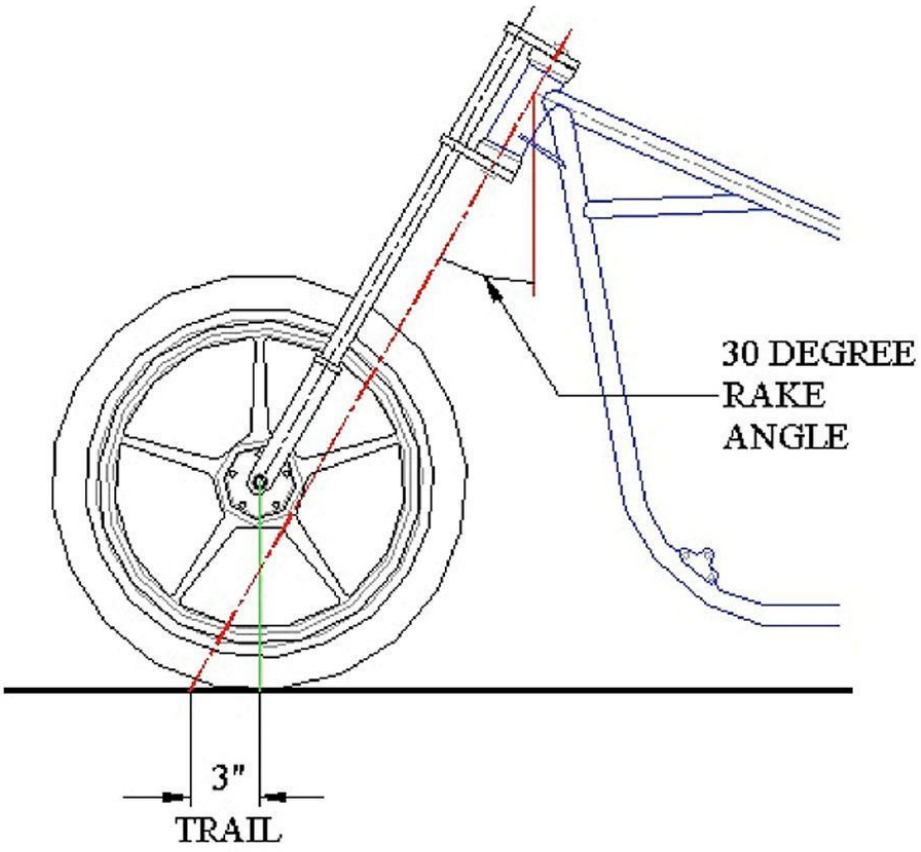
Playing the Angles

Gain and understanding of Rake and Trail

By Mark ZimmermanPhotography by Mark Zimmerman and Image Courtesy of Chopper Builders Handbook April 19, 2016

Bogie and Bacall, Lennon and McCartney, bacon and eggs: they're all appealing on their own, but as combinations they're just about unbeatable, and so it is with Rake and Trail. While most of us are conversant with the terms, obtaining a complete and coherent explanation is sometimes difficult. What follows should help clear the



waters.

Getting a complete grasp on rake and trail can be a little difficult to understand at first.

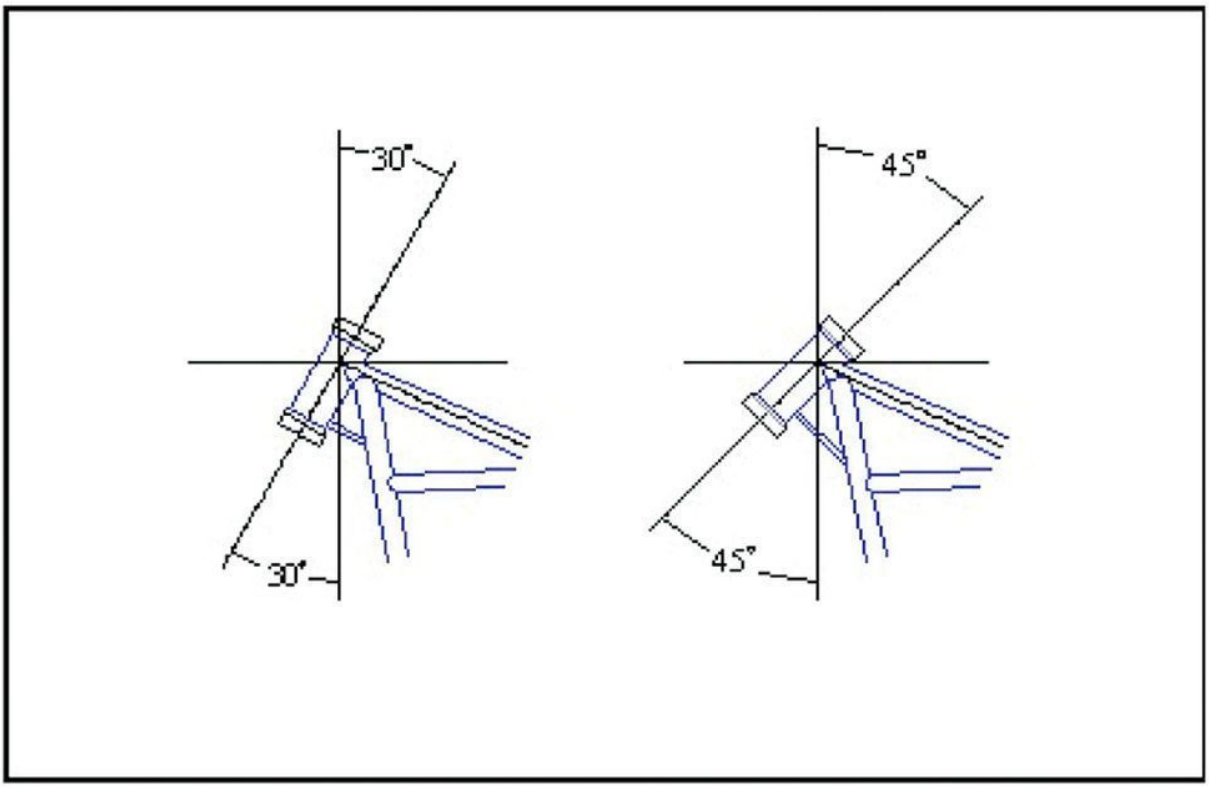
Courtesy of Chopper Builders Handbook

Defining Rake and Trail

Rake

Rake, which is sometimes referred to as steering head inclination, steering head angle or steering axis inclination, is defined as the rearward inclination of the steering head as measured from the vertical, and is always described in degrees. Although there are exceptions, the accepted practice is to consider a vertical steering head—one placed at 90-degrees to the pavement—as having a zero-degree angle. Consequently, the rearward inclination, or rake, is normally in the 22 to 36 degree range.

Although the fork angle is normally identical to the steering head angle, it doesn't have to be, and because of that when we discuss rake in the normal context, what we're talking about is the steering head inclination. Since the major factor in the calculation of trail is the steering head angle, it's important that we're all on the same page here.



Rake is the rearward inclination of the steering head as measured through the center of the steering stem.

Courtesy of Chopper Builders Handbook

Trail

If we draw two lines, one through the center of the steering head, (following the same angle), and the other vertically through the center of the front wheel, we'll see that

they intersect the ground some distance apart. The distance between those two points is called trail, for the simple reason that it's the distance that the center of the tire's contact patch trails behind the steering axis. The trail dimension is given in either inches or millimeters, and varies from about four to perhaps seven inches. Trail also affects the rear wheel, but since its effect is less pronounced, I mention it here only in passing.

Handling

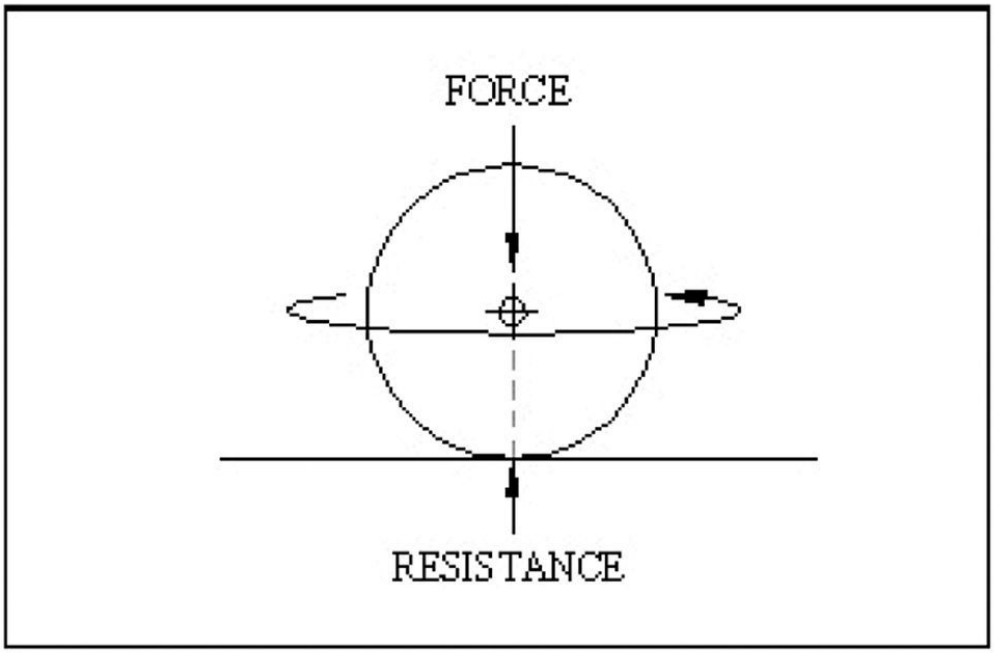
Coming up with a formal definition of handling is kind of tough, in part b cause, as opposed to the race track where such things can be quantified by telemetry or a stop watch, on the street handling is largely subjective. So rather than a formal definition, let's just say that handling might best be described as how much effort it takes to get the bike to do what we want it to do, when we want to do it, and how stable the bike is while doing it.

Playing The Angles (Why We Need Rake)

In the nascent days of two-wheeled, self-propelled locomotion, early velocipedes like the boneshakers had their forks positioned vertically. At a walking pace, or maybe slightly faster which was about as fast as a boneshaker could travel, the upright fork worked passably well. Unfortunately, any time the pace picked up, or the front wheel was deflected by an obstacle, the front wheel exhibited what we now call caster flutter, or shimmy, which is an uncontrolled oscillation around the wheel's vertical

axis. Many of us have experienced a mild form of this, usually when decelerating from about 55 to 40 miles an hour with a light grip on the bars, and it's unnerving. Imagine how much fun it was when the fork might rotate 180 degrees, with the predictable unpleasant outcome. This nasty turn of events could even be initiated if the rider's attention lapsed and he relaxed his grip on the bars at the wrong time, which as you might imagine, often made riding an early two-wheeler way more exciting than it had to be.

In any event, some bright spark soon discovered that inclining the fork rearward a few degrees induced stability. Once rake was introduced, the wheel no longer tried to change directions at the slightest provocation. The extreme riders of the day soon realized you could even ride the newfangled designs with your hands off the bars, a stunt that no doubt impressed the young lovelies of the day to no end.

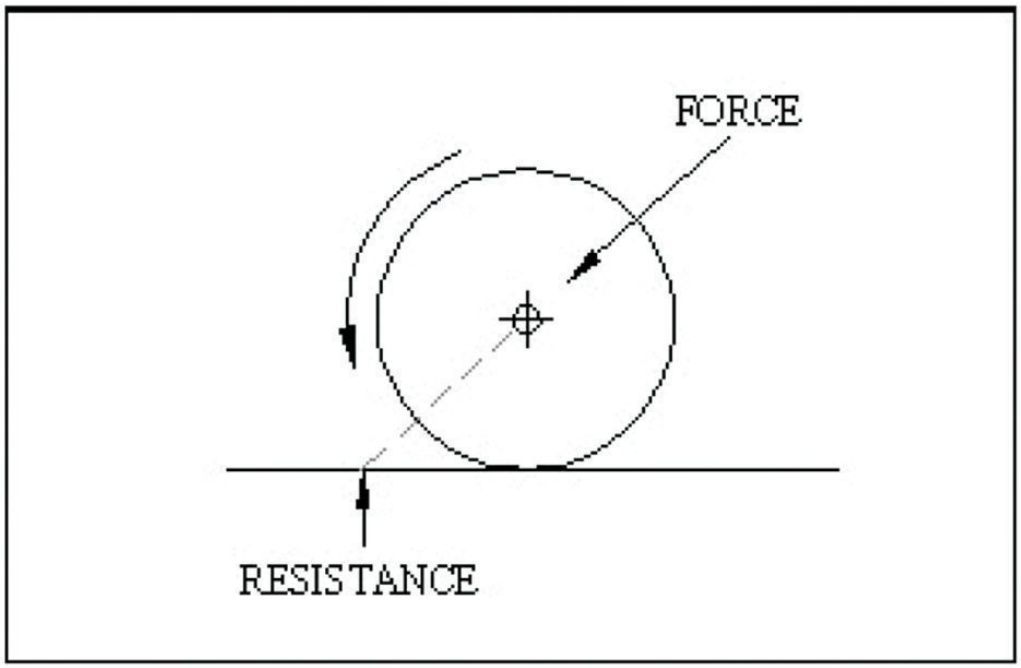


...when round objects have a force applied to their axis, they prefer to follow a course that's in opposition to that force…

Courtesy of Chopper Builders Handbook

So why did inclining the forks rearward stop the shimmy? The simple explanation is that when round objects like wheels have a force applied to their axis, they prefer to follow a course that’s in opposition to that force. In this case, since the force applied by the rider was coming from directly overhead, the wheel had tendency to rotate around its axis, rather than move forward.

Once that force changed direction and was applied in a forward direction however, the wheel moved in the opposite direction. Furthermore, because the steering axis now contacted the ground at some point forward of the wheel’s vertical axis, it also created a levering effect on the wheel that tended to stabilize it when it was in motion. That lever is trail.



Inclining the fork rearward and therefore applying the force at an angle induces stability.

Courtesy of Chopper Builders Handbook

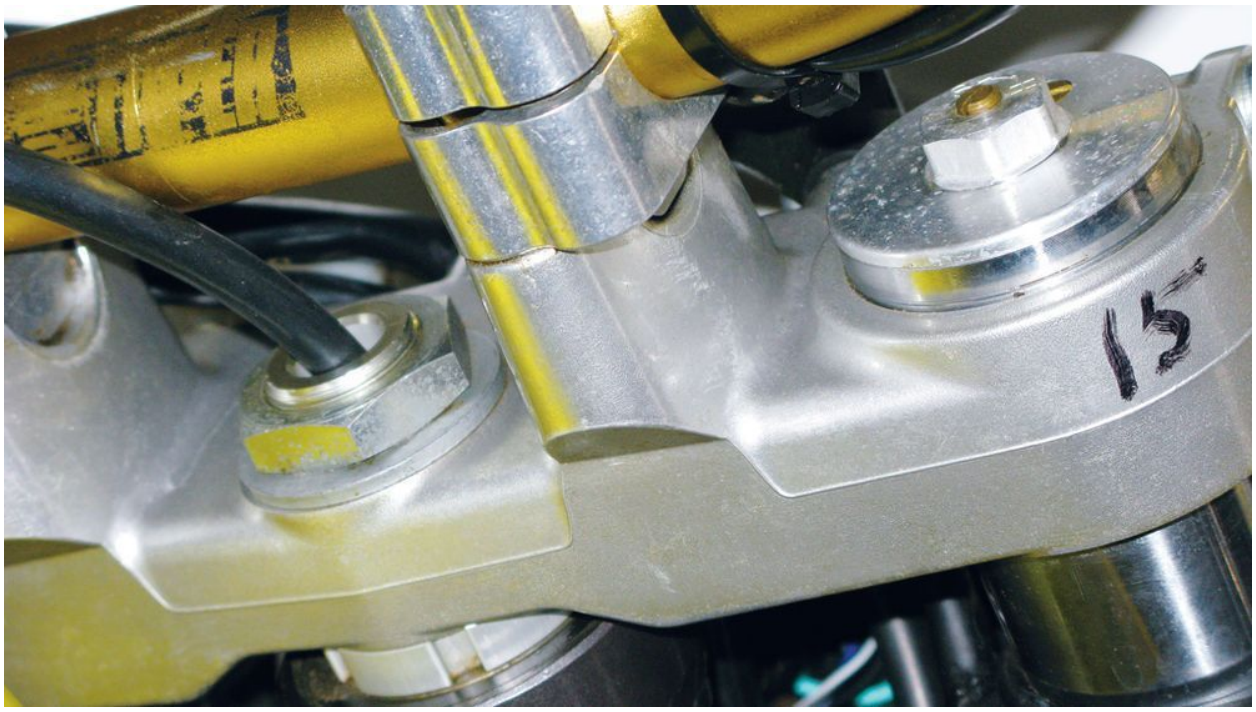
Why We Need Trail

Although the words “rake and trail” tend to roll off your tongue as compared to “trail and rake,” which sounds like a gardening term, of the two, trail is arguably the more important factor in how our bikes steer and handle. Indeed, experiments by chassis

designer Tony Foale have shown that a bike with zero rake handles and feels just fine, as long the proper amount of trail is present.

Essentially, trail is what gives our bikes directional stability at anything above a walking pace. Without it, the front wheel would try to revolve around itself like a broken shopping cart caster at the slightest provocation, making the bike unrideable.

Because the center of the tire's contact patch is behind the steering axis (a self-centering force), an imaginary lever—so to speak—is created. (see first image) It's this lever that enhances a motorcycle's stability, and helps restore it when it's disturbed. In basic terms, it works like this; when you're riding in straight-line, the wheel is held in the straight-ahead position by a combination of rake and the trail "lever." If something turns the front wheel, be it an obstacle or the rider's input, the lever instantly tries to turn the wheel back to the straight-ahead position. But that's not all it does. The length of the trail lever determines how much effort it takes the rider to make the bike turn, and how much effort it takes to hold the bike in a turn, and it's also largely responsible for the way our bike "feels" as we're steering it. This is because the trail acts directly against the front wheel, and that input is transmitted via the fork and handlebars directly to the rider. Reduced trail provides more input, and large trail less, because it tends to dampen the feedback. As you can see, while the basic concept of trail is easily understood, the nuances can get quite involved.



"Most motorcycles have their fork tubes placed at some distance from the steering stem."

Photography by Mark Zimmerman

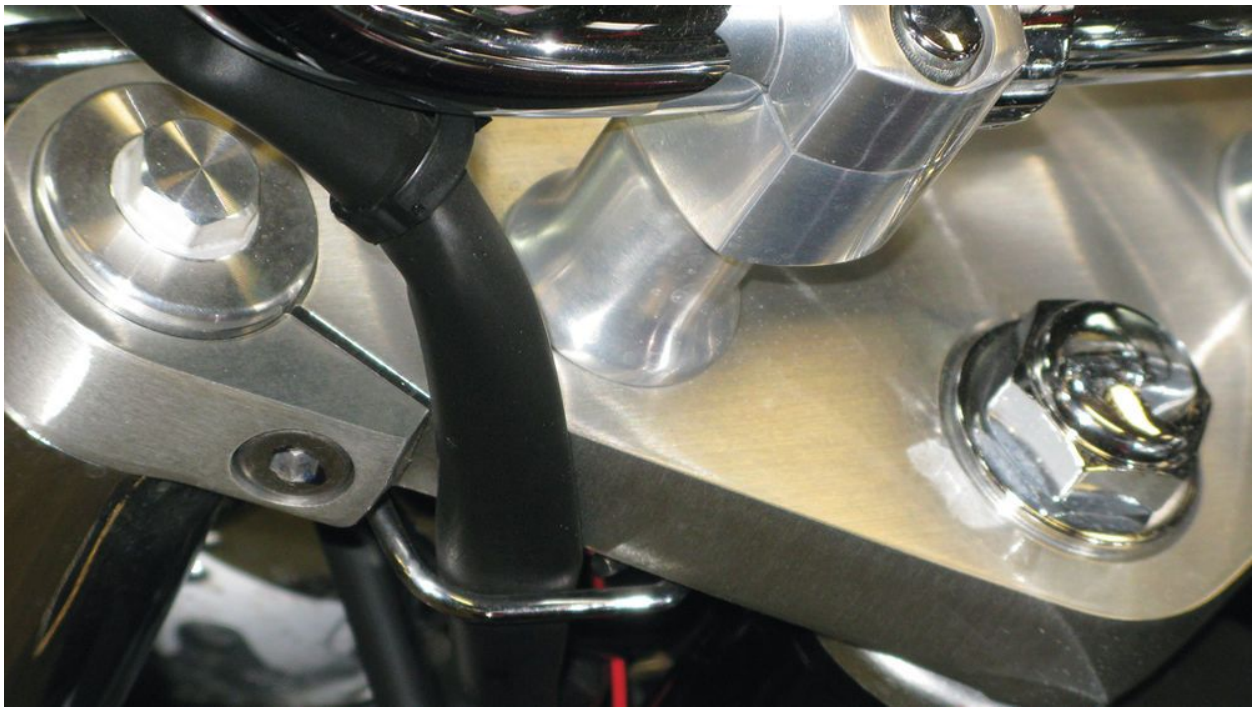
Practical Application of Rake and Trail

Rake and trail enhance stability, so bikes with lots of both, such as cruiser, custom or touring rigs—which typically have rake angles of close to 30 degrees or more, and a trail measurement of maybe five to seven inches— tend to be extremely steady in their habits. They generally have impressive, some might say ocean liner-like solidity

in a straight line, and maintain their composure through the corners. On the downside, they're often less maneuverable than we might prefer, especially at low speeds, and usually require a manly hand on the bars to initiate and maintain a tight turn (as an aside, this is one reason cruisers have such wide bars; the leverage reduces steering effort). Obviously, other factors including the bike's weight and wheelbase play a role here, but all things being equal, the more rake and trail we build into a motorcycle, the slower it will respond to rider inputs, and the more stable it'll be in a straight line.

As rake and trail are reduced, the bike will become more maneuverable and quicker to respond to steering inputs. It'll also develop a lighter feel at the handlebars. Unfortunately, it will also lose some of stability. Pure sport bikes, with their steep rake angles and short trail measurements (rakes of 24-degrees and trail measurements around four inches aren't uncommon), turn and handle extraordinarily well, but their overall steering demeanor might best be described as nervous. Though highly maneuverable, they also have a tendency to feel a little twitchy or unstable at high speed, so a steering damper is usually fitted to prevent things from getting out of control.

The bottom line here is that the more rake and trail we have, the more stable the bike will become, although both steering and maneuverability may suffer for it. Conversely, when rake and trail are reduced, the bike will steer quicker and become more maneuverable, though it's usually at the expense of stability.



"There are no hard and fast rules as to what dimensions work best for any given situation."

Photography by Mark Zimmerman

Manipulating Rake and Trail

As a general rule, as rake increases so does trail, but there are times when more or less of either is desirable for a given application. We'll come back to this, but I'll point out now that as far as rake and trail goes, there are no hard and fast rules as to what dimensions work best for any given situation.

Fortunately, you can adjust either dimension separately. Most motorcycles have their fork tubes placed at some distance from the steering stem. This is known as offset and it allows the frame designer to move the wheel forward or backward in relation to the steering stem, thereby increasing or decreasing the amount of trail.

As the fork tubes move forward in relation to the steering stem, the angle between the front wheel axis and the point where rake and the pavement intersect narrows, so trail decreases. As you'd expect, decreasing the offset (which moves the wheel closer to the steering stem) increases trail. At the risk of belaboring the obvious, when the steering stem and the fork lay in the same plane the fork has zero offset, and when that's the case, trail becomes a function of rake and tire diameter.

Anything that affects the way the bike sits in relation to the road can affect rake and trail.

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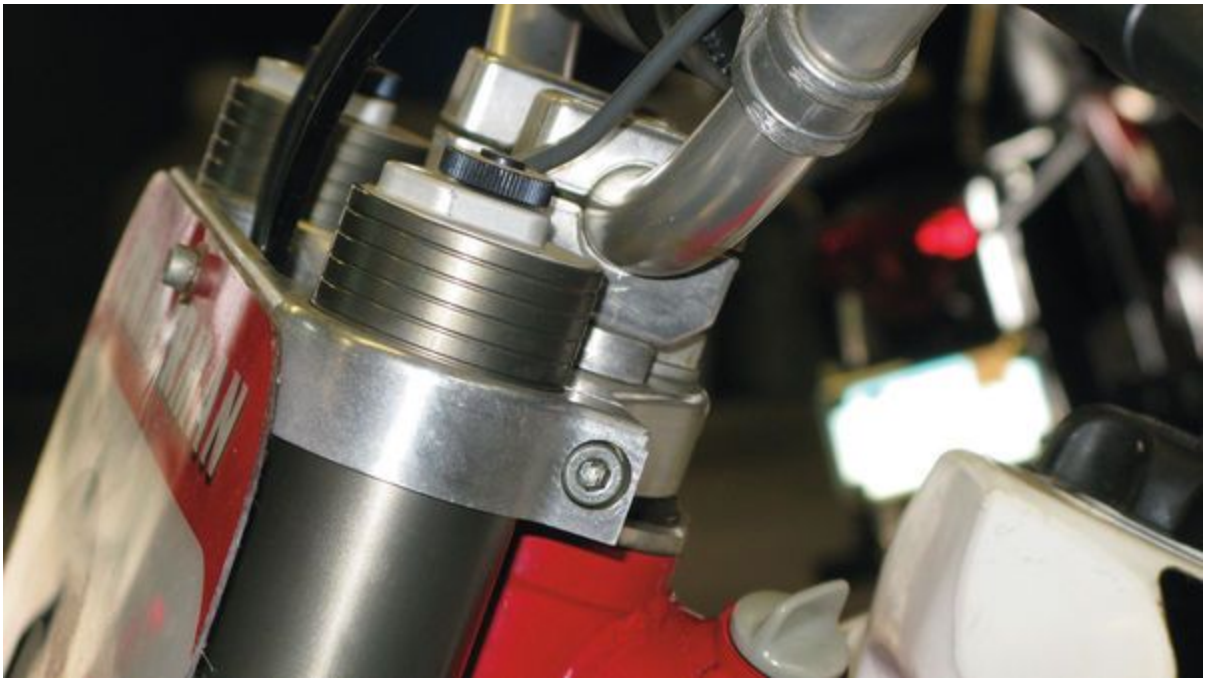

"...the more rake and trail we have, the more stable the bike will become, although both steering and maneuverability may suffer for it."

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"Offset can also be incorporated into the front axle mount."

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Offset can also be incorporated into the front axle mount. Placing the axle carrier in front of the fork, as is done on many off-road bikes, has the same effect as increasing offset.

What else influences rake and trail? In short, anything that affects the way the bike sits in relation to the road. For example: installing a larger tire at both ends of the bike adds trail because raising the bike, even slightly, increases the angle between the steering head and the road. This adds rake, which increases trail. Installing a larger

tire on only the front wheel will bring about an even bigger change, because as the front of the bike raises in relation to the rear, a proportionally larger increase in the rake angle occurs.

To decrease rake, which also decreases trail, you can install a smaller diameter tire, or slide the fork tubes up in their clamps to give them a steeper angle—a trick many racers use to make their bikes turn quicker—or install longer rear shocks. If you've ever looked at a superbike or GP racer and wondered why they had a nose-down "stink- bug" look to them, it's because the forks have been shortened or rear ride height increased in an effort to enhance their cornering ability. Sliding the forks down in their clamps to give them a shallower angle relative to the pavement increases rake and trail, as does installing a shorter rear shock to lower the back of the bike.

Playing with the angles, and even getting a larger tire, changes the rake and trail.

Photography by Mark Zimmerman

Rake and trail changes can also be made inadvertently. Something as simple as changing to a tire with a stiffer sidewall or different profile or loading the bike down with a passenger and luggage may have unintentional consequences, so think carefully before making any changes that will affect your bike's suspension geometry.

The lesson here is that rake and trail can be adjusted to suit an individual rider or situation, even unintentionally. It's also important to realize that any changes you make to your bike's suspension, and that includes fitting non-approved accessories or replacement parts, (including tires), can have unintended and possibly dire consequences.

Harley put the fork tubes where???

At low speeds, the effect of rake is more pronounced than trail. This is one reason why cruisers are sometimes such a handful when riding in town and during parking maneuvers. In 1980, Harley-Davidson wanted to reduce the steering effort of the then-new Tour Glide so they reduced the rake. That had the desired effect, but it reduced trail to the point where the bike became twitchy at high speed. Even with zero offset there wasn't enough trail, so in a bit of inspired engineering, they placed the

fork tubes behind the steering stem. This gave the front-end an unusual negative offset, but it pulled the wheel back, thus increasing trail. Viola, they now had a bike that was maneuverable at low speeds, yet very stable at high speed. It looked odd but the fairing hid the unusual fork and the design eventually migrated to the rest of H-D's touring bikes.

Summing Up The Angles

In the simplest terms, rake and trail are the major forces in determining the steering and handling characteristics of our motorcycles. Rake might be best be described as the steering component that makes a motorcycle directionally stable, while trail can be thought of as the component that restores stability when it's disturbed.

Although the principles behind rake and trail are well understood and it's easy to generalize, there are no hard, fast rules concerning the right rake and trail for a particular bike. Engineers spend countless hours experimenting with steering geometry, and even then don't always get it right, leaving any fine-tuning to the rider.

By the same token, if you understand how rake and trail interact and how each affects the motorcycle's handling even on a relatively superficial level, then picking the right bike for your type of riding becomes that much easier (as does correcting any deficiencies in its behavior). It all boils down to playing the angles.