Technical Session

This Technical Session describes the steer axis geometry now included in the SIMON vehicle model. Steer axis geometry defines the orientation of the axis about which the wheel steers. Note in previous simulation models, the wheels were assumed to steer about a vertical axis through center of the wheel plane. This is a simplification of the actual case. The wheel actually steers about an axis that is neither vertical nor through the center of the wheel plane. Rather, the steer axis lies inboard of the wheel plane and is tilted with respect to both the wheel plane and the vehicle-fixed axes.

Steer axis geometry is defined by the following parameters for each steerable wheel:

- Caster
- Camber
- Inclination Angle
- Steering Offset
- Stub Axle Length

These parameters are shown in Figure 1. A description of each follows.

Caster is the rearward tilt of the steering (kingpin) axis. Caster causes the steering axis to intersect the ground at a point ahead of the tire's contact point. This produces a moment arm about the steering axis. This moment arm is called mechanical trail (see Figures 1 and 2). If you can imagine a wheel that is steering about a rearward-tilted axis, you can see that the elevation of the tire's contact point with the ground varies with respect to the vehicle: As the steer angle increases the contact point z-coordinate decreases. Thus, gravity's force on the tire tries to steer the tire. Generally, other factors present would try to steer the tire outward.

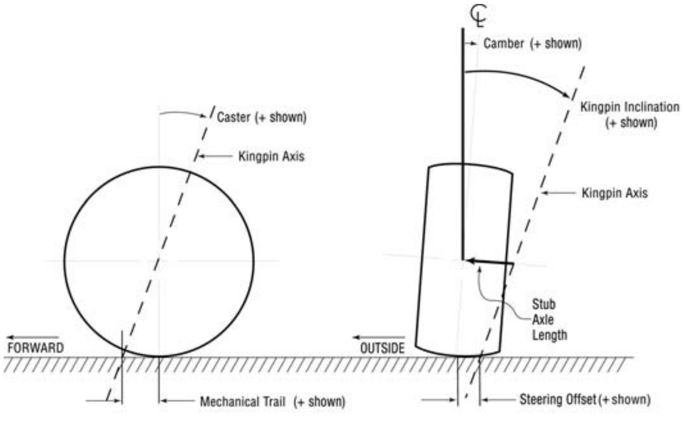


Figure 1 - Steer Axis Geometry

Camber is the inward tilt of the wheel plane. It is caused by suspension geometry. As the wheel jounces (up) and rebounds (down), the camber angle changes because of axle roll for solid-axle suspensions and control arm angles for independent suspensions. Generally speaking, the goal of the suspension designer is to keep the wheel plane vertical to the road plane. Solid axle suspensions are superior in this regard, but other factors also influence the designer's task. Note that all 3-D *HVE* simulations have previously included camber, so this part of the equation is not new.

Inclination Angle is the inward tilt of the steering axis. Its effect is similar to caster angle. If you can imagine a wheel that is steering about an inward-tilted axis (see Figures 1 and 2), you can see that the elevation of the tire contact point will change (just as for caster; see above) unless the steer axis intersects the tire contact point at the wheel plane.

Steer Offset (sometimes called ***scrub radius***) is the distance from the point where the steer axis intersects the ground plane to the tire contact point. This distance is important because any tire force at the tire contact point produces a moment about the steer axis (see Figure 2). This moment arm is equal to the steer offset when the wheel is steered straight ahead; the moment arm changes as the wheel is steered.

Stub Axle Length is the distance from the wheel center to the steer axis taken normal to the wheel plane. The direction along this distance vector, therefore, also defines the axis about which the wheel spins.

There is a rather complicated inter-relationship between the five parameters that define the steer axis geometry. This inter-relationship can be observed directly in the Steer Axis Geometry dialog (see Figure 3). Editing the Inclination Angle or Stub Axle Length affects the Steering Offset. (Editing the Camber also

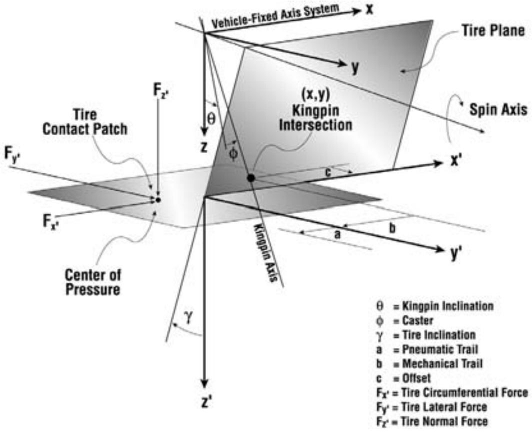
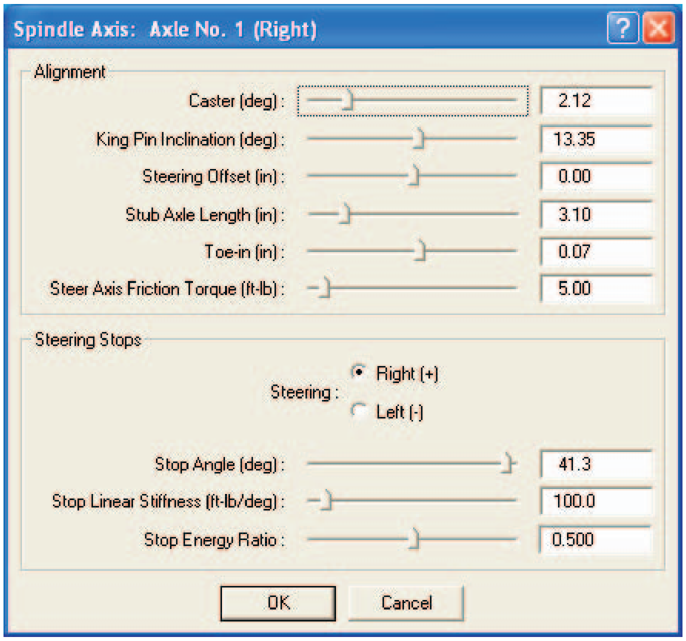


Figure 2 - Relationship between steer axis and tire-ground contact point



Spindle Axis: Axle No. 1 (Right)

Alignment

Caster (deg) : 2.12

King Pin Inclination (deg) : 13.35

Steering Offset (in) : 0.00

Stub Axle Length (in) : 3.10

Toe-in (in) : 0.07

Steer Axis Friction Torque (ft-lb) : 5.00

Steering Stops

Steering : ● Right (+) ○ Left (-)

Stop Angle (deg) : 41.3

Stop Linear Stiffness (ft-lb/deg) : 100.0

Stop Energy Ratio : 0.500

Figure 3 - Steer Axis Geometry dialog

affects Steering Offset, but Camber is in a different dialog, so you won't notice the effect directly.) Similarly, editing the Steering Offset affects the Stub Axle Length. The Steer Axis dialog knows these relationships and includes them automatically as you edit various fields in the dialog.

Steer axis geometry has another effect: As the wheel is steered, it not only moves up and down (in the z-direction), the wheel also moves in the x and y directions relative to the vehicle axis system. Thus, the wheelbase and trackwidth change as the wheel is steered.

Figure 4 shows a wheel steered 25 degrees to the right. This wheel has a caster angle of 10 degrees, inclination angle of 20 degrees and a steering offset of 0 inches (resulting in a stub axle length of 4.42 inches). The camber angle is 0.0 degrees. (These angles are exaggerated to show the effect.) The effects on wheel location and orientation are clearly visible.

So, why is the steer axis geometry important? Because it directly affects the self-centering properties that encourage a vehicle to follow a straight path as it travels down the highway. Here's how it works:

As the right wheel steers to the right, the vehicle-fixed elevation of its tire contact point will move down. Because there is pavement beneath the tire, the vertical tire force will increase on the right-side tire. As the left wheel steers to the right, the elevation of it's tire contact point will move up, thus decreasing the vertical force on the left-side tire. Each of these tires will seek its lowest potential energy state, so the right-side tire will try to steer to the left and the left-side tire will try to steer to the right. The state of lowest potential energy is achieved when both wheels are steered straight ahead. You can see this effect if you set up a SIMON event at low speed (to reduce dynamic weight transfer) and create a steer table that varies continuously from, say, +450 degrees (at the steering wheel) to -450 degrees. Use the Key Results window took at $F_{Z'}$ for the two front tire. See the change in $F_{Z'}$?

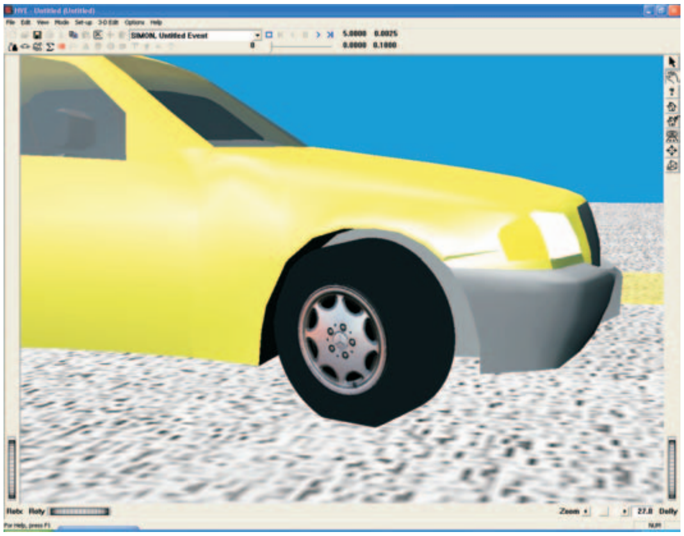


Figure 4 - Wheel location and orientation are affected by steer axis geometry.

This self-centering effect also explains why proper suspension alignment is so important: If the steer axis geometry on the right side is different from the left side, the lowest potential energy state will *not* be straight ahead, and the vehicle will wander (or *pull*) to the right or left, requiring corrective steering by the driver.

Because the wheels are spinning at a frequency that varies with road speed, there is a potential for vibration in a steerable wheel. This is commonly called wheel *shimmy*. The combative forces between the right- and left-side tires described earlier also create tension (or compression, depending on the linkage design) in the steering linkage and suspension ball joints, taking any natural slack out of the system. This helps to reduce or prevent the tendency for wheel shimmy.

Including the steer axis geometry in SIMON has one more important implication: Sidewall impact (such as is modeled by the new *HVE* Tire-Terrain model), produces moments about the steer axis, causing a steerable wheel to steer. These moments, and resulting steering, are included in SIMON's Steer Degree of Freedom model.