

Countersteering. I think I understand it all now!

I do not say that countersteering has not been fully explained in some learned tome somewhere, I only say that I have never seen an explanation that fully explained it to me. After a Web Forum discussion of motorcycle dynamics I have come to the following explanation of the phenomenon.

There is no math in this paper, partly because, if there was, your eyes would glaze over and you would lose interest, and partly because, as a Civil Engineering dropout from the 1960's, I am not able to give it! I am prepared for persons more learned than I to take this apart and prove or disprove my theories but I am sure there is value in here somewhere, so if you are sitting comfortably, I will begin.

Countersteering works in all modes of a motorcycles operation, except VERY low speed manoeuvring where the bike actually leans AWAY from the turn. I will call this Mode 1. Trials riders are very familiar with Mode 1 but the road rider rarely operates there. This paper does not address Mode 1.

There are two other modes of operation where countersteering is used, not surprisingly, I will call these Mode 2 and Mode 3.

Mode 2 is where the motorcycle is moving upright and in a straight line.

Mode 3 is where the motorcycle is leaned over and moving in a curve.

The curve may be the arc of a circle, but is probably a transition curve (I do remember these from my Civil Engineering studies!) What sort of curve is not important to my explanation. It will doubtless affect the math but I have intentionally left this out. You can see this was the right decision already!

The explanation of countersteering in Mode 2 is the easiest to understand. This is where the rider uses countersteering to initiate a turn from the straight ahead position, and is the only Mode for which I have ever seen any explanation. In fact, I have seen two explanations for this, both of which I believe are applicable, and are covered below.

Countersteering is so named because, on a single track vehicle, to initiate a right turn you actually turn the handlebars to the LEFT. This is the

opposite of the steering input required on a tricycle, which is why you found it so hard to graduate from your tricycle to your first bicycle as a child. You kept turning the wrong way! A good job Dad was running along behind ready to grab the saddle! Eventually your BODY learned to do it right, but, in many riders, this has remained unconscious knowledge. If this is you, you may choose to stop reading right now, because I am trying to explain something your mind does not believe!

Are you still with me? Good!

So, to initiate a turn to the right you countersteer to the left by turning the bars to the left slightly. In practice you PUSH on the right bar rather than pull on the left bar, but this is a mute point. To train riders to turn a motorcycle the mantra is “Push Right, Lean Right, Go Right”. You will now be taught this at riding schools.

OK, what is happening in Mode 2? After the steering input, the Steering Head of your motorcycle (through which the forks pivot) moves to the right of the centre of gravity. How far to the right is determined by the speed and duration of your steering input, the further the steering head moves to the right, the more violent the resultant steering response will be.

There are two questions here, what is the force moving the steering head to the right and what is the force causing the steering response?

Question 1. What is the force moving the steering head to the right?

There are two possibilities, first the physical effort you put into your push, acting at the tyre/road interface. The effect of this is related to the friction at the tyre/road interface and the amount of Rake and Trail designed into your motorcycle (Rake is the angle of the steering head and trail is the distance from the tyre contact point to the intersection of a line through your steering head to the road surface). The amount of Rake and Trail determines how far the steering head moves, and how much effort is required to move it. I am not qualified to explain the subtleties of Rake and Trail but, as it is obvious that a zero rake and trail (ie with a vertical steering head) would have zero to little effect, then, as these measurements increase so must the effect of moving the steering head to the right. I think we are all aware that the values of Rake and Trail are very significant in determining how quickly a motorcycle steers and how stable it is. This tells me that this ‘possibility’ is of major significance.

This effect occurs at any speed, including when the motorcycle is stationary, something you can easily demonstrate for yourself with a pushbike. So this possibility can be upgraded to a certainty, agreed?

Rather embarrassingly I can report that in late 2000, at the end of a quick stop in traffic, I failed to notice that I had actually stopped and tried to correct my line by countersteering. Result? The bike fell on its side, so fast I did not even get my foot off the footpeg! I can therefore absolutely confirm that countersteering works at zero speed! Pity really...

The other possibility is Gyroscopic Precession, the force generated when a spinning gyroscope is deflected from its axis. This is much favoured as THE cause in many explanations of countersteering, but I intuitively feel that the significance of gyroscopic precession is overstated. First, what is gyroscopic precession? Again, I am not qualified to explain to you the subtleties of gyroscopic precession, so what follows is my understanding. If you want the *why* and the *how* you must read up on it yourself! The *what*, however, I will 'explain'. When a spinning gyroscope, in this case your front wheel, is turned to the left, a force is generated at right angles to the turning moment (ie to the right) and vice versa. In our example, attempting a turn to the right, the wheel is turned left, generating a force to the right which moves the steering head in that direction. If you have ever conducted the school experiment of holding a spinning, weighted, bicycle wheel by its axle whilst sitting on a rotating stool you will remember that turning the wheel caused you, and the stool, to rotate. So Gyroscopic Precession can be empirically experienced. Another possibility can be upgraded to a certainty, agreed?

OK, that is *what* gyroscopic precession is and it obviously assists us with the desired turn. However, as the countersteering *effect* works at zero speed, gyroscopic precession cannot be PRIMARILY responsible for the countersteering effect. In fact, as the faster you are travelling in a straight line the GREATER the countersteering effort required to initiate a turn, I feel that the gyroscopic effect of your rotating wheels tends to RESIST initiating a turn. This partly explains why bikes continue merrily when the rider has fallen off, the bike frequently recovering from an unstable position. It is also an empirical observation for me. Also, as I read that reducing the rotational mass of wheels gives QUICKER steering, I am sure that the effect of gyroscopic precession is overstated. I agree that it IS present, and once the wheel is turned, will have an effect

but, unlike some of my correspondents, I do not believe it is THE explanation.

Question 2. What is the force causing the steering response?

Gravity and the 'Power Thrust Vector'!

First, Gravity. As the steering head moves, the centre of gravity also moves, and once the vertical line through the Centre of Gravity (CG) of the motorcycle moves outside the contact point of the tyres the bike will fall to the right. Everyone has experienced this, and if the motorcycle is stationary and you don't support the bike with your right leg, it will fall over. Embarrassing and expensive! If the motorcycle is moving, as the CG falls to the right the motorcycle commences turning in a curve to the right. The longer you maintain the countersteering input, the further the CG moves to the right and the further the motorcycle will turn to the right. Are you still with me? Have I said anything that you disagree with? I hope not! Once you remove the countersteering input the curve on which the motorcycle is travelling will stabilise as the front wheel is now pointing along the line of the curve. Hopefully this curve matches the road on which you are travelling, otherwise your ride will shortly be painfully terminated in a shower of plastic!

It is at this point that I need to introduce the concept of Vectors. I would like to emphasise here that Vectors are a real mathematical concept; some of my correspondents seem to think it is a figment of my imagination! A linear force can be considered to be the result of two vectors acting in different directions, a vector being a force acting at an angle. An example of this is being towed on a motorcycle (not easy on a modern motorcycle, but I have done this on a Vincent Comet many years ago. Wow, that would be 1967!) If you loop the tow rope around the left hand bar you can comfortably be towed in a straight line with the tow rope at an angle to the towing motorcycle on your left. The tension in the towrope has two vectors, one straight ahead and the other to the left. You balance your off centre attachment to the rope with the correct angle to produce a comfortable straight ahead vector.

Vectors allow us to visualise the forces involved. We know that it is harder to hold up a stationary motorcycle the further it leans over, don't we? This is because the gravity vector pushing to the right increases as the angle of lean increases. At the same time the gravity vector acting through the CG to the tyre contact point decreases. The sum of these

gravity vectors is always equal to the weight of the motorcycle (and rider of course). You can experiment with this concept by standing vertically next to a wall with your shoulder against the wall. There is no pressure against your shoulder, is there? If you now move your feet away from the wall, so that you are leaning against the wall, you can feel a pressure on your shoulder. The further away from the wall you move your feet, the greater the pressure on your shoulder. This pressure is caused by the horizontal gravity vector. If you don't believe me, try it!

I had thought this would be unarguable, but one of my correspondents insists this force is caused by the wall. No, the force is caused by gravity, the pressure on your shoulder is the equal and opposite force provided by the wall. Without this you would fall through the wall!

Next, the 'Power Thrust Vector'. This is the effect which, I have realised from additional correspondence with one of my web forum partners, Simon Durrant (thanks Simon!), also aids the steering response. Simon identified 'Camber Thrust' for me and I initially thought that he was describing what I now call the 'Power Thrust Vector'. This is original thought on my part and it makes eminent sense to me but, after additional correspondence, I now realise this is NOT 'Camber Thrust'

When the front wheel is turned left the motorcycle is 'hinged' around the steering head and the thrust at the rear wheel tends to 'fold' the machine to the right. An extreme example of this is when you attempt to mount a kerb with the wheel turned. If you try this the steering head is violently forced to the 'countersteering' side. This is the 'Power Thrust Vector'. (Can I copyright this term do you think?)

This is a valuable contribution to an explanation of both Mode 2 and Mode 3 countersteering. It provides an explanation for my long held belief that the forward motion of the motorcycle is somehow responsible for Mode 2 countersteering. This provides a force, in addition to gravity, to contribute to the right horizontal vector. This is a force proportional to the speed of the motorcycle, gravity, on the other hand, remains constant. This would seem to be exactly what is required, more force available to induce a turn, the faster you go. I like it!

I now see that this is a major force contributing to the steering response. This also explains the empirical observation that acceleration while countersteering will tighten your line. Now why did I not realise that before? I wonder if Keith Code knows this and just forgot to tell me!

‘Camber Thrust’, on the other hand is experienced when a conical, or semi conical, object is rolled along. The cone will turn towards the tapered end. The theory is that the front wheel, once leaned over is making contact with the road on two diameters, the smaller on the inside of the turn, thus inducing ‘Camber Thrust’, a force assisting the horizontal gravity vector to move the CG to the right. I have a great deal of trouble accepting this concept in the real world of motorcycle dynamics. I do not believe that the deformable tyre is acting like a rigid cone and, my most significant objection, if this effect did normally occur, it would generate a strong self servo effect which would be both undesirable and very noticeable to the rider. I do not notice this EXCEPT when my front tyre is very worn. Then I find a turn hard to initiate and I DO notice a self servo effect, especially at slow speed. I actually need to hold back the countersteer. I find this most unpleasant! QED, this does not happen with the tyre in good condition, and thank God it doesn’t!

If camber thrust was responsible it would exist at every instance the motorcycle was leaned over and yet empirical experience shows, that when you stop giving a steering input, the motorcycle lean angle stabilises, whereas the proposed camber thrust force cannot be removed by removing the steering input, therefore nothing the rider could do would prevent the turn rate increasing until the maximum possible traction was exceeded and the motorcycle would be sliding on its side in straight line! Actually you would not NEED a steering input, the bars would be wrenched out of your hands onto full lock. Nasty.

Once the motorcycle IS stabilised in a turn it is obvious that there is some force which is balancing the horizontal gravity vector in order to stop the motorcycle lean angle increasing until the motorcycle has fallen on it’s side, yes? As this is unlikely to be a conveniently placed wall running around our curve, it must be something else.

That something else is centrifugal force.

Centrifugal force is generated when a moving object deviates from a straight line. (I will avoid any discussion of the difference between centripetal and centrifugal force to avoid unnecessary confusion) It is probably appropriate to quote Newtons first law of Motion here. “*A body in motion continues to move in a straight line with uniform velocity unless acted upon by some external force*”. In other words, in order to

move a motorcycle from a straight line, a force is required. This force is provided by the horizontal gravity Vector. Centrifugal force balances this, the tighter and or faster the turn, the greater the centrifugal force and the further the motorcycle must lean over.

At a certain point the centrifugal force will exceed the available gravity vector and the additional cornering force must be provided by the available traction at the tyre/road interface. Now you begin to scrub your tyres and, at some further point, the centrifugal force may exceed the sum of the gravity vector and the available traction side thrust. At this point you have just lost the front end! Implicit in this explanation is that there may be combinations of speed and turn radius that can be obtained WITHOUT requiring any side thrust from the tyres.

I have struggled a little with this statement, I intuitively feel this is possible as this explains the phenomenon of a motorcycle being able to be ridden on black ice. I have several times read of people only falling on black ice once they have stopped and attempted to dismount! Not only that; Ben, a friend of mine who is an extremely gentle rider, has achieved over 25,000 klm from his Goldwing tyres with hardly any noticeable wear, whereas I, who throw my Goldwing around like my VFR, wear the front tyre out first in less than 15,000 klm. I am obviously using more side thrust than Ben, perhaps he is not using any?

Some of my young staff, recent engineering graduates, insist this is rubbish! Summoning my rusty maths I have convinced myself that a motorcycle, or any other object, when leaned over, must have an equal and opposite horizontal gravity vector acting at the ground. The question I ask myself is, once there is centrifugal force at play, acting through the centre of gravity and neutralising the horizontal gravity vector acting in the direction of the turn, is there still an opposing horizontal gravity vector at the tyre ground interface? If the answer is no, then the riding on black ice trick could have an explanation. However, I do recognise that whenever the 'Power Thrust Vector' is present, there will be a side thrust required, but this is only present when the motorcycle is both under power and there is a countersteering input. Moral, don't add power or steering input on black ice!

OK, I am reasonably happy with the above explanation of countersteering in Mode 2. Now we come to discuss countersteering in Mode 3. Mode 3, remember, is when the motorcycle is already banked over in a turn to the right and you wish to turn to the left (or vice versa)

I have never seen any explanation of countersteering in Mode 3, this is completely original thinking on my part, but I have to thank Simon for inspiring my 'Power Thrust Vector' addition, so the credit, or blame, must be shared! I have been grappling with an explanation since 1983 but, as a result of my web forum discussions, now believe I understand Mode 3 countersteering. Can I convince you, that is the question?

In our Mode 3 example we are executing a high speed right turn, say on Winton circuit (where I first pondered the problem) and there is a left hand turn rapidly approaching. We have our right footrest on the deck and give a mighty countersteering input to the left by pushing (hard) on the left hand bar. Bang! Almost instantly we are on the footrest on the left hand side. How did we do that? Our steering head obviously cannot fall UP, but that is what just happened, very fast! How?

Some would have you believe that gyroscopic precession is totally responsible for lifting the steering head up from maximum lean to the right to maximum lean to the left. I cannot believe this and have long believed that the forward motion of the motorcycle must somehow be responsible. Only now, however, do I believe I can explain it.

In our Mode 3 example you are turning to the right at maximum lean with your footrest on the deck. You are in a position of stable equilibrium, that is, the centrifugal force generated by your deviation from a straight line is exactly balanced by the gravity vector to the right and the side thrust at the tyre road interface and your wheels are in line with the curve on which you are travelling.

The left turn is approaching at high speed and you need to turn left, what do you do? You add a large countersteering input, by pushing (hard) on the left hand bar. This will lift the steering head in the same way it moved when the bike was vertical, by leverage against the front tyre contact patch, plus the gyroscopic precession force. This reduces the right horizontal gravity vector and immediately liberates a component of the centrifugal force plus the 'Power Thrust Vector' is now available. It is the enormous quantities of available Centrifugal Force which lift the motorcycle around the tyre contact patches, rather like letting the genie out of the bottle! As the CG rises, the horizontal gravity vector diminishes and the available opposing horizontal centrifugal vector increases dramatically. It seems to me that it is the rapidly increasing horizontal vector of Centrifugal Force which provides the energy to snap

a motorcycle from right footrest to left footrest, or rather, as a reviewer of this document pointed out, from footrest to vertical. At that point we are in Mode 2 again!

I believe the 'Power Thrust Vector' will be proportional to the angle the wheel is turned and this does not increase as the CG rises, rather the reverse, therefore it is not a major contributor to Mode 3 countersteering. In addition, the 'Power Thrust Vector' is only available when the power is on, and you can still turn in Mode 3, even when you have closed the throttle. Having said that, I am sure that I have empirically observed that power in a Mode 3 turn is beneficial, therefore 'Power Thrust' must be a contributor, even though I still maintain that the liberated horizontal Centrifugal Force vector is King!

That is my new understanding of Countersteering in all its applications, and I am happy with it. Now that I have finally put it down on paper it seems so obvious. Why did it take me 18 years to put it together?

What do you think? Valuable, or a load of rubbish? I am sure you will let me know! I should add that Simon does not agree with ALL of this, so don't take it out on him!

Since this paper was first published I have had responses from all round the world, some have liked it, others tell me it is rubbish, but I have yet to be convinced that they have any valid reasons for saying so. Perhaps you have some? I am but a seeker after truth!

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