Positive Steering

When riding a motorcycle through a bend at speed, you use 'Positive Steering', whether you are aware of doing so or not.

In this article I will explain what we mean by the term 'Positive Steering', which used to be called 'Counter Steering' and the physics that underpins the technique.

What is Positive Steering?

Pushing away gently on the ***Left*** handlebar end, makes the bike go to the Left.

Pushing away gently on the ***Right*** handlebar end, makes the bike go to the Right.

Common sense would say that this should not happen…..so, why does it?

It seems illogical that if you push away on the Left handlebar end, making the front wheel point to the right, that the bike should then go to the left; equally so, if you push away on the Right handlebar end, making the front wheel point to the left, that the bike should then go to the right.

To understand the mechanics of Positive Steering, you first need to understand Torque, because Positive Steering results from changes in Torque applied to the front axle of the bike, when pushing away on one handlebar end or the other.

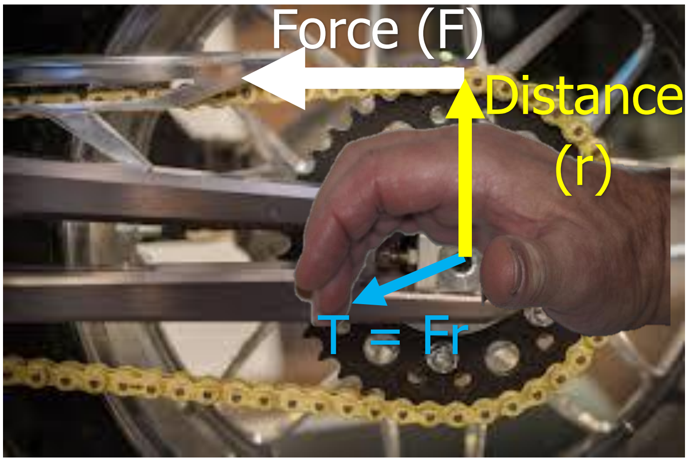
Torque: *(For a full explanation of Torque, see the Blog on: '**Torque and Horse Power**')*

In short, Torque is a vector quantity, as it has both 'size' and 'direction'; as shown in the diagram below:

Torque is defined as 'the turning effect of a Force'.

Torque is the product of Force and the Distance through which the Force is applied to generate turning motion.

In this diagram, the Force (F) pulls the chain to the left and the point of application of the Force is directly above the axis about which the wheel rotates, at a distance equal to the radius of the rear sprocket: shown as (r).



Torque = Force x Radius

T = F x r (Note: F x r is normally written as Fr)

The 'direction' of the Torque vector is given by the 'Right Hand Rule':

Curl the fingers of the right hand in the direction of rotation and the right thumb will point in the 'direction' of the applied Torque'. (As shown in the diagram above.)

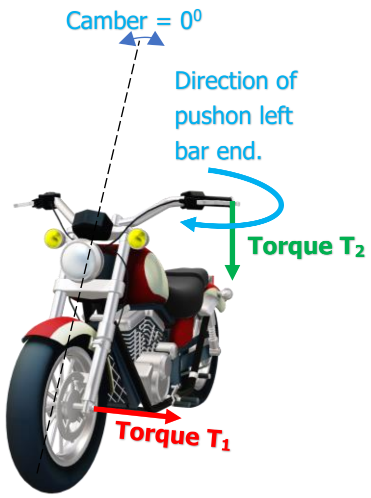
If this makes sense, read on; but if not, please read the Blog entitled: 'Torque and Horse Power' before going any further with your exploration of Positive Steering.

How Torque produces 'Positive Steering'

'Camber' more correctly referred to as 'Camber Angle', is the angle between the plane of a motorcycle and a vertical plane at right angles to the road surface.

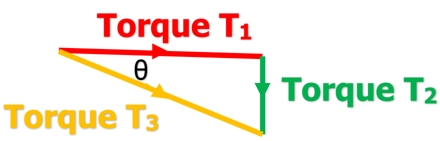
When upright, Camber is zero, but if the motorcycle leans to the right or left off the vertical plane, Camber increases.

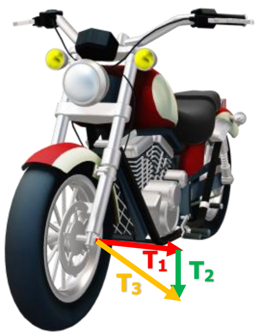
In this diagram, the motorcycle is being ridden along the road, with zero Camber (I.E. the bike is vertical). The **Torque** generated by the driving Force pulling on the chain, is shown by the red arrow; and although generated at the rear wheel, it also applies to the front wheel: however, only the Torque on the front wheel is shown here for the purpose of this explanation. The direction in which $\mathbf{T_1}$ acts, is given by the **Right-hand Rule** and is shown to point out to the left, along the axis of rotation, in line with the axle of the wheel.



On approach to a left bend, the rider pushes gently away on the left handlebar end to induce 'Positive Steering', as shown by the light blue circular arrow. This generates a new Torque about the Headstock, which we will call **Torque $\mathbf{T_2}$**. This new Torque acts vertically down, in accordance with the **Right-hand Rule** and it is shown in the diagram to the right by the green arrow. The combined effect of both $\mathbf{T_1}$ and $\mathbf{T_2}$ on the front wheel is ($\mathbf{T_1}$+$\mathbf{T_2}$).

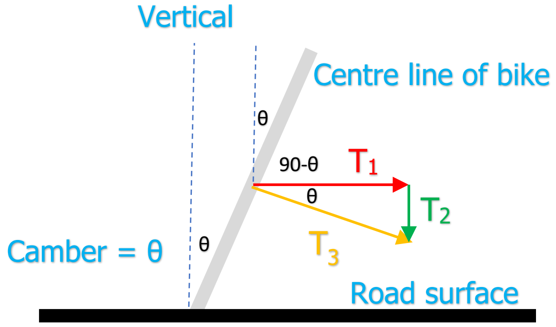
The summation of the Torques is shown enlarged in the diagram below, for clarity:

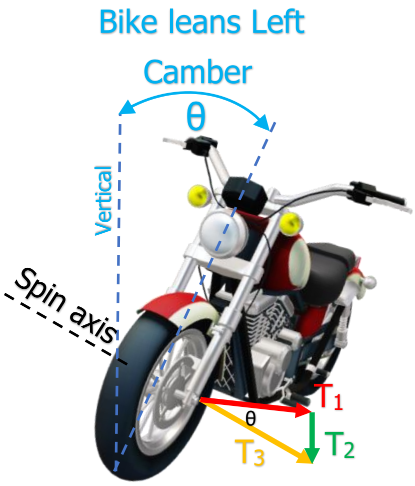




Torque $\mathbf{T_3 = T_1 + T_2}$

The angle Theta (θ) between **T_1** and **T_3** is geometrically equal to the Camber Angle (θ), I.E. the angle that the bike leans off the vertical when in a bend, as shown below.





The front wheel tilts left until its axis of spin lines up with the combined Torque acting on the front wheel: Torque **T_3**

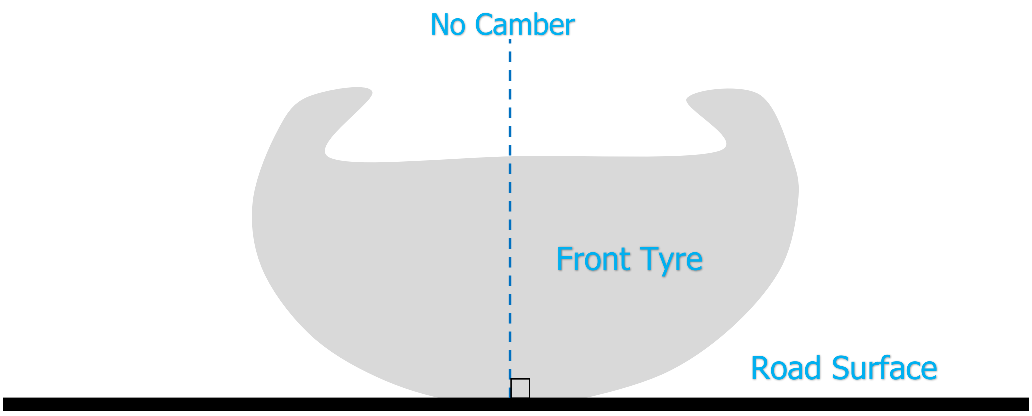
This makes the bike lean with Camber θ to the vertical.

The initial action of pushing away on the handlebars and the resulting lean is known as 'Positive Steering'.

Rolling Cone Effect

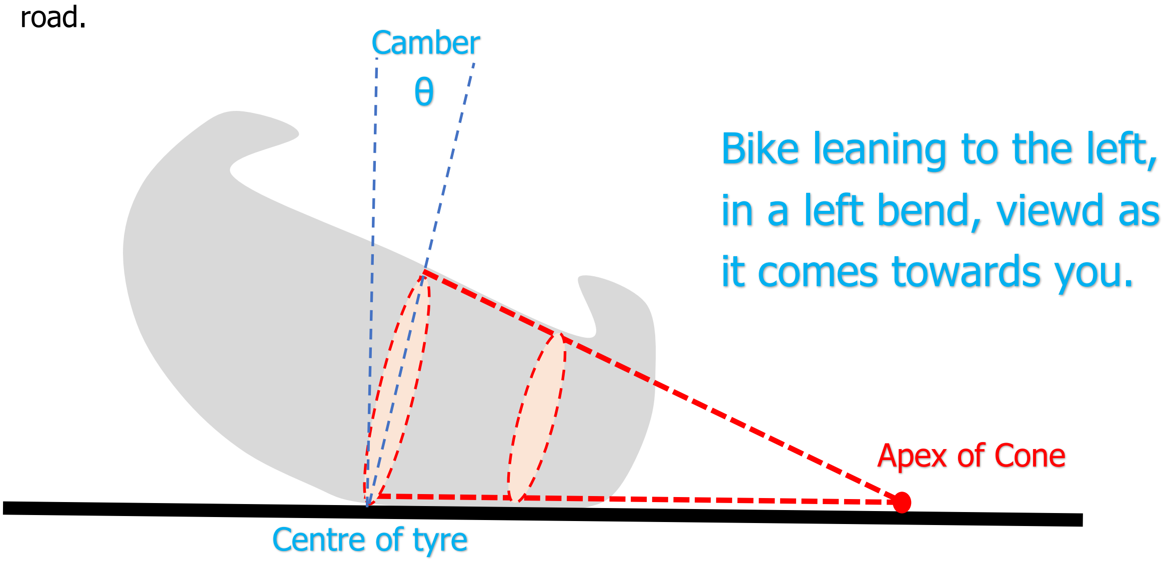
With the bike leaning to either side off the vertical, the **Rolling Cone Effect** takes over and allows it to track through the bend.

To understand the Rolling Cone Effect, consider the profile of a motorcycle tyre.

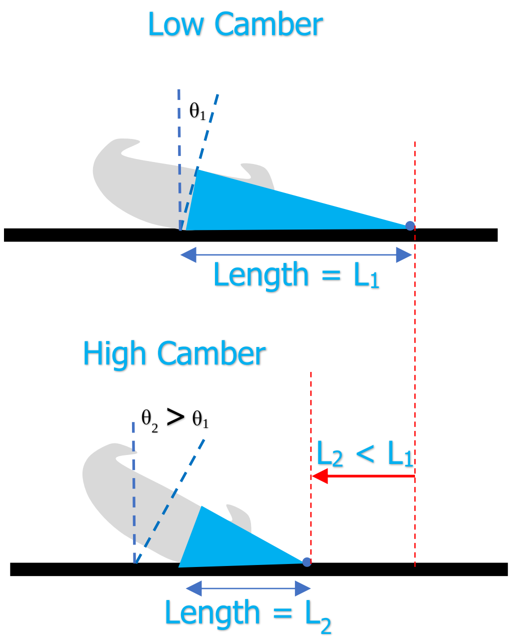


When vertical, there is no Camber and the centre line of the tyre is at right angles to the road surface.

On leaning off the vertical with Camber θ, the Contact Patch spreads out a bit more on the road.



An imaginary Cone shape can now be drawn, with its Apex a few feet out to the left of the Contact Patch, relative to the rider's line of sight, as shown in the diagram above for the bike coming towards you in a left bend. How far the Apex is from the centre of the tyre depends on the Camber. When the Camber is small, the Apex is relative far from the centre of the tyre (**L_1**); when the Camber increases, the distance to the Apex from the centre of the tyre reduces (**L_2**).

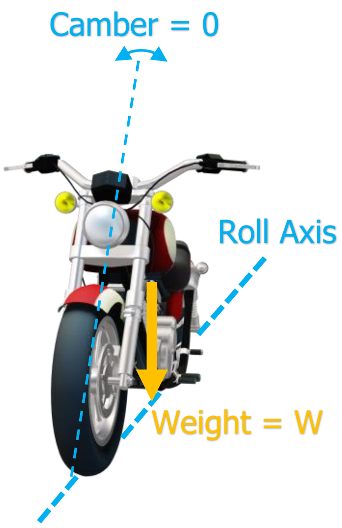


If a cone is placed on its side, on a flat surface and given a nudge forward, it follows a curved path as it rotates about its Apex: this is because of the Cone's geometry. In the diagram at the top of the page, for every rotation of the larger cross section, the smaller cross section also rotates once; because they are both integral parts of a 'solid' object. I.E. the body of the tyre. The circumference of the larger cross section is greater than that of the smaller cross section, so the only way they can both rotate once in the same time, is if the Cone follows a curved path with its Apex as centre and this is exactly what the motorcycle tyre does: it tries to rotate about the Apex of the Cone formed by the shape of the tyres, when the bike leans off the vertical.

Positive Steering simply initiates the lean, at which point the Rolling Cone Effect takes over and makes the bike sweep through the bend because of the tyre geometry.

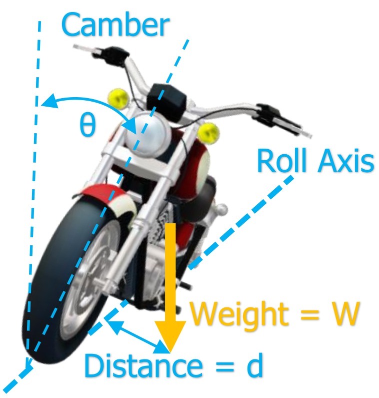
Camber Generated Torque

Whilst the Rolling Cone Effect is influencing the path taken by the bike, a further Torque is generated as it leans off the vertical, and we will refer to this as **Camber Torque**.
The 'Force' component of Camber Torque is the Weight of the bike and rider, which we will show acting through the Centre of Gravity of the bike.



In the diagram to the right, the bike is upright with no Camber and the Weight vector acts vertically down from the Centre of Gravity, passing through the Roll Axis, which is the 'imaginary line' joining the front and back tyre Contact Patches. The Weight does not generate Torque ***about*** the Roll Axis, because it passes through it; hence the 'distance' from the Weight to the Roll Axis is zero, as such, Torque generated about the Roll Axis by the Weight of the bike and rider is also zero as: Torque = Weight x 0

With the bike leaning over to one side or other off the vertical plane with a Camber Angle of θ, Torque is then generated as the Weight vector is off-set by a distance (d) from the Roll Axis:
we will call this the **Camber Torque** (**T_c**):



$$T_c = Wd$$

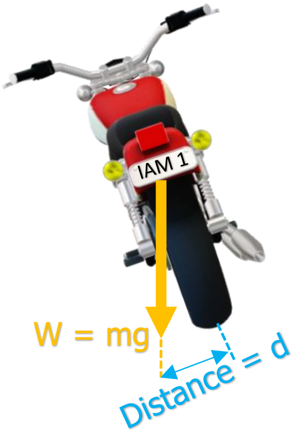
$$T_c = mgd$$

Note: Newton's Second Law tells us Weight (W) is the product of the Mass (m) of the bike and rider and the Acceleration of Gravity (g).
Weight can therefore be expressed as: $W = mg$

When leaning off the vertical to the left, the Weight of the bike tries to rotate it counter-clockwise about the Roll Axis, as viewed by the rider.

The ***'size'*** of the Camber Torque ($T_c = mgd$) will increase if any of its three components parts increases: namely the mass of the bike and rider (m); the Acceleration of Gravity (g) or the horizontal off-set distance (d) from the Weight vector to the Roll Axis.

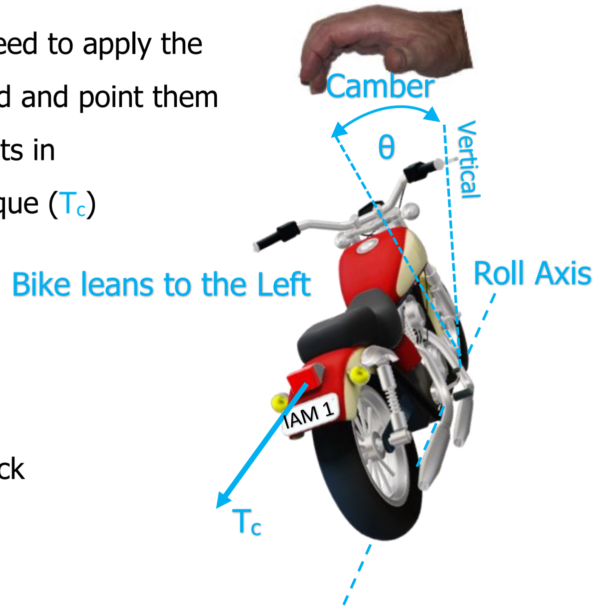
The mass of the bike and rider will not change just because the bike enters a bend and the Acceleration of Gravity is a constant; however, the off-set distance between the Weight vector and the Roll Axis increases as the Camber increases, resulting in an increase in Camber Torque with Camber. I.E. the ***'size'*** of the Camber Torque increases with the amount of lean off the vertical, as the off-set distance (d) from the vertical line of the Weight vector to the Roll Axis, increases as the lean increases.



To find the ***'direction'*** of the Camber Torque, we need to apply the Right-hand Rule I.E. curl the fingers of the right hand and point them in the direction of the roll; the right thumb then points in the direction of the Torque, in this case Camber Torque (T_c)

'Size' of Camber Torque: $T_c = mgd$

'Direction' of Camber Torque, is directly out the back of the bike, as shown by the Right-hand Rule.



The Weight of the bike and rider is one of the two components of the Camber Torque and the Weight is trying to rotate the bike counter-clockwise, relative to the rider. We have seen that Camber Torque increases as the lean angle increases, (I.E. as Camber increases) and we will see later that Camber Torque continues to increase until balanced by an equal and opposite Torque that tries to rotate the bike clockwise, when in a left bend. The Force responsible for this balancing Torque is the Camber Thrust and we will see that the bike stops leaning into the bend, when Camber Torque is equal and opposite to the Torque generated by the Camber Thrust.

Effect of Camber Torque on front wheel

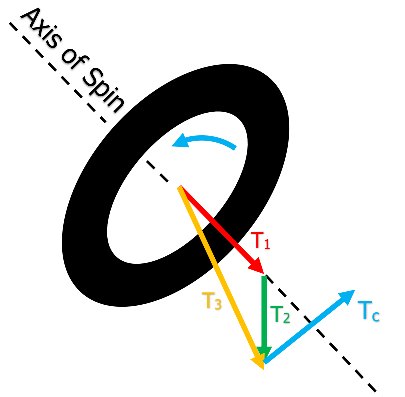
Camber Torque adds to the Torques already acting on the front wheel of the motorcycle.

T_1 Torque on wheel due to rotation

T_2 Torque from Left push on handlebar

$T_3 = T_1 + T_2$

T_C Camber Torque

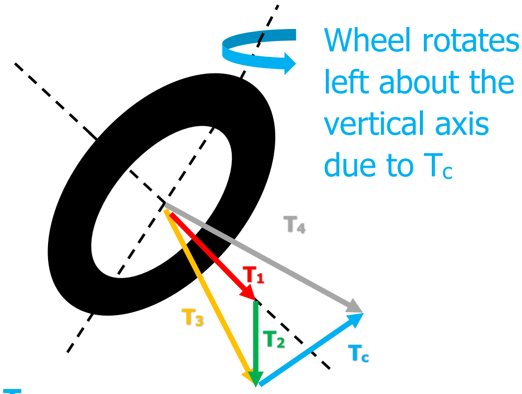


Front wheel leaning left

When $\mathbf{T_c}$ is added to $\mathbf{T_3}$, itself the combination of Torques $\mathbf{T_1}$ and $\mathbf{T_2}$, which results in a new overall Torque acting on the front wheel: namely T_4

$$T_4 = T_3 + T_c$$

$$T_4 = (T_1 + T_2) + T_c$$



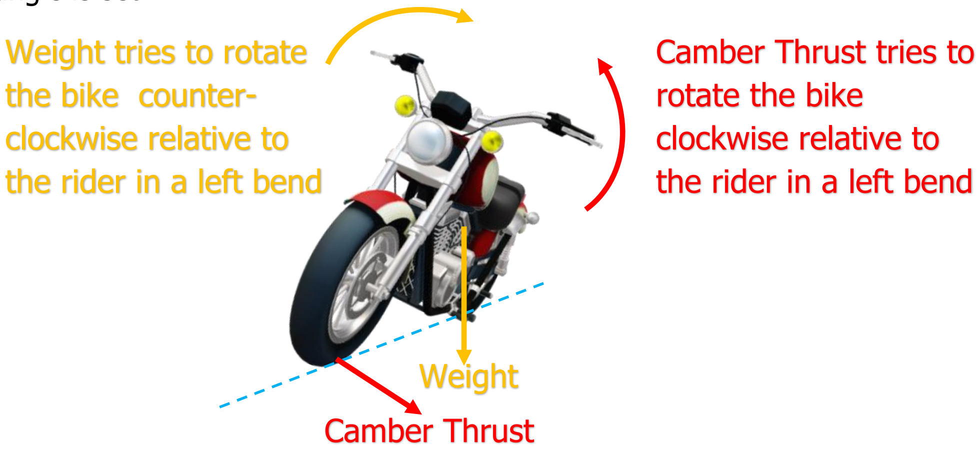
Recall that the front axle lines up with the overall Torque Acting on the wheel. Having tipped left (in a left bend) to Line up with $\mathbf{T_3}$, a Camber is introduced, which generates $\mathbf{T_c}$ On adding $\mathbf{T_c}$ to $\mathbf{T_3}$, the resultant overall Torque on the front Wheel becomes T_4: the axle of the front wheel therefore lines up with T_4, causing the front wheel to rotate left slightly, towards the back of the bike. This left sweep of the front wheel adds to the Rolling Cone Effect in making the bike track to the left through the bend.

The same arguments apply when going through a right bend, only this time the front wheel tilts to the right; the Camber Torque then points out the front of the bike in the direction of travel and the front wheel sweeps right helping the Rolling Cone Effect in making the bike track to the right through the bend.

Camber Torque Vs Torque generated by Camber Thrust

For a full explanation of the Physics behind this balancing act between the Camber Torque trying to rotate the bike about the Roll Axis between the front and rear Contact Patches, to the left in a left bend and to the right in a right bend and the opposing Torque generated by the Camber Thrust, see the Blog on 'Does the weight of a bike affect the angle at which it leans in a bend?'

For the purpose of this Blog exploring the physics that underpins Positive Steering, it will suffice to say that the bike leans in a bend, until these opposing Torques balance and at that point the lean angle is set.



Conclusion

This Blog set out to explain the Physics behind 'Positive Steering'; fortunately, it is far easier to apply 'Positive Steering' than it is to explain it!

To test your understanding, see if you can 'explain' what happens when the rider pushes away on the Right handlebar end: everything you need is stated above!

Physics is fun!
George A Cairns
CWCAM Chief Observer