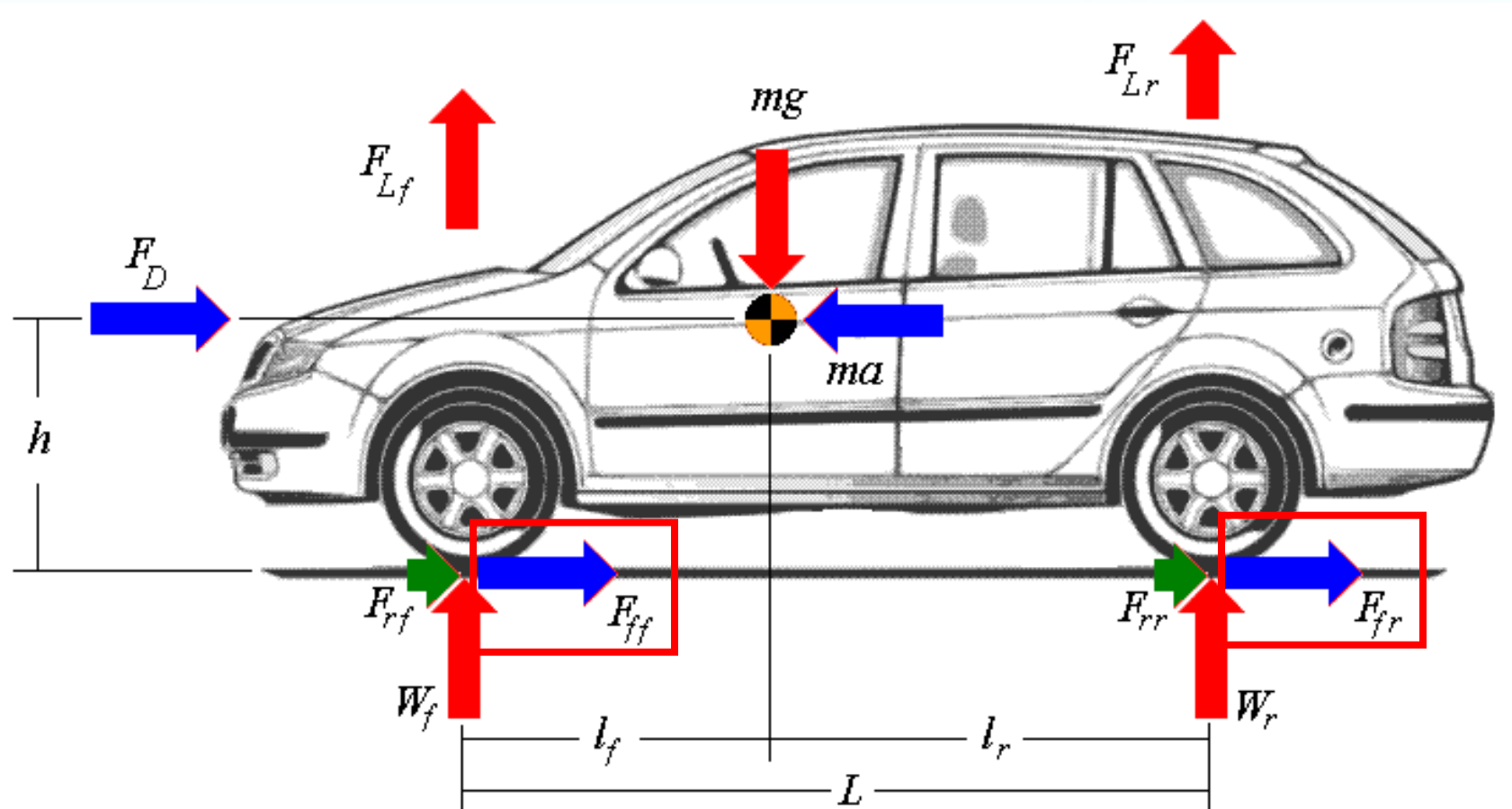
$$P_e = T_e \omega_e$$

Where:

η_t - The **efficiency** of a power transmission system . It is
 $\eta_t = 0.93$;

i - slip of a power transmission system;

Braking forces





Braking forces

From the previous figure we can define the total friction force (F_f), the total rolling resistance (F_r) and the net vertical force (F_v):

$$F_f = F_{ff} + F_{fr} = \mu F_v$$

$$F_v = mg - F_{Lf} - F_{Lr} = mg - F_L = (1 - F_L/mg)mg = (1 - 0.5\rho C_L A v^2/mg)mg$$

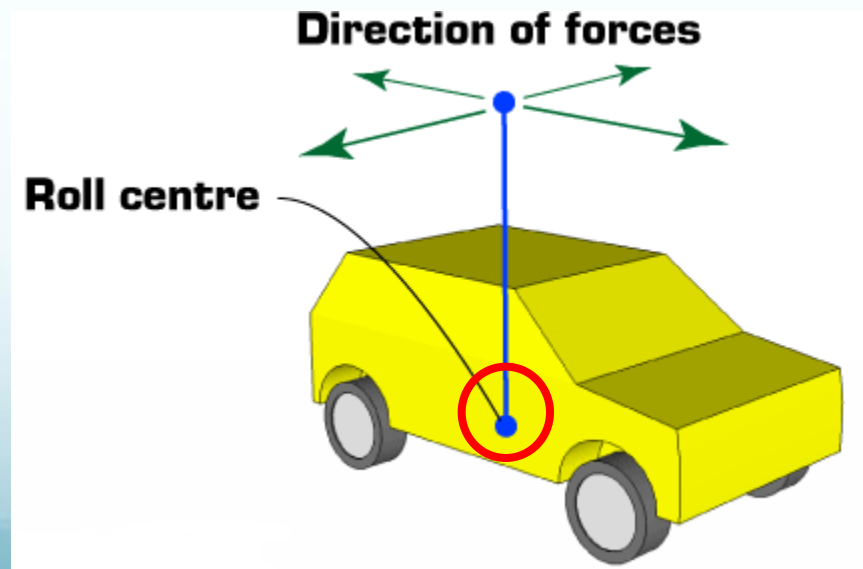
Where:

ρ = atmospheric air density ($= 1.225 \text{ kg/m}^3$); C_{DA} = drag factor; C_{LA} = lift factor; m = vehicle mass; g = gravitational acceleration ($= 9.80665 \text{ m/s}^2$); μ = tyre road friction coefficient; f_r = rolling resistance coefficient

Weight transfer

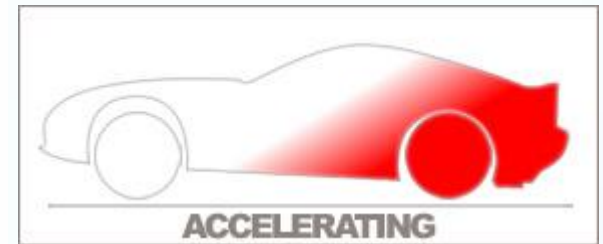
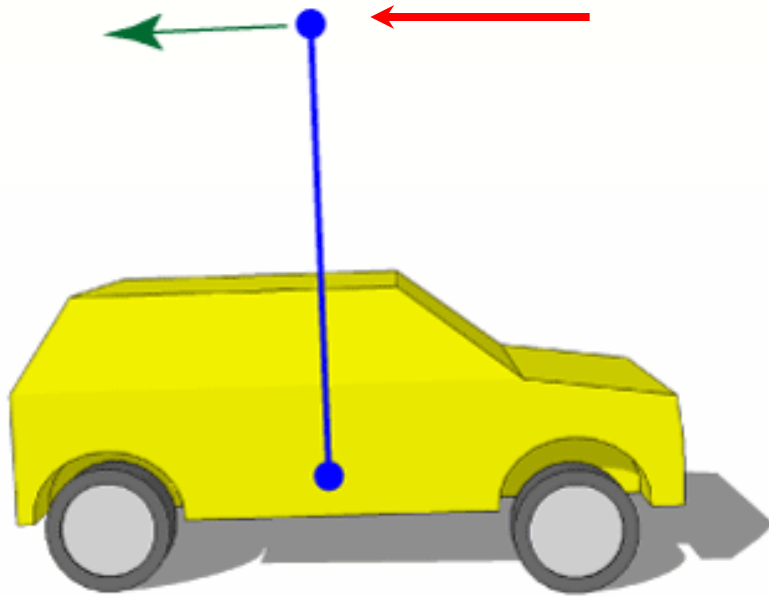
The major effect of the basic vehicle dimensions is weight transfer. Weight transfer is unavoidable.

Weight transfers occur as a result of the chassis twisting around the car's roll centre.





Rear Weight transfer due to acceleration

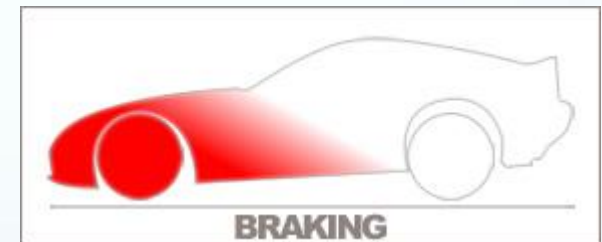
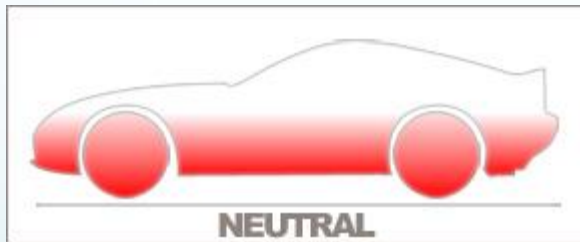


When you accelerate, the weight of the car is thrown backwards. This causes the rear suspension to compress slightly and increases the available grip at the rear tires.



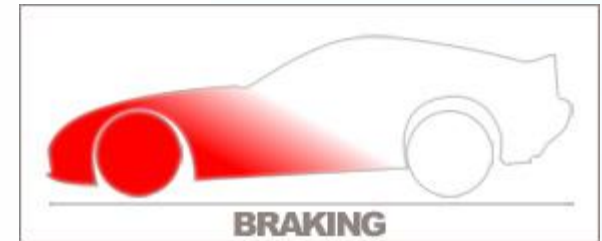
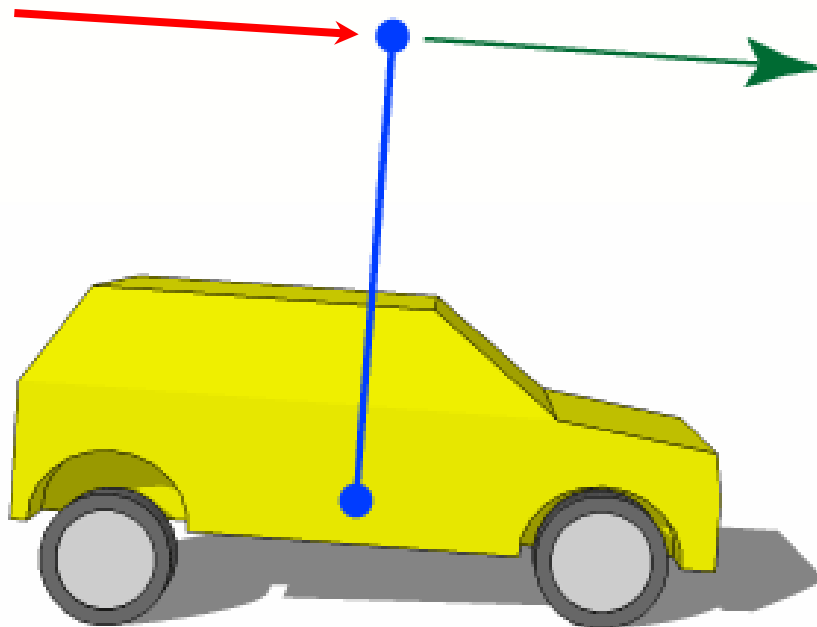
Weight transfer

The major effect of the basic vehicle dimensions is weight transfer. Weight transfer is unavoidable.



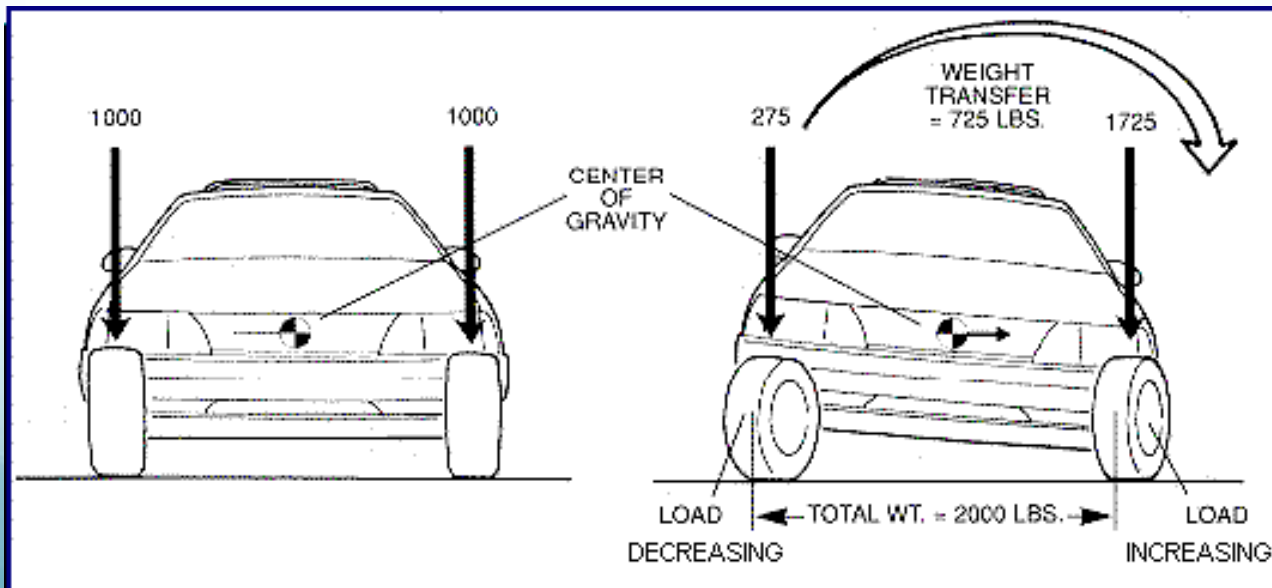
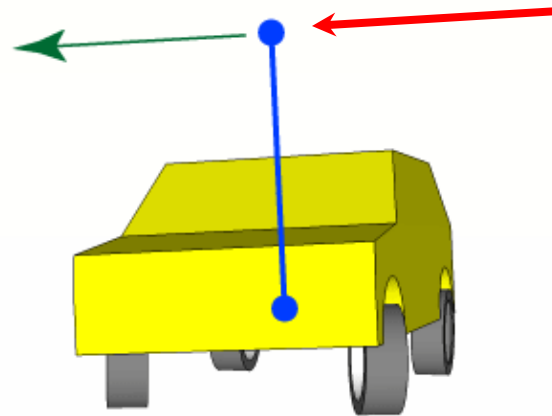


Forwards Weight transfer due to braking

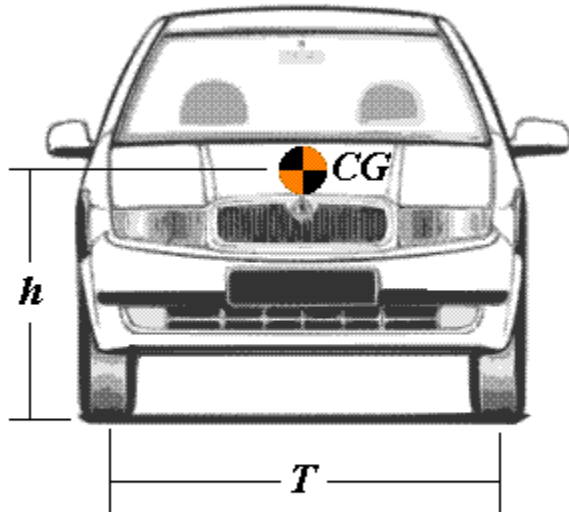


Weight transfers under braking are thus more likely to affect the balance of the car.

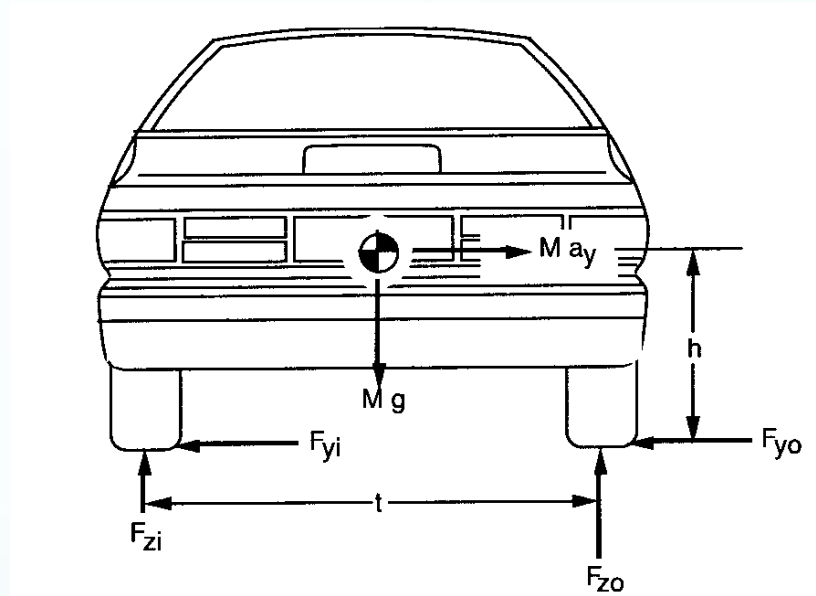
Weight transfer as a result of steering



Rollover forces

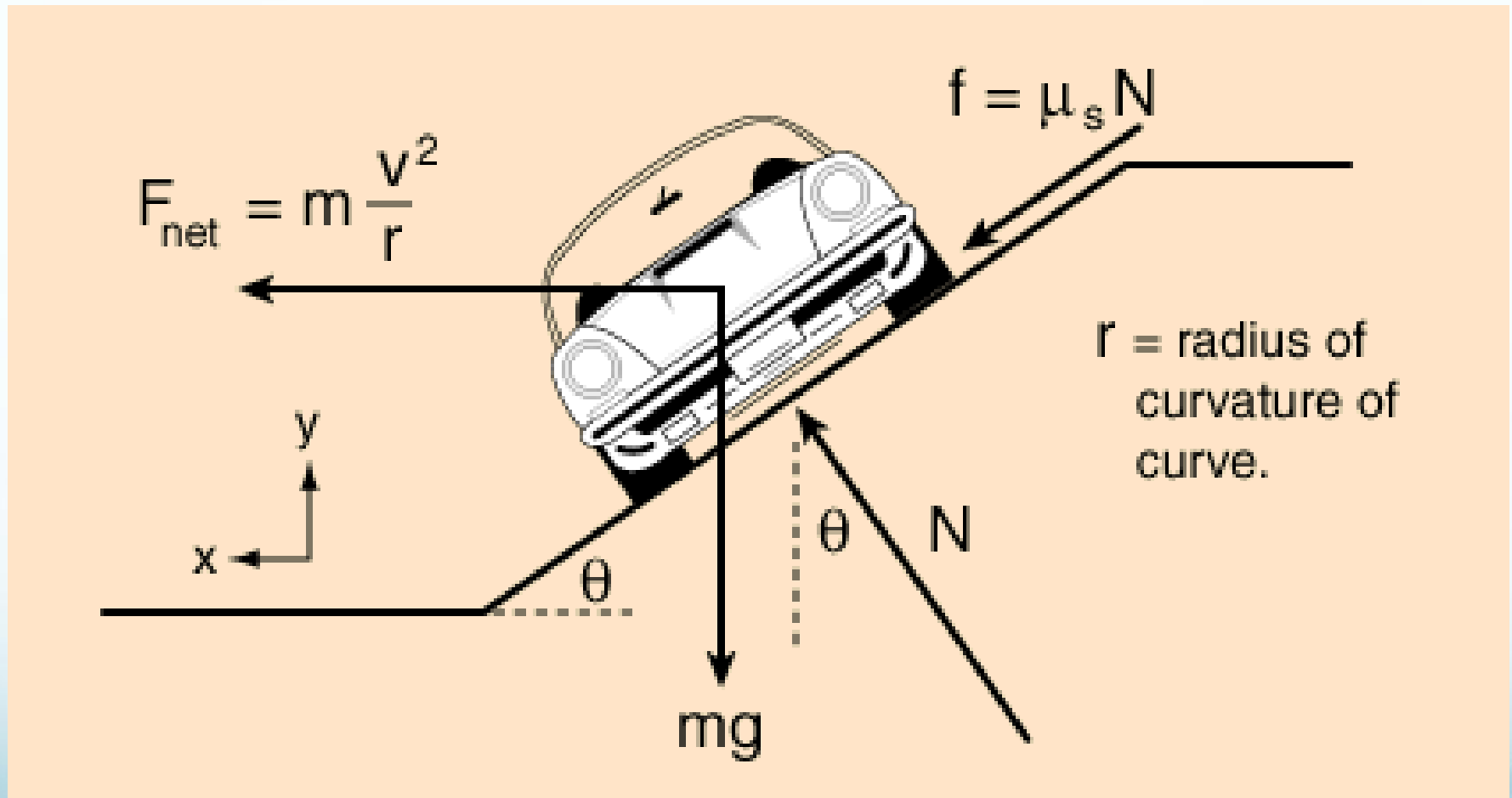


dimensions



Forces acting to roll over a vehicle

Maximum Speed on Banked Roadway





Maximum Speed on Banked Roadway

Equation of maximum speed:

$$v_{\max} = \sqrt{\frac{rg(\sin \theta + \mu_s \cos \theta)}{\cos \theta - \mu_s \sin \theta}}$$

The limiting cases are:

$$v_{\max} = \sqrt{rg \tan \theta}$$

Frictionless case

$$v_{\max} = \sqrt{rg \mu_s}$$

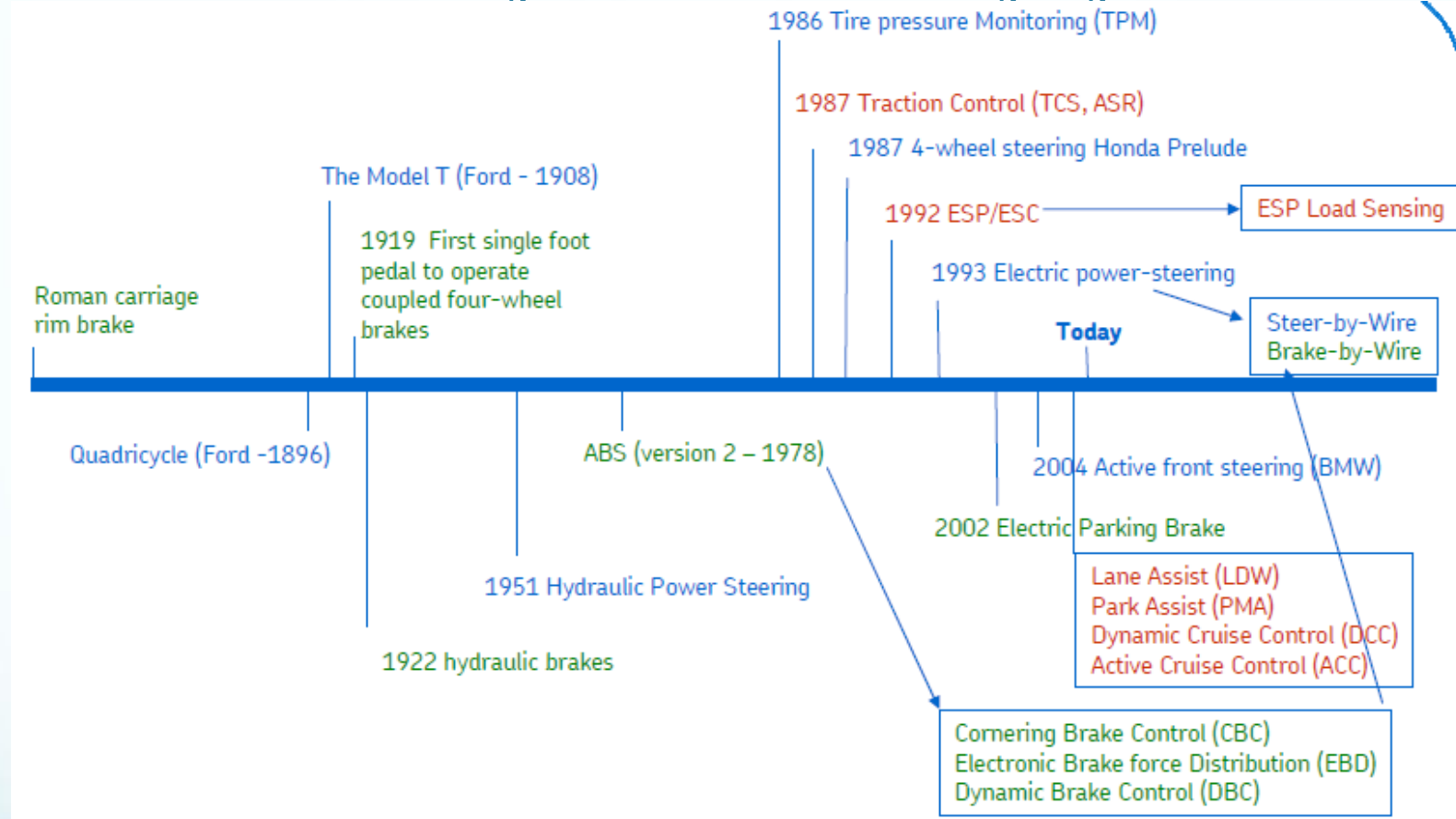
Flat roadway



Active Safety Systems which control forces of vehicles



History of main safety systems



We can see that the hydraulic brakes were designed only in 1922. ABS **anti-lock braking system** only in 1978. Electronics Stability program only in 1992. Today we can see a lot of safety systems, as: dynamic cruise control, lane assist and others.



Active Safety Systems

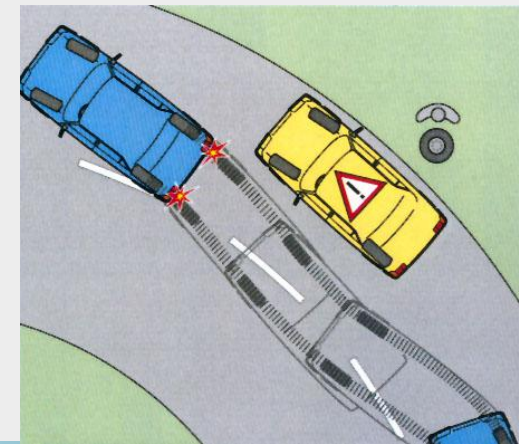
- Antilock braking system ABS;
- Traction control system TCS;
- Electronic Stability-Program.



Antilock Braking System

- Prevents the wheels from locking and thus allows avoiding obstacles;
- The vehicle remains under control even while braking on one-sided slippery road;
- The stopping distance is usually shortened compared to locked wheels.

(ABS)





Traction Control System

TCS prevents the vehicle from skidding when accelerating too much in a turn.

(ASR)





Electronic Stability-Program



Different names for ESP

- **Electronic Stability Program (ESP)** - Holden, HSV, Hyundai, Kia, Mercedes Benz, Jeep, Renault, Saab, Chrysler, Citroen, Maybach, Peugeot, Ssangyong
- **Dynamic Stability Control (DSC)** - Ford, FPV, BMW, Mazda, Land Rover, Aston Martin, Jaguar
- **Vehicle Stability Control (VSC)** – Suzuki, Toyota
- **Vehicle Dynamic Control (VDC)**- Nissan, Subaru, Alfa Romeo
- **Dynamic Stability And Traction Control (DSTC)** - Volvo
- **Electronic Stabilization Program (ESP)** – Audi, Volkswagen



ESP – Electronic Stability Program

What does ESP do?

ESP actively enhances vehicle stability (staying in lane and in direction);

- Through interventions in the braking system or the engine management;
- To prevent critical situations (skidding), that might lead to an accident;





ESP – Electronic Stability Program

What is so special about ESP?

- ESP watches out:
 - Surveys the vehicle's behavior (longitudinal and lateral dynamics);
 - Watches the driver's commands (Steering angle, brake pressure, engine torque);

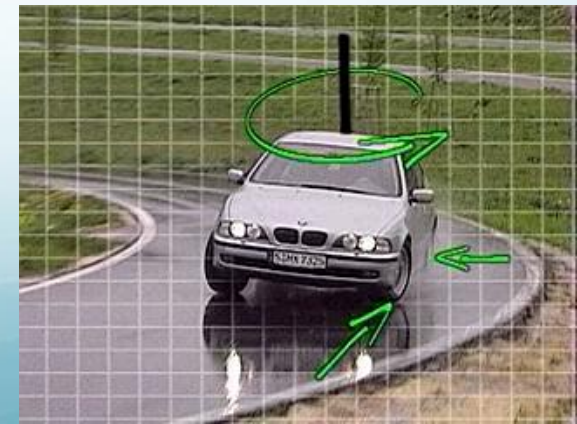




ESP – Electronic Stability Program

What is so special about ESP?

- ESP knows:
 - recognizes critical situations – in many cases before the driver does;
 - considers the possible ways of intervening:
 - Wheel-individual brake pressure application
 - Intervention in the engine management





ESP – Electronic Stability Program

Why is ESP so important?

- Frequent cause for accidents:

The driver loses control of his vehicle. I.e. through:

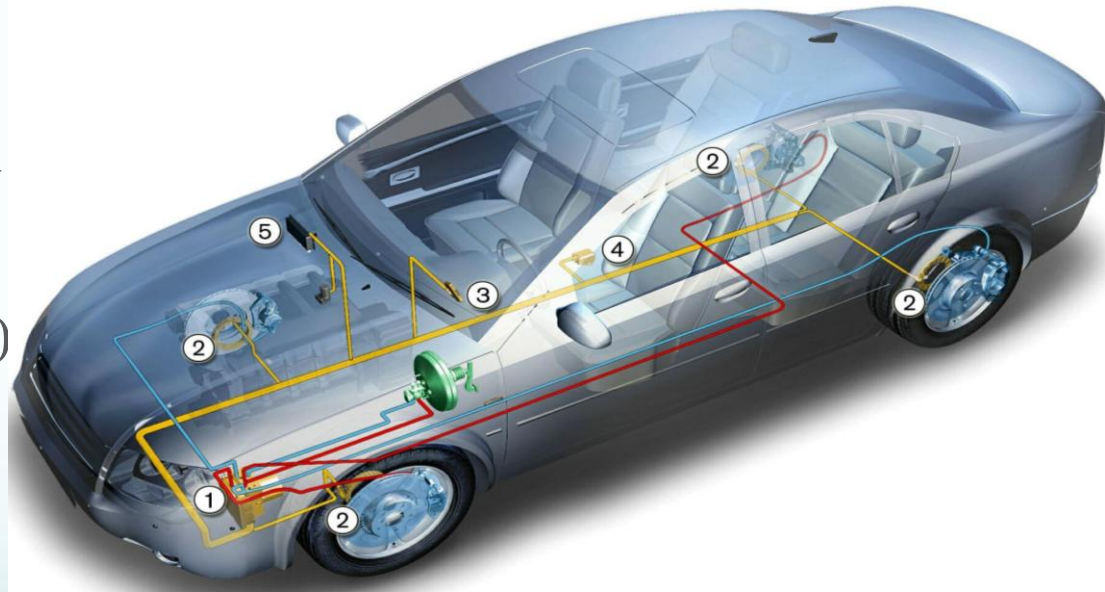
- Speeding;
 - misinterpretation of the course or the road condition;
 - sudden swerving.



ESP – Electronic Stability Program

The parts of the ESP are:

- Hydraulic modulator with ESP ECU and integrated hydraulic valves (1)
- Wheel brakes and wheel-speed sensors (2)
- Steering wheel angle sensor (3)
- Yaw sensor with acceleration sensor (4)
- Engine management ECU (5)
- Brake master cylinder (6).





ESP – Electronic Stability Program

The input parameters of the ESP system are:

- Longitudinal velocity
- Lateral acceleration
- Yaw rate
- Brake pressure
- Throttle pedal position
- Steering wheel angle



ESP – Electronic Stability Program

How does ESP work? (1)

ESP analyzes: What is the driver's intention?

Position of the steering wheel

+ wheel speed

+ position of the accelerator

+ brake pressure

= ECU recognizes driver's intention





ESP – Electronic Stability Program

How does ESP work? (2)

ESP examines: How does the vehicle behave?

Yaw speed
+ Lateral forces

= ECU calculates the vehicle's behaviour .

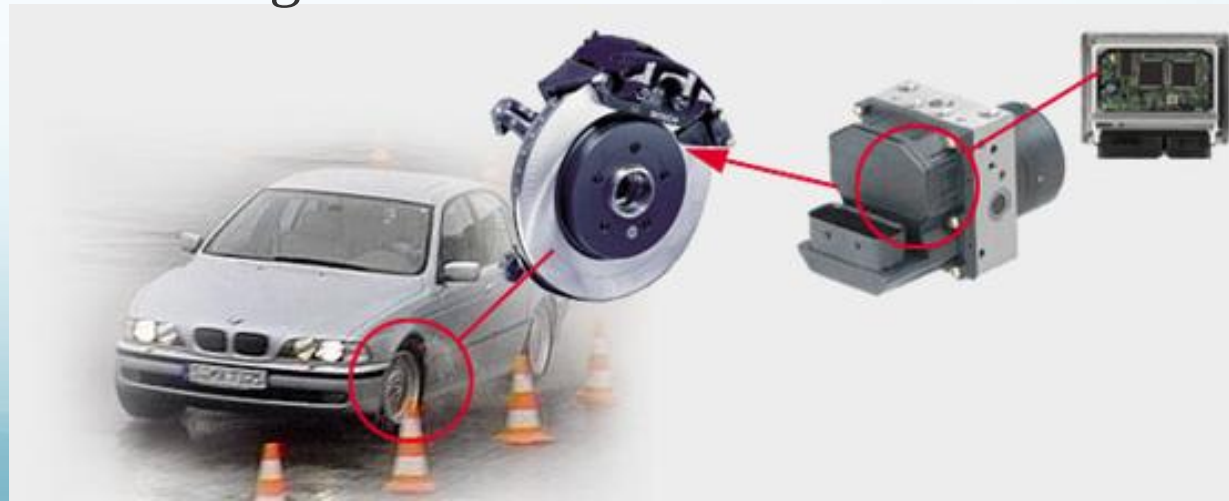




ESP – Electronic Stability Program

ESP acts: It "steers" through brake-application

- The ECU calculates the required measures
- The hydraulic unit quickly and individually supplies the brake pressure for each wheel
- In addition, ESP can reduce the engine torque via connection to the motor management





ESP – Electronic Stability Program

In what situations is ESP needed?

- Examples:
 - Avoiding an obstacle;
 - Sudden wrenching of the steering wheel;
 - Driving on varying road surfaces (especially important on the ice or snow surfaces);



ESP – Electronic Stability Program



Without ESC



With ESC

The Electronic Stability Program keeps car safely on track.



Thank for attention