CHAPTER 33
Wheel Alignment Principles
After studying Chapter 33, the reader will be able to:

1. Prepare for ASE Suspension and Steering (A4) certification test content area “D” (Wheel Alignment Diagnosis, Adjustment, and Repair).
2. Discuss which vehicle handling problems can and cannot be corrected by an alignment.
3. Define camber, toe, caster, SAI, included angle, scrub radius, turning radius, setback, and thrust line.
4. Explain how camber, caster, and toe affect the handling and tire wear of the vehicle.
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DEFINITION OF A WHEEL ALIGNMENT

- A wheel alignment is the adjustment of the suspension and steering to ensure proper vehicle handling with minimum tire wear.
- When a vehicle is new, the alignment angles are set at the factory.
- After many miles and/or months of driving, the alignment angles can change slightly.
- The change in alignment angles may result from one or more of the following conditions:
  - Wear of the steering and the 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

- Most alignment diagnosis is symptom-based diagnosis.
- This means that the problem with the alignment is determined from symptoms such as excessive tire wear or a pull to one side of the road.
  - PULL
  - LEAD OR DRIFT
  - ROAD CROWN EFFECTS
  - WANDER
  - STIFF STEERING OR SLOW RETURN TO CENTER
  - TRAMP OR SHIMMY VIBRATION
  - CAMBER
ALIGNMENT-RELATED PROBLEMS

**FIGURE 33–1** A pull is usually defined as a tug on the steering wheel toward one side or the other.
ALIGNMENT-RELATED PROBLEMS

FIGURE 33–2 The crown of the road refers to the angle or slope of the roadway needed to drain water off the pavement. *(Courtesy of Hunter Engineering Company)*
ALIGNMENT-RELATED PROBLEMS

FIGURE 33–3 Wander is an unstable condition requiring constant driver corrections.
ALIGNMENT-RELATED PROBLEMS

FIGURE 33–4 Positive camber. The solid vertical line represents true vertical, and the dotted line represents the angle of the tire.
ALIGNMENT-RELATED PROBLEMS

FIGURE 33–5 Negative camber. The solid vertical line represents true vertical, and the dotted line represents the angle of the tire.
FIGURE 33–6 Zero camber. Note that the angle of the tire is true vertical.
FIGURE 33–7 Excessive positive camber and how the front tires would wear due to the excessive camber.
ALIGNMENT-RELATED PROBLEMS

FIGURE 33–8 Excessive negative camber and how the front tires would wear due to the excessive camber.
FIGURE 33–9 Positive camber tilts the tire and forms a cone shape that causes the wheel to roll away or pull outward toward the point of the cone.
ALIGNMENT-RELATED PROBLEMS

FIGURE 33–10 Negative camber creates a pulling force toward the center of the vehicle.
FIGURE 33–11 If camber angles are different from one side to the other, the vehicle will pull toward the side with the most camber.
FIGURE 33–12 Positive camber applies the vehicle weight toward the larger inner wheel bearing. This is desirable because the larger inner bearing is designed to carry more vehicle weight than the smaller outer bearing.
ALIGNMENT-RELATED PROBLEMS

FIGURE 33–13 Negative camber applies the vehicle weight to the smaller outer wheel bearing. Excessive negative camber, therefore, may contribute to outer wheel bearing failure.
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.

- The 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 center of the upper bearing mount and the lower pivot point is the lower ball joint.

- Zero caster means that the steering axis is straight up and down, also called 0 degrees or perfectly Vertical.
FIGURE 33–14 Zero caster.

FIGURE 33–15 Positive (+) caster.
FIGURE 33–16 Negative (-) caster is seldom specified on today’s vehicles because it tends to make the vehicle unstable at highway speeds. Negative caster was specified on some older vehicles not equipped with power steering to help reduce the steering effort.

FIGURE 33–17 As the spindle rotates, it lifts the weight of the vehicle due to the angle of the steering axis. (Courtesy of Hunter Engineering Company)
**FIGURE 33–18** Vehicle weight tends to lower the spindle, which returns the steering to the straight-ahead position.

**FIGURE 33–19** High caster provides a road shock path to the vehicle.
A steering dampener is used on many pickup trucks, sport utility vehicles (SUVs), and many luxury vehicles designed with a high-positive-caster setting. The dampener helps prevent steering wheel kickback when the front tires hit a bump or hole in the road and also helps reduce steering wheel shimmy that may result from the high-caster setting.
FIGURE 33–21 As the load increases in the rear of a vehicle, the top steering axis pivot point moves rearward, increasing positive (+) caster.
Caster Angle Tire Wear

**TECH TIP**

- The caster angle is generally considered to be a non-tire-wearing angle. However, excessive or unequal caster can *indirectly* cause tire wear. When the front wheels are turned on a vehicle with a lot of positive caster, they become angled. This is called *camber roll*. (Caster angle is a measurement of the difference in camber angle from when the wheel is turned inward compared to when the wheel is turned outward.) Most vehicle manufacturers have positive caster designed into the suspension system. This positive caster increases the directional stability.

- However, if the vehicle is used exclusively in city driving, positive caster can cause tire wear to the outside shoulders of both front tires.
FIGURE 33–22 Note how the front tire becomes tilted as the vehicle turns a corner with positive caster. The higher the caster angle, the more the front tires tilt, causing camber-type tire wear.
TOE

- **Toe** is the difference in distance between the front and rear of the tires.
- Toe is the most important of the alignment angles.
- As viewed from the top of the vehicle (a bird’s eye view), zero toe means that both wheels on the same axle are parallel.
- Toe is also described as a comparison of horizontal lines drawn through both wheels on the same axle.
- If the front of the tires is closer than the rear of the same tires, then the toe is called **toe-in** or positive (+) toe.
- If the front of the tires is farther apart than the rear of the same tires, then the wheels are **toed-out**, or have negative (-) toe.
**FIGURE 33–23** Zero toe. Note how both tires are parallel to each other as viewed from above the vehicle.
FIGURE 33–24 Total toe is often expressed as an angle. Because both front wheels are tied together through the tie rods and center link, the toe angle is always equally split between the two front wheels when the vehicle moves forward.
FIGURE 33–25 Toe-in, also called positive (+) toe.

FIGURE 33–26 Toe-out, also called negative (-) toe. (Courtesy of Hunter Engineering Company)
FIGURE 33–27 This tire is just one month old! It was new and installed on the front of a vehicle that had about 1/4 inch (6 mm) of toe-out. By the time the customer returned to the tire store for an alignment, the tire was completely bald on the inside. Note the almost new tread on the outside.
FIGURE 33–28 Excessive toe-out and the type of wear that can occur to the side of both front tires.
FIGURE 33–29 Excessive toe-in and the type of wear that can occur to the outside of both front tires.
FIGURE 33–30 Feather-edge wear pattern caused by excessive toe-in or toe-out.
FIGURE 33–31 Rear toe-in (+). The rear toe (unlike the front toe) can be different for each wheel while the vehicle is moving forward because the rear wheels are not tied together as they are in the front. *(Courtesy of Hunter Engineering Company)*
FIGURE 33–32 Incorrect toe can cause the tire to run sideways as it rolls, resulting in a diagonal wipe.
FIGURE 33–33 Diagonal wear such as shown here is usually caused by incorrect toe on the rear of a front-wheel-drive vehicle.
FIGURE 33–34 Toe on the front of most vehicles is adjusted by turning the tie rod sleeve as shown. (Courtesy of John Bean Company)
Why Doesn’t Unequal Front Toe on the Front Wheels Cause the Vehicle to Pull?

FREQUENTLY ASKED QUESTION

• Each wheel could have individual toe, but as the vehicle is being driven, the forces on the tires tend to split the toe, causing the steering wheel to cock at an angle as the front wheels both track the same. If the toe is different on the rear of the vehicle, the rear will be “steered” similar to a rudder on a boat because the rear wheels are not tied together as are the front wheels.
**Smooth In, Toed-In; Smooth Out, Toed-Out**

**TECH TIP**

- Whenever the toe setting is not zero, a rubbing action occurs that causes a feather-edge-type wear. A quick, easy method to determine if incorrect toe could be causing problems is simply to rub your hand across the tread of the tire. If it feels smoother moving your hand toward the center of the vehicle than when you move your hand toward the outside, then the cause is excessive toe-in. The opposite effect is caused by toe-out. This may be felt on all types of tires, including radial-ply tires where the wear may not be seen as feather edged. Just remember this simple saying: “Smooth in, toed-in; smooth out, toed-out.”
Smooth In, Toed-In; Smooth Out, Toed-Out

FIGURE 33–35 While the feathered or sawtooth tire tread wear pattern may not be noticeable to the eye, this wear can usually be felt by rubbing your hand across the tread of the tire. (Courtesy of John Bean Company)
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 kingpin inclination (KPI) and is the imaginary line drawn through the kingpin as viewed from the front.

SAI is also called ball joint inclination (BJI), if SLA-type suspension is used, or MacPherson strut inclination (MSI).
STEERING AXIS INCLINATION (SAI)

FIGURE 33–36 The left illustration shows that the steering axis inclination angle is determined by drawing a line through the center of the upper and lower ball joints. This represents the pivot points of the front wheels when the steering wheel is rotated during cornering. The right illustration shows that the steering axis inclination angle is determined by drawing a line through the axis of the upper strut bearing mount assembly and the lower ball joint.
FIGURE 33–37 The SAI causes the spindle to travel in an arc when the wheels are turned. The weight of the vehicle is therefore used to help straighten the front tires after a turn and to help give directional stability.
INCLUDED ANGLE

- The **included angle** is the SAI added to the camber reading of the front wheels only.
  - The included angle is determined by the design of the steering knuckle, or strut construction.

**FIGURE 33–38** Included angle on a MacPherson-strut-type suspension.
INCLUDED ANGLE

FIGURE 33–39 Included angle on an SLA-type suspension. The included angle is the SAI angle and the camber angle added together.
INCLUDED ANGLE

**FIGURE 33–40** Cradle placement. If the cradle is not replaced in the exact position after removal for a transmission or clutch replacement, the SAI, camber, and included angle will not be equal side-to-side.
• **Scrub radius** refers to the *distance* between the line through the steering axis and the centerline of the wheel at the contact point with the road surface.
FIGURE 33–41 A positive scrub radius (angle) is usually built into most SLA front suspensions, and a negative scrub radius is usually built into most MacPherson strut-type front suspensions.
FIGURE 33–42 With negative scrub radius, the imaginary line through the steering axis inclination (SAI) intersects the road outside of the centerline of the tire. With positive scrub radius, the SAI line intersects the road inside the centerline of the tires.
FIGURE 33–43 With a positive scrub radius, the pivot point, marked with a + mark, is inside the centerline of the tire and will cause the wheel to turn toward the outside, especially during braking. Zero scrub radius does not create any force on the tires and is not usually used on vehicles because it does not create an opposing force on the tires, which in turn makes the vehicle more susceptible to minor bumps and dips in the road. Negative scrub radius, as is used with most front-wheel-drive vehicles, generates an inward force on the tires.
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, abbreviated TOT or TOOT, and is determined by the angle of the steering knuckle arms.

- Turning radius is a nonadjustable angle.
TURNING RADIUS (TOE-OUT ON TURNS)

- The turning radius can and should be measured as part of an alignment to check if the steering arms are bent or damaged.
- Symptoms of out-of-specification turning angle include the following:
  - Tire squeal noise during normal cornering, even at low speeds
  - Scuffed tire wear
To provide handling, the inside wheel has to turn at a greater turning radius than the outside wheel.

The proper toe-out on turns is achieved by angling the steering arms.
Setback is the angle formed by a line drawn perpendicular (at 90 degrees) to the front axles. Setback is a nonadjustable measurement, even though it may be corrected. Positive setback means the right front wheel is set back farther than the left; negative setback means the left front wheel is set back farther than the right.
FIGURE 33–46 (a) Positive setback. (b) Negative setback.
FIGURE 33–47 Cradle placement affects setback.
THRUST ANGLE

- **Thrust angle is the angle of the rear wheels as determined by the total rear toe.**
- If both rear wheels have zero toe, then the thrust angle is the same as the geometric centerline of the vehicle.
- The total of the rear toe setting determines the **thrust line**, or the direction the rear wheels are pointed.
- On vehicles with an independent rear suspension, if both wheels do not have equal toe, the vehicle will pull in the direction of the side with the most toe-in.
FIGURE 33–48 (a) Zero thrust angle. (b) Thrust line to the right. (c) Thrust line to the left.
TRACKING

- The rear wheels should track directly behind the front wheels.
- If the vehicle has been involved in an accident, it is possible that the frame or rear axle mounting could cause **dog tracking**.

**FIGURE 33–49** (a) Proper tracking. (b) Front wheels steering toward thrust line.
FOUR-WHEEL ALIGNMENT

- **Four-wheel alignment** refers to the checking and/or adjustment of all four wheels.
- Four-wheel alignment is important for proper handling and tire wear, to check the camber and the toe of the rear wheels of front-wheel-drive vehicles.
- Some rear-wheel-drive vehicles equipped with independent rear suspension can be adjusted for camber and toe.
- Rear-wheel caster cannot be measured or adjusted because to measure caster, the wheels must be turned from straight ahead.
• Since rear wheels are securely attached, a caster sweep (turning the wheels to take a caster reading) is not possible.
• While rear camber can cause tire wear problems, by far the greatest tire wear occurs due to toe settings.
• *Unequal* toe in the rear can cause the vehicle to pull or lead.
• The rear camber and toe are always adjusted first before adjusting the front caster, camber, and toe.
• This procedure ensures that the thrust line and centerline of the vehicle are the same.
SUMMARY

1. The need for a wheel alignment results from wear or damage to suspension and steering components.

2. Camber is both a pulling angle (if not equal side-to-side) as well as a tire wearing angle (if not set to specifications).

3. Incorrect camber can cause tire wear and pulling if camber is not within 1/2 degree from one side to the other.

4. Toe is the most important alignment angle because toe is usually the first requiring correction. When incorrect, toe causes severe tire wear.
SUMMARY

5. Incorrect toe causes excessive tire wear and creates instability if not within specifications.

6. Caster is the basic stability angle, yet it does not cause tire wear (directly) if not correct or equal side-to-side.

7. SAI and included angle (SAI and camber added together) are important diagnostic tools.

8. If the toe-out on turns (TOOT) reading is not within specifications, a bent steering spindle (steering knuckle) is the most likely cause.

9. A four-wheel alignment includes aligning all four wheels of the vehicle.
1. Explain the three basic alignment angles of camber, caster, and toe.

2. Describe what happens to tire wear and vehicle handling if toe, camber, and caster are out of specification or not equal side-to-side.

3. Explain how knowing SAI, TOOT, and included angle can help in the correct diagnosis of an alignment problem.

4. Explain what thrust angle means.
1. When performing an alignment, which angle is the most important for tire wear?
   a. Toe
   b. Camber
   c. Caster
   d. SAI (KPI)
2. Positive camber means __________.
   a. The top of the tire is tilted outward.
   b. The top of the tire is tilted inward
   c. Either a or b
   d. Both a and b
3. Which alignment angle is adjustable on all vehicles?
   a. Camber
   b. Caster
   c. Toe
   d. SAI (KPI)
CHAPTER QUIZ

4. Positive (+) toe is __________.
   a. Toe-in
   b. Toe-out
5. If the top of the steering axis is tilted 2 degrees toward the rear of the vehicle, this is ________.
   a. Positive camber
   b. Negative camber
   c. Negative caster
   d. Positive caster
6. A steering dampener may be needed to reduce shimmy on vehicles that have high positive _________.
   a. Camber
   b. Caster
   c. Toe
   d. Included angle
7. If the turning radius (toe-out on turns, or TOOT) is out of specification, what part or component is defective?
   a. The strut is bent.
   b. The steering arm is bent.
   c. The spindle is bent.
   d. The control arm is bent.
8. Which angle determines the thrust angle?
   a. Front toe
   b. Rear toe
   c. Rear camber
   d. Front caster, SAI, and included angle
9. Included angle is ________.
   a. SAI + caster
   b. Camber + caster
   c. Camber + SAI
   d. Toe + camber
10. Two technicians are discussing scrub radius. Technician A says that scrub radius can not be measured. Technician B says that scrub radius can not be adjusted. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both technician A and B
   d. Neither technician A nor B