

Section 10 Topics

Advanced Diagnostic Techniques

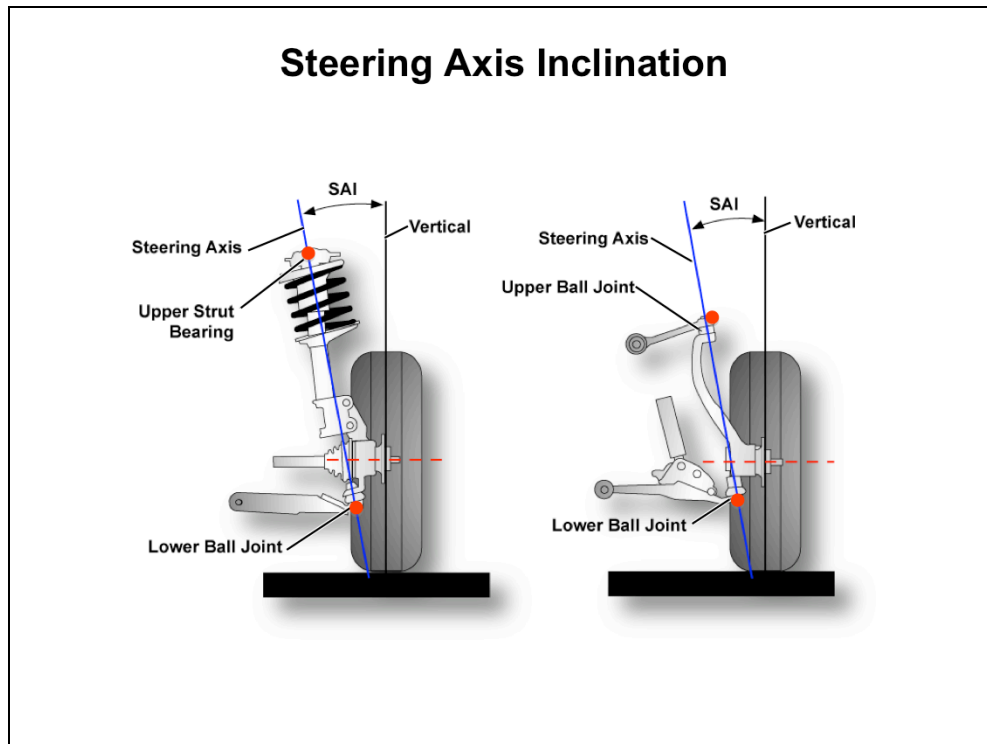
- ▶ **Steering Axis Inclination**
- ▶ **Included Angle**
- ▶ **Scrub Radius**
- ▶ **Turning Angle**
- ▶ **Setback**
- ▶ **Bump Steer**
- ▶ **Point-to-Point Measurement**



 **Diagnosing Using SAI and IA**

Technician Objectives

1. Describe steering axis inclination and included angle, and explain their relationship to camber for both double wishbone and MacPherson strut suspension designs.
2. Describe how to identify structural damage or bent components using SAI, IA and camber values.
3. Explain positive and negative scrub radius and the effects of each.
4. Explain setback and list two possible causes.
5. Explain bump steer and list several causes.
6. List the benefits of point-to-point measurement for identifying structural damage.
7. Describe how to perform the X – measurement, strut tower location, and lower ball joint location inspections.
8. Advanced Alignment Geometry Quick Training Guide QT411D.



Introduction

In some situations the inspection and correction of basic wheel alignment geometry **may not eliminate a handling complaint**, or you may find a vehicle's basic alignment geometry is incorrect and nonadjustable. When faced with these situations you have some additional inspections at your disposal to **pinpoint the root cause of the problem**.

Besides caster, camber and toe, there are several other wheel alignment elements that influence vehicle handling. Inspection of these secondary elements will allow you to identify **bent components** or uncover **structural damage** that is preventing you from properly adjusting the wheel alignment.

This section will explain the **secondary alignment angles** and detail their use in diagnosing the root cause of handling complaints. Also, several other pinpoint diagnosis methods will be outlined that will help you identify the source of difficult handling complaints.

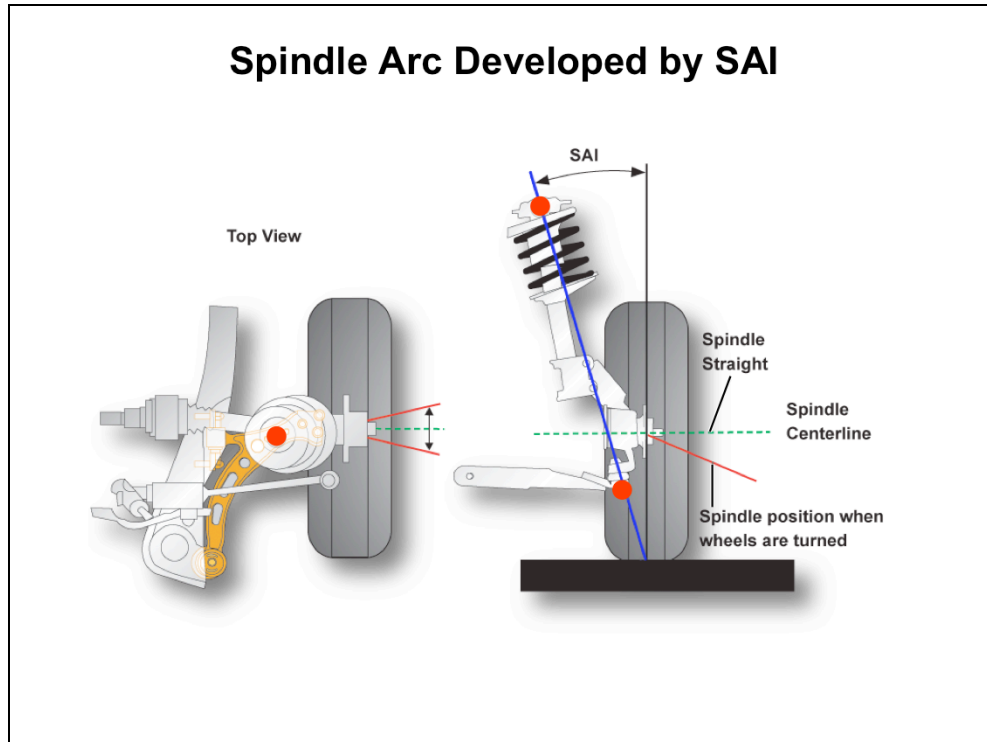
The secondary angles are primarily **nonadjustable** or are influenced by the primary alignment geometry. However, their influence on vehicle handling and diagnostic value is quite significant.

Steering Axis Inclination

Steering Axis Inclination (SAI), also known as ball joint or kingpin inclination, describes the tilt of the steering axis inward toward the center of the vehicle compared to vertical.

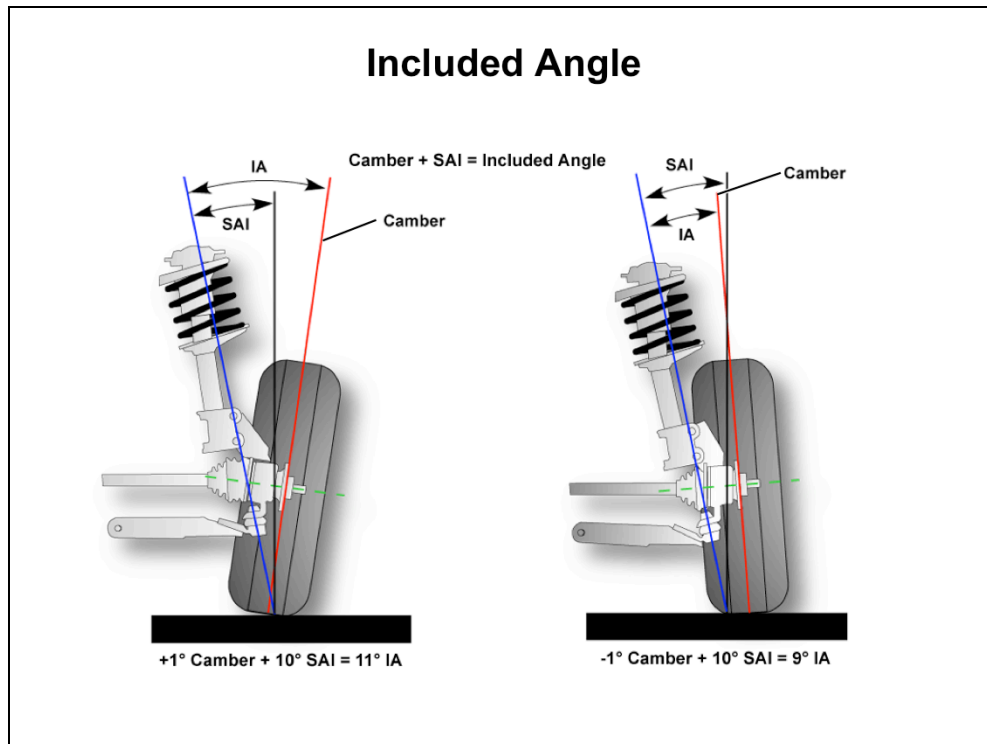
SAI has three primary functions:

- Promote steering returnability and directional stability
- Allow for use of smaller caster angles
- Enhance road isolation

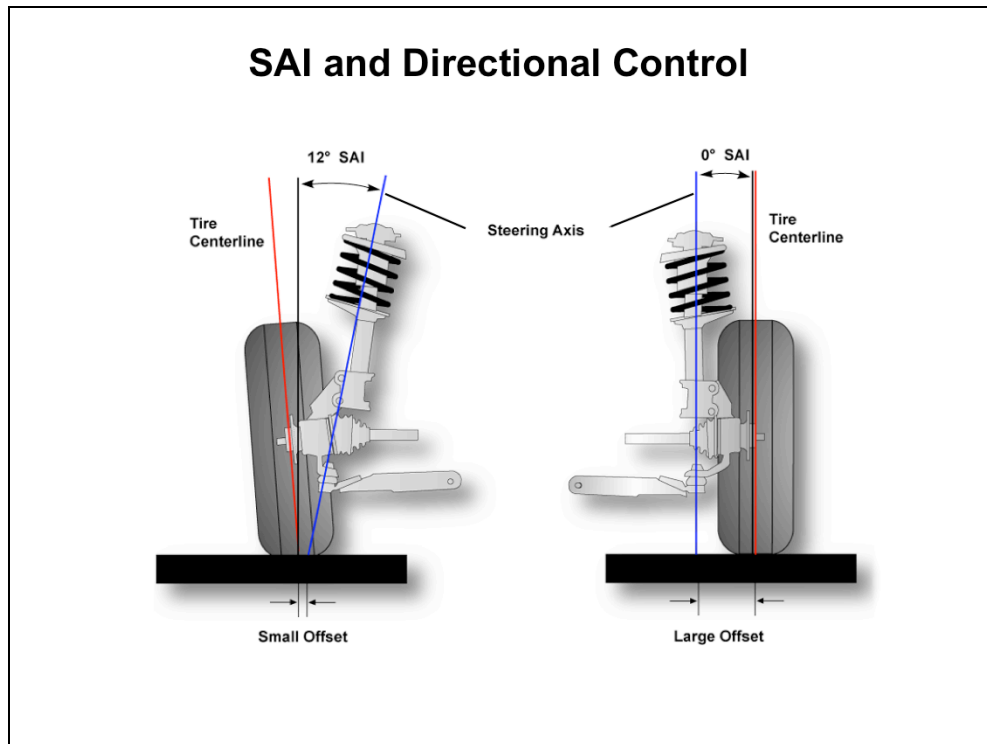


Spindle Arc Tilting the steering axis inward results in a **spindle arc** condition similar to the spindle arc developed by caster. When the steering axis is tilted, the **spindle moves downward** as it is turned from center in either direction (assuming 0° caster). This spindle movement raises the vehicle as the spindle cannot force the wheel and tire any lower. The weight of the vehicle provides steering returnability and directional stability, as the spindles will try to return to their centermost position (similar to caster). Typical SAI values for Toyota vehicles range approximately 9° - 15°.

As explained in Section 7, a positive caster angle provides improved stability and road isolation by reducing the leverage on the spindle. By tilting the steering axis inward a similar effect is produced. **Tire wear is minimized, road shock reduced and handling improved by using SAI instead of caster to reduce this lever effect.**



Included Angle SAI combined with camber forms the **Included Angle (IA)**. By definition the IA is the angle formed by the steering axis and the tire's centerline. A positive camber angle results in an Included Angle value larger than the SAI value, and a negative camber value creates an Included Angle smaller than the SAI value. This relationship between the position of the steering axis and the spindle is **very valuable for diagnosing bent or damaged components**.



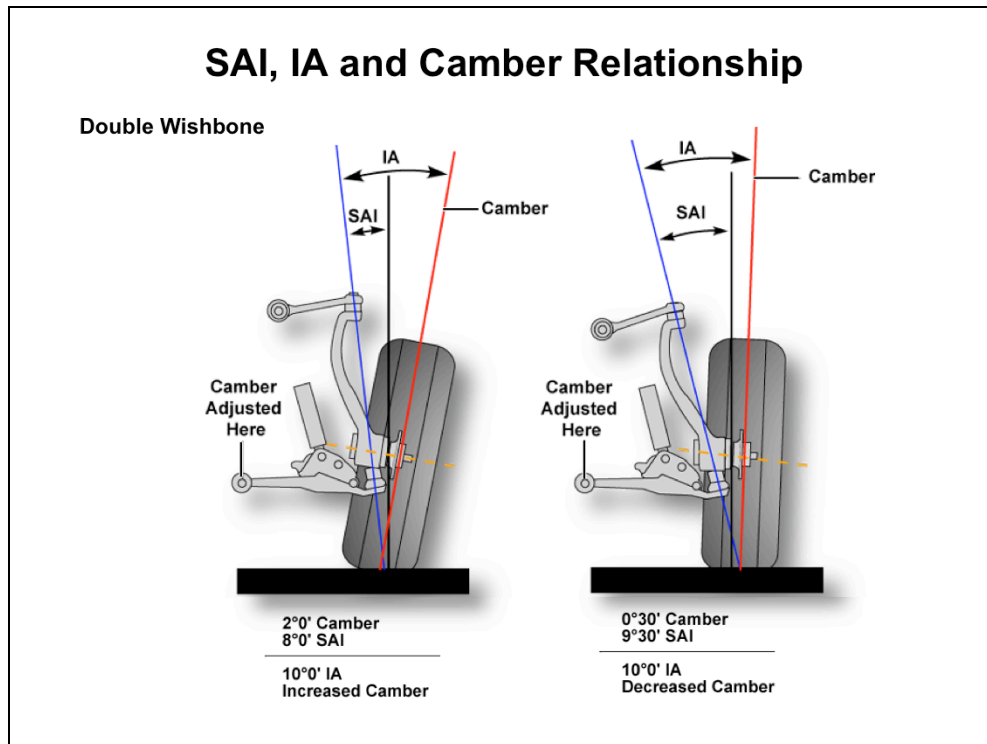
Steering Offset

SAI is considered a **non-tire wearing angle**. However, significant differences in SAI or IA between the left and right sides of the vehicle **may create a directional control complaint**. Left-right differences exceeding 30' - 45' (1/2° to 3/4°) can result in a pulling condition in the direction of the smaller (least positive) SAI value.

A change in SAI changes the point where the steering axis meets the road surface. This point compared to the tire centerline is described as **steering offset**. Steering offset influences the leverage applied to the steering knuckle as the vehicle rolls down the road. Pulling occurs because greater leverage is applied to the steering knuckle at the side of the lower SAI value and larger offset.

Measuring SAI/IA

Similar to caster, SAI is calculated by measuring the arc through which the spindle travels during a 20° to 40° turn of the wheels. The amount of change in spindle attitude between the extremes of the turn provides an accurate indication of how much the steering axis is tilted. Some electronic alignment systems can measure both caster and SAI simultaneously. However, more accurate readings for both values are obtained by making separate measurements for each.



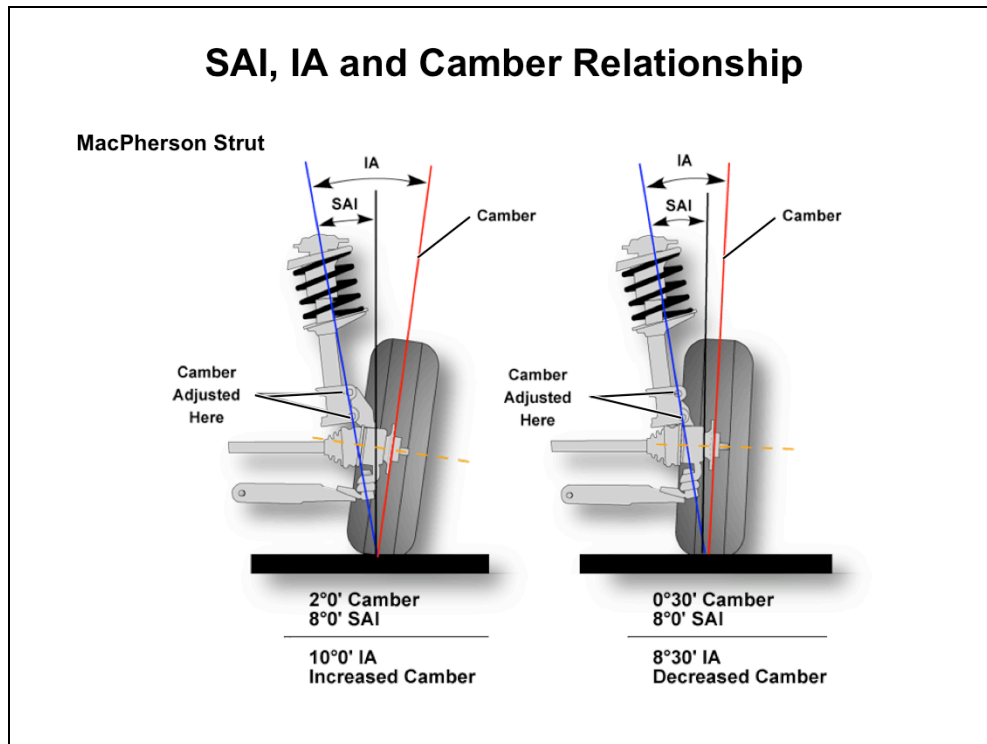
Diagnosing Using SAI/IA

SAI and IA should be inspected anytime a vehicle's primary alignment geometry:

- Is incorrect and nonadjustable.
- Is adjusted to its maximum at one or both sides of the vehicle.
- Is being inspected or adjusted following collision repair.
- Does not reveal the root cause of the handling complaint and is not apparent during inspection of the primary geometry.

Before making any diagnostic judgment using SAI, **pay particular attention to camber and camber spread**. Changing camber may alter SAI or IA depending upon the type of suspension and the method of camber adjustment.

On double wishbone designs, the SAI changes as camber is adjusted while the IA remains constant.



SAI, IA and Camber Relationship – MacPherson Strut

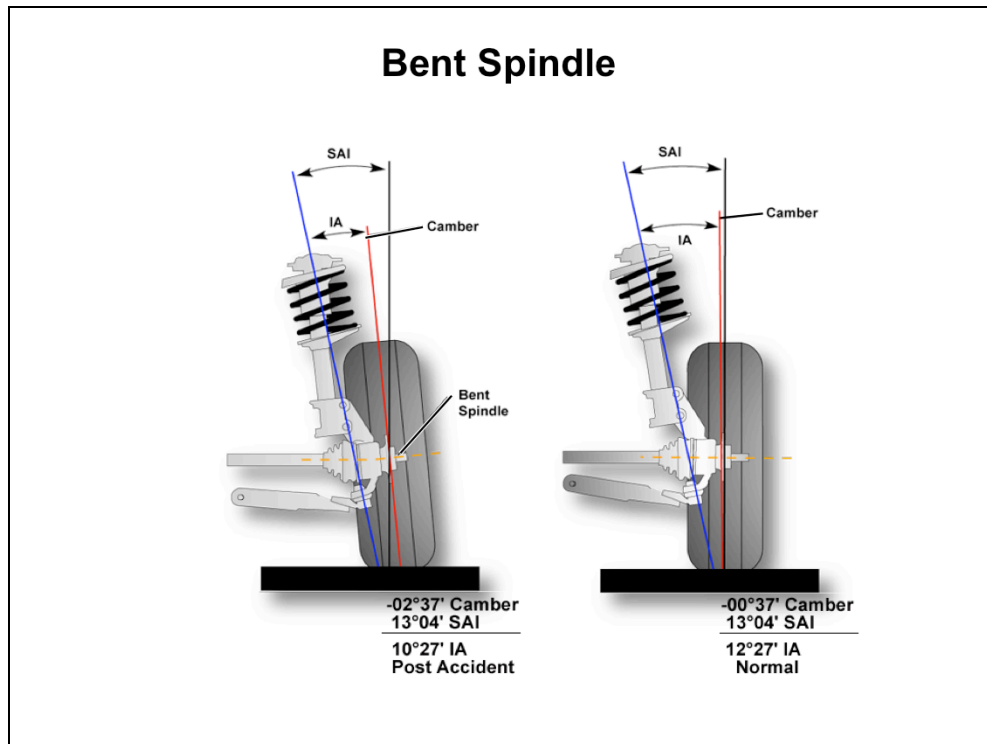
On MacPherson strut suspension; a **change in camber changes IA** while the angle of the **SAI remains constant**. During your diagnosis remember, camber spread will create a difference in either SAI or IA side to side and must be considered.

The relationship between SAI, camber, and IA can be effectively **used to identify bent components and/or structural damage**. Diagnosis varies slightly between double wishbone and MacPherson strut suspensions as a result of their design differences.

Between both designs, one diagnostic rule holds true:

- IA is a direct indication of spindle condition.

If the spindle is OK, the IA should be correct. While Toyota service specifications do not list IA values, simply add the SAI and camber valued to obtain a specified IA reading. When comparing SAI and IA values there should be a maximum difference between the left and right sides of the vehicle of 30' to 45' (1/2° to 3/4°) depending upon application.

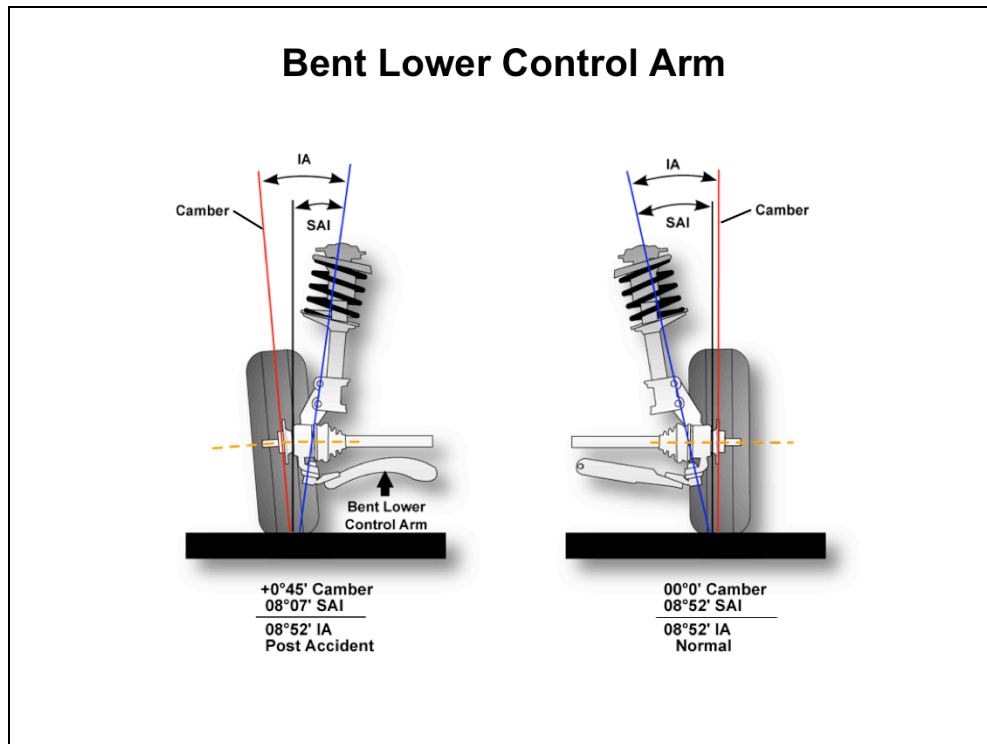


**Diagnostic Example –
Bent Spindle**

To illustrate the relationship between SAI, camber, IA, and their benefit to diagnosis, consider the following example.

The right **spindle is bent upward in an accident, reducing camber** by 2°. The measured alignment values are indicated above. Assume no other damage and correct alignment geometry before the accident.

The **difference in camber is causing a significant pulling condition**. Notice the position of the steering axis did not change, only camber and IA. Neither the lower control arm or the strut could cause this condition, only a bent spindle.



Diagnostic Example – Bent Lower Control Arm

Consider another example using the same vehicle. The owner complains of a pulling condition caused by a **bent lower control arm**. An initial inspection reveals a camber spread of 45' ($3/4^\circ$) with the left more positive than the right. This variance is outside of specification and the spread is large enough to **cause the pulling complaint**.

When the left lower control arm is bent upward in the center, the angle of the SAI decreases. The spindle also moved downward, increasing positive camber. The IA remained intact as SAI decreased and positive camber increased proportionally.

SAI/IA Diagnostic Table

MacPherson Strut

Your inspection finds:

SAI	Camber	Included Angle	Possible Cause
Correct	Less	Less	Bent spindle* and/or strut
Correct	Greater	Greater	Bent spindle* and/or strut
Less	Greater	Correct	Bent control arm or strut tower out at the top
Greater	Less	Correct	Strut tower in at top
Greater	Greater	Greater	Strut tower in at the top and spindle and/or strut bent
Less	Greater	Greater	Bent control arm or strut tower out at the top and bent spindle and/or strut
Less	Less	Less	Bent control arm or strut out at the top and spindle and/or strut bent

* **Note:** A bent or misaligned spindle may also be caused by a bent steering knuckle or other suspension component damage.

Diagnostic Table – MacPherson Strut

This diagnostic table applies to **MacPherson strut designs** and details the various combinations of SAI, camber and IA. Each of the combinations listed follows similar logic as the two previous diagnostic examples.

Identifying structural damage, such as bent strut tower, may require additional inspections. Point-to-point measurements may be necessary to determine if the vehicle's unibody structure requires straightening. This inspection method will be covered in detail later in this section.

SAI/IA Diagnostic Table

Double Wishbone

Your inspection finds:

SAI	Camber	Included Angle	Possible Cause
Correct	Less	Less	Bent spindle
Less	Greater	Correct	Bent lower control arm
Greater	Less	Correct	Bent upper control arm
Less	Greater	Greater	Bent lower control arm and spindle

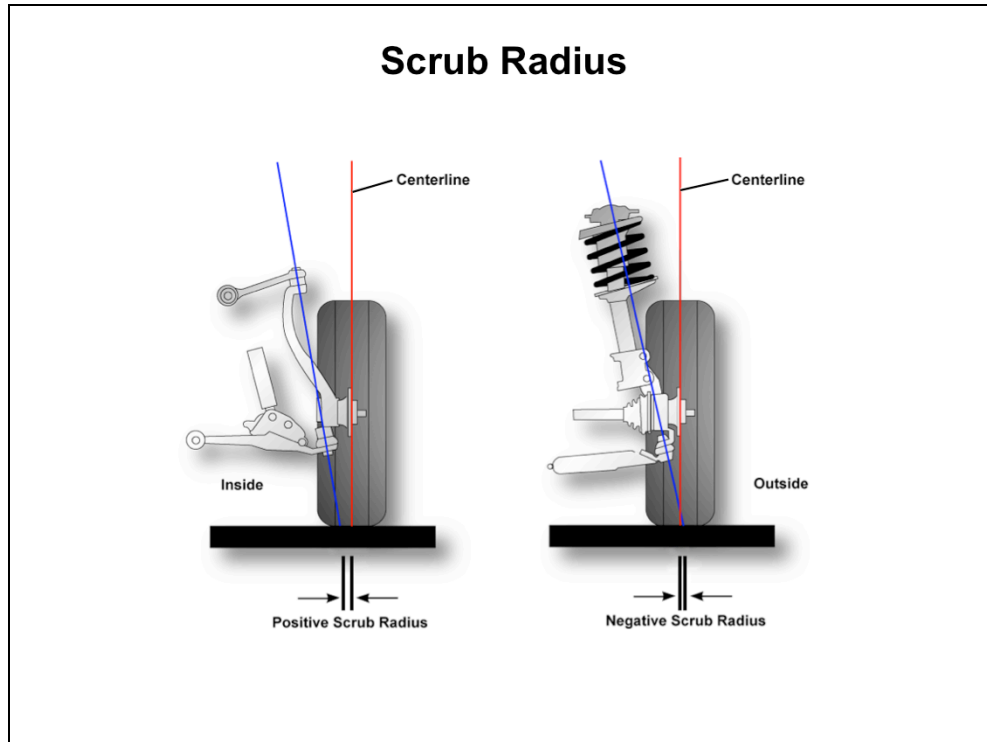
Diagnostic Table – Double Wishbone

The diagnostic table applies to **double wishbone designs** and details the various combinations of SAI, camber and IA. Each of the combinations listed follows similar logic as the two previous diagnostic examples.

Identifying structural damage, such as bent strut tower, may require additional inspections. Point to point measurements may be necessary to determine if the vehicle's unibody structure requires straightening. This inspection method will be covered in detail later in this section.

NOTE

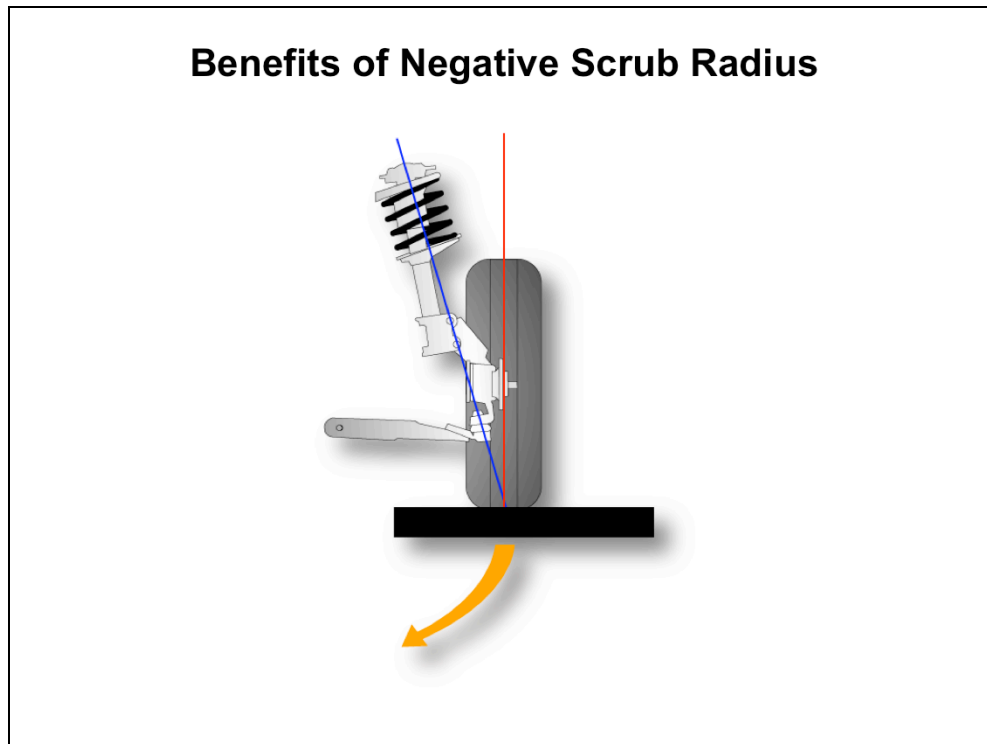
These diagnostic tables may also be found in the appendix.



Scrub Radius

Scrub radius is a function of IA and wheel offset. The point at which the SAI meets the road surface, provides significant influence on a vehicle's handling characteristics. This point, compared to the intersection of the wheel centerline and the road surface forms the **scrub radius of steering offset**.

The front wheels pivot at the point where the SAI meets the road surface. As the wheel centerline is offset from this pivot point, both steering effort and road feel increase. The **greater the scrub radius, the greater the effort required to turn the wheels**. As scrub radius decreases, with all other factors remaining equal, steering effort and the amount of road feedback to the driver decreases. Scrub radius can be classified as either positive or negative.



Positive or Negative Scrub Radius

When the SAI intersects the road surface inside the wheel centerline the scrub radius is positive. **Positive scrub radius** creates a force that causes the wheel to turn or **toe outward** as the vehicle moves forward. This force requires the front wheels to be toed-in statically. Positive scrub radius is generally used on rear wheel drive vehicles, which have a conventional braking system that provide equal braking force between the left and right wheels.

Negative scrub radius describes the SAI intersecting the road surface outside the wheel centerline. A negative scrub radius creates a force that causes the wheel to turn inward or **toe in**. To counteract this tendency static toe-out or a minimal toe-in setting is used.

Front wheel drive vehicles with diagonal-split braking systems typically use negative scrub radius to balance the slightly different braking forces between the left and right wheels. This negative scrub helps the driver to maintain direction control of the vehicle during heavy braking.

A negative scrub radius also **reduces torque steer**. The inward turning effect of the wheels helps to counteract the unequal driving forces applied to them by the drive axles.

Another benefit of negative scrub radius is improved handling in case of a tire failure. The vehicle is less likely to pull toward the blown tire as the negative scrub radius causes the tire to turn inward instead of outward.

453 Suspension, Steering and Handling

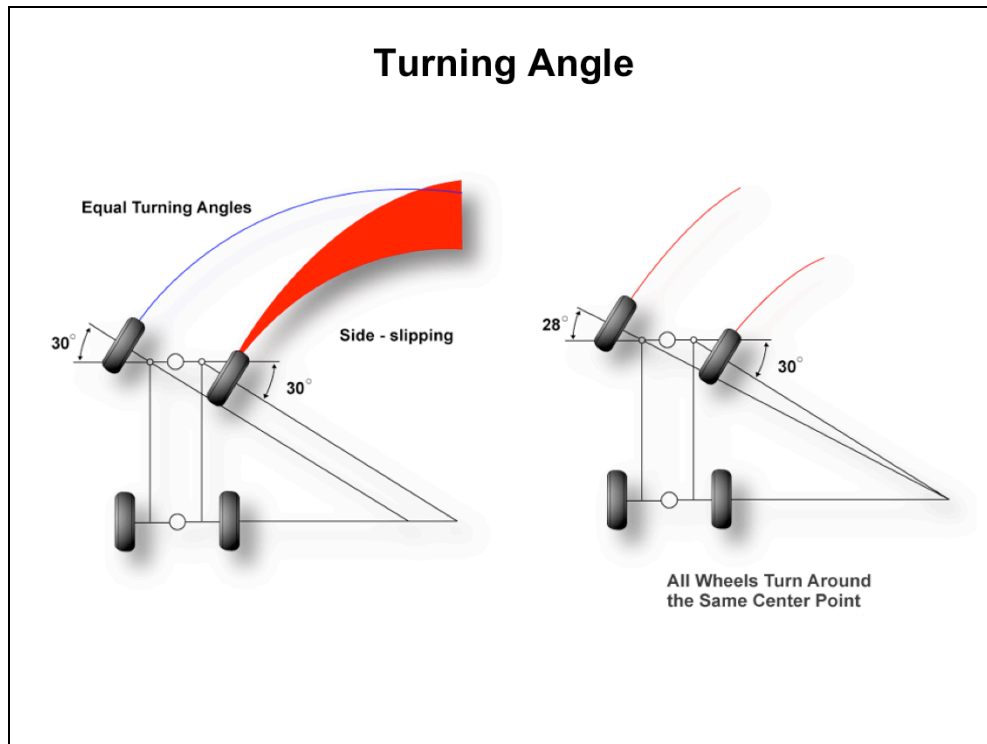
Zero Scrub Radius Zero scrub radius describes the steering axis and the wheel centerline intersecting right at the road surface. A zero to a slightly negative scrub radius provides **optimum steering response**. The nimble handling results from the small pivot point for the steering axis. One drawback to this small pivot point of minimal scrub radius is **reduced road feel** or steering feedback to the driver. Zero scrub requires a minimal to zero static toe setting as the inward or outward forces applied to the wheel are greatly reduced.

Measurement of Scrub Radius While not measurable like the other alignment angles, scrub radius is a definitive element of a vehicle's handling characteristics. Scrub radius, steering ratio, power assist, tire size, and static alignment values all determine the vehicle's steering effort and road feel. Any change in wheel offset or overall tire/wheel diameter from OEM will change the scrub radius.

NOTE

Tire/wheel appearance may be a critical issue to your customer, it is important to note that significant changes in scrub radius may **alter the vehicle handling** enough to cause a safety problem; particularly on front wheel drive cars during hard braking. Also, the static toe specification may no longer be accurate which could result in premature tire wear, wander, or shimmy complaints.

Moving the wheel centerline outward also **multiplies the lever effect**, increasing road shock, reducing direction stability, and increasing the load on the outer wheel bearing. To maintain optimum handling and ride quality, Toyota recommends maintaining OEM offset.

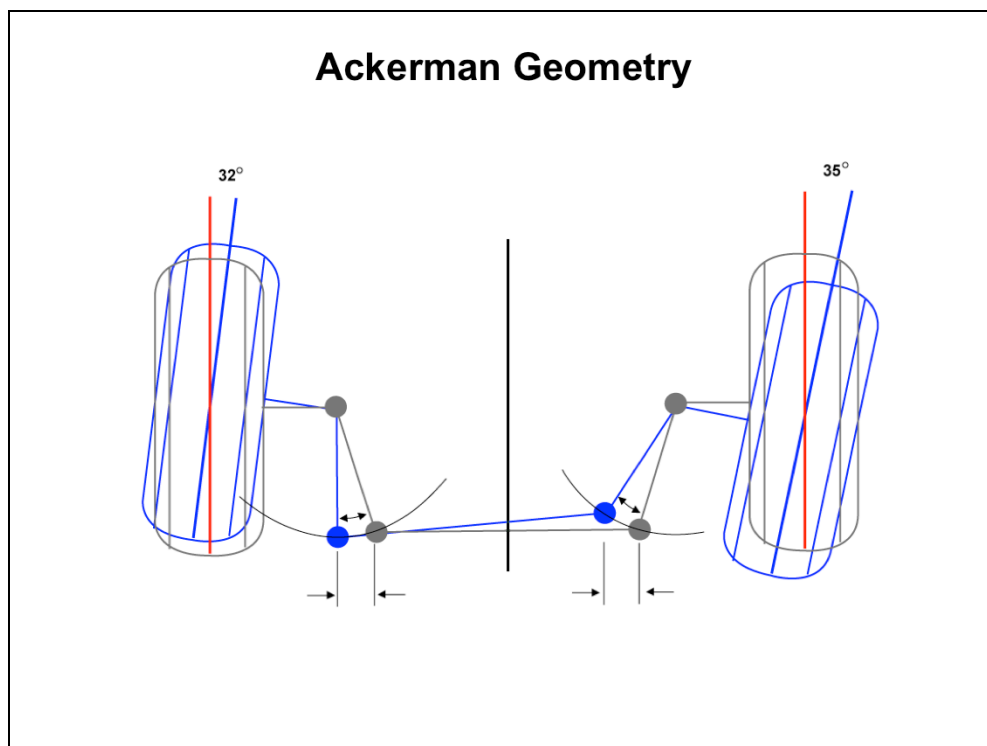


Turning Angle Turning angle is a comparison of the wheel centerline and the front axle centerline when the front wheels are turned.

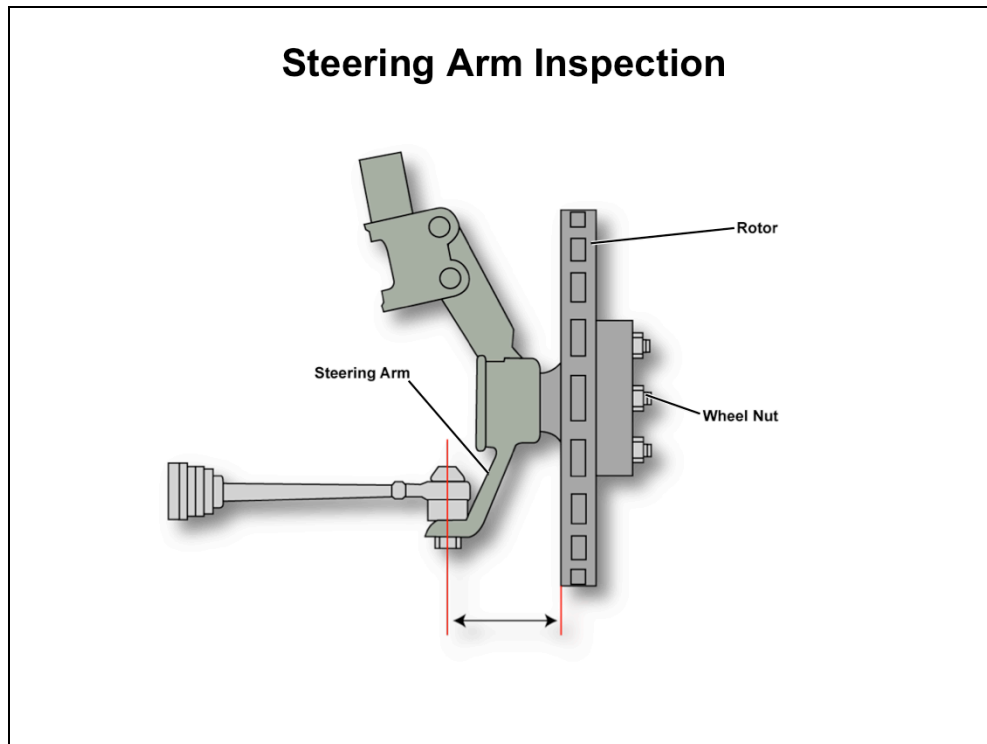
If the left and right wheels are turned by the same amount, i.e., the turning angles are equal, each wheel would **turn around different center points** or follow different circles. A difference in these center points effectively means the wheels are turning around different circles and **one tire will be forced to slip across the road surface**.

If the front wheels are to **turn around the same circle**, the inside wheel must **turn at a sharper angle** than the outside wheel.

In practical application, the steering linkage is designed to allow for a different turning radius between the wheels. The inside wheel turns at a greater or sharper angle than the outside wheel. The sharper turning angle of the inside wheel allows it to travel around a smaller circle (less distance) than the outside wheel, **preventing side scrub treadwear**. The inside wheel generally turns sharper than the outside by 2°-5°. This difference in turning angle between the wheels is also described as **toe-out on turns**.



Ackerman Geometry To achieve this difference in turning angle, the steering arms attached to each spindle are **nonparallel**. When the steering linkage is mounted behind the front axle centerline, the arms are angled inward. A line projected rearward from each arm intersects at the center of the rear axle when the front wheels are straight ahead. This design, which provides toe-out on turns, is defined as the **Ackerman effect**.



Measuring Turning Angle

Turning angle or toe-out on turns is **nonadjustable** and it should be inspected if the vehicle squeals when turning corners or has abnormal front tire wear that cannot be identified. Inspection is done simply using the turn plates on the alignment rack by **comparing the difference in turning angles** between the left and right wheels.

It is important to note that **static toe should be adjusted to specification** before inspecting turning angle to ensure an accurate reading. Also, center the vehicle on the turn plates for the most accurate results.

Steering Arm Measurement

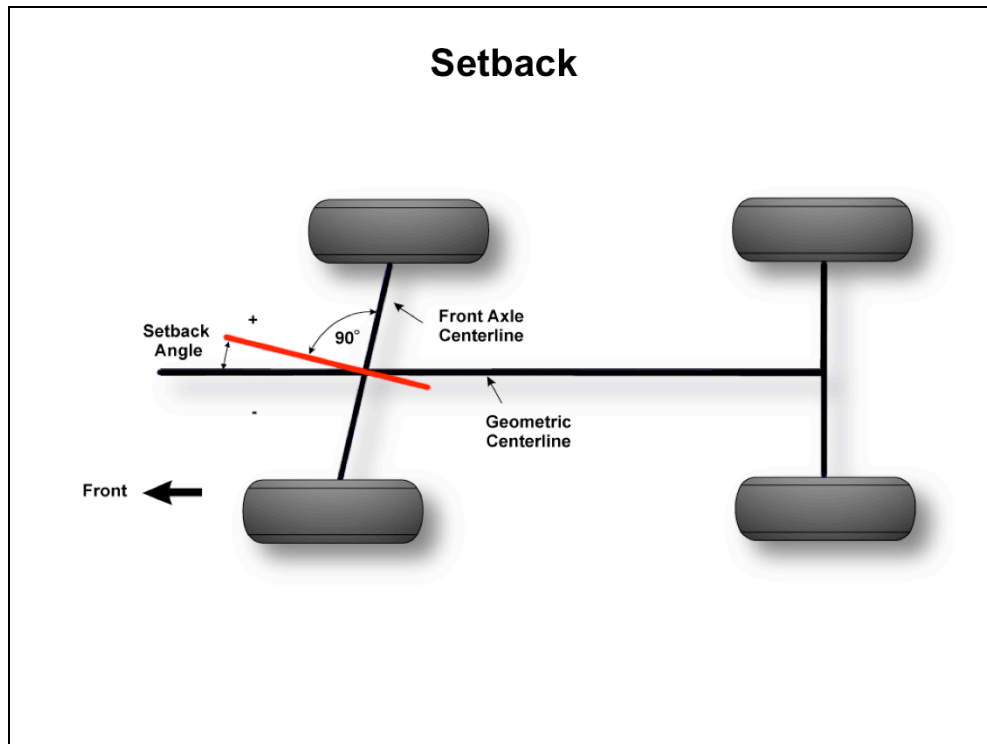
If turning angle values are incorrect by 1.5° or more, a bent steering arm is likely the problem. Typically the right arm will see the most abuse from hitting curbs or other obstructions. To confirm a bent steering arm, first measure tie-rod length. A variance of only **1.5 mm maximum** is allowed between the left and right tie rods on most models (3.0 mm on trucks).

If the tie rods are OK, remove the tie rod end from the steering arm and measure the distance between the tie rod end center and the brake rotor. Values should be the same between the left and right sides of the vehicle.

As with all suspension and steering components, **DO NOT ATTEMPT TO STRAIGHTEN BENT PARTS.**

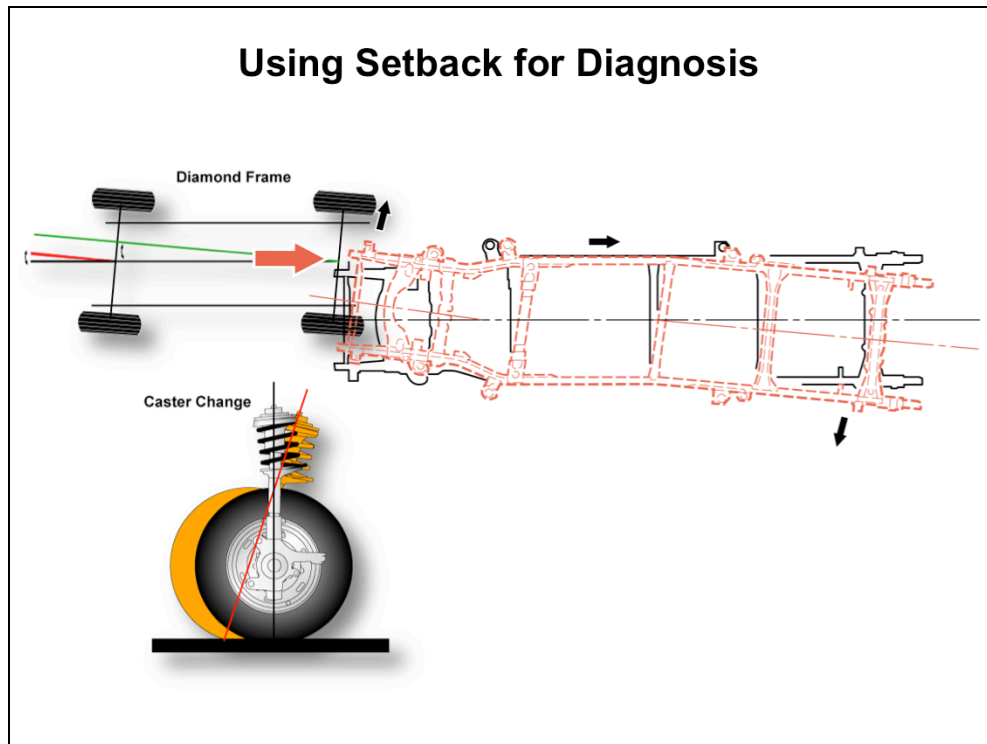
Maximum Turning Angle

On some models, the maximum turning angle for each wheel is adjustable by changing the length of the knuckle stop bolt. Maximum turning angle should not exceed specification to prevent the tires from contacting the vehicle's frame. Replace the caps covering the bolts following any adjustment. This adjustment only changes the maximum turning angle and does not effect toe-out on turns.



Setback Setback describes a **difference in wheelbase** between the left and right sides of the vehicle. The setback angle is formed by the vehicle's geometric centerline and a line perpendicular (90°) to the front axle centerline. A positive setback value indicates the right side of the vehicle is shorter than the left. Negative setback indicates the vehicles left wheelbase is shorter than the right.

A difference in wheelbase between the left and right sides of the vehicle **may result in a pulling condition**. The vehicle will tend to pull toward the side with the shortest wheelbase and a torque steer condition may also result.



Measuring Setback

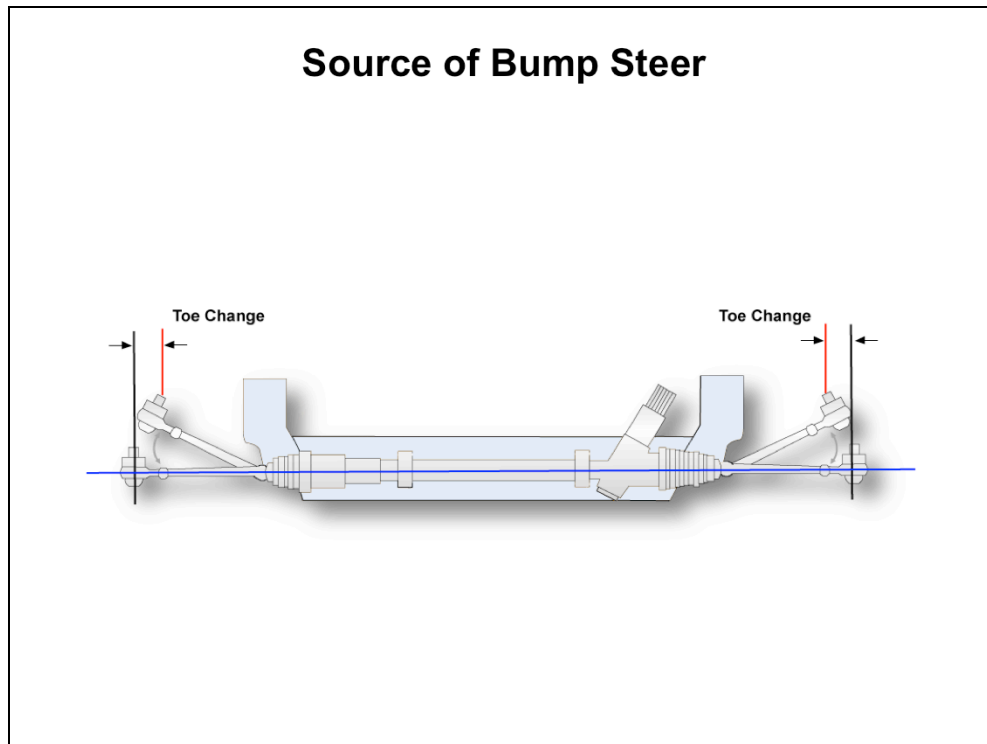
A quick check of setback is to see if the wheel is centered in the wheel opening with the steering wheel centered.

Before measuring setback, individual caster and toe values must be equal to ensure an accurate reading. Electronic alignment equipment measures setback by comparing the individual positions of each front wheel. Setback should generally be zero, however any **caster spread will produce a setback value.**

Except for setback due to caster spread, a measurable setback value may indicate structural or component damage or a shifted sub-frame. Therefore, setback can be used to identify structural damage that is preventing alignment adjustment or causing an incorrect alignment value. But be sure to consider the elements of front and rear toe, caster, and thrust when diagnosing setback conditions. For example, if the thrust angle and setback values are nearly equal and in the same direction, a diamond frame condition is indicated.

If a lower control arm were bent rearward, caster spread would show a more negative value on the side of the vehicle with the bent arm and a corresponding setback value.

Setback alone is not a very valuable element for diagnosis. But when combined with the other elements of alignment geometry, setback can be helpful in determining the wheel's position and the cause of any inaccuracy.

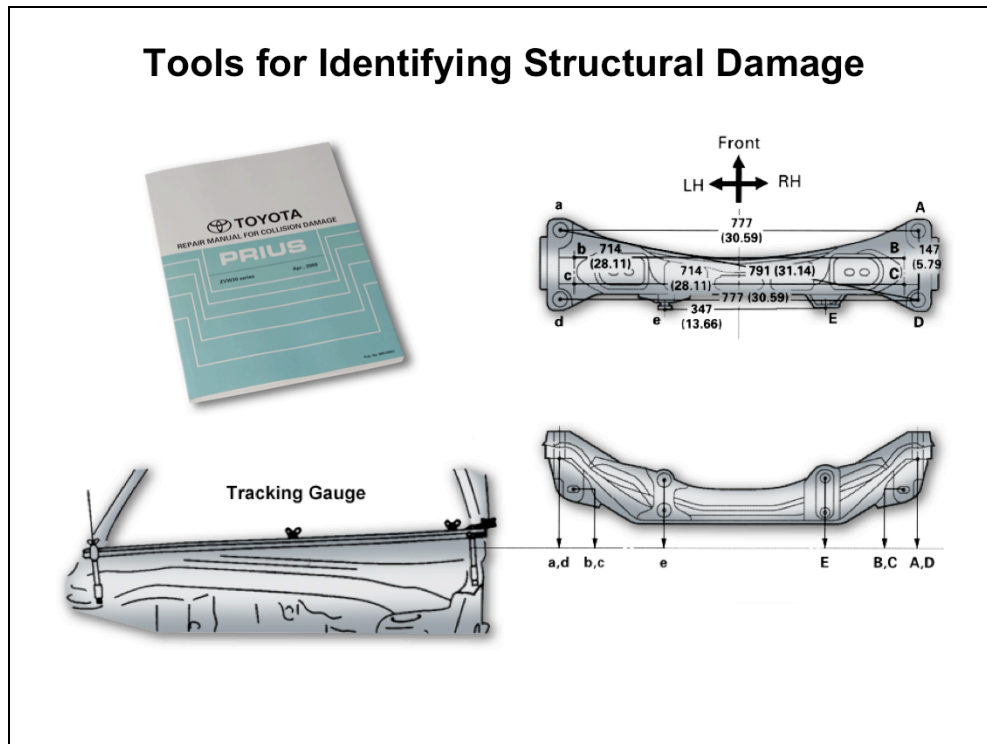


Bump Steer Bump steer describes the change in the front toe as the suspension moves through compression and rebound. The toe value changes as a result of the differing arcs or travel paths that the suspension and the steering linkage follow as the suspension is compressed. Some bump steer cannot be eliminated. Bump steer can however cause **significant handling concerns when excessive** or drastically different than originally intended by the vehicle's design engineers. Generally a bump steer condition will manifest itself as instability when traveling over road irregularities or during braking.

Measuring Bump Steer Bump steer is easily measured when the vehicle is on the turnplates of the alignment rack. With the static toe adjusted correctly and the vehicle steered straight ahead, move the suspension through compression and rebound several inches each direction while observing the change in front wheel toe. The **toe change should be minimal**, about 1/16" (1.6 mm) or less as a general rule. More importantly, the toe change should be the same amount and in the same direction (positive or negative) at both wheels.

Causes of Bump Steer Toe that changes in opposing directions or is excessive usually indicates one or more of the following:

- Unlevel steering linkage
- Ride height problems
- Worn or bent steering system joints
- Loose or worn rack mounts
- Structural damage



Point-to-Point Measurement

Determining when a vehicle requires unibody or frame alignment can be a puzzling task using only wheel alignment equipment. Confirmation of a vehicle's structural alignment often allows you to determine if unibody damage or bent suspension components are causing alignment inaccuracy on nonadjustable vehicles.

Confirmation of a vehicle's structural integrity may be accomplished quickly and easily using one of three inspections.

- X-measurement
- Strut tower location
- Lower ball joint location

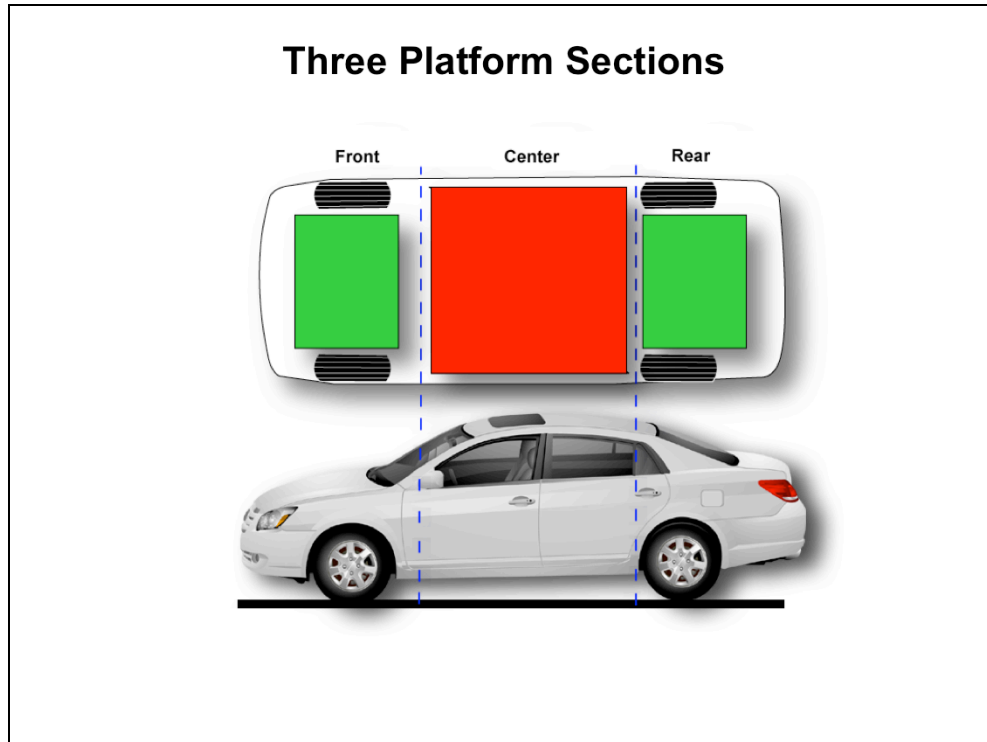
These inspections are described as **point-to-point measurements** and all require a **tracking gauge** or similar device for measuring. A tape measure will not provide precise enough measurements between the specified points for comparison to published dimensions. The vehicle's structure is built to precise tolerances and accurate measurements are crucial. Many Toyota vehicles require accuracy to within 1 mm on all structural dimensions (full frame vehicles are 3 mm). Differences from specification exceeding 1 mm may indicate damage.

The tracking gauge measures distances using an adjustable bar with pointers at each end. It is only an indicator of possible damage. Final confirmation of unibody damage requires advanced measurement/correction equipment.

The **Toyota Body Collision Damage Repair Manual** provides the measurement points and correct dimensions for the entire vehicle structure.

When using a tracking gauge follow several important cautions including:

- Measure from the center of reference holes not the outside edges.
- Keep the height of the pointers equal.
- Hold the bar as straight as possible when making measurements.



Three Box Construction

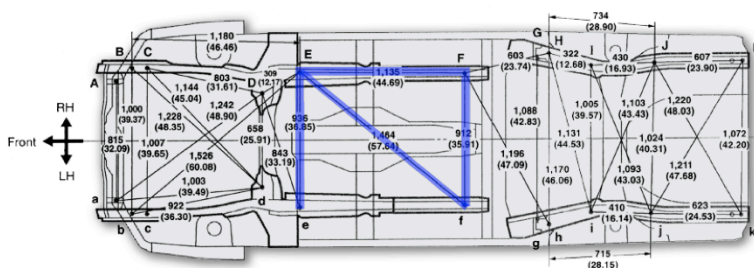
The vehicle platform forms a rectangle that is comprised of three individual boxes or platform sections. The forward, center, and rearward boxes must all be square to one another for correct alignment geometry and proper vehicle tracking.

Measuring the vehicle's structural integrity **starts with confirmation of the center platform**. The dimensions for the vehicle's center section provides the foundation for all other measurement points and should be verified prior to making any other inspections. Under the vehicle, you will make three quick checks to verify the center platform:

1. Left and right dimensions of the center platform.
2. Diagonally across the center platform.
3. Side-to-side across the front and rear of the center platform.

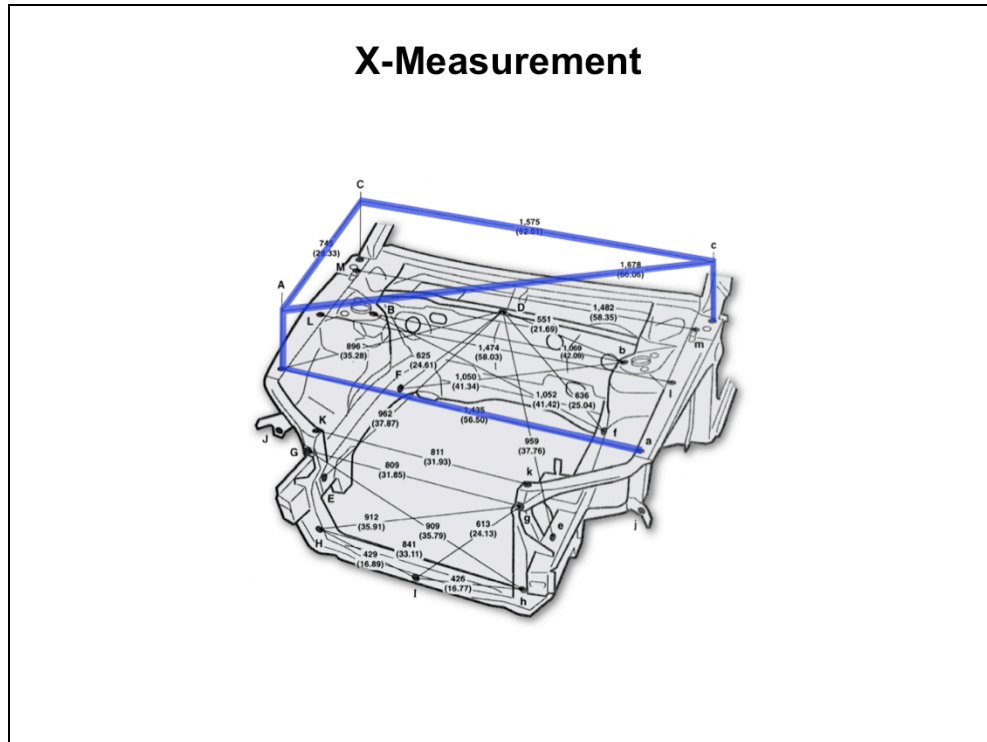
Your results should be within approximately 1 mm in all directions on most unibody models and 3 mm on frame models. After verifying the center section is within specifications, you have a valid basis for measurements of the forward and rearward sections.

Reading Underbody Dimensions



Reading Underbody Dimensions

Dimensions are provided for every major point of the vehicle's structure. As an alignment technician you will only be concerned with a limited number of perimeter points for each section of the vehicle.

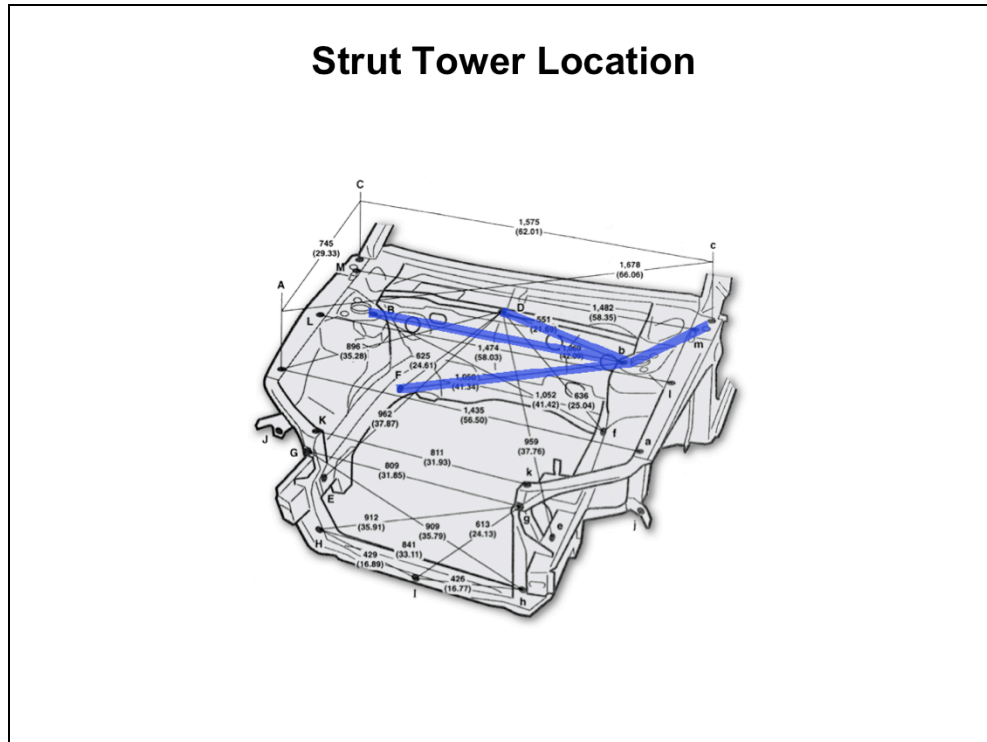


X-Measurement The X-measurement is used to confirm the integrity of the forward vehicle structure. If the basic alignment geometry suggests the forward box is out-of-square or asymmetrical, (such as setback, thrust, and toe errors in the same direction) an X-measurement compares the distances across the forward box from corner-to-corner.

A square box has equal dimensions from corner to corner. A difference between the two measurements confirms structural damage. A professional body service technician must straighten the vehicle's structure before wheel alignment geometry can be corrected.

Measurements are made underhood using the same tracking gauge used for underbody measurements. While actual measurement points may vary slightly between vehicle models, it is important to compare dimensions to the given specifications. Equally important is comparing measurements between the left and right sides of the vehicle. Similar inspections can be made of the vehicle's rearward platform or box if structural damage is suspected in this area as well.

453 Suspension, Steering and Handling

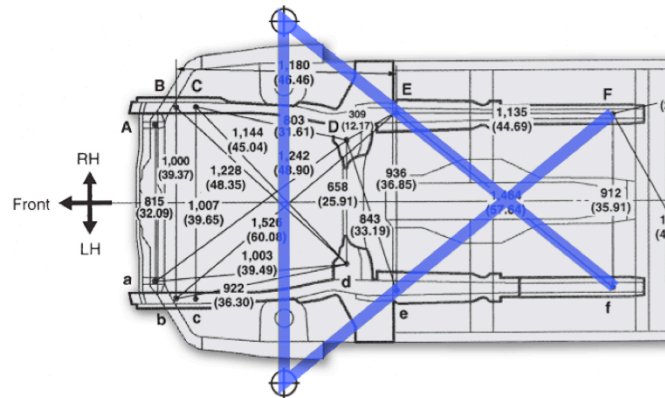


Strut Tower Location

Following an X-measurement, the **proper location of the strut tower** can also be confirmed with underhood measurements using the tracking gauge. These dimensions are found in the Toyota Body Collision Damage Repair Manual.

Recall that SAI and/or IA errors may be caused by structural damage to the strut tower. Measuring the distance between the two strut towers as well as the forward and rearward placement of each tower can confirm or refute any suspicions of damage. Tower placement is critical to proper wheel alignment geometry and **if not within recommended specification (as small as 1 mm on most models) the vehicle structure must be straightened.**

Lower Ball Joint Location



Lower Ball Joint Location

The position of the lower ball joint can prove valuable for identifying **control arm or sub-frame damage**. After confirming the dimensions of the center platform, the position of the lower ball joint can be verified. Dimensions for the position of the ball joint are not published, however their proper location is simple to confirm.

First, measure the distance forward from a perimeter point of the center platform to the ball joint on one side of the vehicle. (Point g to the ball joint and point G to the ball joint). Compare this measurement to the same points on the opposite side of the vehicle.

Second, measure diagonally from a perimeter point of the center box to the opposite ball joint and compare this measurement side-to-side. If the measurements are within 3 mm side-to-side, the ball joint is most likely in the correct position. This measurement helps verify the lower control arm and frame rail on each side of the vehicle.

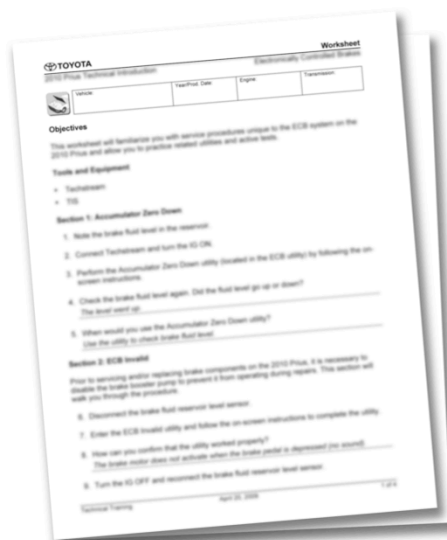
Referencing each dimension given in the body dimension drawing can make further confirmation of the forward or rearward platform sections. Your goal is not to pinpoint the exact location of the structural damage, rather to **determine if the vehicle has any structural damage that could be causing a handling complaint**.

These inspections will allow you to confidently send the vehicle to a body service professional for repair or to identify the bent component that is preventing you from correcting the wheel alignment geometry.

Worksheet

Diagnosing Using SAI and IA (In Class)

In this worksheet you will diagnose structural damage or bent components using SAI, IA, and camber values from case study vehicles



Use this space to write any questions you may have for your instructor.

NOTES:

This page is intentionally blank.