Reference Manual

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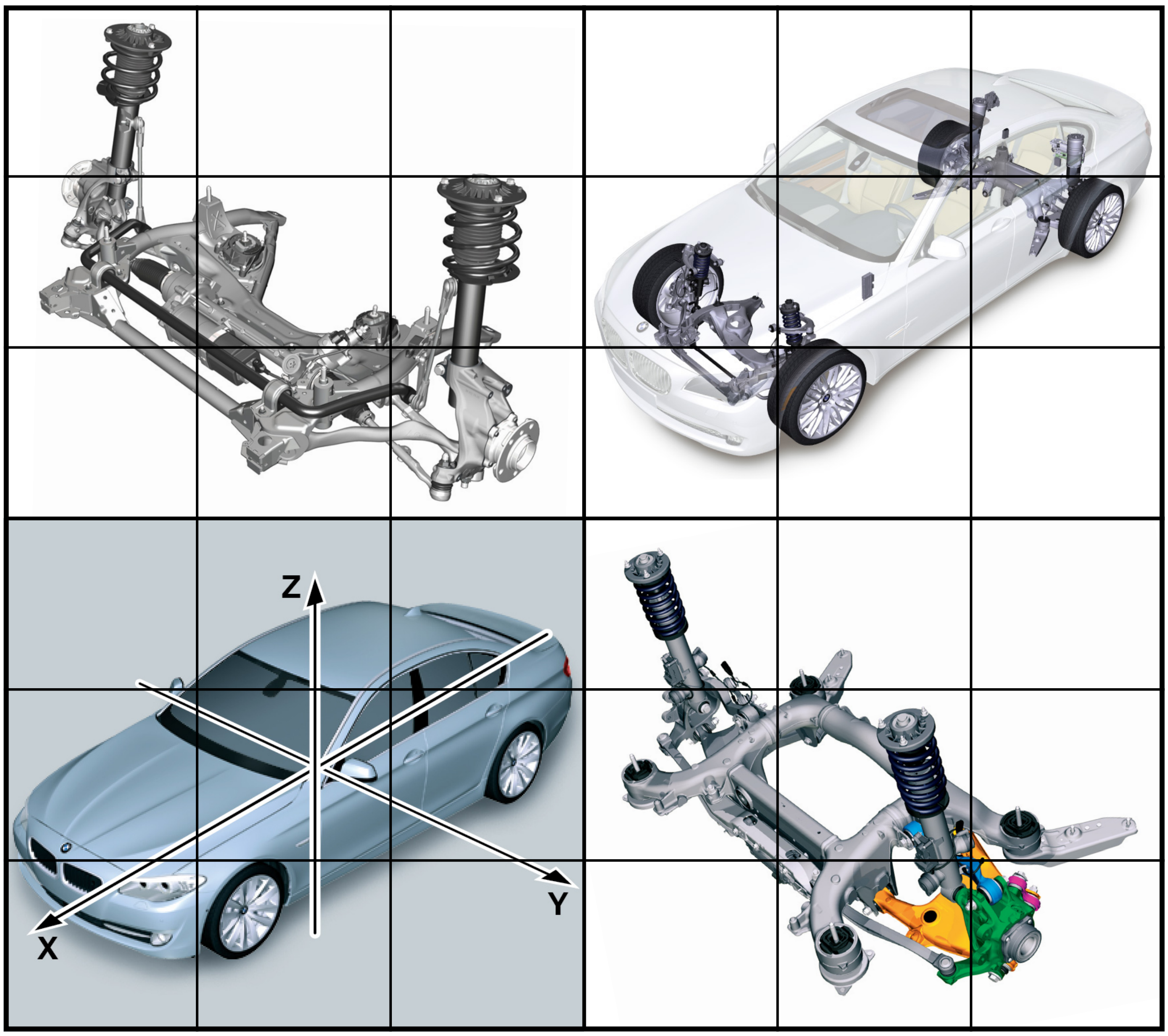
Chassis Dynamics



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Basic Suspension Geometry

Model: All

Production: All

OBJECTIVES

After completion of this module you will be able to:

- Acquire Basic Suspension Geometry.
- Recognize the relationship between alignment angles and ride quality.
- Distinguish the effect of alignment angles on tire wear.

Introduction

The safety, stability, handling and performance of a vehicle depends on many factors. One of the most important aspects of these characteristics is the design of suspension and steering systems. BMW vehicles are known for their superior handling and road holding performance.

The design of the BMW suspension systems is a key factor in achieving these goals. Suspension geometry is defined as: "The angular relationship between the suspension, the steering linkage and the wheels - relative to the road surface."

There are several alignment geometry angles which relate to the suspension components and steering linkages including:

- Caster
- Camber
- Toe-In/Toe-Out
- Steering Roll Radius (Steering Offset)
- Steering Axis Inclination (SAI) and Included Angle (IA)
- Toe Out on Turns
- Thrust Line and Thrust Angle

All of these angles influence:

- The ease with which the vehicle can be steered
- The overall vehicle stability (handling, tracking and safety)
- Tire wear

The suspension geometry for any given vehicle is a result of the Engineering development and the design criteria for that particular vehicle.

History

Even the very first wagons that mankind used to carry his loads had to be steerable. This was easy to achieve with the first single axle vehicles which were pulled by men or animals. Later on, however, with the advent of motorization, it became necessary to attach wheels in a way that allowed them to rotate and swivel, thereby steering the vehicle.

Since the beginning of vehicle construction, this has been one of the basic design tasks. Development has ranged far and wide, from simple carriage steering which was usually a pivot axle design, right through to the steering systems used today. The breakthrough for a four-wheel vehicle steered via the front axle came with the patent for the **Ackermann/ Lankensperger king-pin steering system (1818).** This type of steering could not gain acceptance in carriage construction. It only came into more widespread use with the advent of the technically more challenging automobile at the beginning of the 19th century. The reason for this is that this steering design required a great deal more design effort than, for example, the pivoted bogie steering which was in widespread use at that time. The development of the king-pin steering system made it possible to turn the steered wheels at different angles. This meant that, when cornering, the extensions of the wheel axles met at the centre point of the curve. This ensured that the wheels turned correctly, from a point of view of geometry.

This form of steering system featured the main geometric parameters which are still relevant for modern steering systems. These are the chassis-specific terms which will be examined in this module. These include, for example:

- Wheelbase
- Track width
- Track
- Camber
- SAI
- Caster
- Steering roll radius
- Toe-differential angle

Requirements of a Modern Steering System

- Ensure “steerability” adapted to the driving conditions.
- Function, comfort and safety aspects taken into account.
- Vibration damping.
- Transfer of relevant road surface information to the driver.
- Wheels return after cornering.

Today, a passenger car steering system is expected to carry out a host of different tasks. It is no longer sufficient just to move the vehicle in the desired direction. The steering process must take function, comfort and safety aspects into account. The vehicle should follow even slight steering movements precisely and on target, without the driver having to make any further corrections at the steering wheel.

However, the vehicle should not respond too directly. Fast steering wheel movements should not result in the vehicle swerving. The steering forces at the wheel should not increase excessively when performing slight steering actions, for example when driving in a straight line at high speed. A high level of comfort is expected as well.

Comfort also means that the number of steering wheel turns should not be so high as to make parking a nuisance. To ensure that the vehicle can be kept safely under control at high speeds as well, the steering system must ensure good contact with the road. The driver should still be able to "feel" the road surface quality. On the other hand, road surface unevenness, such as potholes and expansion joints, should not snatch the steering wheel out of the driver's hands or start the vehicle yawing.

Likewise, poorly balanced wheels should not cause excessive steering wheel vibrations. As a result, quite a lot is demanded of the steering system in terms of vibration damping. It must be designed so that it is possible to transfer relevant road surface information and filter out any interference. After each steering maneuver, the steering wheel is expected to return smoothly to the center position. Modern axle geometry must therefore enable the vehicle to be guided and in the process provide feedback to the driver regarding driving conditions and road surface quality.

Axle Geometry Terms

Wheel Position

The wheel positions are what give a chassis its properties. The wheel position describes the geometric position of the wheel with respect to the body and road. This position is determined by a host of different geometric parameters. Some of these parameters can be determined directly in the course of an axle alignment operation. Others are the result of the kinematic relationships arising during steering movements.

The wheel position is extremely important:

- For ensuring correct straight line running performance.
- For ensuring good tire adhesion during cornering.
- For tire wear.

The wheel position is determined by:

- Wheelbase
- Track width
- Track
- Caster
- Camber
- Toe
- Steering roll radius
- Steering Axle Inclination (SAI)
- Included Angle (IA)
- Toe-differential angle
- Geometric Axis
- Thrust Line/Thrust Angle

The position of the wheel influences how the vehicle handles during cornering. A distinction is made between:

- Understeer
- Oversteer
- Neutral steer

Wheelbase

Wheelbase (1) is the distance between the centerline of the two wheels on the same side of the vehicle. This is a static measurement which will change when the suspension travels on a moving vehicle.

A vehicle with a long wheelbase is of course larger and more spacious. The ride comfort is improved due to less “pitching” motion and the vehicle is more stable at speed. In contrast, a vehicle with a shorter wheelbase is capable of tighter “cornering”.

Track Width

The track width (1) is the distance from the centerline (wheel contact point) of two wheels on the same axle. The track width considerably influences a vehicle's cornering performance. A wide track width allows the vehicle to take corners at higher speeds.

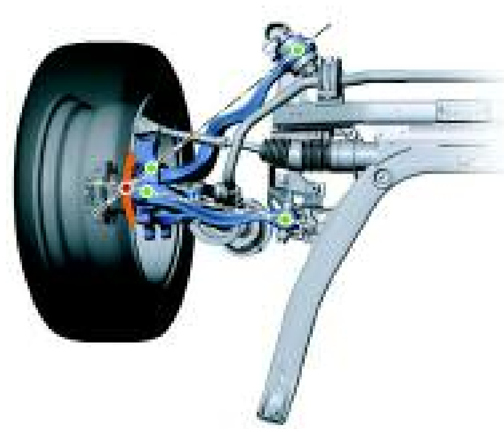
In the case of independent wheel suspension with control or semi-trailing arms, a change in track width occurs during wheel compression and rebound. Roll resistance and tire wear increase as a result. If the change in track width is too great, the vehicle's straight line stability deteriorates.

Steering Axis / Pivot Axis

The pivot axis (red) is the effective axis about which the wheel being steered is turned. In reality, this should not be the center axis of an axle component (e.g. suspension strut). It lies on the line connecting the upper and lower pivot points of the wheel suspension. The design dictates that the upper pivot point is in the center of the spring strut support bearing. The lower pivot point is in the outer ball joint of the control arm.

Wheel suspension kinematics can cause this axis to move when the steering angle changes.

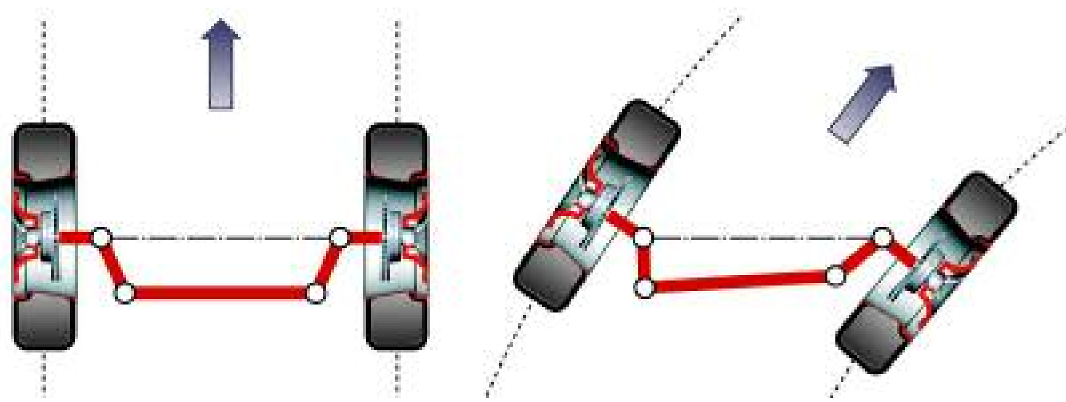
Note the special feature of the universal joint McPherson axle in this regard. The effective lower pivot point is the intersection of the effective extensions of the lower arms. This point is not static but dependent on the respective steering angle.



Universal joint McPherson axle / Determining the lower pivot point

Steering Trapezoid

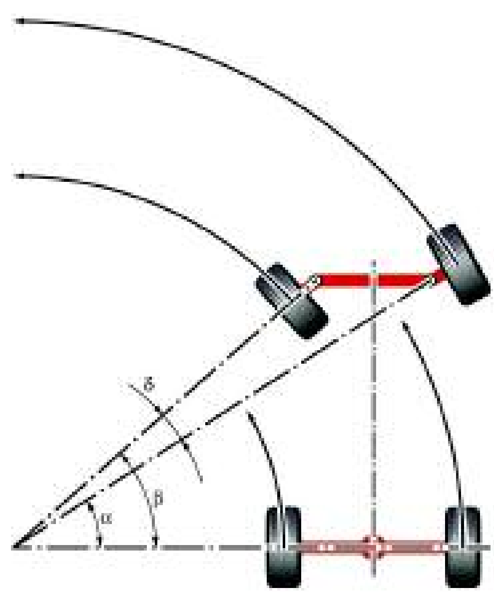
Optimum adhesion between tire and road is only guaranteed if the tire contact area runs along the road surface (static friction) and is not pushed (sliding friction). If the rubber tire is pushed over the road surface, power cannot be transferred. This transfer capability will be affected even if just individual areas of the effective tire contact area are being pushed by interfering forces (e.g. lateral forces/braking forces).



The steering trapezoid enables the steered wheels to be turned at different angles.

When cornering, the wheels of both axles cover different distances. If the steered wheels were turned at the same angle, one of the two wheels would not be able to follow its natural path. Each wheel is affected by the other wheel and is forced out of its natural path by the occurring lateral forces. The wheels would "grind" on the road, increasing tire wear and impairing driving safety. For the wheels to run without any sliding movement, the wheel on the inside of the turn must be turned in more than the wheel on the outside of the turn.

The front axle, steering arm and track rod together form the steering trapezoid. This geometric shape enables a toe-differential angle, in other words, the wheels on the inside and outside of the turn can be turned at different angles.



The steering trapezoid enables all wheels to turn about a common cornering center point.

The **toe-differential angle (δ)** is the difference in the steering angle between the wheels on the inside and outside of the turn.

$\delta = \beta - \alpha$

Kinematics

As explained in the Introduction section of this Reference Manual, from a physics point of view, kinematics are the laws which give rise to sequences of movements. Where chassis engineering is concerned, kinematics is the sequence of movements at the wheels and wheel-guiding components.

Kinematics therefore have a direct effect on the position of the wheel for the respective load conditions.

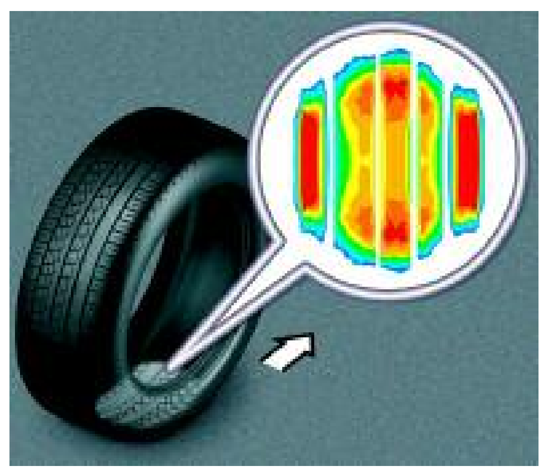
Tire Contact Area

The tire contact area is the area which is covered by the wheel standing on the road.

Tire Contact Patch

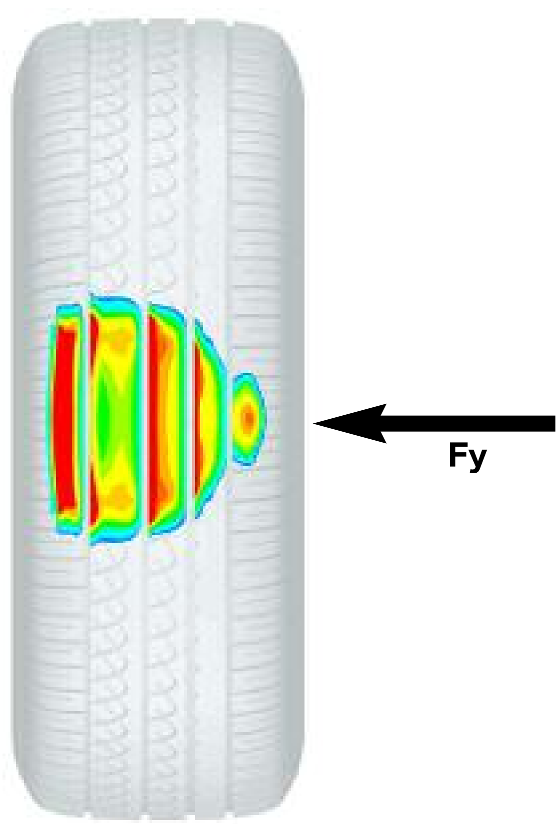
The tire contact patch is the effective contact area of a tire in operation. It is therefore the tire contact area which is deformed by interfering forces (lateral forces, braking and acceleration forces) and by road surface quality.

The tire contact patch describes the area of road which is touched by the tire when the vehicle is in operation.

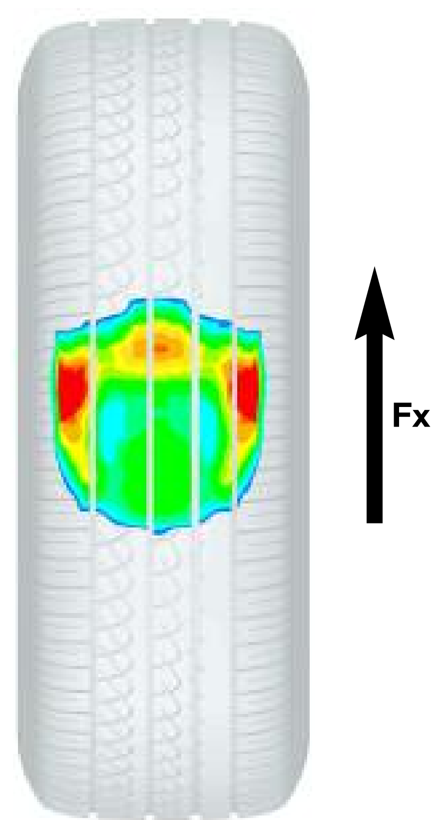


Tire contact patch / Dynamic tire contact area

The sum of these dynamic wheel contact areas represents the direct connecting link between the road and the vehicle. All acceleration (drive axle only), deceleration and lateral forces must be transmitted via this resulting overall area.



Tire contact patch affected by lateral force, e.g. cornering (Fy)



Tire contact patch affected by logitudinal force, e.g. braking force (Fx)

Slip Angle

The slip angle is the angle which the wheel plane forms with the direction of travel (wheel's direction of movement). If lateral forces (e.g. wind forces, centrifugal forces) are acting on a vehicle as it is moving along, the direction of travel of the wheels will change: They will run at an angle different to the original direction of travel.

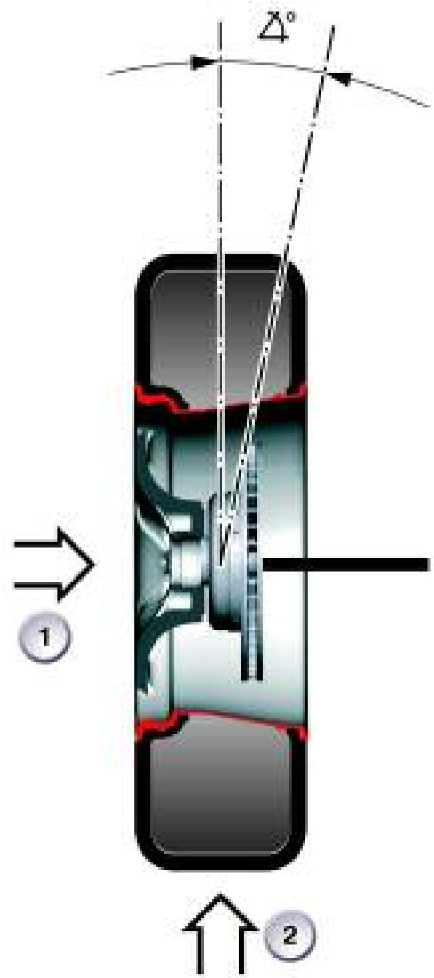
If the slip angle is the same at the front and rear, the vehicle is said to have neutral steer. If the slip angle is greater at the front, this produces understeer; if it is greater at the rear, there is oversteer.

The slip angle is dependent on:

- Wheel load
- Lateral force
- Tire design
- Tire profile
- Tire pressure
- Coefficient of friction

Kamm's Circle

Index	Explanation
Fx	Driving force
Fy	Cornering force
Fz	Wheel contact force
F_{re}	Resulting force
K	Maximum force area



Slip angle (viewed from above)

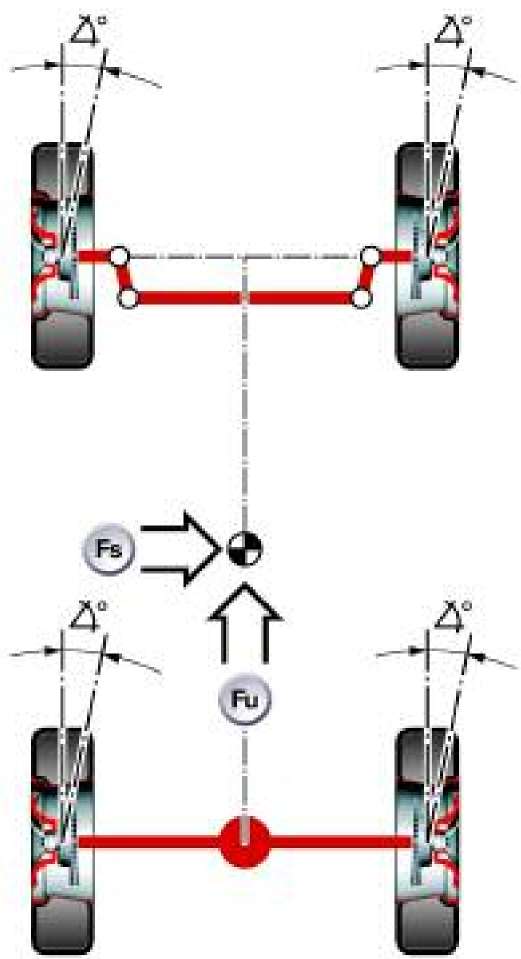
Index	Explanation
1	Lateral force
2	Driving force

Special Terms Relating to Cornering

A vehicle's cornering performance is also referred to as its self-steering properties. This handling performance is considerably influenced by the changing ratio of lateral force to wheel load on the front and rear axles. Lateral force increases as centrifugal force increases.

Neutral Steer

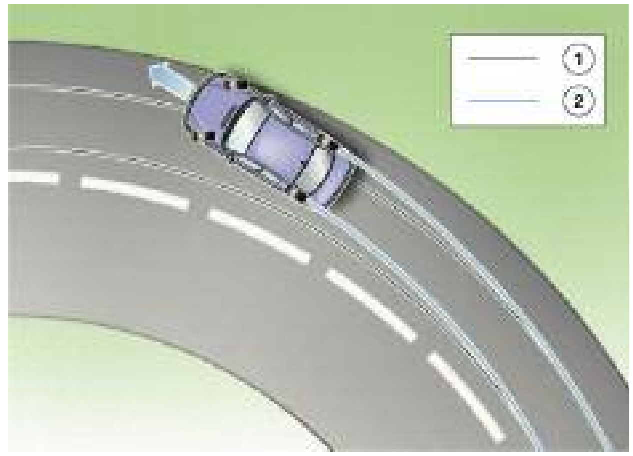
The slip angles arising as a result of lateral force are the same on the front and rear axles. Neutral cornering facilitates the best use of lateral forces and thereby the highest limit cornering speeds. However, it also reduces the subjective feel for vehicle stability. In addition, vehicle breakaway cannot be calculated as it can occur via both the front and rear axles.



Neutral steer:
All slip angles are the same

Understeer

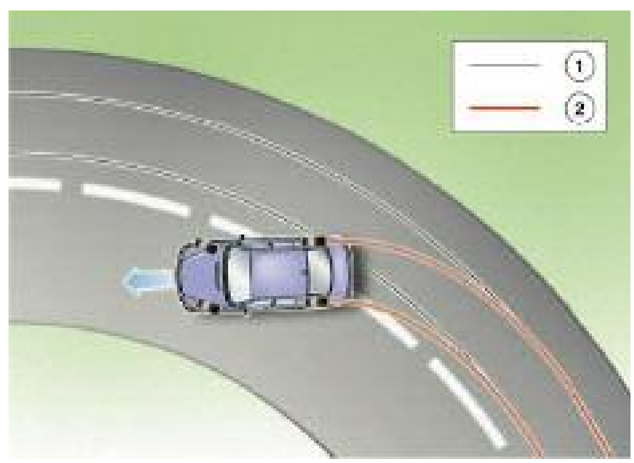
The ratio of lateral force to wheel load is greater on the front axle than on the rear. The vehicle follows a larger cornering radius than that corresponding to the steering angle. It also slides to the outside of the turn via the front axle. When designing the chassis, this behavior is often the preferred option, because when the vehicle breaks away it can be returned to a straight line course which it is possible to calculate. Take, for example, a vehicle which begins to break away via the front axle whilst being driven to the limits; if the steering angle is then reduced, the vehicle will recover to assume a straight line course. BMW chassis are designed so that they have slight understeer characteristics.



Understeer:
Vehicle slides outwards via the front axle

Oversteer

The ratio of lateral force to wheel load is greater on the rear axle than on the front. The vehicle follows a smaller radius than that corresponding to the steering angle. The vehicle slides to the outside of the turn via the rear axle.



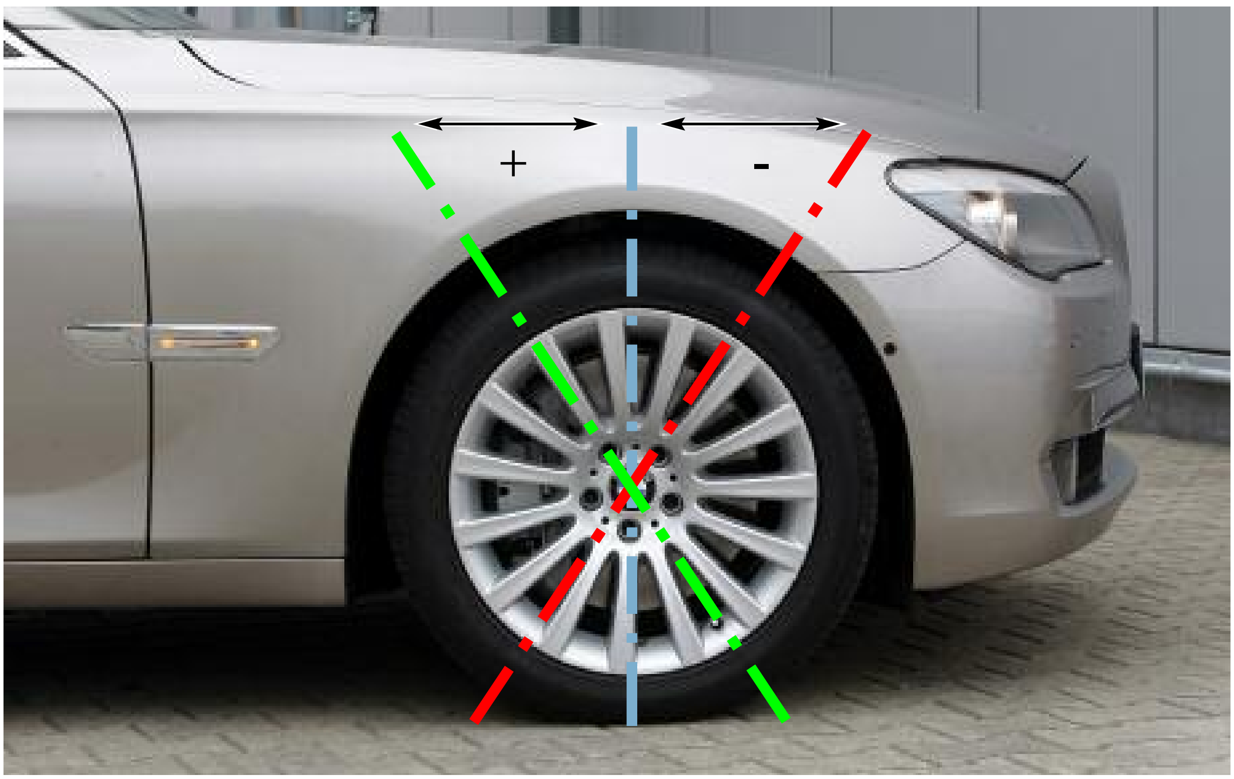
Oversteer:
Vehicle slides outwards via the rear axle

Alignment Angles

Caster

Caster is the forward or rearward tilt of the steering axis centerline as viewed from the side of the vehicle and is measured in degrees. When the steering axis centerline is exactly perpendicular to the road surface, the Caster is considered to be at zero degrees.

When the top of the steering axis centerline is tilted rearward (toward the bulkhead), the caster is considered to be **positive (+)**. When the top of the steering axis centerline is tilted forwards, the caster is considered to be **negative (-)**.



Most vehicles have a caster angle from zero degrees to a positive angle. Negative caster is not very desirable because it reduces the vehicle stability especially at high speeds. BMW vehicle always have a positive caster angle. Positive caster promotes high speed stability and provides feedback to the driver.

Positive caster also promotes "steering return" which increases driver comfort and safety. Caster angles which are more negative (or not very positive) can increase the effect of wheel "shimmy", create sensitivity to high winds and creates poor steering return.

When the caster angle differs greatly from side to side, the vehicle may "pull" to the side which has the "least positive" caster.

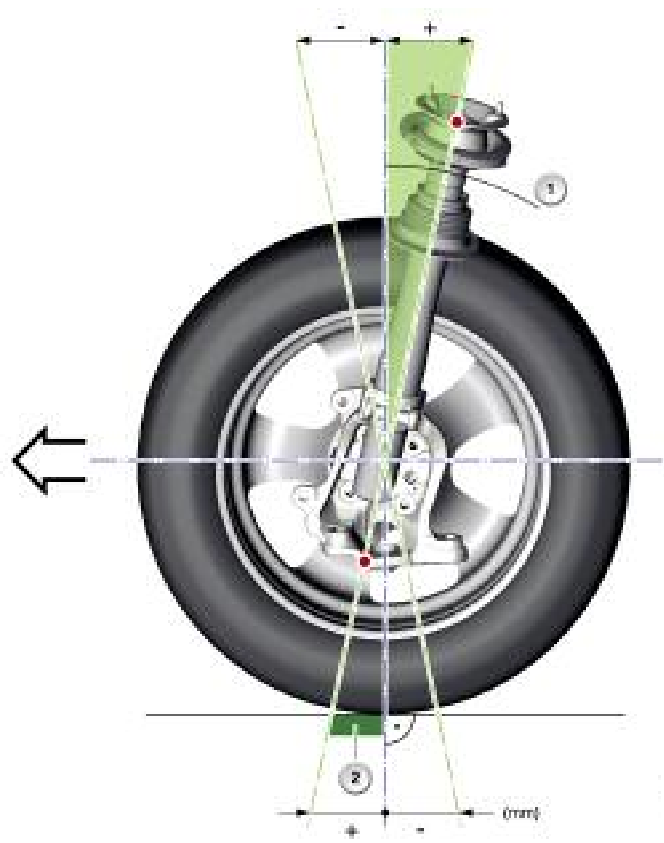
One of the main characteristics of positive caster is the positive effect on high speed steering stability. However, low speed steering effort is increased. This characteristic is counteracted by the power steering system and in particular the Servotronic system. Servotronic will be discussed in later training modules.

Caster is not a directly measured angle. It can only be measured by sweeping the steering through an angle of 20 degrees in both directions. This is important to know during the alignment procedure.

On BMW vehicles, caster can only be measured, there is no adjustment. However, caster measurement can be used to detect and diagnose alignment concerns. Caster which is out of specification could indicate damaged or worn components.

Caster Offset

Caster offset also known as Trail angle is the distance between the centerline of the wheel contact point and the intersection point of the extended pivot axis. The greater the offset, the more effort required to turn a moving wheel. The negative effects of more increased offset are counteracted by the BMW double pivot suspension system and the Servotronic steering system (if equipped).



Index	Explanation
1	Caster Angle
2	Caster Offset

Interaction

- **The caster and SIA lift the vehicle body during steering maneuvers. This brings about a wheel alignment force because of the wheel load.**
- **When the wheel is turned, the caster angle generates a negative camber in the wheel that is on the outside of the turn.**

Fault Symptoms

- **Caster too positive (+): high steering and holding forces.**
- **Caster too negative (-): poor steering return, prone to tire faults (conicity, angle effect), may cause vehicle to pull to one side -wheel shimmy - sensitivity to side winds.**
- **Caster different on left and right-hand side of vehicle: vehicle prone to pulling to one side.**

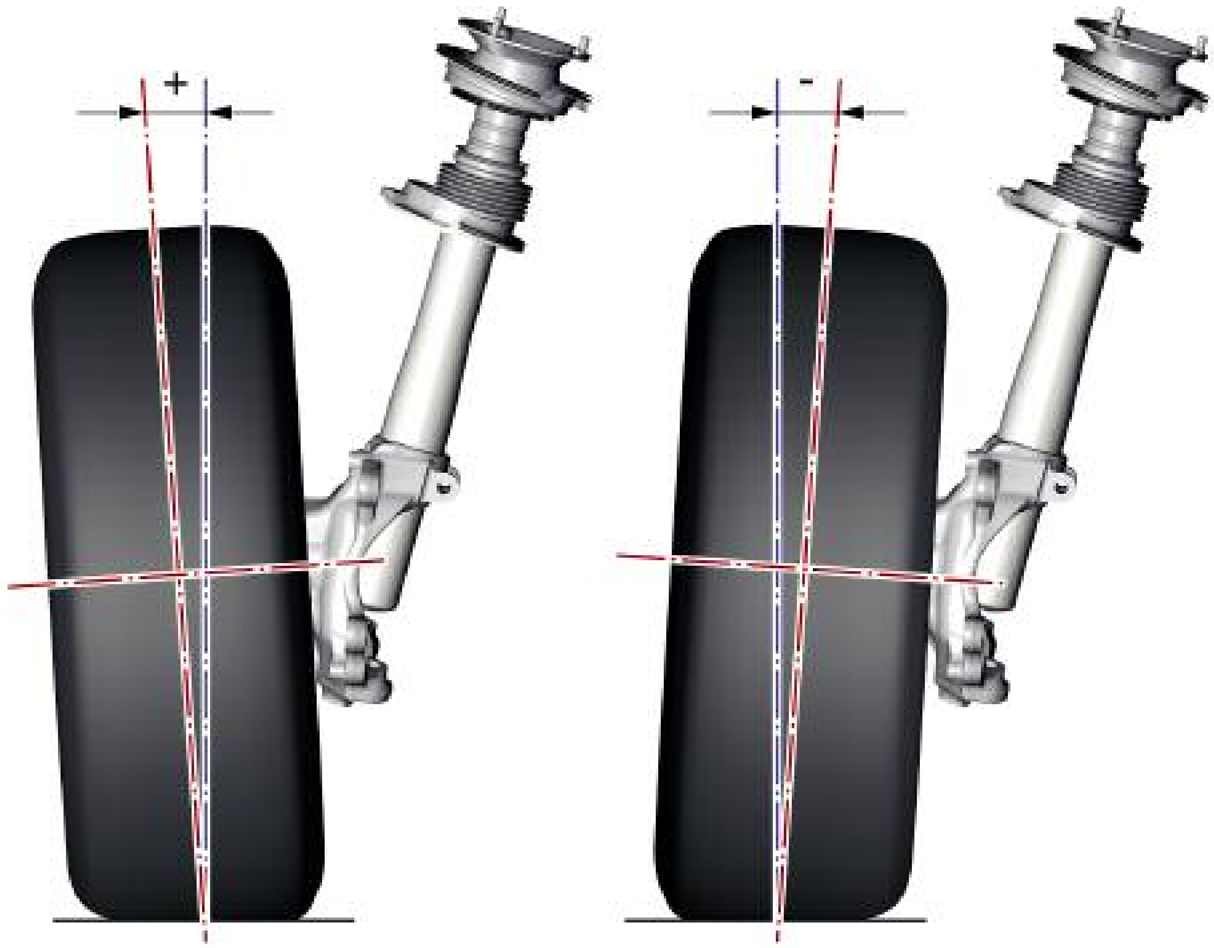
Workshop Hint
Like SIA, the caster is measured indirectly by applying a steering angle of 20°.

Camber

Camber is the inward or outward tilt of the wheels when viewed from the front of the vehicle. The amount of tilt is measured in degrees from the vertical and is called the camber angle.

The camber angle is the angle between the wheel center point and a perpendicular line (in the wheel contact point) with respect to the road surface. Camber angle is considered **positive (+)** if the upper part of the wheel is angled outward from the wheel center point and **negative (-)** if it is angled inward.

Positive Camber **Negative Camber**



Wheels running at a camber want to follow a circular path, like an overturned cone. Therefore, vehicles which have excessive camber angles will tend to pull to one side. As a general rule, the vehicle will tend to pull to the side of the vehicle which has the most positive camber.

Front camber angle on most current BMW vehicles is set at a slightly negative value. This promotes good straight line stability. This is due to the fact that slight negative camber causes the wheels to “track inward”. As long as the side-to-side camber is roughly equal, the vehicle will track in a straight line.

Camber angle also has an effect on component wear. For instance, the wheel bearings will perform well and last longer as long as the camber is within specification. Camber which is out of specification will cause undue load on the wheel bearings. Excessive camber angle also causes wear on the outer edges of the tire. The outside of the tire will wear if the camber is too positive and the reverse is true with excessive negative camber. The same holds true for the rear camber angle.

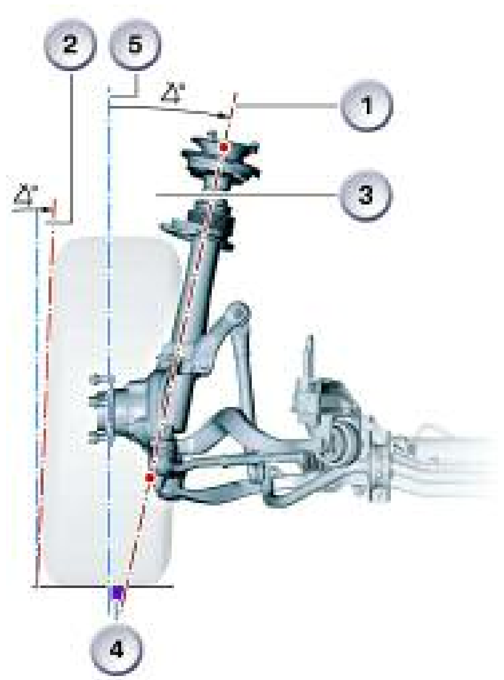
Positive Camber
Older vehicles often had a positive camber on the front axle. The design made this necessary, as the tapered roller bearings would not withstand any other type of load. In a steering maneuver, the front axle wheel on the outside of the turn is shifted to the negative camber range by the caster angle and the spread. The desired cornering stability is achieved in this way. When cornering, no positive camber should arise at the outer wheel of the steered axle.

Negative Camber
On modern BMW chassis, it is possible to set a negative camber for the straight-ahead position on the front axle as well. This has been made possible by using two rows of ball bearings. The rear wheels on BMW vehicles have always had a negative camber.

This is a compromise. The wheels on the rear axle cannot be shifted to the negative camber range by steering movements. To improve cornering stability, a negative camber has to be pre-set.

Interaction

- **Camber has an indirect influence on steering roll radius. The wheel contact point continues to shift in the direction of or away from the vehicle longitudinal axis. For this reason, the camber changes a steering roll radius parameter.**
- **Camber also influences track, and must therefore be set before the track is set.**



Index	Explanation
1	SAI
2	Camber
3	SIA
4	Steering roll radius
5	Perpendicular line in wheel contact point

Fault Symptoms

- **Excessive negative (-) camber: causes increased tire wear on the inside of the wheels and increases tire flexing. Cornering stability improved. However, excessive camber at high speeds and with high axle loads causes the tire shoulder areas to heat up excessively. This can cause tire damage (tires overheating, inner wear). The front axle will also demonstrate excessively aggressive steering properties.**
- **Camber too low [positive (+)]: Cornering stability worsens, increased outer tire wear.**

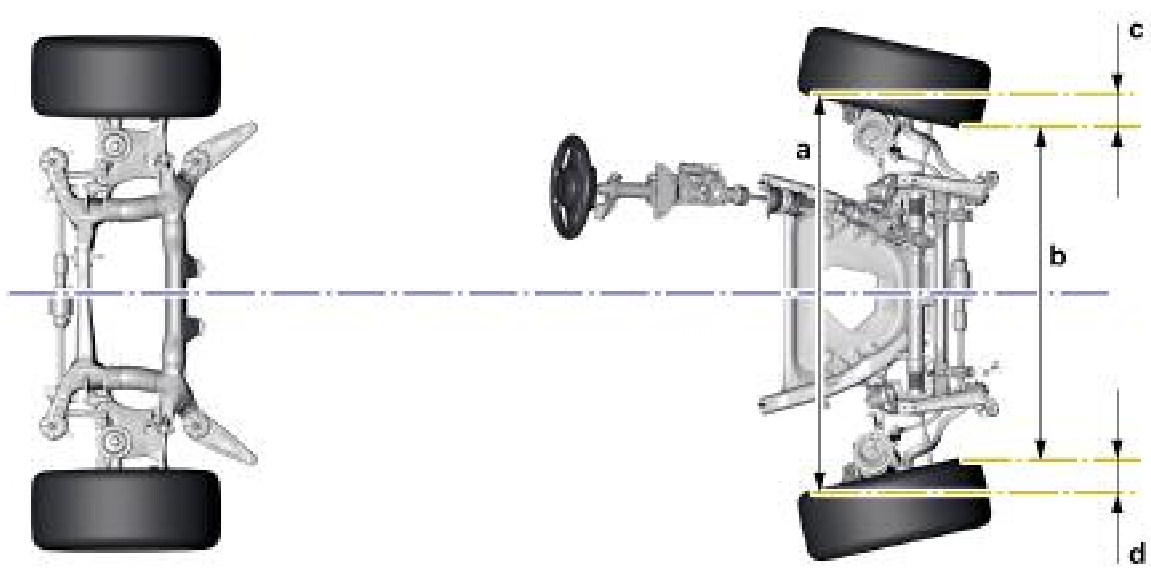
Toe

Total Toe represents the left and right toe specs added together. Total toe is the difference between the leading and trailing edges of both tires with respect to one another. It may be measured in degrees and minutes.

Toe is measured at the center of the wheels from one wheel rim to the other. When the distance is greater at the rear of the wheels, it is called toe-in. When the distance is greater at the front of the wheels, it is called toe-out.

Rear wheel drive vehicles generally will have a small amount of toe-in at the front wheels. This will allow the wheels to toe out when rolling to achieve a zero running toe.

Toe is measured in degrees when using BMW specifications. Front toe is adjustable on all BMW vehicles. Rear toe is only adjustable on some models.



Toe has a major influence on vehicle handling, straight line stability and the position of the steering wheel. An incorrect toe setting will have a negative effect on tire wear. A toe angle which is out of specification will cause the tires to wear in a relatively short time.

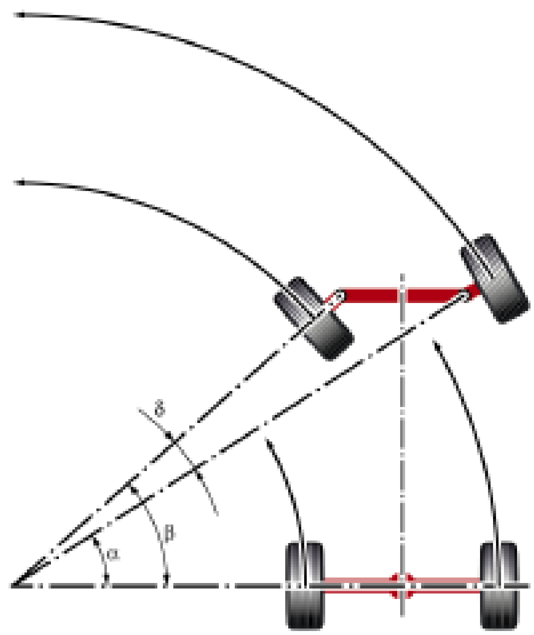
Fault Symptoms

- **Excessive Toe-out: Tire wear on the inside, poor straight-line running performance.**
- **Excessive Toe-in: Tire wear on the outside, poor straight-line running performance.**

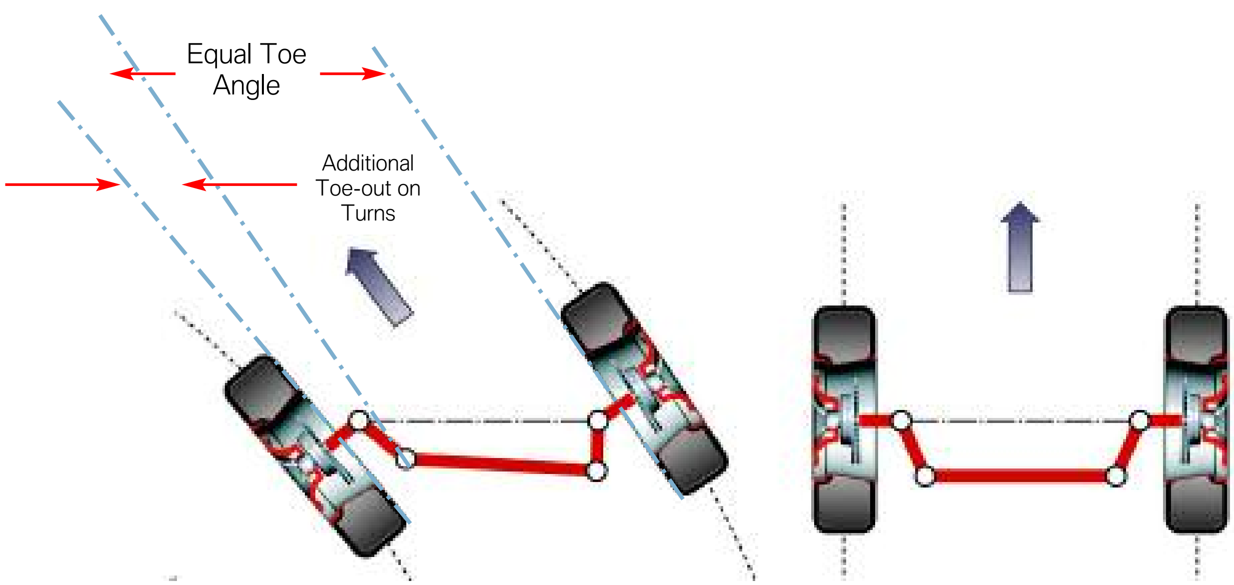
Toe Out on Turns

Also referred to as “Turning Angle” or “Toe differential angle”. Toe out on turns results from the different angles (arcs) taken by the front wheels when driving through a corner. When turning a corner, the outside wheel must travel a greater distance than the inside wheel. The additional toe angle is determined by the steering arm design.

Deviations from the specified value could indicate possible bent steering linkage.
A typical complaint that would be associated with this condition would be excessive tire squeal or “scrubbing” on turns. When looking for this specification in ISTA, search for the **“Track Differential Angle”** specification.



Toe-differential angle:
$\delta = \beta - \alpha$



The steering trapezoid

If set correctly, the toe-differential angle will be the same for both left and right-hand steering inputs, taking into account permissible angular tolerances. The resulting angular difference (toe differential angle) between the angles of the steering arms increases as the steering angle increases.

Workshop Hint
Measurement of the Toe-out in turns is done by turning the wheel on the inside of the turn by 20°. Toe-in is taken into account in the measurement.

Fault Symptoms

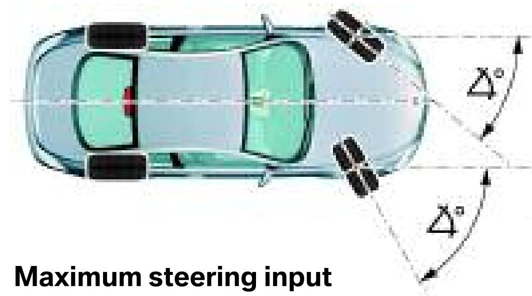
- **Loss of adhesion in tire contact patch.**
- **Tires squeal when cornering.**
- **Increased tire wear.**
- **Vehicle breaks away when cornering.**
- **Poor steering return with large steering inputs.**

NOTES

Maximum Steering Angle

The maximum steering angle is the angle of the center plane of the inner and outer wheels with the steering wheel at full left- and right hand lock (in relation to the longitudinal center plane of the vehicle). The maximum steering angle has an influence on a vehicle's turning circle.

The maximum steering angle is usually not an angle that can be adjusted while performing a wheel alignment.



Maximum steering input

Workshop Hint
In the case of vehicles with recirculating ball steering, the center position of the steering lever must be checked as otherwise the steering trapezoid will be at an angle. This will be evident from the different toe-differential angles. Measuring the maximum steering angle in conjunction with the steering wheel position may help in this regard.

Fault Symptoms

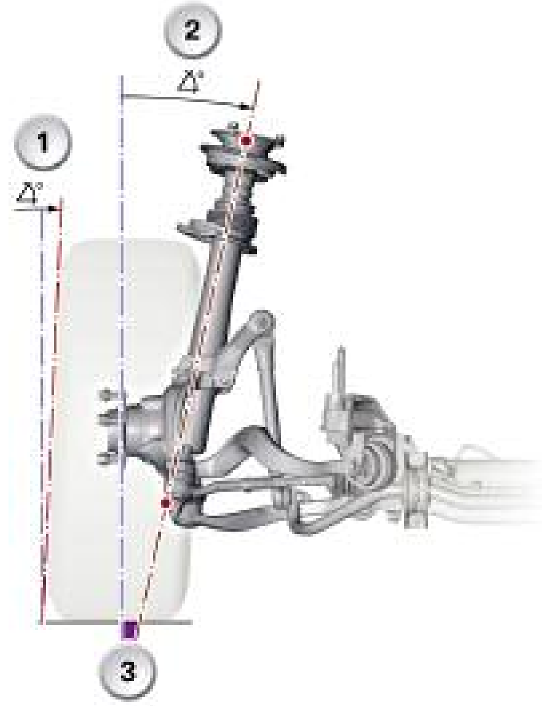
- **Vehicle has different turning circles.**

Steering Roll Radius (Steering Offset)

The steering roll radius is the distance between the point of contact of the projected line drawn through the steering axis to the road surface and the center point of the tire contact area. The roll radius is the distance between these two lines.

The roll radius can be positive or negative:

- A **positive** roll radius exists when the steering axis line is **inside** the center line of the tire (in other words, the imaginary intersection of these two lines is below the road surface).
- A **negative** roll radius exists when the steering axis line is **outside** of the tire center line (in other words, the imaginary intersection of these two lines is above the road surface).



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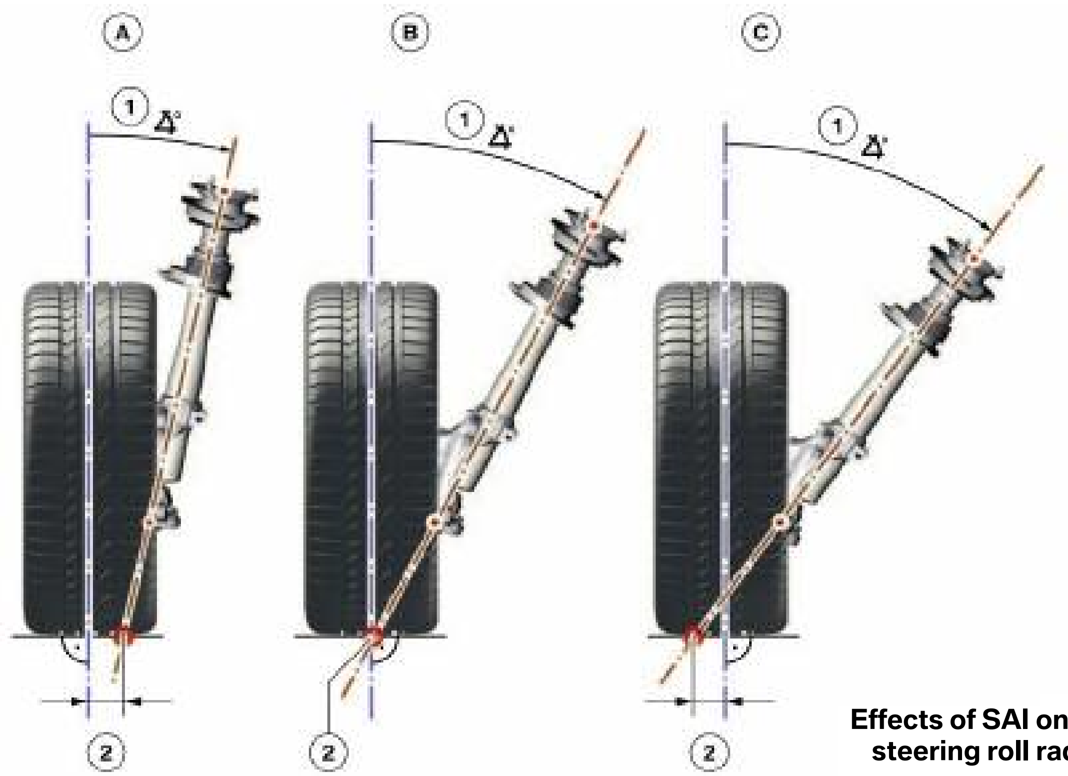
1	Camber	3	Steering Roll Radius
2	Steering Axis Inclination		

The steering roll radius influences the steering by means of a “torque effect”. During braking, uneven brake forces will influence the steering towards the side with the most braking force. This becomes more evident when the roll radius is excessively positive. A positive roll radius also provides more feedback to the driver regarding road surface conditions.

A steering roll radius which is excessively positive, reduces vehicle stability during braking. However, when roll radius is excessively negative, the directional stability is reduced (when not braking) and there is reduced feedback to the driver through the steering wheel. This is why BMW vehicles are designed with a steering roll radius which is slightly positive. This gives the driver a better “road feel” without compromising braking stability.

Steering Roll Radius is not adjustable, but can be influenced by camber, SAI and rim offset. This can become evident by installing improper tire and wheel combinations. Wheels with incorrect offsets can compromise handling characteristics.

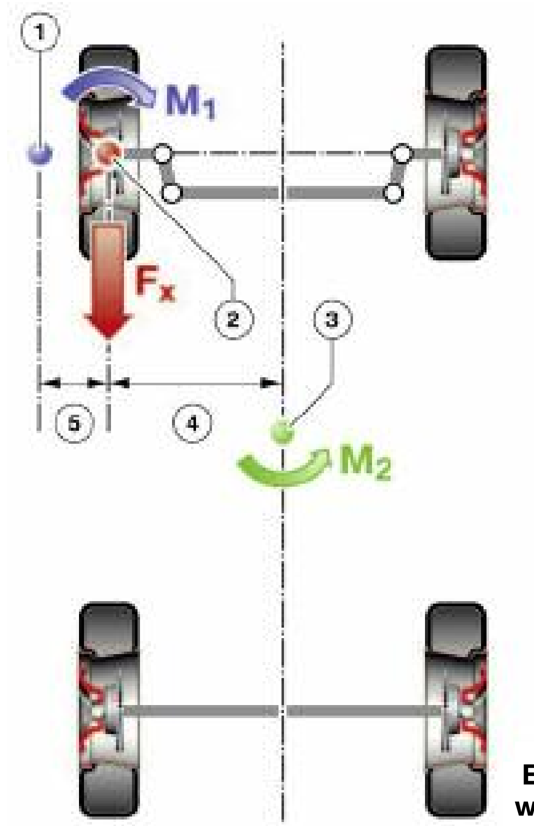


Effects of SAI on the steering roll radius

Index	Explanation	Index	Explanation
A	Positive Steering Roll Radius	1	Steering Axis Inclination
B	Zero Steering Roll Radius	2	Steering Roll Radius
C	Negative Steering Roll Radius		

The term “Steering Roll Radius” is also known as Scrub Radius, Steering Offset or King Pin Offset.

The action of the steering roll radius can be understood from the example shown in the graphic. This vehicle exhibits a negative steering roll radius.



Effect of Steering Roll Radius with One-sided Braking Force

Let us assume that a one-sided braking **force Fx** is exerted on the left-hand front wheel. It is exerted at a **distance (5)** from the wheel's center of rotation. This distance corresponds exactly to the steering roll radius. A clockwise torque is thereby created on this wheel. If the driver permits it, the steering will therefore be turned slightly to the right.

Conversely, in reference to the vehicle's center of gravity, the **force Fx** acts upon **distance (4)**. This produces a counterclockwise torque on the vehicle. The vehicle reaction would be to turn counter-clockwise. Because the counterclockwise turning is only caused as a result of a braking force which is applied on one side, this situation is undesirable.

Due to the effect of the negative steering roll radius, the steering is positioned in the direction which will counteract this undesirable rotational motion in the vehicle. This may be called automatic countersteering.

The steering roll radius is therefore a **lever arm** as it allows forces exerted on the wheel to produce a torque which can influence the steering. This also creates the reset forces on the steering during cornering. These forces also help the driver when returning the steering to the straight ahead position.

Influence of Braking Forces

Positive (+) Steering Roll Radius

If a vehicle is braked more on one side (as a result of road surface quality or the brakes pulling on one side), the vehicle is pulled to the side on which the greater braking force is acting. This is because the pivot point about which the steering roll radius as the lever arm is acting, is on the inside of the wheel. If the steering roll radius is positive, the forces acting on the wheel push the wheel outwards. The wheel which is transmitting the greatest braking force is pivoted outwards more. As a result, the vehicle is steered more in the direction of the side being braked more heavily.

Negative (-) Steering Roll Radius

By using rims with large offsets, it is possible to shift the steering roll radius to the outer half of the tire contact patch. The negative steering roll radius cause the wheels to pivot inwards when braking. The wheel with the greater braking force continues to pivot inwards which creates automatic counter-steer. The vehicle is steered away from the side being braked more heavily and thereby remains virtually on track.

Summary of Properties

- A **positive steering roll radius (+)** produces steady directional stability, although it requires countersteering from the driver if braking action is uneven.
- Conversely, a **negative steering roll radius (-)** will automatically set the steering to countersteering if braking action is uneven.
- If the **steering roll radius is exactly zero**, no disturbing forces are transferred to the steering. However a high level of steering forces is detrimental when the vehicle is stationary because the tire is then not in motion during the steering operation. It is instead turned out of position while stationary at the wheel contact point.

Interaction:

The steering roll radius is influenced by camber, SAI and the rim offset.

Rim Dimensions

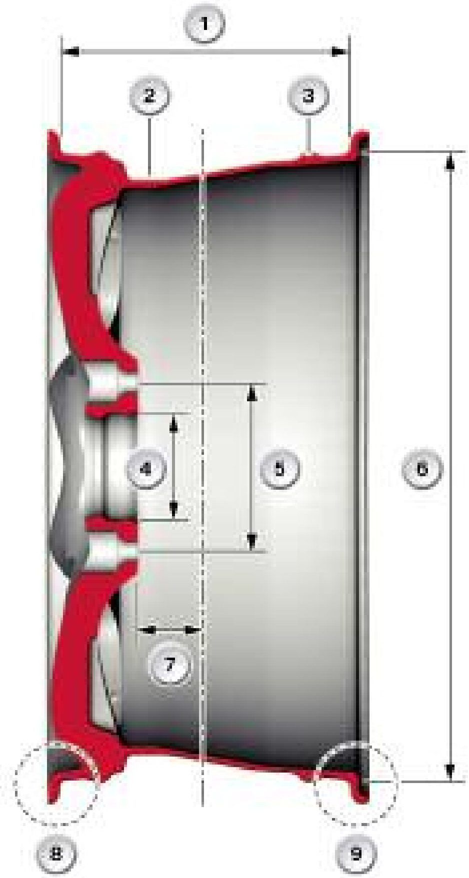
Rim Width
The rim width is the distance between the tire contact surfaces of both rim flanges. This means the inner of the two rim flanges is measured. The dimension is specified in inches. (1 inch equals 2.54 cm).

Well (Drop Center)
The well in the rim makes it easier to fit the tire. When fitting the tire, it is necessary to pull the tire beading over the rim flange. For this purpose, the opposite part of the tire must be pressed into the well.

Center Hole
The center hole serves the purpose of centering the wheel rim. The diameter must precisely match the wheel hub of the vehicle. The center hole must be cleaned and lightly greased as part of the wheel fitting procedure.

Hole Pitch Circle Diameter
The hole pitch circle diameter defines the circle diameter on which the holes for the wheel studs are located.

Rim Diameter
The rim diameter is measured between the opposite contact surfaces of the tire - not to be confused with the distance from rim flange to rim flange. The measurement points are clearly shown in the diagram. The dimension is specified in inches.



Wheel rim cutout

Index	Explanation	Unit of Measure
1	Rim width	[in]
2	Well (drop center)	---
3	Hump	---
4	Center hole	[mm]
5	Hole pitch circle diameter	[mm]
6	Rim diameter	[in]
7	Rim offset	[mm]
8	Outer rim flange	---
9	Inner rim flange	---

Rim Offset

The rim offset is the distance between the vertical wheel mid-point and the inner contact surface of the wheel hub mounting surface. The rim offset can be positive or negative. The rim offset is positive when the inner wheel contact surface faces outwards with respect to the wheel center. The rim offset is negative when the inner wheel contact surface faces inwards with respect to the wheel center.

The rim offset is designed to provide space for the brake.

Rim Flange

The inner and outer rim flanges serve as the side stops for the tire beading. They take up the force resulting from the tire pressure and axial tire load. The rim flange is the outer collar of the rim. An identification letter indicates the height and shape of the rim flange. The J-type rim flange is always used on BMW rims. In this case, the height of the rim flange is 17.3 mm. Depending on the model, some space-saver wheels are equipped with a B-form rim flange.

Hump

The hump was introduced together with the changeover to tubeless tires. The hump prevents the tire from slipping into the well, e.g. extreme cornering, and therefore suddenly loosing air. The types of hump used today on BMW rims refer to Hump 2 (H2) and Extended Hump 2 (EH2) rims.

Steering Axis Inclination (SAI)

Steering Axis Inclination is the inward tilt (angle) of the strut assembly with respect to a vertical line to the road surface. SAI raises the vehicle when the steering wheel is turned, which results in the self-correcting forces that cause the front wheels and steering wheel to return to a straight ahead position after cornering.

SAI is not adjustable, but is affected by damaged suspension components.

Most current alignment equipment can measure SAI and can aid in the diagnosis of damaged parts. Bent strut or spindle assemblies are common causes of incorrect SAI readings.

The term SAI is also known as King Pin Inclination (KPI).

Interaction

**The SAI has a direct influence on the steering roll radius.
The steering roll radius is dependent on:**

- **The position of the piercing point of the extended pivot axis with the road and;**
- **The distance of the piercing point from the wheel contact point.**

The SAI therefore has an effect on how interfering forces are transmitted (see Steering roll radius). During steering maneuvers, SAI and caster lift the body. This generates a wheel alignment force on account of the increased wheel load.

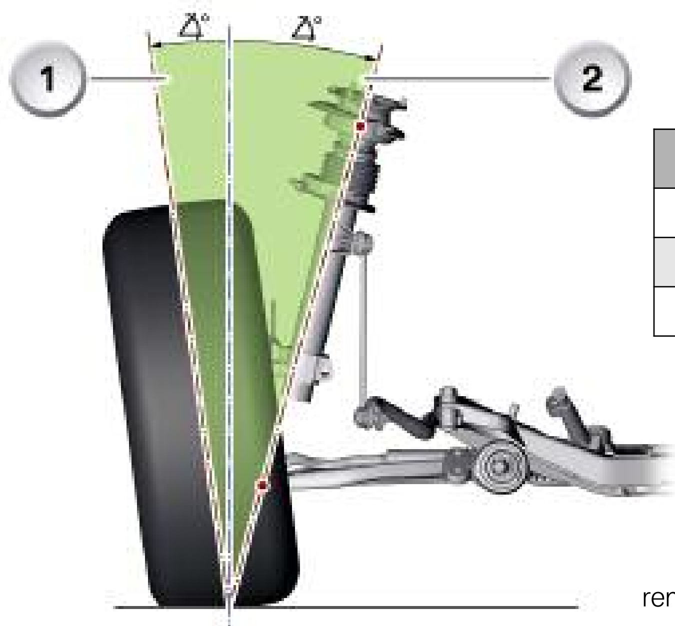
Fault Symptoms

- **SAI too large: high steering and holding forces**
- **SAI too small: poor steering return, prone to tyre faults (conicity, angle effect), may cause vehicle to pull to one side**
- **SAI different on left and right-hand sides of vehicle: vehicle prone to pulling to one side.**

Workshop Hint
Like caster, SIA is measured indirectly by applying a steering angle of 20°.

Included Angle (IA)

Included angle is the Camber angle and SAI combined. IA is also helpful when trying to diagnose bent suspension components. Knowing the IA and SAI is helpful when adjusting Camber. If the desired Camber angle cannot be achieved, then looking at SAI and IA could help determine the cause.



Index	Explanation
1	Camber
2	SAI
1+2	Included Angle

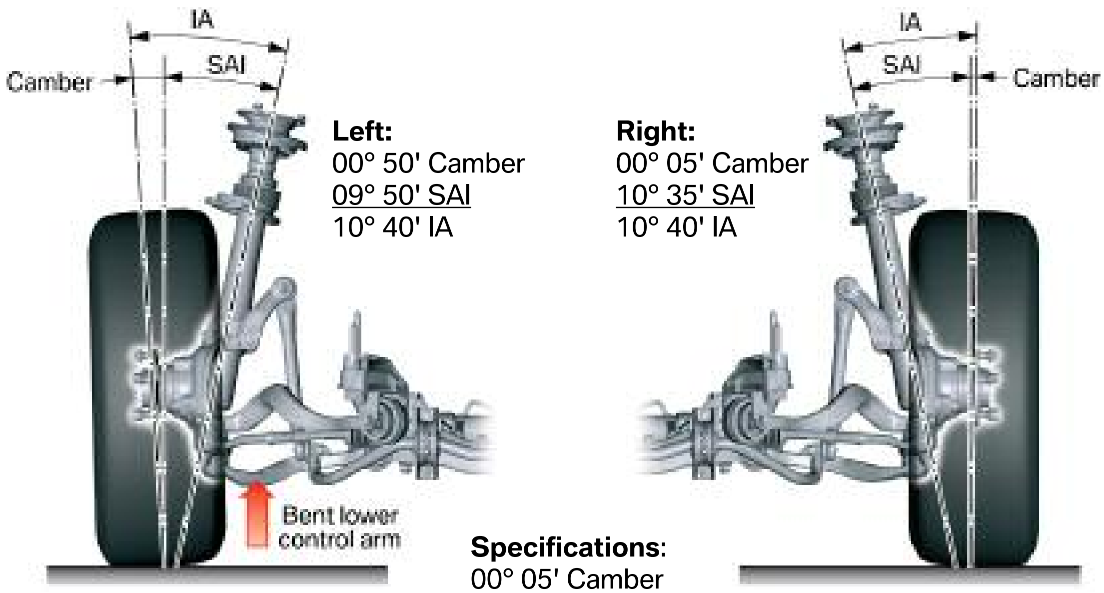
The sum of camber angle (1) and SAI (2) remains constant during wheel compression.

Depending on the type of alignment equipment used, SAI and IA can be measured by raising the vehicle. Look for any excessive deviations from side to side. This could indicate possible chassis (frame) damage or bent components (strut/spindle).

Workshop Hint
The included angle is a good tool to diagnose defective /bent components as spindles and control arms.

Bent Lower Control Arm

In this case, a bent lower control arm creates a reduction in SAI, an increase in camber while included angle remains the same.



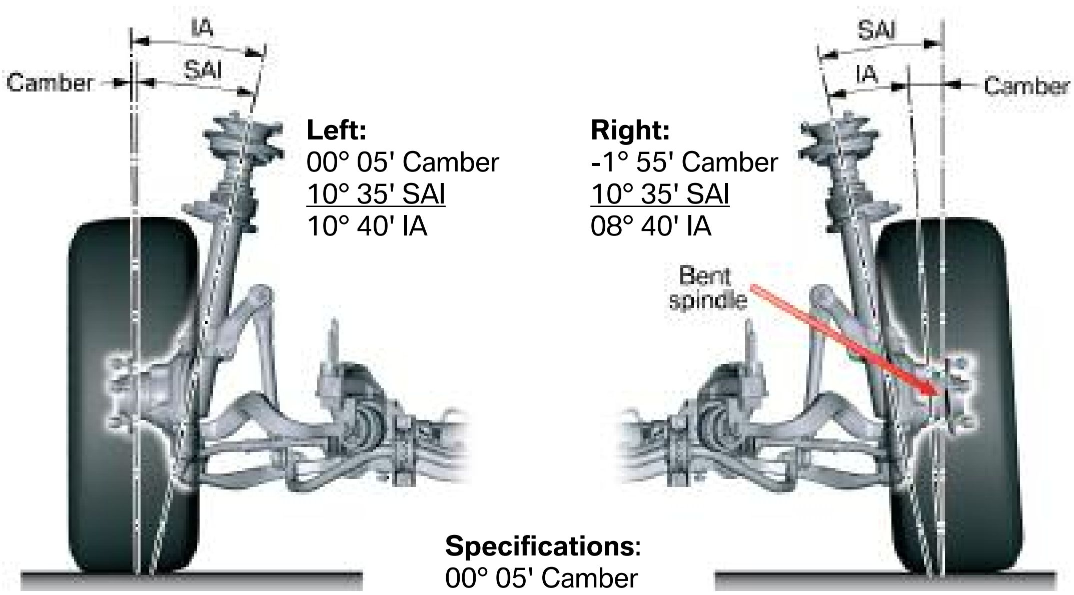
Left:
00° 50' Camber
<u>09° 50' SAI</u>
10° 40' IA

Right:
00° 05' Camber
<u>10° 35' SAI</u>
10° 40' IA

Specifications:
00° 05' Camber
<u>10° 35' SAI</u>
10° 40' IA
(all values +/- 0° 30')

Bent Spindle

When the right spindle was bent, SAI remained unchanged, whole camber and included angle both decreased.



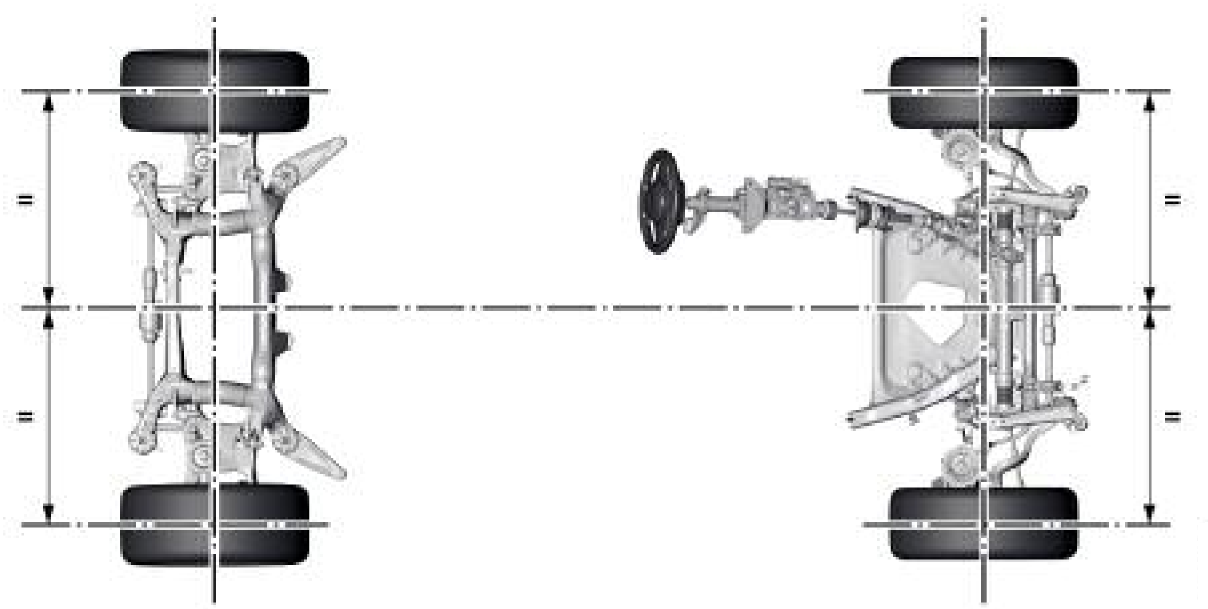
Left:
00° 05' Camber
<u>10° 35' SAI</u>
10° 40' IA

Right:
-1° 55' Camber
<u>10° 35' SAI</u>
08° 40' IA

Specifications:
00° 05' Camber
<u>10° 35' SAI</u>
10° 40' IA
(all values +/- 0° 30')

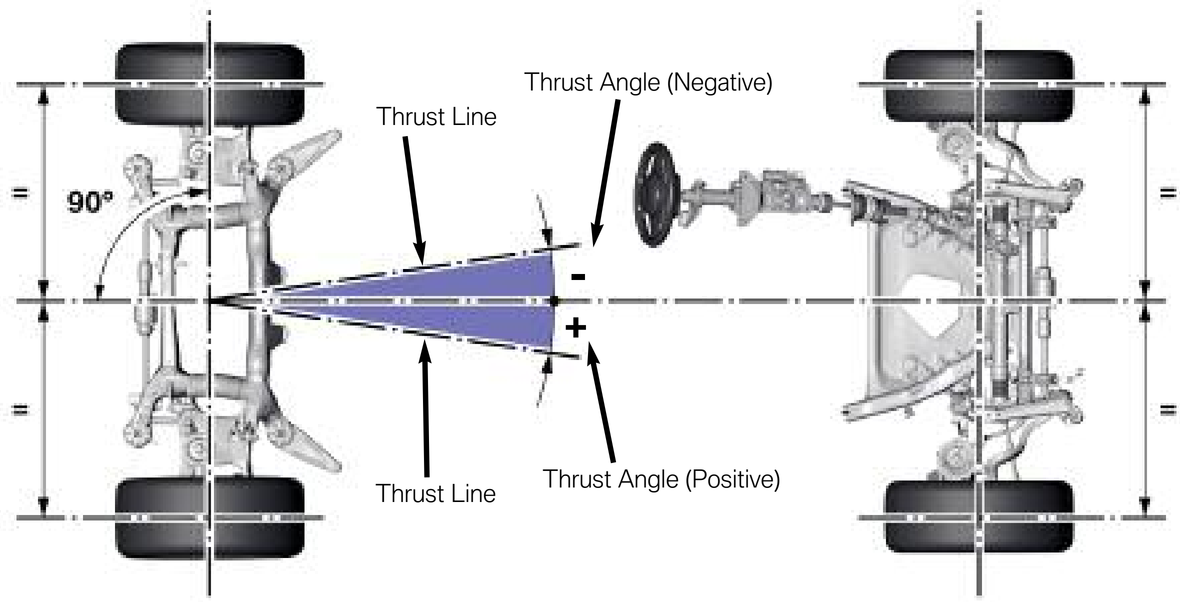
Geometric Axis

The Geometric Axis (Centerline) is an imaginary line that is drawn between the midpoints of both front and rear wheels. The Axis is perpendicular to the axis of the front and rear axles at 90 degrees. This is an imaginary angle that is not adjustable.



Thrust Line / Thrust Angle

The Thrust Line (also known as Geometric Axis deviation) is represented by an imaginary line that bisects the rear toe angle. This angle represents the overall “direction” in which the rear wheels are pointing. The thrust angle is the difference between the Geometric Axis and the Thrust Line. The optimum Thrust Angle is Zero Degrees, any deviation from this will affect the position of the steering wheel.



Positive Thrust Angle

A positive thrust angle is formed when the thrust line is to the right of the Geometric Axis (Centerline). When this situation occurs, the steering wheel position will be off to the right as well. The rear of the vehicle will tend to move to the right which will cause the front of the vehicle to steer left, the driver will move the steering wheel to the right to compensate.

Negative Thrust Angle

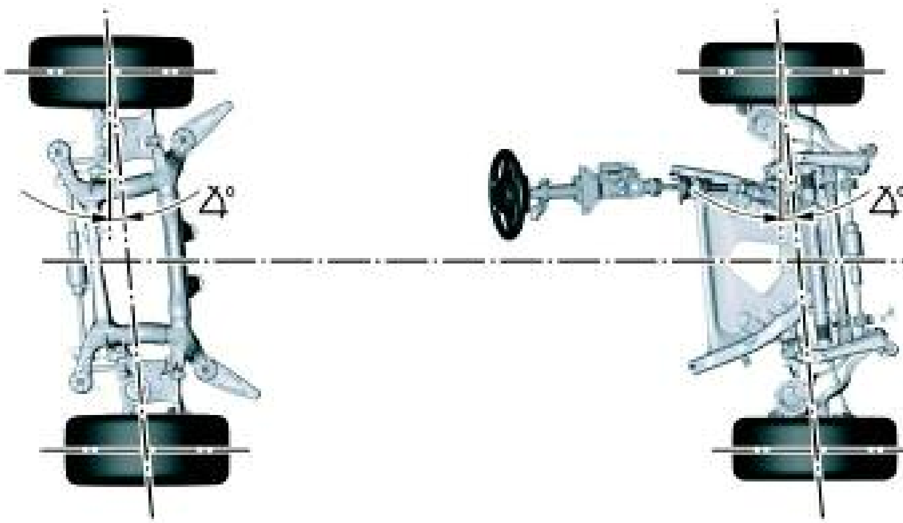
A negative thrust angle is formed when the thrust line is to the left of the Geometric Axis (Centerline). When this situation occurs, the steering wheel position will be off to the left as well. The rear of the vehicle will tend to move to the left which will cause the front of the vehicle to steer right, the driver will steer the vehicle by moving the steering wheel to the left to compensate.

Alignment Procedures:

When performing a wheel alignment, make sure that the thrust angle is as close to zero as possible. Failure to do so can result in a steering wheel that is not centered.

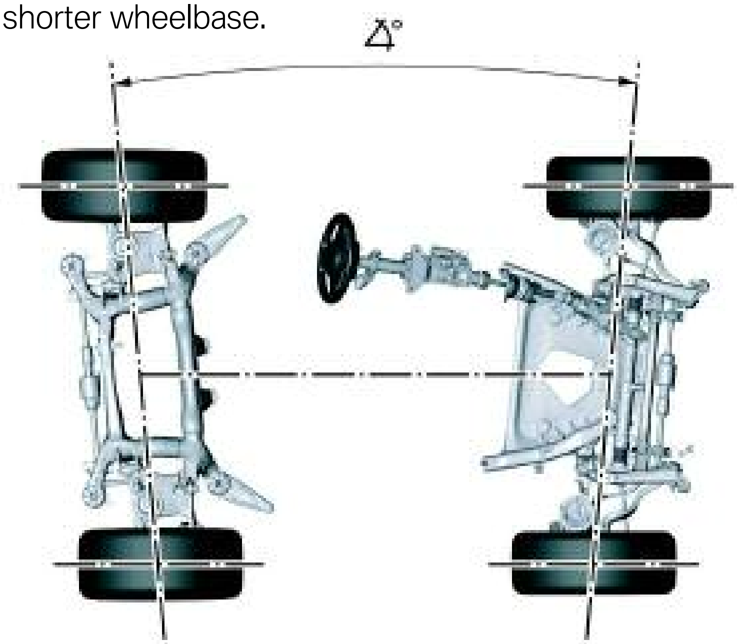
Setback Angle

The Setback angle (also known as front wheel displacement) is the amount by which one front wheel is further back from the front of the vehicle than the other. It is also the angle formed by a line perpendicular to the axle centerline with respect to the vehicle's centerline. If the left wheel is further back than the right, setback is negative. If the right wheel is further back than the left, setback is positive.



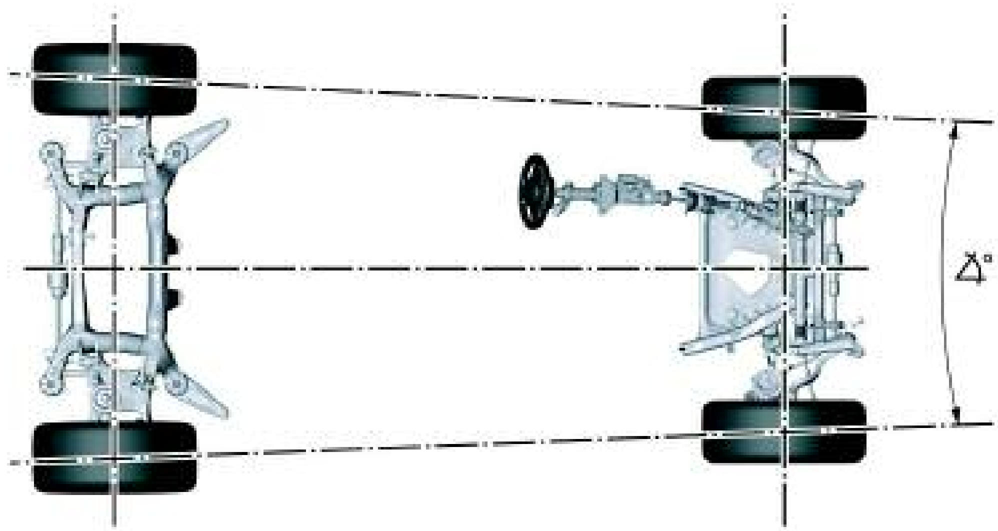
Wheelbase Differential

The wheelbase differential is the angle between the line joining the front wheel contact points and the line joining the rear wheel contact points. The angle is positive if the wheelbase on the right-hand side is greater than that on the left-hand side and negative if vice versa. The wheelbase differential affects cornering. The vehicle will tend to pull to the side with the shorter wheelbase.



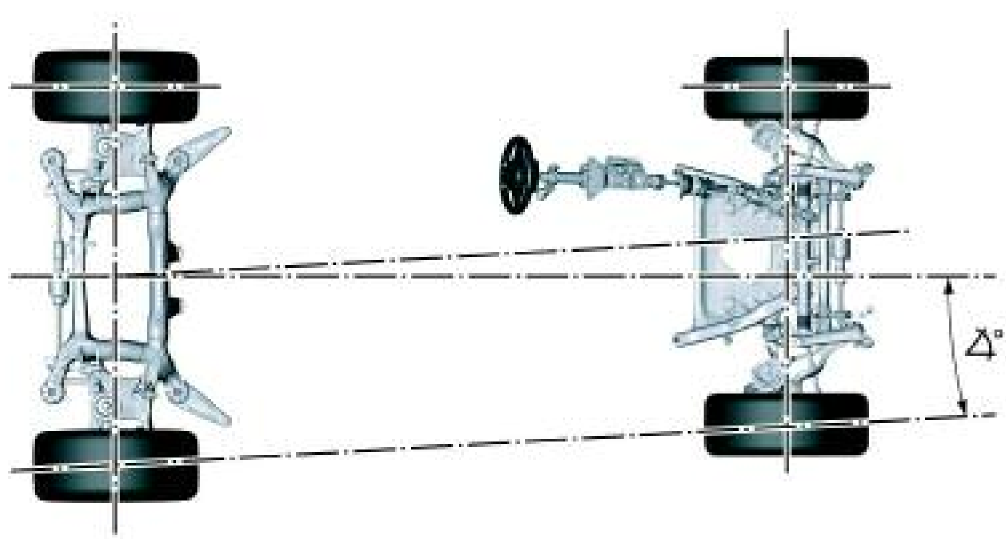
Track Width Differential

The track width differential is the difference between the track widths of the front and rear axles. It is measured in degrees. For this, the position of the lines joining the wheel contact points on the left and right-hand sides of the vehicle with respect to each other is calculated. The track width differential is positive if the rear track width is greater than the front. A track width differential may indicate possible bodywork damage.



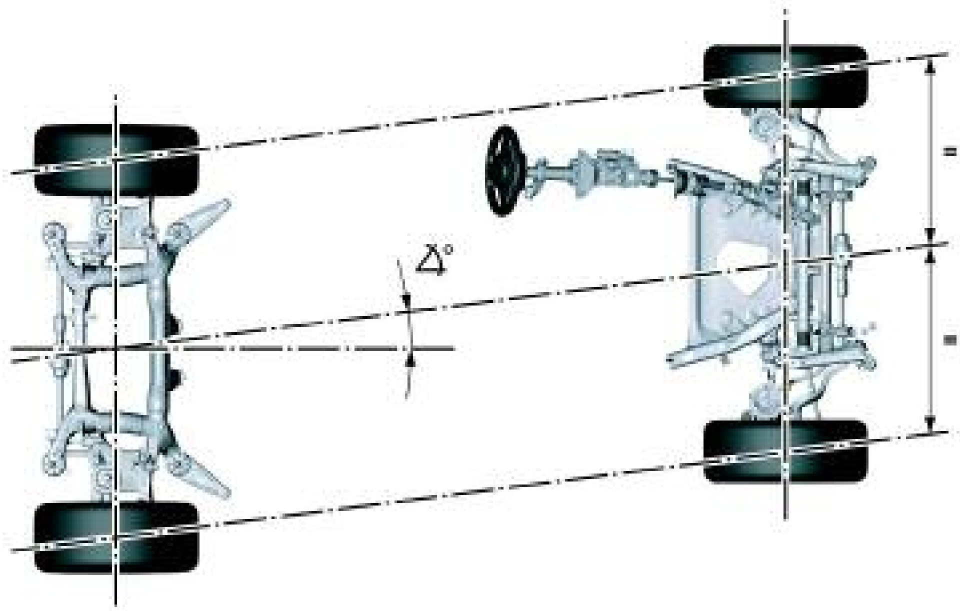
Lateral Offset

The lateral offset is the position of the line joining the wheel contact points on one side of the vehicle, with respect to the geometric axis. This offset is positive if the rear wheel is offset outwards, with respect to the front wheel. This angle may also indicate possible bodywork damage.



Axle Offset

The axle offset angle describes the angle between the angle bisectors of the track width differential and the geometric axis. The axle offset angle is regarded as positive if the rear axle is offset to the right. This angle may also indicate **possible bodywork damage.**



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