Motorcycle Stability and Steering
by Andy Townsend

"Speed Stabilizes the motorcycle" and "press left, lean left, go left" are two phrases heard by students taking the MRC:RSS rider course. During the course students may be told to "trust us on this one...it REALLY works" Well, it DOES really work, but during the course there is little time to explain why speed DOES stabilize the motorcycle and yes, you DO press the left bar to initiate a turn to the left.

So…here are explanations of motorcycle stability and steering! Although reading both sections will give a greater understanding of motorcycle dynamics, the sections do "stand alone", so read either or both at your leisure!

Motorcycle Stability

Keeping balanced in a straight line, assuming the road is flat and there is no crosswind, is a matter of keeping the combined Center of Gravity of rider and motorcycle vertically above a line joining the contact patches where the front and rear tires touch the road. If the bike starts to lean there are two ways to correct this and restore the situation where the contact patch line is under the Center of Gravity:

1. Move the Center of Gravity OVER the new contact patch line.
2. Move the tire contact patch line back UNDER the new Center of Gravity.
3. Ever seen someone balance a bike that is NOT moving forward? The primary balance method is moving their body to try and maintain the Center of Gravity over the contact patch line...tricky! A much easier way to balance, once moving forward, is to use method 2:
4. Moving the tire contact patch line under the new Center of Gravity. This can be done by steering the motorcycle. If the bike starts to lean to the left for example the Center of Gravity will now be vertically to the left of the contact patch line. Restoring balance simply involves steering the front wheel to the left, the front of the bike moves left and the bike tracks left. Once the Center of Gravity is back over the contact patch line, straight line balance is restored.

Several factors conspire to help keep the Center of Gravity over the contact patch line, helping keep the bike upright and moving straight ahead with little or no rider input. As you will see the stabilizing effects of these factors increases with increased speed:

A. Forward inertia of the motorcycle will tend to keep the bike moving in a straight line. The motorcycle will be less susceptible to outside forces trying to change its direction.

   Think of two identical shopping carts:

   Push one straight ahead at 10 mph. Push one straight ahead at 100 mph (I recommend a Pathmark cart: the wheels on A&P carts overheat above 85.....no just kidding...this is a MENTAL exercise!)

Drive next to carts, (don't forget...it's a MENTAL exercise!) apply force sideways, 90 degrees to the forward direction. If the same force is applied sideways for the same duration to both carts, lets say enough force/time to make the sideways velocity 10mph, then the DIRECTION change for the 10mph cart will be much greater than for the 100 mph cart.

The Cart traveling at 10 mph forward will now be traveling 10mph forward 10mph sideways which gives an angle of 45 degrees to the original direction.

The Cart traveling 100mph forward will now be traveling 100mph forward 10mph sideways which gives an angle of 5.7 degrees to original direction. The sideways velocity will be the same for both carts, just angular change of direction will be much less for the 100mph cart. Both carts have inertia, but the greater inertia of the faster cart makes its resistance to a change of direction higher. Inertia is a function of mass as well as velocity, so as mass increases inertia also increases. As I am sure you know, it is more difficult to deflect a heavy shopping cart than a light shopping cart traveling at the same speed. A heavy bike traveling at speed will have greater inertia and tend to be more stable than a light bike traveling slowly.

An A&P shopping cart with smoking wheels loaded with 6 cases of Bud traveling at 100mph is NOT going to make the turn at the end of the isle! Don't ask me how I know! "Spill in isle 7...Bring the BIG mop".

B. Steering geometry (primarily "trail") will tend to straighten the bike if it starts to lean:

If you projected a line through the Center of the bike steering head to the ground you would find the tire contact patch is behind this point. This distance between the two points is "trail". This makes the front wheel inherently stable and want to "follow" where the steering head (and hence motorcycle) is going. Generally, a larger trail will tend to produce a slower steering, more stable motorcycle.

As a result of "trail" if the bike starts to lean left, even without rider input, the front wheel will turn to the left (buy a cheap model motorcycle and try it: roll the bike forward in a straight line, then lean the bike to the left, the front wheel will turn to the left without steering input). The force on the wheel returning it to the "in line" position, should it get out of alignment, increases with speed. This effect is similar to a weather vane pointing into the wind: the greater the wind speed the more rotational force returning it to face into the wind should it get out of alignment.

C. Gyroscopic forces, primarily of the two wheels, but also other components whose axis of rotation is in the same direction as the wheel spindles, tend to resist any change in the angle of lean of the motorcycle. Gyroscopic "resistance" to a change in lean angle increases as the rate of rotation of the wheels increases and the rate of rotation increases as road speed increases. A phenomenon known as gyroscopic precession also has a minor effect but does tend to correct the steering if the bike starts to lean. Precession translates a force trying to rotate the axis of a gyroscope in one plane into a force trying to rotate the axis in a plane 90 degrees offset in the direction of rotation of the gyroscope.

Whew! What this means for the motorcycle is that a leaning movement to the left, through gyroscopic precession, will tend to turn the front wheel to the left. This is why a quarter rolled on the floor will tend to keep upright: if the quarter starts to lean to the left gyroscopic precession makes it TURN to the left, steering the contact patch under the Center of Gravity.

So: The stabilizing effect of inertia increases with speed.
The stabilizing effect of steering geometry increases with speed.
The stability brought about by gyroscopic effects increases with speed.

These are three major reasons why "speed stabilizes the motorcycle". Of course there is a flip side to this: all these effects that make the bike track "straight and level", by definition, also conspire to make it more difficult to turn a motorcycle at speed.

Speaking of turns...how do we initiate a turn when we actually want to????

Motorcycle Steering

Any turn produces centrifugal force on the motorcycle, tending to make the bike lean to the outside of the turn. To balance this centrifugal force the Center of Gravity must be offset toward the inside of the turn. A left hand turn requires a lean to the left. A right hand turn requires a lean to the right. This applies to all turns, fast or slow.

What do we need to do to accomplish this? Our aim is to transition from straight ahead riding to being stabilized in a turn.

If we intentionally move the contact patch line from vertically beneath the Center of Gravity, the bike will start to lean. For example, if while riding the bike straight ahead, we press on the left bar the front wheel points to the right. The front wheel tracks to the right (sometimes called "out tracking"). So the weight of bike and rider is now to the LEFT of it's "support" on the ground, the tire contact patches. Because the weight is to the left, the bike leans to the left. It is important to note, for a LEFT turn, we initiate a lean to the left by pressing on the left bar, turning the front wheel to the RIGHT. This is often referred to as COUNTERSTEERING: a turn to the left initiated by turning the front wheel to the right.

The harder you press the quicker the lean; the longer you press, the further the lean angle.

Once the bike is leaned over to give the turn radius you want, ease pressure on the bar. Motorcycle steering geometry (primarily trail again), tire profile and other factors tend to keep the bike stable in the turn. Depending on a number of factors, the motorcycle may even track through the turn with no subsequent steering input (ie it may require NO steering force in the turn to keep the bike stable through the corner).

"Out tracking" works down to virtually zero speed. Once stabilized in a corner the front wheel will be turned to some degree in the direction of the corner. At higher speeds the steering angle will tend to "self adjust", however at lower speed, for tight turns the steering may not "self adjust", so, even though you are countersteering to initiate the lean you may need to turn the bars yourself in the direction of the turn once you are leaned over.

Once you are in a turn the lean angle can be adjusted by again countersteering until the angle is corrected. Press on the inside bar for more lean, outside bar for less lean.

Gyroscopic inertia and precession do factor in, again to a minor degree, in turning: turning the bars to the right will produce a precession force in the front wheel which would tend to lean the bike to the left. As gyroscopic inertia increases so does the force required to turn the handlebars and so does the resultant leaning force due to precession. Precession does not increase the magnitude of the force, it just translates the direction. The precession torque trying to lean the bike is always less than the steering torque the rider applies. Have someone sit on your motorcycle, now try and lean your motorcycle by lifting up on one end of the front axle, pulling inline with the fork tubes, and pushing down with the same force on the other end of the axle, again, in line with the fork tubes. This is the location and direction of the precession force. Even allowing for the fact your bars are longer than your front axle by perhaps four times, so giving around four times the torque or "twist" for a given force, you can see there is not much effect on your 500lb bike! Ever watch motorcycle racers on a track ride an "S" bend? From leaned over full left to leaned full right in under a second. Imagine how hard you would have to pull up and push down on the front axle to do that!

Again with higher gyroscopic inertia you have to press on the bars harder or for longer, so even though you do get some precession help this is more than offset by the higher force or longer time required pressing the bars to get the front wheel to "out track".

Also a front wheel with higher gyroscopic inertia tends to be heavy and that effects performance in other ways (Increasing the un-sprung weight….but that's another story).

"Out tracking" uses gravity do the work for you. Ever fallen while walking on ice? If your feet slide to the right, YOU will "lean" to the left. This is effectively "out tracking", moving your contact patch away from your Center of Gravity. This "lean" happens quickly: gravity is strong!

So there it is, a little deeper explanation of stability and steering!

Hopefully these ideas will help you get a greater understanding of what actually happens when riding a motorcycle. Understanding what is happening will hopefully help making riding safer and more fun! If nothing else I'm sure you can now see why, during the Rider Course Instructors don't have time to explain this tricky subject!

Ride Safe!

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There is a lot going on when you balance and steer, and there are many and varied explanations out there! Two excellent books that devote a good number of pages to this subject and both give great (although slightly different) explanations are:

- Proficient Motorcycling, by David L. Hough. Publ. Bowtie Press. Motorcycle Safety Foundation Guide to Motorcycling Excellence Publ. Whitehorse Press.
- The MSF Experienced Rider Course Participants Handbook has similar information about countersteering to the MSF Guide to Motorcycling Excellence.