INTRODUCTION

Throughout this article I will address many basics of your vehicle’s steering, suspension, driveline, tires, and wheels. I did not intend this to be a “how to” manual with step by step instructions. It will simply illustrate the concepts. I’ll start with the lift and explain what it did to your steering, suspension, and driveline one aspect at a time.

NOTES ABOUT THE ILLUSTRATIONS: 1) most are “spring under” leaf spring suspension, 2) non-pertinent parts are omitted for clarity, 3) many examples are exaggerated for illustration, and 4) most concepts illustrated also apply to spring over and coil/link suspensions. To cover the differences, I added a separate coil and link suspensions topic. Ready? OK, let’s get started.

You lifted your Jeep and now it wanders all over the road and it vibrates too. What happened?

Well, you just changed a lot of the vehicle’s geometry (probably without knowing it). Here’s a diagram of a stock Jeep and the proper angles. Your caster angle should be between 4 and 8 degrees positive. This caster angle creates an effect called mechanical trail. It’s the force that makes your wheels return to center.

The caster angle shown below is close to stock. The point that the steering axis (black line) intersects the ground to the point to where the rotational axis touches the ground forms the points to measure your caster angle. You can best measure the caster angle from the top of the upper ball joint. I used twin dotted red lines perpendicular to the points these two axes strike the ground to show where to measure mechanical trail. I’ll cover caster in depth and how taller tires also affect the impact of mechanical trail later in the article.

The driveshaft angles shown below are also close to stock. The transfer case and axle pinion angles are parallel to each other. In almost all cases, as long as you have single cardan (single u-joint) driveshafts these angles need to remain parallel regardless of the driveshaft angle to the ground.
The following diagram shows what happened when you put a lift kit on your Jeep. As noted above, although I used a leaf spring example, coil and link suspensions will experience most of the same effects. Your lift not only raised the frame, it increased the distance between the frame and axles. To absorb the new length of your lift springs, you may need longer shackles to allow them to flex (flatten). Your springs will pivot at the frame’s spring mount from swinging away from the frame’s shackle mount (link suspensions perform similarly). First, this will rotate axles slightly (blue rotation arrows) but enough to cause very noticeable side effects. Your caster angle will be reduced though possibly not as far as illustrated in the diagram below (reduced to 0 degrees). As for the driveline, the transfer case yokes didn’t change but the pinions did so they’re no longer parallel.

Now that I’ve illustrated generally what happened, I’ll describe each in more detail.

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CASTER.

What is caster? It’s the angle of the pivot (steering) axis related to the rotational (hub center) axis where they meet the ground. What does it do? Well, it (mechanical trail effect) is the force that returns your wheels to the center position (straight ahead). Without it you’d have to constantly return the steering wheel to the center. You really don’t notice it… that is until you don’t have it any more.

What are the principles? How does it work? How do I measure it? I always like to start with the shopping cart wheel. Although some people debate whether it truly has caster, it can be used to illustrate the different axes we’ll use, where caster angle is measured, and where to measure mechanical trail.

The biggest difference with this method of wheel centering and the application used for automobile caster is that this arrangement has no effect on camber at all. When this wheel turns or centers, it remains completely vertical because the turning axis is perpendicular to the ground. Automobile caster has a distinct effect on camber because its steering axis is angled 4 to 8 degrees off perpendicular. I’ll illustrate that later.

OK, now that I’ve introduced the basics, let’s see how that looks on a typical automotive application. I placed the next two illustrations side by side for a reason, to show the impact of tire size. While they each have the same angles, the tires are a different size. That will be important later. For now let’s go through the aspects of caster. For automobiles the most typical method of setting caster angle is by arranging the upper ball joint behind the lower. This is the case for solid axle (leaf and coil/link suspensions) as well as independent A-arm (coil or torsion suspensions). Using the same elements as the previous illustration, these illustrations show what points form the caster angle and the mechanical trail in an automotive application. The caster angle is identical in these illustrations but the distance to the ground is different. The taller tire moves the axle upward and the steering axis intersects the ground further in front of the wheel. This increases the effect of the mechanical trail which is the force that centers the wheels.

NOTE 1: Taller tires only enhance the existing condition. For positive caster, it will increase mechanical trail. However, if your caster angle is negative, taller tires will make lack of centering (wander) even worse because the tires lead the steering even more.

NOTE 2: Some of you that work on older cars and International Harvester Scouts may notice that these vehicles don’t have positive caster. Many “cars” had slightly negative caster prior to 1975 because, people wanted cars that steered easily and at that time cars didn’t have radial tires. Bias ply tires would distort at highway speed so that the tread’s contact patch moved behind the tire’s rotation centerline (picture a cartoon car speeding along, the tires are usually drawn with a distinct oval shape). The tread’s contact patch is generally behind the steering pivot causing mechanical trail (the effect from positive caster). Putting radial tires on this type of car makes it wander from side to side.
OK… so what did your lift (or longer shackles) do to your caster? Well, as you can see at the right, the suspension only pivots on one end, the axle tips forward. A coil/link suspension would change the same way unless you had adjustable link arms (and made an adjustment).

The upper ball joint has moved forward to the point it doesn’t trail the lower by much.

Such a small change has altered your steering geometry considerably. It reduced your caster angle and mechanical trail force, while reducing your camber change during turns.

This is probably the most common problem encountered after a suspension lift. There are several ways to correct it.

1. You can rotate the “Cs” that hold your ball joints.
2. You can cut off and remount spring perches (or mounts)
3. You can use a offset ball joint or offset mount.
4. On some axles you can grind the perch enough to change the angle.

Ok… let’s say you just bought a used CJ (or YJ) that has a completely stock suspension but the Jeep wanders all over the road. Yes, the suspension is old and many components could be at fault for steering problems, but as covered earlier, wander is caused by lack of positive caster.
I won’t rehash the how caster works but I’ll cover how your stock spring can lose its positive caster. A leaf spring will naturally lose its arc as time, weight, and flexing forces act on it. However, as you can see in this illustration, the spring can not only flatten over time, but also change shape.

Years of braking will rotate the axle in the direction of the red arrow. That reinforces the arch in the front of the leaves but can invert the rear little by little. Eventually, the spring doesn’t recover, resulting in an “S” shape. Even if the spring doesn’t have an inverted arch in the rear, it’s probably flat enough to reduce your positive caster by a few degrees. This tips the steering upper ball joint forward and the lower ball joint back like the previous examples. Since Wrangler YJ springs are arched less from the factory, they are very prone to this condition.
CAMBER.
So you’ve raised your vehicle but your wheels are slanted and tires are wearing. Improper camber takes valuable rubber off the road by riding on the edges of the tire tread. Some positive or negative camber is normal and is used to control turning stability and responsiveness. Too much camber will not only wear tires prematurely but can also make steering difficult or unresponsive.

What is Camber? Camber is measured in degrees, either positive or negative. It affects the “feel” of your steering, either heavy or responsive. For us, camber changes are most often caused by worn parts. With proper camber adjustment and alignment correction, the car will be more responsive and handle better wet or dry. Solid front axle vehicles don’t see this change with a lift because the solid front axle maintains the inboard & outboard position of the ball joints. Those with independent front suspension will since the lift probably moved the upper ball joint’s position relative to the lower.

If the wheel leans away from the car, it has positive camber if it leans in towards the chassis; it has negative camber (see next page). The cornering force of your tires is highly dependent on its angle relative to the road surface, so wheel camber has a major effect on the handling. Typically, tires develop maximum cornering force at around .5 degrees negative which is a small negative camber angle. This is caused by the additional lateral force generated by deformation as tread’s contact area rubber pulls through the tire/road surface.

For many years camber was set from zero to slightly positive to offset vehicle loading and to make steering easier for non-power steering vehicles, however the current trend is to slightly negative settings to increase vehicle stability and improve handling. All solid axle suspensions change and most independent suspensions will vary the camber angle as the wheel moves up and down relative to the chassis.

Positive Camber
When the bottom of the tire is more inwards and the top is out, that is referred to as positive camber. Positive Camber makes the steering “lighter” to the touch and was very helpful when vehicles didn’t have power steering. The penalty for too much positive camber is vehicle under-steer (turning less than your steering input) and wear on the outside of your tires. Today it’s generally the result of a bad alignment or a worn out ball joint. A camber kit isn’t usually required because replacing the worn part and realignment generally corrects the problem.
**Negative Camber**

Negative camber is when the top of the tire is more towards the center of the vehicle and the bottom is outwards. Your suspension should have near 0 degrees camber. Negative camber increases steering force but excessive negative camber will wear the inside of your tires at a rapid rate and lead to over-steer. Over-steer in a short wheelbase vehicle will often result in a spinout since any turns could be abrupt.

I mentioned earlier in the *Caster* topic that your Camber changes during turns. This is because your steering pivot axis is not vertical to the ground.

If your steering’s pivot angle was perpendicular to the ground, your tires would remain vertical as they turned. As you can see in the illustrations below, because of your Caster angle that is not the case. Your tires lean as they turn. The sharper you turn, the more the tires will lean. In addition, the more caster angle (pivot tipped back) you have, the more camber change it causes (tires lean more).

This allows your steering camber to be set to nearly zero degrees for straight line travel while applying the appropriate camber when it’s needed for a turn.
TOE IN/TOE OUT.
Toe-in (or out) is the difference (in inches) between the front edge of your front tires and the rear edge of the front tires. On a vehicle that’s toed-in, the distance between the front wheels is less at the front than at the rear. Toe-in is normally a fraction of an inch. As you drive your vehicle at greater speeds, the steering linkage will expand slightly. Larger tires and wheels that are offset outward from the steering pivot axis have even more effect on this tendency to expand. To reduce tire wear and rolling resistance, your front wheels are initially set so that they are pointing slightly inward (toe-in) allows them to turn straight ahead when the vehicle is underway.

NOTE: The illustrations are highly exaggerated and are for demonstration only.
In the early days prior to radial tires, extra toe-in was added to compensate for tire drag at highway speed.
The subject of **turning radius** comes up from time to time, usually associated with a suspension lift and the installation of a drop pitman arm. While a drop Pitman arm is often required to bring the drag link back into the proper alignment, the problem is caused by a Pitman arm that's shorter than needed. The drop Pitman arm may appear to be the same length but it must be measured from the axis-center of each hole (not a straight line from each hole) as shown in the illustration on the right.

The illustration below shows an example of how much of a steering output reduction is provided because of this difference. Since the Pitman arm swings in a smaller arc, the steering range is narrower.

In the next illustrations you can see that the smaller arc of the shorter Pitman arm doesn't turn the wheels quite as far when the steering is turned to full extension in either direction. Although the difference doesn't seem like much, it makes a big difference in the distance required to turn your vehicle around.

**NOTE:** The differences here are notional for illustration only. Do not use them as a guide to set your steering.
The **Ackerman Angle** is one of those topics that appears on the technical forums once in a while when someone has been reading about steering concepts. While they gain new insight from this reading, they often will find topics that don't apply to their situation.

I only bring this up in case you read about it somewhere or hear about it at an alignment shop.

It's not normally something a do-it-yourselfer should ever try because this is something that's designed in the vehicle and **Jeep CJs and Wranglers were not designed this way**.

As you can see in the illustration, the inside wheel turns sharper than the outside wheel to make the turn smooth because the shorter inside radius requires a sharper turn to travel the circumference path without scrubbing.

Note the position of the steering arms and tie rod (or rack and pinion in some vehicles). It is on the rear of the steering knuckle. It's doubtful you could achieve this angle from the front without contacting the wheel.

The second illustration shows the easiest way to calculate the position of the steering arms. They would ideally be inline with the line drawn to the center of the rear axle.
If your vehicle has the steering linkages in front of the axle (like Jeeps), it most likely doesn't (and probably can't) use the Ackerman angle to compensate for the different arcs your tires would travel while turning.

The illustrations on the top right shows an Ackerman angle arrangement using a solid tie rod. Rack and pinion systems also use the Ackerman angle but their appearance is slightly different due to the rack assembly and it's additional pivot points. The wheels turn to different angles because the steering arms (on knuckles) are in different points on their respective pivot arcs. As one swings out, its arc is primarily oriented outward while the other's arc is oriented forward. That's why you see the tie rod angle changing relative to the axle itself.

The illustration on the left shows the position of the tie rod and steering arms in three different positions: straight, left turn, and right turn.

The bottom right illustration shows the typical utility vehicle steering setup. Because the tie rod ends are in identical positions related to the steering axis, both wheels turn equally.
**TOPIC 5: BUMP-STEER**

**BUMP-STEER.**

This steering malady is experienced by many who put a suspension lift on their vehicle. I often will leave well enough alone myself… meaning I know where I could have a problem but wait to see if I really do have a problem. I didn’t correct my steering geometry at first, hoping that it would be fine. I was wrong. I had a very bad case of bump-steer.

Here’s what a typical alignment of steering components look like. They are nearly parallel to each other. The swing radius (red arrow) on the drag link moves in a gentle arc nearly straight up and down. When you hit a bump with the passenger tire, the steering components will remain relatively neutral and you’ll not get steering feedback.

However, your steering geometry changes when you put on a suspension lift. The drag link is now at a much steeper angle to the tie rod. The wheel’s pivot radius is now going to advance as the passenger wheel goes up and retreat as the passenger wheel goes down. The further the wheel travels (up or down), the more steering effect you’ll have. Because this travel is often associated with hitting bumps, the effect is sudden and sometimes severe. It’s enough to make you lose control of your vehicle.

A sight sometimes seen on highly lifted vehicles is the bent or angled drag link. The drag link may visually appear to be near stock configuration but as you can see in the illustration; these bends don’t change the angles. You will still have bump-steer.

*There is really only one reason to bend or angle the drag link... so it will clear (avoid striking) other components.* For instance, sometimes a spring over conversion puts the direct path of the drag link to steering knuckle through the leaf spring. Since you can’t go through it you’ll need to go around.
So, just how does this advance and retreat of the drag link affect your steering? Well, as the passenger wheel moves upward and the draglink arc moves outward, it moves the steering knuckle to the right and viola, you are performing a right turn. What happens if you hit a dip (or hole) with this same wheel? That’s correct… a left turn. Hey, just to make things exciting, how about a series of bumps and dips? You get the picture. This is not a safe condition.

How do you fix it?

You need to return the drag link to its original alignment by one or the following means.

1. You can replace your Pitman arm with a drop pitman arm. 
   *Note: Since these arms are often shorter than stock they will increase your turning radius.*

2. You can do a tie rod flip or install high steering arms. 
   Which you can/should do is dependent on: 
   a) your axle model (not all have high steer knuckles available -- arms (usually flat-top Dana 44 knuckles))
   b) your spring setup (spring over or under makes a difference).
TOPIC 6: LEAF SPRINGS

Let’s start with how the leaf springs work. The longest leaf attaches the spring pack assembly. While simple, it's also versatile. Each leaf can have a different rate, making load and comfort very tunable.

Most everyone knows that they suspend the vehicle vertically but there are two other aspects. These three aspects of the suspension affect ride quality, steering, and driveline.

The first illustration in this section shows the underside view of a Jeep CJ7. I’ve colored the suspension and some steering components blue.

As you can see, I listed the following primary functions:

1) suspend the vehicle,
2) position the axle fore & aft,
3) maintain the axle side-to-side position. Later I’ll explain how this can effect steering (a secondary function).

You must keep your suspension bushings in good shape and not over-tighten them to perform these tasks properly. The suspension mounting points are marked with an orange box. These points position the axle both fore/aft and side-to-side however, unlike a link-arm suspension, the axle’s front to back position changes more as the suspension articulates.

Now, knowing which way your suspension moves during compression and droop is important for axle placement and tire clearance. Depending on your suspension setup (e.g. shackle reversal), you could encounter tire/body contact with your axle positioned in the same place as someone else. The next two illustrations show how the axle travels through its three positions, at rest, compressed, and extended. The first illustration is stock configuration.
A shackle reversal kit has been installed in this illustration. The setup changes the front spring’s rear mount considerably since the shackle stands the spring between 2 and 5 inches further from the frame. In addition, the front mount may also extend the spring eye further from the frame depending on manufacturer. These changes will most likely change your Caster (one way or the other).

The motion becomes important for tire/body clearance, handling, and driveline. On the stock setup, the frame moves backward relative to the axle when you compress the suspension. So, if you’re trying to climb a rock, the front wheel will work against your momentum slightly, but that may be enough to keep you from climbing the obstacle. Your Jeep will naturally be somewhat neutral during hard braking. Sure, the weight is moving forward and that compresses the spring, but the brakes are countering the wheels’ forward rotation that applies torque to the axle that tends to keep it from compressing. The final consideration is the driveshaft. As the spring compresses, the axle move both up and forward. The makes the pinion move up (closer) but forward (further). It’s possible that you won’t need much range in your driveshaft’s slip shaft.

A shackle reversal kit changes how your suspension behaves considerably. Some kits even include a lift that changes steering geometry. I’ll leave it up to you whether you think it’s for the better or worse. Now, axle positioning is important, if you leave the front axle in the stock position when you install a shackle reversal kit, you could easily impact the fender with the tire (depending on tire size and fender shape).
On the reverse setup, the frame moves forward relative to the axle when you compress the suspension. So, if you’re trying to climb a rock, the front wheel will work with your momentum and that may be enough to get you over the obstacle. Your Jeep tend to nose dive during hard braking. In this case, two things cause the problem. First, momentum transfer weight to the front, compress the spring, and swing the shackles rearward. In this case, the brakes will rotate the axle “nose down” as they stop the wheel rotation, further swinging the shackles back.

Driveshaft measurement and placement is critical. This time, as the spring compresses, the axle moves both up and rearward. The makes the pinion move up AND rearward. Likewise, it moves down and forward when the spring droops. Your driveshaft will move a lot, so make sure your driveshaft’s slip shaft has enough length.

This leads me to the subject of shackles. Let’s talk about how they affect steering. Sometimes wander, shimmy, and wobble are not the fault of the steering. Sometimes a poorly maintained suspension will cause it. Your bushings are what allow suspension flexibility but they also maintain control. They must remain pliable but firm. Old, hardened, worn bushing will not work properly for either suspension or steering. The next illustration shows three conditions involving your shackles.

The illustrations on the next page show some conditions that develop over time with leaf springs and shackles. Stock shackles have a tendency to lean as they get older because the only things that keep them operating as one unit are the bolts and bushings. If the bushings get stiff and brittle, they allow the shackle to start wearing itself apart. For that reason you should maintain your shackle bushings periodically.

If your shackles lean to one side or the other when the suspension is at rest you probably have one of the problems illustrated above. Sometimes it results from wear and sometimes from impact.
Although they are definitely part of the suspension, shackles and bushings in this condition can lead to unwanted “steering” changes.

The *top right* image shows bent bolts. This really only occurs with two-piece shackles since the steel plates can lean independently. It causes your steering alignment to be off and could incorrectly position your axle on all three functions: too low, offset to a side, and closer to the front on one side or both.

The *bottom left* could happen with one-piece or two-piece shackles. Replace the bushings.

The *bottom right* is caused by the shackle plate sliding independently. One-piece shackles won’t do this. Since the bolt holes are wallowed out the shackles must be replaced.

**Both of the bottom** conditions will cause the front of the vehicle to shimmy and the effect is similar to bump steer since the axle moves back and forth in relation to the steering drag link.
Earlier in the article I illustrated how your caster was affected if you have longer shackles.

How do you know what size shackle you need? Shackle length is related to the length of the longest spring in the spring pack.

Let’s start from the front section of the frame. The distance from the rear spring mount to the shackle mount is 43 inches. That means for the ’76-’86 stock spring pack (44.125” long) you need a shackle that lets the spring travel 1.125 inches forward. The stock shackle is about 3 inches bolt to bolt and perfect for this situation.

If you put a longer spring on the Jeep, you may need a longer shackle to allow for the proper flex (spring flattening). How do you know when? For instance, if you had a lift spring with a 47 inch spring, would the stock length shackle work. In extreme compression it wouldn’t let the spring completely flatten but it depends on how you want to handle that situation. You could “bump stop” the axle as it reaches that point or install a longer shackle… up to you. In the example above, I used a spring that is a half inch longer than the swing length of the longer than stock shackle. Once again, it’s in the ballpark but that spring would probably be damaged with a 3 inch stock shackle depending on the terrain encountered and how the axle travel is limited or not.

One final thought, depending on shackle and frame clearance, your shackle could swing beyond parallel with the frame to give you greater flexibility.
One topic that comes up a lot is spring-over suspensions. It may seem that it’s one of the cheapest ways to lift a vehicle. You don’t have to buy a suspension lift kit, right?

It’s more than just relocating your spring perches to the top of the axle, flipping the U-bolts, and tightening the spring plates. You will face all the issues that a spring-under lift will encounter plus the main problem of axle-wrap. You see, springs are designed to withstand certain stresses under certain conditions: 1) specific tire size range and 2) a spring relationship to the axle and ultimately the ground.

**Why is axle-wrap a problem for a spring over but not spring under?** Well, that’s not always the case. There are many suspensions that are designed for spring-over operation. For instance, most pickup trucks use spring-over suspension for the rear axle. Unlike coil springs, each leaf can add to the cumulative spring rate versus a constant rate from a coil. This allows for both a smoother ride while unloaded and greater capacity when loaded. The key aspect of this suspension is that it was built for **load capacity** and not flexibility. The leaves were designed from the start to handle the torque from the spring position over the axle. These springs are designed to withstand the torque from the greater distance to the ground.

As you can see in the first illustration, the distance from the ground to the longest leaf increased by 5.5 inches when the spring was changed from spring-under to spring-over. That change increases the torque applied to the leaf springs considerably.

When you change springs designed for spring-under operation to spring-over, you’ve changed the operating condition by adding leverage to the torque of the turning wheels. If you install taller tires it will increase the torque even more. Since the springs were not designed for that stress, there’s a good chance they will twist under the load.

In the second illustration, a spring-under suspension lift was installed. You can see that the distance from the ground to the long leaf has not changed. In addition, most suspension lift springs are designed for taller tires since that’s most often the reason for the lift.
**TOPIC 7: SPRING-OVER SUSPENSION**

*So, what is axle wrap?* This occurs when the torque forces overcome the spring pack’s ability to maintain the proper shape and orientation of driveline components. This torque is enough to deform the spring and cause both spring and driveline failure over time. The axle shaft angles will shift considerably more than the normal 2-3 degree range causing vibration and binding.

This illustration only shows the force from forward acceleration but this effect also occurs in the opposite direction during deceleration and braking.

Since most off-roaders are looking for ground clearance and suspension flex, a stiffer spring to withstand the torque isn’t a desirable option. So, there are a couple of other ways to solve this problem. One is the anti-wrap (“ladder”) bar. This solution allows a more flexible spring to do what it’s best at while the bar alone combats the torque. These bars come in many shapes and sizes but they all do the same basic function—keep the spring from twisting and axle pinion from pitching up and down from torque. Most designs (shapes) are based on the need to clear other components or for ground clearance.

The bar attaches to mounts above and below the axle tube and to a shackle (or other pivot) on the frame or crossmember. The bar will keep the axle from twisting but still allow vertical travel. Earlier in the article I illustrated how leaf springs move out as they compress and in as they extend—that’s why you need the shackle on the anti-wrap bar.

The next option is used on pickup trucks a lot. Here, the intent is to stabilize the axle under load and not for a flexible suspension. A longer, thicker steel plate is installed under the short leaf that serves as a stop when the axle twists too far. It will contact the leaves above and stop the twist. It also helps with heavier loads as the springs flatten since it doesn’t bend.

I specifically didn’t illustrate “traction bars” since they are more specific to drag (or street) racing and thus, torque in one direction due to extreme power application. *Anyway, I think if I put a 454 in a Camaro for drag racing, I’d convert over to coil and link to fight that problem.*
TOPIC 8: DRIVELINE

DRIVELINE.

Driveline angles are probably the least understood by most shade tree mechanics. From the factory, your driveline didn’t have much of an angle to adjust to and your u-joints were primarily to allow axle movement without binding.

The universal joints (u-joints hereafter) allow your driveshift to operate smoothly at various angles. However, it must be properly set to avoid oscillation (vibration).

On the right you see two u-joints. In the leftmost illustration the transfer case output and the driveshaft are completely inline so both the output axis and the driveshaft axis travel in the same plane. The illustration on the right shows the driveshaft angled downward. Now, the axis for the output travels on one plane and the driveshaft travels on another. This is well within the capability of the u-joint’s function to transfer rotation but it’s not without impact.

The drive axis (in this case the transfer case output shaft) has constant velocity. The driven axis (your driveshaft) has two speed changes per revolution and the higher your drive shaft’s deflection angle is, the greater the speed change. This isn’t a problem if your driveshaft has a matching angle at the other end where it drives the axle pinion. If the angles match, the driveshaft’s speed changes will be translated back into constant velocity for the axle.

This next example shows one typical cause for driveline vibration. We’ll look at the driveshaft and yokes from the side, while we look at the associated u-joints from the rear. You’ll see the output shaft is parallel to the ground (two planes) and the driveshaft is angles downward. So far so good but your pinion is angled directly up the driveshaft (single axis).

That setup will transfer the two-phase speed change directly to the pinion. This difference in speed causes the ends of the driveshaft to oscillate (your vibration).
The illustration below shows two complete rotations of the transfer case (or transmission if two-wheel drive) using the same color references on the previous page. Please note that in this illustration I use the term “input shaft” for the transfer case output yoke and “output shaft” for the driveshaft.

So, continuing the previous discussion, the transfer case yoke drives the green poles and the orange poles drive the driveshaft. At the beginning of the rotation, the transfer case yoke poles are in the vertical position. This is the point of greatest speed difference between the input and output. The speed difference increased rapidly to this point where it is 2:1 (using the 60° shaft deflection example). While most other deflection angles are not this dramatic, it occurs for all but 0° deflection. While the faster than input deviations are greater than the slower than input, the durations are shorter.

The slower than input speed durations are longer than the faster than input speed durations. I included an input shaft position rotation degrees scale to illustrate. Once again, using the 60° deflection angle example, the driveshaft rotates 60° faster, 120° slower, 60° faster, and 120° slower.
Driveline offsets
When we discuss driveline angles we tend to concentrate on only one set of angles, those created by the vertical offset. There are two reasons we do that: 1) it is the offset is most prone to being increased and 2) the angles (BLUE ARROWS) of the components on each end can be adjusted to compensate for the vertical offset.

Vertical offset: This offset is the distance from the vertical center of the transfer case yoke to the vertical center of the pinion yoke. The offset creates the driveshift angle relative to the ground and has some bearing on the deflection angle at the two yokes.

Horizontal offset: This offset is used on most vehicles to ensure the U-joints have a small angle to compensate for and spread needle bearings lubrication. This offset is far less prone to change since you’d need to change a major component to affect this, e.g. a new axle or offset transfer case. The biggest difference with this offset is the inability to change the angles. All you can do is reposition components to reduce the offset, if possible.

The driveshaft’s operating angle is a combination of the two offsets (RED ARROW) running from centerline (CROSSED BLACK DOTTED LINES) transfer case yoke to the centerline pinion yoke. In this case, the driveshaft angles upward and to the driver’s side (rear view).

The stock configuration has the same two aspects but under normal driving conditions they (together) do not create much of a deflection angle for the U-joint. They provide just enough to keep the needle bearings moving until the suspension moves up/down. At that point they provide the flexibility for the driveline to move freely.
So, what can you do about it? Well, there are a few things.

If you’re going to keep a single cardan driveshaft you need to make your angles match.

**Your first option** is to lower the transfer case output to match the pinion.

You can buy or make a kit to lower the transfer case. This not only reduces the driveshaft angle at the u-joint but also changes the output shaft angle. When you install a kit, the engine, transmission, and transfer case tip back and down. **Make sure your fan still clears the radiator and no part of the engine strikes the firewall.**

The illustration below shows the corrected rear driveline angles. The front driveshaft is now in an unusual arrangement with the output yoke tipped upward.

**Your second option** is to shim or relocate the axle perches to lower the pinion to match the transfer case output yoke. At this point many people opt for a double cardan driveshaft.

**Your third option** is a double cardan driveshaft. In the illustration on the previous page, I stated that the angles **must be parallel**... well; the truth is that they just need to **match**. The next illustration shows both yokes approaching from the same side.
What if this driveshaft were cut down to form a single assembly? This is how a double cardan joint works. The joint assembly does the speed differentiation... constant velocity in and constant velocity out. *The speed phase changes are handled by the two u-joints in the assembly. A cutaway of the double cardan module is illustrated on the next page.*

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**Single Cardan Driveshaft**

*This is a NON-TYPICAL but acceptable configuration*

- All that's required for balance is matching angles—those angles are measured from drive shaft's centerline
- This shows how a double cardan joint (circled below) works—imagine this drive shaft as a double cardan joint

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**Double Cardan Driveshaft**

*Pinion yoke should be 2 degrees below driveshaft angle*

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The illustration below shows the driveline in the proper position for double cardan driveshafts. In this case you want to keep your output shaft in the stock position and raise the axle pinion to 2 degrees below the driveshaft centerline. The driveline is now fixed and assuming your driveshafts are balanced, vibration free.

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**4 inch suspension lift**

*(with double cardan drive shafts)*

- Output yoke & pinion yoke angles will not be parallel
- REAR pinion angle 2 degrees below shaft centerline for double cardan driveshaft
- FRONT pinion within 2 degrees of shaft centerline for double cardan driveshaft

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Now, I’ll compare the two primary types of CV joints. First is the captured ball. Unlike a single cardan or a double cardan assembly, it does not use universal joints. It has an outer “shell” that is grooved inside to match a grooved sphere. A ball assembly (usually more than 4-ball) moves smoothly along these grooves, constantly adjusting for angle changes. They always operate on one plane since neither the inner grooved sphere nor the outer grooved-shell holds the ball assembly in an absolute position. The ball assembly constantly rolls to the equilibrium point between the two components.

Captured ball joints are used most often for front wheel drive and all-wheel drive axle shafts. Some high-end Jeep aftermarket front axle shafts are also captured ball. They offer greater strength at higher angles, smoother rotation, and more stable torque transfer. One cautionary note if you have captured ball joints. Unlike the sealed u-joint, a captured ball joint must have a boot that covers the joint (some of the axle shaft joints boots cover the entire joint) and is sealed on each shaft. Any tear in the boot will allow dirt and grit to eventually destroy it.

The most common CV shaft for off-road vehicles is the double cardan shaft. It uses a self-balancing assembly that automatically positions the two U-joints at the same angle.

During operation, the two U-joints are connected to the assembly by adjacent poles while the driveshaft and transfer case (TC) yoke are connected to the opposite poles. A pilot pin on the driveshaft, inserted inside the pivot ball on the TC-side, is the mount for the TC yoke. This ensures that any change to the driveshaft-side angle tips the TC yoke U-joint to the identical angle relative to the assembly. No matter how you tip the driveshaft, the assembly and opposing U-joint will follow. The assembly may make two speed changes per revolution but the input and output are CV.
WHEELS AND TIRES.

Wheel Basics:

Wheels have changed a lot over the years. In years past, most wheels were stamped steel with a negative offset. Today most vehicles have a wider axle and the mounting surface is outside the wheel’s centerline (positive offset). Knowing what you have is important to knowing what you need to buy if you change your wheels and tires.

The illustration on the right identifies the main components you need to be familiar with when choosing a wheel to match your axle AND your tire.

First, I’ve talked to many people that don’t know what width their rims are. Most of the time they are off by 1 inch… why is that? Well most of them measured the width from wheel flange to wheel flange. Your wheel width is that measurement minus .5 inch for each flange. So a 7 inch rim measures 8 inches from flange to flange… an 8 inch rim measures 9 inches and a 10 inch measures 11 inches.

Second, most folks don’t know what backspacing is and how it relates to wheel fitment. In short, your wheel’s offset is determined by the rim width and the backspacing. That will make a big difference when choosing wheels. If you had positive offset wheels before and you buy negative offset wheels your tires will stick out… possibly a lot. Conversely, if you do the opposite your tires will likely be on your frame.

Positive Offset

Here are three examples of positive offset wheels used on most new cars and trucks. Find your wheel’s center by dividing the rim width by 2 then measure your backspace from the inboard flange to the mounting surface. Find your offset by subtracting that figure from your wheel’s center. If your backspace puts the wheel mounting surface outboard of the centerline then you have a positive offset. Most often this type of wheel is a larger diameter than its negative offset counterpart since brake components must fit into the wheel without obstruction.
Negative offset.

Here are three examples of negative offset wheels used on most older cars and trucks. The backspacing isn’t as much as the positive offset wheels so the axle hub and brake components don’t go as far into the wheel itself.

Your goal when buying new wheels is to determine what you want to do and make your adjustments from this position.

So…
1. If you want your tires to stick out more then select a wheel that will give you less positive or more negative offset.

2. If you want your tires to stick out less then select a wheel that will give you more positive or less negative offset.

TIRE & WHEEL FITMENT

Now, let’s do a little wheel & tire comparison on a vehicle. This Jeep illustration had a wide-track axle and all parts not related to this discussion removed.

I lifted this Jeep 4 inches so I could put 3 different tire/wheel combinations on it. I actually drove my Jeep for a year with this combo on it… looked pretty dorky.

First combination
15 X 7 inch rim with a 30 X 1050 tire.

This combination fits well inside the fender flare.

Tire: The tire’s cross section is 10.5 inches so 1.25 inches of tire protrude past each side of the rim’s flange (8” flange to flange). The tread patch is about 8.5 inches.

Wheel: The wheel mounting surface is 1 inch offset (3” backspace). The brake disk rotor and caliper are right at the rim’s edge.
Second combination
15 X 8 inch rim with a 32 X 1150 tire.

This combination fits inside the fender flare but the outside of the tread patch is now at the edge of the flare.

Tire: The tire’s cross section is 11.5 inches so 1.25 inches of tire protrude past each side of the rim’s flange (9” flange to flange). The tread patch is about 9.5 inches.

Wheel: The wheel mounting surface is 1.5 inches offset (3” backspace). The brake disk rotor and caliper are roughly where they were for the 7 inch rim (rim edge).

Third combination
15 X 10 inch rim with a 35 X 1250 tire.

With this combination your tire/wheel sticks beyond the fender flare and part of the tread patch is now outside edge of the flare. The tire height becomes an issue for both body clearance and frame clearance (turning).

Tire: The tire’s cross section is 12.5 inches so only .75 of an inch of tire protrude past each side of the rim’s flange (11” flange to flange). The tread patch is about 11 inches. Unless you cut your fender wells, you’ll probably need more lift to clear these tires off-road without problems.

Wheel: The wheel mounting surface is 1.75 inches offset (3.75” backspace). The backspacing was increased to keep the wheel close to the original position. The brake disk rotor and caliper are now inside the rim.
TOPIC 10: DEATH WOBBLE--WHEEL BALANCE

WHEEL (DEATH) WOBBLE AND WHEEL BALANCE.

One of the problems many of us will face from time to time is wheel wobble. It can be very severe and cause loss of control.

What causes it? Well, it depends.

To diagnose the problem, you need to know the answer to these questions.

1. **Does it wobble all the time?**
   If your answer is yes then you’ve got a steering part that is loose, broken, or worn out. Put your vehicle on a lift and examine ball joints, tie rod ends, steering box, and hubs. One more place to look is the suspension system. Dried, shrunken, or worn bushings can cause a wobble by letting the entire axle to move. I’ll cover that later.

2. **Does it wobble on all terrain?**
   If your answer is, “it does it on smooth terrain/roads,” then you need to do the same thing as the previous condition. If your answer is, “it does it only on rough terrain/roads,” then look at your steering linkage angles. You could have bump-steer. Bump-steer is most often noted on roads at higher speeds but the effect off-road can be more pronounced by extreme lifting of the passenger tire/wheel.

3. **Does it wobble only at certain speeds?**
   If you steering wobbles at the same speed all the time and stops if you go faster or slower then you have a balance problem. Let’s start with why larger wheels and tires are more of a problem than the stock setup.

**Taller, wider tire/rims.**
Your stock rims and tires kept things close to the wheel/hub centerline, both in width and height. The effect of yaw on your balance, while there, was not that noticeable. That assisted with balance because all you really had to worry about was oscillation (vibration) on one axis (red arrows) outward from the hub center.

This allowed balancing weights to be applied to only the outside of the rim (static balance) to counteract this oscillation.

The other axis, yaw (blue arrows) was always there but most of the time it wasn’t significant enough to deal with so you could get your tire/wheels statically balanced. However, when you change to taller, wider tires and wheels the yaw effect is amplified.
Here’s the tricky part. These oscillation effects will gradually grow as you approach the resonance speed the decrease as you depart. The longer you stay at that speed the more the effect will amplify itself. If the effect is only up and down you’ll experience vibration. If it is yaw, you’ll experience shaking. In both cases, it becomes more and more severe until you speed up or slow down.

Take your wheels to mechanic that can perform a dynamic balance on your wheels and insist that they do it. Some service centers try to tell you it’s not needed but if you’ve got oversize wheels/tires, it is.

OK, there are many things that can cause this imbalance such as losing a tread block, mud on the inside of the rim, and spinning the tire on the wheel.

NOTE: Since rear axles are non-steering they don’t experience this Yaw effect and those wheels could be static balanced. You won’t feel wobble, just vibration. If you intend to rotate your tires you need get them dynamically balanced too.

*Spinning a tire on the rim*

I mentioned that spinning a tire can put your tire/wheel out of balance. Here’s how.

Each tire/wheel is balanced together as one unit in the position they were mounted at that time.

One hazard many of you who “air down” are aware of is losing the seal between tire bead and wheel. Not many consider that while “aired down” you can spin the tire on the rim without breaking the bead. How can you detect if you’ve spun a tire? After you have your tires balanced, use a china marker to draw an arrow on the wheel and tire that point to each other (illustration’s left wheel). If you’ve spun the rim, the arrows will not point at each other (illustration’s right wheel) and you can bet the wheels are not balanced.
Since most of the Jeeps on the road today don’t use leaf springs, I decided to add this section.

The suspension requirements didn’t change, but technology did and the suspension design did. There are some significant differences between the old and new technology. However, I stayed with solid axles rather than cover independent suspensions. So in this section I’ll describe how a coil and link suspension operates and from time to time I’ll highlight how that’s different from the leaf spring suspension.

First, let’s start with an illustration of the stock Jeep Wrangler TJ suspension. I labeled the major suspension and steering components on this bottom view. Like the leaf spring example, I’ve colored most steering and suspension components blue. The addition, track bars (not needed for leaf springs), are green.

Coil and link suspensions perform the same primary functions as leaf springs, but unlike leaf springs, coil and link suspensions use three different components to hold the axles on the three planes. Another major difference is the spring rate. While a leaf spring pack can have a different spring rate for each leaf, most coils have one (sometimes two) spring rate.

I listed each component by the function it performs.

1) **Coil springs**: suspend the vehicle
2) **Link arms**: position the axle fore & aft
3) **Track bars**: maintain the axle side-to-side position (not needed with triangulated link arms)
The stock suspension is a 4-link short-arm, parallel link setup. It needs a track bar to keep the axle in the correct lateral position. The track bar allows the axle to travel up and down while keeping the axle in the same relative position. This is a very stable suspension but it tends to be bit less flexible due to the short, stacked pivot points of the parallel arms. The short arms operate at a higher angle, rotate more for the same suspension travel, and the torsion is greater at the frame mount. I’ll illustrate the track bar more specifically later.

The next two illustrations depict long-arm suspensions in different configurations. The first long-arm suspension is similar to the stock system setup (parallel) in the front. The rear suspension is 3-link (two parallel and one center) to reduce suspension binding.
This illustration shows two different triangulated link configurations. No track bar is needed for either configuration.

**FRONT:** The upper arm is a special one-piece triangulated unit. It provides fore/aft & lateral control. This one has curved arms to clear the oil pan and driveshaft. The lower arms are parallel (fore/aft control only).

**REAR:** The upper & lower arms are both triangulated.

As you can see in the illustration on the right, having a centered pivot point without a track bar helps reduce binding considerably.
These two illustrations are provided to show the difference in link-arm angles. Both suspensions are the same height but one is a long-arm kit and the other is a short-arm kit. That affects the swing arc the axle will take as the spring compresses and extends.

When you have tall springs, a short-arm suspension’s swing arc is more angled; forward/up and rearward/down than a similar height long-arm suspension.

![Wrangler (TJ) Frame](image)

It’s also important to note that the axle travels in a slight arc versus the leaf spring suspension’s straight line. The leaf spring pack lengthens and shortens, while the link arm maintains a constant length.

**Bent (angled) link-arms:** Just like the drag link mentioned earlier, the only reason to have bent link arms is to avoid striking other components or obstacles.
Some aspects to consider about link-arm angle.

1) The greater the link arm angle, the more road shock can be transferred up the link-arm
2) The link-arm angle can pass the point where it will actually “walk” under the frame instead of pushing it forward depending on climb angle and vehicle center of gravity.

The one new component I introduced above is the radius-arm suspension link. This is a very flexible suspension setup since there are only two arms (each arm “forks” at the axle to function as both upper and lower arms). This could be called a two-link setup since there are only two arms. You will need a track bar for lateral axle control.
The final comparison to a CJ is how the steering links are arranged.

**NOTE:** The stock Wrangler TJ track bars are bent to avoid striking the differential cases, as illustrated above.

The steering setup for TJs and CJs is very different. The TJ draglink connects to the tie rod versus the draglink connecting to the steering knuckle (CJ).

As illustrated above, the angles for the draglink and track bar are nearly the same, because of the tie rod connection. In this setup, the axle moves left or right in parallel with the drag link. This parallel motion keeps the axle and tie rod links in the same relative position, minimizing bump-steer.

The axle will move left/right further as you lift it higher unless you relocate the track bar lower as you add more lift. In addition, the track bar drag link relationship is important. If you install a drop Pitman arm, you must install a similar length track bar relocation bracket to keep their relative pivot paths the same.
While I covered a lot of the topics I see on countless repeated threads in the tech forums, I couldn’t cover them all. And like I said earlier, this isn’t intended to be a “how to” article. Its focus was to explain concepts and provide some background for your troubleshooting effort.

There are many other aspects of steering, suspension, driveline, and wheels/tires that I could cover but they often require a specialist and special equipment. I also didn’t cover steering topics such as Steering Axis Inclination, Included Angle, Scrub Radius, Thrust Angle, and Toe Out on Turns. Likewise, I didn’t cover link angle calculation, including squat or anti-squat, since most of you aren’t building a coil/link suspension from scratch. If I see questions on those topics appearing a lot on the forums, I’ll add them to the article.

I hope this gives you a better understanding of what you can expect. If you can’t fix it, you can explain it to someone that can.

Gojeepin,

Mike