



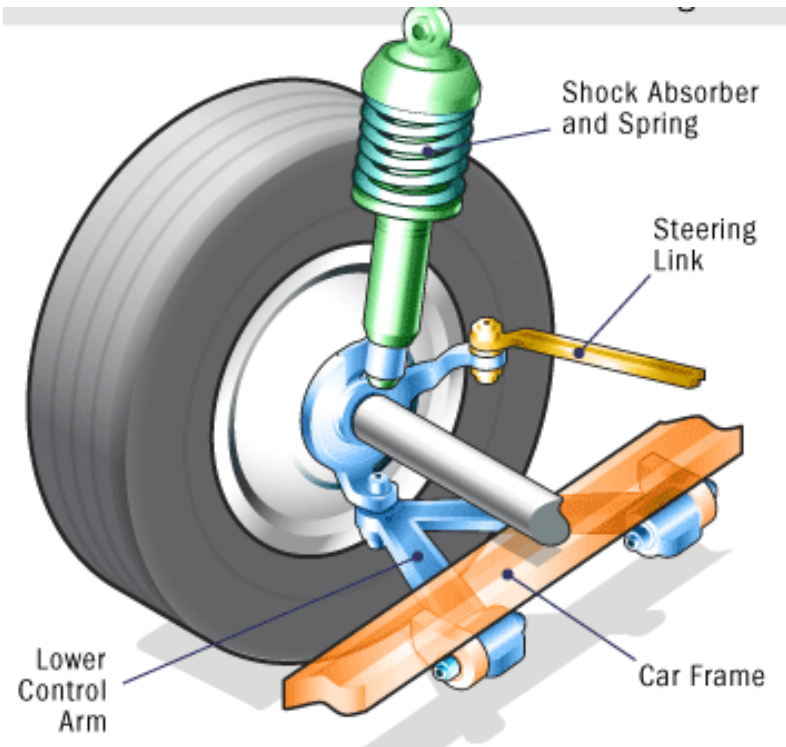
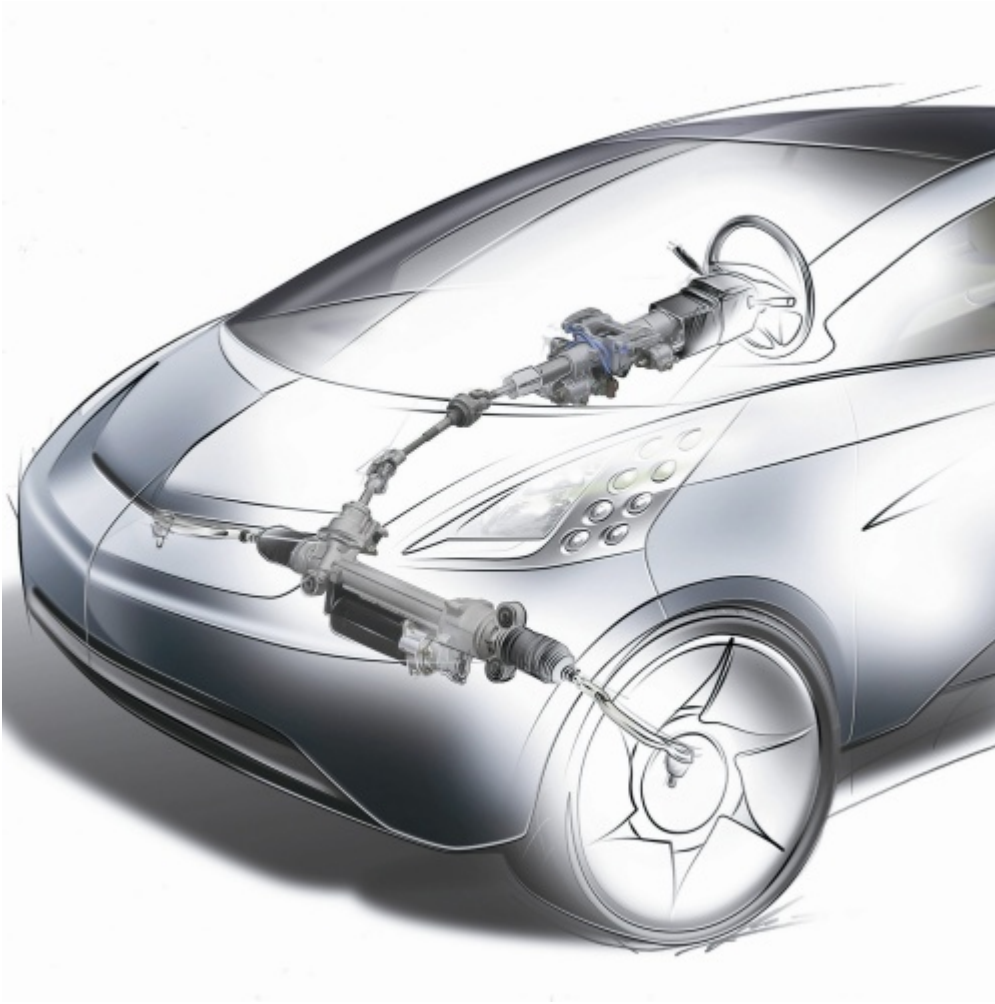
# Session-3

Thursday, 17-12-2009;4.00 PM-5.30 PM

## Vehicle Suspension-Kinematics and Compliance

- Wheel Alignment
- Wheel Kinematics and Compliance
- Steering Performance Criteria for Handling

# Wheel Geometry



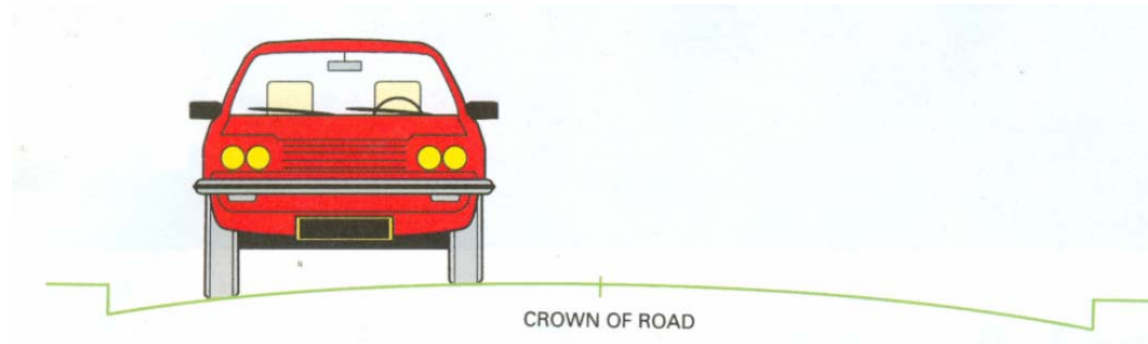


# Wheel Alignment

- A wheel Alignment is the adjustment of the suspension and steering to ensure proper vehicle handling with minimum tire wear
- A change in alignment angles may result from one or more of the following factors
  - Wear of the steering and suspension components
  - Bent or damaged steering and suspension parts
  - Sagging springs, which can change the ride height of the vehicle and therefore the alignment angles

# Alignment- Related Problems

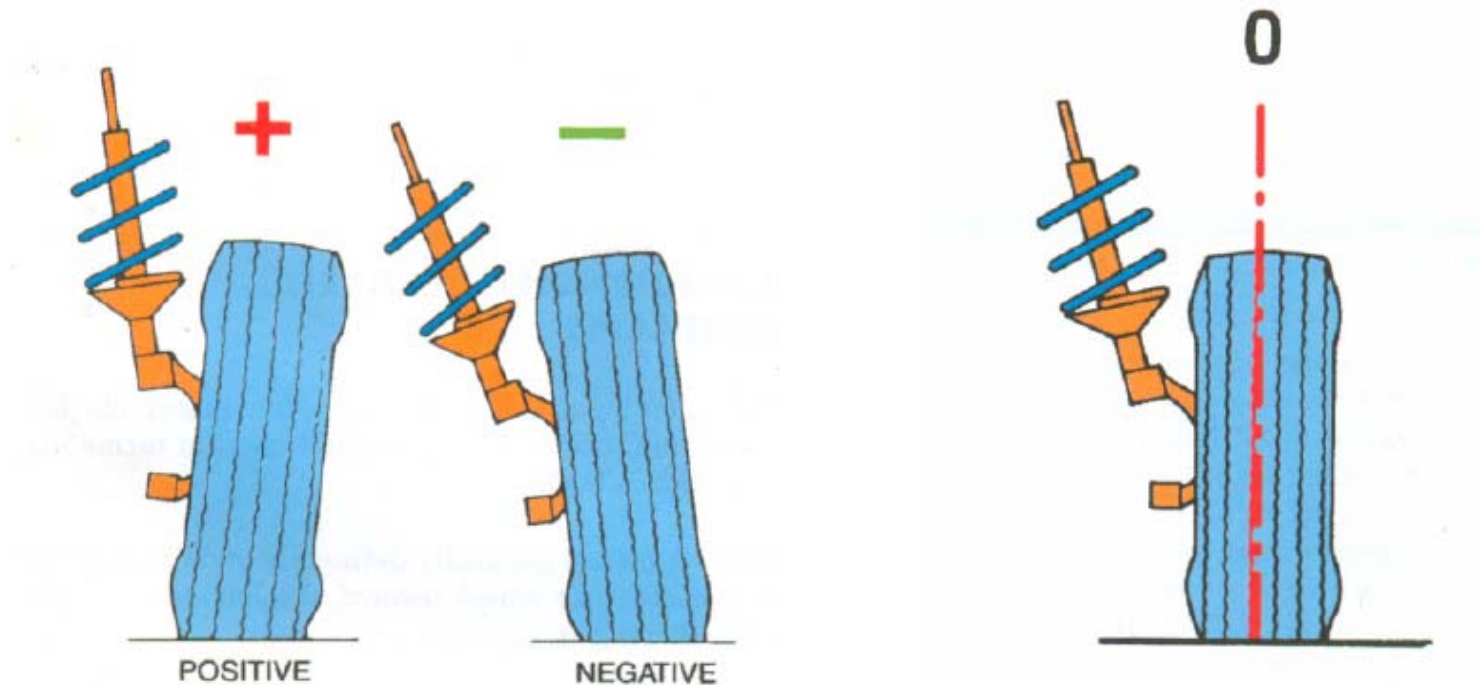
- Pull
  - A pull is generally defined as a definite “tug” on the steering wheel toward the left or the right while driving straight on a level road
- Lead or drift
  - It is a mild pull that does not cause a force on the steering wheel that the driver must counteract. When the vehicle moves toward one side or the other, this is called a lead or drift could be caused by the crown of the road



- Wander
  - A wander is a condition in which almost constant steering wheel corrections by the driver are necessary to maintain a straight-ahead direction on a straight level road

# Camber

- Camber is the inward or outward tilt of the wheels from true vertical as viewed from the front or rear of the vehicle





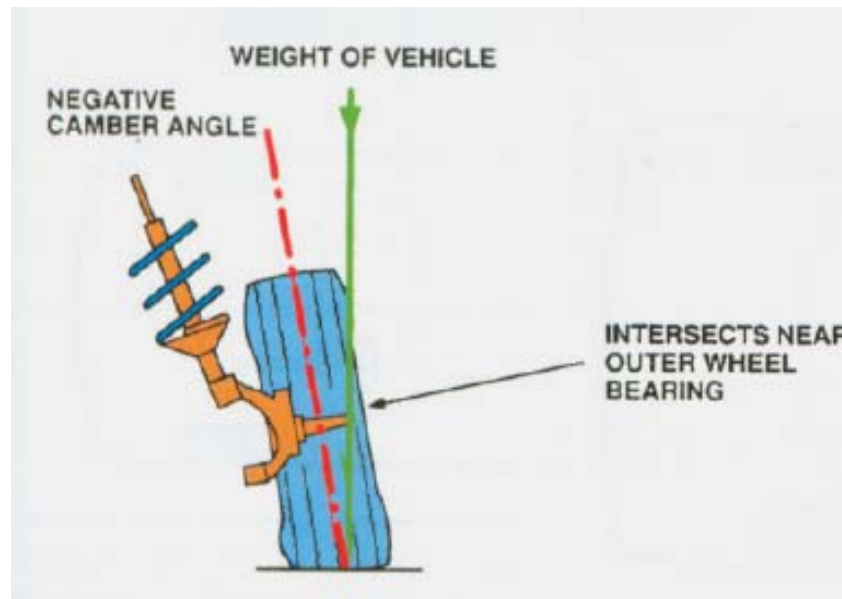






# Camber

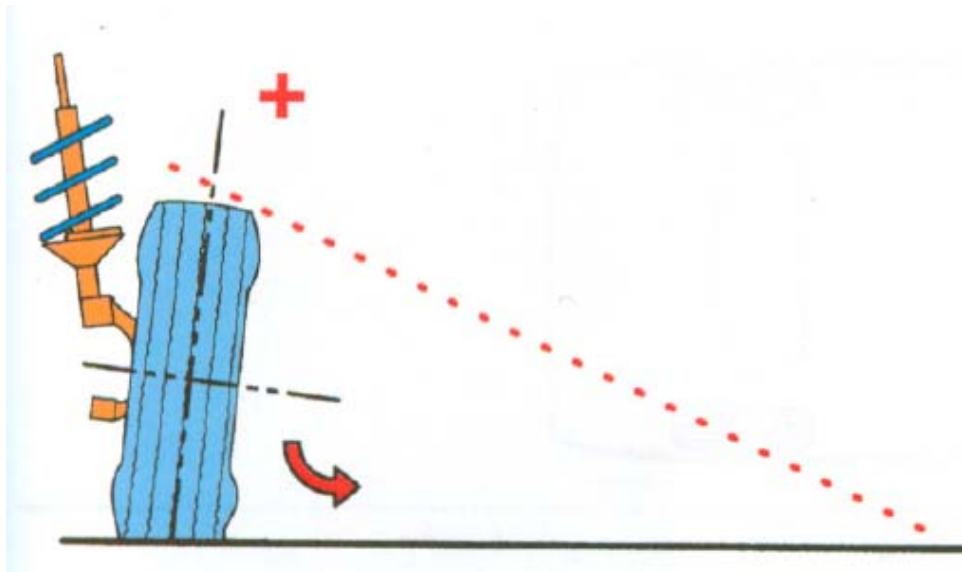
- Incorrect camber can cause excessive wear on wheel bearings. Many vehicle manufacturers specify positive camber so that the vehicle weight is applied to the larger inner wheel bearing and spindle. As the vehicle is loaded or when the spring sag, camber usually decreases. If camber is kept positive, then the running camber is kept near zero degrees for best tire life





# Camber

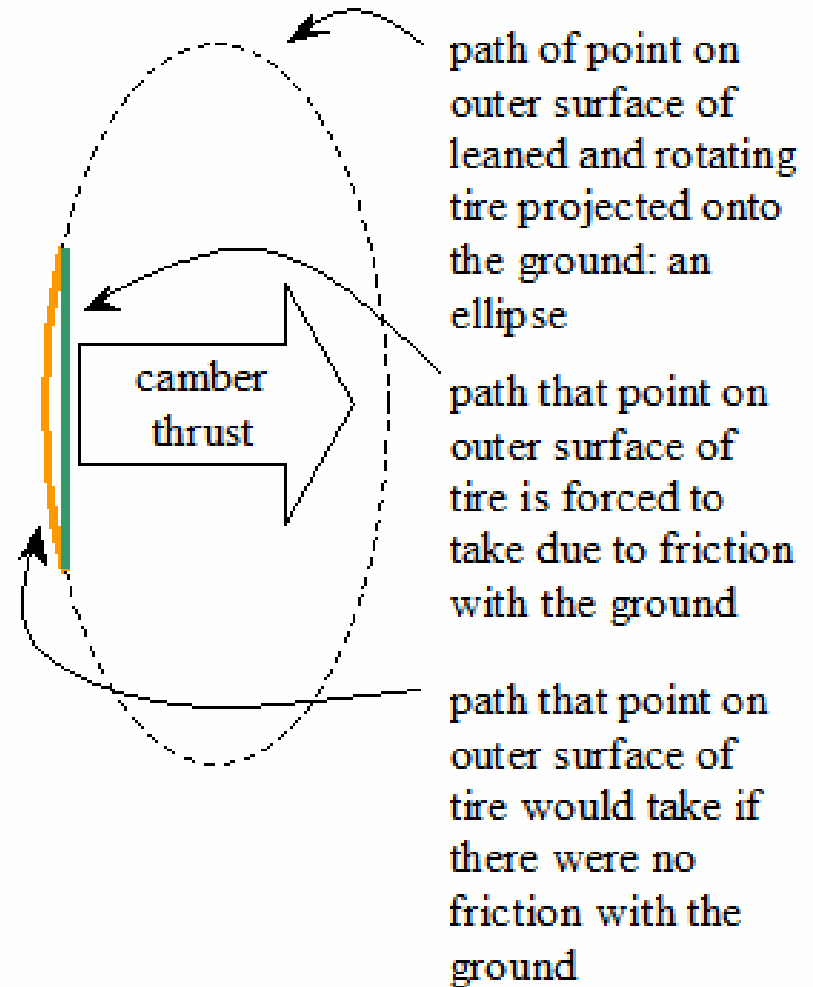
- Camber can cause pull (Camber Thrust) if it is unequal side to side. The vehicle will pull toward the side with the most **positive (or least negative) camber**. A difference of more than half a degree from one side to the other will cause the vehicle to pull



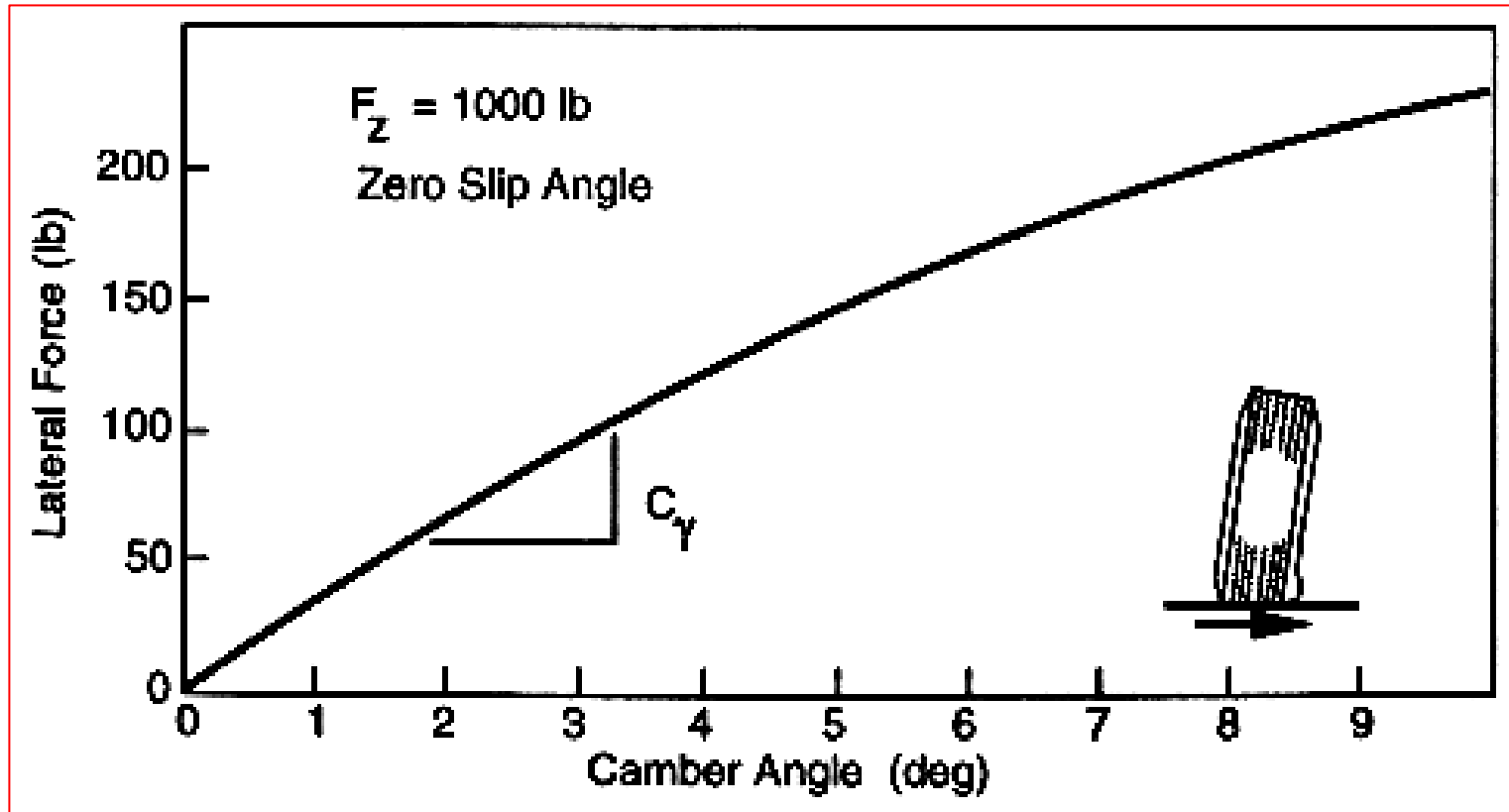
# How Camber Produces Camber Thrust

- Camber thrust** and **camber force** are terms used to describe the force generated perpendicular to the direction of travel of a rolling tire due to its camber angle and finite contact patch. Camber thrust is generated when a point on the outer surface of a leaned and rotating tire, that would normally follow a path that is elliptical when projected onto the ground, is forced to follow a straight path due to friction with the ground. This deviation towards the direction of the lean causes a deformation in the tire tread and carcass that is transmitted to the vehicle as a force in the direction of the lean.

View from above

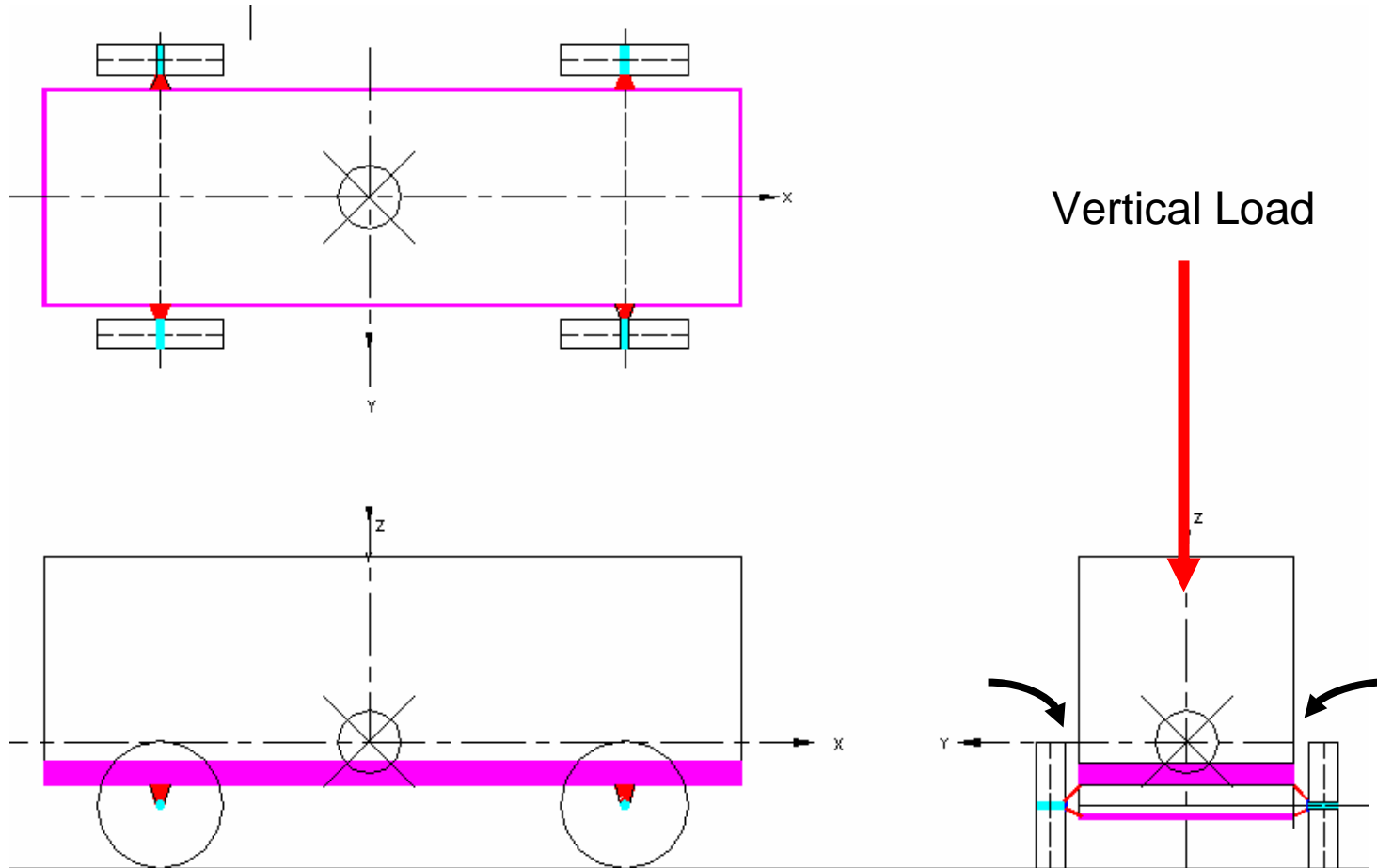


# Camber Thrust



- Camber thrust is approximately linearly proportional to camber angle for small angles. Bias-ply tires have been found to generate more camber thrust than radial tires. **Camber stiffness** is a parameter used to describe the camber thrust generated by a tire and it is influenced by inflation pressure and normal load. The net camber thrust is usually in front of the center of the wheel and so generates a **camber torque**.

# Camber Changes

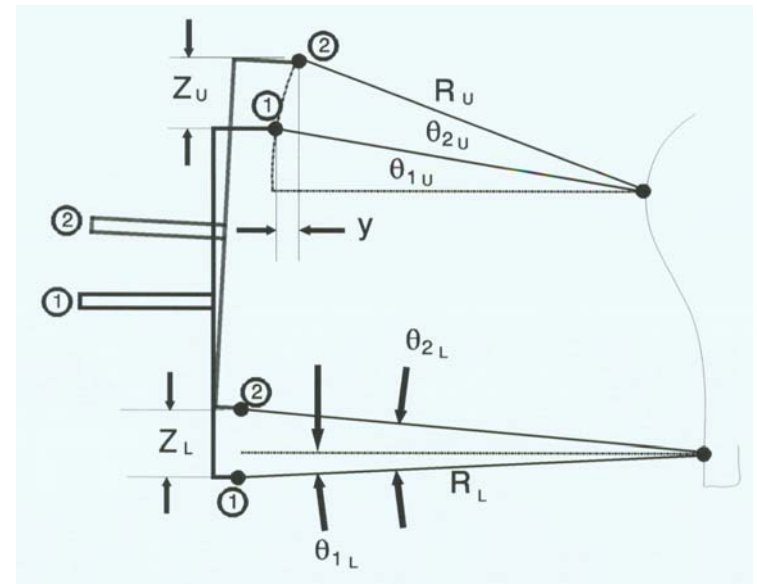
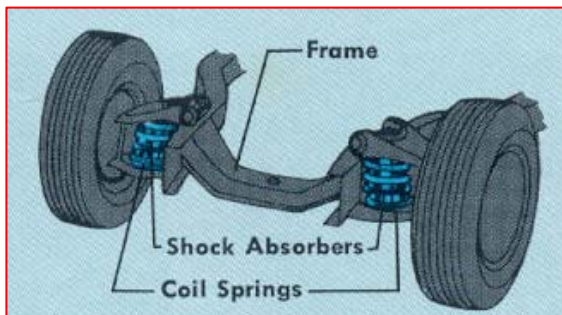
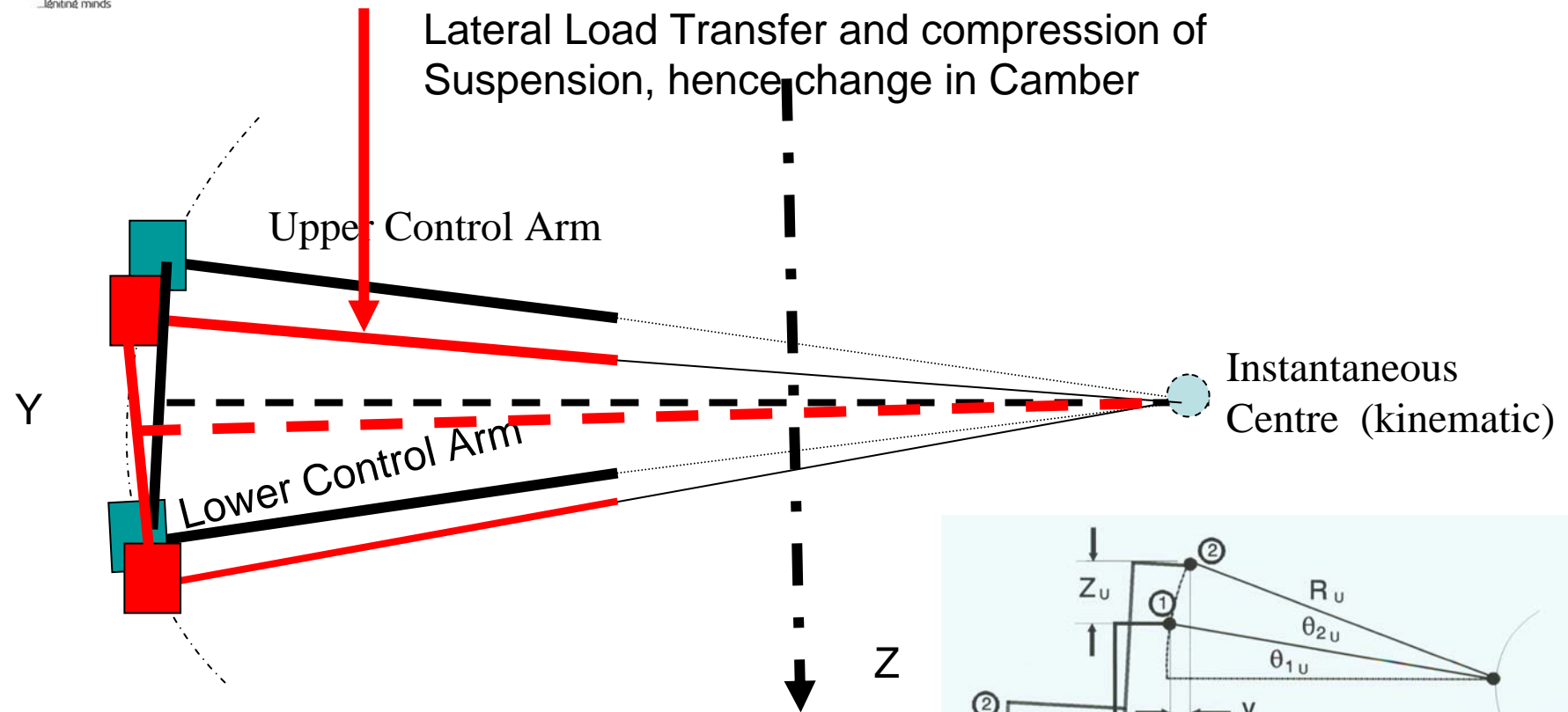


Positive Cambered Wheels move inward when loaded

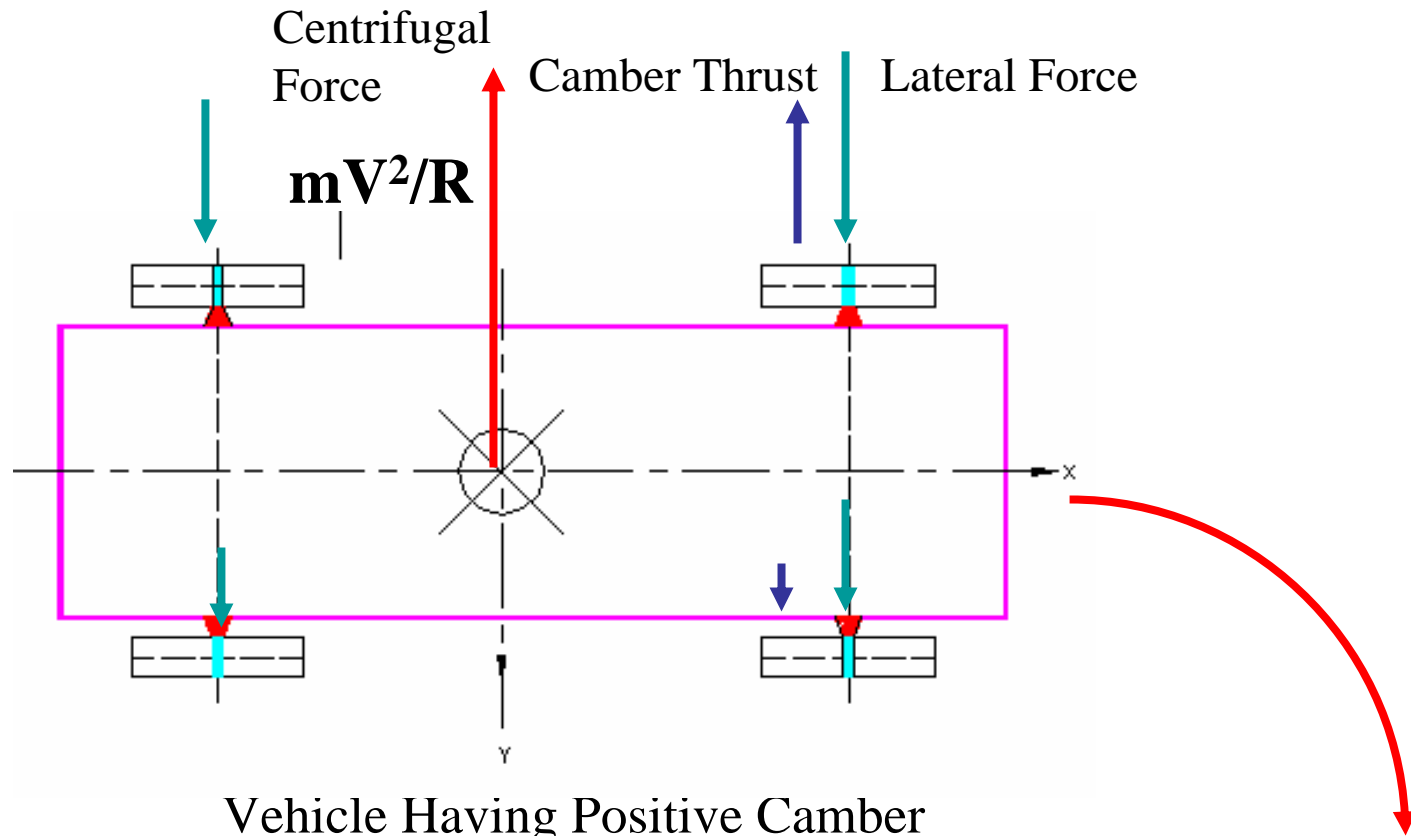


# Camber Change

Lateral Load Transfer and compression of Suspension, hence change in Camber



# Camber Change Effect in Cornering

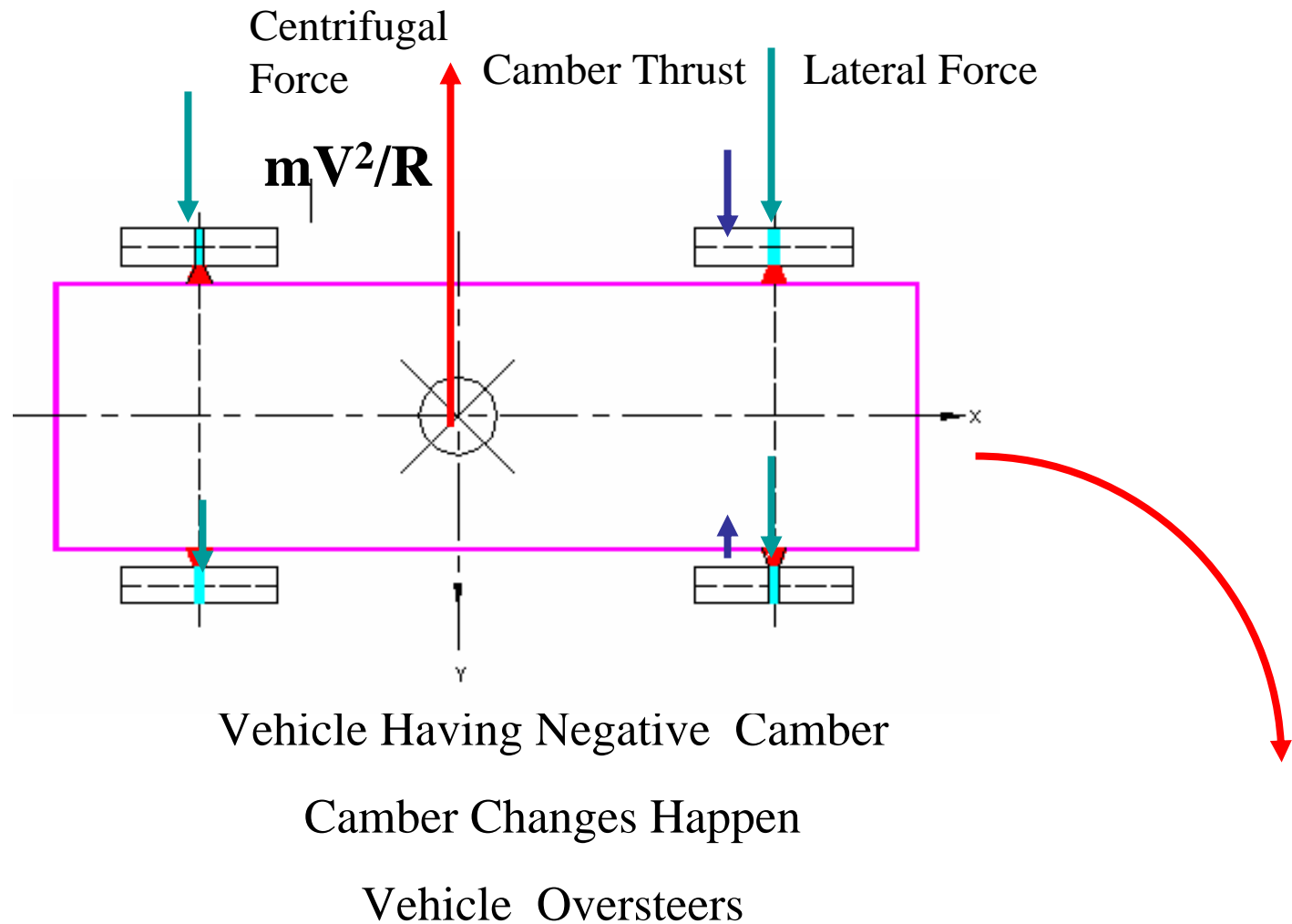


Vehicle Having Positive Camber

Camber Changes Happen

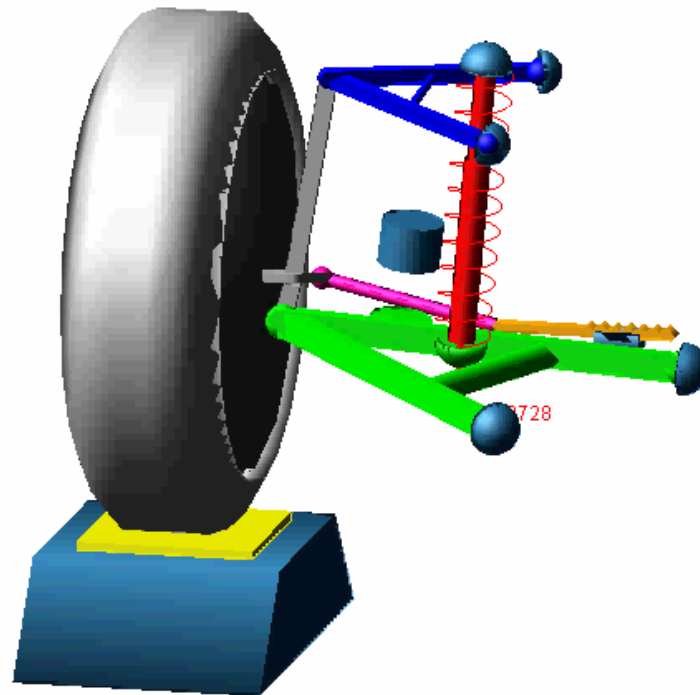
Vehicle Understeers

# Camber Change Effect in Cornering



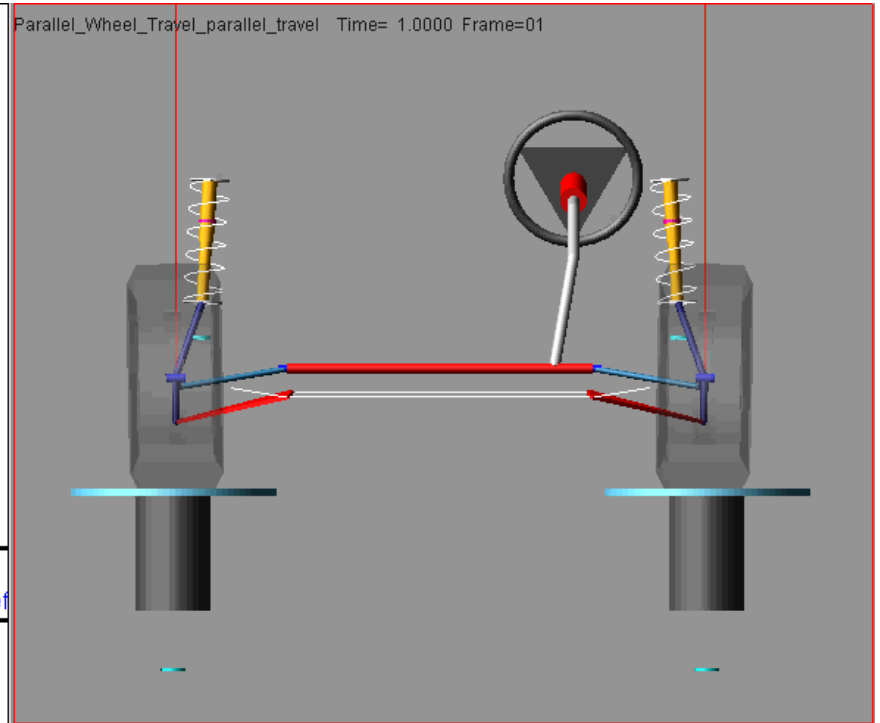
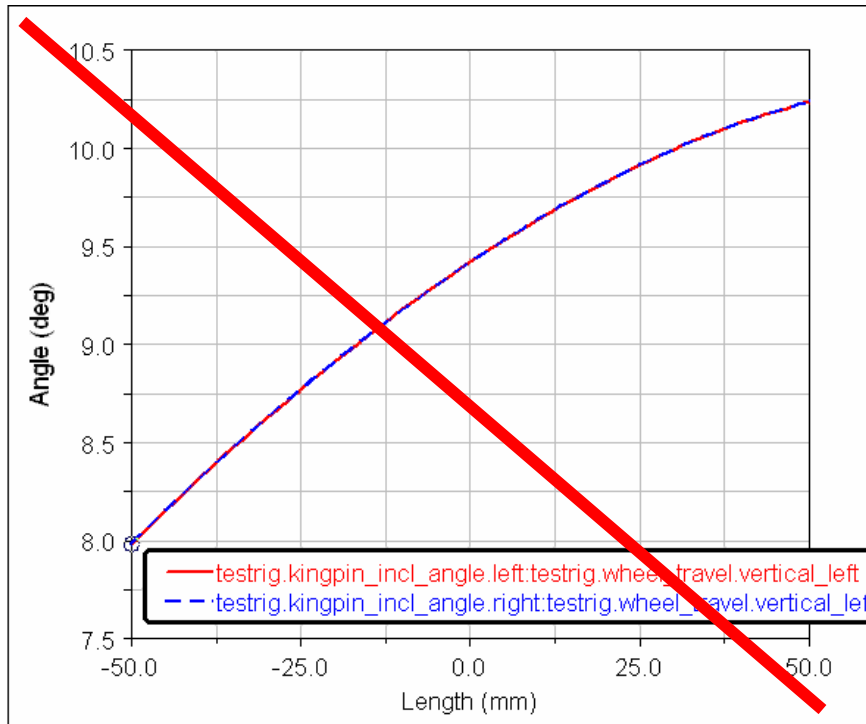
# Suspension Travel

Last\_Run Time= 0.0000 Frame=0001





# Parallel Wheel Travel



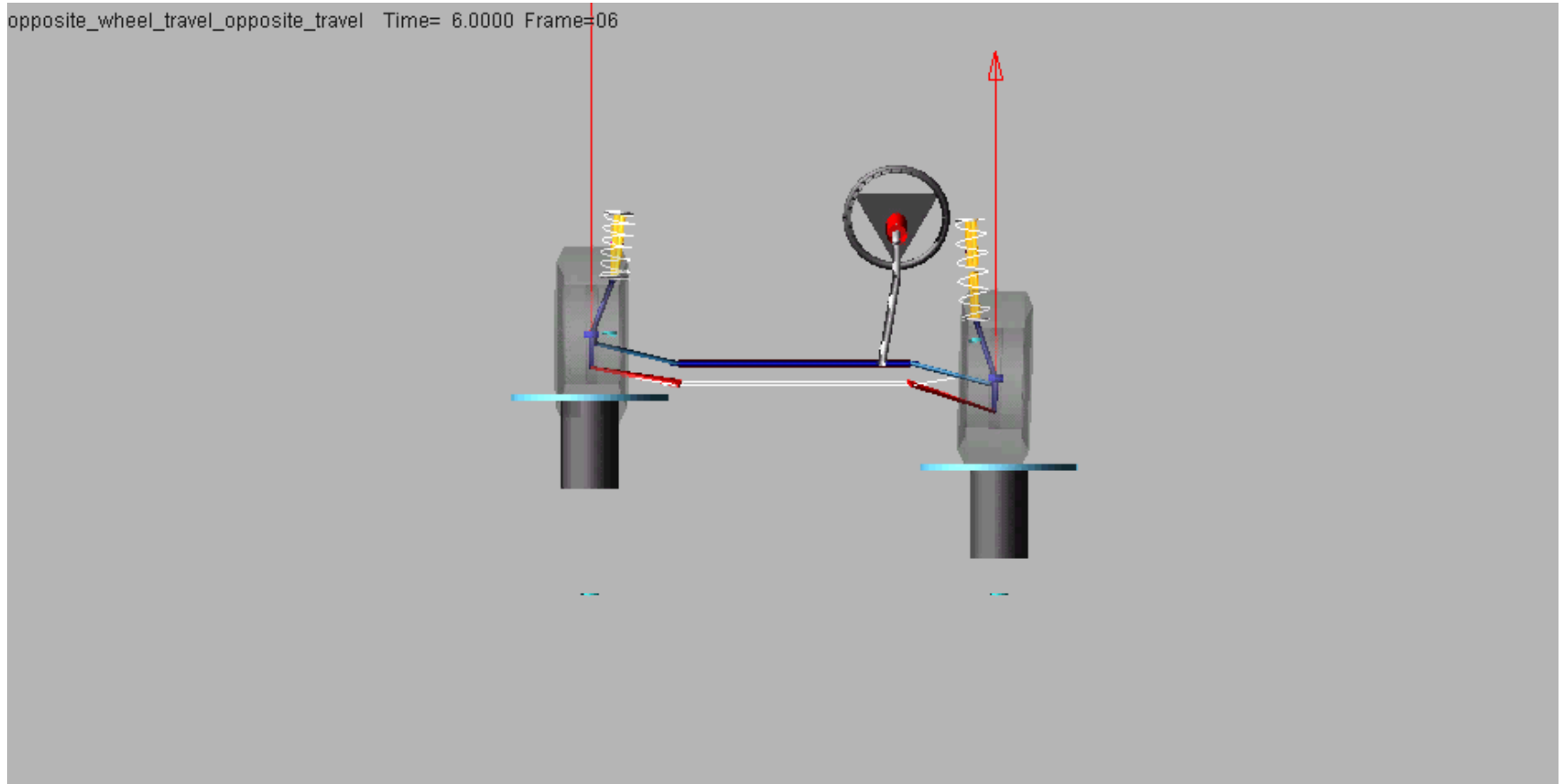
# Camber Change



# Bump Steer

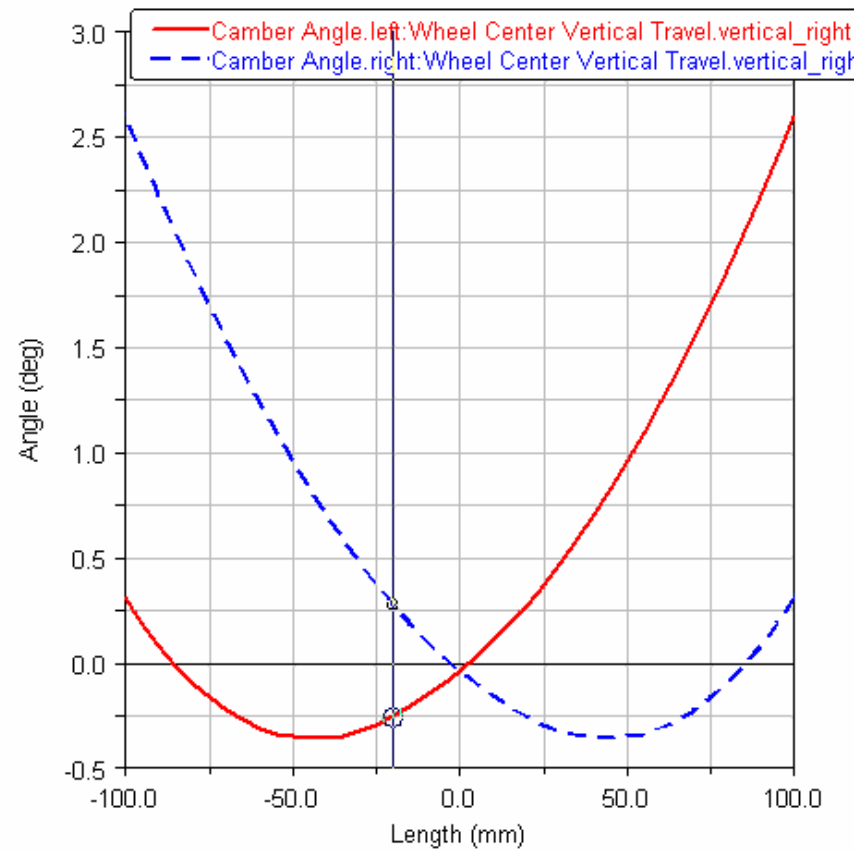
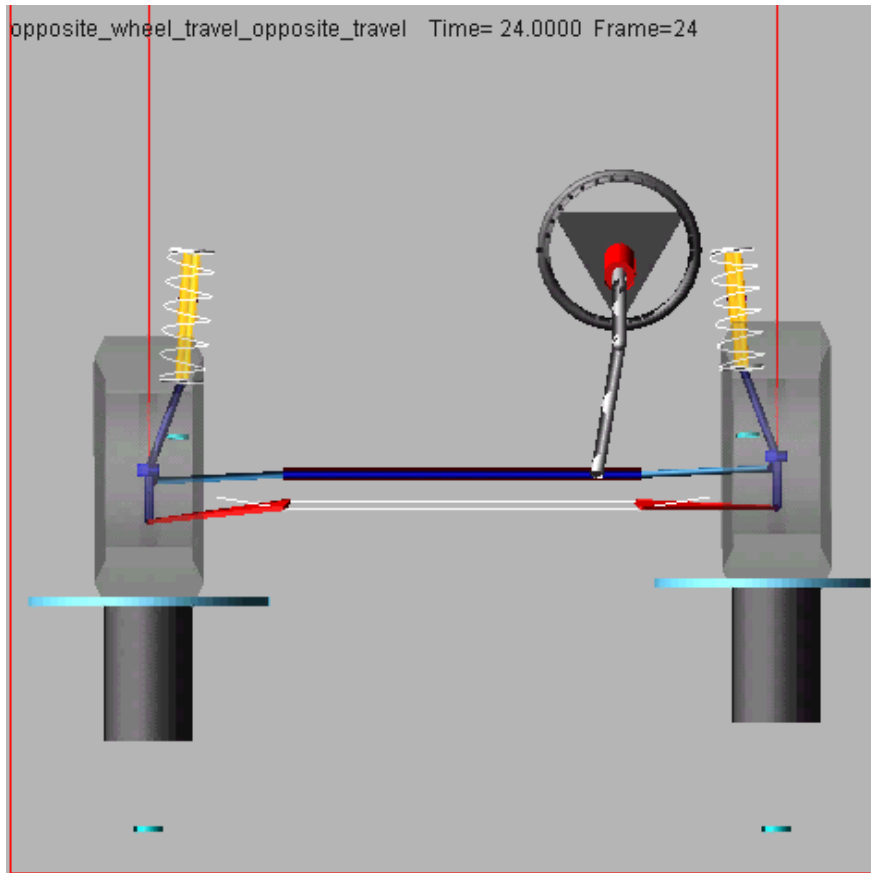
- **Bump Steer** is the term for the tendency of a wheel to steer as it moves upwards into jounce. It is typically measured in degrees per metre or degrees per foot.
- On modern cars the front of the tire moves outwards, as the suspension is raised, a process known as the front wheels "toeing out". This gives roll understeer. The rear suspension is usually set up to minimise bump steer, where possible.
- A typical value is two degrees per metre, or perhaps more, for the front wheels.
- Excessive bump steer increases tire wear and makes the vehicle more difficult to handle on rough roads.
- Solid axles generally have zero bump steer, but still have roll steer, in most cases. That is, if the wheels move upwards by the same amount, they tend not to steer.
- Roll steer is an important part of the budget used to define a vehicle's understeer, known as a Bundorf analysis.

# Parallel Opposite Wheel Travel

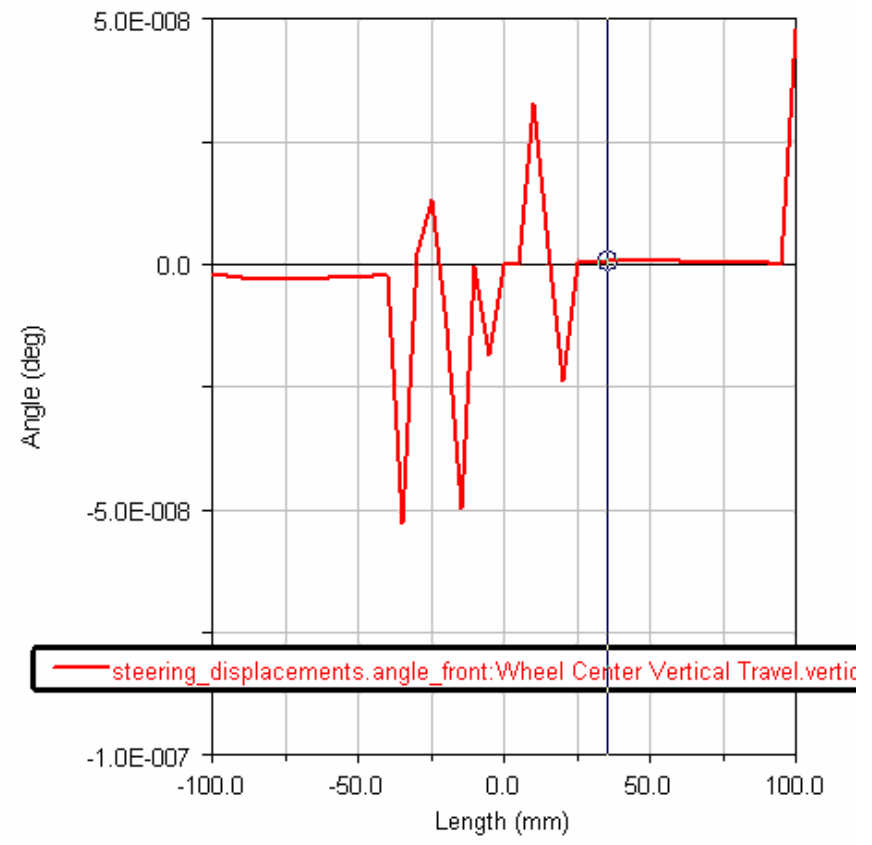
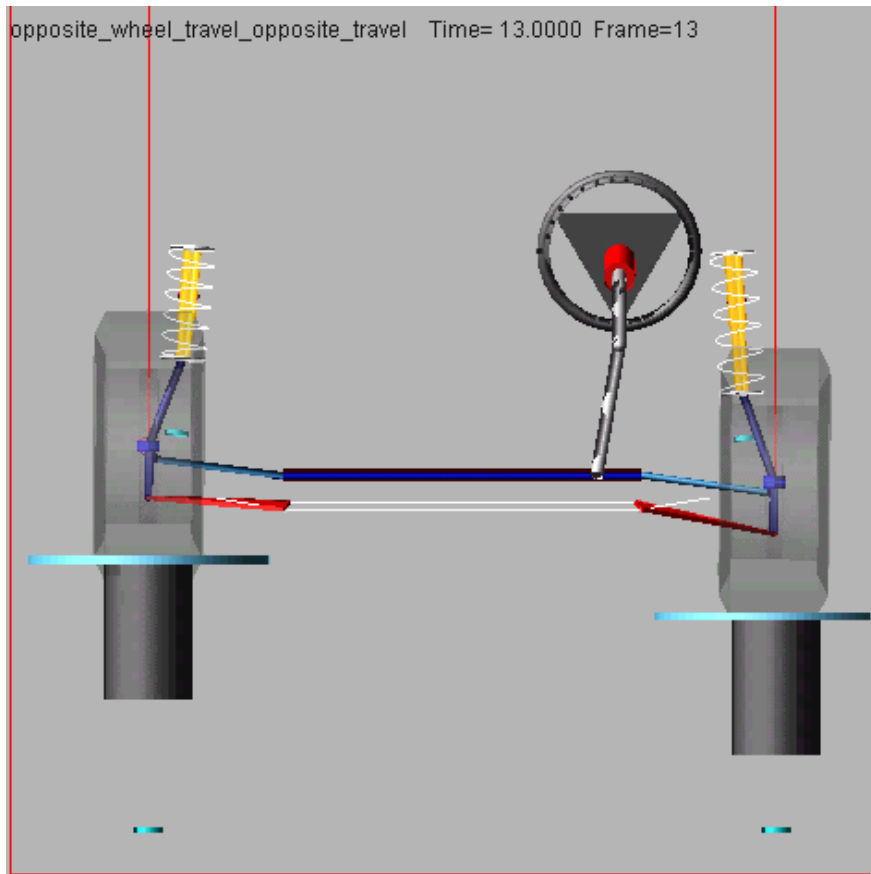




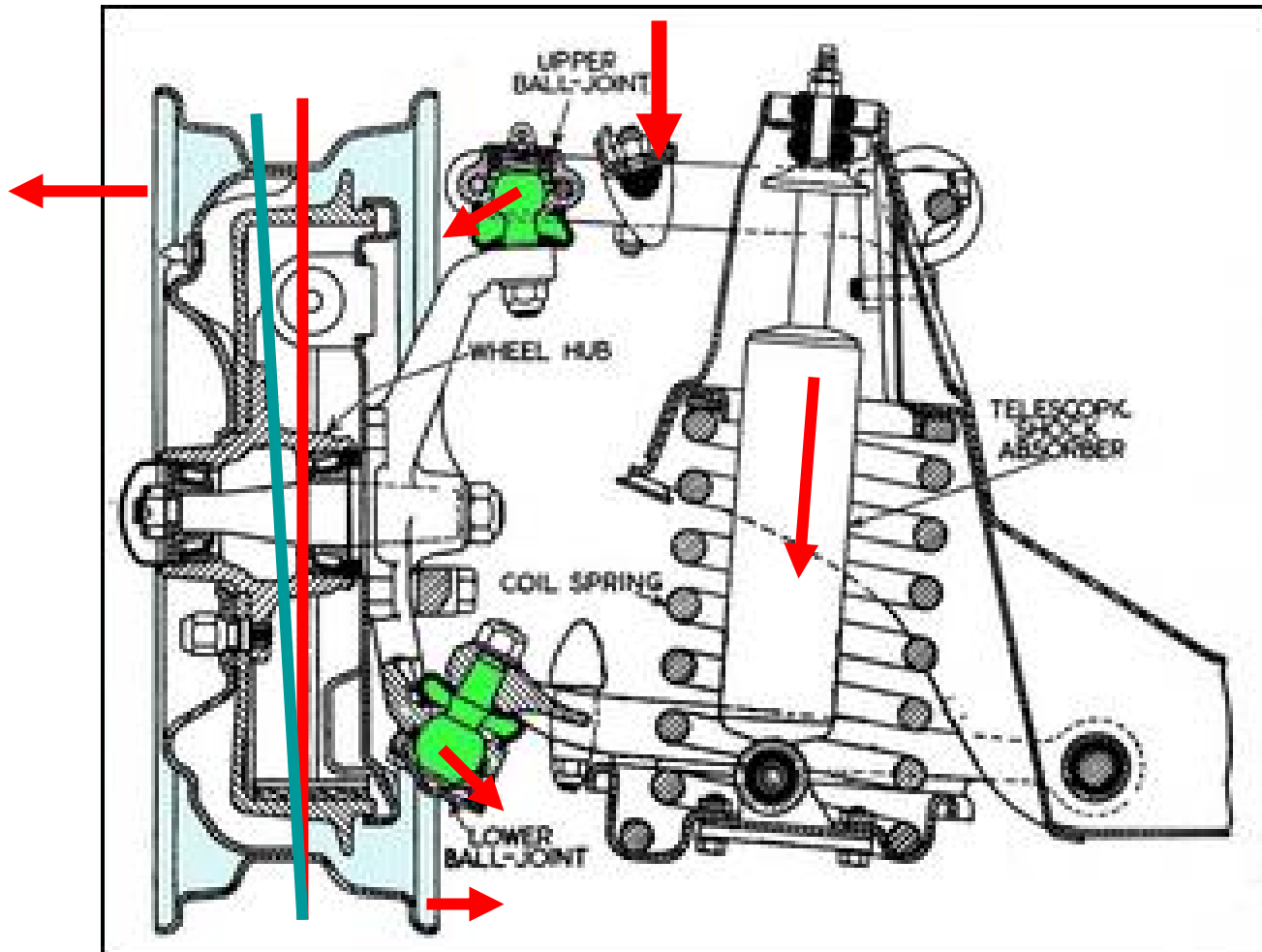
# Camber Change



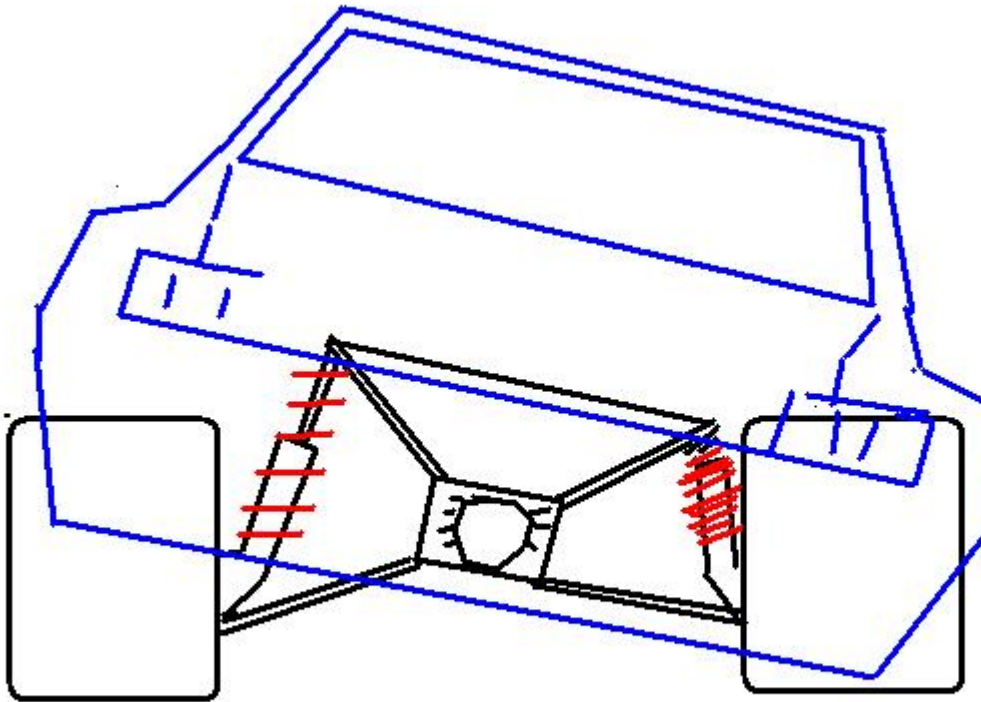
# Steering Angle



# How Camber Changes Happen



**Camber Changes due to the movement of Control arms in Y Direction**

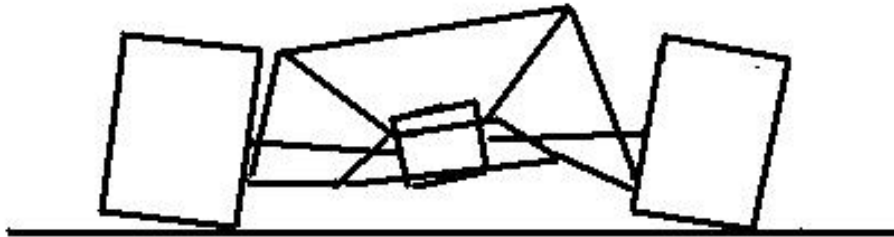


A double wishbone suspension can be made to allow camber change by using un-equal length or diverging/converging arms

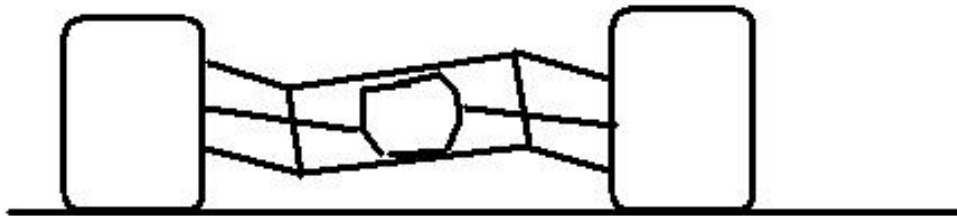




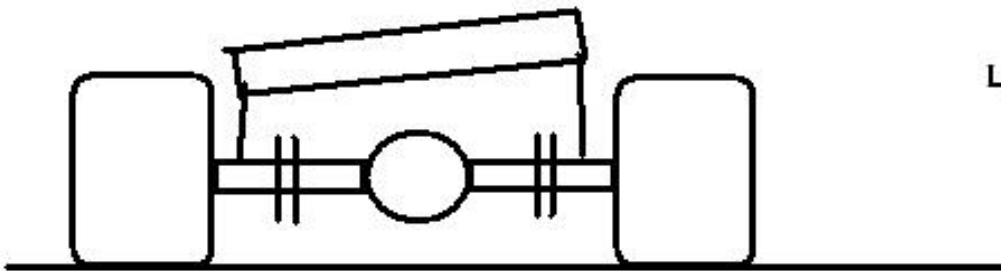
## RIGHT HAND TURN



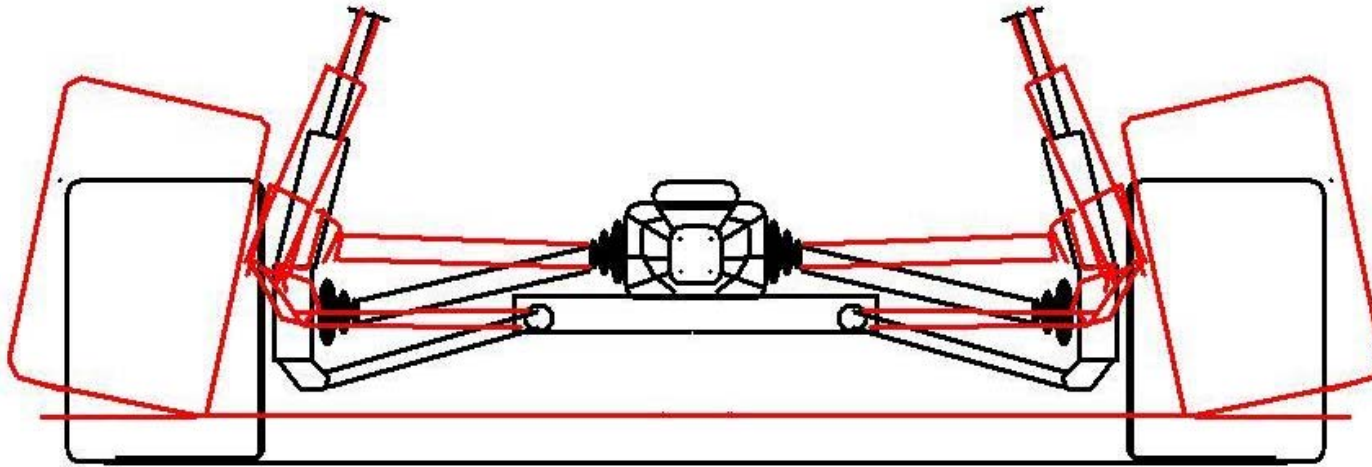
BAD SINGLE  
WISHBONE  
DESIGN



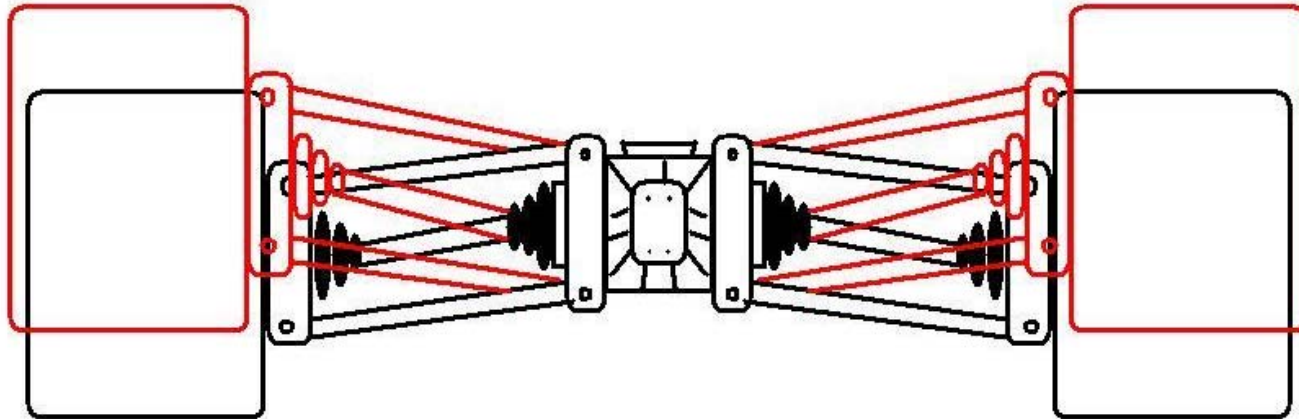
DOUBLE  
WISHBONE



LIVE AXLE

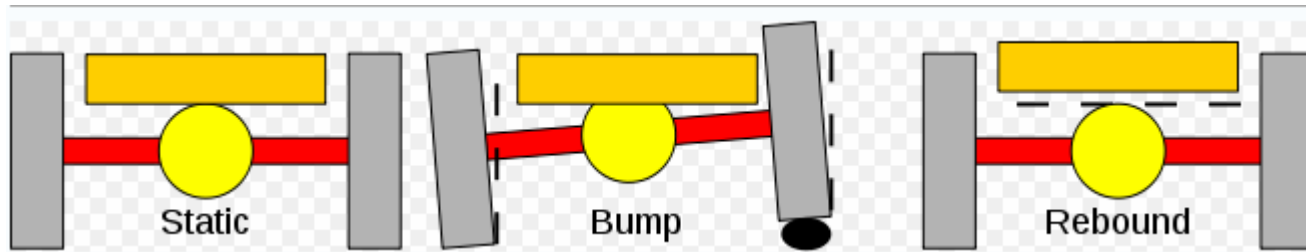


SINGLE WISHBONE SUSPENSION HAS BAD CAMBER CHANGES UNDER SQUAT AND DROOP, RESULTING IN A LOSS OF TYRE FOOTPRINT



UPPER AND LOWER WISHBONES GIVE THE BEST CONTROL ON WHEEL GEOMETRY AND IF DESIGNED RIGHT CAN GIVE POSITIVE AND NEGATIVE CAMBER IN ROLL AND ANTI-SQUAT GEOMETRY ETC ETC (IN PURE SQUAT AND DROOP THE ABOVE SET UP BEHAVES JUST LIKE A LIVE AXLE)

# Camber Change in Solid Axle Suspension



Solid axle suspension characteristics: Camber change on bumps, none on rebound, large unsprung weight



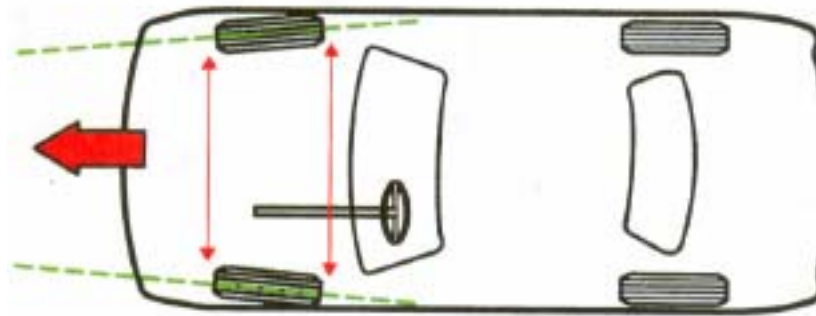
# Camber

- Camber is not adjustable on many vehicles
- If camber is adjustable, the change is made by moving the upper or the lower control arm or strut assembly by means of one of the following methods
  - Shims
  - Eccentric Cams
  - Slots
- Camber should be equal on both sides; however, if camber cannot be adjusted exactly equal, make certain that there is more camber on the front of the left side to help compensate for the road crown (half a degree maximum difference) in LHD, opposite for RHD

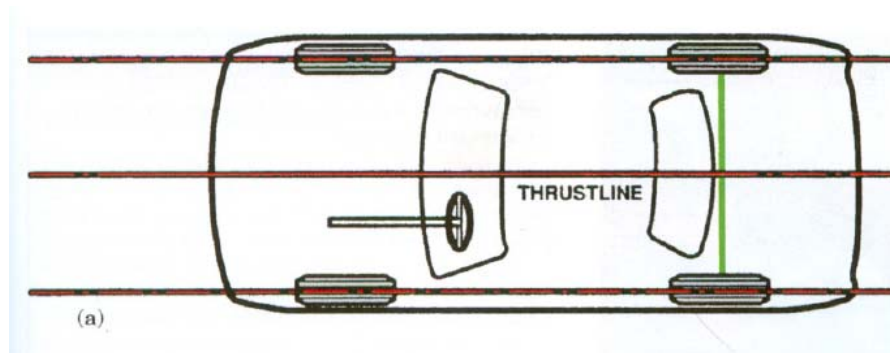
# Toe

- Toe is the difference in distance between the front and rear of the tires

## Toe- Rear Wheel Drive



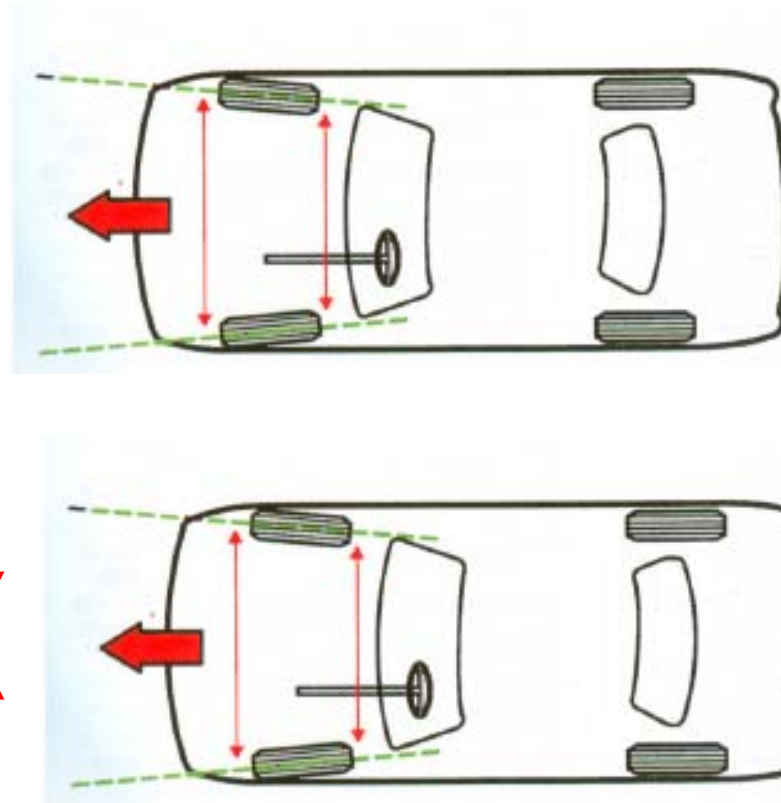
**Wheels toe out  
during running**





# Toe

- Front wheel Drive



Drive Axles Toe in during running

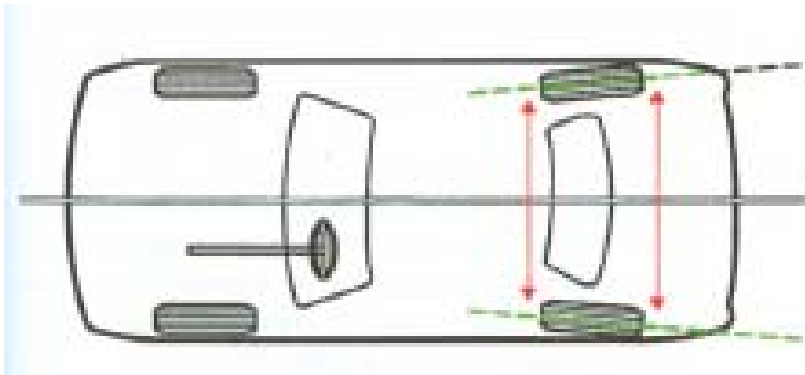
# Toe

- Toe is measured in fractions of degrees or in fractions of an inch (usually sixteenths), millimeters(mm), or decimals of an inch (such as 0.06")
- Incorrect toe is the major cause of excessive tire wear
- Toe causes camber –type wear on one side of the tire if not correct



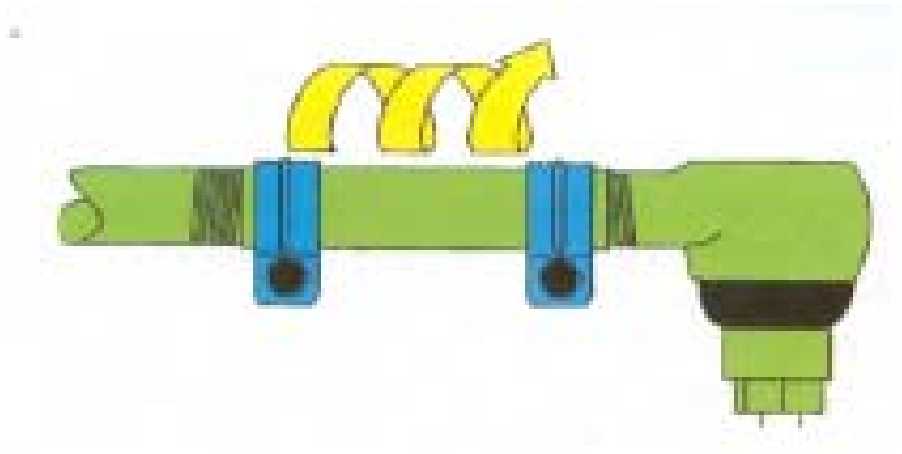
# Toe

- Incorrect front toe does not cause a pull condition. Incorrect toe on the front wheels is split equally as the vehicle is driven because the forces acting on the tires are exerted through the tie rod and steering linkages to both wheels
- Incorrect (unequal) rear toe can cause tire wear. If the toe of the rear wheels is not equal, the steering wheel will not be straight and will pull toward the side with the most toe-in



# Toe

- Front toe adjustment must be made by adjusting the tie rod sleeves correctly

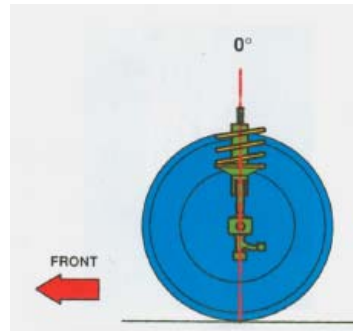


# Toe

- Most vehicle manufacturers specify a slight amount of toe – in to compensate for the natural tendency of the front wheels to spread apart (become toed-out) due to the centrifugal force of the rolling wheels acting on the steering linkage
- Some manufacturers of front wheel drive vehicles specify a toe-out setting to compensate for the toe-in forces created by the engine drive forces on the front wheels
- Normal wear to the tie rod ends and other steering linkage parts usually causes toe-out

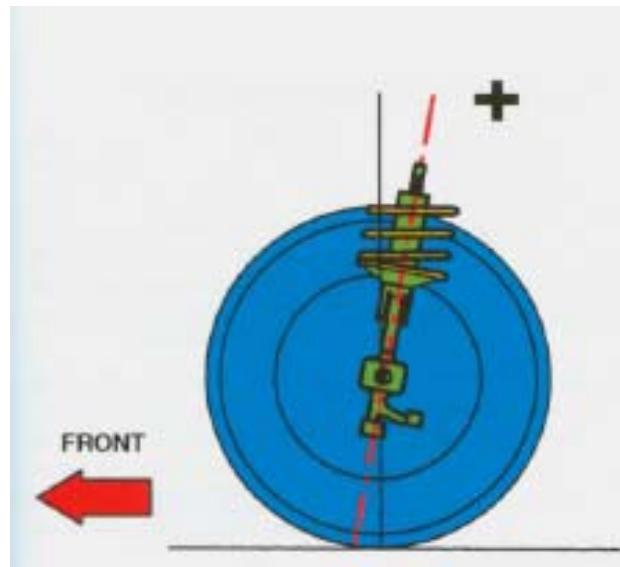
# Caster

- Caster is the forward or rearward tilt of the steering axis in reference to a vertical line as viewed from the side of the vehicle. Steering axis is defined as the line drawn through the upper and lower steering pivot points.
- On an SLA suspension system, the upper pivot is the upper ball joint and the lower pivot is the lower ball joint. On a MacPherson strut system, the upper pivot is the centre of the upper bearing mount and the lower pivot point is the lower ball joint.
- Zero Center means that the steering axis is straight up and down, also called zero degrees or perfectly vertical



# Caster

- Positive caster is present when the upper suspension pivot point is behind the lower pivot point (ball joint) as viewed from the side
- Negative caster is present when the upper suspension pivot point is ahead of the lower pivot point (ball joint) as viewed from the side
- Caster is measured in degrees or fractions of degrees

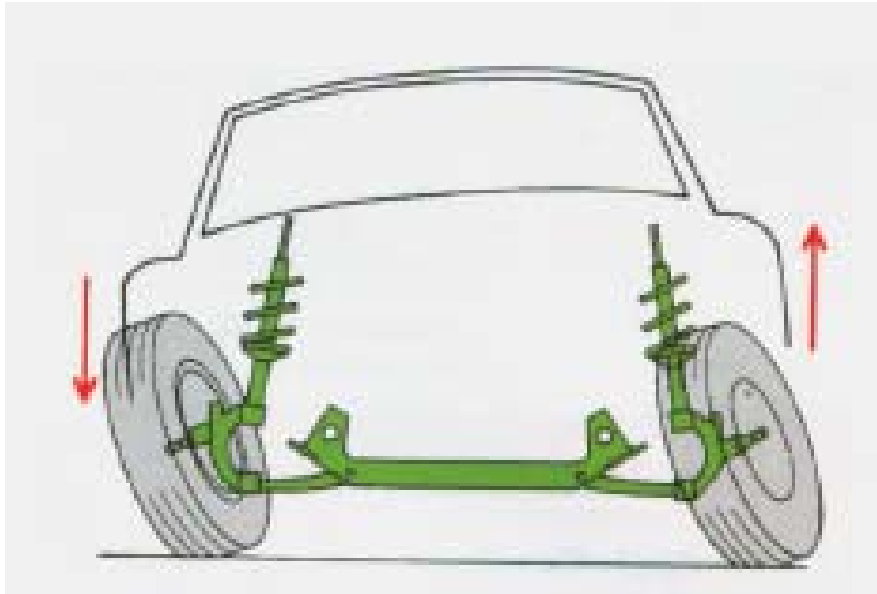






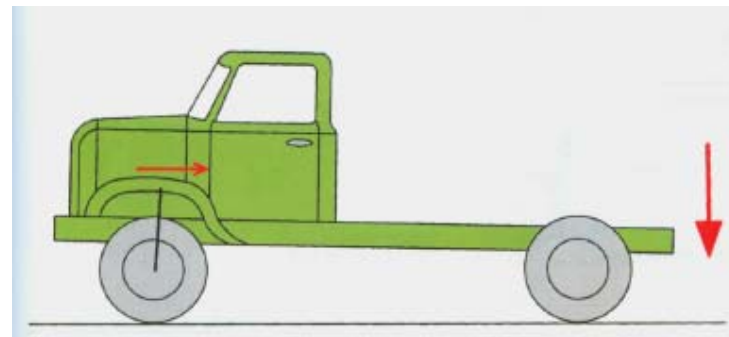
# Caster

- Caster is not a tire wearing angle, but positive caster does cause changes in camber during a turn. This condition is called camber roll



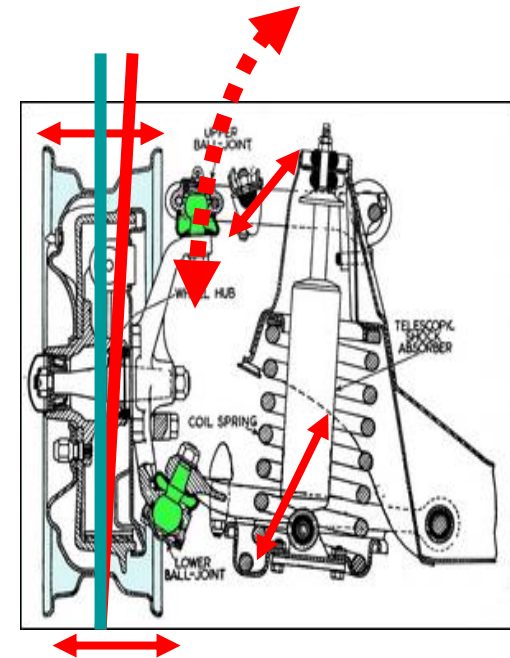
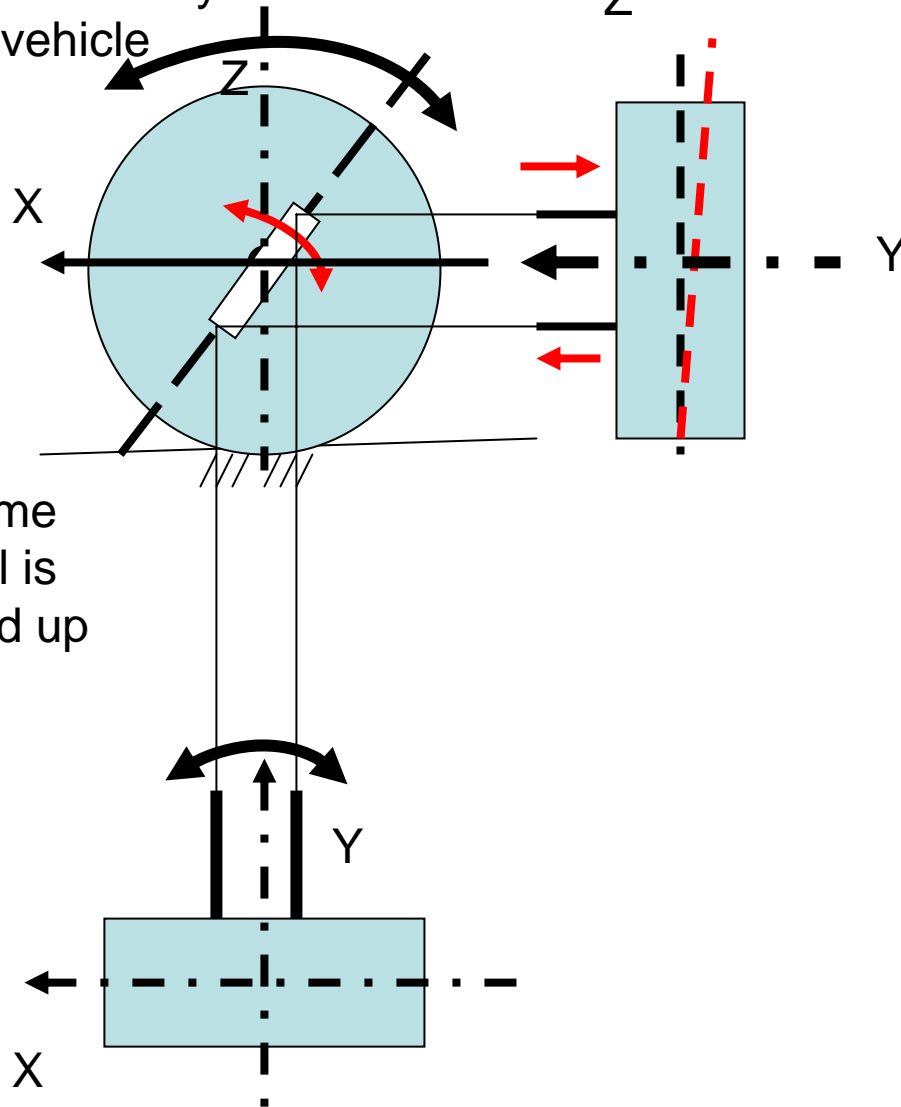
# Caster

- Caster is a stability angle
  - If caster is excessively positive, vehicle steering will be very stable (will tend to be straight with little steering wheel correction needed) and help with steering wheel
  - If the caster is positive, the steering effort will increase with increasing positive caster. Greater road shocks will be felt by the driver when driving over rough road surfaces. Vehicles with as high as eleven degrees of positive caster usually use a steering dampener to control possible shimmy at high speeds and to dampen the snap-back of the spindle after a turn
  - If caster is negative, or excessively unequal, the vehicle will not be as stable and will tend to wander. If a vehicle is heavily loaded in the rear, caster increase as shown



# Caster Changes

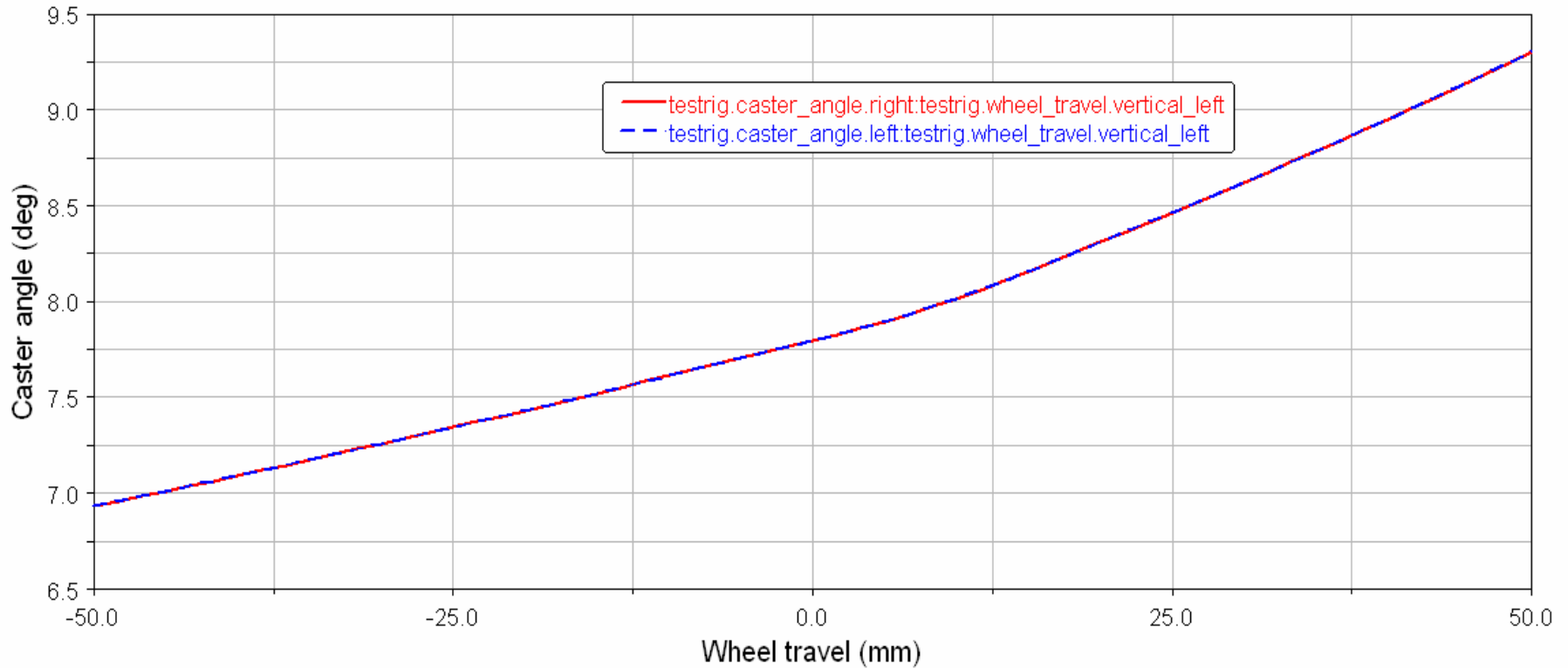
This movement may be due to vehicle inertia



Caster Changes leads to camber change hence camber roll



# Caster angle v/s Wheel Travel (Parallel)





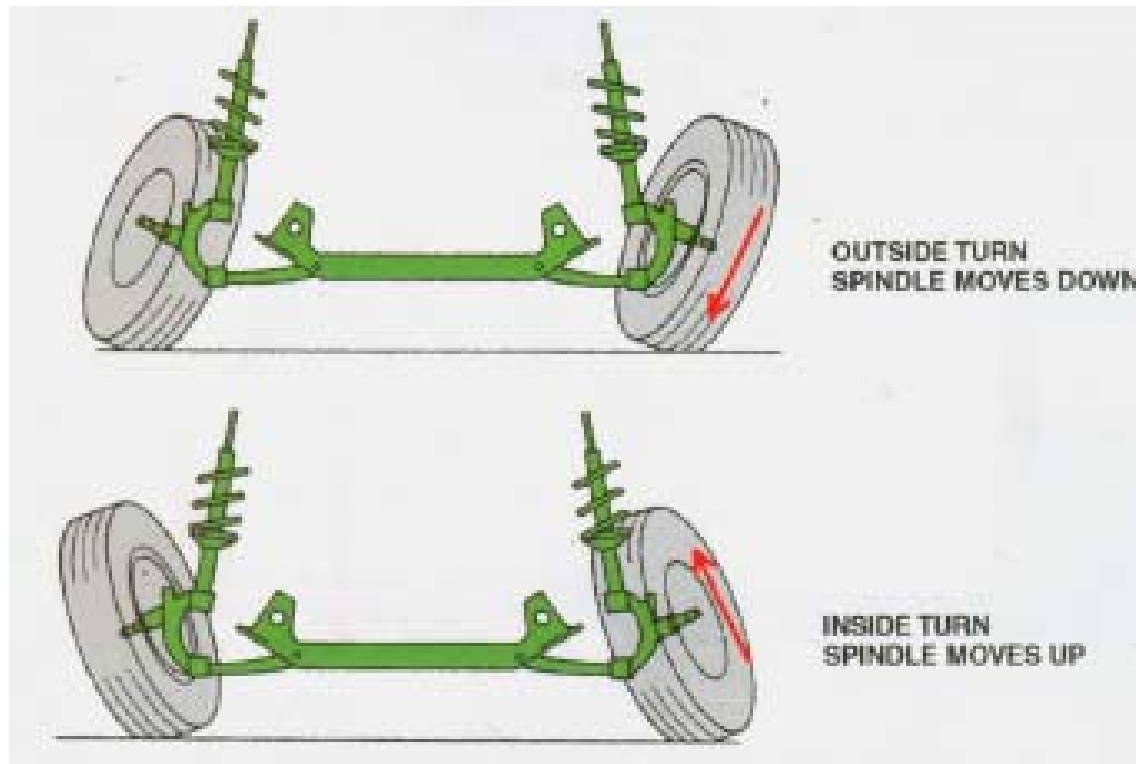
# Caster

- Caster could cause pull if unequal. The vehicle will pull toward the side with least positive caster
- Caster is not adjustable on many vehicles
- If caster is adjustable, the change is made by moving either the lower or the upper pivot point forward or backward by means of one of the following methods
  - Shims
  - Eccentric Cams
  - Slots
  - Strut rods



# Caster

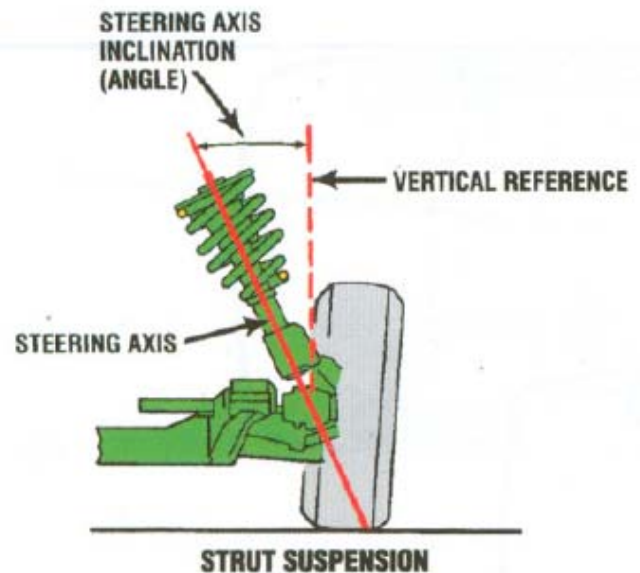
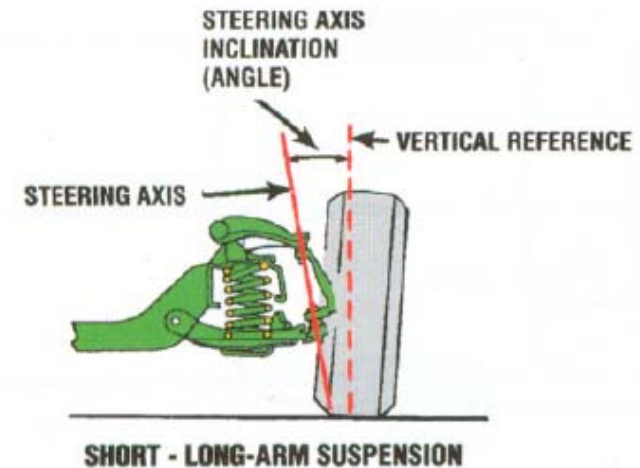
- Caster affects tire wear indirectly –Changes camber during turns





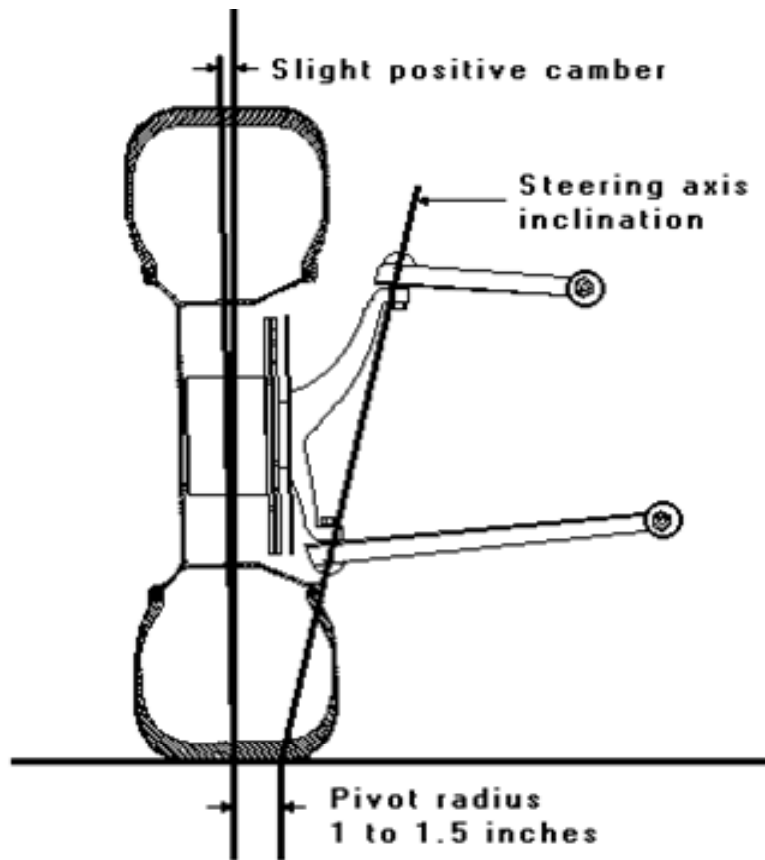
# Steering Axis Inclination (SAI)

- The steering axis is the angle formed between true vertical and an imaginary line drawn between the upper and lower pivot points of the spindle.
- Steering axis inclination (SAI) is the inward tilt of the steering axis. SAI is also known as KPI and is the imaginary line drawn through the kingpin as viewed from the front



# Steering Axis Inclination (SAI)

- The front view axis inclination angle add steering returnability by lifting the front axle in a turn.

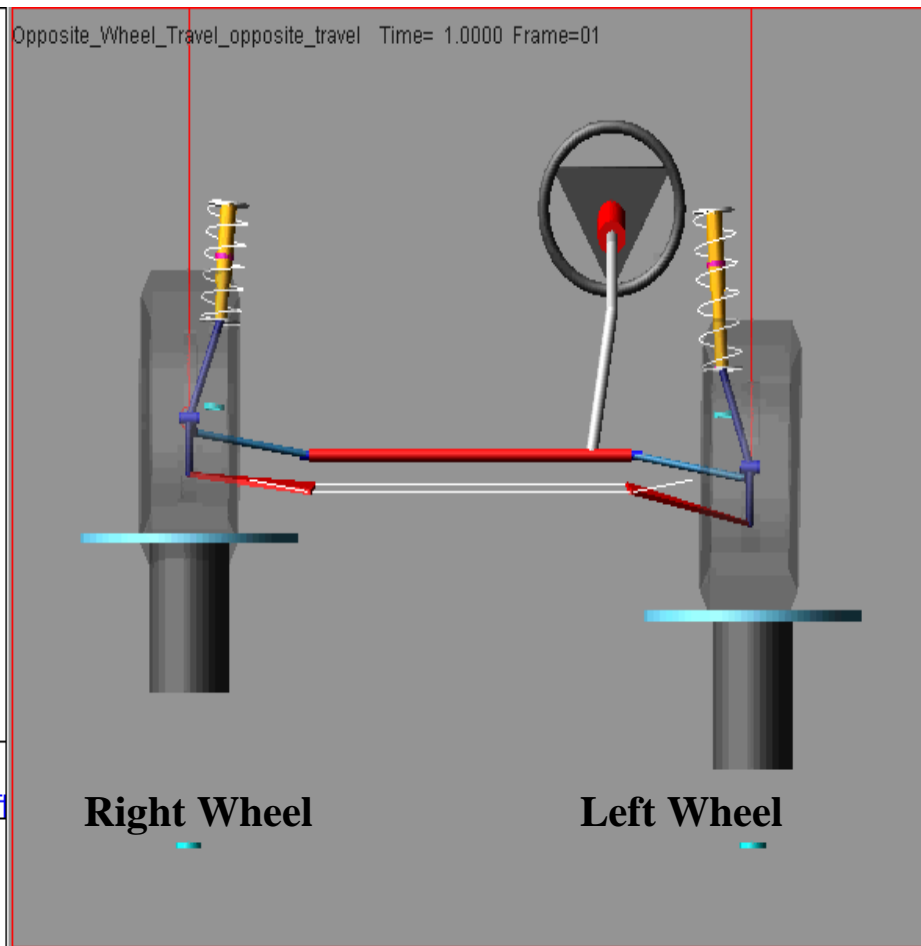
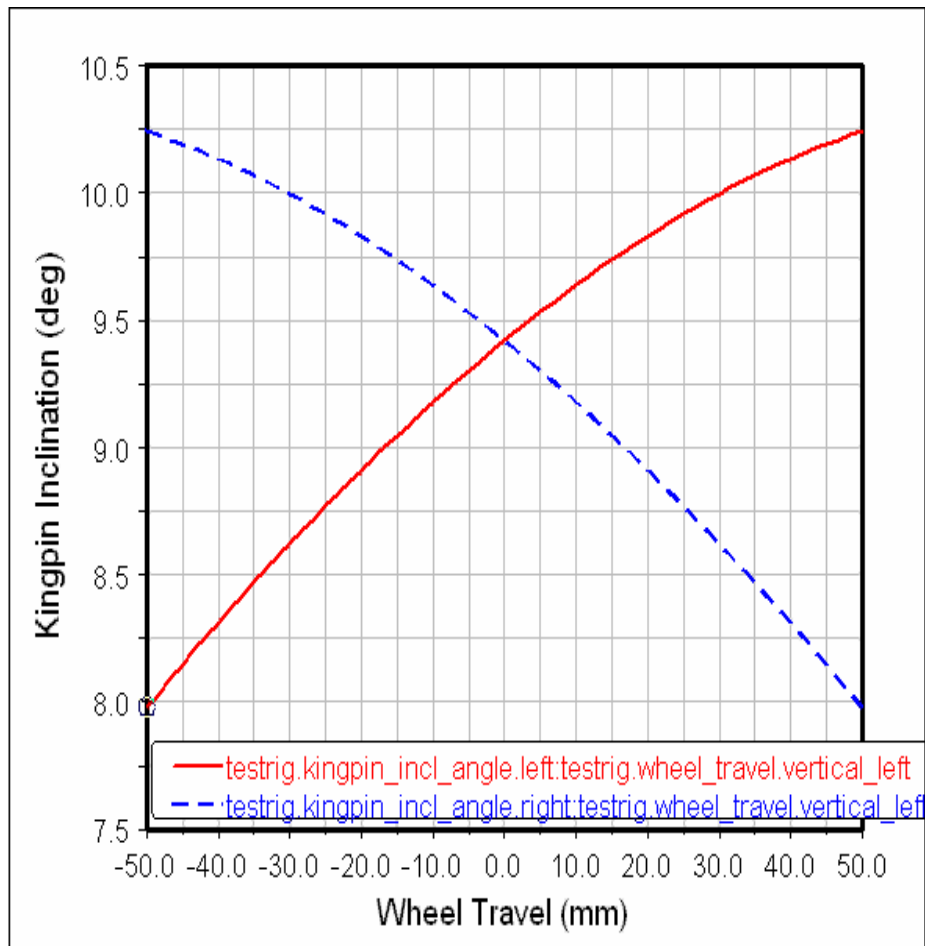


When the wheel is turned, you recognise the lifting of the vehicle (on the ball). If you press the ball, the turned wheel immediately goes into the straight ahead position.

## Opposite wheel travel Analysis

Bump travel=50mm, Rebound travel=-50mm(2 inch)

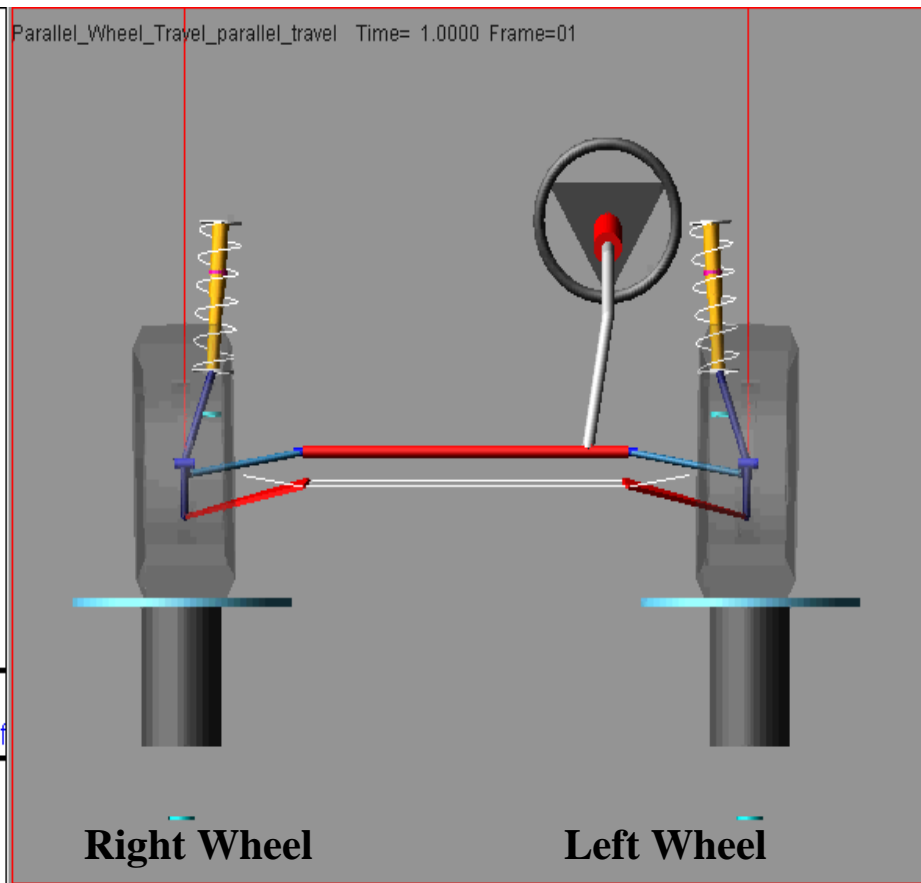
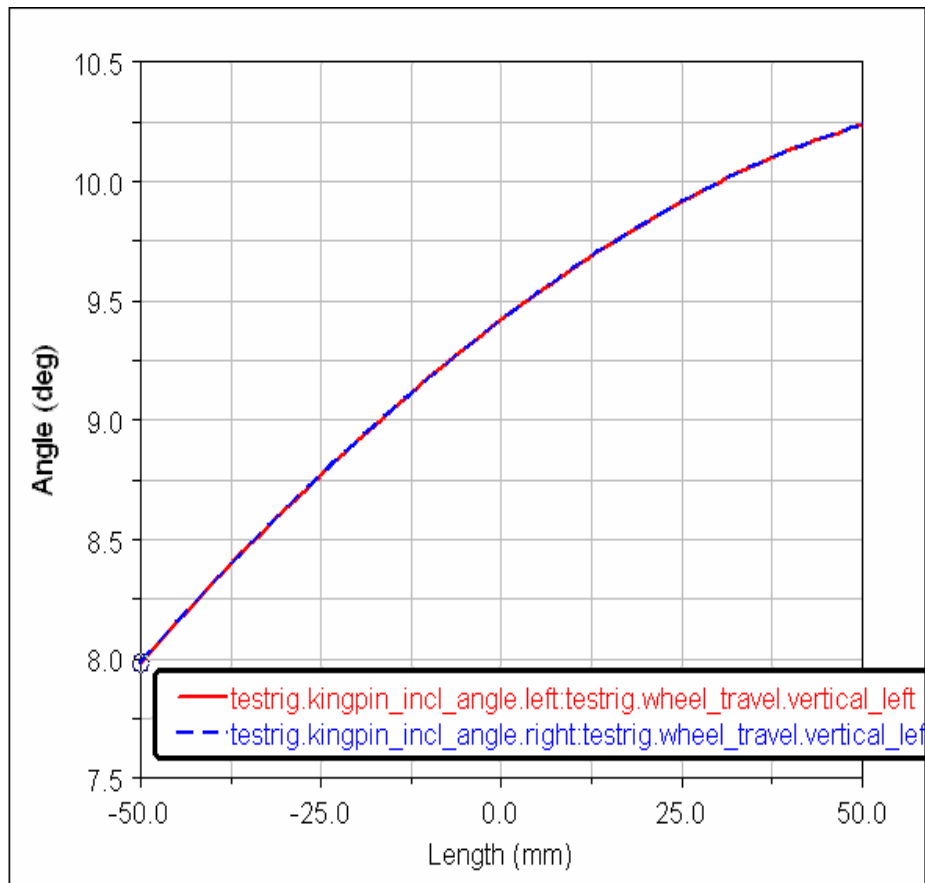
### Kingpin Inclination v/s Wheel Travel



## Parallel wheel travel Analysis

Bump travel=**50mm**, Rebound travel=**-50mm** (2 inch)

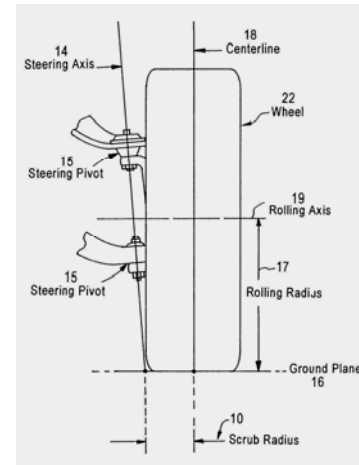
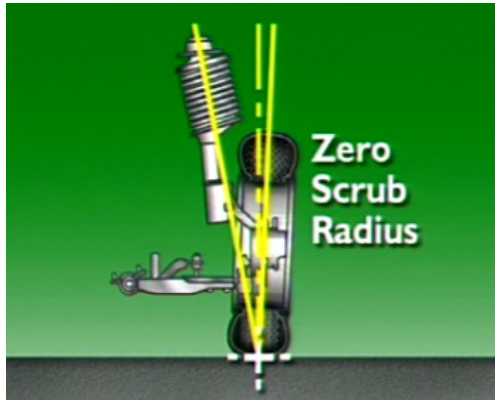
### Kingpin Inclination v/s Wheel Travel







# Scrub Radius

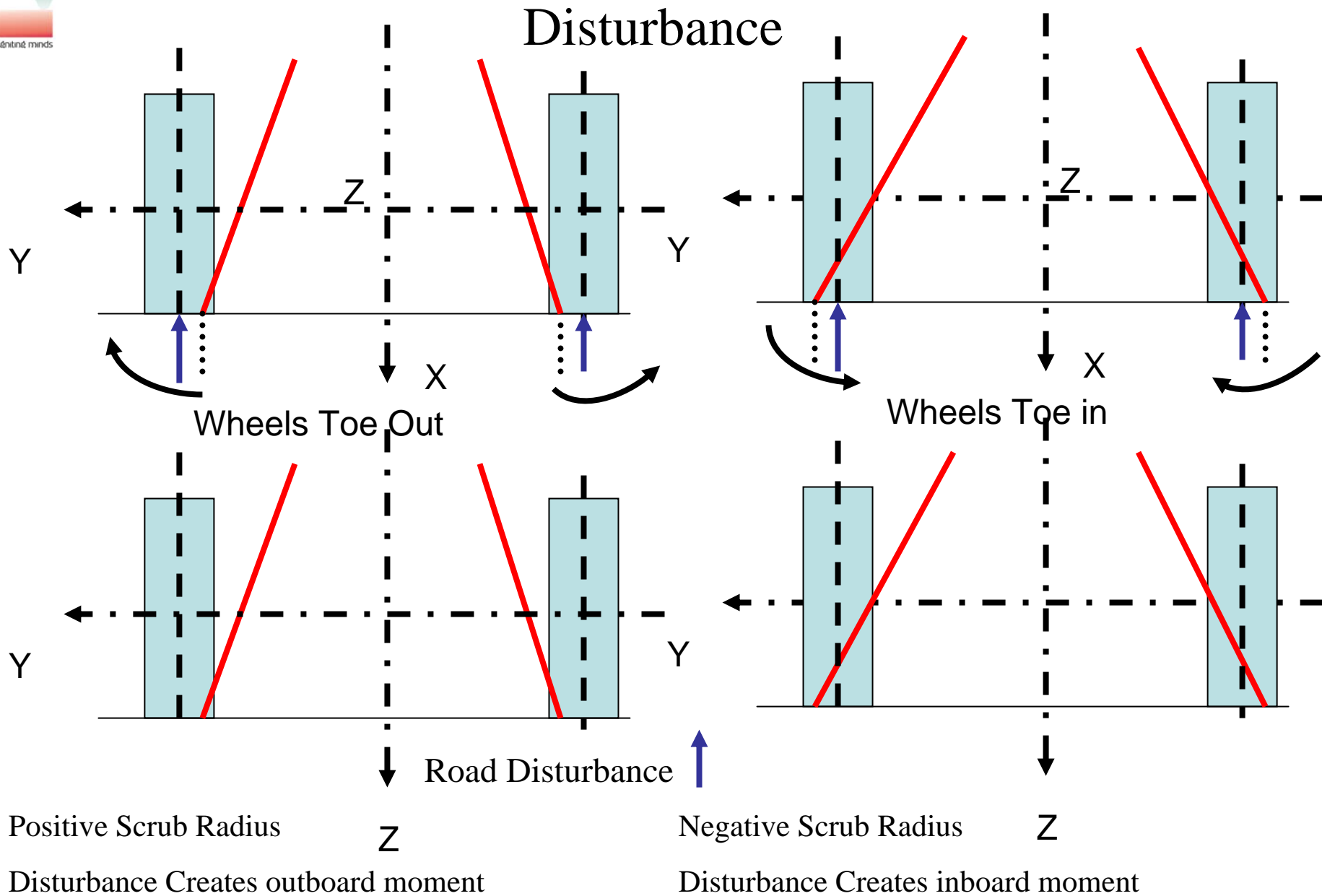


Positive scrub Radius

- Scrub radius is also known as steering offset, and scrub geometry. It is the distance between 2 imaginary points on the road surface - the point of center contact between the road surface and the tire, and the point where the steering-axis center-line contacts the road surface.
- If these two points intersect at the center of the tire, at the road surface, then the scrub radius is zero.
- If they intersect below the road surface, scrub radius is positive.
- If they intersect above the road surface, scrub radius is negative.

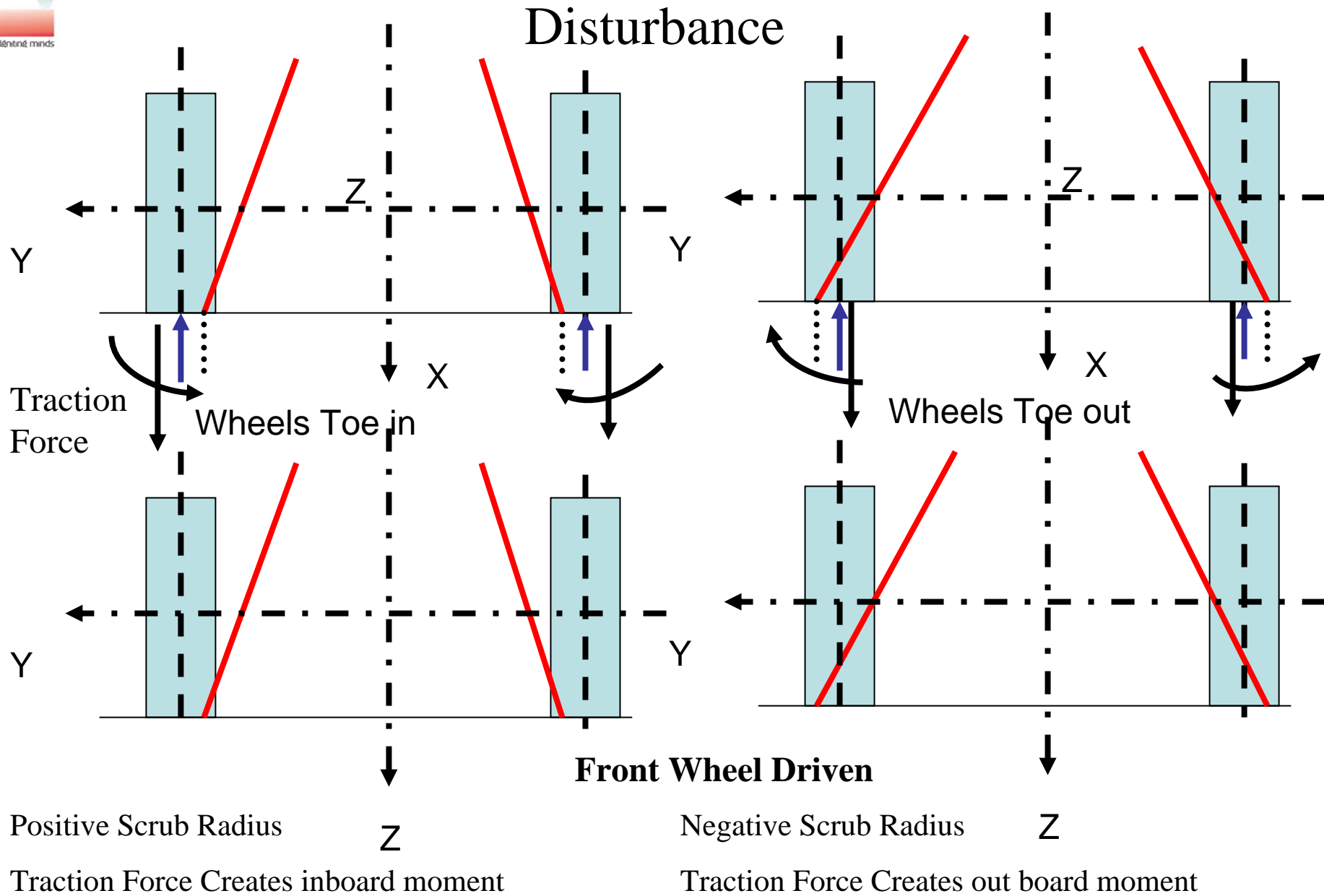


# Effect of Scrub Radius on Steering Due to Road



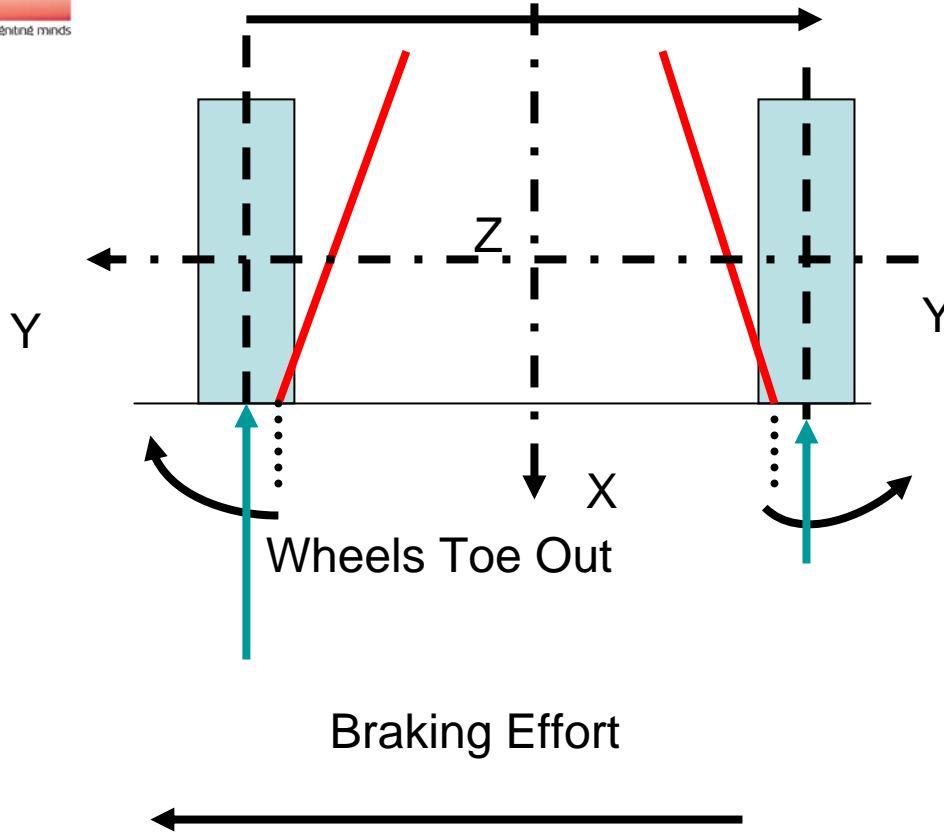


# Effect of Scrub Radius on Steering Due to Road Disturbance

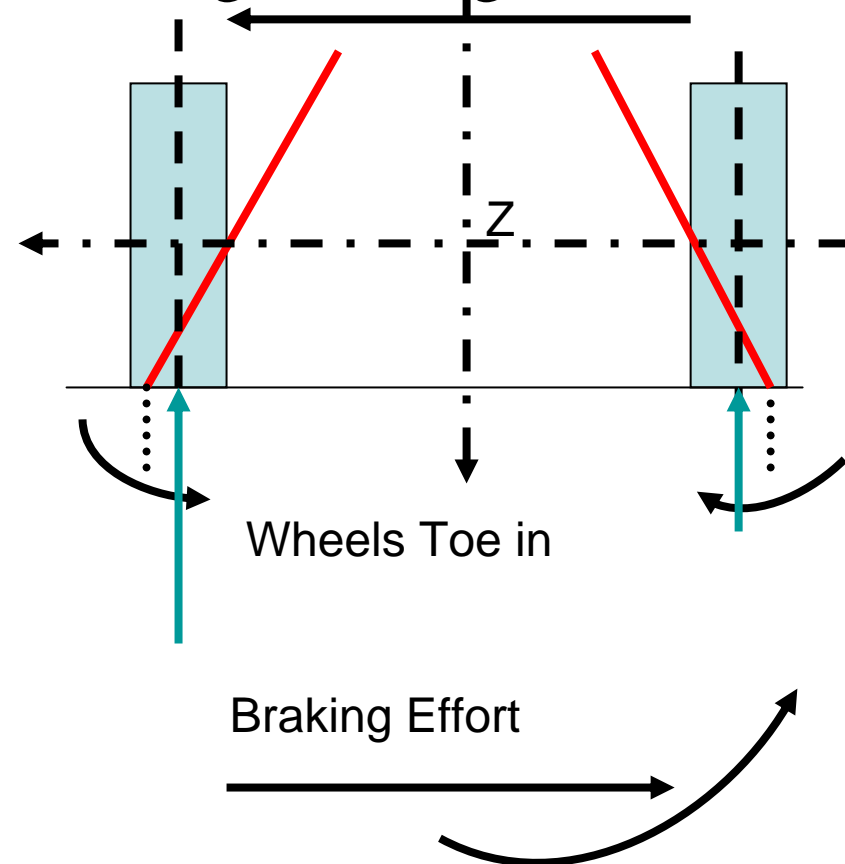




# Effect of Scrub Radius During Braking



Positive scrub radius will cause the vehicle to veer towards the side with the greater effort

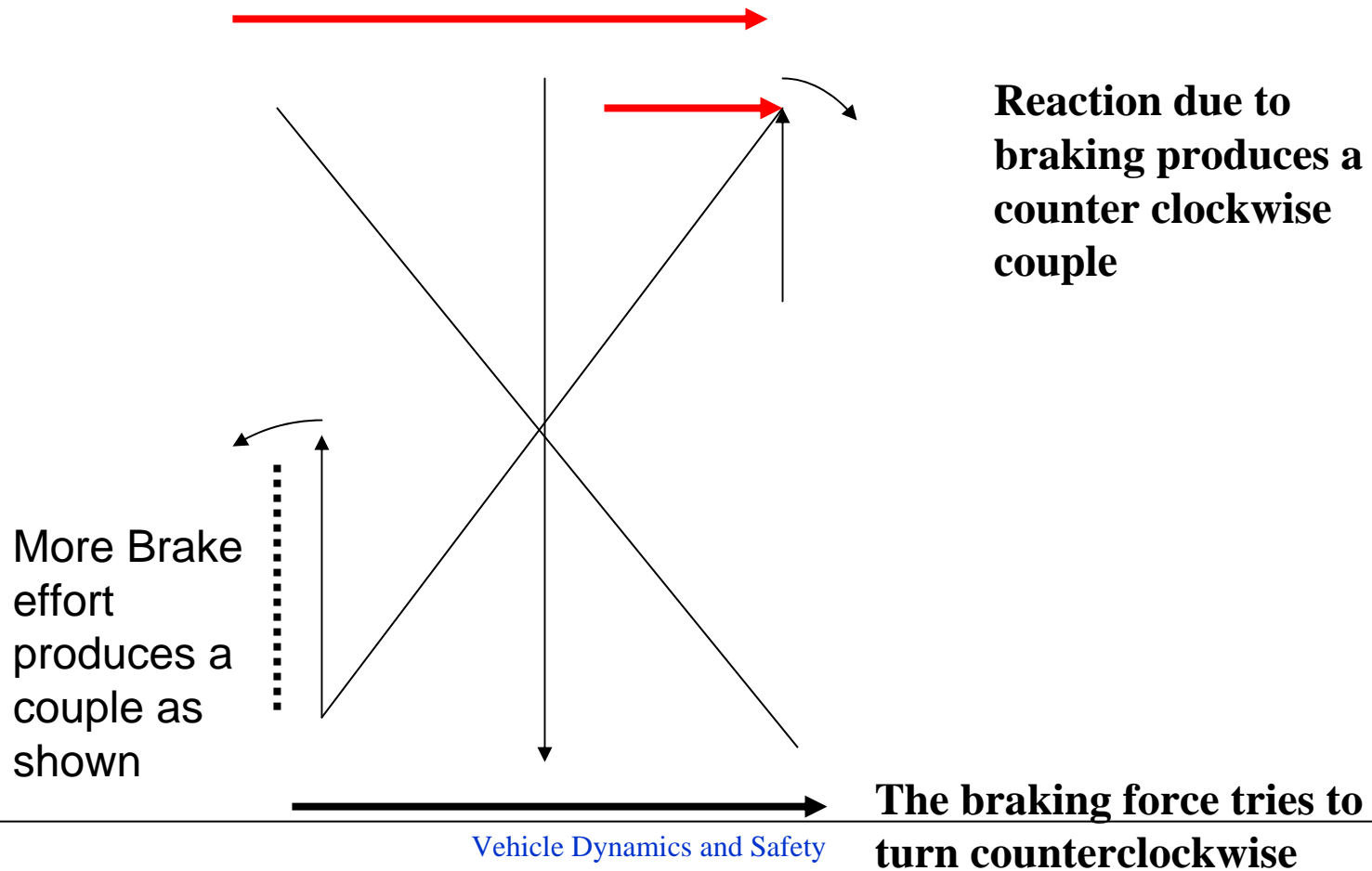


Negative scrub radius will cause the vehicle to veer away from the side with the greater effort

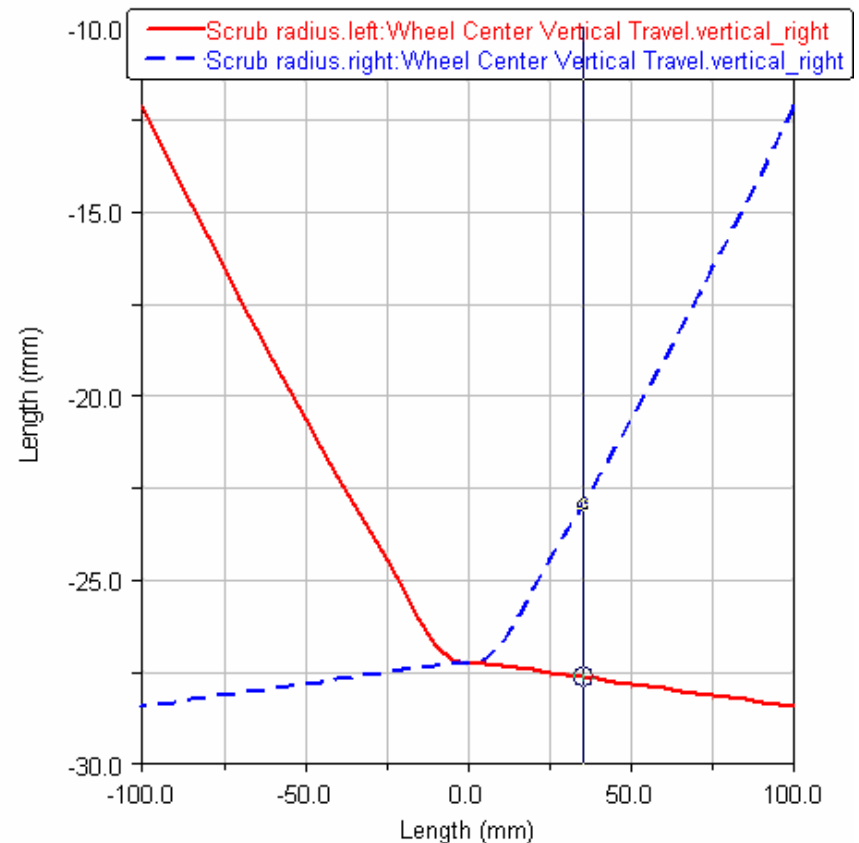
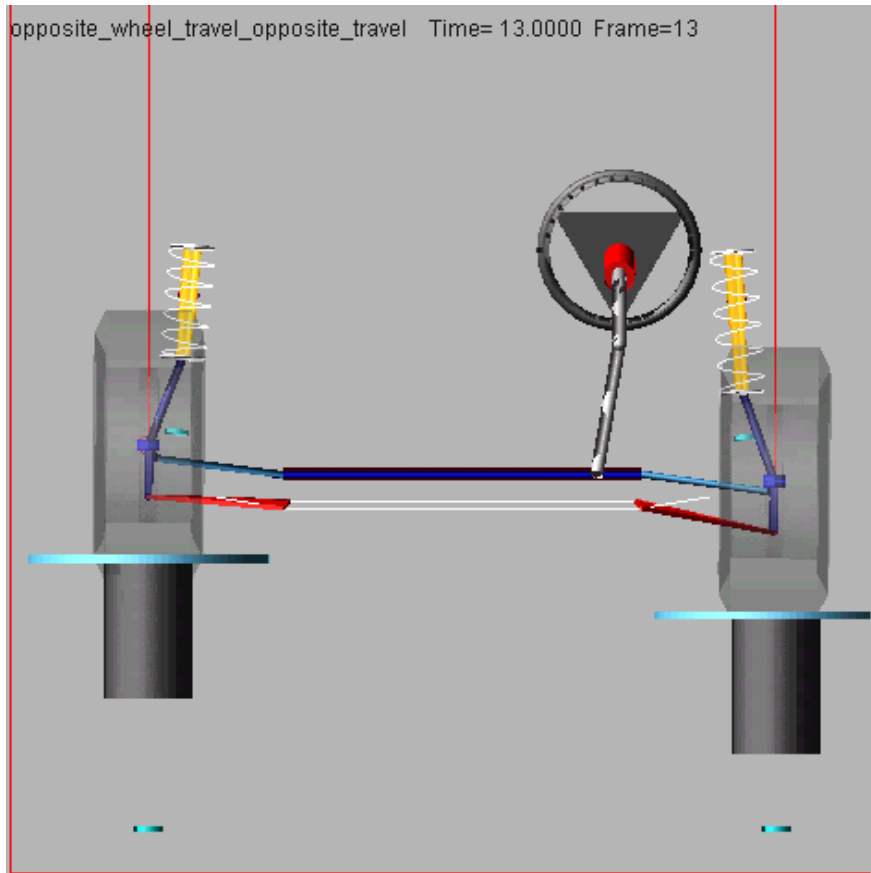


# Scrub Radius and Diagonal Split Brake

- Vehicles with a diagonal-split brake system have negative scrub radius built into the steering geometry. If one half of the brake system fails, then the vehicle will tend to pull up in a straight line.



# Scrub Radius Change

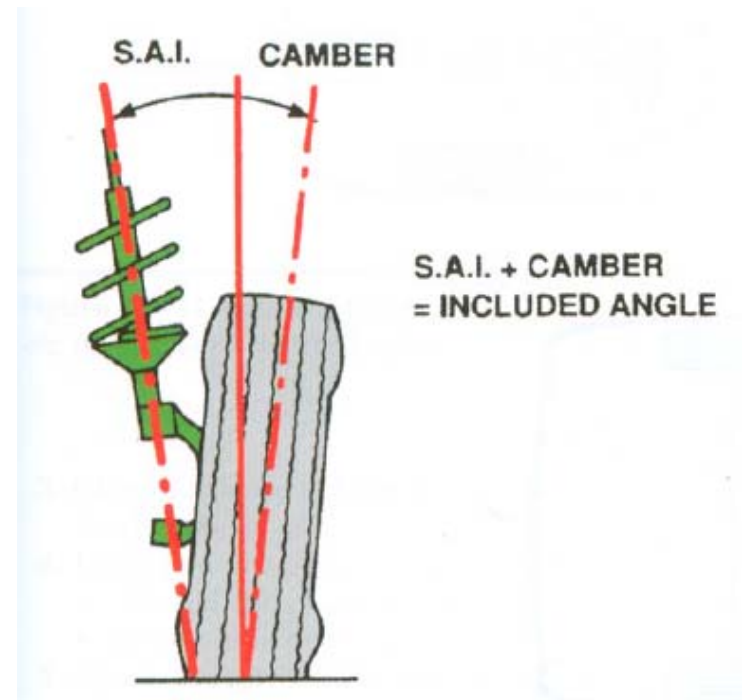


## Scrub Radius v/s Wheel Travel



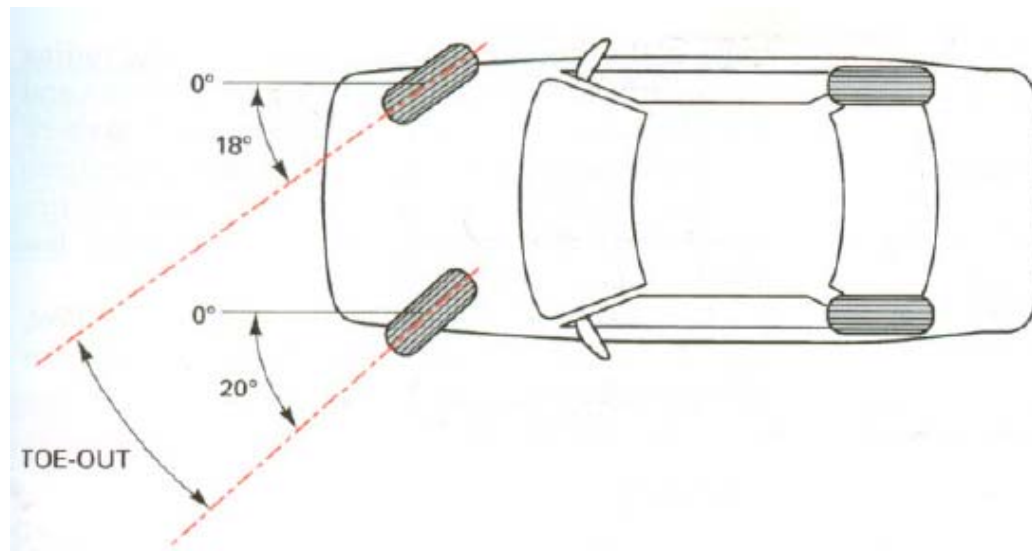
# Included Angle

- The included angle is the SAI added to the camber reading of the front wheel only. Included angle is an important angle to measure when diagnosing vehicle handling or tire wear problems



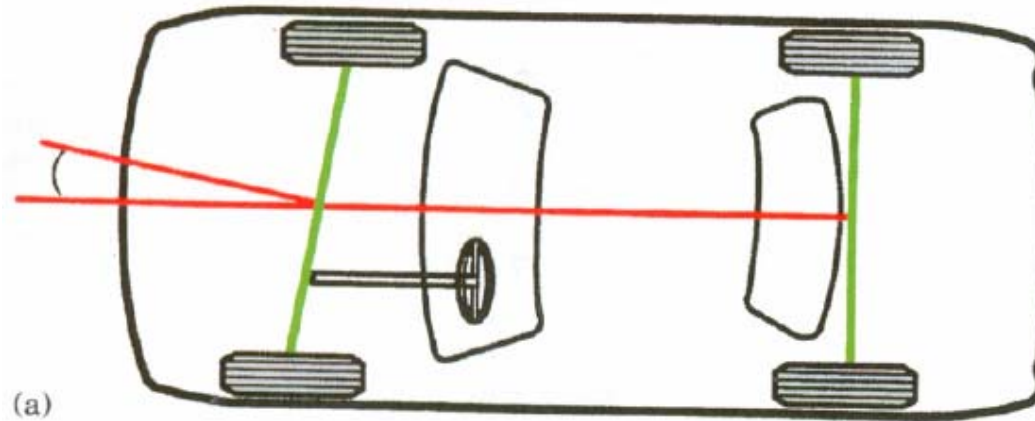
# Turning Radius (Toe-out on Turns)

- Whenever a vehicle turns a corner, the inside wheel has to turn at a sharper angle than the outside wheel because the inside wheel has a shorter distance to travel.
- Turning radius is also called toe-out on turns (TOT or TOOT)
- Turning radius is a nonadjustable angle

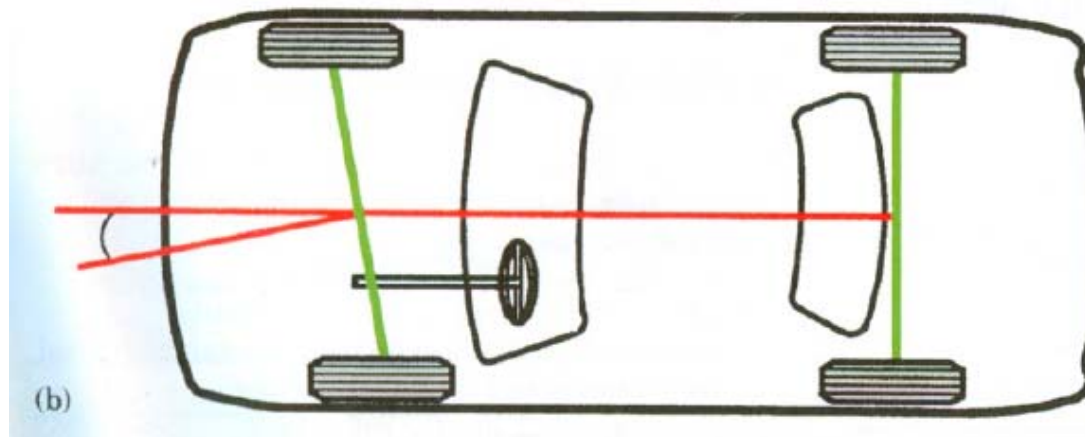


# Setback

- Setback is the angle formed by a line drawn perpendicular to the front axle



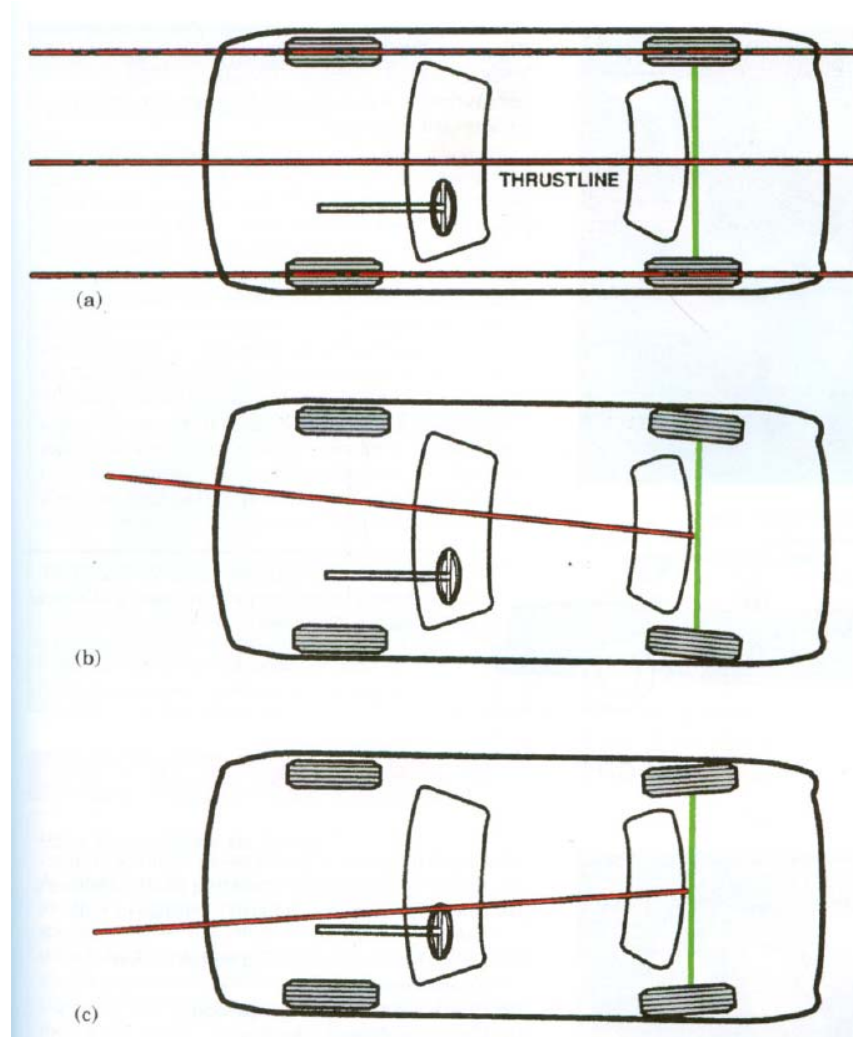
Positive  
Setback



Negative  
Setback

# Thrust Angle

- Thrust Angle is the angle of the rear wheels as determined by the total rear toe



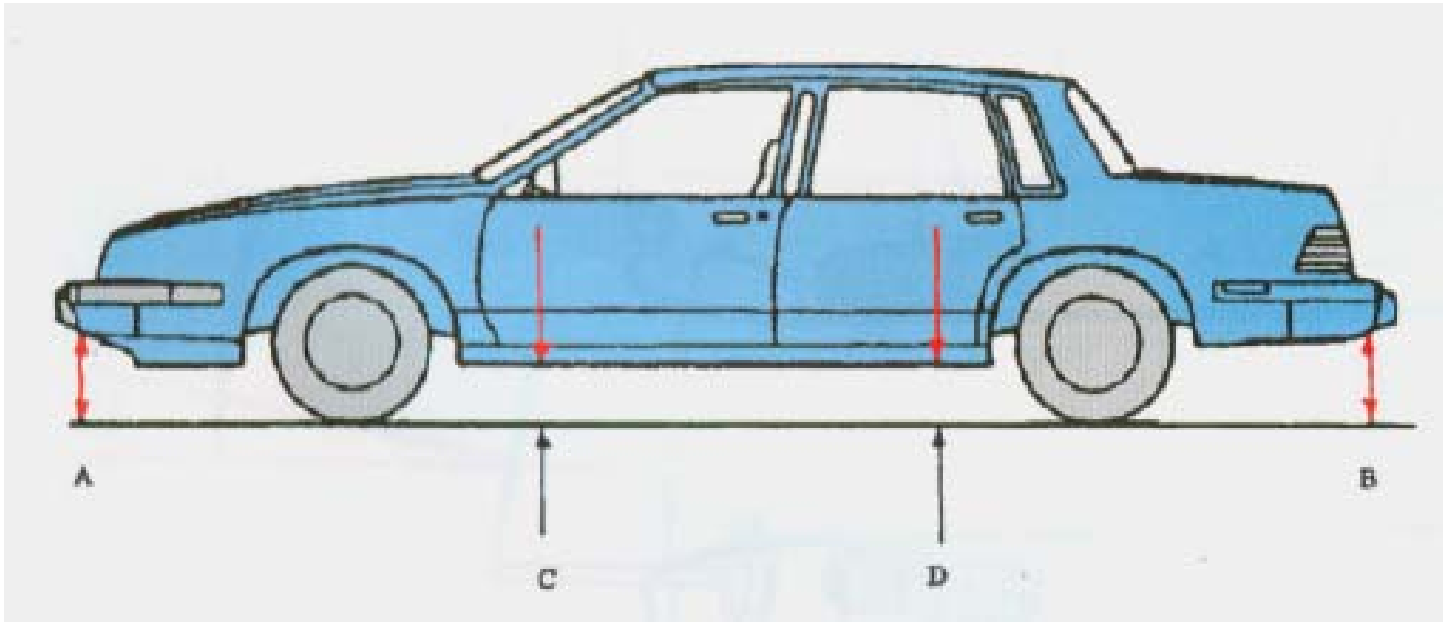




# Tracking

- Tracking is the term used to describe the fact that the rear wheels should track directly behind the front wheels.

# Ride Height



Load transfer changes wheel alignment angles and ride height

# Alignment Specifications at Curb Height

## ALIGNMENT SPECIFICATIONS AT CURB HEIGHT

FRONT WHEEL ALIGNMENT	ACCEPTABLE ALIGNMENT RANGE AT CURB HEIGHT	PREFERRED SETTING
CAMBER . . All* .....	-0.6° to +0.6°	+0.0°
*Side To Side Differential .....	0.7° or less	0.0°
TOTAL TOE All Vehicles (See Note) Specified In Degrees .....	0.4° In to 0.0°	0.2° In
CASTER* .....	REFERENCE ANGLE	
All Models .....	+2.0° to +4.0°	+3.0°
*Side To Side Caster Differential Not to Exceed .....	1.0° or less	0.0°
REAR WHEEL ALIGNMENT	ACCEPTABLE ALIGNMENT RANGE AT CURB HEIGHT	PREFERRED SETTING
CAMBER . . All Models .....	-0.6° to +0.4°	-0.1°
TOTAL TOE* All Vehicles (See Note) Specified In Degrees .....	0.2° Out to 0.4° In	0.1° In
THRUST ANGLE .....	-0.15° to +0.15°	
*TOE OUT When Backed On Alignment Rack Is TOE IN When Driving.		
NOTE: Total toe is the arithmetic sum of the left and right wheel toe settings. Positive is Toe-in, negative is Toe-out. Total Toe must be equally split between each front wheel to ensure a centered steering wheel. Left and Right toe must be equal to within 0.02 degrees.		



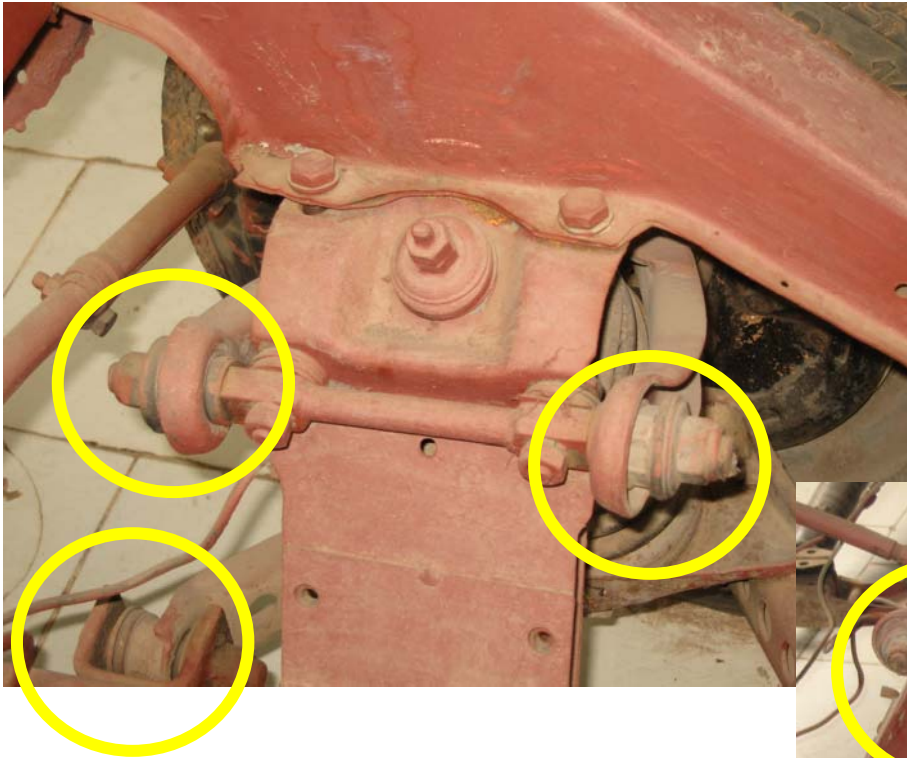
# Suspension Kinematics

- A basic characteristic of suspension system is the change in orientation and position of the wheel under the wheel stroke, which is called kinematic characteristic and it strongly influences the handling and the stability of the vehicle
- Kinematic design of a suspension system involves determining the positions of hardpoints or kinematic design points
- Suspension **static design factors** such as toe, camber and caster are decided by the location of hardpoints.



# Compliance

- Compliance is deliberately introduced into the suspension systems through bushings to achieve good ride.
- Bushings are rubber members provided in suspension and steering sub-systems to avoid metal-to-metal friction during kinematic motion.
- Two types of compliance are of interest – lateral and longitudinal force compliance.
- Specific Bushings are required to have desirable stiffness in specific orientations to meet compliance



# Bush Stiffness

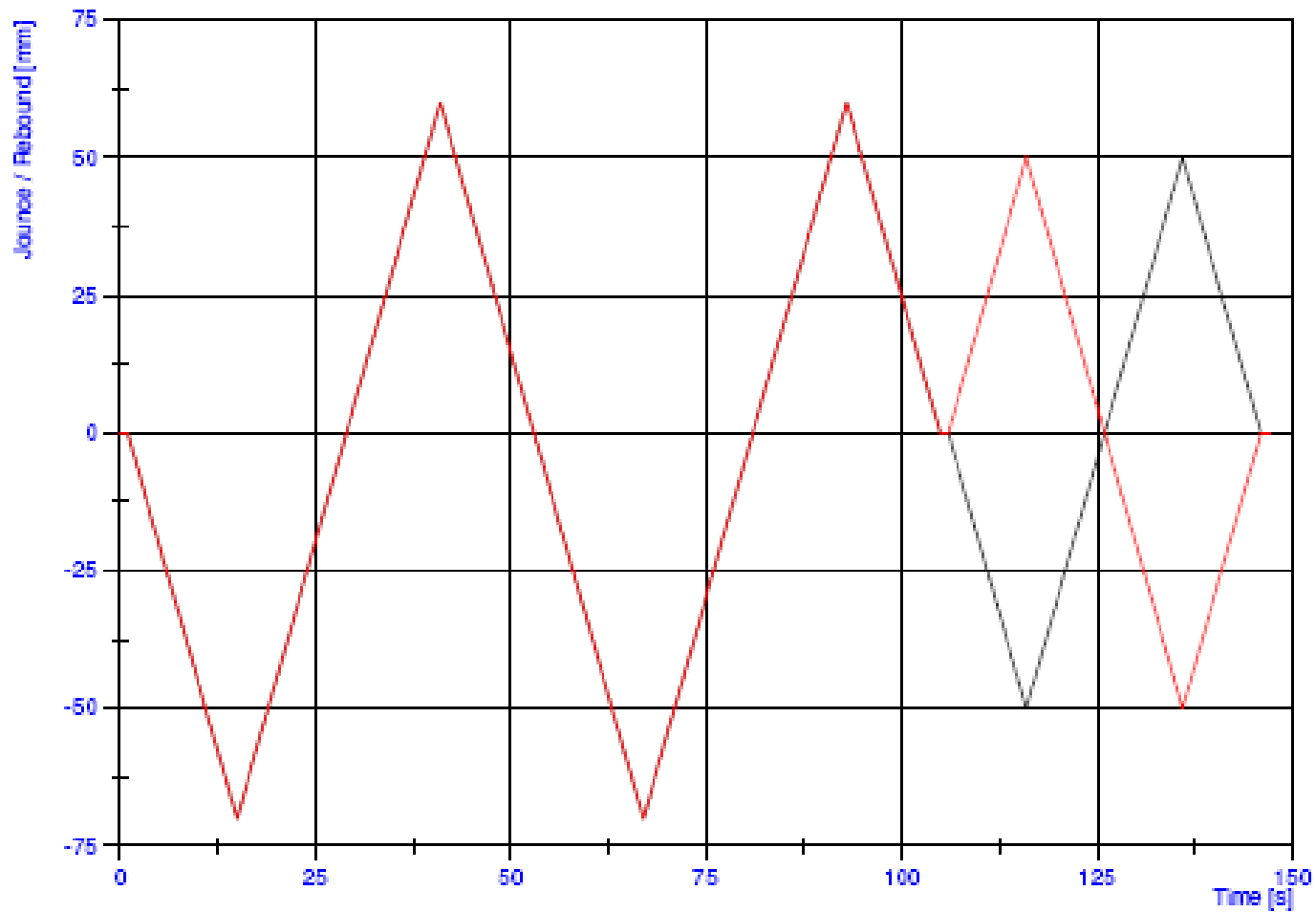
- *For MacPherson Suspension*
- *Y* stiffness of lca\_front and lca\_rear bushings affects toe and camber in braking and driving
- *X* stiffness of rack\_house bushing (steering sub-system) affects toe and camber in braking and driving
- *Z* stiffness of rack\_house bushing (steering sub-system) affects toe and camber under lateral forces



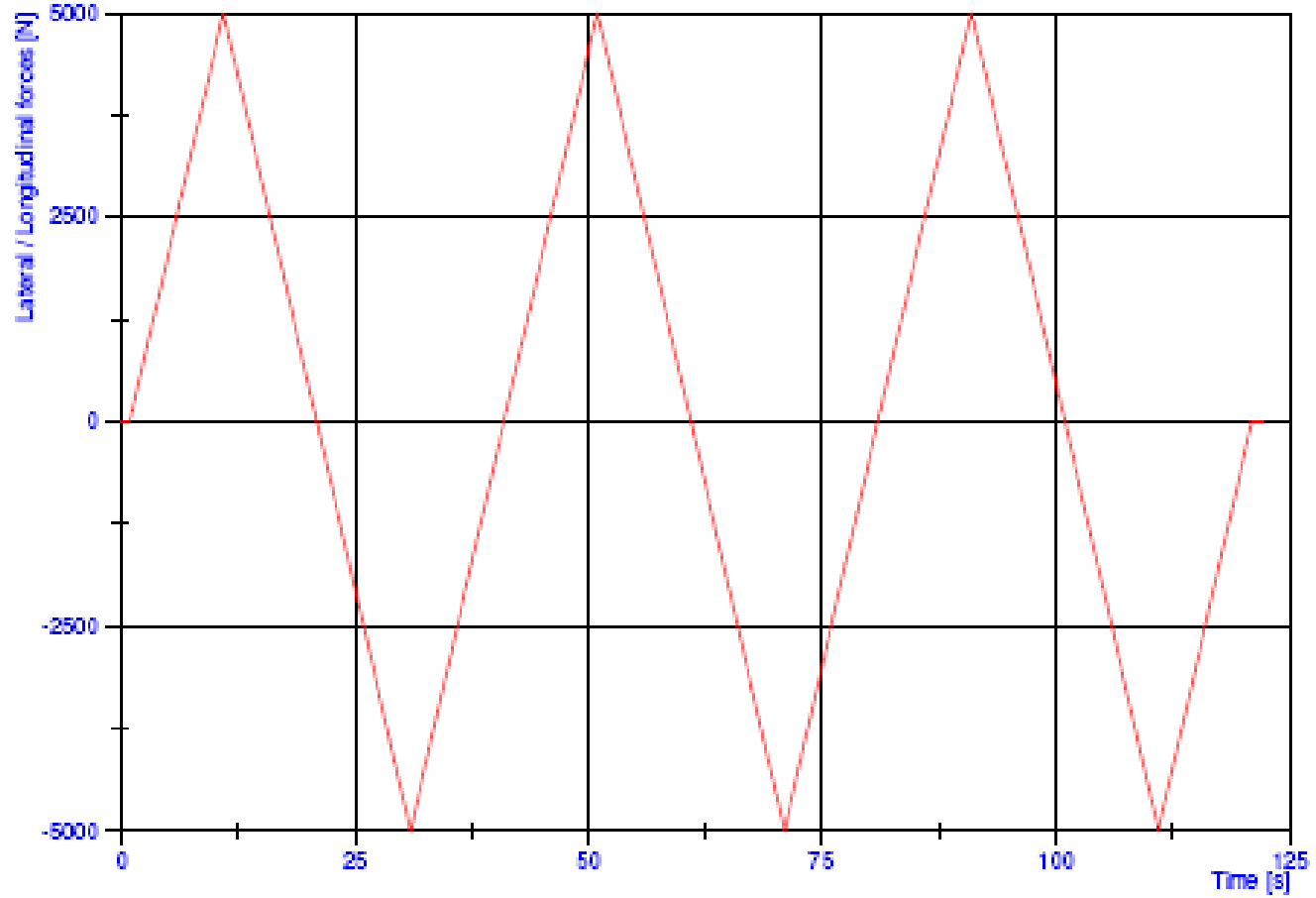
# Kinematics and Compliance Test Rig with Test Vehicle



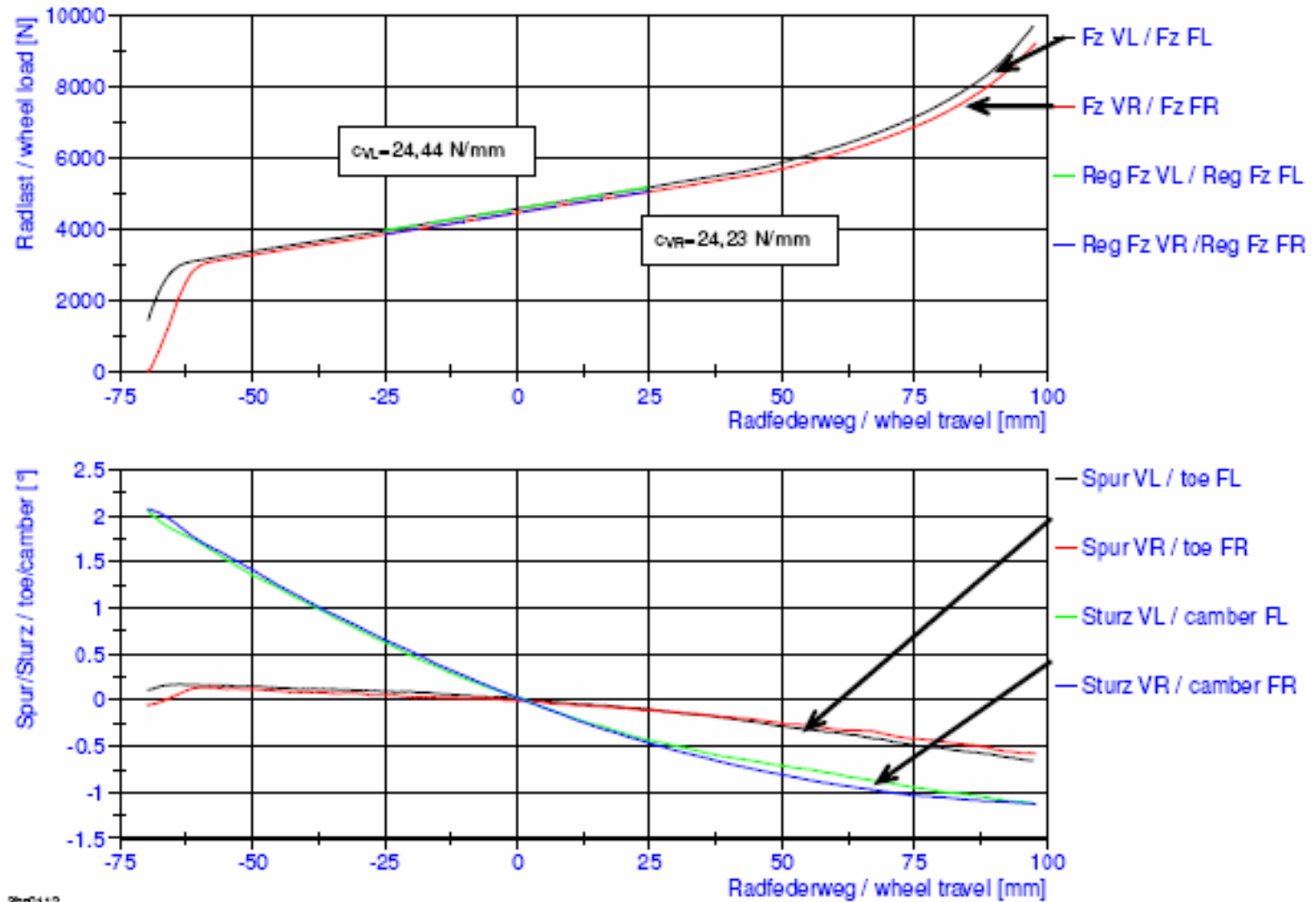




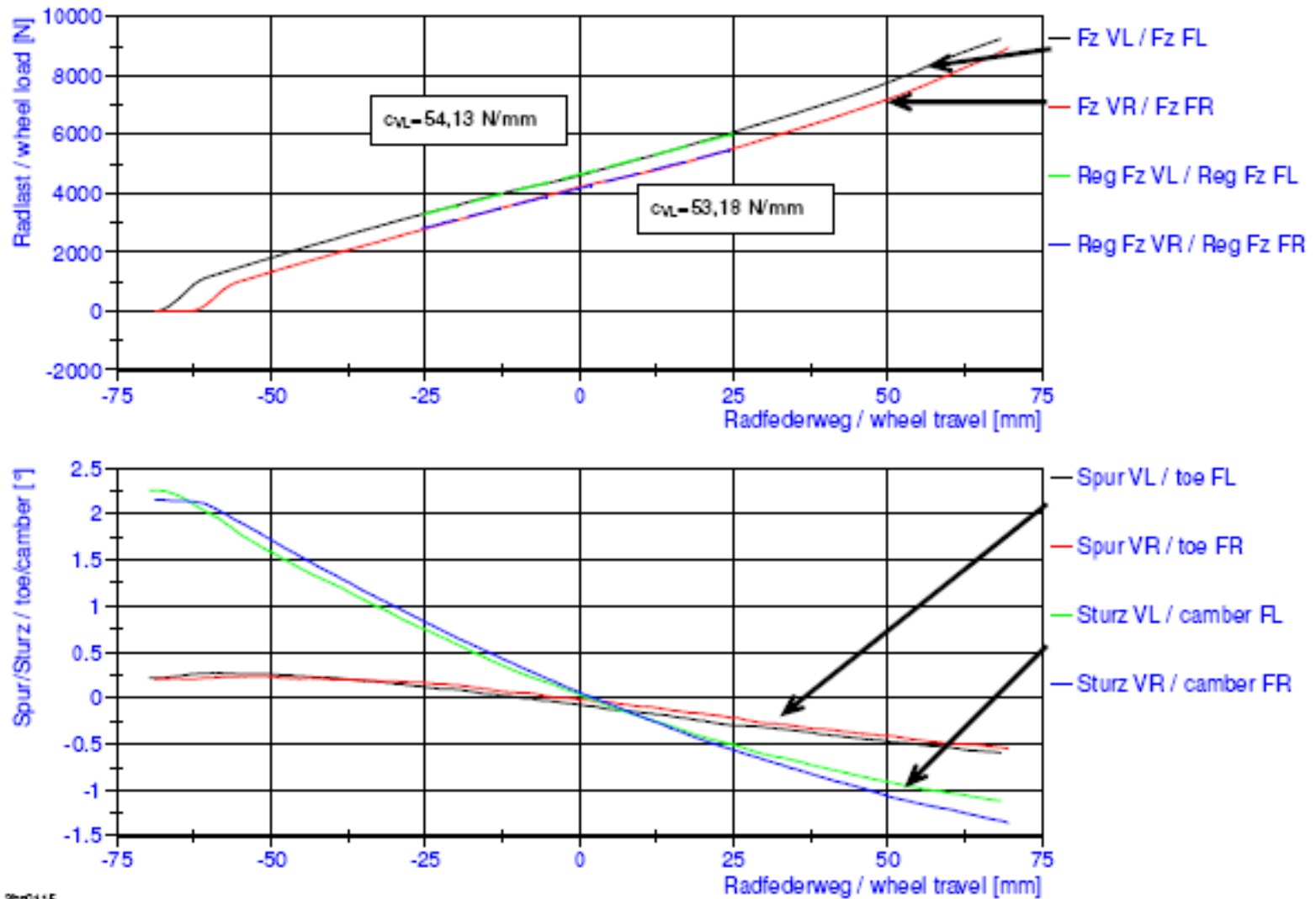
Desired values for the jounce and rebound measurement



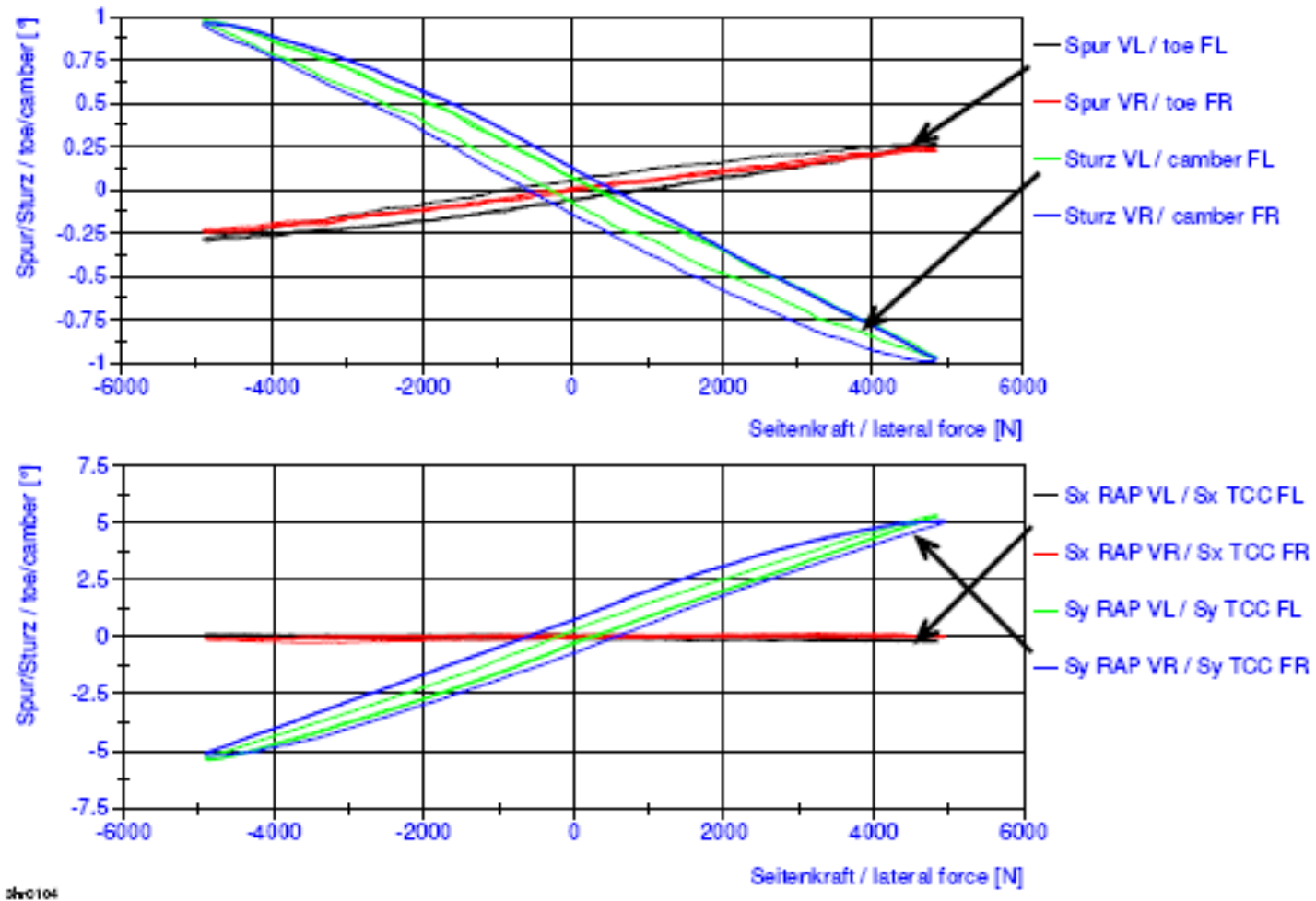
Desired values of the lateral / longitudinal force measurement



Pic. 5-1: Curve of wheel loads and toe/camber changes during bounce springing on front axis



Pic. 5-2: Curve of wheel loads and toe/camber changes during roll springing on front axis



c. 5-3: Toe/camber changes and displacement of the center of tire contact during lateral force initiation

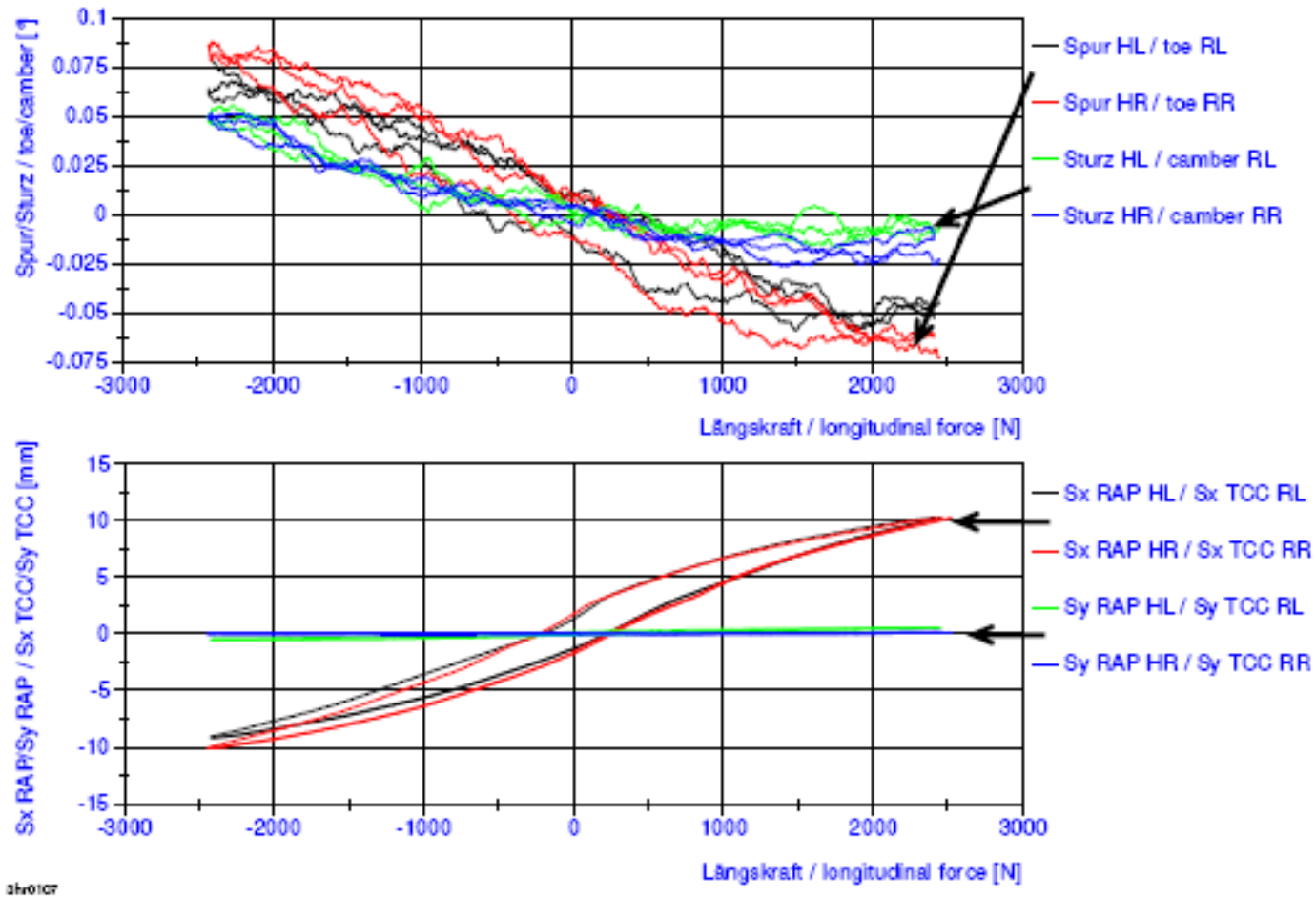
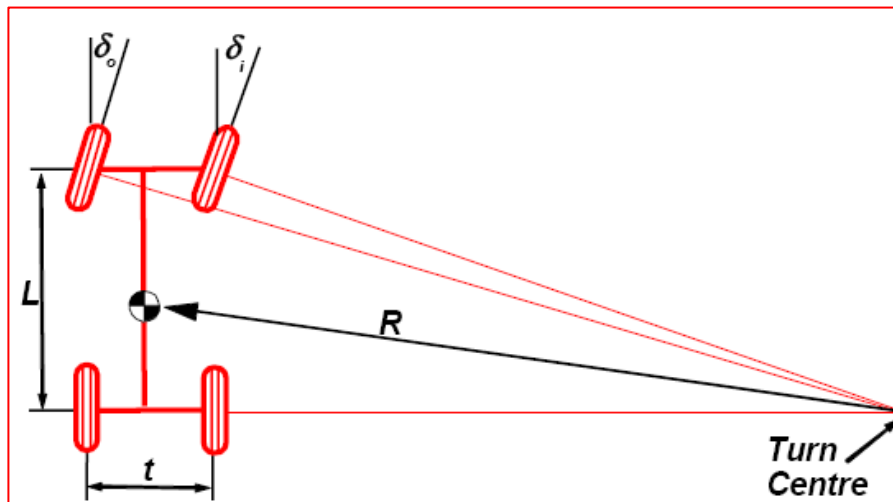


Fig. 5-4: Toe/camber changes and displacement of the center of tire contact during longitudinal force initiation

# Steering System

- The steering system must performs important functions like
  - Provide precise control of the front-wheel direction
  - Jolts from irregularities in the road surface must be damped as much as possible during transmission to the steering wheel. However, such damping must not cause the driver to lose contact with the road
  - The basic design of the steering kinematics must satisfy the Ackermann conditions



At Low speeds

$$\cot \delta_o - \cot \delta_i = \frac{t}{L}$$



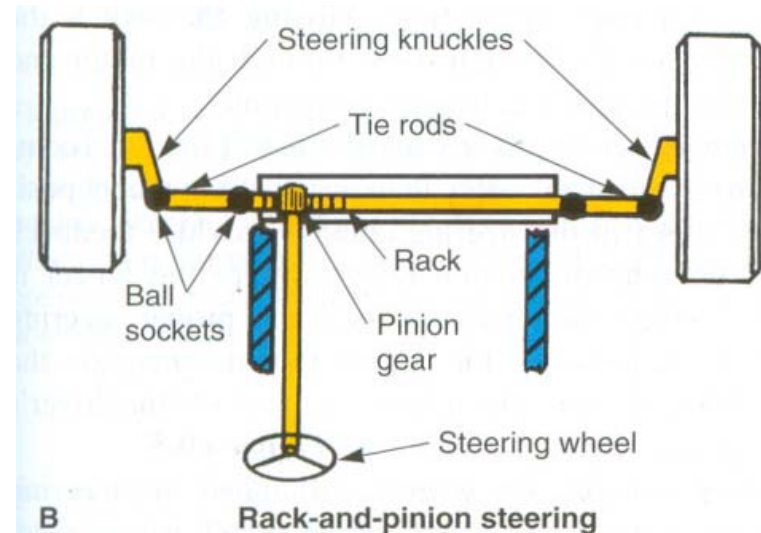
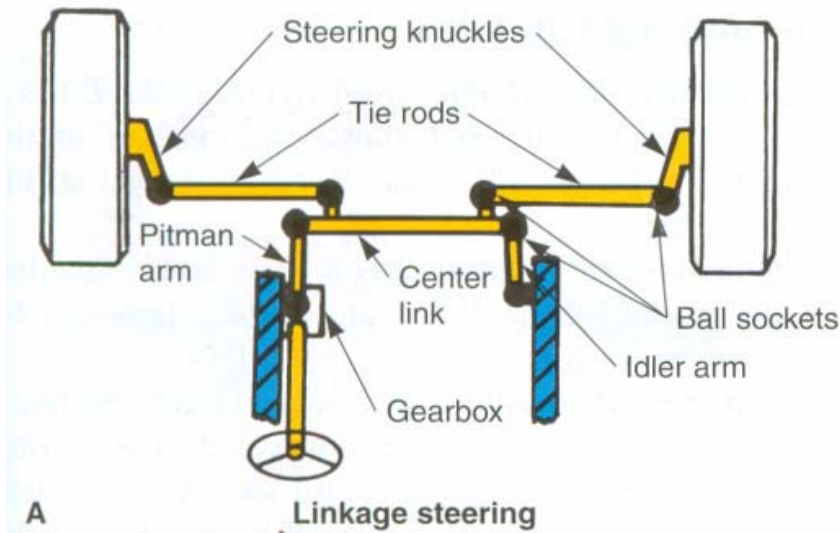


# Steering System

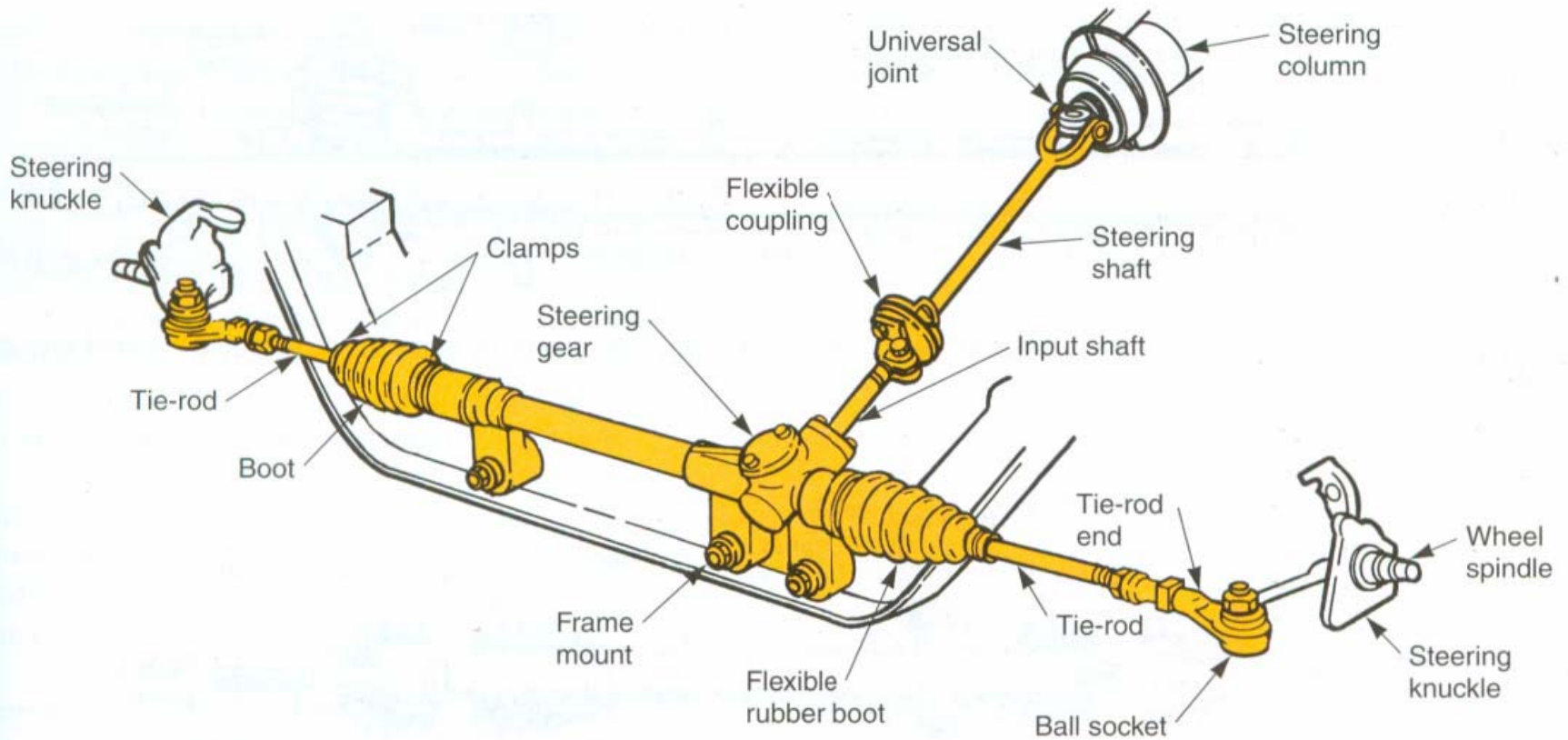
- The vehicle must react to minute steering corrections by means of suitable directness of the steering system and must transmit road feel (slight steering wheel pull caused by road surface) to the driver's hands
- When the steering wheel is released, the wheels must return automatically to the straight-running position and must remain stable in this position
- The steering should have as low a ratio as possible (number of steering-wheel turns from lock to lock) in order to achieve ease of handling. The steering forces involved are determined not only by the steering ratio but also by the front suspension load, the turning radius, the suspension geometry (caster angle, kingpin angle, kingpin offset) and the properties of the tire tread and road surface

# Basic Steering Systems

- There are two basic kinds of steering systems in wide use today:
  - Linkage (worm gear) steering systems
  - Rack-and-pinion steering systems
- They may be operated manually or with power assist

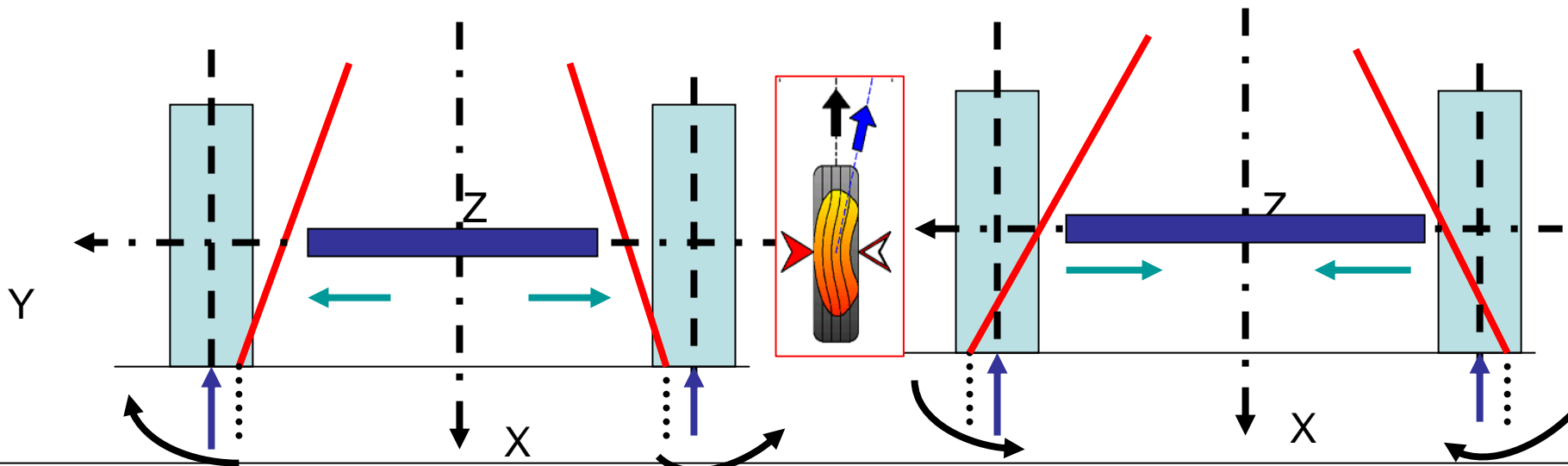


# Steering System Nomenclature



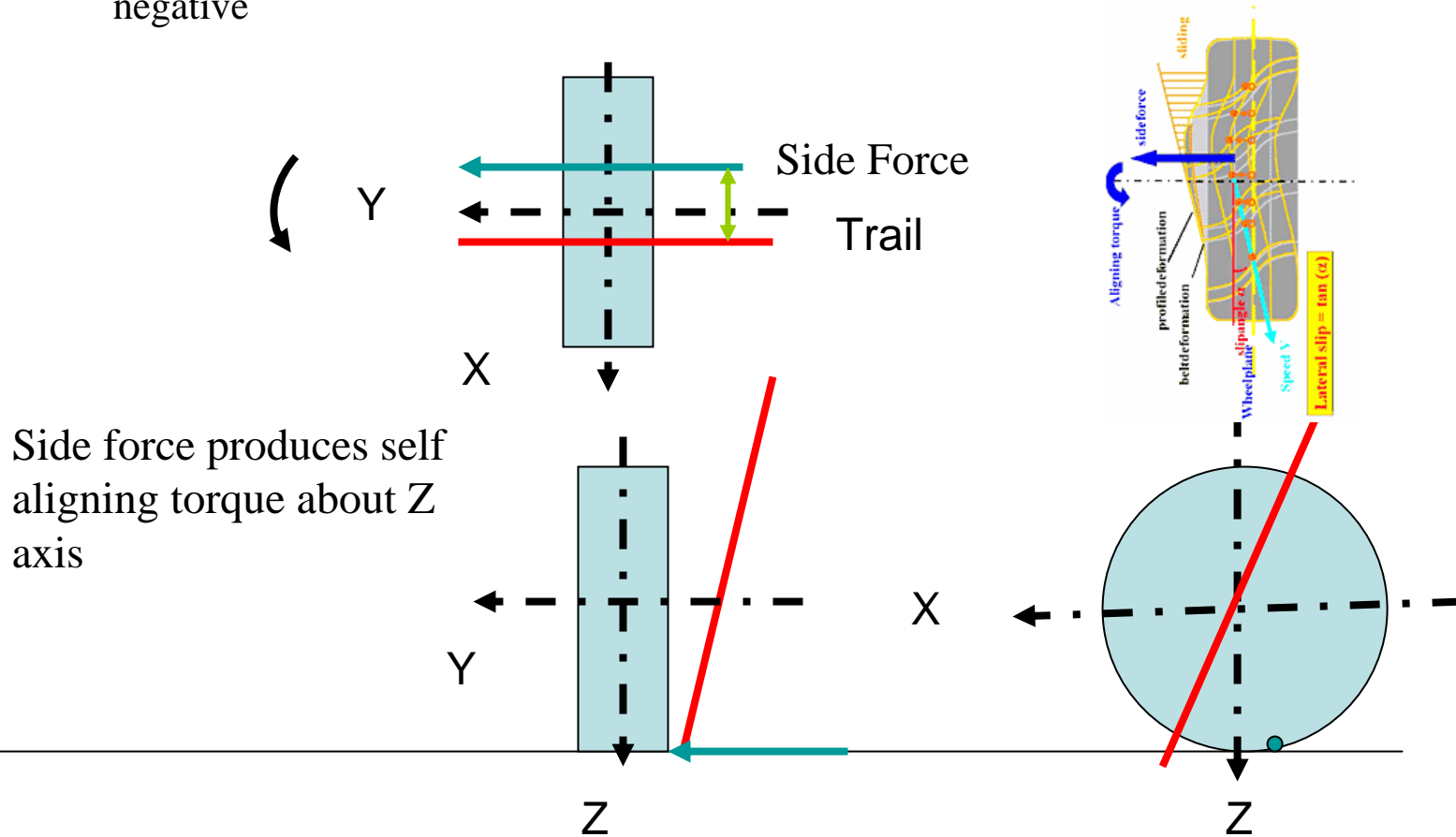
# Steering Kinematics

- Steering kinematics and axle design must be such that, although the driver receives feedback on the adhesion between wheels and road surface, the steering wheel is not subjected to any forces from the spring motion of the wheels or from motive forces (front wheel drive)
  - Steering –Axis inclination causes the front section of the vehicle to lift when the wheels are at an angle. This leads to a caster dependent on the steering angle
  - Toe-in (toe-out) is a slip angle present even during straight running travel. This tensions the linkages and causes a rapid build-up of transverse forces when the wheels are at an angle



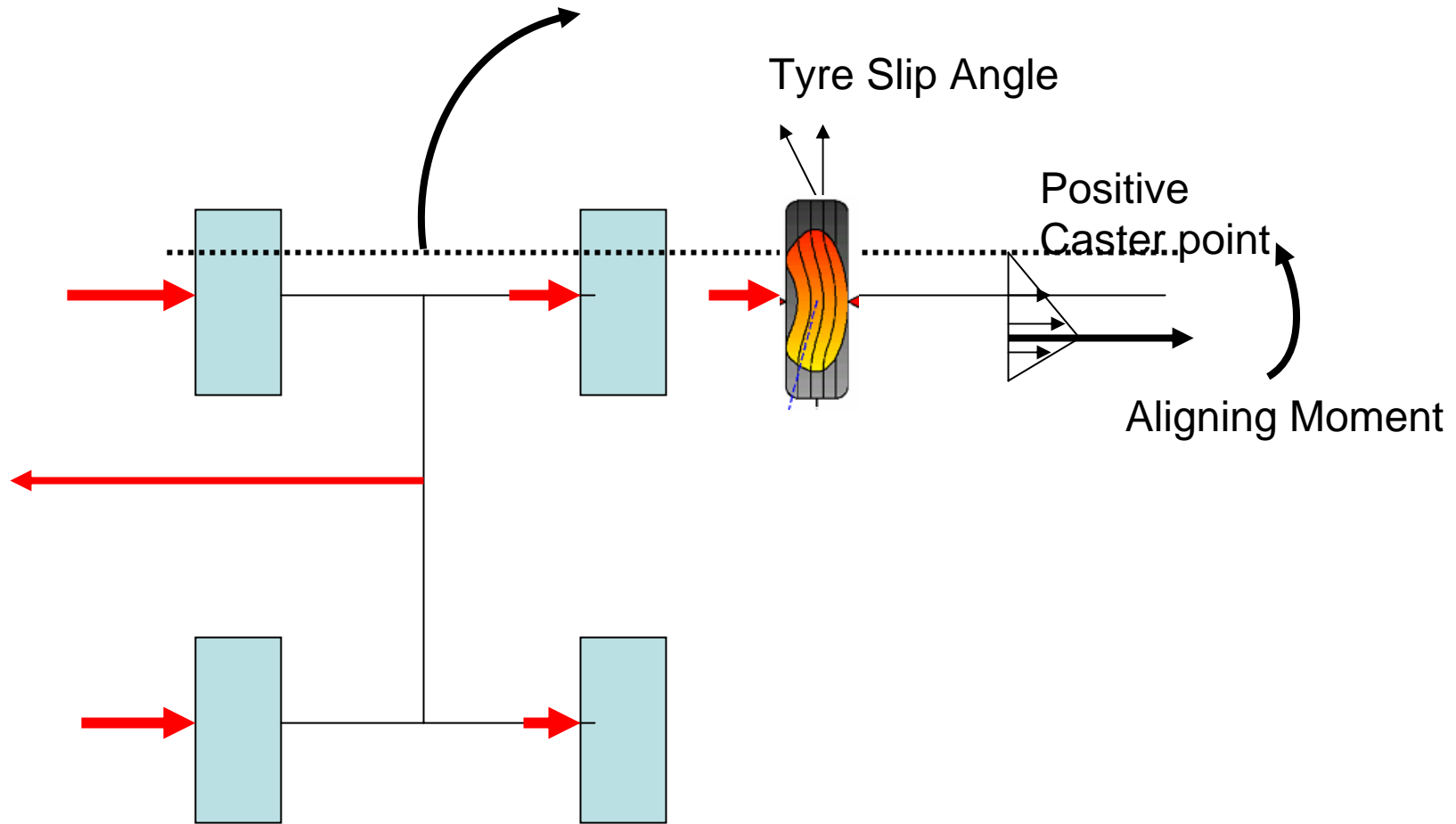
# Steering Kinematics

- Caster produces a lever arm for side forces, i.e. speed dependent return torque (Alignment Torque)
- Kingpin offset determines the extent to which the steering system is affected by interference factors :brakes pulling unevenly, motive forces under traction/overrun in front wheel drive vehicles. In modern designs, the aim is to achieve a steering offset which is zero to slightly negative



Trail Varies as caster varies, hence self aligning torque

# Caster Change and Aligning Moment

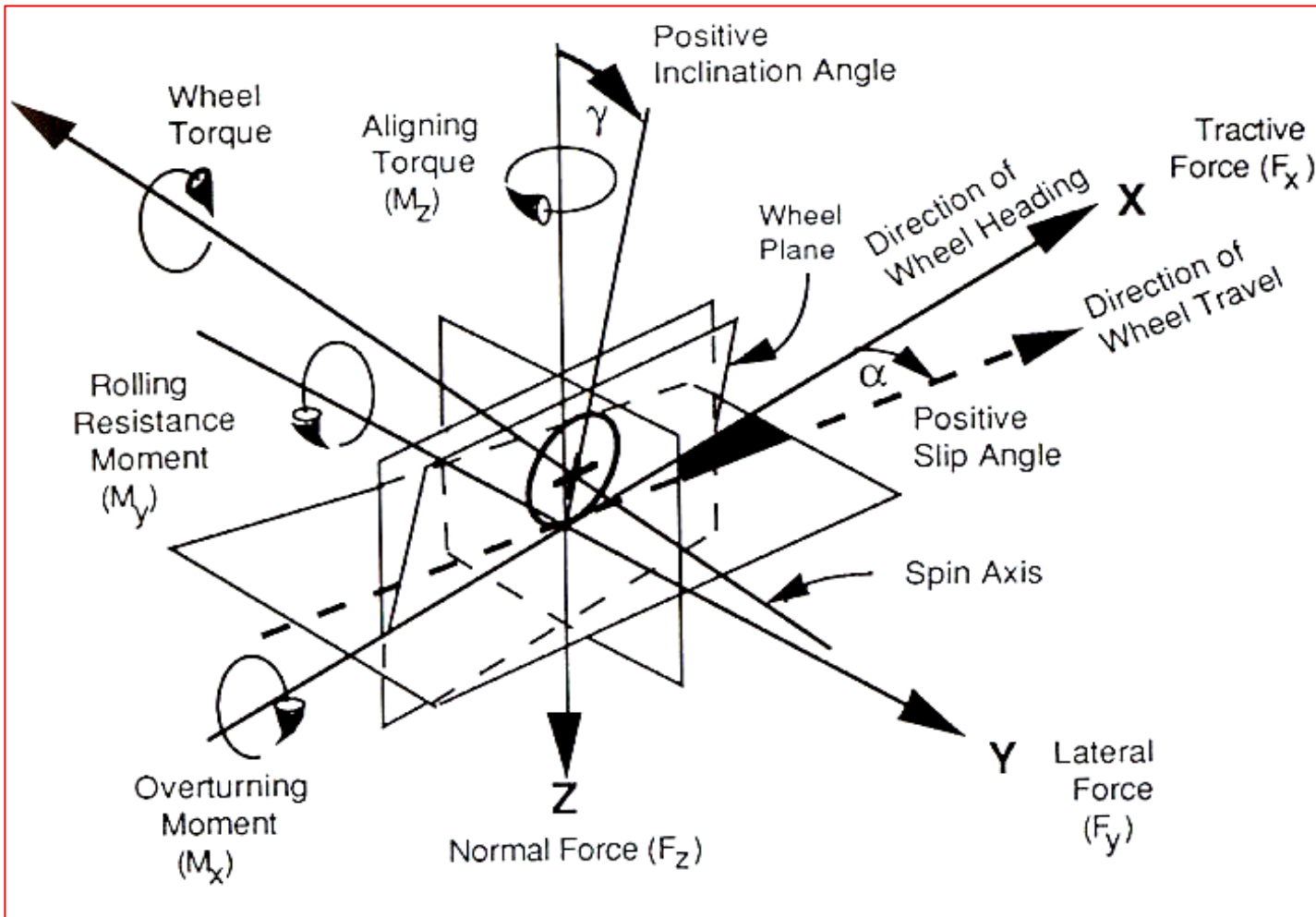


# Steering System Forces and Moments

- The ground reactions on the tire are described by three forces and moments, as follows:
  - Normal force                      Aligning torque
  - Tractive force                      Rolling resistance moment
  - Lateral force                      Overturning moment
- On front-wheel-drive cars, an additional moment is imposed by the drive torque.

# Steering System Forces and Moments

- The forces and moments imposed on the steering system emanate from those generated at the tire-road interface.

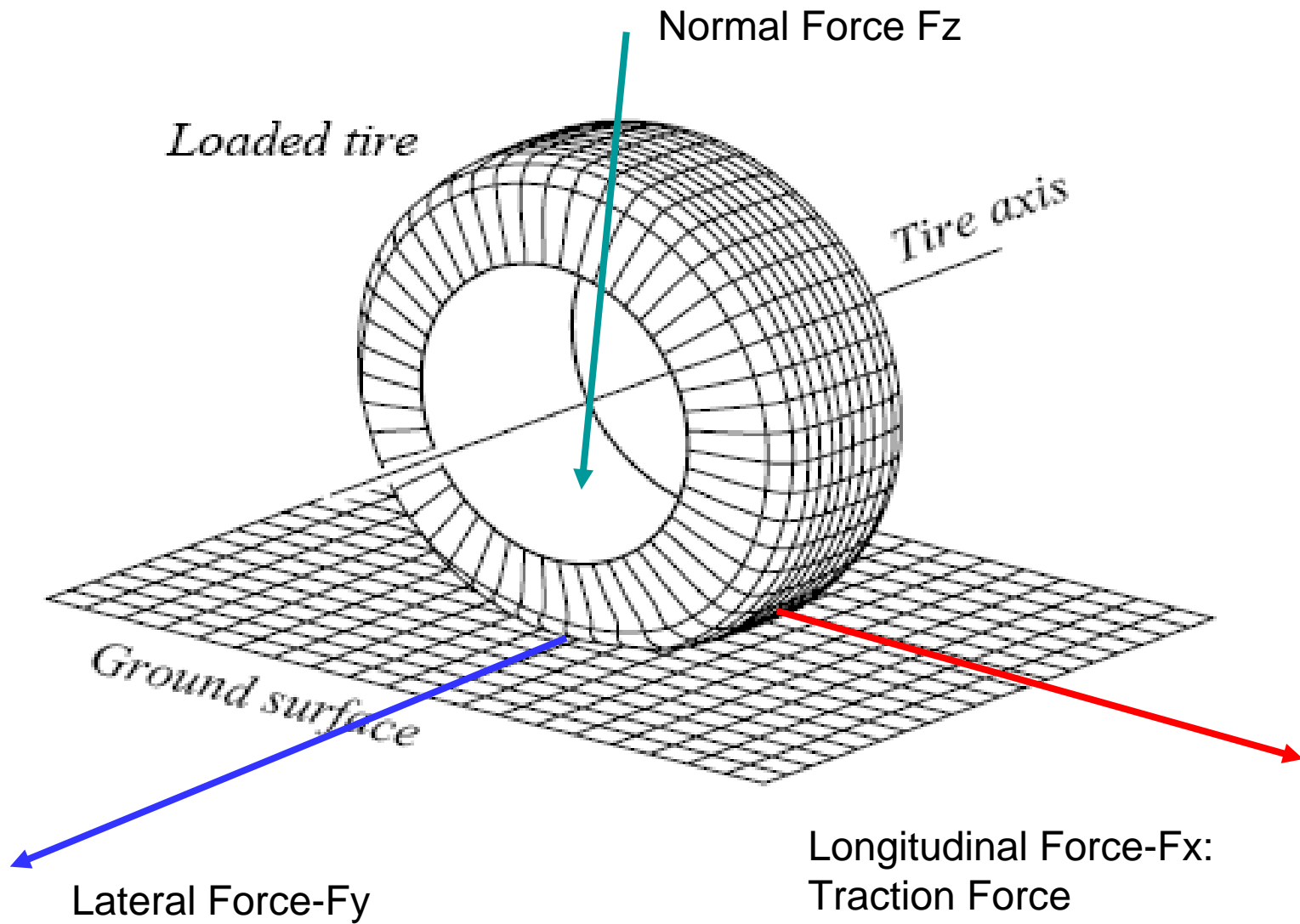


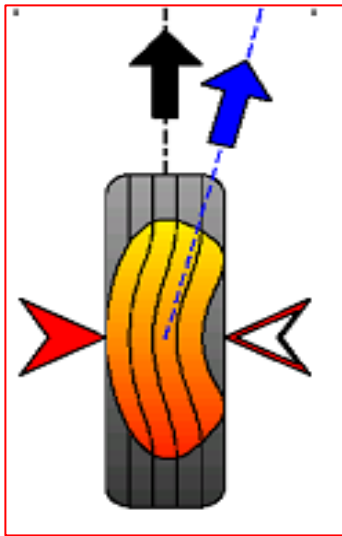




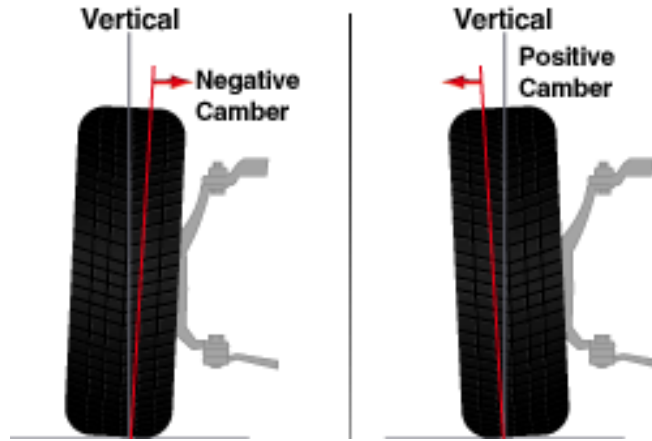
# Steering Wheel Torque

- The reaction in the steering system is described by the moment produced on the steer axis, which must be resisted to control the wheel steer angle.
- The sum of moments from the left and right wheels acting through the steering linkages with their associated ratios and efficiencies account for the steering-wheel torque feedback to the driver.



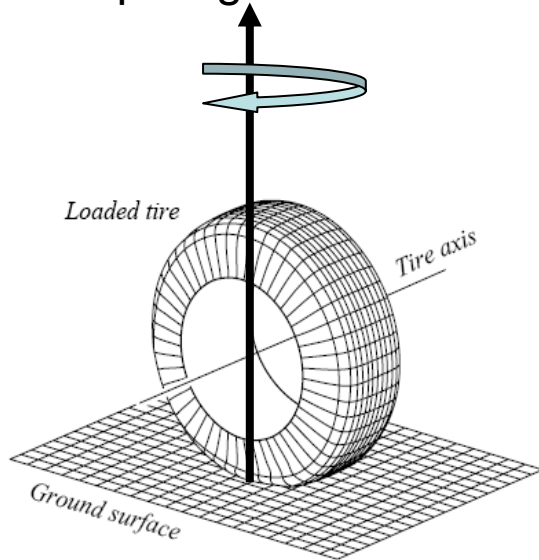
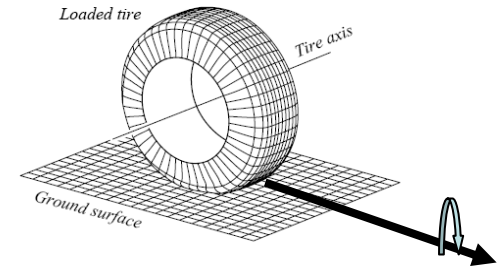


Slip Angle

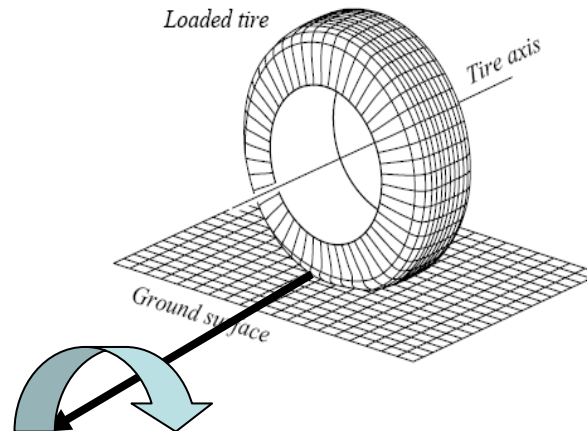


Camber

Overturning Moment  $M_x$

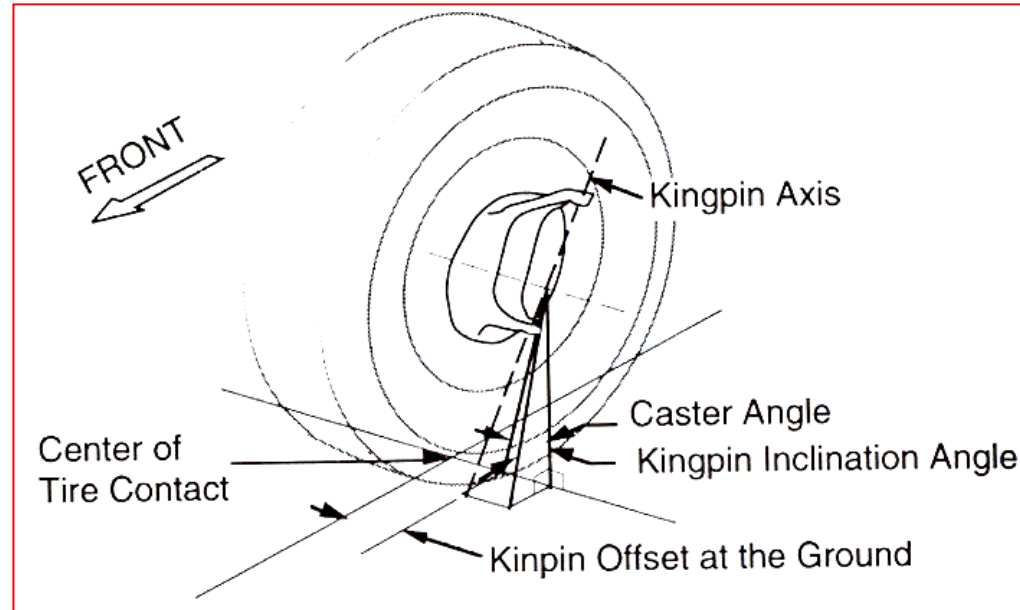


Aligning Moment ( $M_z$ )



Rolling Resistance Moment ( $M_y$ )

# Estimation of Steering Forces and Moments



$M_v$  = Total moment from left and right wheels

$F_{zl}, F_{zr}$  = Vertical load on left and right wheels

$d$  = Lateral offset at the ground

$\lambda$  = Lateral Inclination Angle (KPI)

$\delta$  = Steer Angle

$\upsilon$  = Caster Angle

# Steering Forces and Moments

- The moment arising from vertical force acting

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

- The moment arising from lateral force

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

- The moment arising from traction force

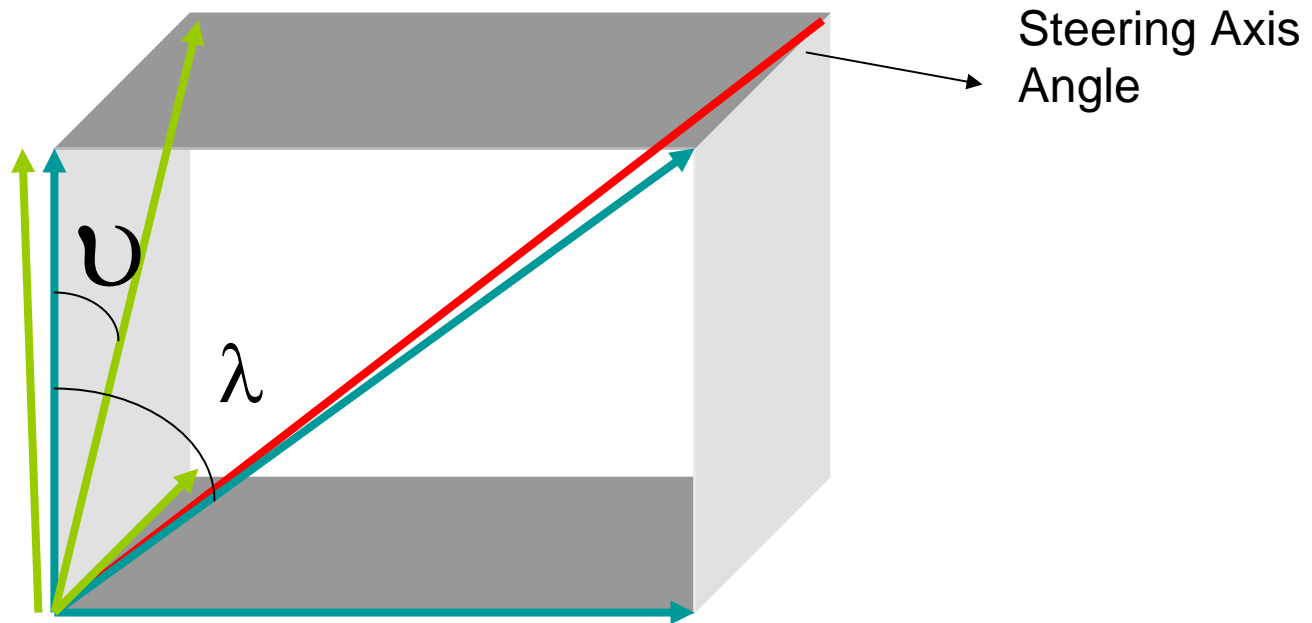
$$M_T = (F_{xl} - F_{xr})d$$

- Aligning Torque

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

- Rolling resistance and Overturning moments have second order effect and are neglected

# Kingpin Inclination

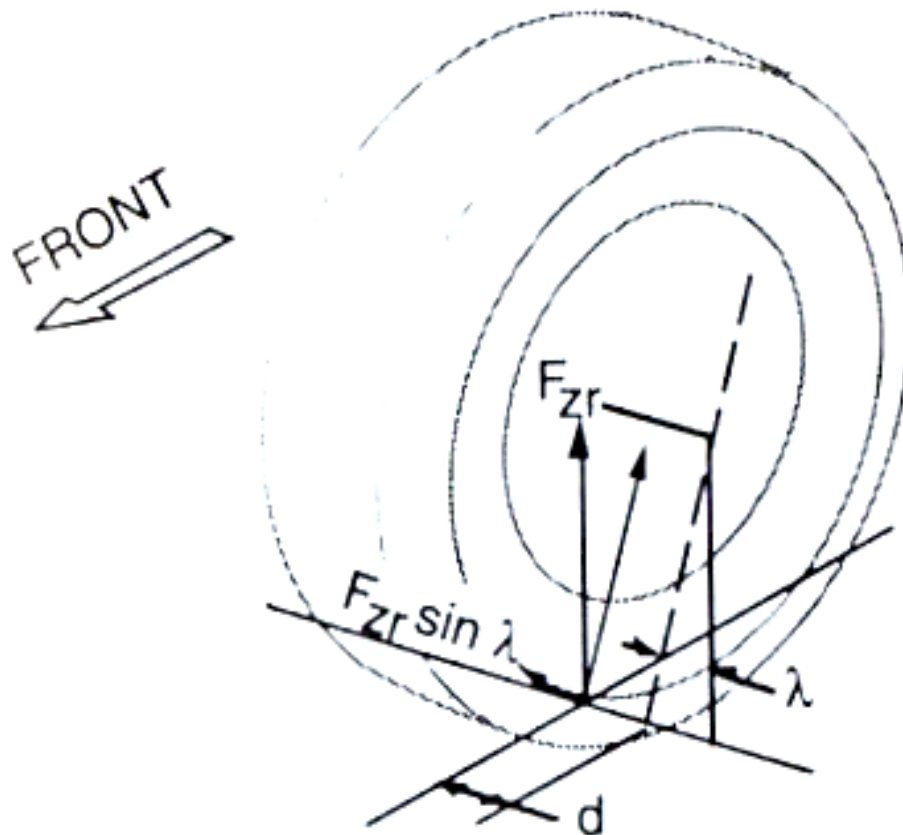


$\lambda$  = Lateral Inclination Angle (KPI)

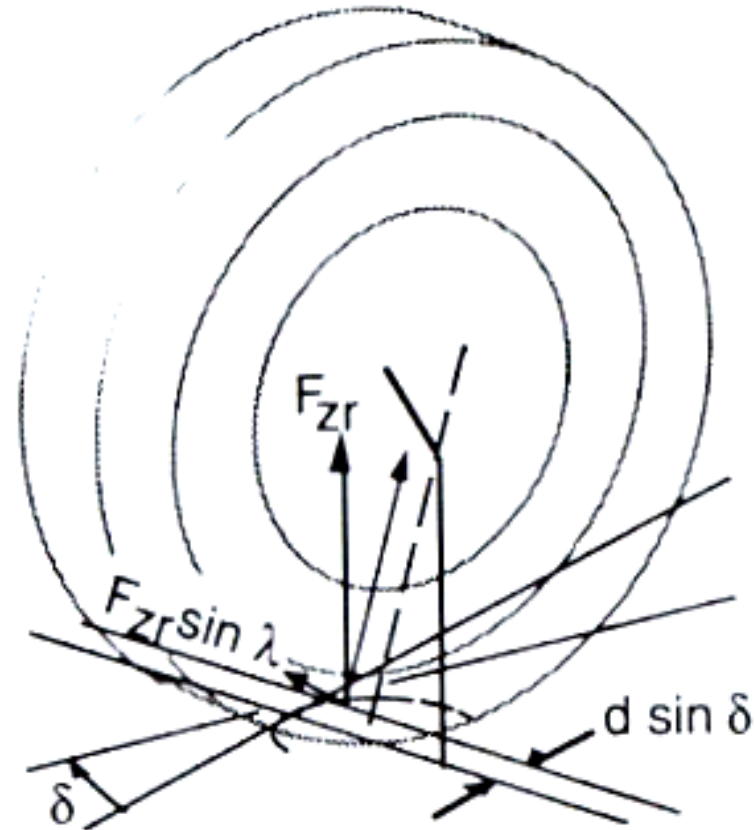
$\psi$  = Caster Angle

# Moment produced by Vertical Forces acting on Lateral Inclination Angle

No Steer

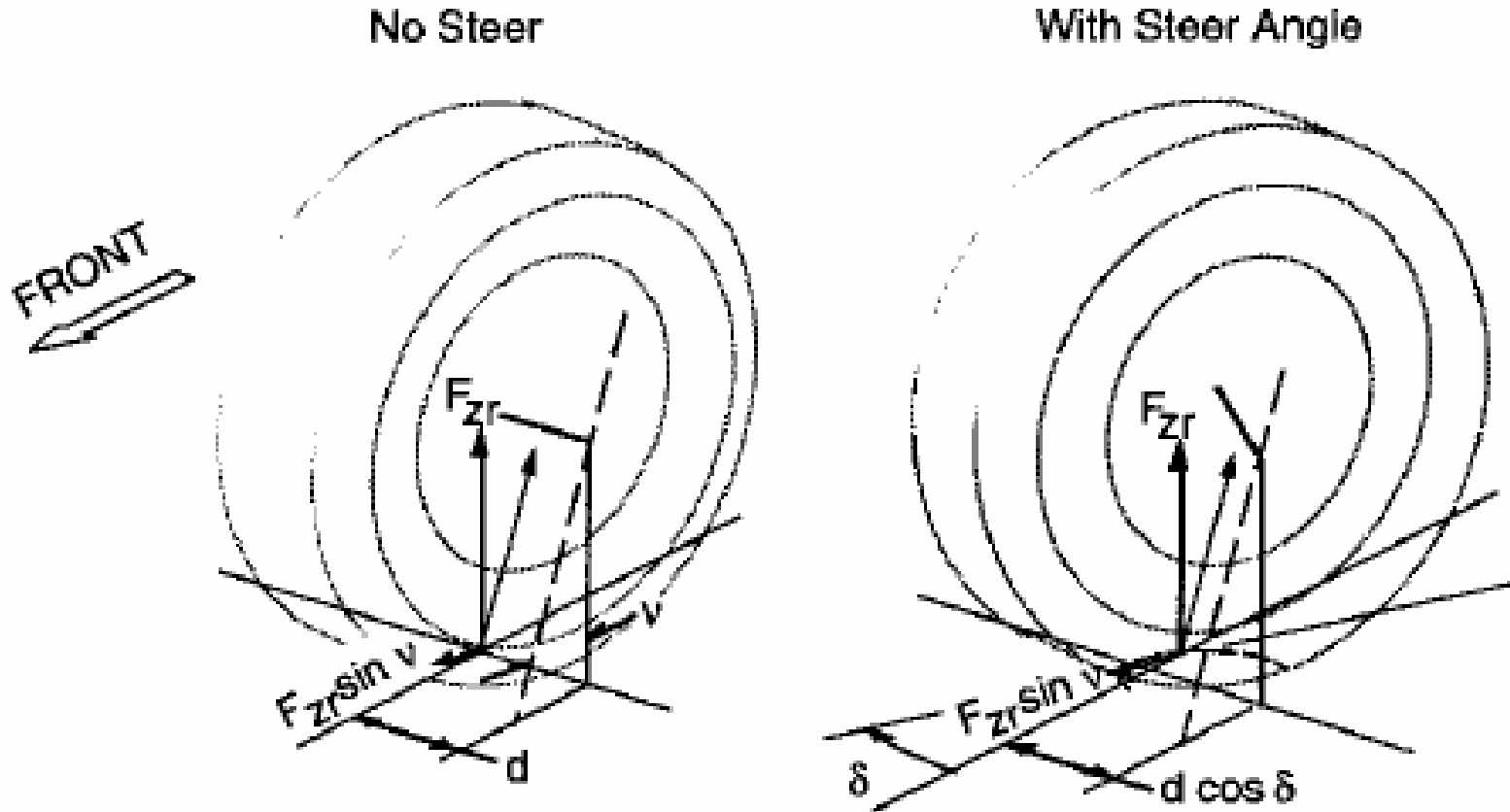


With Steer Angle



$$M_{V\lambda} = -(F_{zl} + F_{zr})d \sin \lambda \sin \delta$$

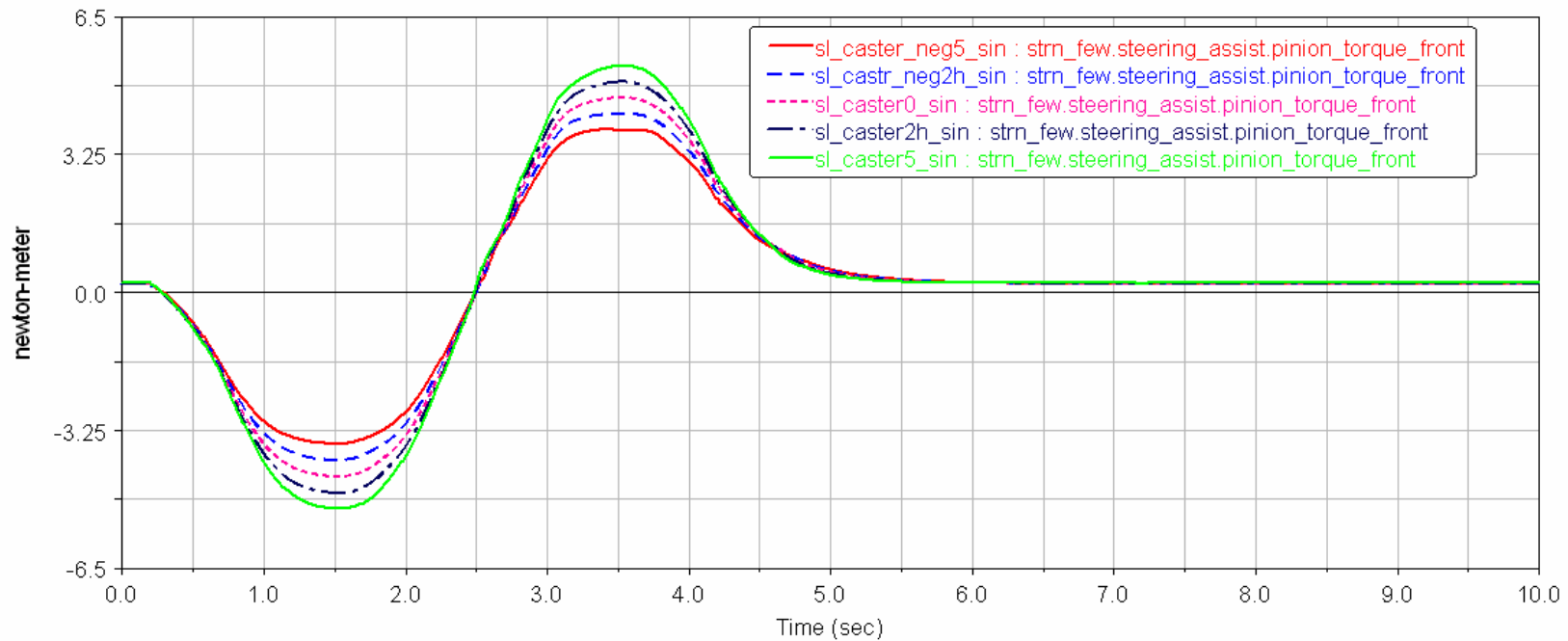
# Moment Produced by Vertical Force Acting on Caster Angle



$$M_{V\nu} = (F_{zl} - F_{zr})d \sin \nu \cos \delta$$



# Steering Torque Variation with Caster



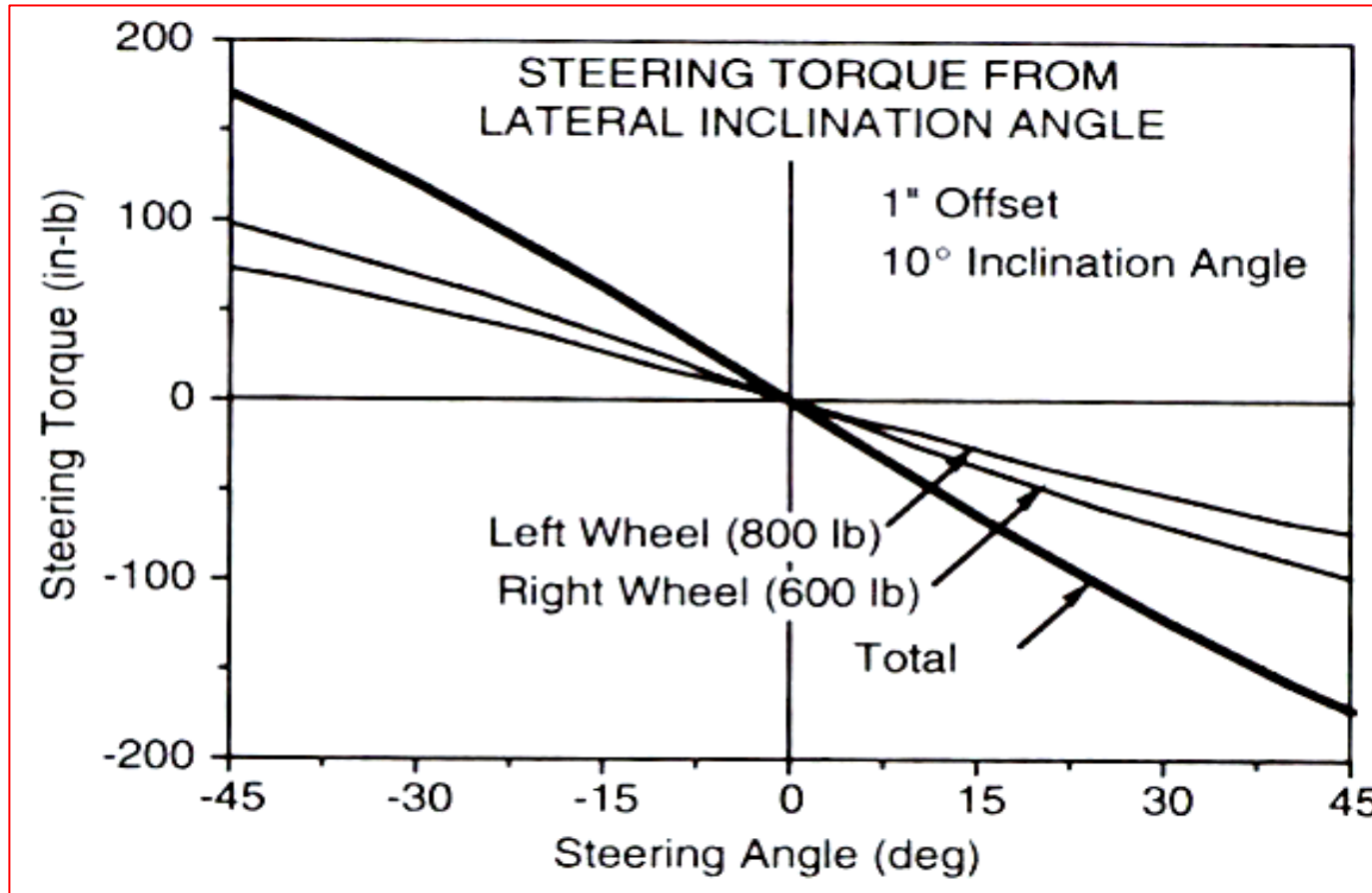
Steering Torque high for positive caster and low for negative caster



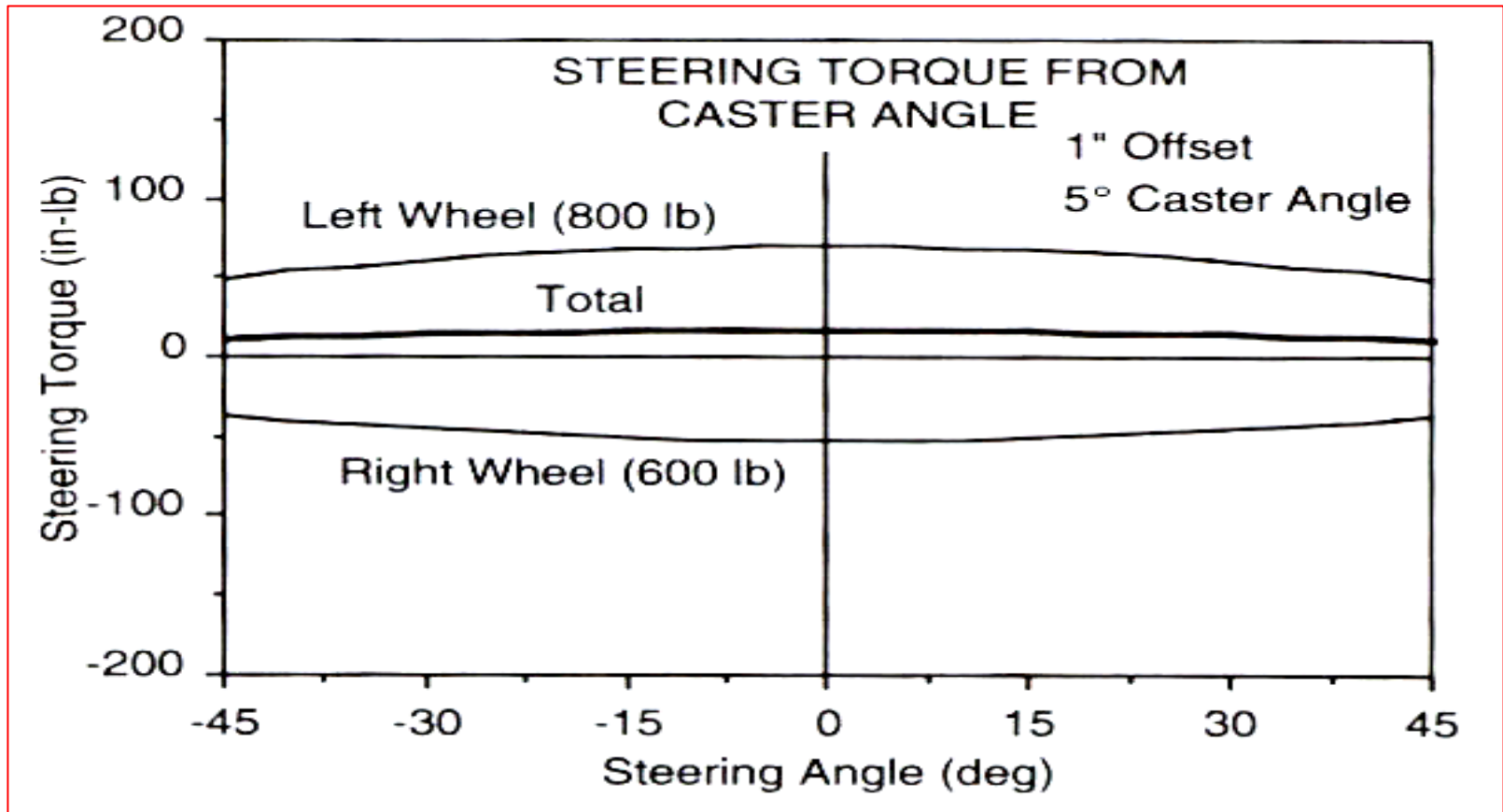
- The moment arising from vertical force acting

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

# Steering Torque

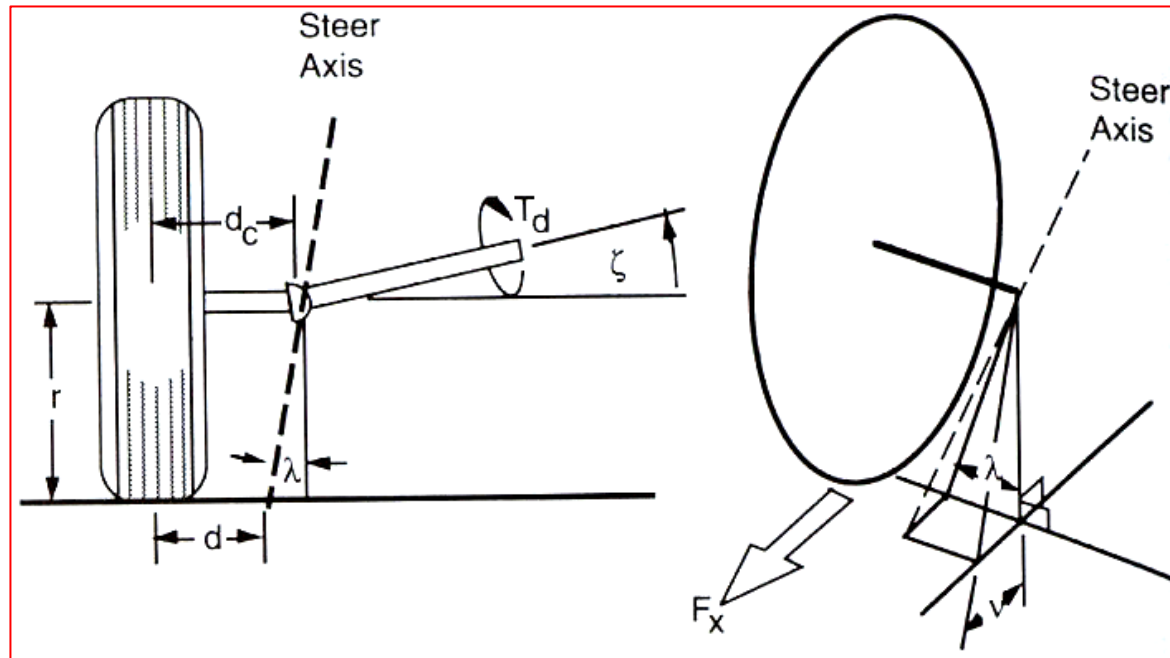


# Steering Torque



# Moment about SA due to drive line Torque

- The torque in the driveline produces a moment about the steer axis.



$$T_d = F_X r$$

$$M_{SA} = F_X [d \cos \nu \cos \lambda + r \sin(\lambda + \zeta)]$$



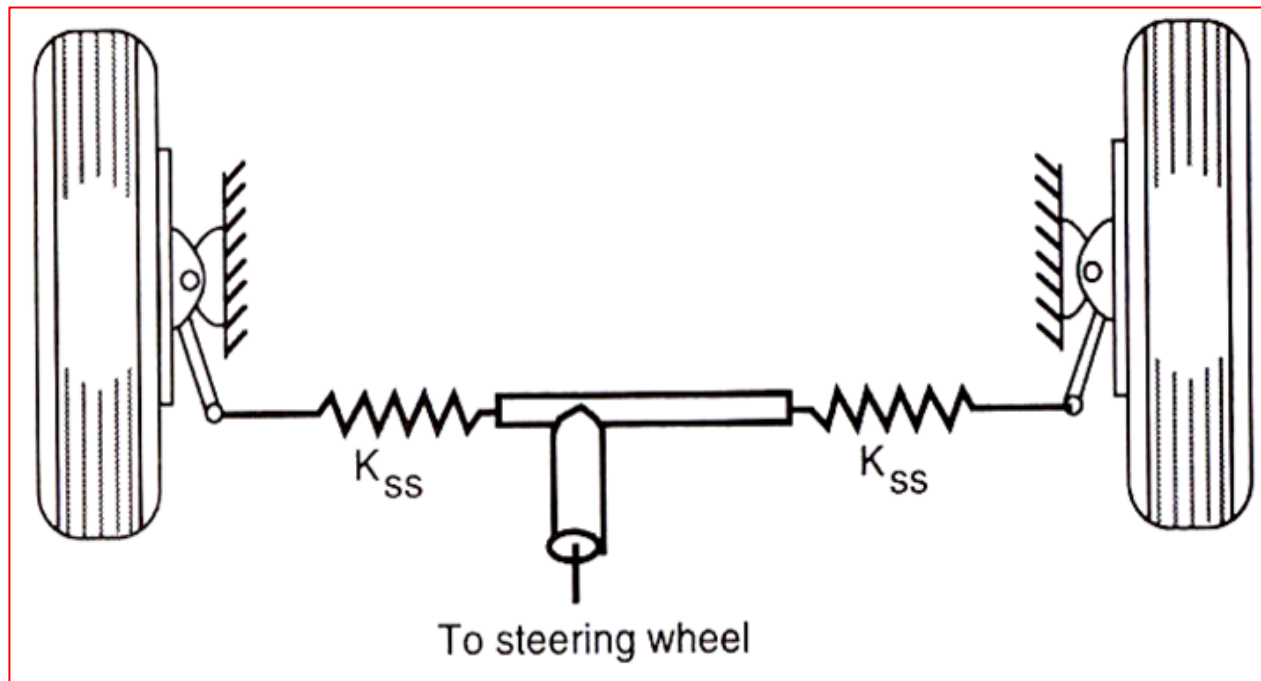
The lateral inclination and caster are small enough that the cosine function can be assumed unity. Hence

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

The forward force introduces a moment in the steering system which opposes the steer angle trying to steer the vehicle out of turn-make the vehicle understeer. That is hwy in Front wheel drive vehicles toe out is provided

# Steering System Models

- The effects can be modeled and torque feedback to the steering wheel can be determined



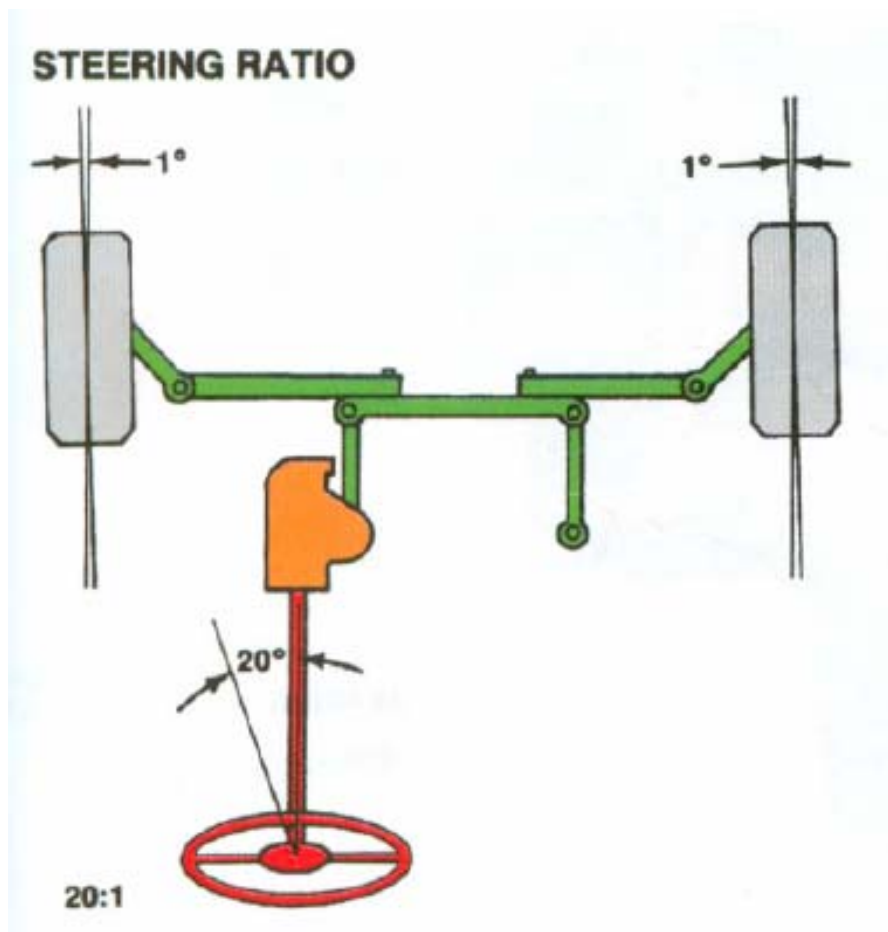


# Steering System Performance Measures

- The specific design of a steering system geometry has a well-recognized influence on steering performance measures such as
  - Center feel,
  - Returnability,
  - Steering efforts
  - Steering ratio to cornering
  - Steering ratio to braking

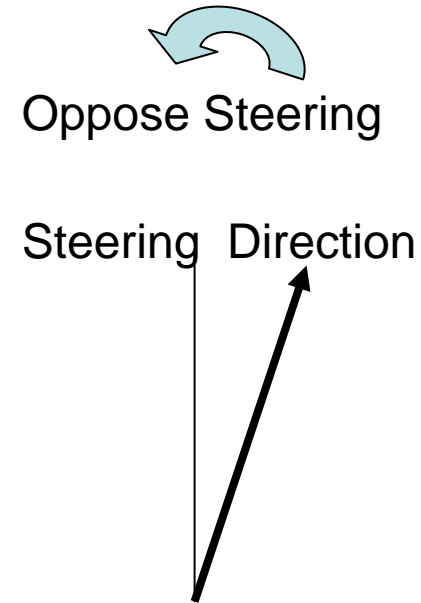
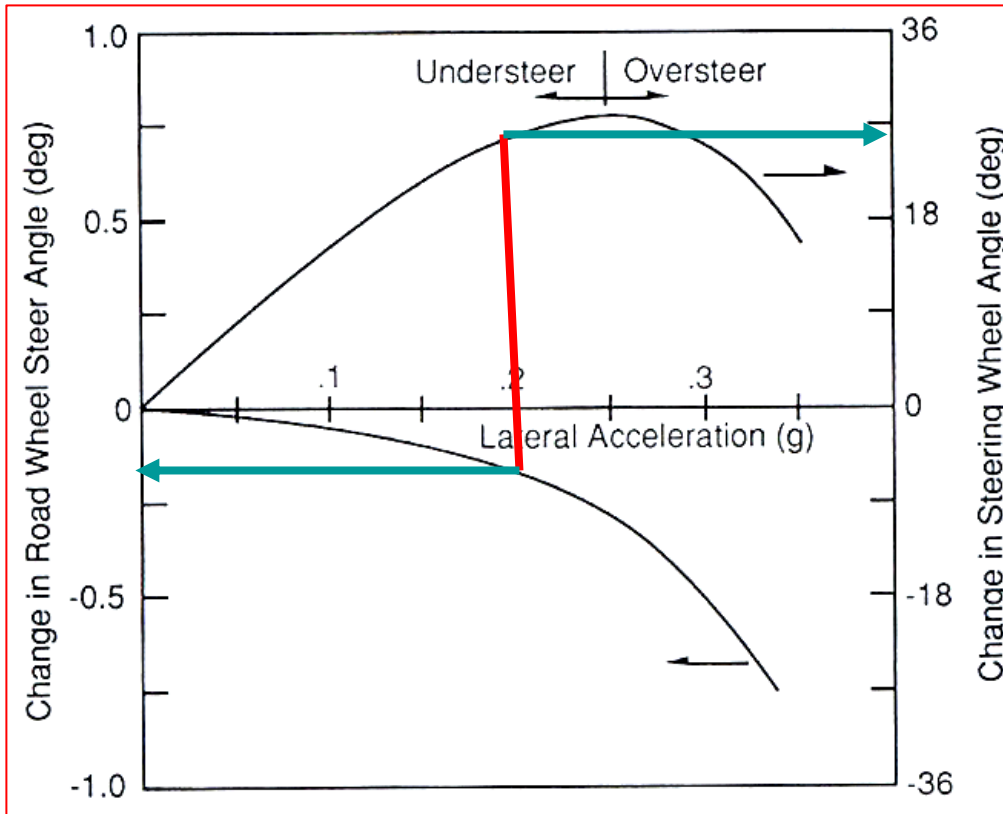


# Steering Ratio



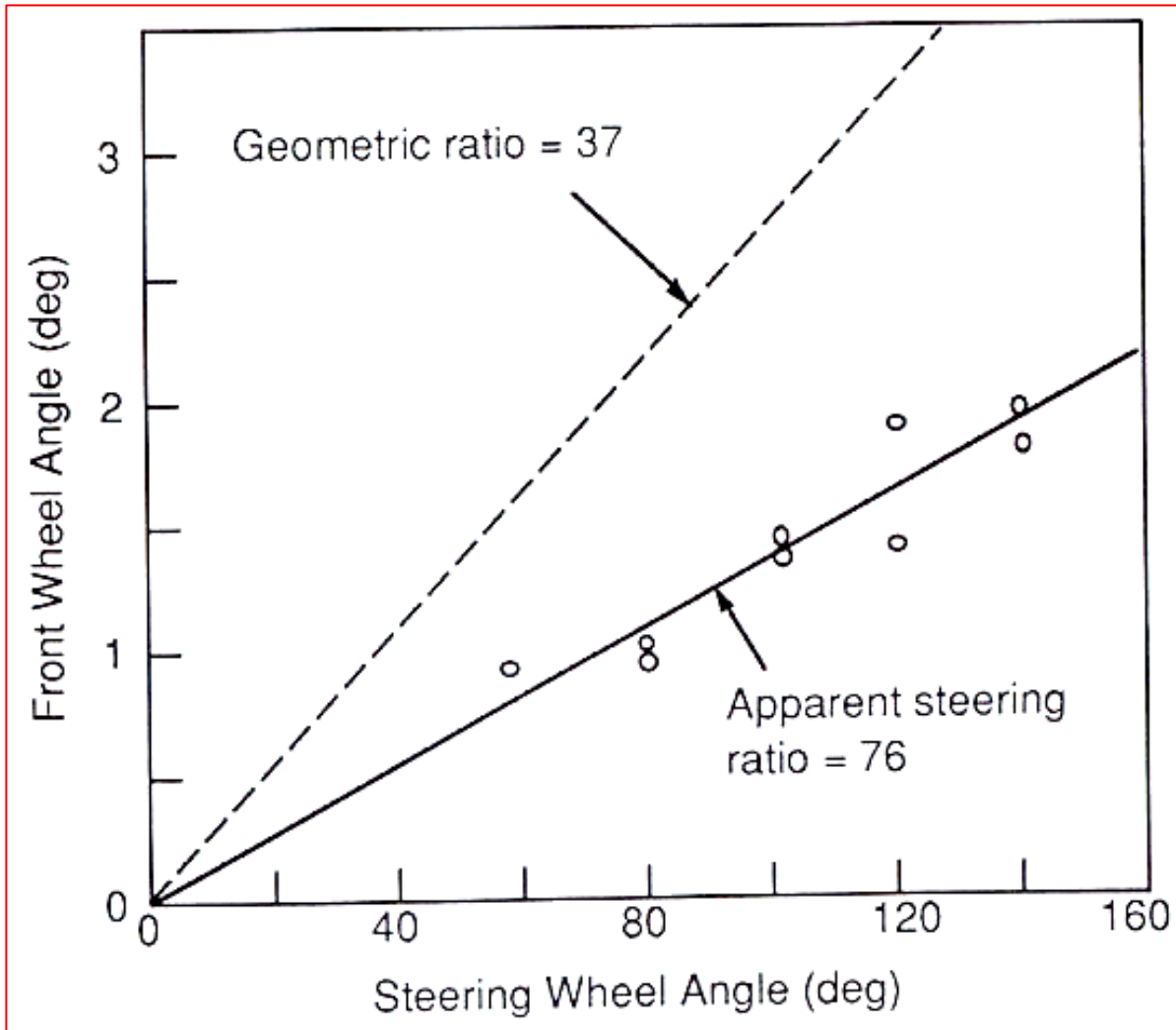
- The steering ratio is defined as the ratio of steering wheel rotation angle to steer angle at the road wheels.
- Normally these range from 15 or 20 to 1 on passenger cars, and 20-36 to 1 on trucks.
- Steering ratio allow for easy steering of the front wheels. Low ratios such as 12:1 give quick but stiff steering where as high ratios such as 20:1 provide slow but easier steering
- Because of the compliance and steer torque gradients with increasing steer angles, the actual steering ratio may be as much as twice the designed ratio
- The compliance property is constant on a vehicle, the torque gradient will vary with load on the front tires, tire type, pressure, coefficient of friction, etc. Hence, the actual steering ratio may vary (always exceeding the design value) and influencing the low-speed maneuverability of the vehicle.

# 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
- The deviation is equivalent to an apparent gradient of 4 degrees/g at the road wheel
- The difference arises from deflections in the steering linkage as the reactions on the road wheels act against the steering compliances

# Steering Ratio

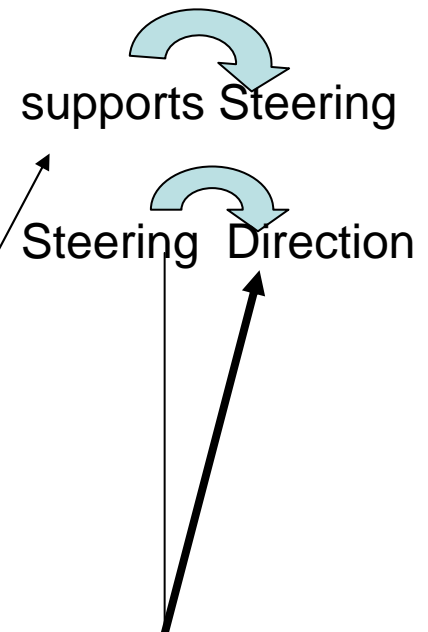
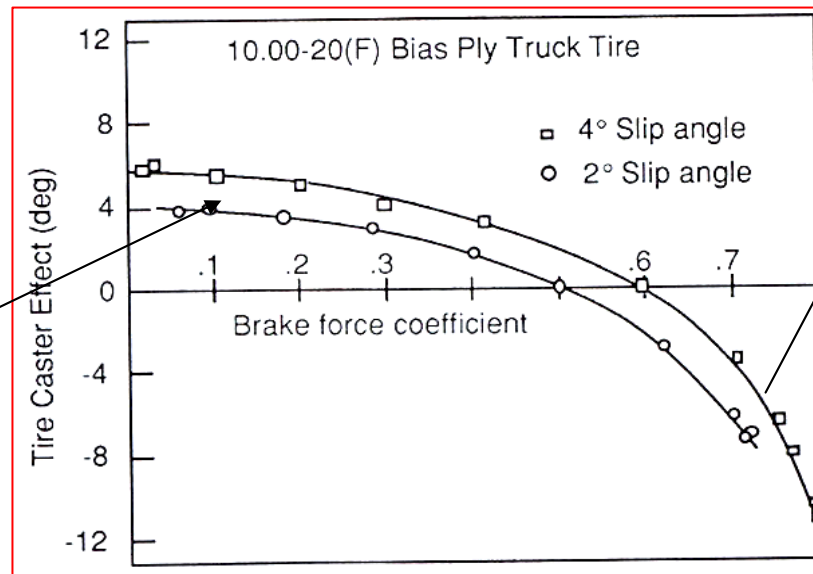
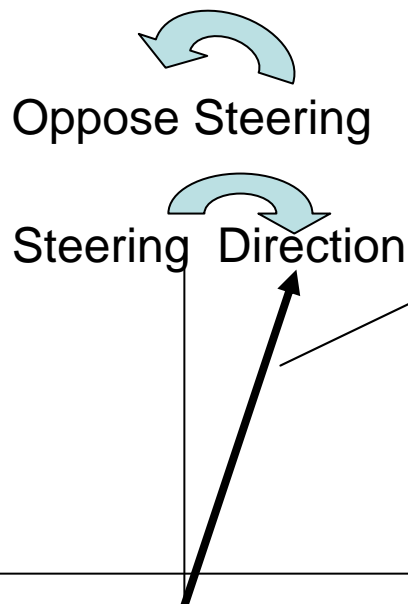


Because of the compliance and steer torque gradients with increasing steer angles, the actual steering ratio may be as much as twice the designed ratio.

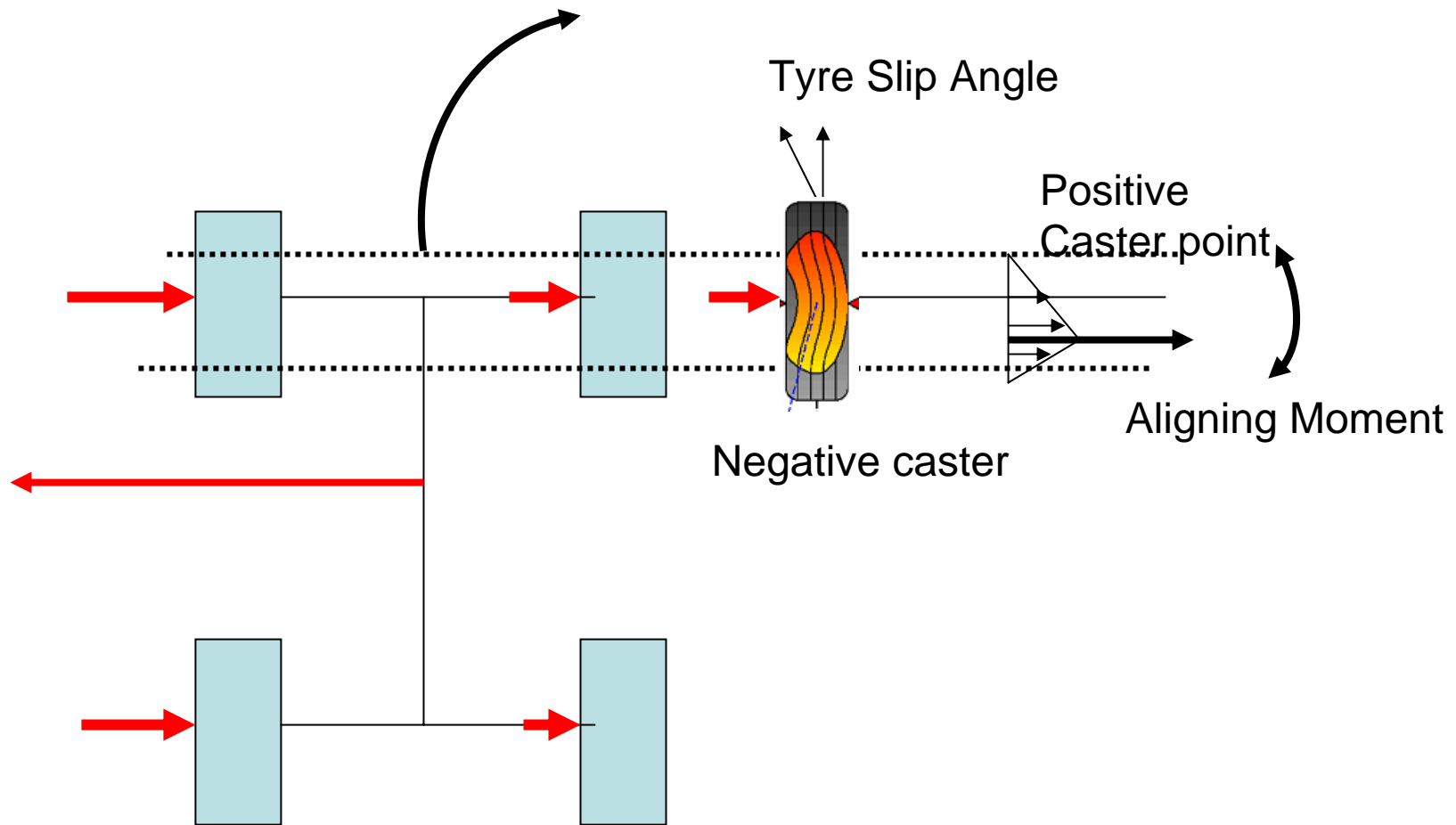
**Fig** shows experimental measurements on a truck which illustrate the phenomenon

# Braking Stability

- Braking is a special case in which steering system design plays an important role in directional response.
- The tire aligning torques which effectively act like 4-8 degrees of caster angle (increase pneumatic trail) under free-rolling conditions can reverse in direction during braking
- Brake force imbalance (due to brake malfunction or a split-coefficient surface) will also act on the compliant steering system, attempting to steer the vehicle.



# Caster Change and Aligning Moment

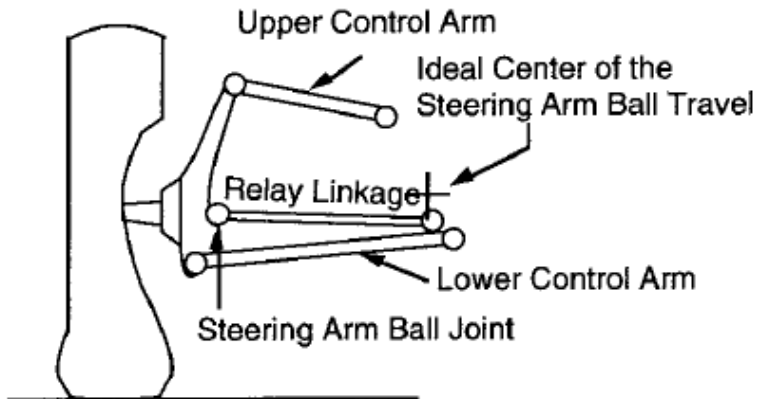




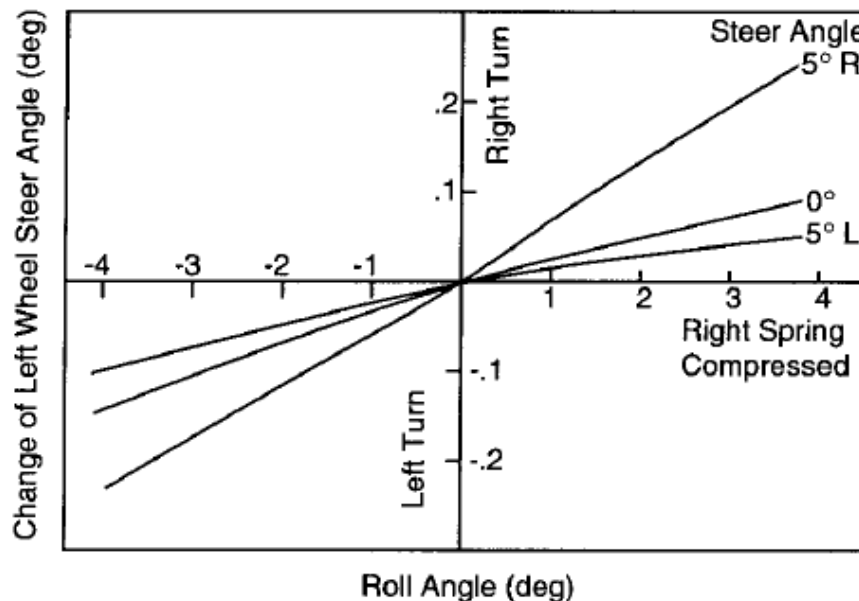
# Braking Stability

- At low braking coefficients the aligning torque acts in the direction to steer the tire in its direction of travel, which on the steered wheels attempts to steer the vehicle out of the turn (an understeer influence).
- But at high braking coefficient, the aligning torque reverses direction and may reach elevated negative levels, which will attempt to steer the tire into the direction of turn (an oversteer influence).
- As a result, the normal stabilizing effects of positive caster and tire aligning torque may be substantially reduced or eliminated during high-level braking.

# Roll Steer



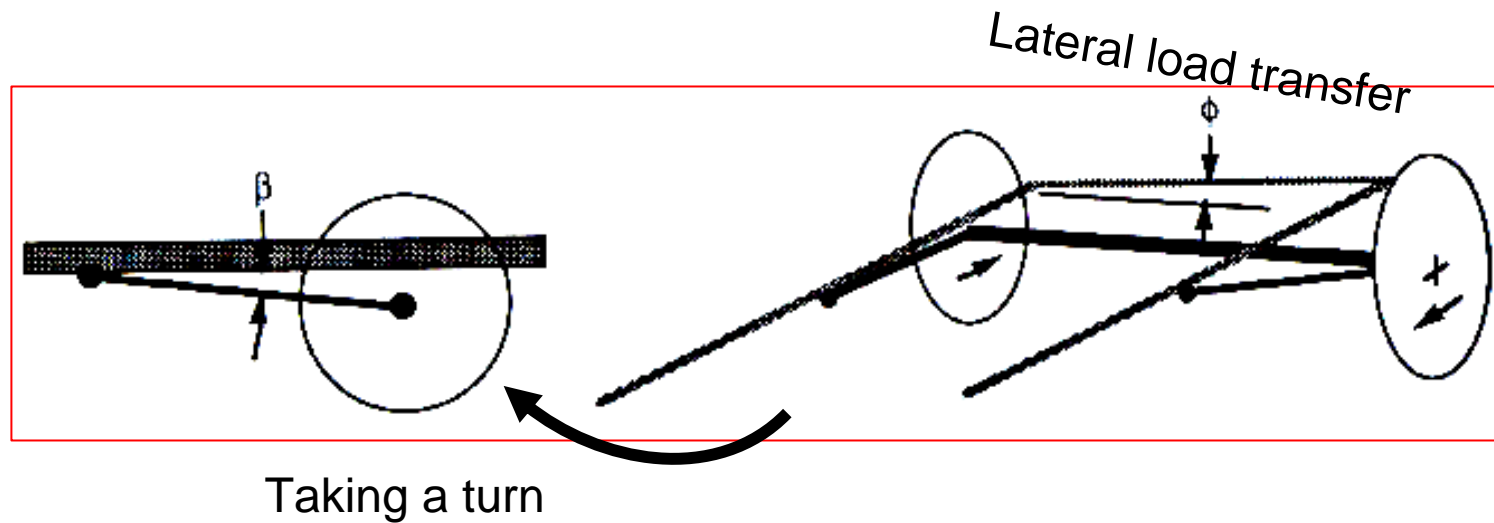
Relay Linkage (Tie Rod) centre is placed below the ideal centre, due to wheel bounce and jounce, the centre point moves up or down steering the wheel.



The slope of the curve is the Roll Steer Coefficient  $\epsilon$

$$K_{\text{roll steer}} = \epsilon \frac{d\phi}{da_y}$$

# Roll Steer due to Suspension







# Roll Steer and Bump Steer

## **Difference between Bump Steer and Roll Steer**

In a bump steer, both wheels rise together. In roll steer, one wheel rises as the other falls. Typically this produces more "toe in" on one wheel, and more "toe out" on the other, thus producing a steering effect. In a simple analysis you can just assume that the roll steer is the same as bump steer, but in practice things like the sway bar geometry have an effect that modifies it.

Roll steer is usually measured in degrees of toe per degree of roll, but can also be measured in degrees of toe per metre of wheel travel.

## **Method of Adjustment**

The linearity of the bump steer curve is important. If it is not straight then the length of the tie rod needs to be adjusted.

Bump steer can be made more toe out in jounce by lifting the rack or dropping the outer tie rod, if the rack is in front of the axle. The reverse applies if the rack is behind the axle. Usually only small adjustments (say 3mm) are required.



# Active Steering

- Need for Active Steering
  - When vehicle Yaws during Braking due to imbalanced braking forces
  - Vehicles yaws due to split  $\mu$
  - Vehicle Aligning moment changes its direction due to caster change
- Steering Ratio should be small to reduce the yaw rate by steering in the opposite direction quickly
- Normal speeds and normal conditions, steering torque rate should not have steep gradient-reasonable steering ratio
- Hence, need for variable steering ratio

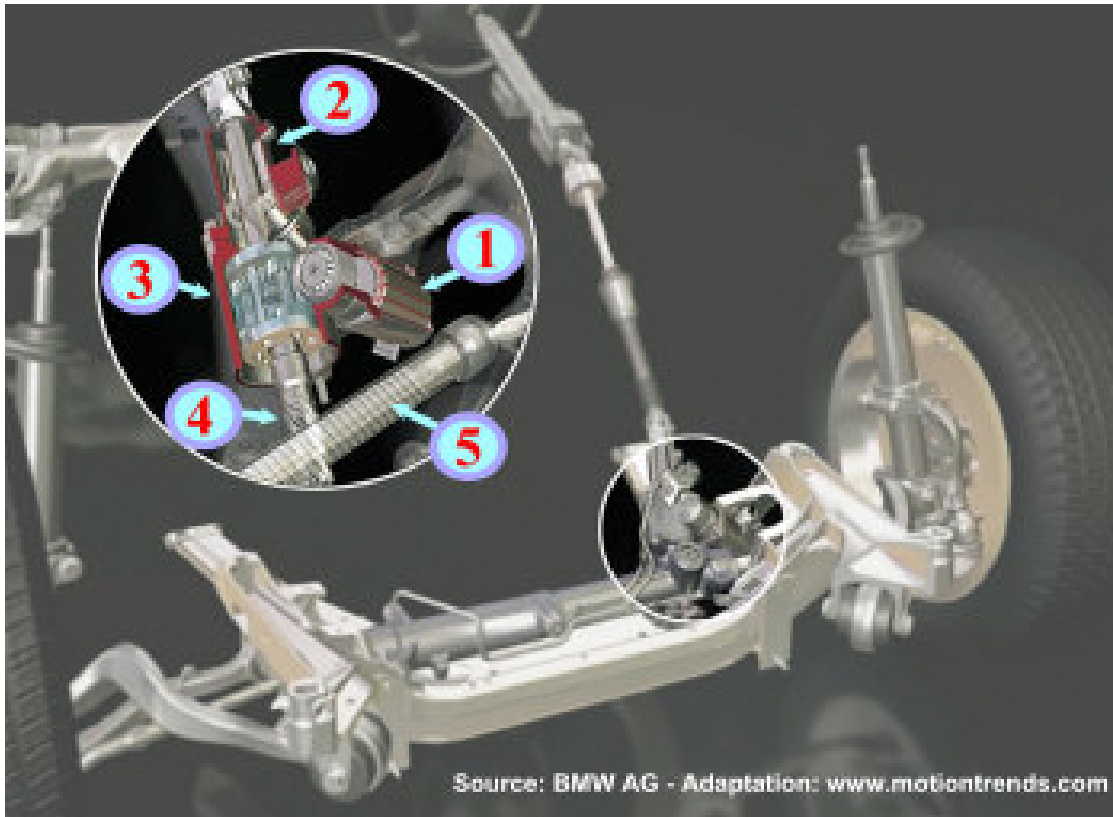


# Active Steering Concept

- When driving at lower speeds - such as in city traffic, when parking or on winding mountain roads, Active Steering increases the size of the steering angle- Low steering ratio
- At medium speeds, steering is easier
- To ensure smoothness at higher speeds, as of around 120 to 140 km/h Active Steering becomes more indirect. Active Steering therefore reduces the amount of change in the steering angle for every movement of the steering wheel. This gives the driver the advantage of more precise steering at higher speeds, and ensures great stability and more comfort
- If the vehicle is threatened with instability, such as by oversteering or braking on a changeable surface, Active Steering helps to overcome it. For example, in order to reduce unsafe yaw, Active Steering can increase the angle of steering wheels faster than even the most expert driver.

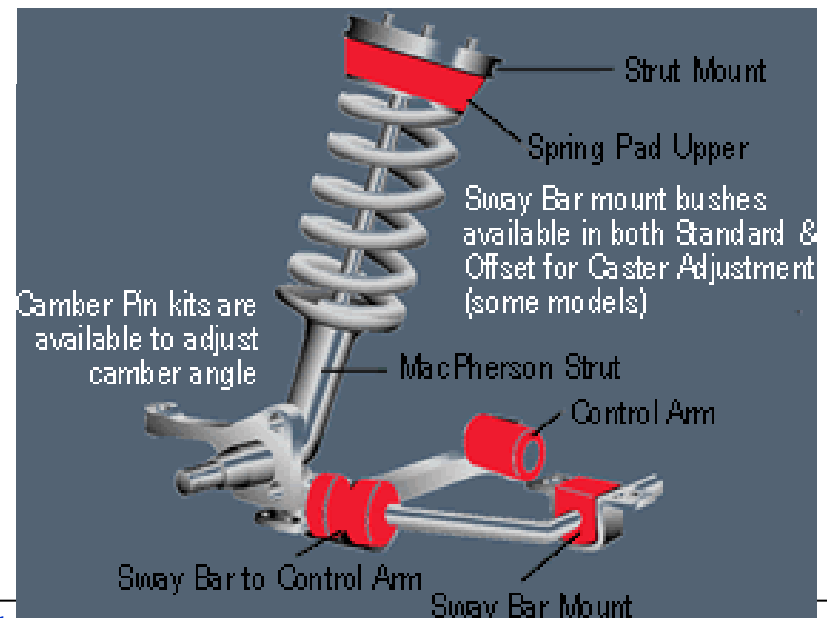
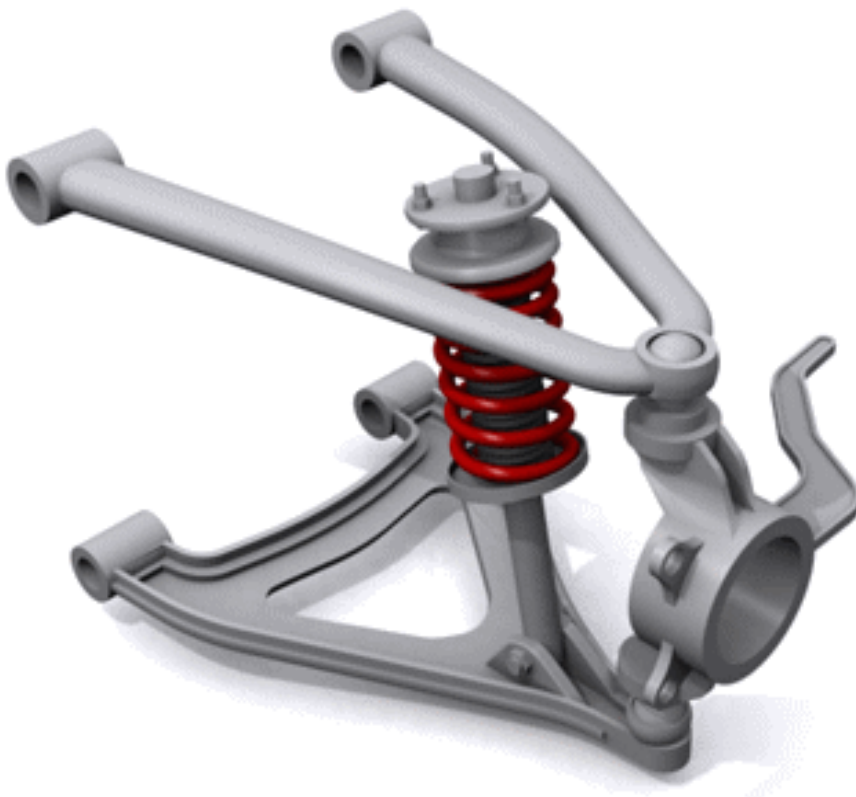
# Active Steering Concept

At the heart of Active Steering system is the planetary gear set integrated into the steering column. An electric motor in the joint adjusts the front wheels' steering angle in proportion to the Sedan's current speed.



# Elastomer/Rubber Bushes

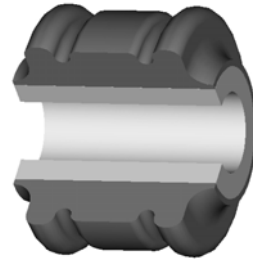




# Suspension Bushes

## Single Bonded Bushes

Provides a low cost pivot

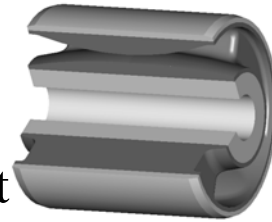


### Applications:

- Damper bushes
- Engine torque rods
- Low cost suspension arms

## Double Bonded Bushes

Provides a controlled stiffness pivot

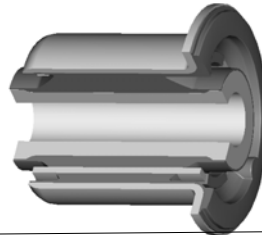


### Applications:

- Damper bushes
- Suspension arms, where there is insufficient support for a single bonded bush

## Interleaved Bushes

Provides a controlled stiffness pivot with low torsional stiffness



### Applications:

- High articulation positions
- Multi-link sports suspensions

## Hydraulic Bushes

Provides damping control



### Applications:

- Front suspension compliance bushes
- Rear suspension trailing arm bushes
- Subframe mountings

# Conventional Suspension Bush

Conventional bush used in a vertical orientation in a front control arm.

