دانشگاه سمنان

دانشکده مهندسی مکانیک

Semnan University
Faculty of Mechanical Engineering

دانشکده مهندسی مکانیک

درس طراحی سیستم های شاسی خودرو

VEHICLE CHASSIS SYSTEMS DESIGN

Chapter 8 – Steering System

Class Lecture

❑ ***CONTENTS:***

دانشگاه سمنان

INTRODUCTION

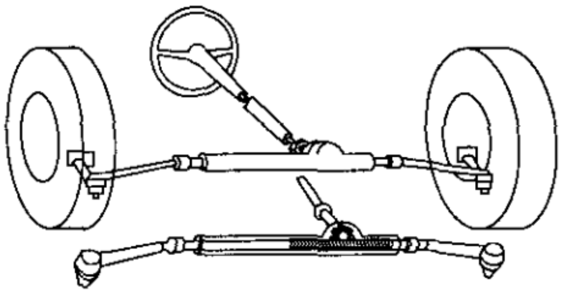
- The design of the steering system has an influence on the directional response behavior of a motor vehicle.

- The function of the steering system is to steer the front wheels in response to driver command inputs in order to provide overall directional control of the vehicle.

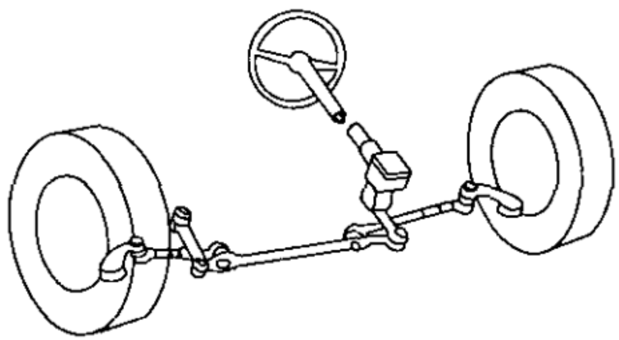
- However, the actual steer angles achieved are modified by the geometry of the suspension system, the geometry and reactions within the steering system, and in the case of front-wheel drive (FWD), the geometry and reactions from the drivetrain.

THE STEERING LINKAGES

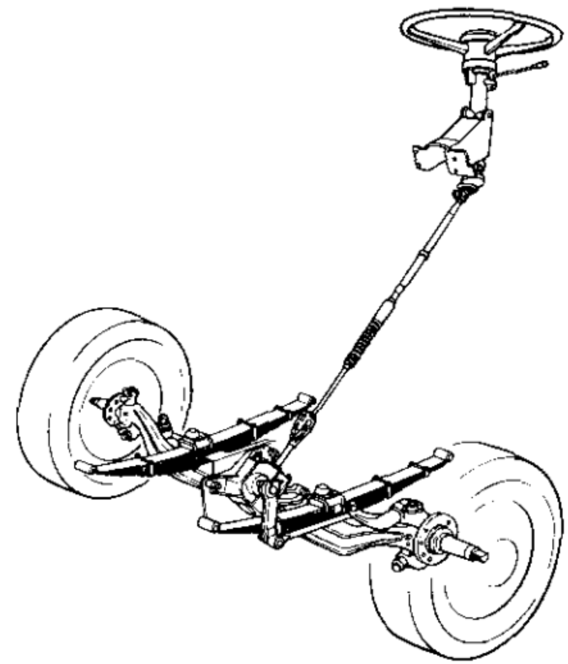
- The steering systems used on motor vehicles vary widely in design, but are functionally quite similar.



Rack-and-pinion linkage



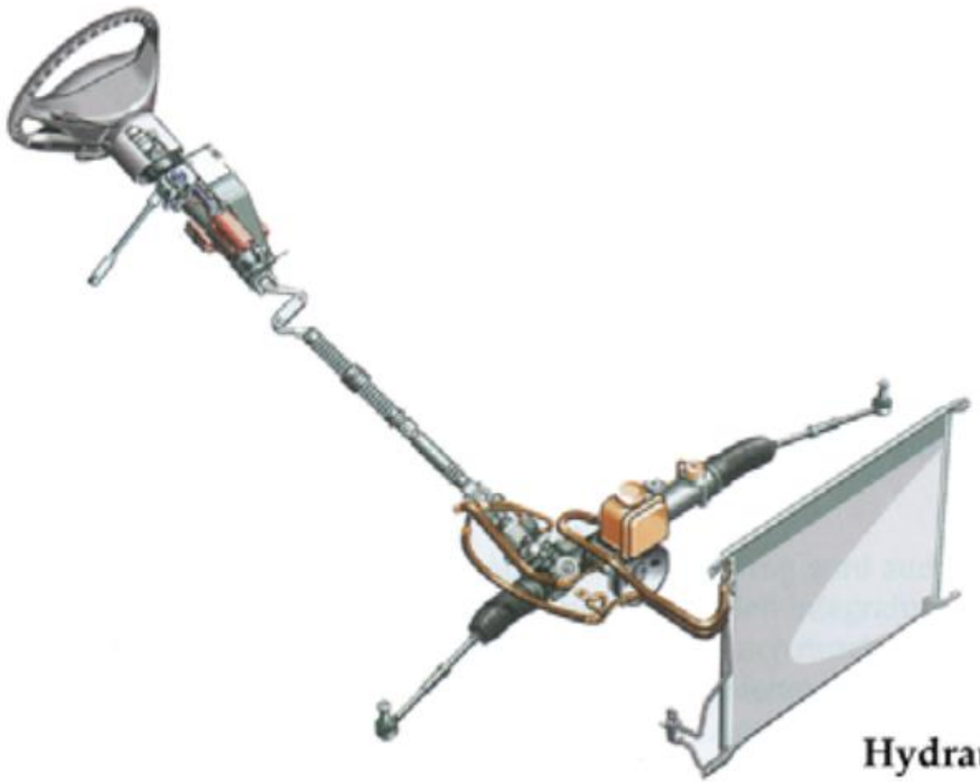
Steering gearbox



Truck steering system

The Steering Linkages

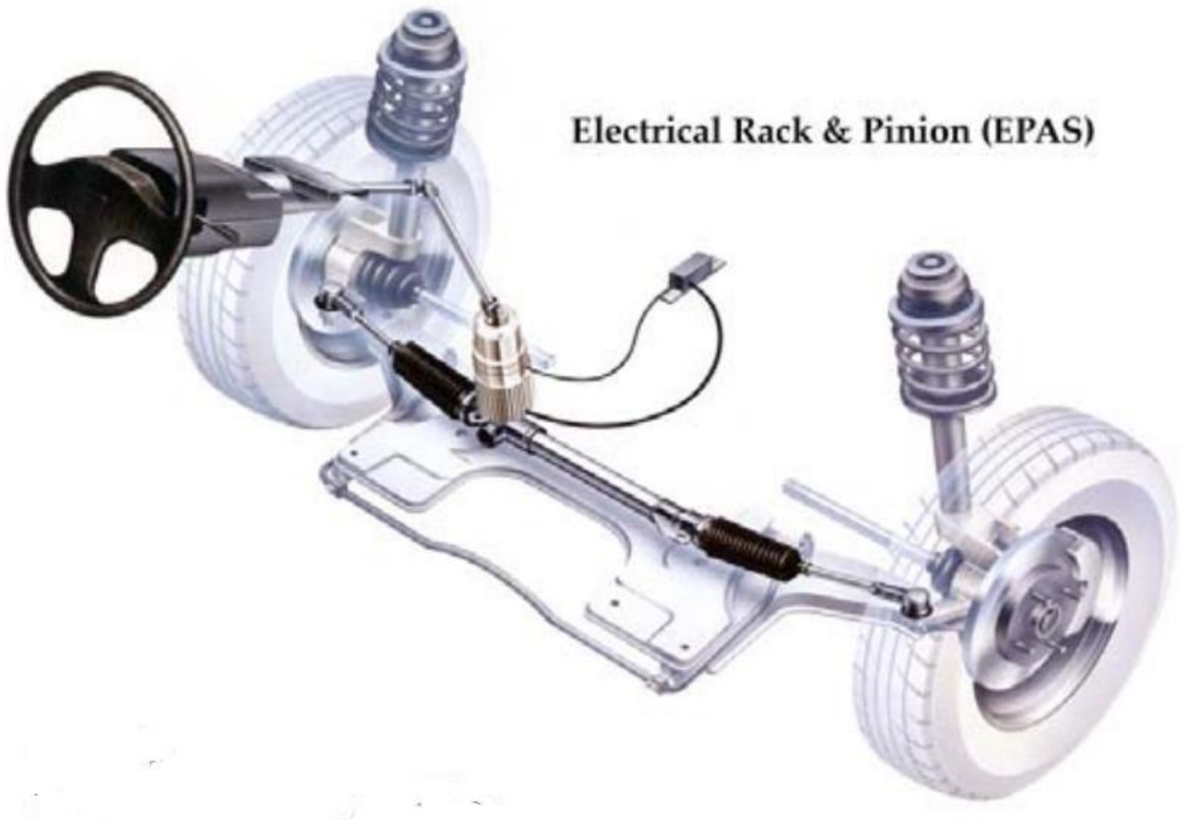
- Hydraulic power assisted steering



Hydraulic Power Assisted Steering

The Steering Linkages

- Electric steering



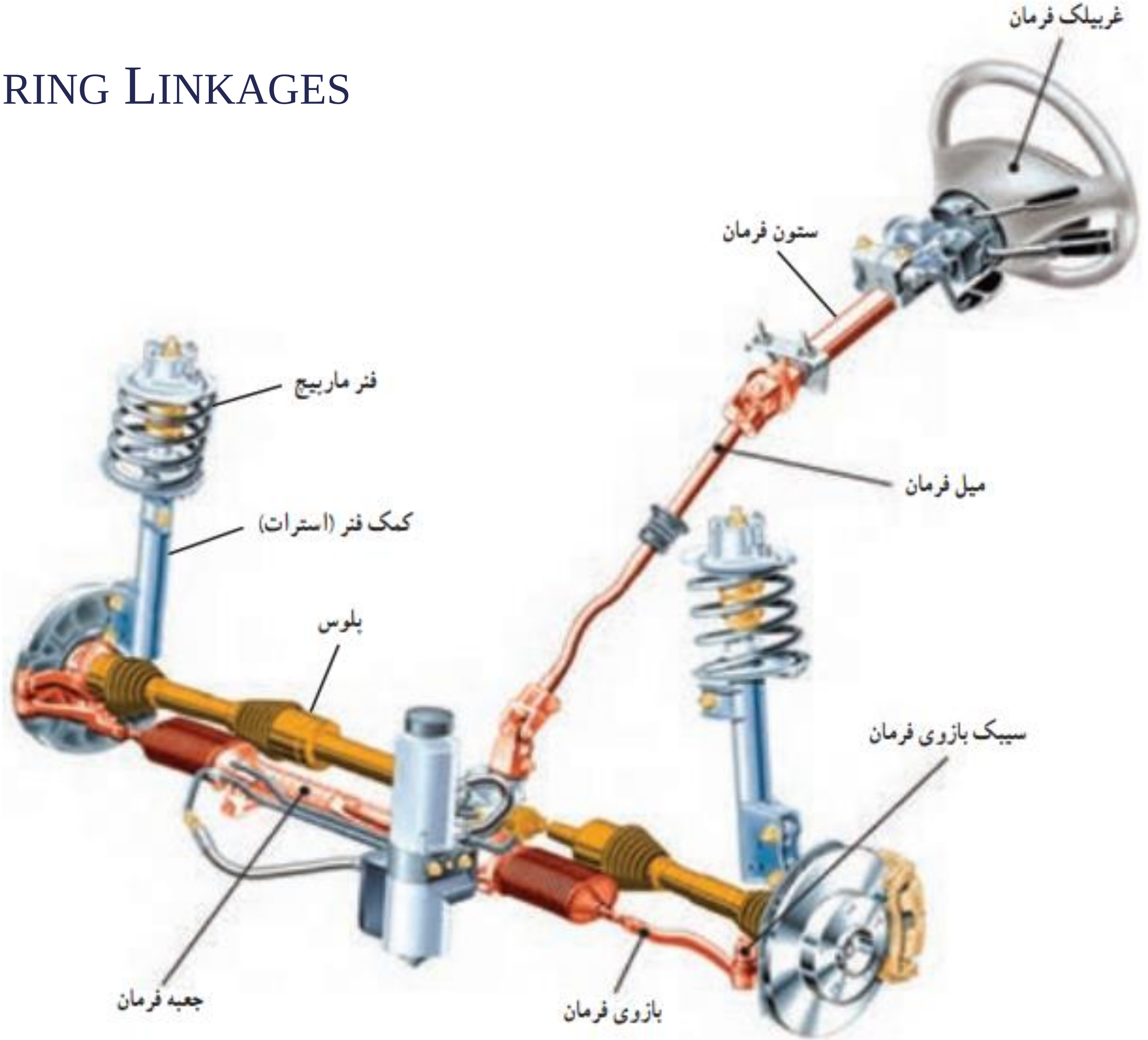
The Steering Linkages

- The steering wheel connects by shafts, universal joints, and vibration isolators to the steering gearbox whose purpose is to transform the rotary motion of the steering wheel to a translational motion appropriate for steering the wheels.

- The rack-and-pinion system consists of a linearly moving rack and pinion, mounted on the firewall or a forward cross member, which steers the left and right wheels directly by a tie-rod connection.

- The tie-rod linkage connects to steering arms on the wheels, thereby controlling the steer angle.

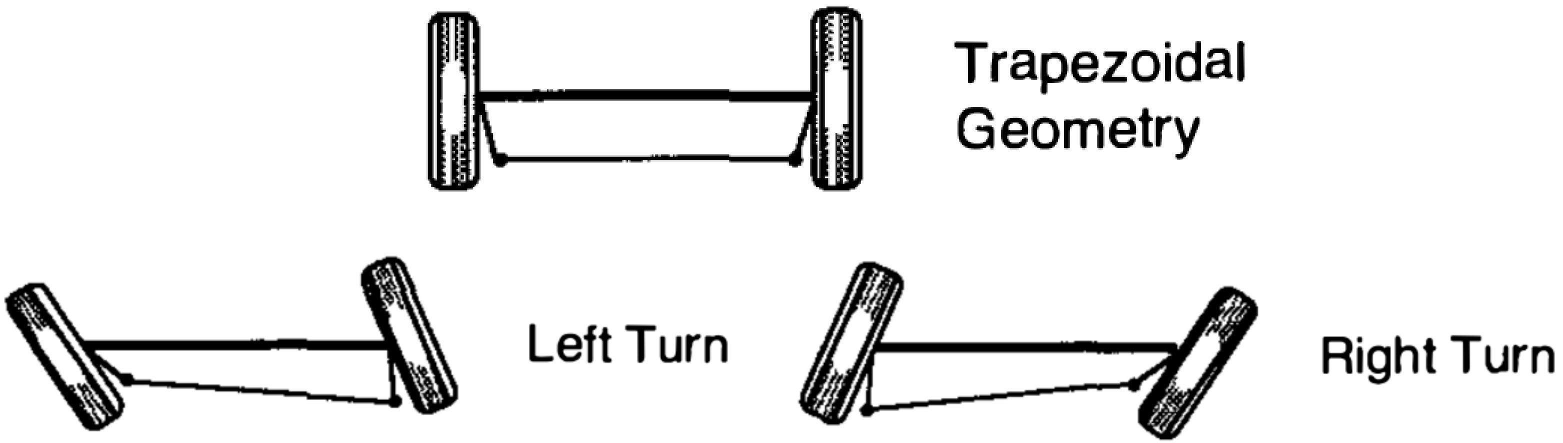
THE STEERING LINKAGES



THE STEERING LINKAGES

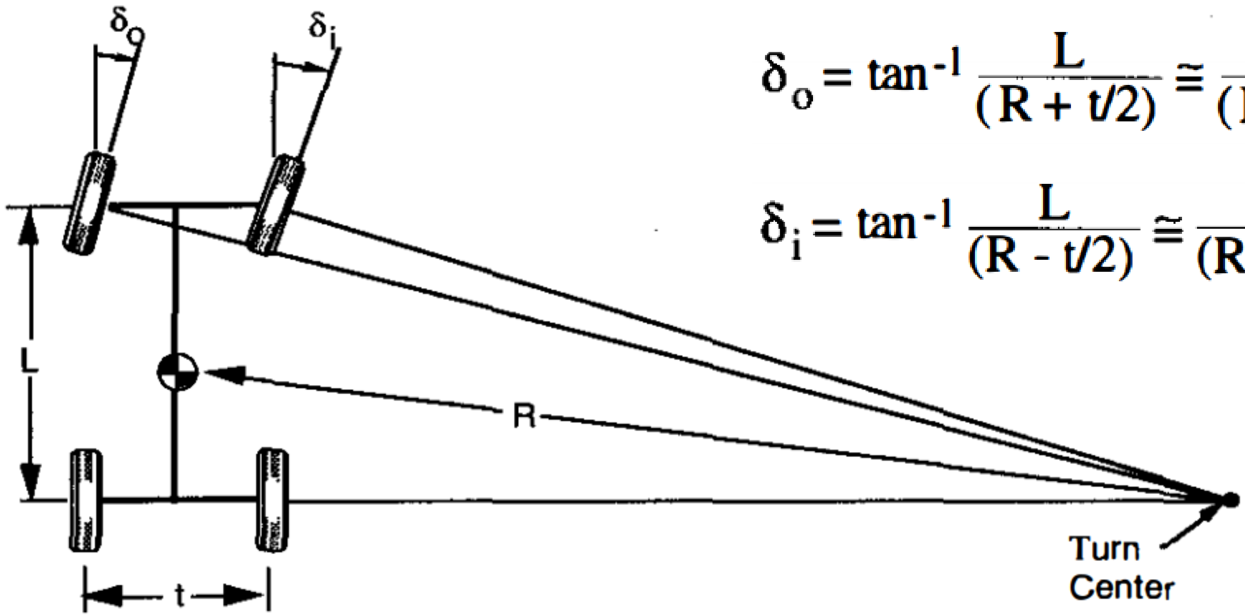
- The steering wheel to road wheel angle ratios normally vary with angle, but have nominal values on the order of 15 to 1 in passenger cars, and up to as much as 36 to 1 with some heavy trucks.

- The lateral translation produced by the gearbox is relayed through linkages to steering arms on the left and right wheels.



THE STEERING LINKAGES

- The Ackerman geometry



$$\delta_o = \tan^{-1}\frac{L}{(R + t/2)} \cong \frac{L}{(R + t/2)}$$

$$\delta_i = \tan^{-1}\frac{L}{(R - t/2)} \cong \frac{L}{(R - t/2)}$$

- Perfect Ackerman is difficult to achieve with practical linkage designs, but is closely approximated by a trapezoidal arrangement

Steering Geometry Error

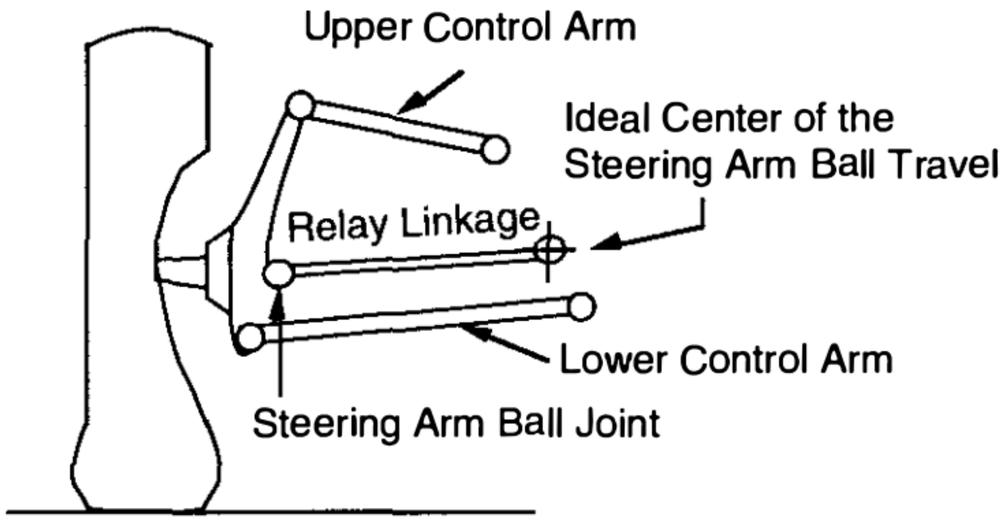
- In the typical steering system the relay linkages transfer the steering action from the gearbox on the body of the vehicle to the steering arms on the wheels.

- The steering action is achieved by translational displacement of the relay linkage in the presence of arbitrary suspension motions.

- There is obvious potential for steering actions to arise from suspension motions, which are known as steering geometry errors.

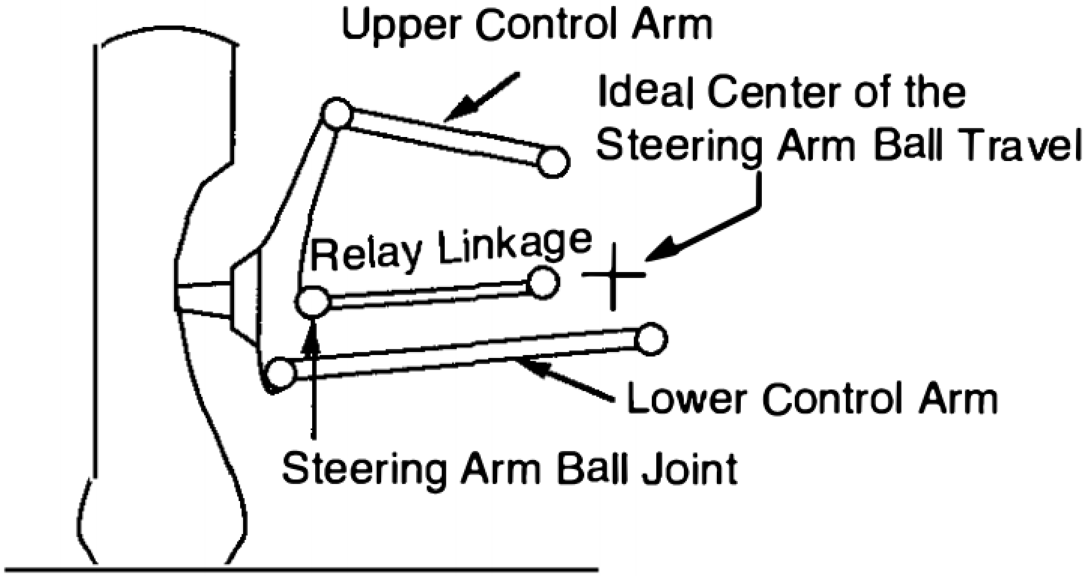
Steering Geometry Error

- For an ideal steering system the relay linkage is designed such that the arc described by its ball connection to the steering arm exactly follows the arc of the steering arm during suspension deflections.
- In practice, it is not always possible to achieve this ideal because of packaging problems, nonlinearities in the motion of the suspension, and because of geometry changes when the wheels are steered.



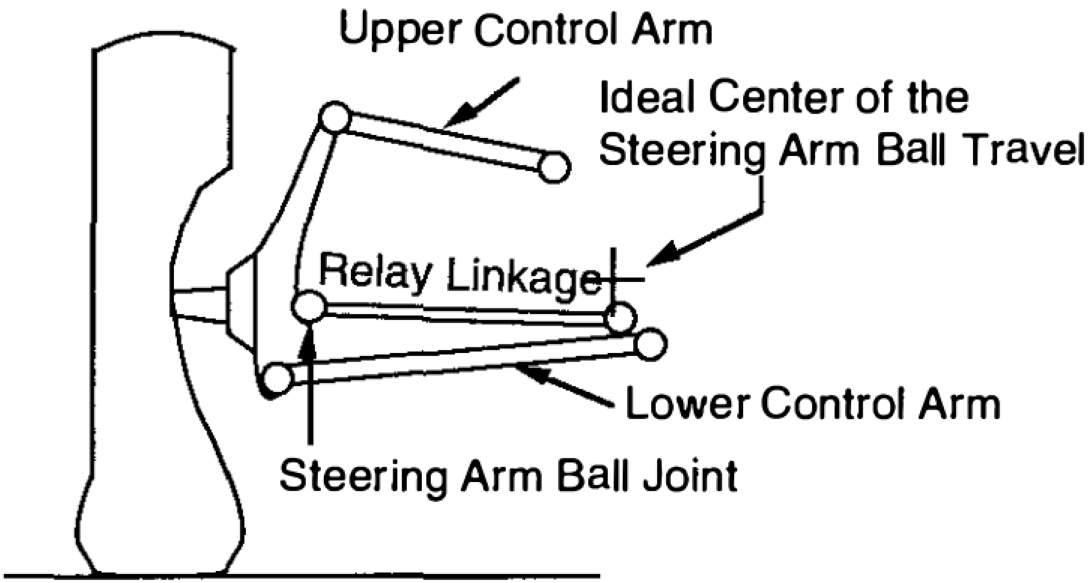
Steering Geometry Error

- Toe Change
  - A toe-out error occurs when the wheels are at any position other than the design ride height, and proper toe will be difficult to maintain due to its dependence on front-wheel load condition.



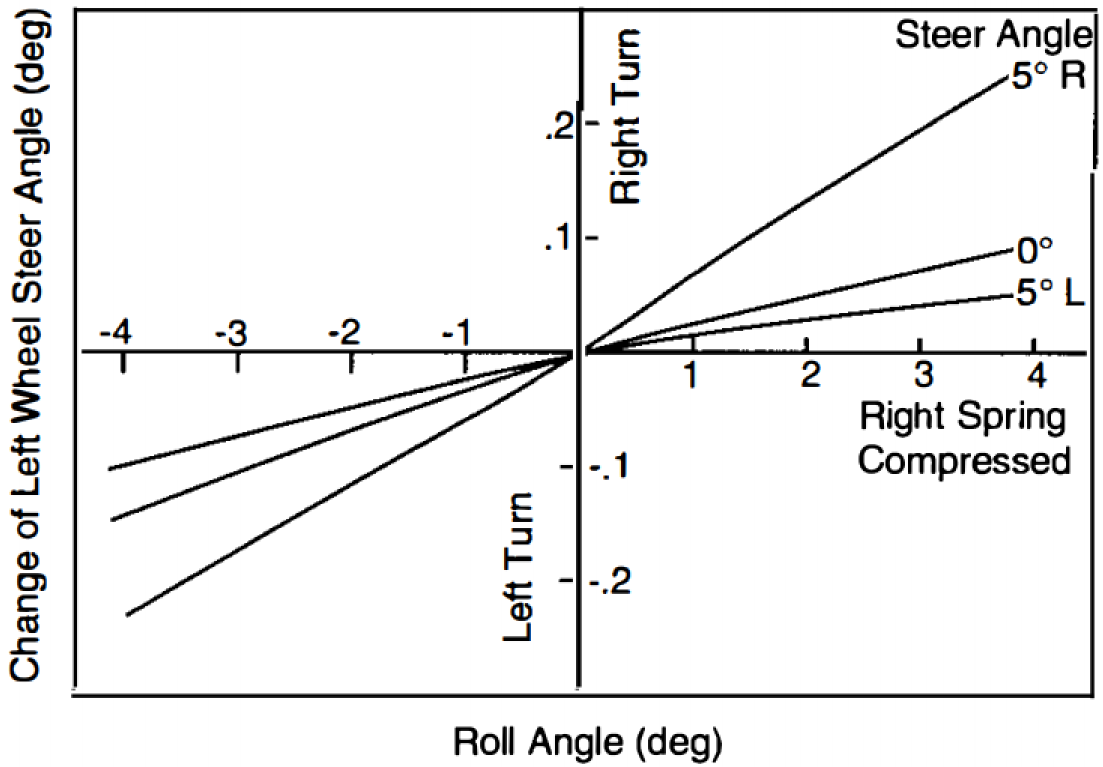
Steering Geometry Error

- Roll Steer
  - Both wheels will steer in the same direction when the body rolls.
  - For example, in a turn to the right, the body rolls to the left inducing jounce on the left wheel and rebound on the right. Thus both wheels steer to the left (out of the turn) adding an understeer effect



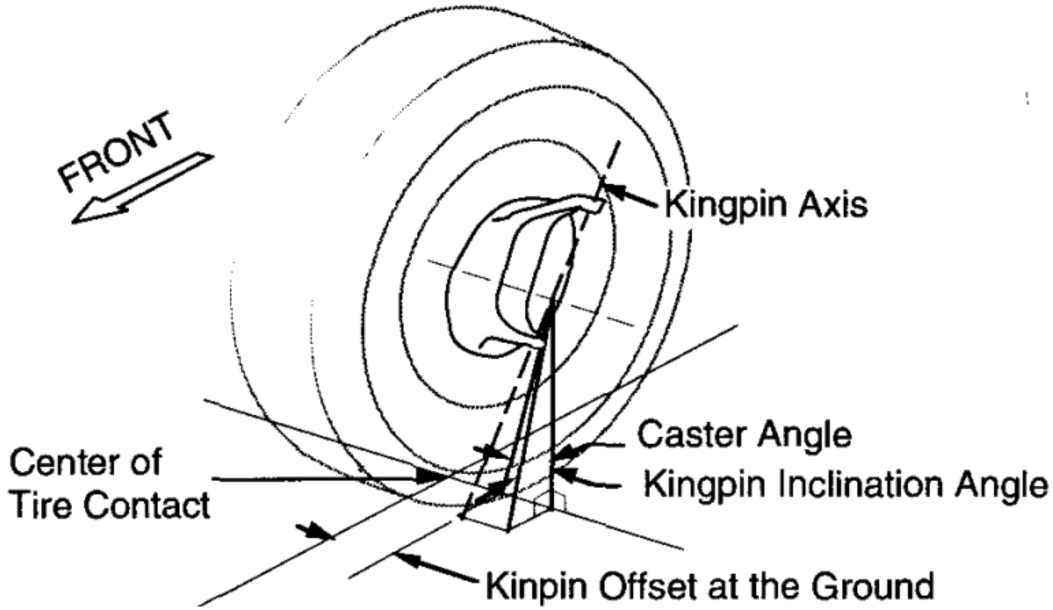
STEERING GEOMETRY ERROR

- Roll Steer
  - Experimentally measured roll steer behavior
    - ✓ At any steer angle, the slope of the curve is roll steer coefficient. $K_{roll\ steer} = \varepsilon \frac{d\,\phi}{d\,a_y}$



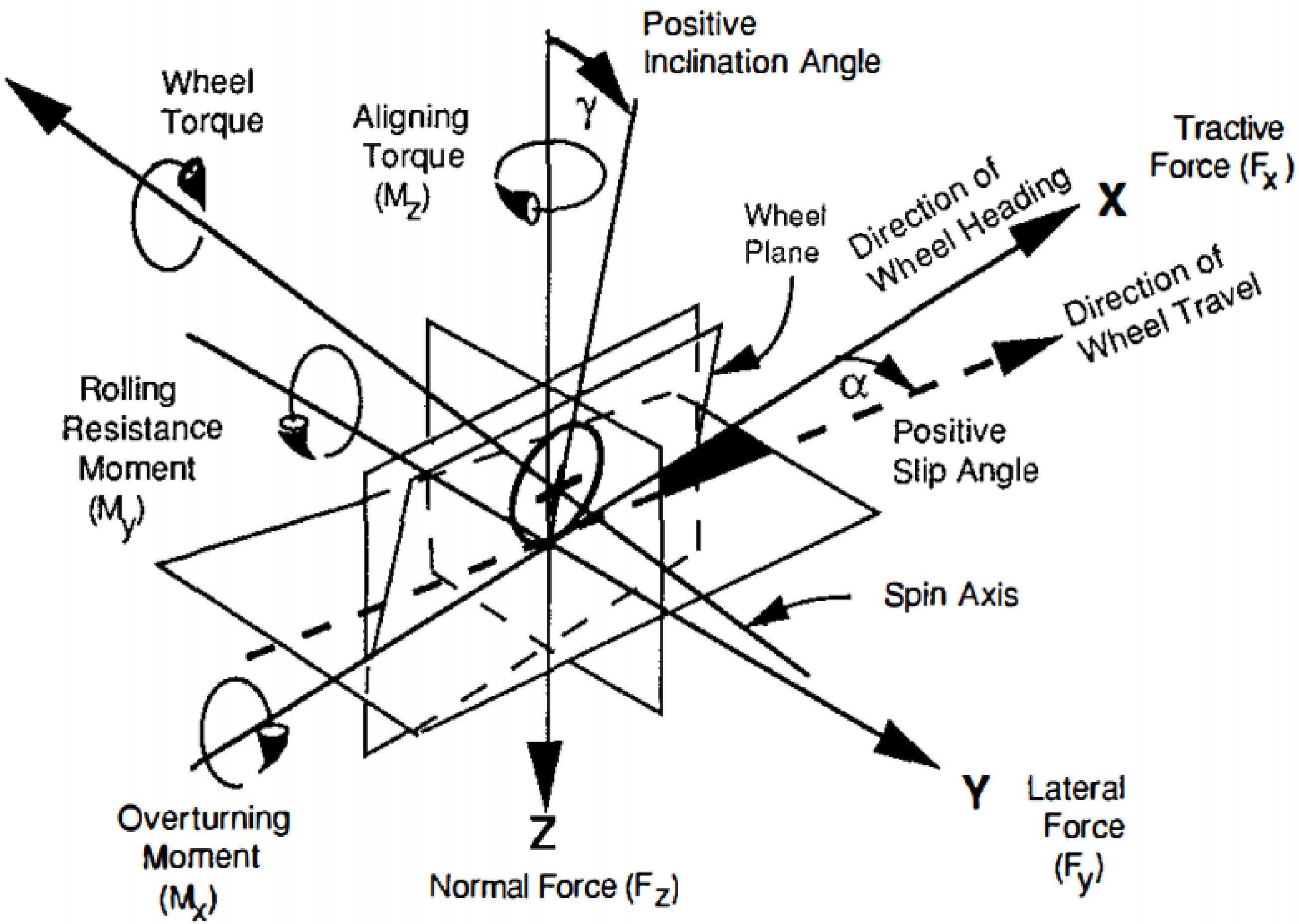
Front Wheel Geometry

- The important elements of a steering system consist not only of the visible linkages, but also the geometry associated with the steer rotation axis at the road wheel.
- This geometry determines the force and moment reactions in the steering system, affecting its overall performance.



Steering System Forces and Moments

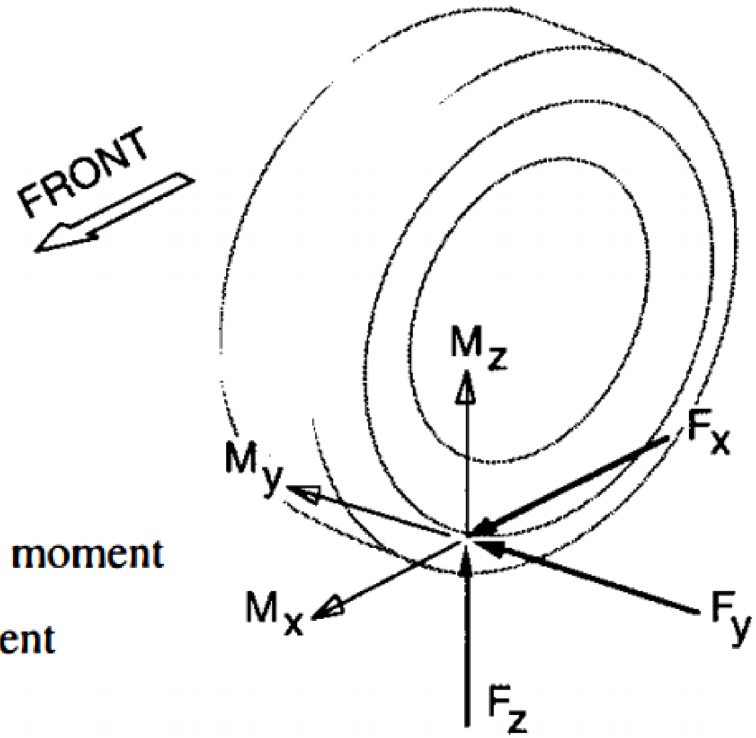
- The ground reactions on the tire



STEERING SYSTEM FORCES AND MOMENTS

- Three forces and moments acting on a right-hand road wheel

Normal force	Aligning torque
Tractive force	Rolling resistance moment
Lateral force	Overturning moment



Steering System Forces and Moments

- Vertical Force
  - Because the steering axis is inclined, Fz has a component acting to produce a moment attempting to steer the wheel.

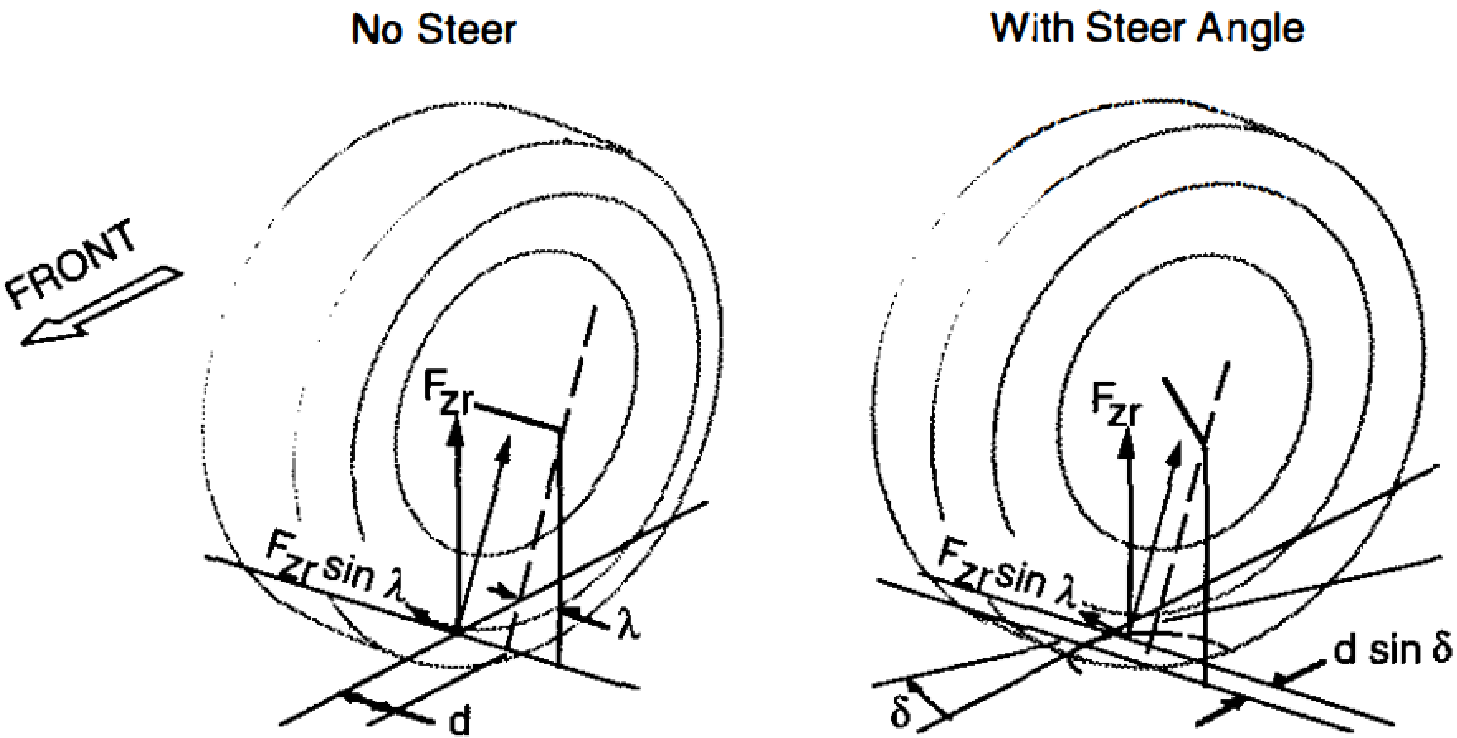
$$M_V = -(F_{zl}+F_{zr})\, d \sin\lambda \sin\delta + (F_{zl} - F_{zr})\, d \sin\nu \cos\delta$$

M_V = Total moment from left and right wheels
F_{zl}, F_{zr} = Vertical load on left and right wheels
d = Lateral offset at the ground
λ = Lateral inclination angle
δ = Steer angle
ν = Caster angle

✓ lateral inclination angle and caster angle effect.

Steering System Forces and Moments

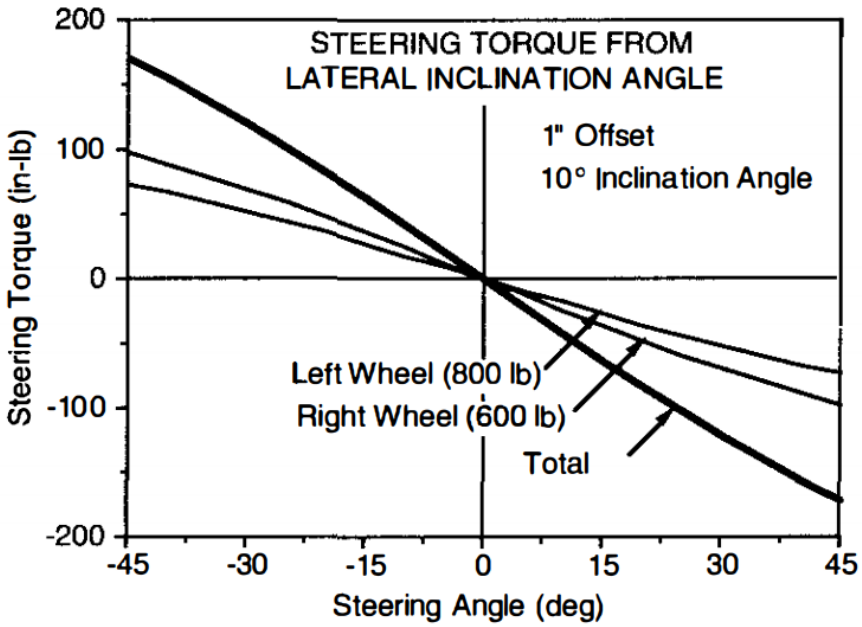
- Vertical Force
  - Moment produced by vertical force acting on lateral inclination angle



STEERING SYSTEM FORCES AND MOMENTS

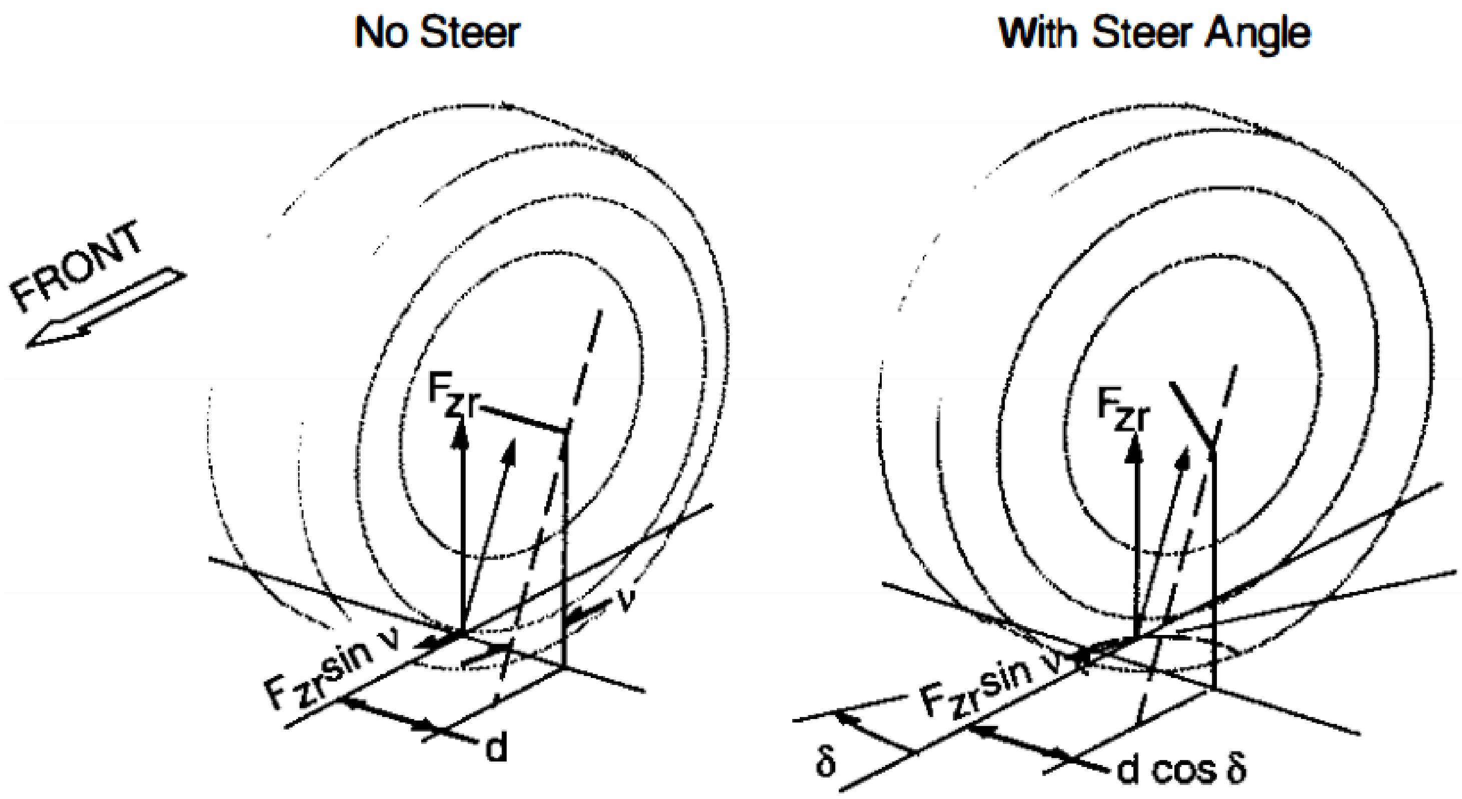
- Vertical Force
  - Steering torques arising from lateral inclination angle

- Torque = - $(F_{zl}+F_{zr})\, d \sin \lambda \sin \delta$
- Axle lifts when steered
- Unaffected by left-right load differences
- Torque gradient depends on:
  - — wheel offset at the ground
  - — inclination angle
  - — axle load



STEERING SYSTEM FORCES AND MOMENTS

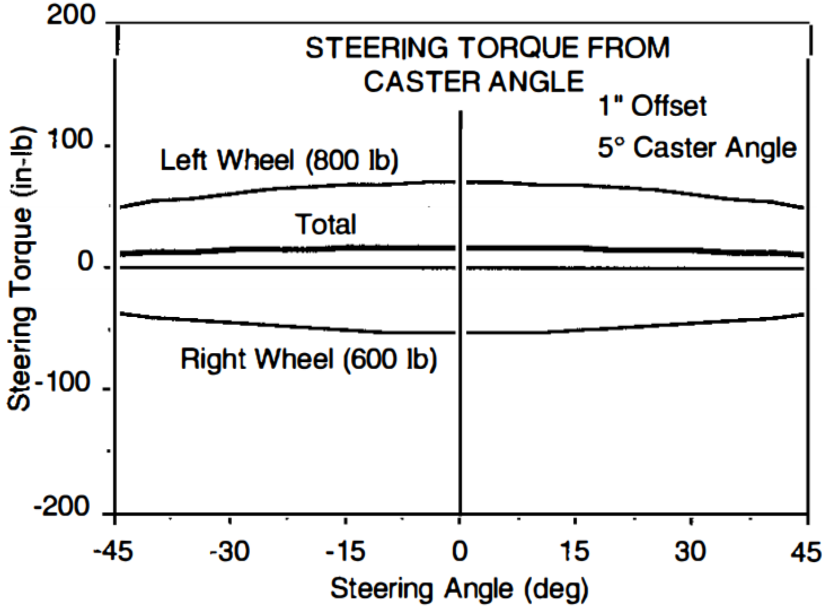
- Vertical Force
  - Moment produced by vertical force acting on caster angle



Steering System Forces and Moments

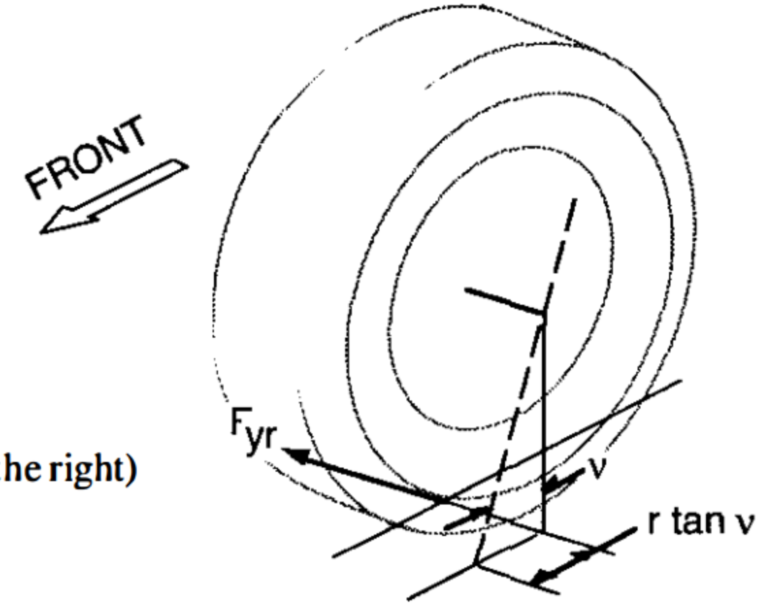
- Vertical Force
  - Steering torques due to caster angle

- Torque = $(F_{zl} - F_{zr})\, d \sin \nu \cos \delta$
- Axle rolls when steered
- Sensitive to left-right load imbalance (load or spring asymmetry)
- Torque gradient depends on
  - — wheel offset at the ground
  - — caster angle
  - — left-right load difference in cornering
    - ·front and rear suspensions roll stiffnesses
    - ·suspension roll center height
    - ·center of gravity height
    - ·lateral acceleration level



Steering System Forces and Moments

- Lateral Force



$$M_L = (F_{yl}+F_{yr})\ r \tan v$$

F_{yl}, F_{yr} = Lateral forces at left and right wheels (positive to the right)

r = Tire radius

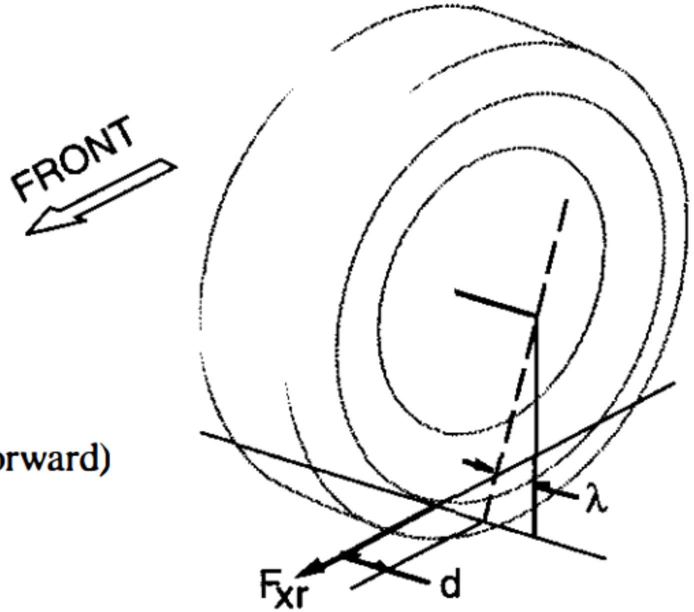
- The lateral force is generally dependent on the steer angle and cornering condition, and with positive caster produces a moment attempting to steer the vehicle out of the tum. Hence, it is a major contributor to understeer.

STEERING SYSTEM FORCES AND MOMENTS

- Tractive Force

$$M_T = (F_{xl} - F_{xr})\, d$$

F_{xl}, F_{xr} = Tractive forces on left and right wheels (positive forward)



- The left and right moments are opposite in direction and tend to balance through the relay linkage.
- Imbalances, such as may occur with a tire blowout, brake malfunction, or split coefficient surfaces, will tend to produce a steering moment which is dependent on the lateral offset dimension.

Steering System Forces and Moments

- Aligning Torque

$$M_{AT} = (M_{zl} + M_{zr}) \cos \sqrt{\lambda^2 + v2}$$

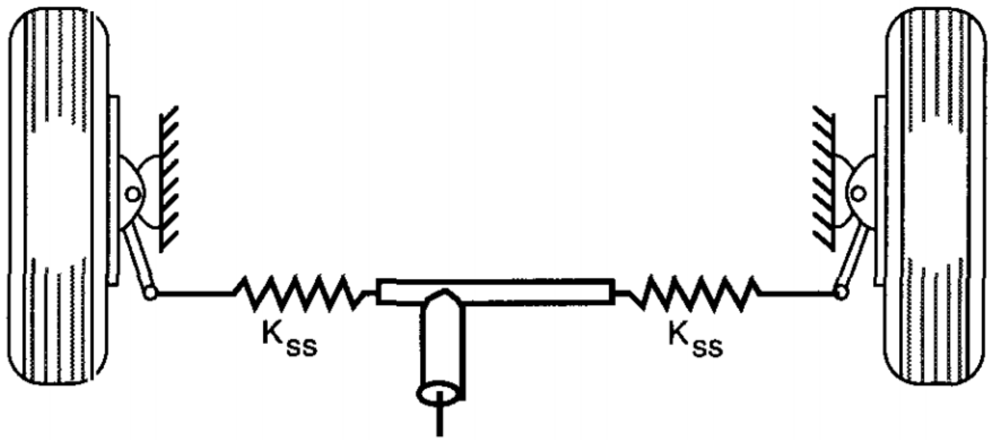
M_{zl}, M_{zr} = Aligning torques on the left and right wheels

  - ✓ Under normal driving conditions, the aligning torques always act to resist any turning motion, thus their effect is understeer.

- Rolling Resistance and Overturning Moments
  - ✓ These moments at most only have a sine angle component acting about the steer axis.
  - ✓ They are second-order effects and are usually neglected in analysis of steering system torques.

Steering System Models

- Model of the steering compliances
  - The significant properties of the linkages are the stiffnesses.



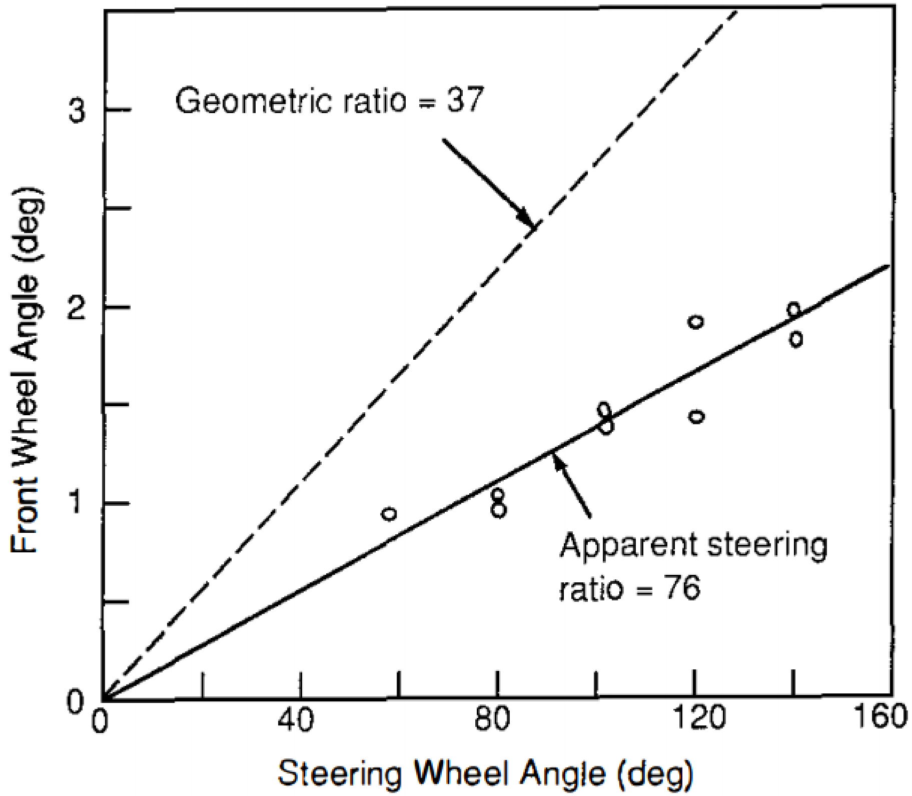
  - The model can be obtained by considering steering gearbox, Ackerman angles and moments and forces described above…

Examples of Steering System Effects

- Steering Ratio
  - The steering ratio is defined as the ratio of steering wheel rotation angle to steer angle at the road wheels.
  - Normally these range from 15 or 20 to 1 on passenger cars, and 20-36 to 1 on trucks.
  - Because of the compliance and steer torque gradients with increasing steer angles, actual steering ratio may be as much as twice the designed ratio.

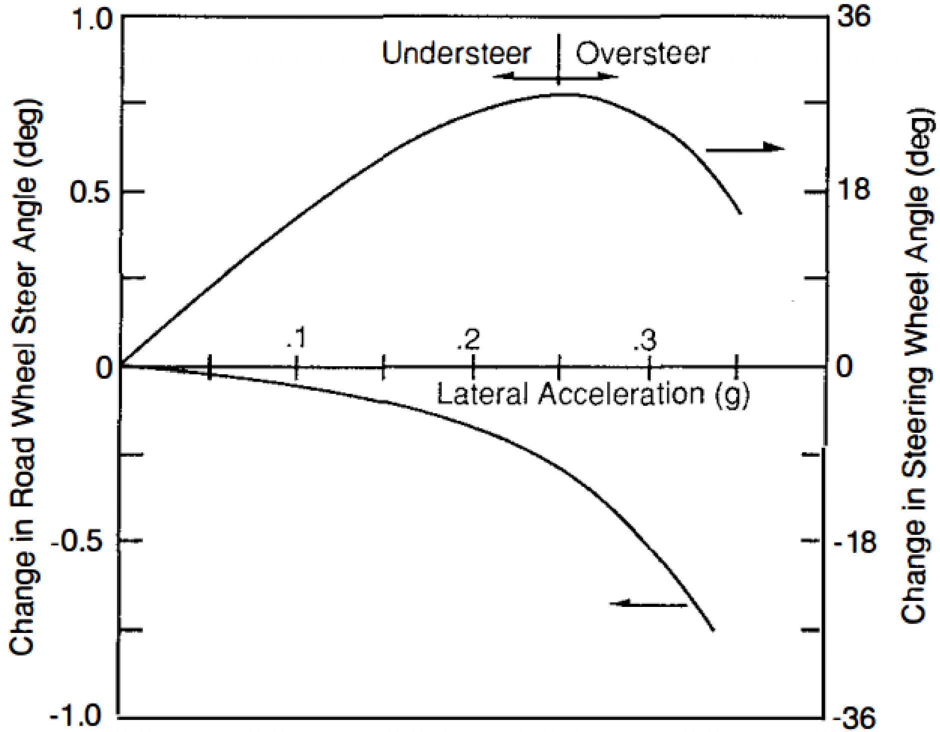
Examples of Steering System Effects

- Steering Ratio
  - Experimental measurement of steering ratio on a truck



Examples of Steering System Effects

- Understeer
  - Because compliance in the steering system allows the road wheels to deviate from the steering wheel input, the results obtained are influenced by the steering system properties.



Examples of Steering System Effects

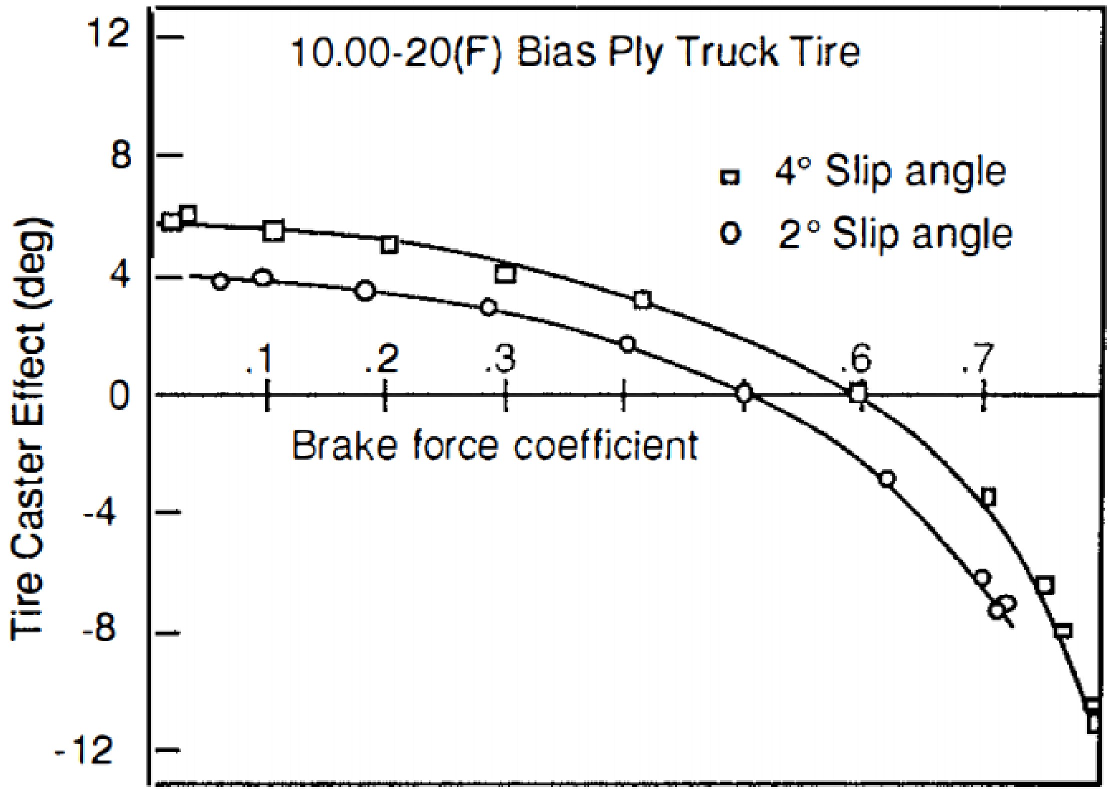
- Understeer
  - The magnitude of the steering system contribution is dependent on the front-wheel load and caster angle.
  - From a simple analysis for the understeer influences in which the lateral forces and aligning torques are dominant (neglecting vertical force effects), the understeer gradient is:

$$K_{strg} = \frac{W_f (r\,\nu + p)}{K_{ss}}$$

K_{strg} = Understeer increment (deg/g) due to steering system
W_f = Front wheel load (lb)
r = Wheel radius (in)
p = Pneumatic trail associated with aligning torque (in)
ν = Caster angle (rad)
K_{ss} = Steering stiffness (in-lb/deg) between road wheel and steering wheel

Examples of Steering System Effects

- Braking Stability
  - Change of tire aligning torques with braking coefficient.



INFLUENCE OF FRONT-WHEEL DRIVE

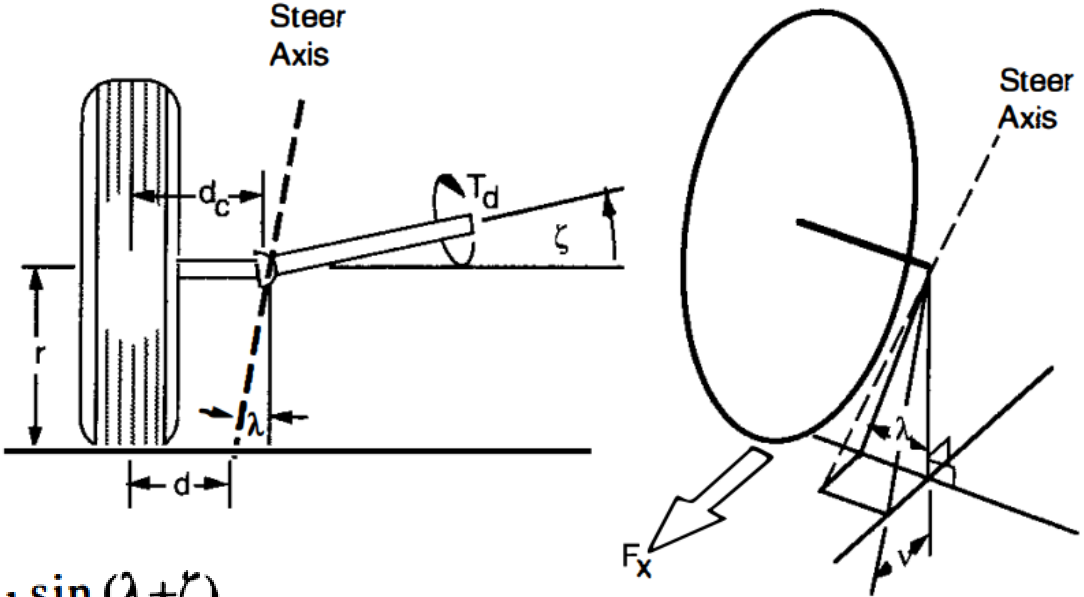
- It is generally recognized that with front-wheel-drive (FWD) vehicles, the turning behavior varies with the application of engine power.

- In most cases, throttle-on produces understeer, and throttle-off produces oversteer.

- The turning equation developed would suggest just the opposite behavior. Obviously, other mechanisms must be at work. Three have been identified and will be discussed here.

INFLUENCE OF FRONT-WHEEL DRIVE

- Driveline Torque About the Steer Axis



$$M_{SA} = F_x\, d \cos \nu \cos \lambda + T_d \sin (\lambda + \zeta)$$

$$T_d = F_x\, r \longrightarrow M_{SA} = F_x\, [d \cos \nu \cos \lambda + r \sin (\lambda + \zeta)]$$

$$\longrightarrow M_{SA} = F_x\, [d + r \sin (\lambda + \zeta)]$$

INFLUENCE OF FRONT-WHEEL DRIVE

- When a vehicle goes into a tum, body roll causes the halfshaft on the outside wheel to reduce its inclination angle, while the angle on the inside wheel increases.

- Thus the moment arm about which the drive force acts gets smaller on the outside wheel and larger on the inside wheel.

- With a drive force (in the forward direction) this imbalance introduces a moment in the steering system which opposes the steer angle, trying to steer the vehicle out of the tum (understeer).

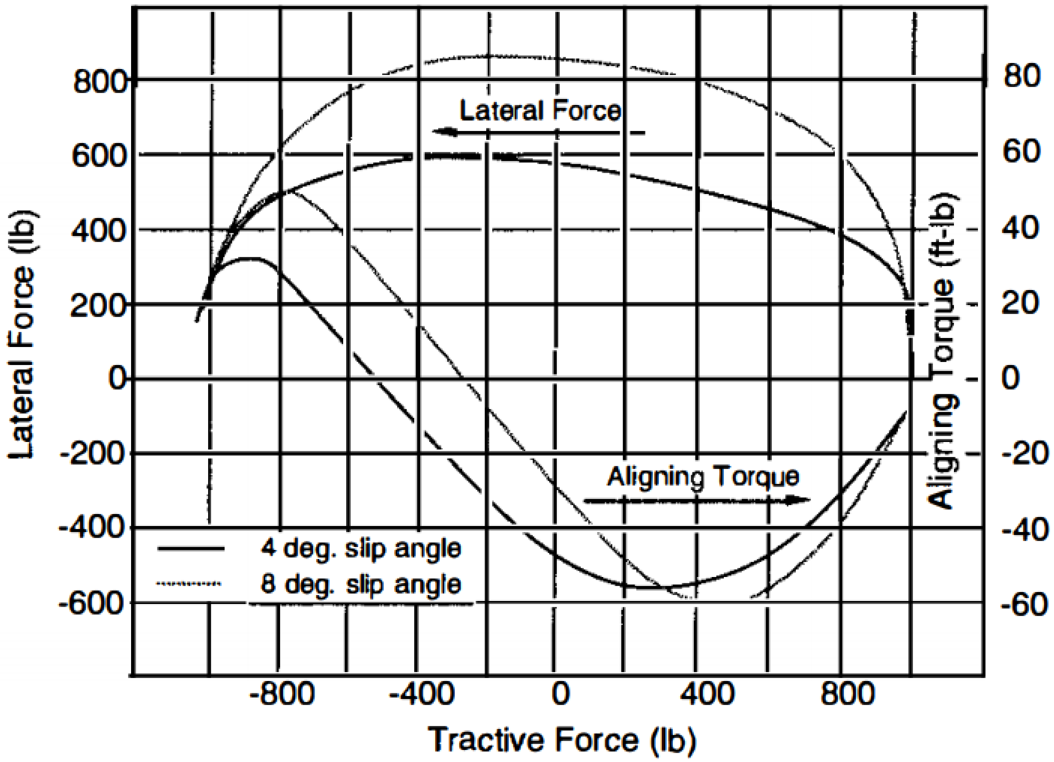
INFLUENCE OF FRONT-WHEEL DRIVE

- The magnitude of the moment is dependent on:
  - ✓ The degree of body roll
  - ✓ The difference created in links angles
  - ✓ The difference between kingpin inclination angles on the left and right side during body roll
  - ✓ Caster angles
  - ✓ Any geometric differences between the left- and right-hand sides (tire radius, etc.)

- The understeer influence is proportional to the magnitude of the moment divided by the stiffness of the steering system. Thus minimizing body roll and stiffening the steering system minimizes the effect.
- Although the influence is specific to each vehicle, the understeer change from throttle-on to throttle-off is estimated to be on the order of 1 degree/g for a typical vehicle

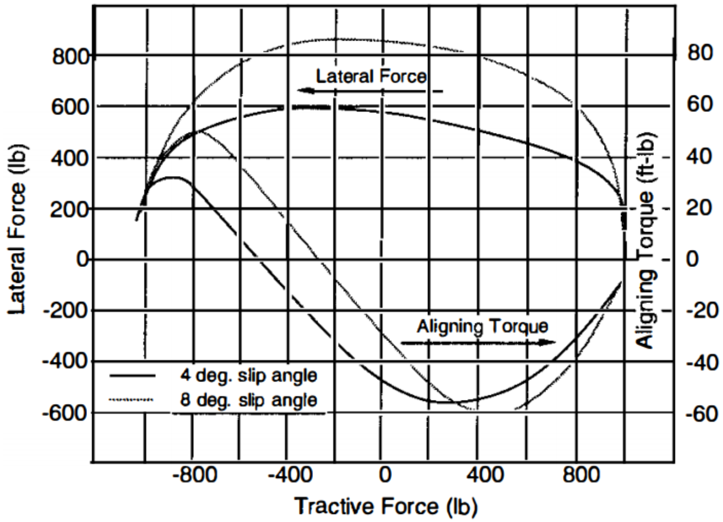
Influence of Front-Wheel Drive

- Influence of Tractive Force on Tire Cornering Stiffness
  - Effect of tractive force on:
    - ✓ Tire lateral force
    - ✓ Aligning moment



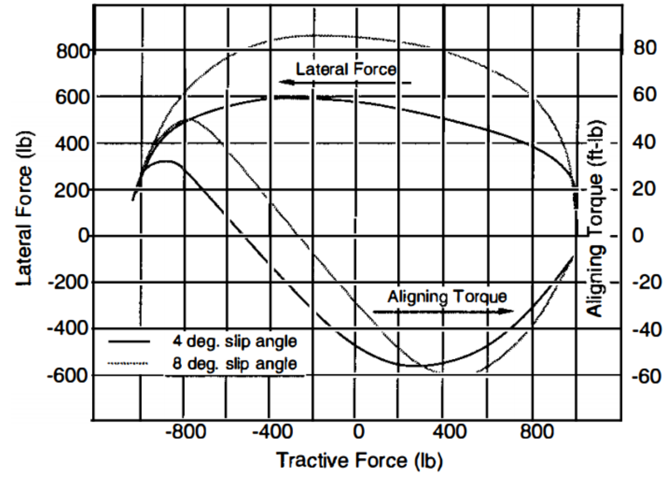
Influence of Front-Wheel Drive

- Influence of Tractive Force on Tire Cornering Stiffness
  - ✓ The application of throttle causes the front tires to lose cornering force, and the tires must seek a higher slip angle. This, of course, produces understeer.
  - ✓ It is estimated that the understeer change will be in the range of 0 to 2 degrees/ g for the throttle change going from 0.2 g acceleration to 0.05 g deceleration.



Influence of Front-Wheel Drive

- Influence of Tractive Force on Aligning Moment
  - Tractive force tends to increase the aligning moment produced by a tire.
  - The additional aligning moment tends to steer the vehicle out of the turn, and is thus understeer.
  - The magnitude of the understeer depends on the change in aligning moment divided by the stiffness of the steering system.
  - It has been estimated that this mechanism contributes on the order of 0.5 to 1 degree/g of understeer.



INFLUENCE OF FRONT-WHEEL DRIVE

- Fore/Aft Load Transfer
  - Understeer is normally characterized only in steady speed turns.
  - Yet it has been necessary to consider the difference between accelerating and decelerating conditions for purposes of describing the influence of FWD on understeer.
  - When the vehicle accelerates, load is transferred to the rear wheels dynamically. This causes the rear wheels to achieve a higher cornering stiffness, while the front wheels lose cornering stiffness (causing understeer).
  - It is worthwhile to estimate this effect for comparison purposes…
  - For a typical car, the understeer influence for the throttle changes described above is on the order of I degree/g

Influence of Front-Wheel Drive

- Summary of FWD Understeer Influences

1) The lateral component of drive thrust—While this mechanism is relatively weak (<0.5 deg/g), it is oversteer in direction.
2) Drive torque acting about the steer axis—Highly dependent on driveline geometry and the degree of body roll in cornering, this mechanism is understeer in direction (about 1 deg/g).
3) Loss of lateral force—A tire property which causes understeer (about 1-1.5 deg/g).
4) Increase in aligning moment—A tire property which causes understeer (about 0.5-1 deg/g).
5) Fore/aft load transfer—Although present on FWD and RWD vehicles, it is always understeer in direction (about 1 deg/g).

FOUR-WHEEL STEER

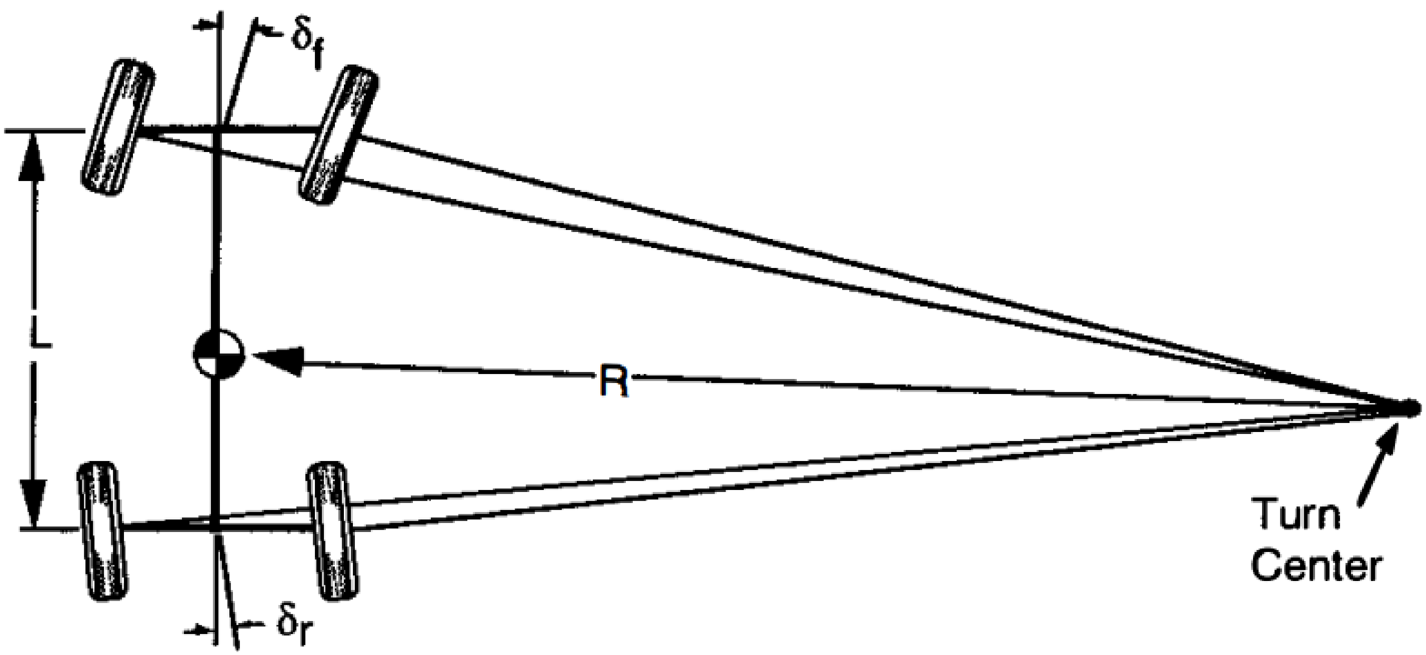
- Vehicle performance in turning can be enhanced by actively steering the rear wheels as well as the front wheels (4WS).

- Active steering is accomplished by steering action applied directly to the rear wheels, in contrast to passive steering in which compliances are purposely designed into the suspension to provide incremental steer deviations that improve cornering.

- Four-wheel steering may be used to improve low-speed maneuverability and/or high-speed cornering.

FOUR-WHEEL STEER

- Low-Speed Turning
  - Low-speed turning performance is improved by steering the rear wheels out-of-phase with the front wheels to reduce the tum radius, thus improving maneuverability



FOUR-WHEEL STEER

- Low-Speed Turning
  - Normally, the rear-wheel steer angles are a fraction of that at the front (typically limited to about 5 degrees of steer), and may only be applied at low speeds or at high steer angles typical of low-speed turns.
  - Analysis of the turning performance is simplified by assuming average angles for the front and rear wheels, analogous to the bicycle model approximation.

FOUR-WHEEL STEER

- Low-Speed Turning
  - The turning equations

$$\delta_r = \xi\,\delta_f$$

$$\delta_f + \delta_r = \delta_f + \xi\,\delta_f = \delta_f\,(1 + \xi) = L/R$$

$$\longrightarrow \quad R = \frac{L}{\delta_f(1+\xi)}$$

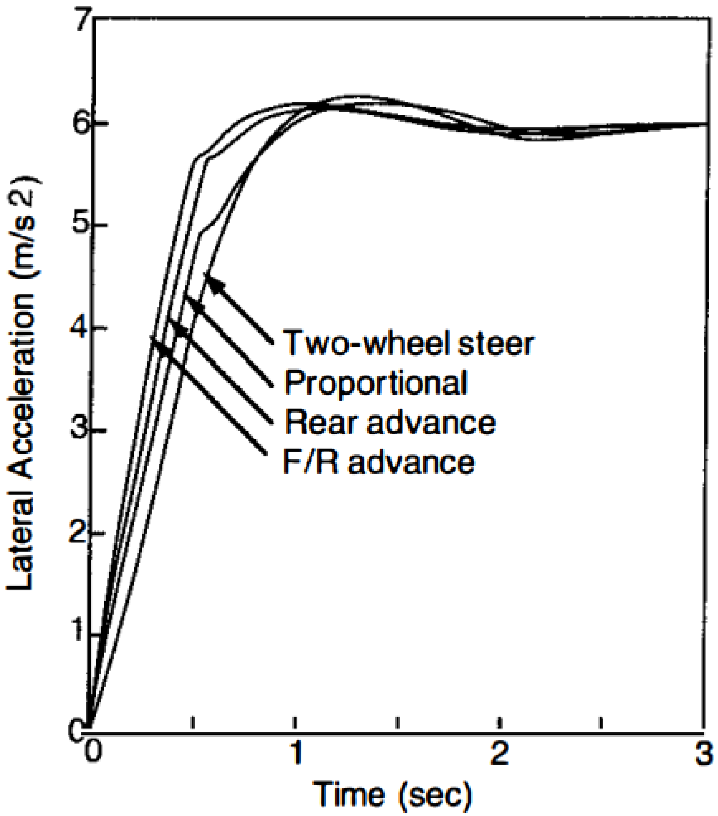
- ✓ At 50 percent rear steer, a one-third reduction in tum radius (1/1.5) is achieved.
- ✓ At 100 percent rear steer (steering the rear wheels to the same magnitude as the front wheels), a 50 percent reduction in tum radius (1/2) occurs.

FOUR-WHEEL STEER

- High-Speed Cornering
  - The out-of-phase rear steer used for low-speed maneuverability would be inappropriate for high-speed turning because the outward movement of the rear wheels would constitute an oversteer influence.
  - Thus an in-phase rear steer is used at high speed (e.g., 20 mph and above), although limited to a few degrees of steer.
  - The transition between out-of-phase and in-phase steering is accomplished by sensing vehicle speed and changing the steering control algorithm in electronically controlled systems, or in mechanical systems.
  - In general, 4WS systems yield a quicker response with better damping of the yaw oscillation that occurs with initiation of a turn.

FOUR-WHEEL STEER

- High-Speed Cornering
  - Lateral acceleration response to a step steer



FOUR-WHEEL STEER

- High-Speed Cornering
  - Response in sideslip angle as a turn is initiated