Fundamentals of Steering Systems
ME5670

Lecture 3

Class timing
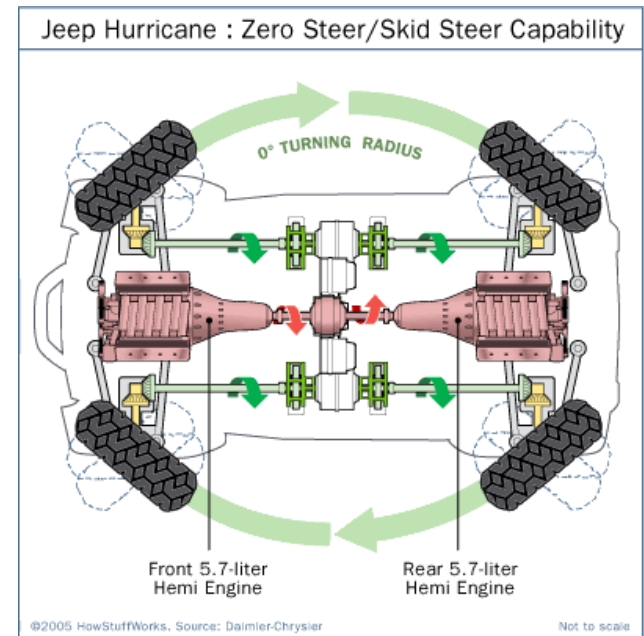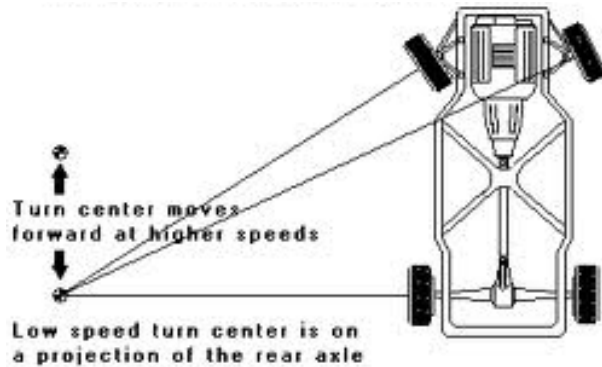*Monday: 14:30 Hrs – 16:00 Hrs*
Thursday: 16:30 Hrs – 17:30 Hrs

Date: 12/01/2015

Steering System

- To control the angular motion of the wheels and thus the direction of vehicle motion

- To provide the direction stability of the vehicle

- There are different types of steering systems

  - ❑ Front wheel steering system
  - ❑ Rare wheel steering system
  - ❑ Four wheel steering system

- Four wheel steering system is arranged so that the front wheels roll without any lateral slip

- In this system, the front wheels are supported on front axle so that they can swing to the left or right for steering.

- Such movement is produced by gearing and linkage between the steering wheel and steering knuckle

- There are two types of steer modes: rear steer mode for slow speeds and crab mode for high speeds.

- To control the direction stability of the vehicle using steering system, the force/moment analysis is important
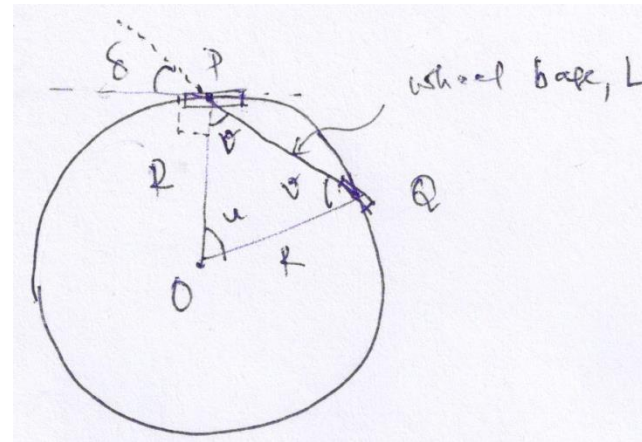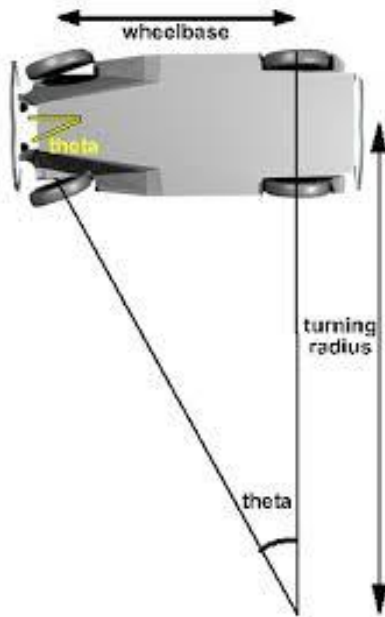
Ackerman Steering Mechanism

- At any angle of steering, the center point of all the circular path traced by all the wheels will coincide at a common point.

Turn center moves forward at higher speeds

Low speed turn center is on a projection of the rear axle

ACKERMANN STEERING MECHANISM

Jeep Hurricane : Zero Steer/Skid Steer Capability

0° TURNING RADIUS

Front 5.7-liter Hemi Engine

Rear 5.7-liter Hemi Engine

©2005 HowStuffWorks. Source: Daimler-Chrysler

Not to scale

- It is difficult to achieve with simple linkages. However, it is applicable for low speed.

Turning Radius

- Turning circle of a car is the diameter of the circle described by the outside wheels when turning on full lock.

For triangle OPQ

$$u + 2v = 180°$$

Also, $\delta + v = 90°$

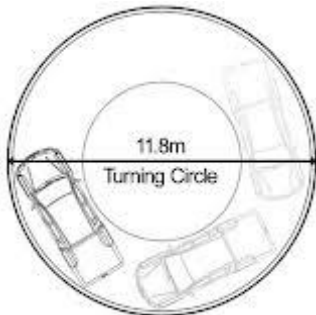$$\therefore \quad v = 90° - \delta$$

$$u = 180° - 2v$$

$$= 180° - 180° + 2\delta$$

$$u = 2\delta$$

$$L^2 = R^2 + R^2 - 2R^2 \cos u$$

$$L^2 = 2R^2 \left[1 - \cos 2\delta \right]$$

$$L^2 = 2R^2 \left[1 - \cos 2\delta \right]$$

$$L = 2R \sin \delta$$

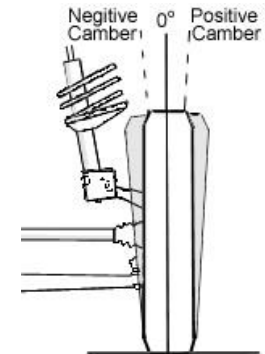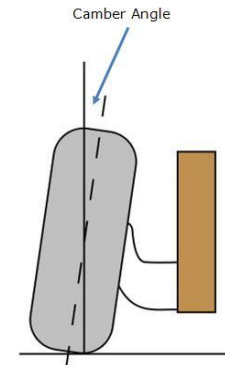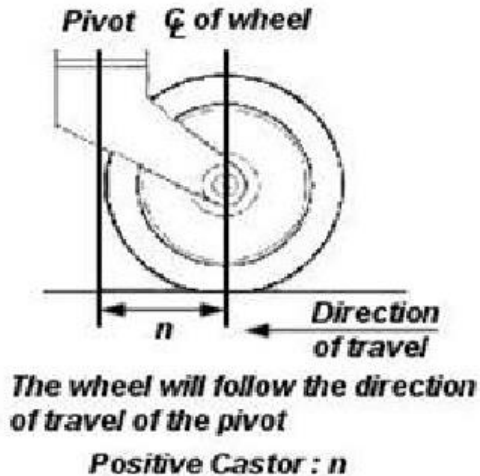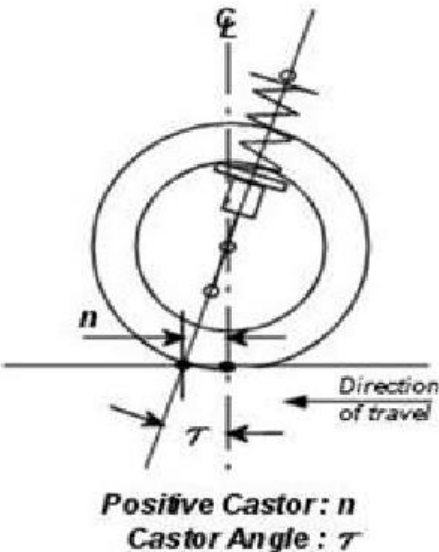$$\boxed{R = \frac{L}{2 \sin(\delta)}}$$

- A typical turning radius of a car is 35.5 feet.

Steering Axle Inclination, Caster, and Camber Angles

- The angle between the vertical line and center of the king pin or steering axle, when viewed from the front of the wheel is known as *steering axle inclination or king pin inclination* (0-5 degrees for trucks and 10-15 degrees on passenger cars).

- *Caster:* The angle between the vertical line and kingpin center line in the plane of the wheel (when viewed from the side) is called *caster angle*.
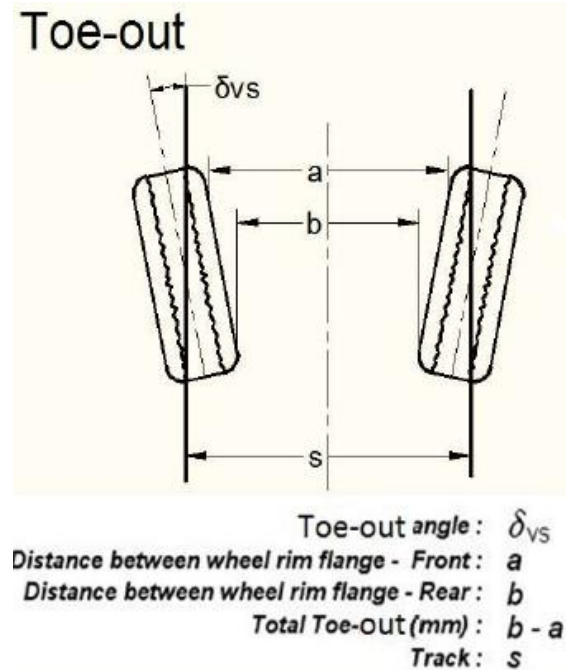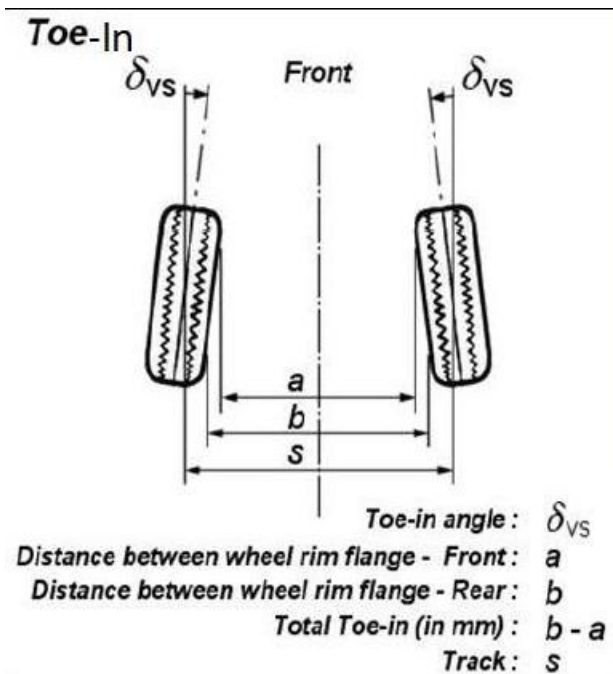
Kingpin Angle

Camber Angle: γ
Kingpin Angle or Kingpin Inclination (KPI): σ
Kingpin Offset or Steering Scrub Radius: r_s

- *Camber*: The angle between the center line of the wheel and the vertical line when viewed from the front

Positive Castor: n
Castor Angle: τ

The wheel will follow the direction of travel of the pivot
Positive Castor : n

Pivot ℄ of wheel

Direction of travel

n

Negitive Camber | 0° | Positive Camber

Camber Angle

Positive Camber: Upper portion is tilted outward.
Negative Camber: Upper portion is tilted inward
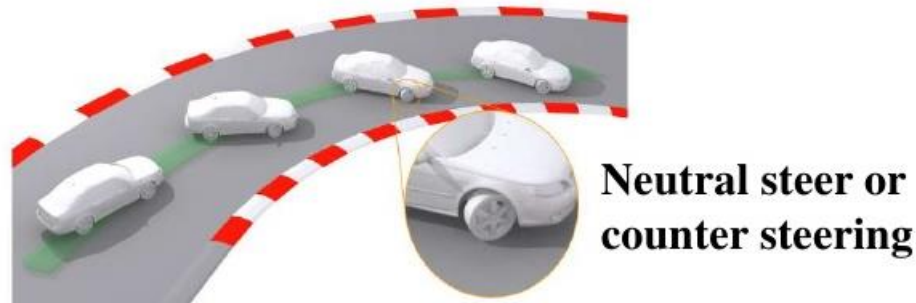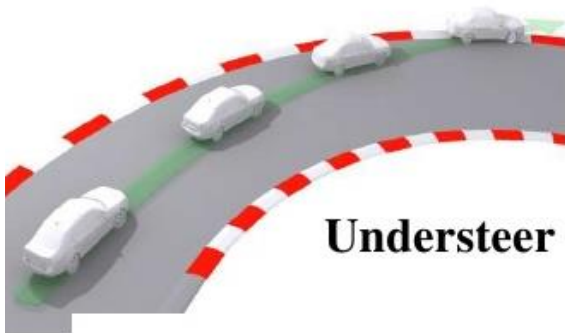
Toe-In and Toe-Out

- Toe-in: The front wheels are usually turned in slightly in front so that the distance between front ends is slightly less than the back ends when viewed from the top. *The difference between these distances is called toe-in*

- The difference in angle between the two front wheels and the car frame during turns. The toe-out is secured by providing the proper relationship between the steering knuckle arms, tie rods and pitman arm.

Toe-In

δ_{vs} Front δ_{vs}

a
b
s

Toe-in angle :	δ_{vs}
Distance between wheel rim flange - Front :	a
Distance between wheel rim flange - Rear :	b
Total Toe-in (in mm) :	b - a
Track :	s

Toe-out

δvs

a
b

s

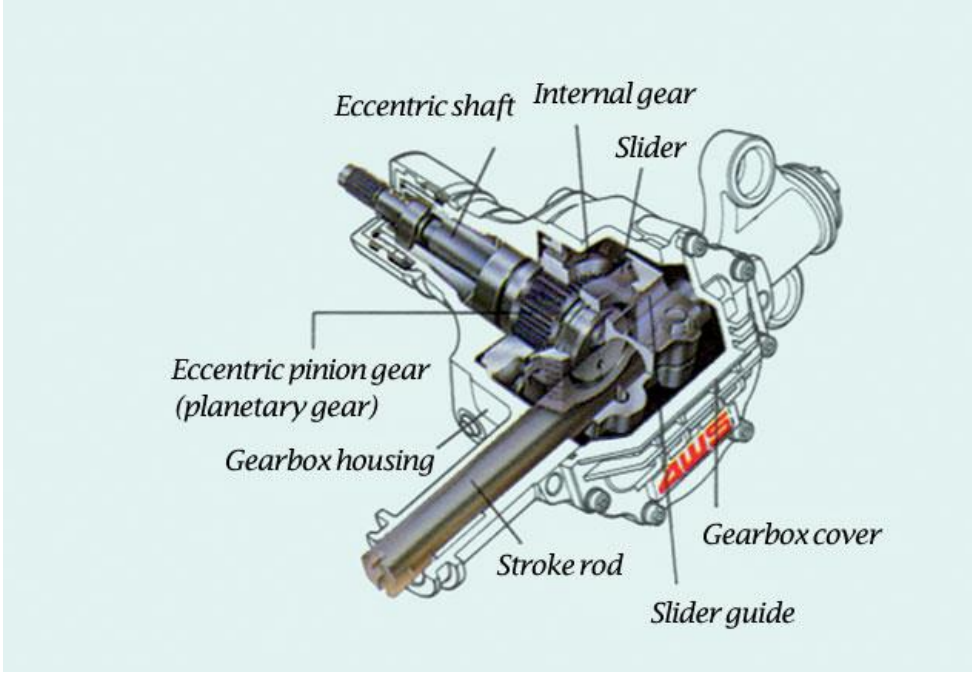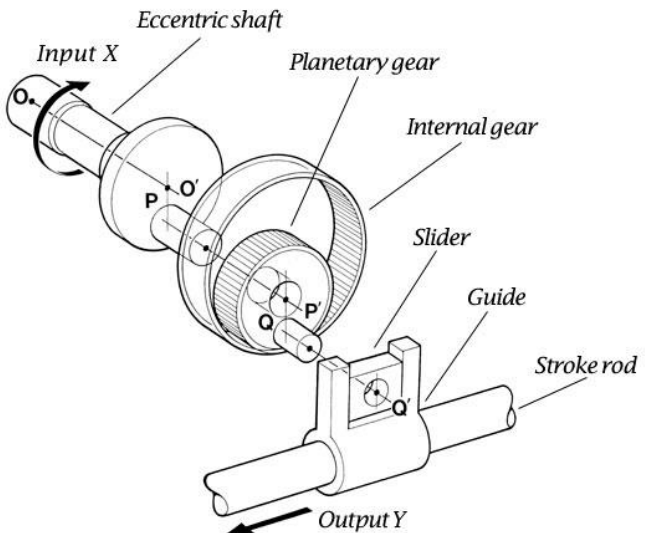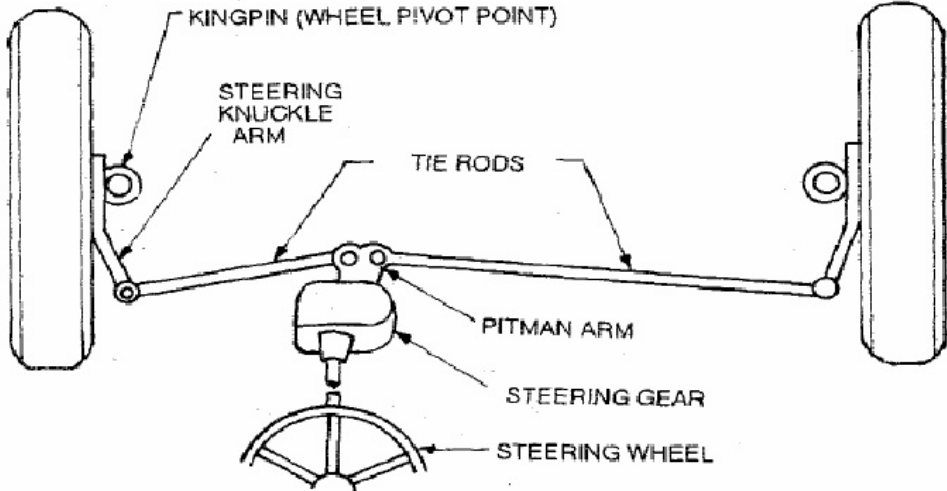|	
Toe-out angle :	δ_{vs}
Distance between wheel rim flange - Front :	a
Distance between wheel rim flange - Rear :	b
Total Toe-out (mm) :	b - a
Track :	s

Vehicle Dynamics and Steering

- *Under steer*: When the slip angle of front wheels is greater than the slip angle of rear wheels

- *Over steer*: When the slip angle of front wheels is lesser than the slip angle of rear wheels

- *Neutral steer or counter steering*: When the slip angle of front wheels is equal to the slip angle of rear wheels
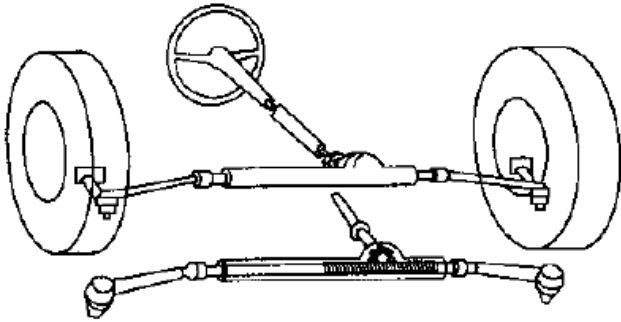

Understeer

Oversteer

Neutral steer or counter steering

Steering Gear Boxes

KINGPIN (WHEEL PIVOT POINT)

STEERING KNUCKLE ARM

TIE RODS

PITMAN ARM

STEERING GEAR

STEERING WHEEL

Eccentric shaft

Input X

Planetary gear

Internal gear

Slider

Guide

Stroke rod

Output Y

Eccentric shaft   Internal gear

Slider

Eccentric pinion gear (planetary gear)
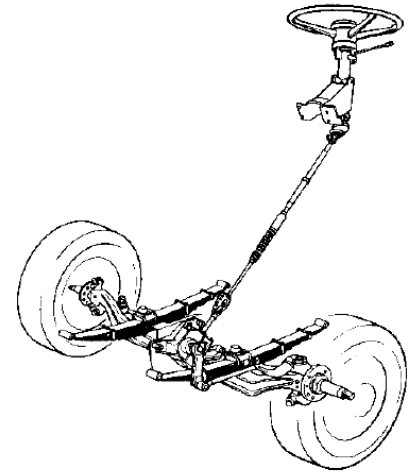
Gearbox housing

Stroke rod

Gearbox cover

Slider guide

Typical Steering Systems

Rack-and pinion linkage:

Truck steering system
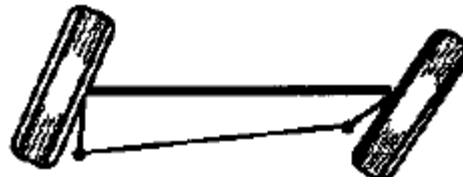
Steering gearbox

Differential steer
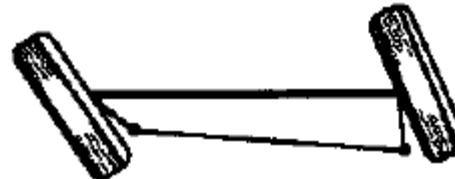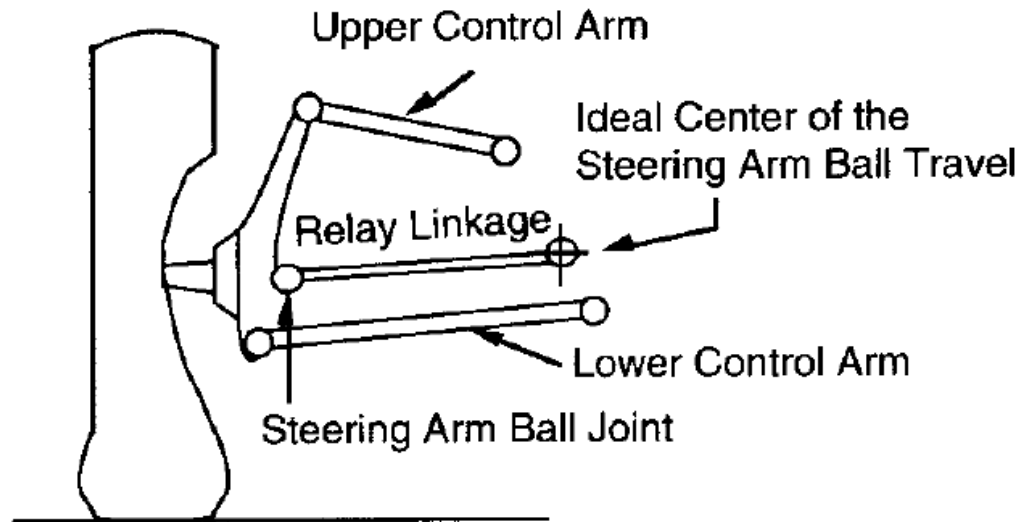
Trapezoidal tie-rod arrangement
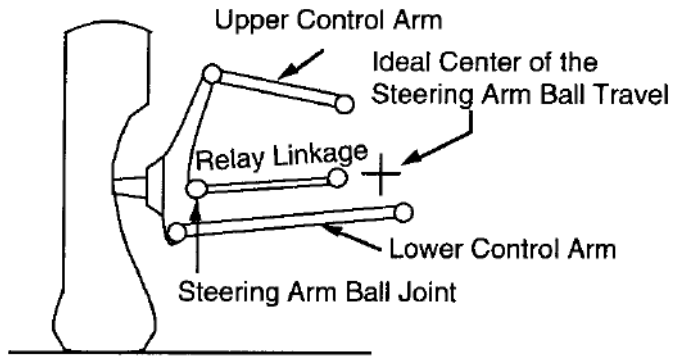
Right turn
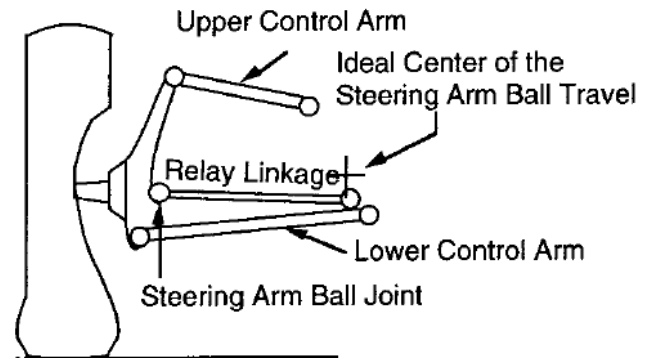
Left turn

Ideal Steering Geometry

- Tie rod end connect with the relay linkage end at the ideal centre.

- Relay linkage is connected to the pivot of the wheel

- If the linkage joint is either inboard or outboard of this point, the steering geometry error will cause a steer action as the wheels moves into jounce or rebound

Steering Geometry Error

Error due to toe change

Error due to understeer

Such phenomena leads to understeer/oversteer condition.

Tire Force/Moment Convention

SAE Tire Axis
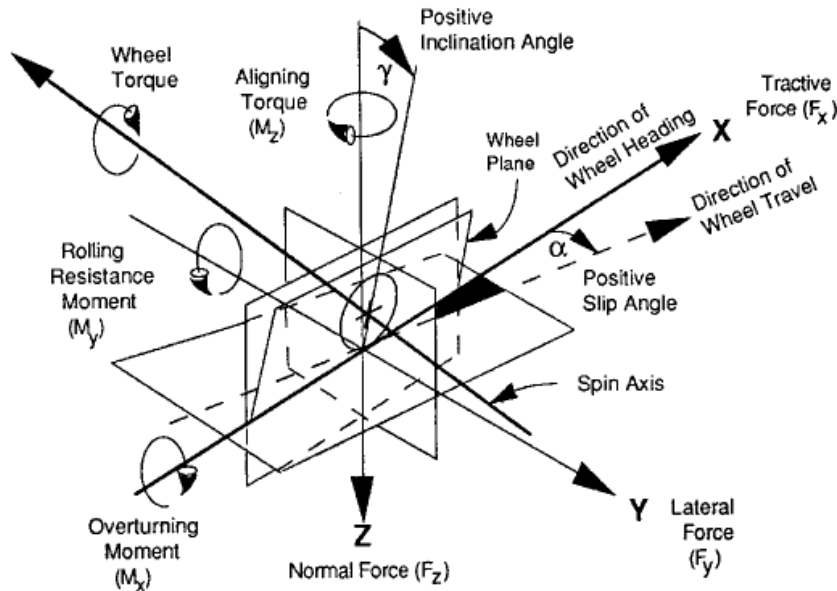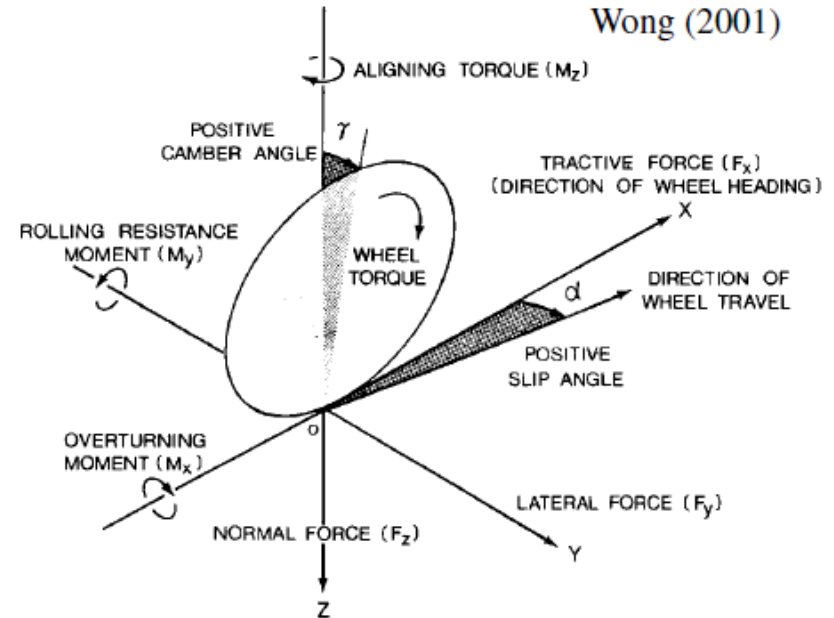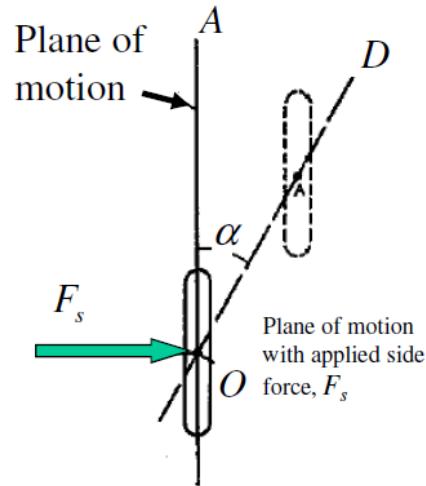
Three forces and three moments at the tire-surface interface w.r.t. O

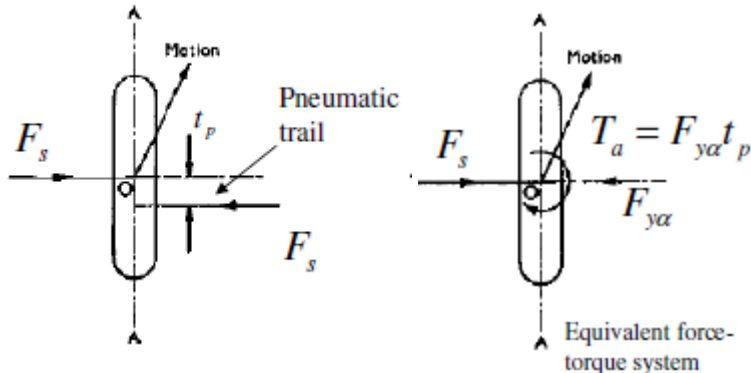

Fig. 10.3 SAE tire axis system. Gillespie (1992)

Wong (2001)

Different angles are selected to minimize the front type wear rather than handling.

Lateral or Cornering Force on Wheels/Tires

Plane of motion

A

D

α

F_s

Plane of motion with applied side force, F_s

O

Motion

Pneumatic trail

F_s

t_p

F_s

Motion

F_s

$T_a = F_{y\alpha} t_p$
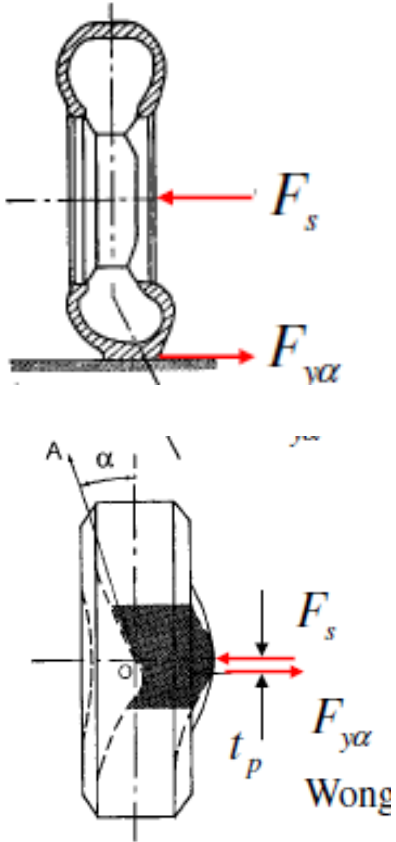
$F_{y\alpha}$

Equivalent force-torque system

- A slip angle, α, defines the difference between the wheel plane and the direction of motion, which may arise due to induced motion or because of an applied side force, F_s.

- A cornering force, F_{ya}, is induced in the lateral direction between the tire and ground, and it is found to be applied along an axis off the wheel axis. This force can be treated as the frictional force

- The couple T_a acting on the wheel tends to turn it so its plane coincides with the direction of motion.

- Steering and suspension systems must constrain the wheel if it is to stay, say, in the plane OA.

More on Tire Cornering Forces

F_s

$F_{y\alpha}$

A α

F_s

t_p $F_{y\alpha}$

Wong

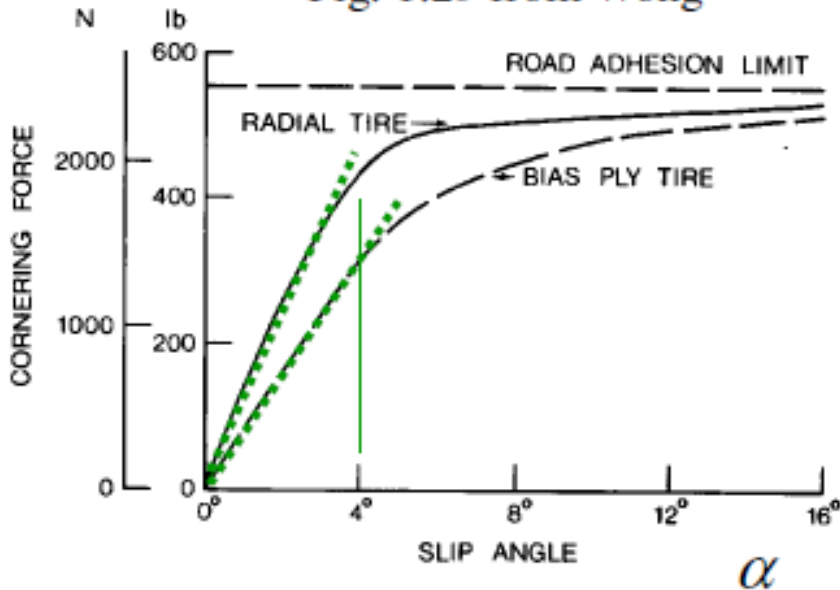*"…side slip is due to the lateral elasticity of the tire."*

- The slip angle, α, is shown here as the angle between the direction of heading and direction of travel of the wheel (OA).

- The lateral force, F_{ya}, (camber angle of the wheel is zero) is generated at a tire-surface interface, and may not be collinear with the applied force at the wheel centre. The distance between these two applied forces is called the pneumatic trail.

- The self-aligning torque is given by the product of the cornering force and the pneumatic trail

- The induced self-aligning torque helps a steered wheel return to its original position after a turn.

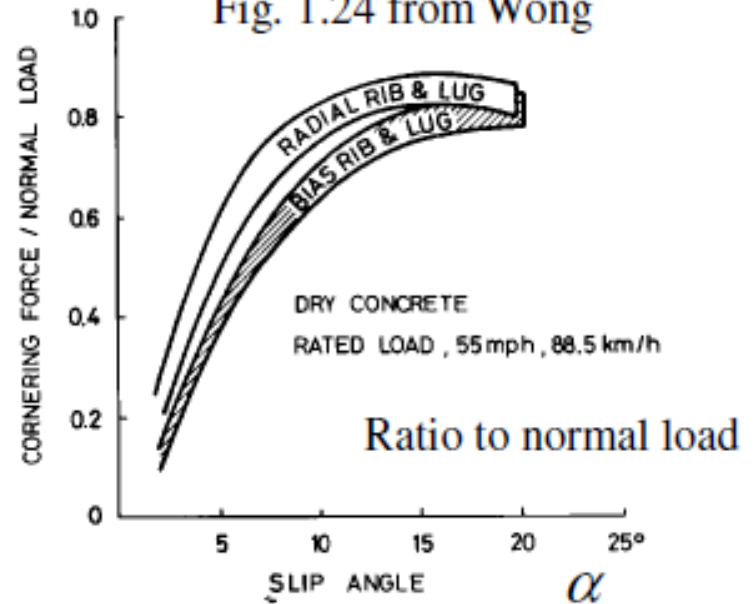# Cornering Force Data for Pneumatic Tires

Fig. 1.23 from Wong

Fig. 1.24 from Wong

"linear region"

Maximum cornering forces:
- passenger car tires: 18 degrees
- racing car tires: 6 degrees

(Wong)

Variables that impact cornering force:
- Normal load
- Inflation pressure
- Lateral load transfer
- Size

In general, tractive (or braking) effort will **reduce** the cornering force that can be generated at a given slip angle. This can be important in acceleration or braking in a turn, or in maintaining stability subject to disturbances.
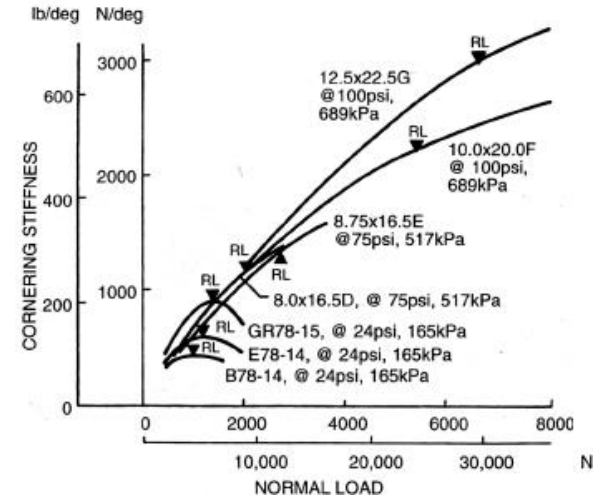
Cornering Stiffness and Coefficients

- The cornering stiffness will depend on tire properties such as:

  – tire size and type (e.g., radial, bias-ply, etc.),
  – number of plies,
  – cord angles,
  – wheel width, and
  – tread.

Fig. 1.27 from Wong

- Dependence on load is taken into account through the cornering coefficient, where F_z is the vertical load.

$$CC_\alpha = \frac{C_\alpha}{F_z}$$

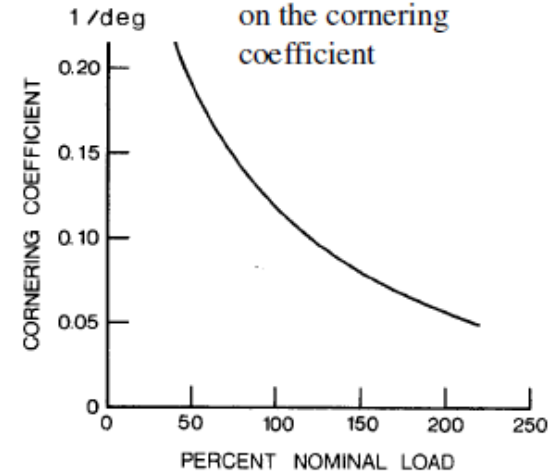Effect of normal load on the cornering coefficient

Fig. 1.28 from Wong

Example of Yaw Instability

Yaw instability can occur when front and rear wheels do not lock up at the same time.

- – Rear tires lock and **ability to resist lateral force decreases**.
- – A perturbation about the yaw center of the front axle will be developed
- – Yaw motion progresses with increased acceleration, with a decrease as it completes 180 degree turn.

Lock-up of front tires causes loss of directional control, but not directional instability. This is because a self-correcting inertial moment about the yaw center of the rear axle is induced whenever lateral movement of the front tires occurs.
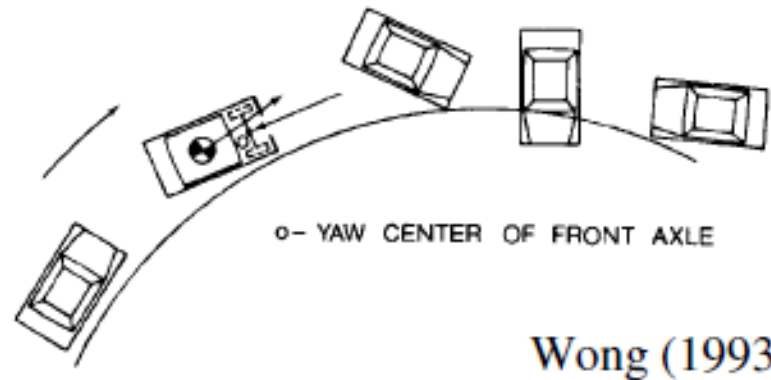

o– YAW CENTER OF FRONT AXLE

Wong (1993)

Fig. 3.48 Loss of directional stability due to lock-up of rear tires.