Did You Ever Wonder?

by Ken Condon

UNLESS YOU ARE a science buff, you probably haven't taken the time to discover the complex physics of how your motorcycle works. After all, the subject of motorcycle dynamics consists of some rather mind-bending information that can make even the most intelligent rider's head spin.

My goal with this installment is to answer several hypothetical questions about motorcycle dynamics that affect the typical rider on every ride he or she takes. Hopefully, this will provide you with a deeper understanding of how motorcycles work so you can develop a closer interaction with your motorcycle.

A lot of people have written about how a motorcycle turns, slows and accelerates, including Tony Foale, whose book, *Motorcycle Handling and Chassis Design,* is the go-to resource for understanding motorcycle dynamics. If you want to learn more, I recommend adding Tony's book to your library, available at www.tonyfoale.com.

What Makes It Lean?

Motorcycles must lean to turn and the most efficient and effective way to initiate lean is to push on the handgrip on the side that you wish to go; push the left handlebar forward to lean left, and push the right handlebar to lean right. This is the action referred to as countersteering. You're not alone if countersteering confuses you. After all, turning the handlebars right to go left and vice versa just seems incorrect. The fact is that if you've ridden a motorcycle before, or a bicycle for that matter, you've used countersteering.

Several factors cause a motorcycle to lean, including *out tracking*, *tire camber thrust*, *gyroscopic effect*, and *centripetal force*, commonly mistaken for centrifugal force (Figure 1).

Out tracking refers to what happens when you turn the handlebars, causing the front tire contact patch to steer out from underneath the bike's center of gravity (CofG) and allowing gravity to pull the motorcycle into a lean. This also causes the contact patch to move away from the tread's center onto the tire's smaller outside diameter, which further promotes lean. This is called *camber thrust.* As the motorcycle begins the turn, *centripetal force* (or center seeking force) takes effect, which is the attempt of the mass to return to its straight ahead path. The amount of lean angle is the result of keeping centrifugal force (perceived outward force) and gravity in balance, allowing the motorcycle to stay on the circular path.

A lot of folks believe that the effect of *gyroscopic force* from the spinning wheels is most responsible for leaning. While gyroscopic force plays a huge role in stability, it actually plays a relatively small role in why your motorcycle leans. It's understandable that people believe it plays a larger role than it does, because of the way a rotating wheel responds to steering inputs. The gyroscopic effect can be felt through a little experiment. Hold a spinning motorcycle wheel by the axle ends and notice that the wheel strongly banks left when turned right and vice versa. This effect is called gyroscopic precession and is a significant force. But, because friction between the tire and the road is even greater, gyro force is less influential. If the tire had no contact with the road, then gyroscopic forces would have a much larger role. See how dirt bikes can be crossed up in mid-air for how this gyroscopic force can work without friction against the road.

Why Can't I Feel Countersteering?

Most times, turning a motorcycle is instinctual and we hardly need to think about how to do it. So, it's easy to ignore the fact that we do indeed countersteer to make our motorcycle turn. Also, countersteering can be further disguised by certain factors, such as slow speeds or the steering geometry of some motorcycles.

Countersteering can be almost undetectable at slow speeds because very little effort is needed to overcome the minimal inertial and gyroscopic forces necessary to initiate lean. Also, at slow speeds the rider quite obviously "steers" the front wheel to maintain balance, which can further convince some riders that they steer rather than countersteer to initiate lean.

At highways speeds, inertia and gyroscopic forces are strong, which makes countersteering much more obvious, because it takes significantly more handlebar force to change direction.

Why Can I Relax Steering Pressure Once Leaned?

Once your motorcycle is leaned into a turn, other forces take over to maintain the cornering arc. We discussed *camber thrust* earlier, which describes the force that occurs when the tire's contact patch moves from the tread center toward the outer edge of the tread when leaned. Since motorcycle tires have a rounded profile, when leaned, the contact could be seen to describe a cone and cones naturally roll in circles, thus a leaned-over tire will roll in a circle. This is one reason why very little additional force is required to maintain your path through a turn. Steering corrections may be required, but these inputs are typically minimal (Figure 2).

Why Is It Easier To Balance At Higher Speed?

The spinning wheels of a motorcycle serve as gyroscopes, and gyroscopes want to maintain their relative position, which contributes to stability. The faster the wheels spin, the stronger the gyroscopic force, which helps keep the motorcycle upright. At parking lot speeds, your motorcycle feels like it wants to fall over. But, a slight increase in speed makes your otherwise wobbly motorcycle much more stable. Not only does the speed in which the wheels are spinning affect how strong the gyroscopic force is, gyroscopic effect is also determined by gyro weight. This is one reason why lightweight wheels are fitted to racing motorcycles—to create

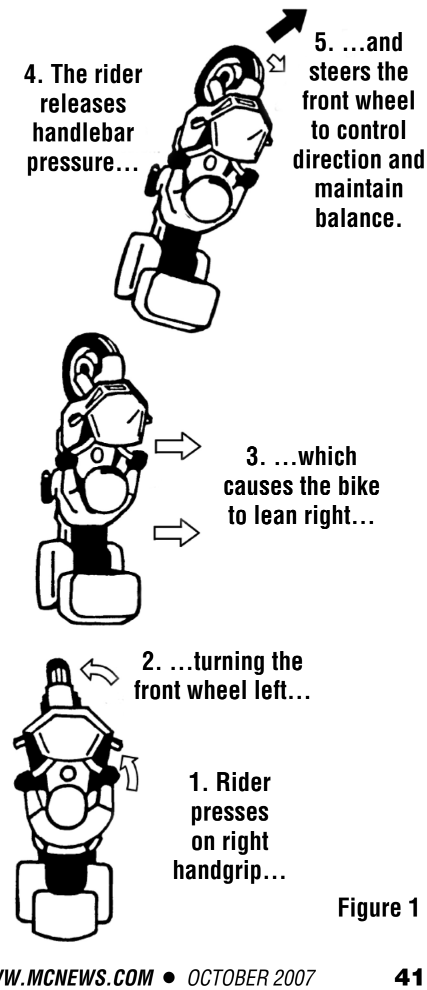
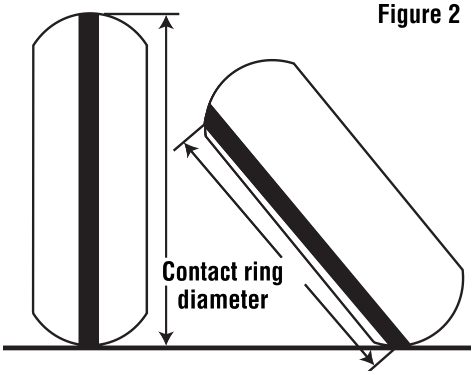


Figure 1

Figure 2



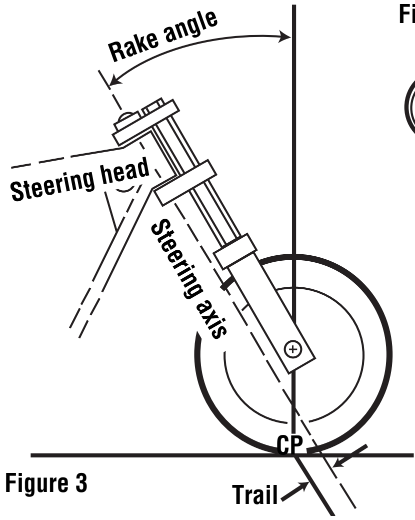
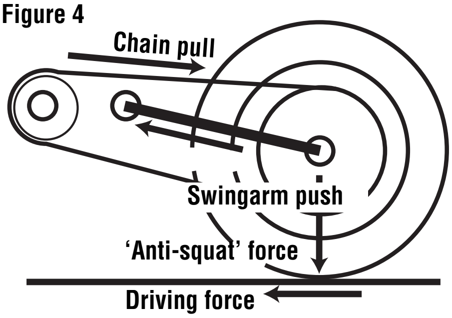


Figure 3

Figure 4



less gyroscopic force for quicker changes in direction.

Gyroscopic forces are a significant stabilizing force, but steering geometry also contributes to stability. Every motorcycle is designed with the front tire contact patch located behind the pivot line of the steering stem. This measurement is called "trail," which is typically between 3.5"–7.5". Trail causes the front tire to stay in line much like the caster wheels on a shopping cart. Motorcycles with steeper steering angles (rake) typically have smaller trail measurements and are typically less stable (Figure 3). The latest sportbikes are now fitted with steering dampers to maintain stability with their steep rake and short trail measurements.

So, the combination of a fast spinning wheel acting as a gyroscope along with the caster effect of trail gives you the stability that allows you to ride at highway speeds with no hands, if you so desire.

Why Does Mid-corner Acceleration Help Preserve Ground Clearance And Traction?

You hear us constantly say that for maximum control and traction you should roll on the throttle throughout curves. This is to stabilize the chassis, but it also helps prevent the chassis from dragging on the ground.

Most people assume that the front forks extend under acceleration and that the rear shock compresses as the rear end "squats." But this assumption is only half right. Yes, the front forks extend under acceleration, but did you know the rear shock *also extends*? This isn't readily apparent due to the feeling we have of being thrown rearward when we twist the throttle. This "anti-squat" effect is largely responsible for increased ground clearance when accelerating.

The swingarm acts in relation to the rear tire's contact patch when drive force is applied, causing the chain to pull back and down on the motorcycle, while to a lesser degree, the swingarm counteracts by pushing forward and up. The result is an anti-squat force that pushes the rear tire into the road surface and raises the rear of the motorcycle slightly under acceleration. Every motorcycle is designed with different amounts of anti-squat, so the effect will vary (Figure 4).

Acceleration not only raises the chassis for added ground clearance, it also helps preserve traction by letting the suspension do its job. When cornering, the springs are compressed by the addition of side forces. Acceleration keeps the suspension near the middle of its travel so it can absorb large bumps or dips and keep the tires in contact with the road.

Steady drive through a turn keeps the suspension in its "sweet spot" and hard parts away from the road, which is a particular benefit to those who ride low slung motorcycles with limited clearance. Unfortunately, many riders instinctively chop the throttle when hard parts start to drag, which causes the suspension to compress further and those parts to drag harder. It's best to maintain steady throttle to avoid dragging the chassis.

Some situations make maintaining steady acceleration through corners difficult, such as cornering while descending a hill. Depending on how steep the hill is the descent can actually cause the bike to accelerate even with the throttle closed and without the benefit of driving force. The best solution is to brake early, slowing enough to allow a slight throttle opening to help balance the load between front and rear wheels. Open the throttle sparingly to avoid cornering too fast.

Why Does My Motorcycle Drift Wide In Corners When I Accelerate?

Accelerating in a corner increases the centripetal force that wants to push the motorcycle to the outside of the turn. To demonstrate this effect, twirl a rock on the end of a string and let it go. The good news is that this effect can be used to your benefit. Acceleration "lifts" the motorcycle out of the corner, causing the bike to move toward the outside of the turn. This helps "finish" the corner and execute the ideal cornering line.

Because centripetal force causes your motorcycle to drift outward, you must lean more to keep the bike on its intended path. It's important to modulate the throttle with just the right amount of acceleration. Too much acceleration can unload the front tire, which means less "bite" to turn the bike. The result is a bike that drifts too wide.

Why Do New Tires Feel So Different From Worn Tires?

There can be several factors that cause you to feel like a new set of tires makes a huge difference over the last set you used. If you changed tire brands or models, then that alone can be why you detect better (or worse) handling and grip. However, it may be more of a mystery why you feel a difference when you replace old tires with the exact same brand, model and size as before.

The answer lies in the fact that tire wear affects handling. Most riders don't notice the slow deterioration of handling over the many weeks and miles it takes to wear tires down, so when new rubber is mounted, it can be surprising just how much better they feel.

A tire that is worn flat in the center has a significantly different profile (cross-section) than when it was new. This flattened center can cause slow turn-in and abrupt cornering transitions, because as the motorcycle rolls into the lean, it must "step up" onto the sharp ridge between the excessively worn center and the outside edge of the tread. Traction can even be momentarily compromised because of the reduced size of the contact patch at this narrow ridge (Figure 5).

It isn't practical or economical to replace our tires whenever a flattened center begins, so most of us live with less than optimum handling until replacement is deemed necessary. But, your bike will perform best on tires with the original profile as delivered when brand-new, which is one reason why track day organizers recommend relatively new tires for riding on the racetrack.

Whether you notice any deterioration in handling or not, it's best to replace tires before they are too worn. Monitor tread depth by using the tread wear indicators; these are raised bars located at the bottom of tread channels.

Tread wear is not the only reason for poor performing tires. Rubber hardens with age, so tires that have not been replaced for a few years will have reduced traction, regardless of remaining tread depth. Tire representatives suggest replacing tires after five or six years, but many riders prefer to use tires that are less than three years old.

If you do decide to change tire brands or models, it's good to know how tire profiles can affect handling. Triangulated profiles offer quick turn-in and more cornering traction, while rounder profiles offer straight-line stability and smoother cornering transitions. Tire selection is very important to handling, but there are no hard and fast rules. Find a tire with a profile and construction that suits your riding style.

Why Does My Rear Tire Skid Easily Under Hard Braking?

Rear tire skids are a significant cause of crashes. Part of the reason so many riders skid the rear tire is because they do not understand how rear tire traction changes when powerful brake forces are introduced.

When the brakes are applied, the combined weight of the bike and rider transfers forward and the front tire contact patch is forced down onto the pavement, providing *more* traction at the front. Forward load transfer increases front tire traction but it *decreases* rear tire traction, which makes a rear wheel skid more likely. The most radical example of reduced rear tire contact when braking is the stoppie, where 100% of the weight and braking force is on the front wheel and the rear wheel completely lifts off the ground.

So why should you use the rear brake at all if it is so touchy? First, if you learn to use both brakes effectively, stopping distances are reduced. Second, in low-traction situations, the rear brake becomes more important, because less overall brake force is possible and therefore, less forward load transfer occurs. Third, the rear brake contributes to straight line stability by keeping the rear wheel in line with the front wheel (Figure 6).

The key to maximum effort stops is to become familiar with the power of your motorcycle's brakes through regular practice. To brake effectively without skidding, apply the rear brake firmly, progressively reducing pressure as the load transfers forward. Through purposeful practice, your muscles can retain a "memory" of how much pressure can be given to the brake controls without skidding either tire.

A more subtle form of rear wheel braking that you must consider is *engine braking*. By simply rolling off the throttle some weight shifts forward, sometimes rather dramatically. Poorly timed downshifts or releasing the clutch abruptly can make matters worse and increases the risk of skidding the rear wheel.

Why Can Heavyweight Cruisers Stop In Shorter Distances Than Lightweight Sportbikes?

It may sound weird, but cruiser motorcycles can often stop in shorter distances than high-performance sportbikes despite their heavier weight and inferior brakes. The answer lies with load transfer, which affects different motorcycles to varying degrees. Tourers and cruisers resist load shifts caused by speed adjustments because of their long wheelbases and relatively low CofG. Their tendency to "loop" (wheelie or stoppie) is very small (Figures 7 and 8).

In contrast, the frame geometry utilized by high performance motorcycles features a short wheelbase, steeply raked front ends and a comparatively high CofG. This configuration aids in turning precision and quick handling, but also contributes to more severe forward and rearward load shifts. This increases the bike's tendency to loop and limits how much engine or braking power can be used before the sportbike pilot performs a wheelie or stoppie (Figure 2).

This is why long wheelbase cruisers can often stop in a shorter distance than many sportbikes.

I hope this quick run down of how your motorcycle works is useful in helping you "feel" how your actions affect handling so you can improve your cornering and braking skills.

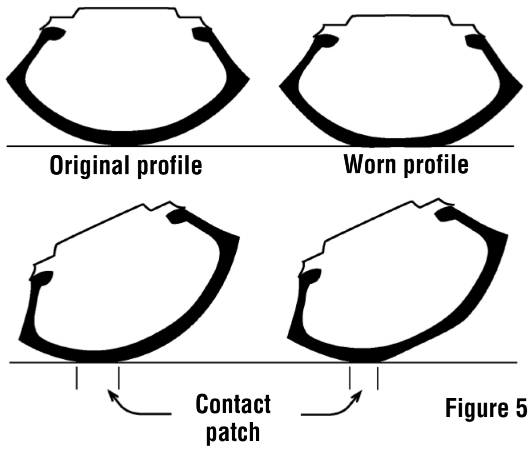


Figure 5

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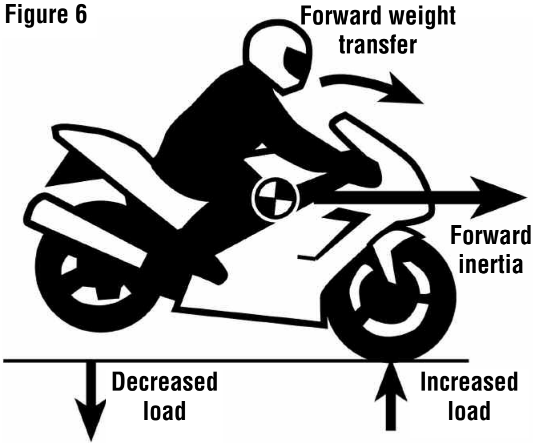

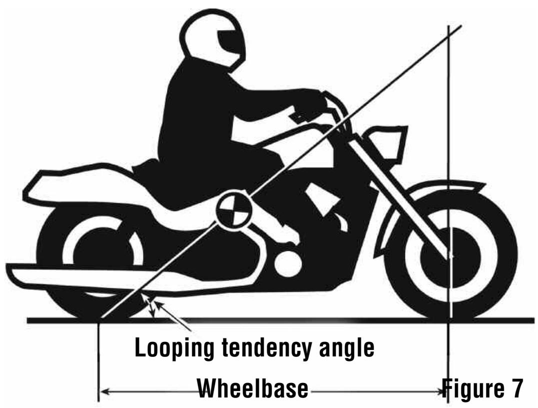

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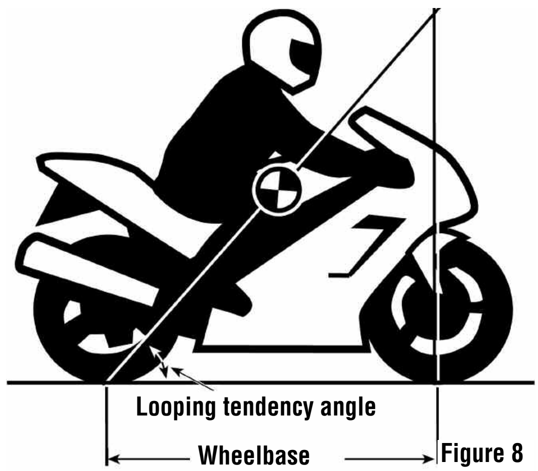

Figure 8