



Semnan University
Faculty of Mechanical Engineering

دانشکده مهندسی مکانیک

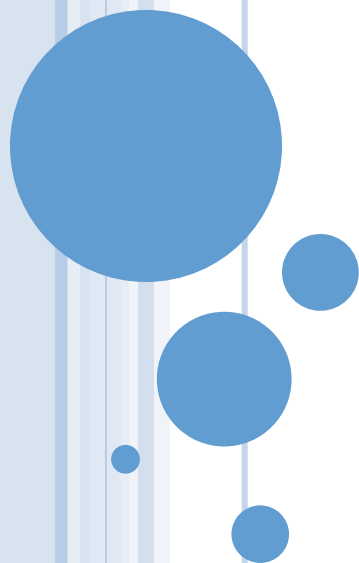


دانشکده مهندسی مکانیک

درس طراحی سیستم های شاسی خودرو

VEHICLE CHASSIS SYSTEMS DESIGN

Chapter 4 – Road Loads
Class Lecture



❑ **CONTENTS:**

- ❖ Chapter 1: Introduction
- ❖ Chapter 2: Accelerating Performance
- ❖ Chapter 3: Braking Performance
- ❖ Chapter 4: **Road Loads**
- ❖ Chapter 5: Ride
- ❖ Chapter 6: Cornering
- ❖ Chapter 7: Suspension
- ❖ Chapter 8: Steering System
- ❖ Chapter 9: Roll-over

AERODYNAMICS

- ❑ Aerodynamics contribution in "road load"
 - ❖ Drag
 - ❖ Lift (or down load)
 - ❖ Lateral forces
 - ❖ Moments in roll, pitch and yaw
 - ❖ Noise
- ❑ These also impact fuel economy, handling and NVH (Noise, vibration, and harshness).
- ❑ Arise from two sources:
 - ❖ Form (or pressure) drag
 - ❖ Viscous friction



AERODYNAMICS

❑ Mechanics of Air Flow Around a Vehicle

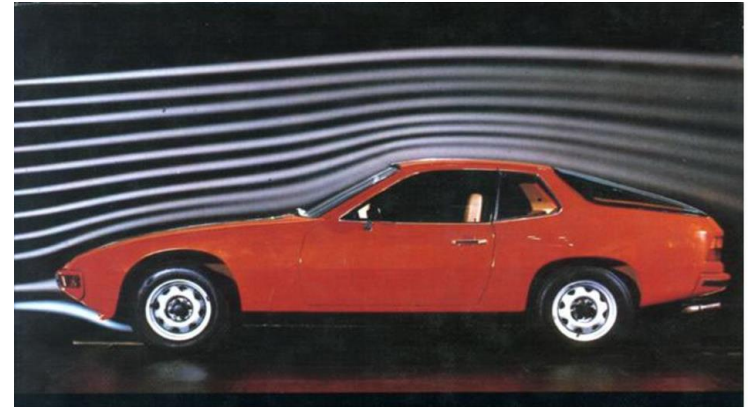
❖ Relationship between velocity and pressure (Bernoulli's Equation)

$$P_{\text{static}} + P_{\text{dynamic}} = P_{\text{total}}$$

$$P_s + 1/2 \rho V^2 = P_t$$

ρ = Density of air

V = Velocity of air (relative to the car)



AERODYNAMICS

❑ Mechanics of Air Flow Around a Vehicle

❖ Visualizing Streamlines:

- ✓ Vehicle as stationary and the air moving (as in a wind tunnel)
- ✓ Using smoke streams

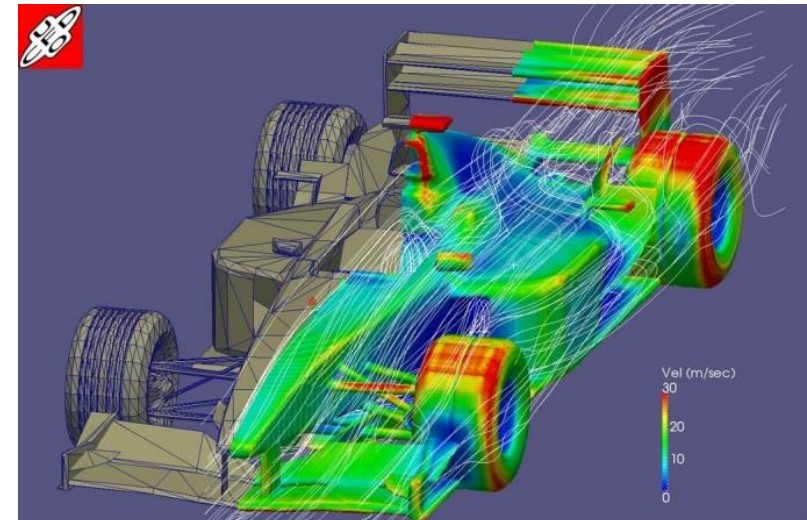
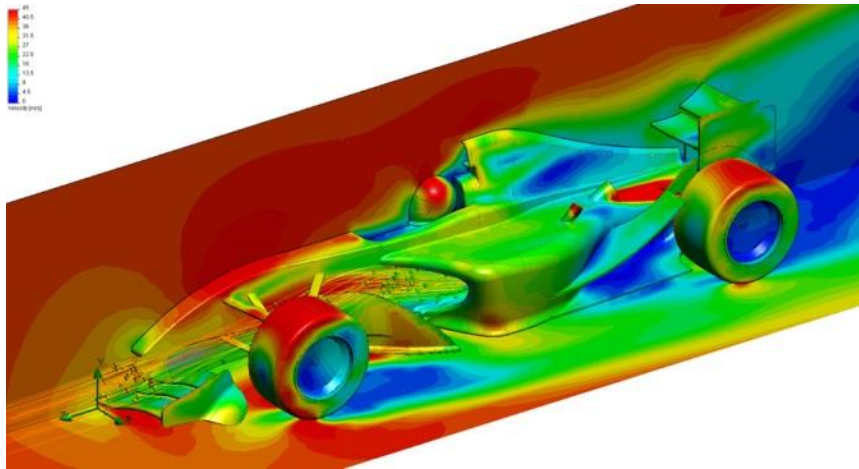


AERODYNAMICS

❑ Mechanics of Air Flow Around a Vehicle

❖ Visualizing Streamlines:

- ✓ Using simulation software

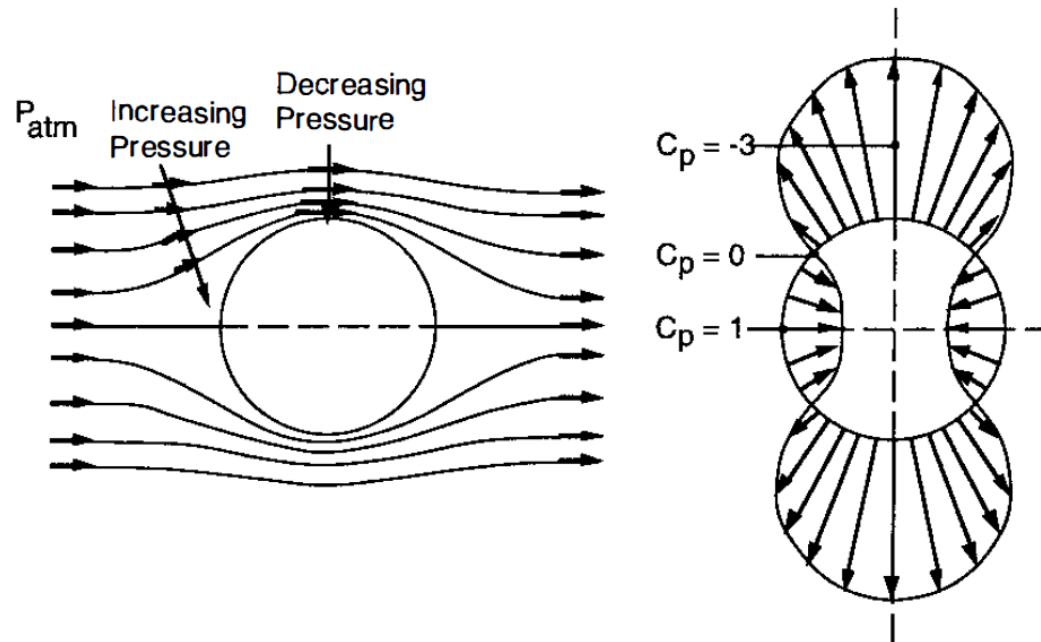


AERODYNAMICS

❑ Mechanics of Air Flow Around a Vehicle

❖ Pressure and velocity distribution (Ideal Flow)

- ✓ Increasing Velocity → Decreasing Pressure
- ✓ Decreasing Velocity → Increasing Pressure



AERODYNAMICS

❑ Mechanics of Air Flow Around a Vehicle

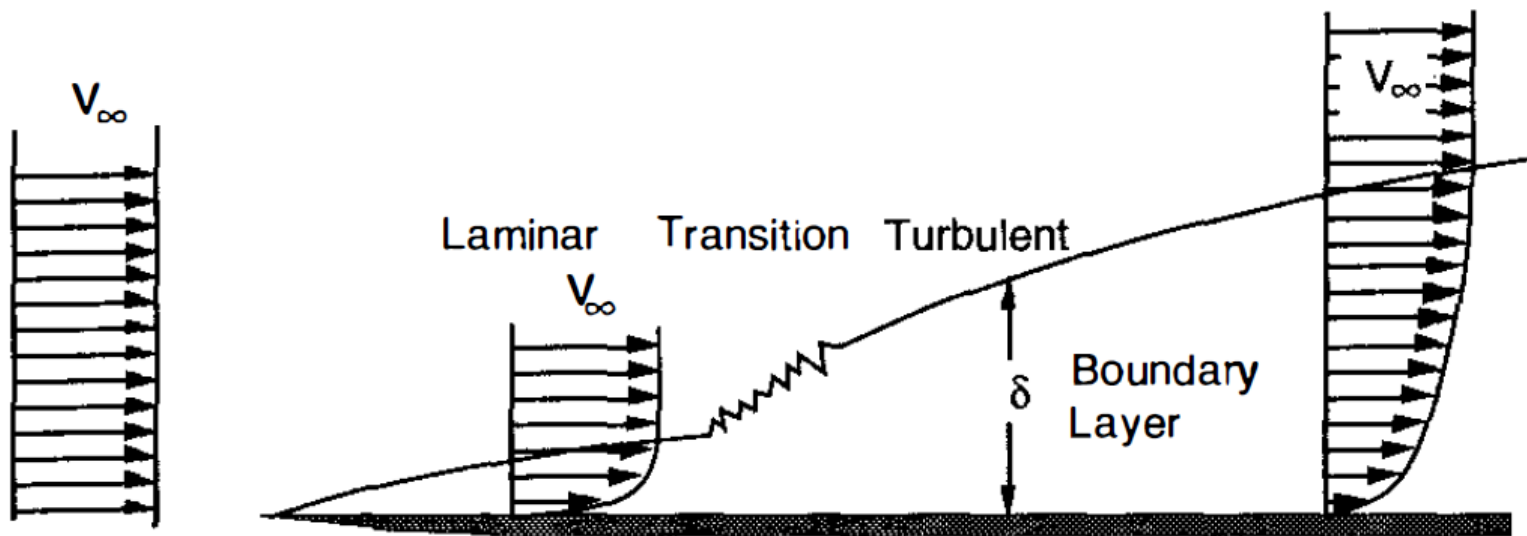
- ❖ In the absence of friction the air would simply flow up over the roof and down the back side of the vehicle, exchanging pressure for velocity and finally there would be no drag produced.
- ❖ However, we know that drag is produced!
- ❖ The drag is due:
 - ✓ Friction of the air on the surface of the vehicle
 - ✓ The way the friction alters the main flow down the back side of the vehicle
- ❖ Its explanation comes about from understanding the action of boundary layers in the flow over an object.



AERODYNAMICS

❑ Mechanics of Air Flow Around a Vehicle

- ❖ Its explanation comes about from understanding the action of boundary layers in the flow over an object.



AERODYNAMICS

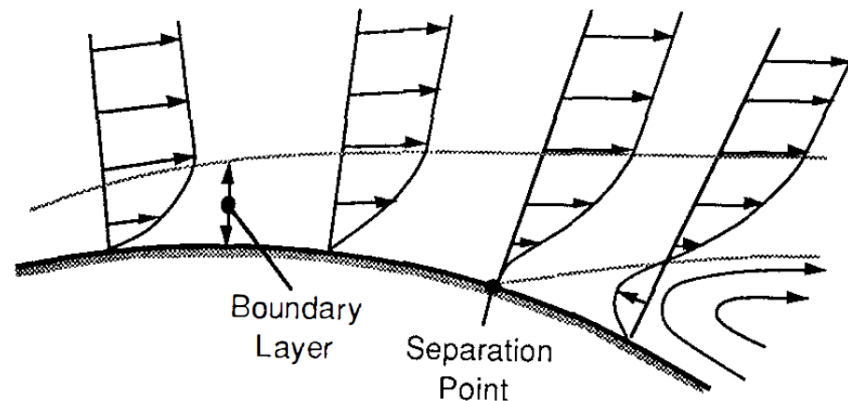
❑ Mechanics of Air Flow Around a Vehicle

- ❖ Approaching the body, all air is traveling at a uniform velocity (laminar flow)
- ❖ As it flows past the body, the air contacting the surface must drop to zero velocity due to friction on the surface.
- ❖ Thus a velocity profile develops near the surface, and for some distance.
- ❖ This region of reduced velocity is known as the "boundary layer".
- ❖ The boundary layer begins with zero thickness and grows.

AERODYNAMICS

❑ Mechanics of Air Flow Around a Vehicle

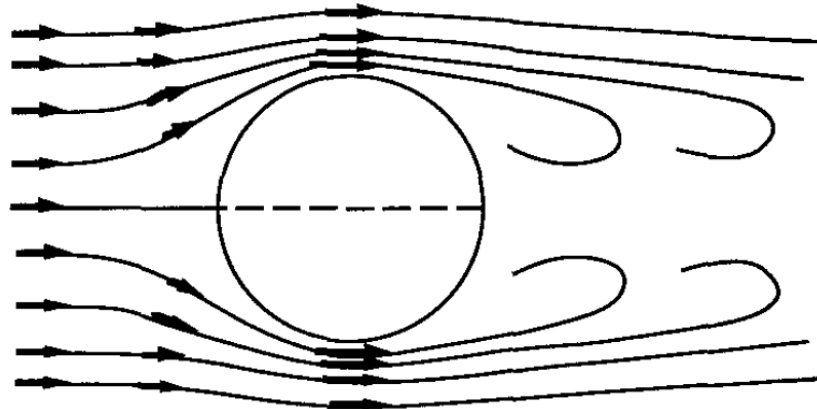
- ❖ Initially, it too is laminar flow, but will eventually break into turbulent flow.
- ❖ The increasing pressure acts to decelerate the flow in the boundary layer, which causes it to grow in thickness.
- ❖ Thus it produces what is known as an "adverse pressure gradient."
- ❖ The point where the flow stops is known as the "separation point."



AERODYNAMICS

❑ Mechanics of Air Flow Around a Vehicle

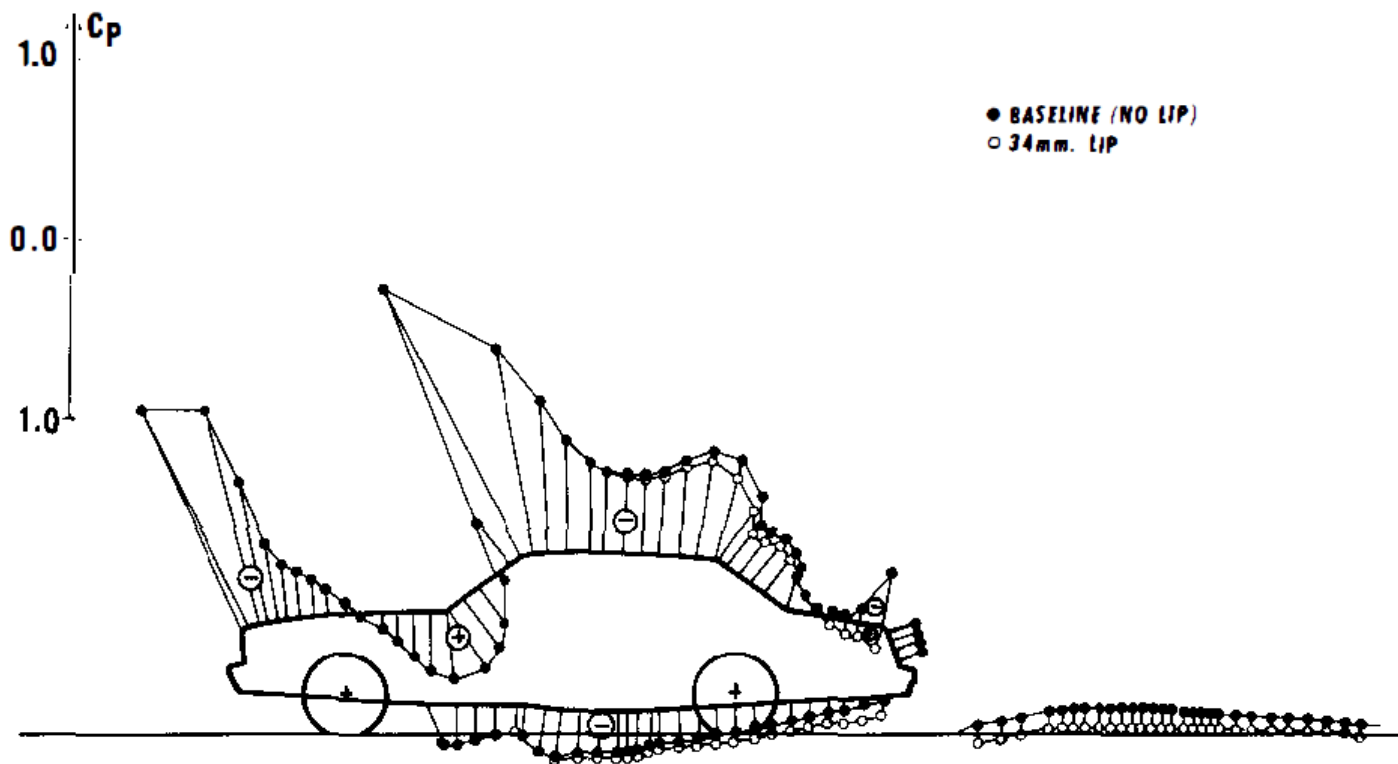
- ❖ At separation point, the main stream is no longer "attached" to the body but is able to break free and continue in a more or less straight line.
- ❖ The pressure in this region drops below the ambient.
- ❖ Vortices form and the flow is very irregular in this region.
- ❖ Under the right conditions, a von-Karman Vortex Street may be formed, which is a periodic shedding of vortices.



AERODYNAMICS

□ Pressure Distribution on a Vehicle

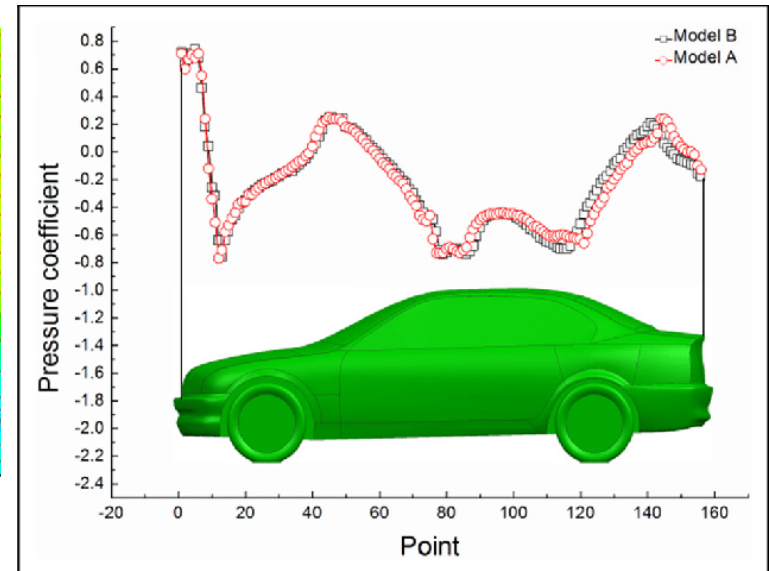
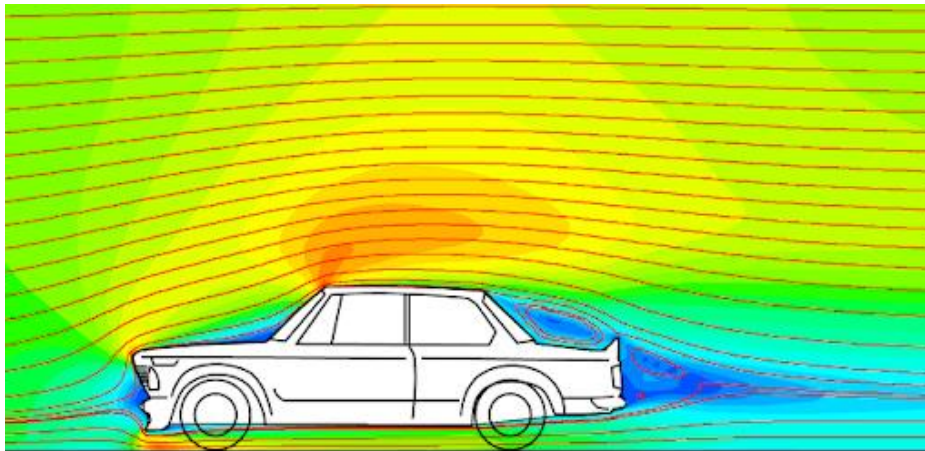
- ❖ Experimentally measured static pressure distribution (Negative or Positive)



PRESSURE COEFFICIENTS PLOTTED NORMAL TO SURFACE

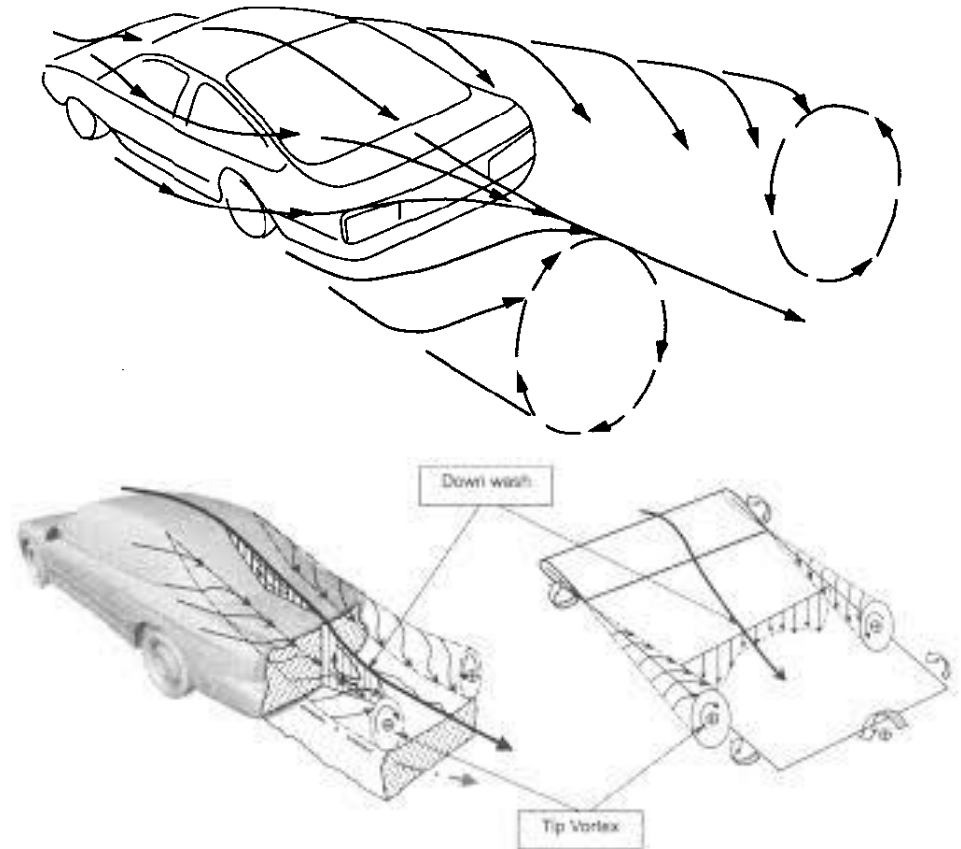
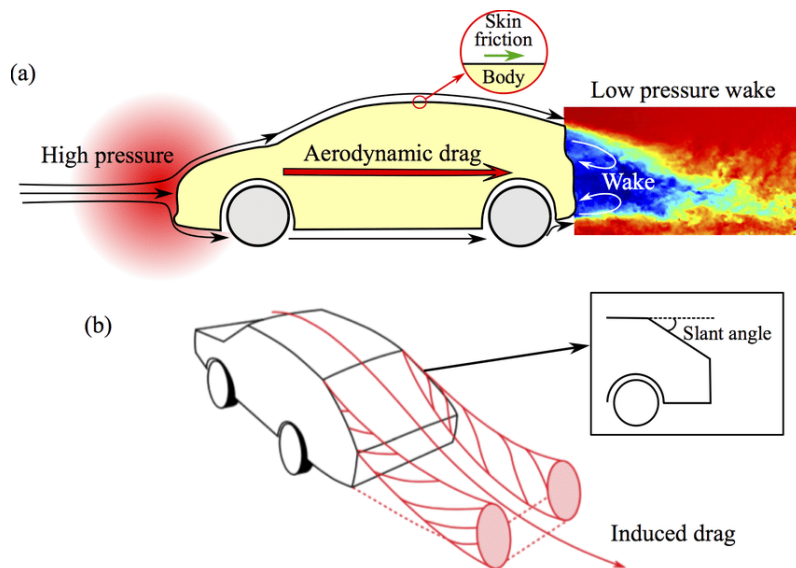
AERODYNAMICS

- Pressure Distribution on a Vehicle
 - ❖ Simulation results



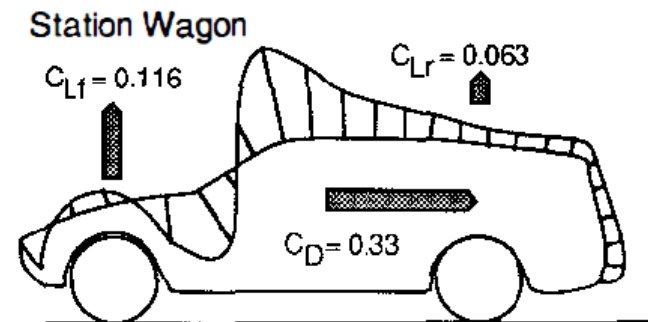
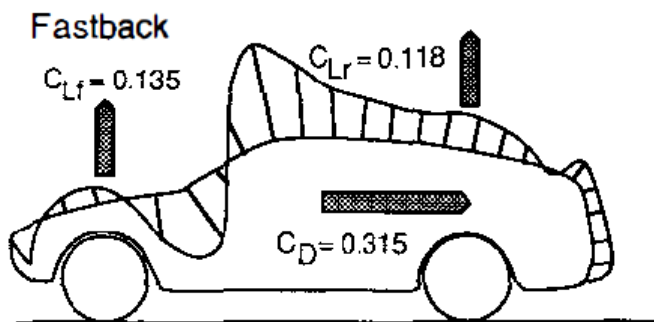
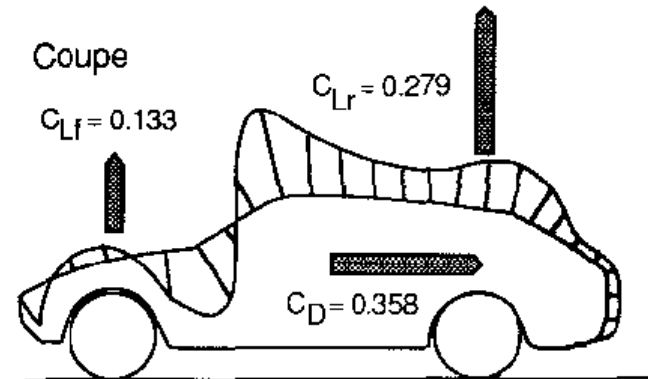
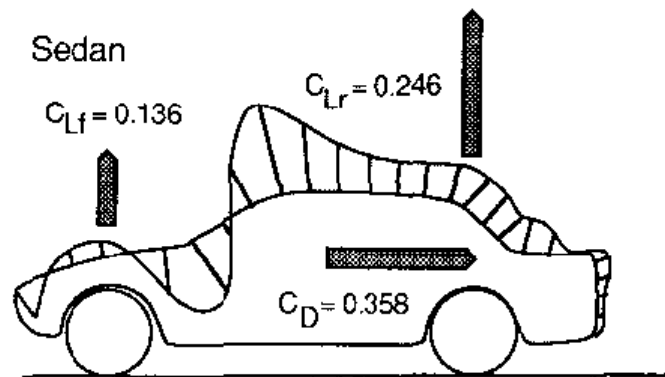
AERODYNAMICS

Trailing vortices behind car



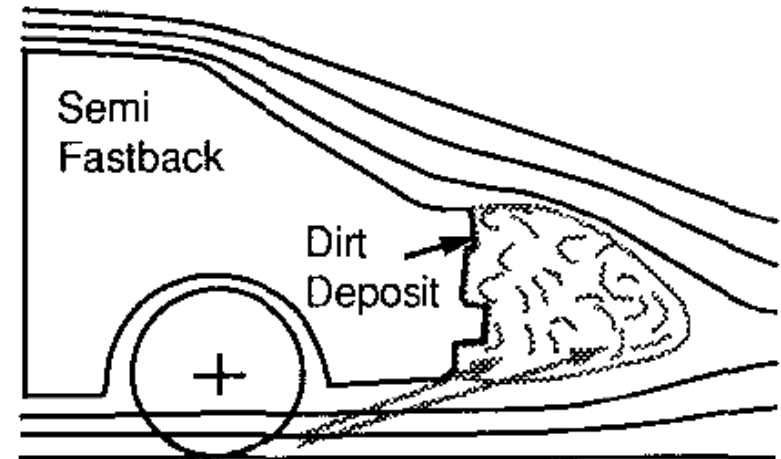
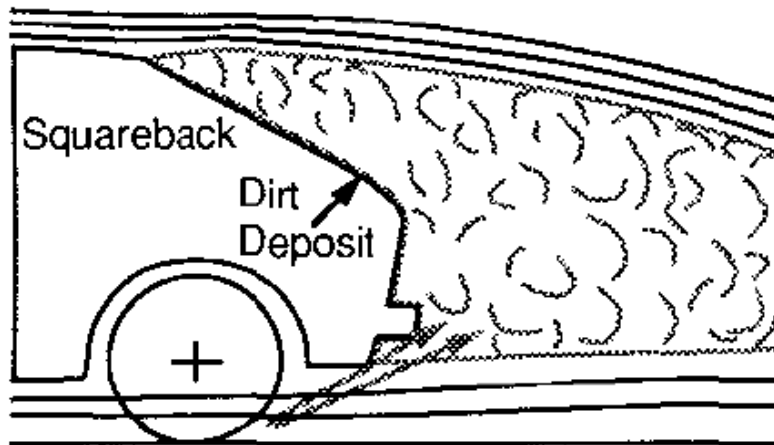
AERODYNAMICS

□ Aerodynamic drag and lift forces (rear and front)



AERODYNAMICS

- Effect of separation point on dirt deposition at the rear

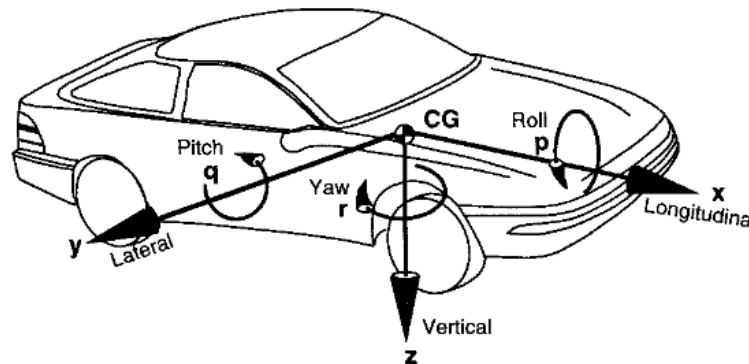


AERODYNAMIC FORCES

□ Aerodynamic forces

❖ Three forces and three moments

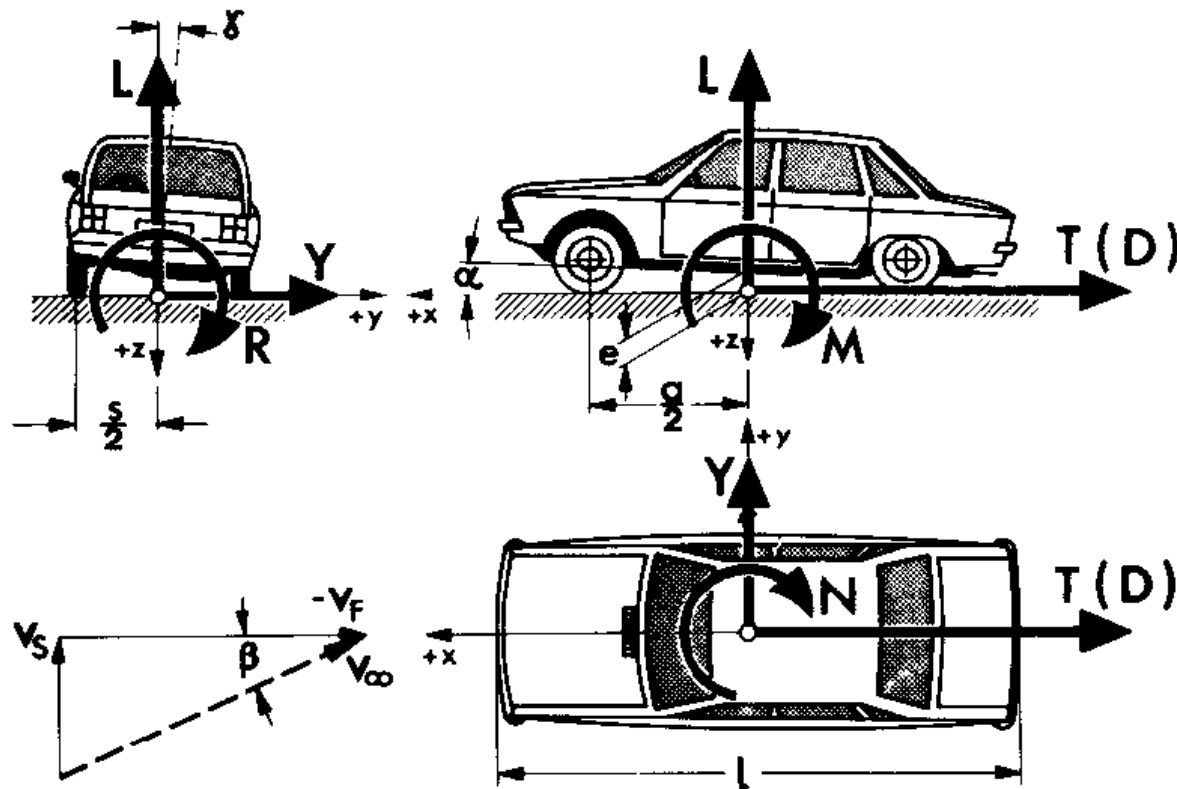
<u>Direction</u>	<u>Force</u>	<u>Moment</u>
Longitudinal (x-axis, positive rearward)	Drag	Rolling moment
Lateral (y-axis, positive to the right)	Sidelforce	Pitching moment
Vertical (z-axis, positive upward)	Lift	Yawing moment



AERODYNAMIC FORCES

□ Aerodynamic forces

- ❖ The origin for the axis system is defined in SAE J1594



AERODYNAMIC FORCES

□ Drag Components

- ❖ Approximately 65% of the drag arises from the body
- ❖ The major contributor is the afterbody because of the drag produced by the separation zone at the rear.
- ❖ The maximum potential for drag reduction is possible in this area.

DRAG COEFFICIENT COMPONENT	TYPICAL VALUE
Forebody	0.05
Afterbody	0.14
Underbody	0.06
Skin Friction	0.025
Total Body Drag	0.275
Wheels and wheel wells	0.09
Drip rails	0.01
Window recesses	0.01
External mirrors	0.01
Total Protuberance Drag	0.12
Cooling system	0.025
Total Internal Drag	0.025
Overall Total Drag	0.42 ¹
VEHICLE OF THE 1980s	
Cars	0.30 - 0.35
Vans	0.33 - 0.35
Pickup trucks	0.42 - 0.46

¹ Based on cars of 1970s vintage.



AERODYNAMIC FORCES

□ Drag

- ❖ Because air flow over a vehicle is so complex, it is necessary to develop semi-empirical models

- ❖ Aerodynamic drag: $D_A = 1/2 \rho V^2 C_D A$

C_D = Aerodynamic drag coefficient

A = Frontal area of the vehicle

ρ = Air density

- ❖ Dynamic pressure of the air: $1/2 \rho V^2$

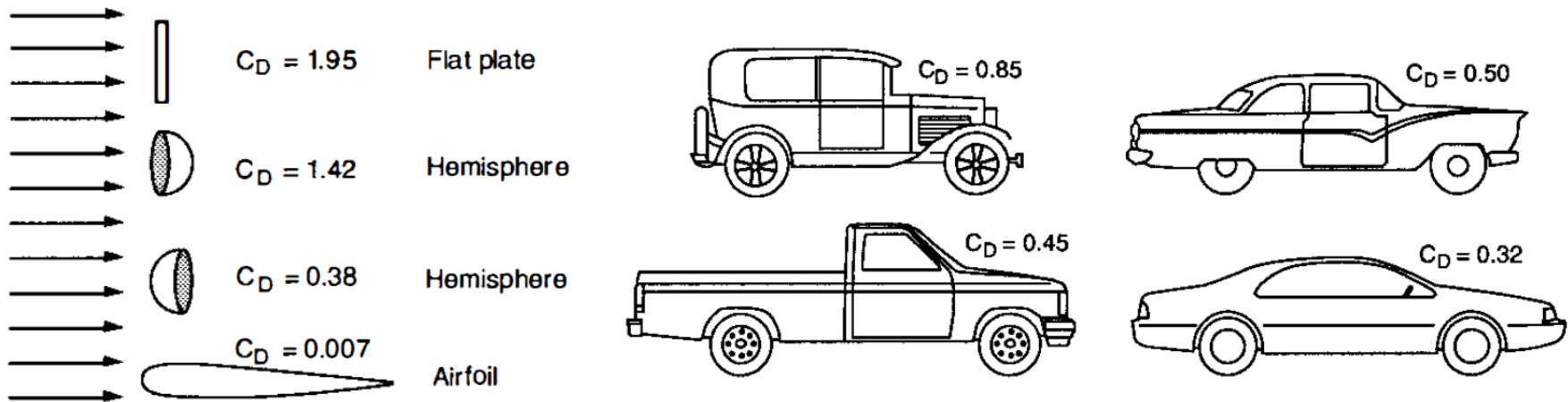
- ❖ The drag coefficient C_D , is determined empirically for the car.



AERODYNAMIC FORCES

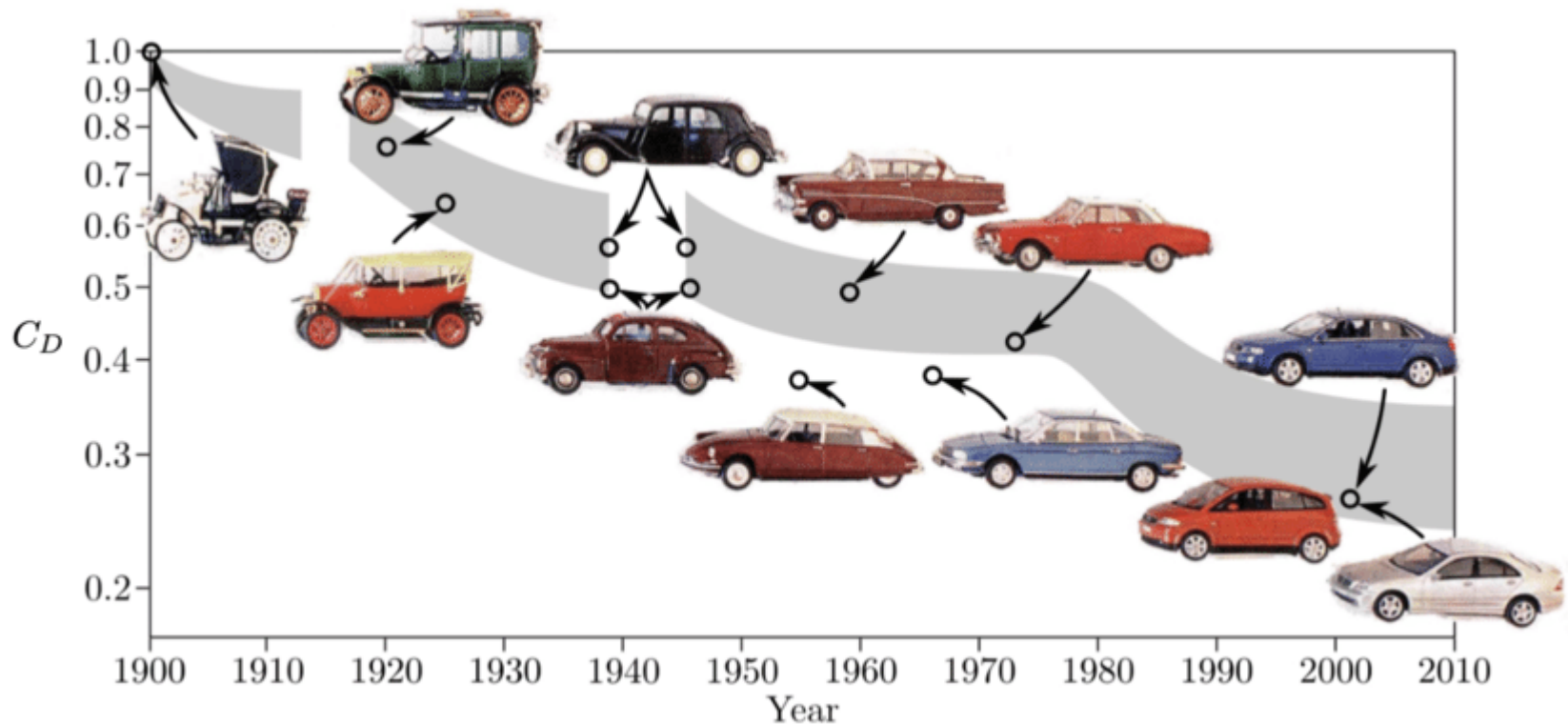
□ Drag Coefficient

$$C_D = \frac{D_A}{\frac{1}{2} \rho V^2 A} = \frac{\text{Drag force}}{(\text{Dynamic pressure}) (\text{area})}$$



AERODYNAMIC FORCES

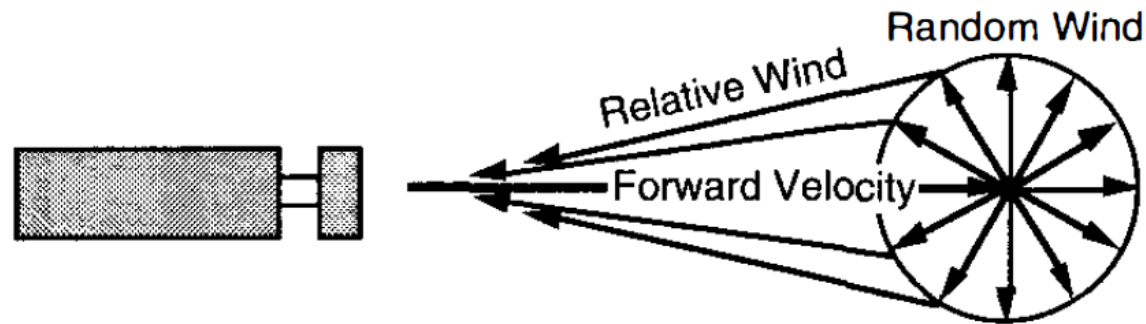
□ Drag Coefficient



AERODYNAMIC FORCES

□ Side wind

- ❖ In practice, a vehicle driving along a road experiences atmospheric winds in addition to the wind component arising from its speed.



- ❖ The relative wind seen by the vehicle will consist of the large component due to its speed, plus a smaller atmospheric wind component in any direction

AERODYNAMIC FORCES

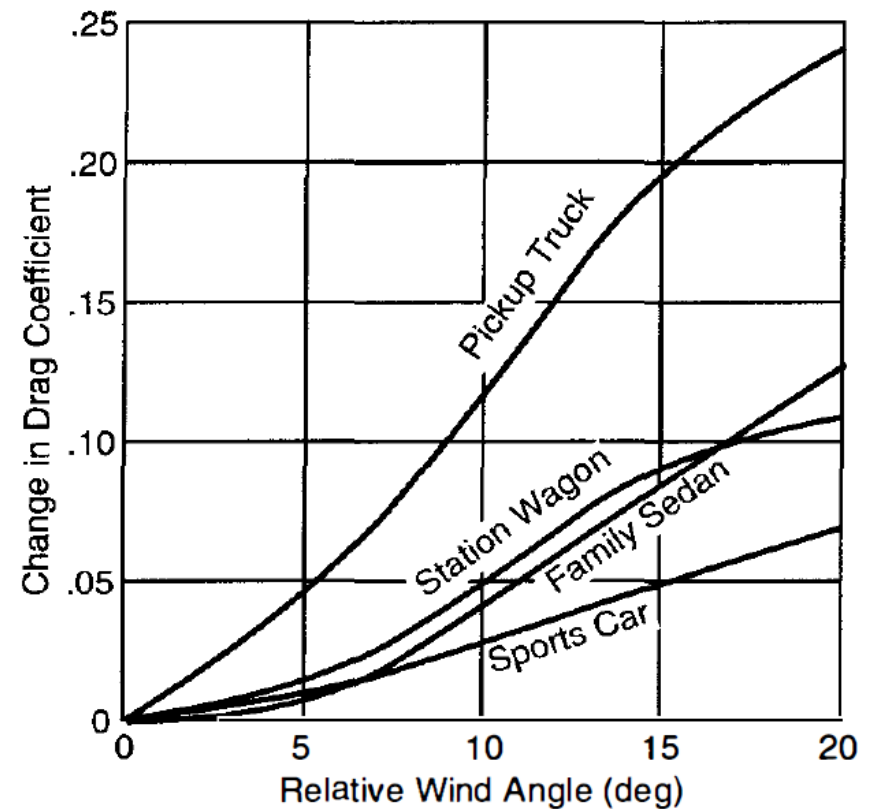
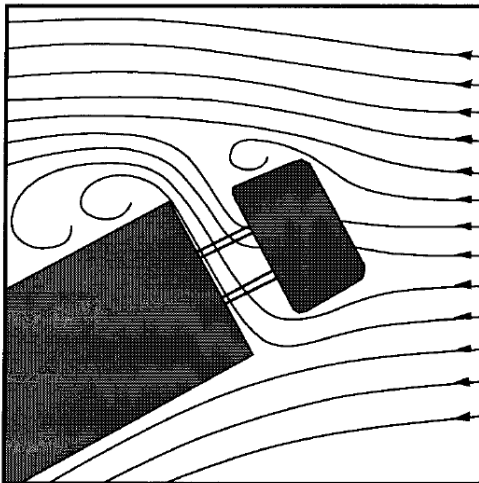
□ Side wind

❖ Total velocity

$$V = V_v + V_w$$

V_v = Vehicle speed

V_w = Wind speed



AERODYNAMIC FORCES

□ Side Force

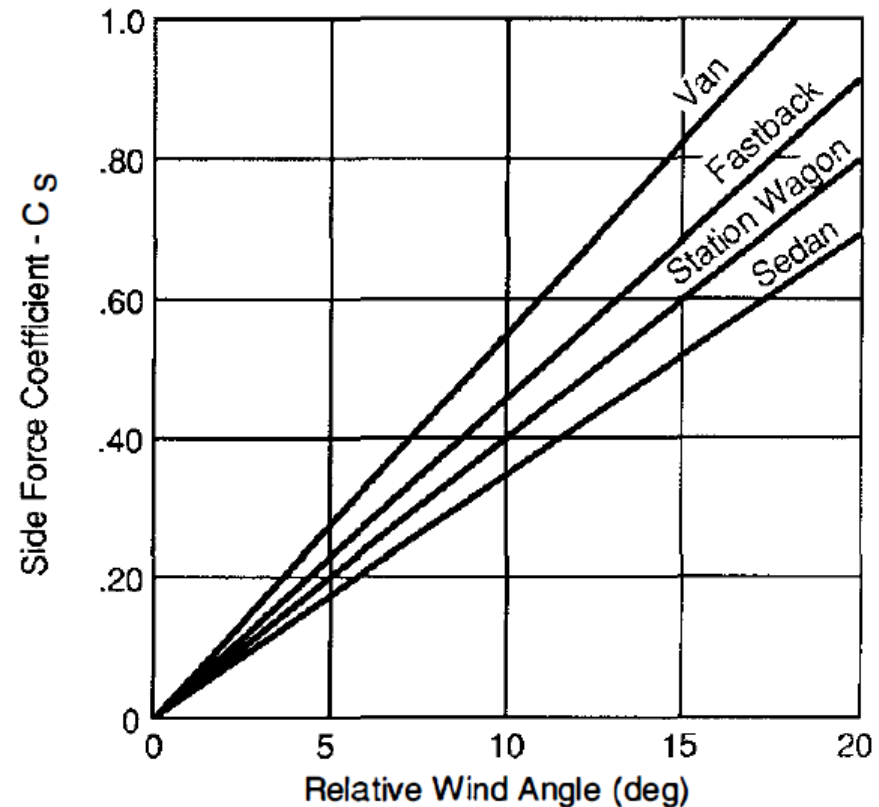
$$S_A = 1/2 \rho V^2 C_S A$$

S_A = Side force

V = Total wind velocity

C_S = Side force coefficient

A = Frontal area



- ✓ Side force coefficient is function of the relative the relative wind angle.

AERODYNAMIC FORCES

❑ Lift Force

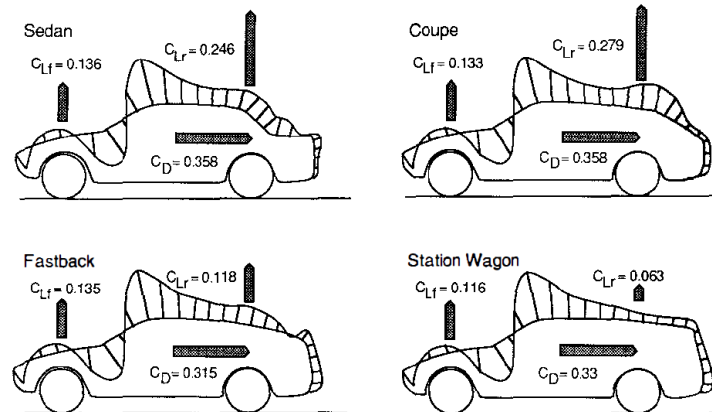
$$L_A = 1/2 \rho v^2 C_L A$$

L_A = Lift force

C_L = Lift coefficient

A = Frontal area

- ❖ At zero wind angle, lift coefficients normally fall in the range of 0.3 to 0.5 for modern passenger cars.
- ❖ But under crosswind conditions the coefficient may increase dramatically reaching values of 1 or more.



AERODYNAMIC FORCES

❑ Pitching Moment

$$PM = 1/2 \rho V^2 C_{PM} A L$$

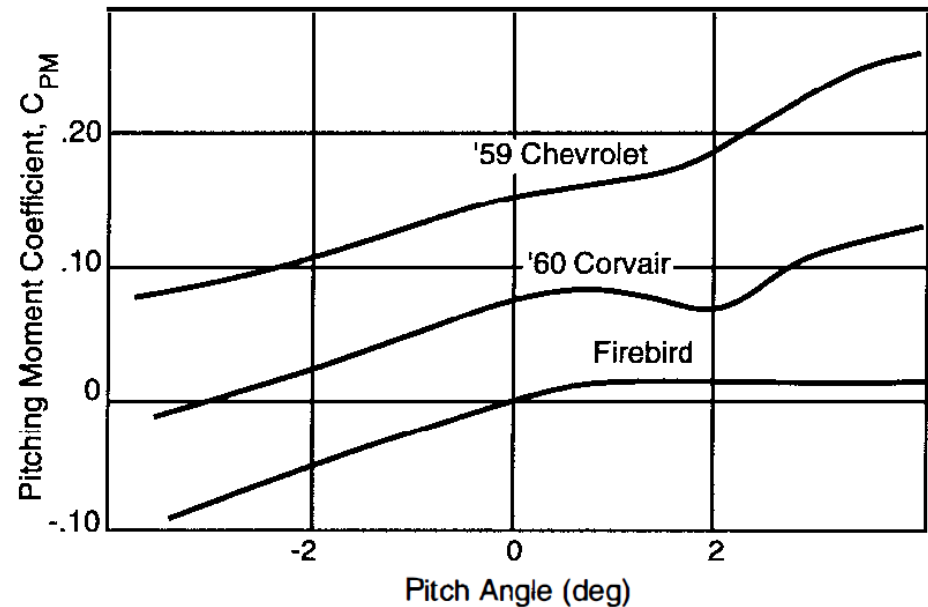
PM = Pitching moment

C_{PM} = Pitching moment coefficient

A = Frontal area

L = Wheelbase

- ❖ Most modern cars have a pitching moment in the range of 0.05 to 0.2, and it is quite sensitive to the angle of attack on the vehicle.



AERODYNAMIC FORCES

□ Yawing Moment

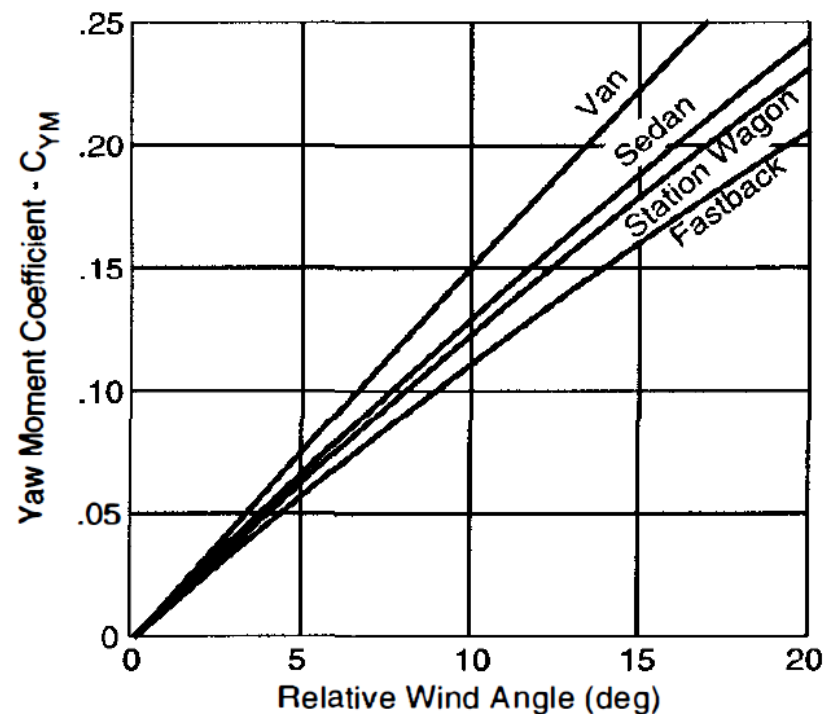
$$YM = \frac{1}{2} \rho V^2 C_{YM} A L$$

YM = Yawing moment

C_{YM} = Yawing moment coefficient

A = Frontal area

L = Wheelbase



AERODYNAMIC FORCES

□ Rolling Moment

$$RM = 1/2 \rho V^2 C_{RM} A L$$

RM = Rolling moment

C_{RM} = Rolling moment coefficient

A = Frontal area

L = Wheelbase

- ❖ The rolling moment coefficient is sensitive to wind direction much like the yawing moment coefficient
- ❖ The slope of the rolling moment coefficient ranges from 0.018/deg to 0.04/deg

AERODYNAMIC FORCES

❑ Crosswind Sensitivity

- ❖ Generally refers to the lateral and yawing response of a vehicle in the presence of transverse wind disturbances which affect the driver's ability to hold the vehicle in position and on course.
- ❖ Key elements:
 - ✓ Aerodynamic properties
 - ✓ Vehicle dynamic properties (weight distribution, tire properties, and suspensions)
 - ✓ Steering system characteristics (compliances, friction and torque assist)
 - ✓ Driver closed-loop steering behavior and preferences



ROLLING RESISTANCE

- The other major vehicle resistance force on level ground is the rolling resistance of the tires.

$$R_x = R_{xf} + R_{xr} = f_r W$$

R_{xf} = Rolling resistance of the front wheels

R_{xr} = Rolling resistance of the rear wheels

f_r = Rolling resistance coefficient

W = Weight of the vehicle

- At low speeds on hard pavement, the rolling resistance is the primary motion resistance force.
- Aerodynamic resistance becomes equal to the rolling resistance only at speeds of 50-60 mph.



ROLLING RESISTANCE

❑ Mechanisms responsible for rolling resistance:

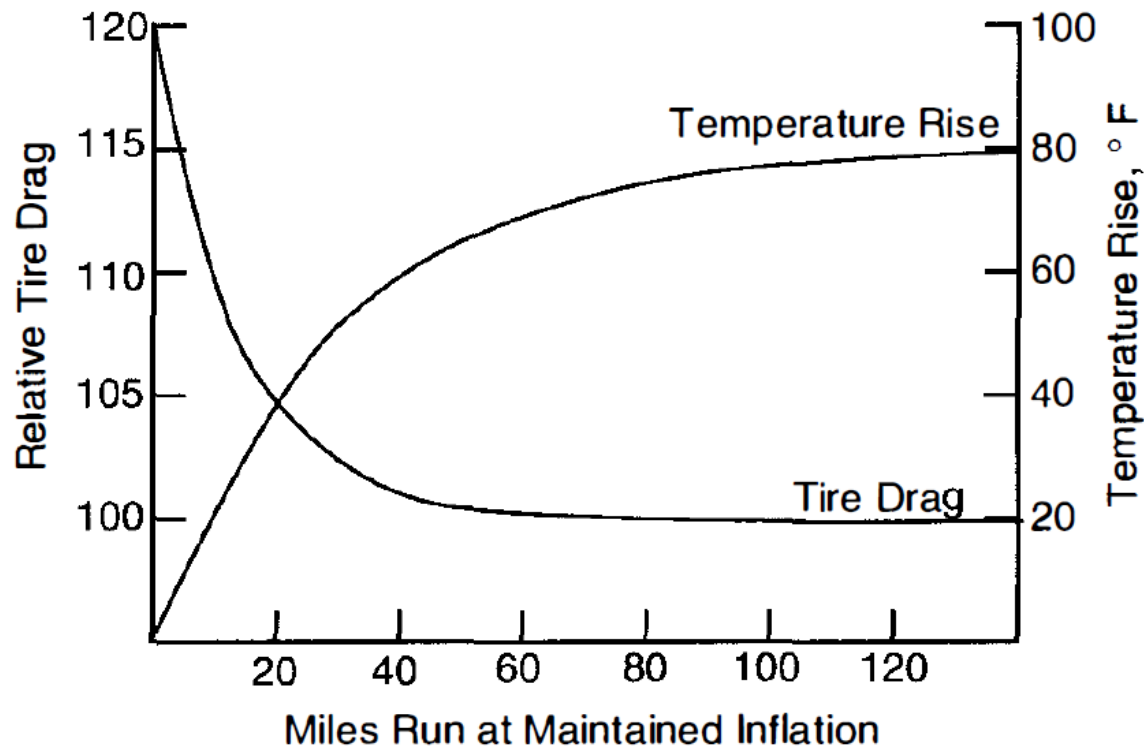
- 1) Energy loss due to deflection of the tire sidewall near the contact area
- 2) Energy loss due to deflection of the tread elements
- 3) Scrubbing in the contact patch
- 4) Tire slip in the longitudinal and lateral directions
- 5) Deflection of the road surface
- 6) Air drag on the inside and outside of the tire
- 7) Energy loss on bumps



ROLLING RESISTANCE

□ Factors Affecting Rolling Resistance

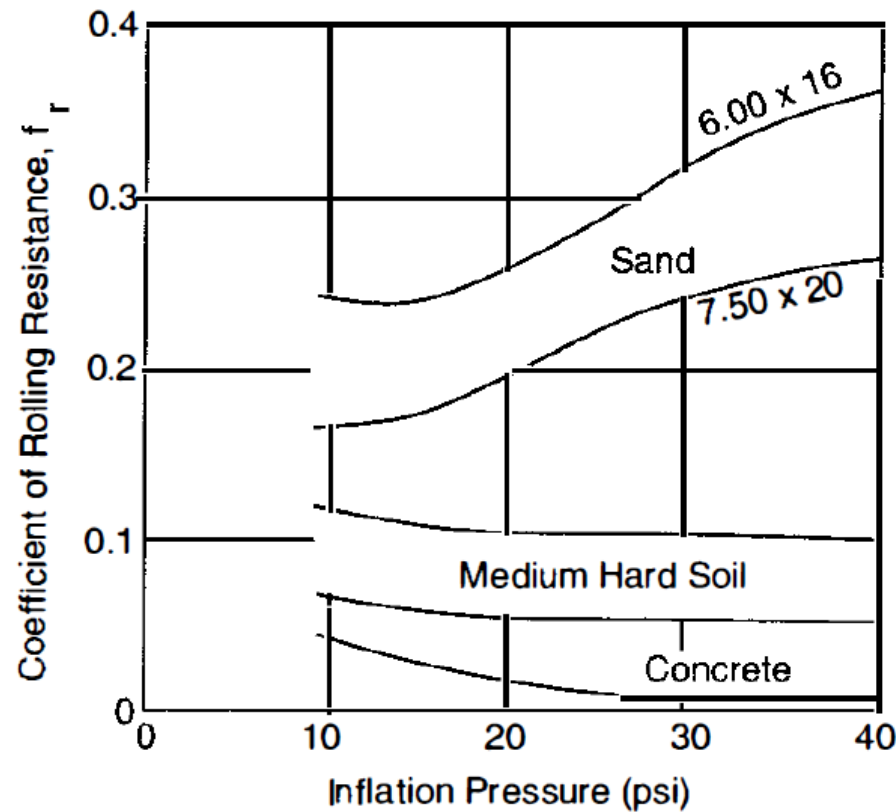
❖ Tire Temperature



ROLLING RESISTANCE

□ Factors Affecting Rolling Resistance

❖ Tire Inflation Pressure/Load

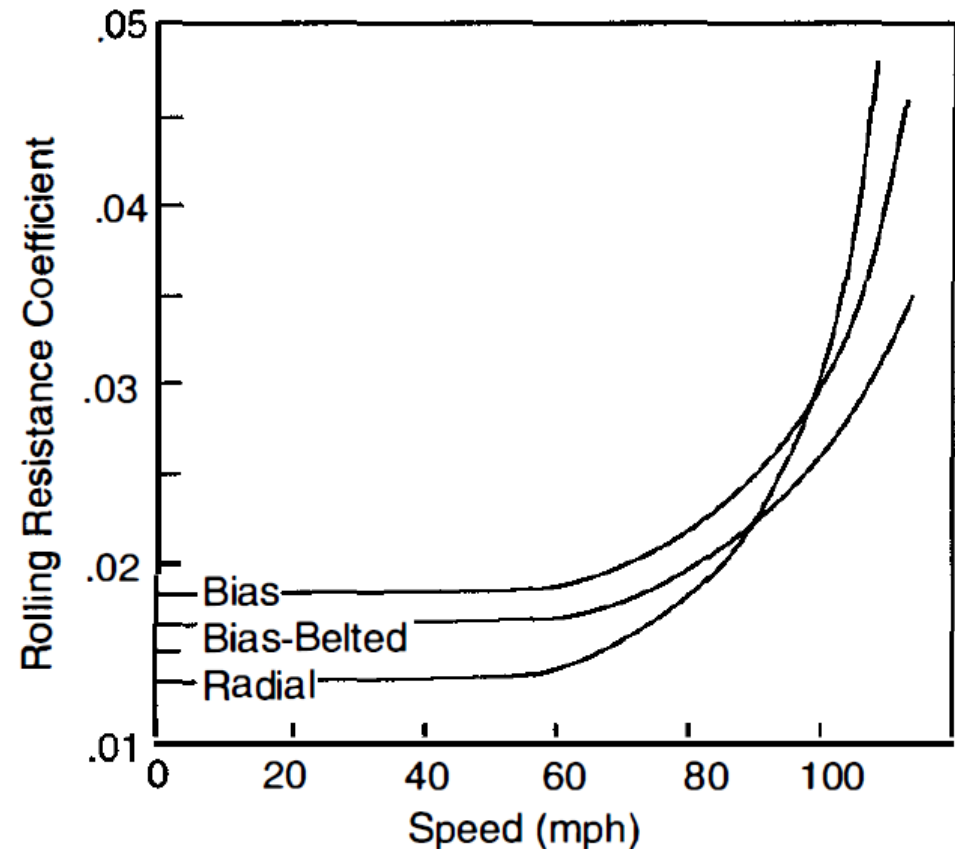


ROLLING RESISTANCE

□ Factors Affecting Rolling Resistance

❖ Velocity

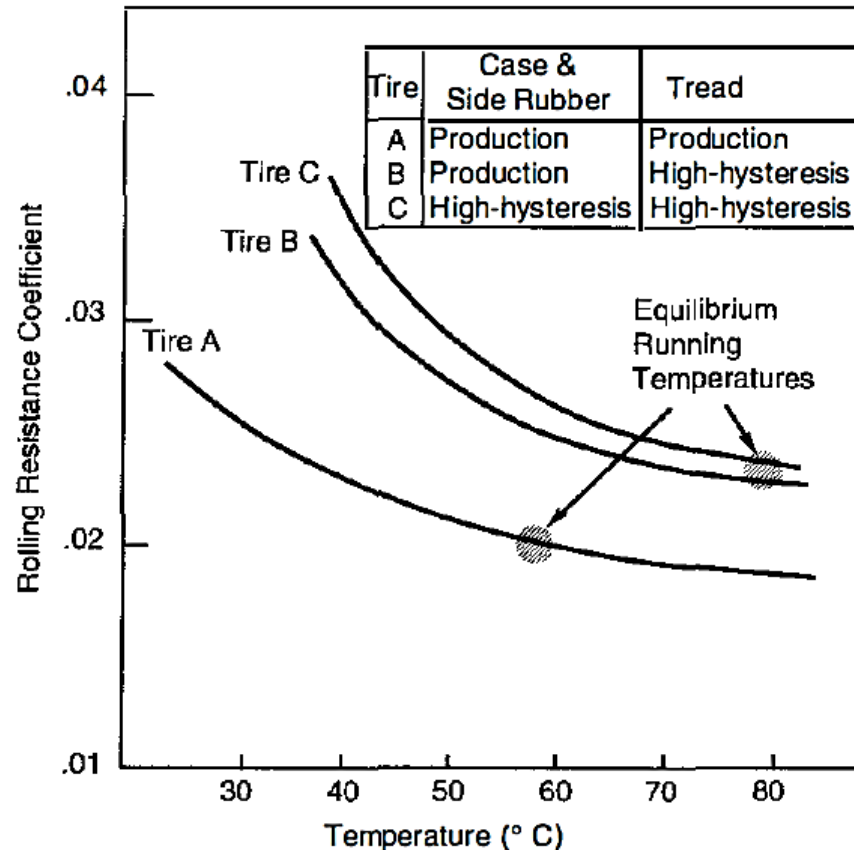
- ✓ The sharp upturn in coefficient at high speeds is caused by a high-energy standing wave developed in the tire carcass just behind the tire contact patch.



ROLLING RESISTANCE

□ Factors Affecting Rolling Resistance

❖ Tire Material and Design

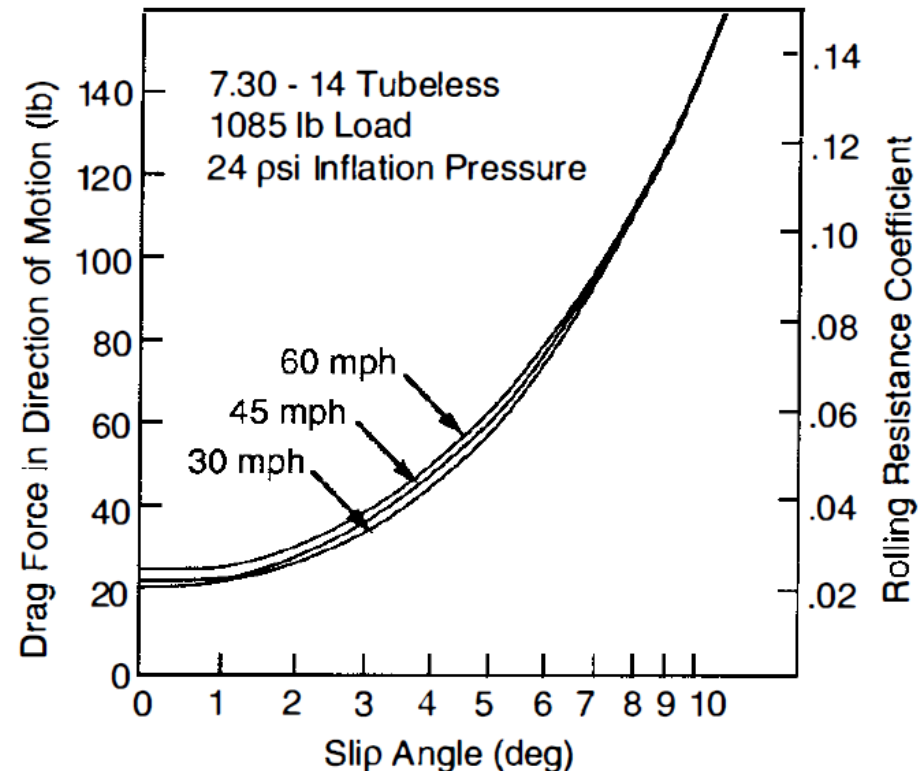


ROLLING RESISTANCE

❑ Factors Affecting Rolling Resistance

❖ Tire Slip

- ✓ Wheels transferring tractive or braking forces show higher rolling resistance due to wheel slip



ROLLING RESISTANCE

□ Factors Affecting Rolling Resistance

❖ Typical Coefficients

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

R_x = Rolling resistance force

W = Weight on the wheel

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

D = Outside diameter

h_t = Tire section height

w = Tire section width

ROLLING RESISTANCE

❑ Factors Affecting Rolling Resistance

- ❖ At the most elementary level, the rolling resistance coefficient may be estimated as a constant.

❖ f_r :

<u>Vehicle Type</u>	<u>Concrete</u>	Surface <u>Medium Hard</u>	<u>Sand</u>
Passenger cars	0.015	0.08	0.30
Heavy trucks	0.012	0.06	0.25
Tractors	0.02	0.04	0.20

ROLLING RESISTANCE

❑ Factors Affecting Rolling Resistance

- ❖ At lower speeds the coefficient rises approximately linearly with speed

$$f_r = 0.01 (1 + V/100)$$

V = Speed in mph

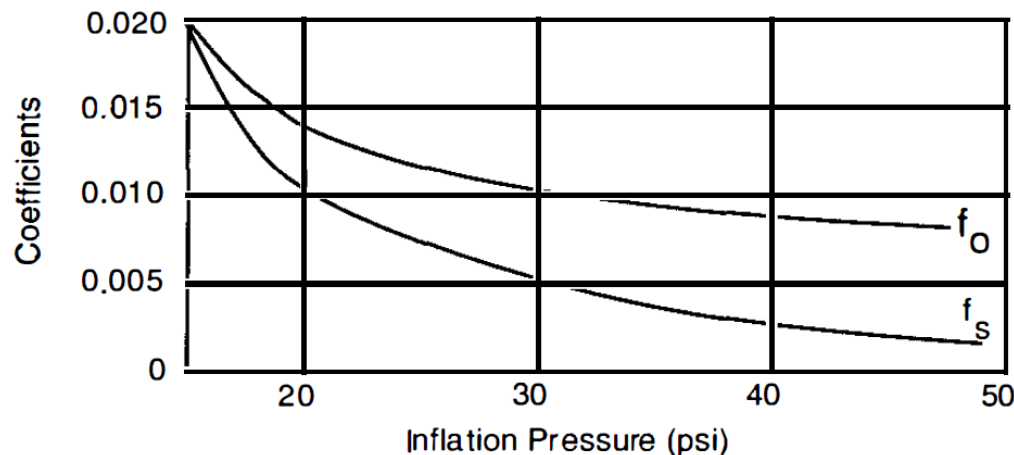
- ❖ Over broader speed ranges:

$$f_r = f_o + 3.24 f_s (V/100)^{2.5}$$

V = Speed in mph

f_o = Basic coefficient

f_s = Speed effect coefficient



ROLLING RESISTANCE

❑ Factors Affecting Rolling Resistance

- ❖ Rolling resistance of heavy truck tires of both the radial and bias-ply types

$$f_r = (0.0041 + 0.000041 V) C_h \quad \text{Radial tires}$$

$$f_r = (0.0066 + 0.000046 V) C_h \quad \text{Bias-ply tires}$$

V = Speed in mph

C_h = Road surface coefficient

= 1.0 for smooth concrete

= 1.2 for worn concrete, brick, cold blacktop

= 1.5 for hot blacktop



ROLLING RESISTANCE

- ❑ Rolling resistance is clearly a minimum on hard, smooth, dry surfaces.
- ❑ A worn-out road almost doubles rolling resistance.
- ❑ On wet surfaces, higher rolling resistance is observed probably due to the cooler operating temperature of the tire which reduces its flexibility.

TOTAL ROAD LOADS

- The summation of the rolling resistance, aerodynamic forces and grade forces constitutes the propulsion load for the vehicle, and is normally referred to as "road load."

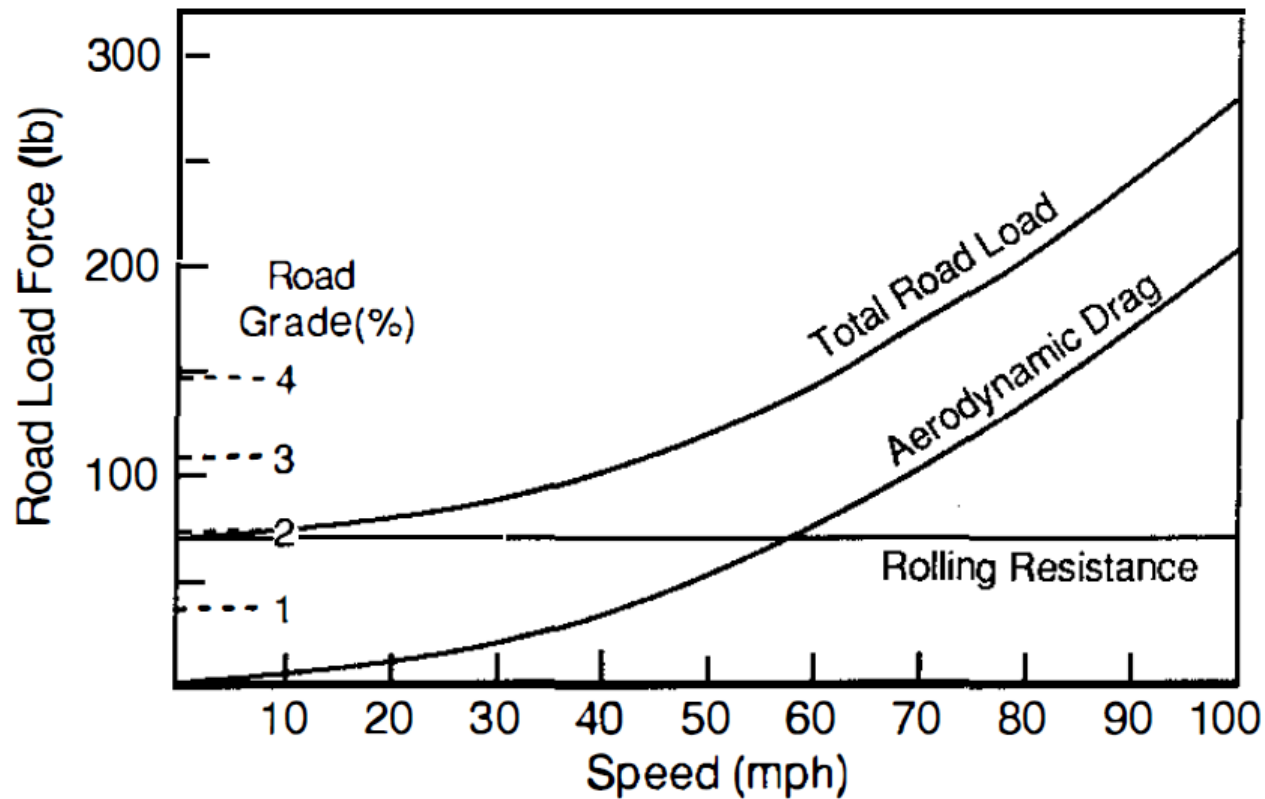
$$R_{RL} = f_r W + 1/2 \rho V^2 C_D A + W \sin \theta$$

- The road load horsepower

$$HP_{RL} = R_{RL} V/550 = (f_r W + 1/2 \rho V^2 C_D A + W \sin \theta) V/550$$

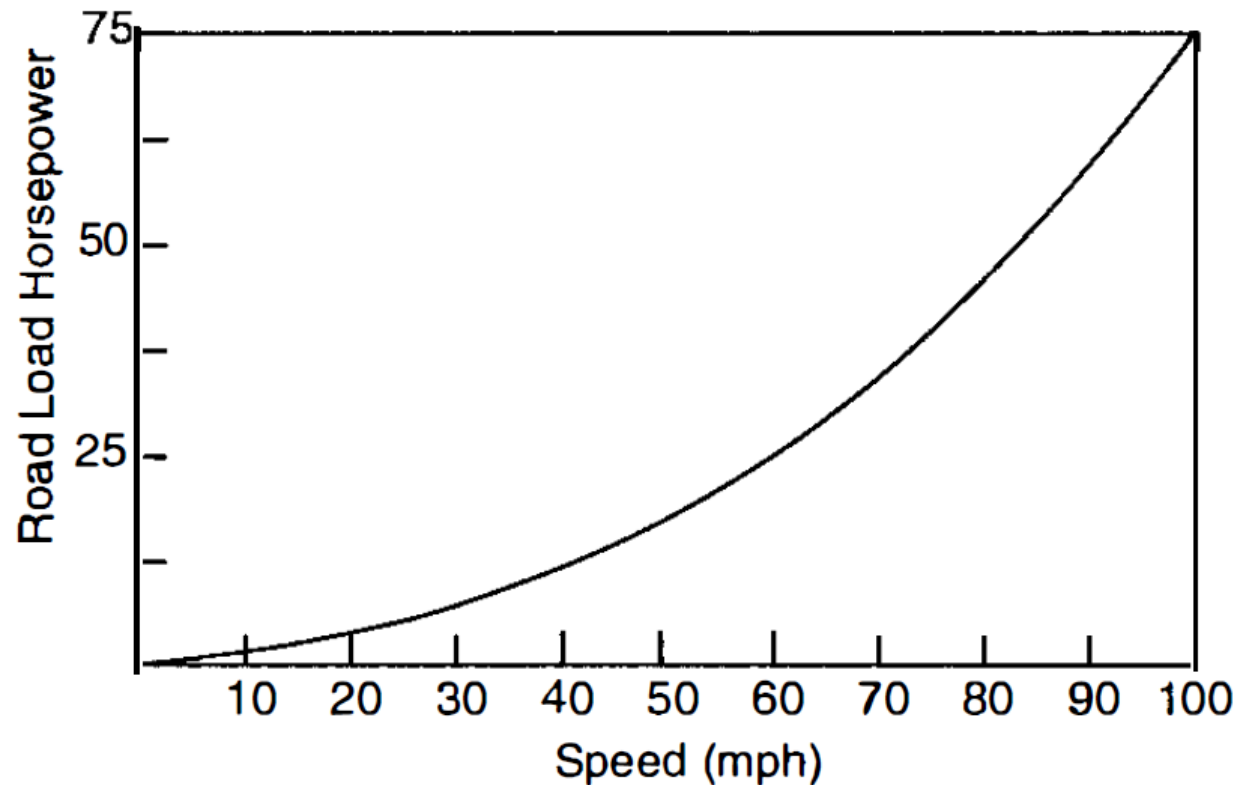
FUEL ECONOMY EFFECTS

□ Road Load plot



FUEL ECONOMY EFFECTS

❑ Road Load power plot



FUEL ECONOMY EFFECTS

- ❖ Today, aerodynamic and rolling resistance forces are of particular interest for their effect on fuel consumption.
- ❖ The exact improvements in fuel economy are difficult to predict because of the uncertainty about the ways cars are used and driven.

