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 <u>push away</u> 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 <u>push away</u> 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 need to understand what we mean by 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'**)*

<p align="center">**Torque is defined as 'the turning effect of a Force'**</p>

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

The ***'size'*** of the 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).
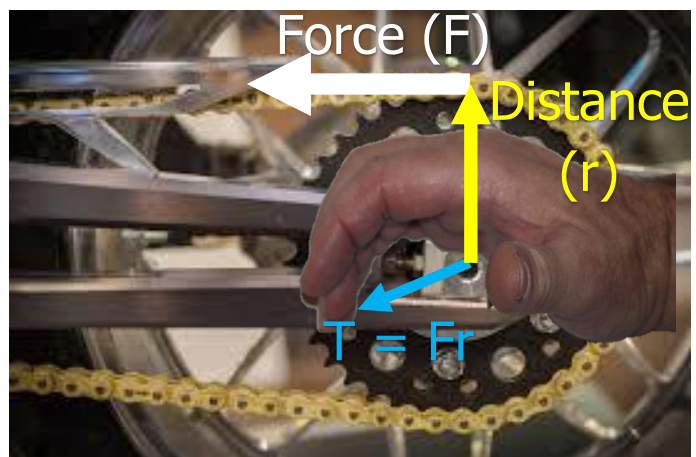
<p align="center">**Torque = Force x Radius**</p>

<p align="center">$$T = F \times r$$ (Note: F x r is normally written as Fr)</p>

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, passing through the Roll Axis, which is the imaginary line joining the front and rear tyre Contact Patches.

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 **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.
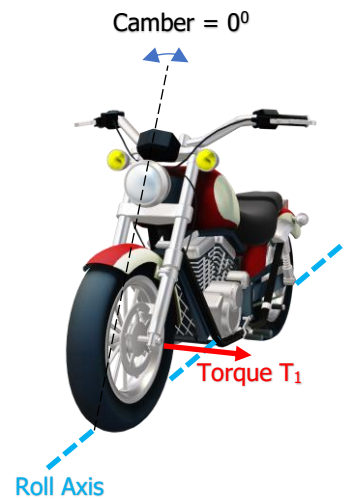
On approach to a left bend, the rider pushes gently away on the left handlebar end to generate 'Positive Steering', as shown by the light blue circular arrow. This generates a new Torque about the Headstock, which we will call **Torque T$_2$**. This new Torque acts vertically down, in accordance with the **Right-hand Rule** and it is shown in the diagram to the right by the green arrow. The push away on the handlebar end, also turns the front wheel to the right and as such, Torque **T$_2$** also acts on the axle of the front wheel.
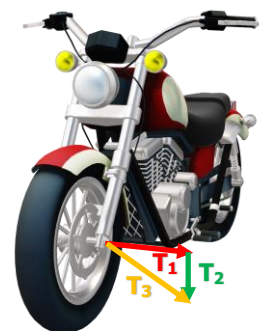The combined effect of both **T$_1$** and **T$_2$** on the front wheel is (**T$_1$**+**T$_2$**).
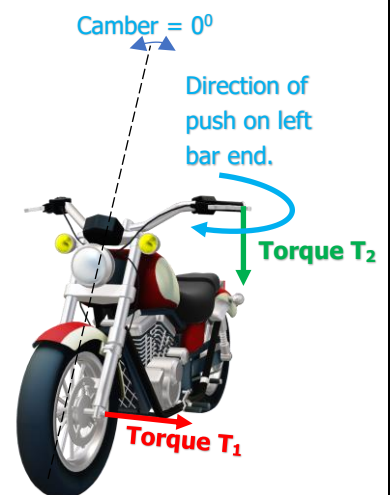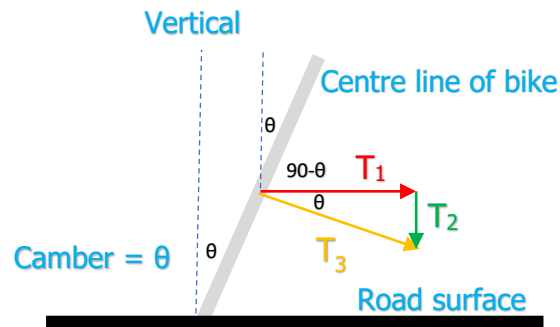
The summation of the Torques is shown enlarged in the diagram below, for clarity:

Torque 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.

Vertical

Centre line of bike

θ

90-θ T_1

θ

T_2

Camber = θ   θ T_3

Road surface

The front wheel tilts left until its axis of spin lines up with the combined Torque acting on the front wheel: Torque T_3 Pushing away on the Left Handlebar End makes the bike lean to the Left with Camber θ to the vertical.

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

Bike leans Left

Camber

θ

Vertical

Spin axis
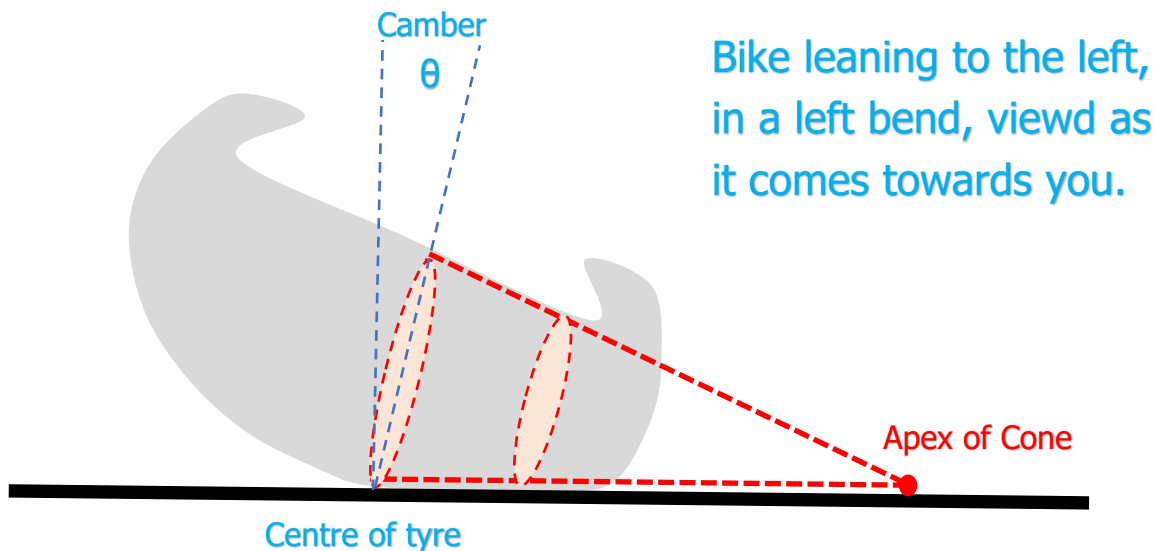
θ T_1

T_3 T_2
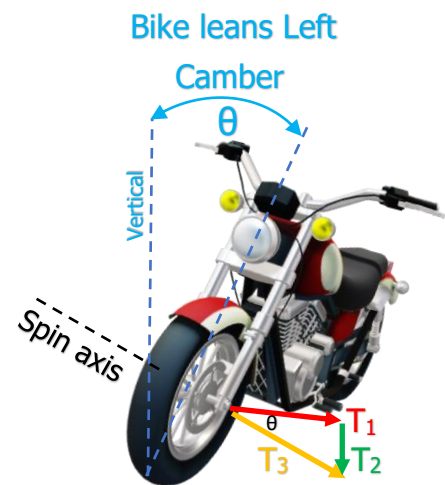
Rolling Cone Effect

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.

No Camber

Front Tyre
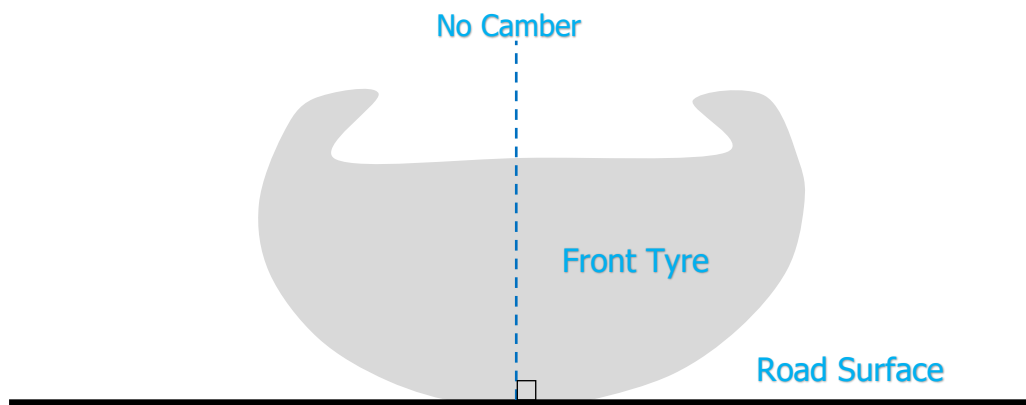
Road Surface

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 on the road, giving more 'tyre surface to road' contact on the side of the tyre tilted in the direction of lean: in this case, on the left side of the tyre, as shown below.

Camber
θ

Bike leaning to the left, in a left bend, viewd as it comes towards you.

Apex of Cone

Centre of tyre

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).

Low Camber

θ_1

Length = L_1

High Camber

$\theta_2 > \theta_1$

$L_2 < L_1$

Length = L_2
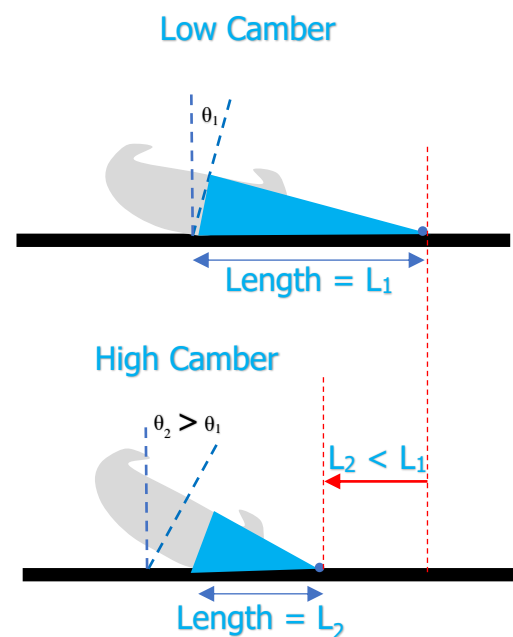
If a cone is placed on its side, on a flat surface and given a nudge forward, it follows a curved path as it rotates about its Apex: this is because of the Cone's geometry. In the diagram at the top of the page, for every rotation of the larger cross section, the smaller cross section also rotates once; 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, which introduces the Rolling Cone Effect; thereafter, it is the tyre geometry that is responsible for the bike sweeping through the bend in the direction of lean.

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.

Camber = 0

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. I.E. 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
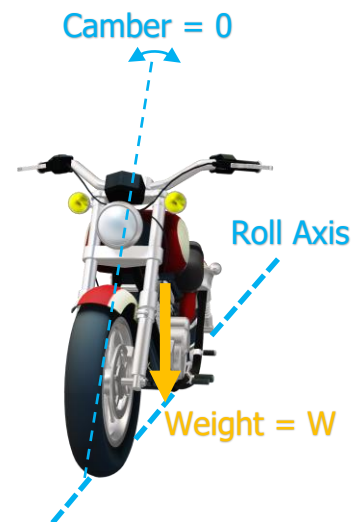
Roll Axis

Weight = W

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 now off-set by a distance (d) from the Roll Axis: we will call this the **Camber Torque** (T_c):

Camber

θ

Roll Axis

$$T_c = Wd$$

$$T_c = mgd$$

Weight = W

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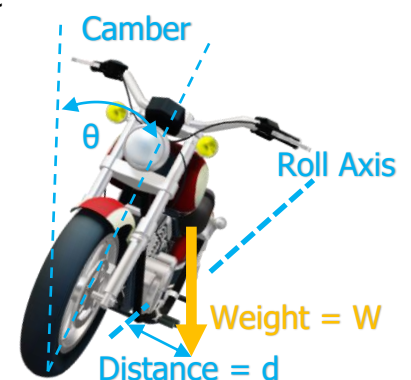
**Note:** Newton's Second Law tells us Weight (W) is the product of the Mass (m) of the bike and rider and the Acceleration of Gravity (g). Weight can therefore be expressed as: W = mg

When leaning off the vertical to the left, the Weight of the bike tries to rotate it counter-clockwise about the Roll Axis, relative to the Rider's line of sight.

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, in any particular location; 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.
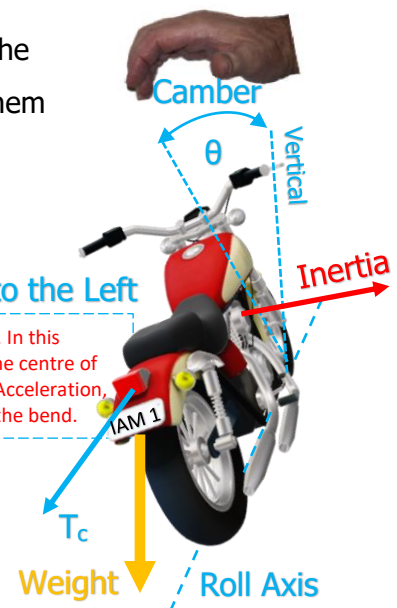

W = mg   Distance = d
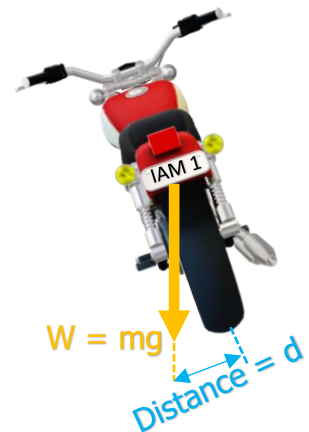
To find the **'direction'** of the Camber Torque, we need to apply the Right-hand Rule I.E. curl the fingers of the right hand and point them in the direction of the roll; the right thumb then points in the direction of the Torque, in this case Camber Torque (T_c)

'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.

Camber
θ
Vertical
Inertia
Bike leans to the Left

Inertia always opposes Acceleration. In this diagram, Inertia points away from the centre of the bend, opposing the Centripetal Acceleration, which points towards the centre of the bend.

T_c
Weight   Roll Axis

Camber Torque Vs the Torque generated by Inertia

The Weight of the bike and Rider is trying to rotate the bike ***counter-clockwise*** in a left bend, relative to the Rider's line of sight and this Torque ***increases*** as the lean angle increases, (I.E. as Camber increases).

Opposing this is another Torque generated by the Force of Inertia, which is trying to rotate the bike ***clockwise*** in a left bend, relative to the Rider's line of sight. This Torque ***reduces*** as the lean angle increases and the Centre of Gravity drops closer towards ground level.

To appreciate why one Torque increases as the other reduces, see the Blog on: **'Does the weight of the bike affect the angle at which it leans?'**

The Rider continues to lean the bike until it feels 'balanced' in the bend and that happens when the reducing Torque generated by the Force of Inertia becomes equal and opposite to the increasing Torque generated by the Weight of the bike and Rider!

Bike leans to the Left

For a full explanation of the Physics behind this balancing act between the Camber Torque and the Torque generated by the Force of Inertia, 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: at that point, the lean angle is set.

Effect of Camber Torque on front wheel

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

Initial Axis of Spin

Final Axis of Spin lined with T_3

→ T_1 is the Torque due to wheel rotation.

→ T_2 is the Torque from the Left push on the handlebar end.

→ $T_3 = T_1 + T_2$

→ T_C is the Camber Torque generated by the Weight of the bike and Rider.

Front wheel leaning left
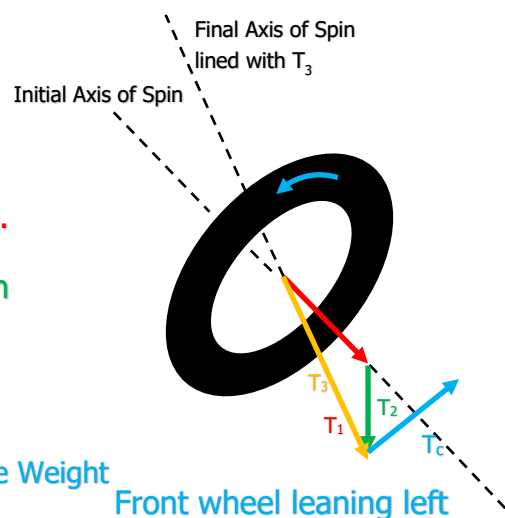
T_c is added to T_3, itself the combination of Torques T_1 and T_2, which results in a new overall Torque acting on the front wheel: namely T_4

Axis of Spin lined with T_3

New Axis of Spin lined with T_4

Wheel rotates left about the vertical axis, due to T_c

$$T_4 = T_3 + T_c$$
$$T_4 = (T_1 + T_2) + T_c$$

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 T_3, a Camber is introduced, which generates T_c
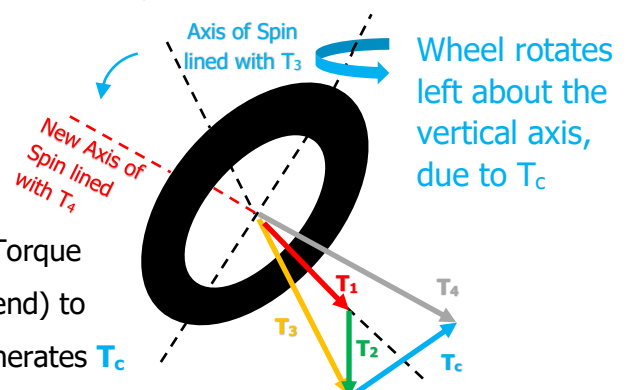
On adding T_c to T_3, the resultant overall Torque on the front Wheel becomes T_4: the axle of the front wheel then lines up with T_4, causing the front wheel to rotate left slightly, towards the back of the bike. This left sweep of the front wheel adds to the Rolling Cone Effect in making the bike track 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 the Force of Inertia

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.

Inertia tries to rotate the bike clockwise _relative to the rider_ in a left bend
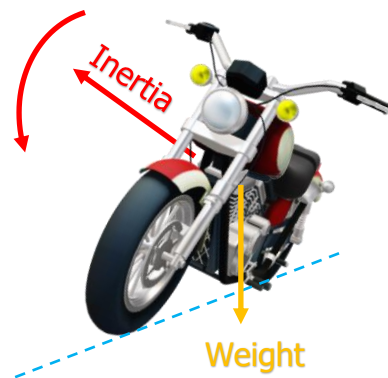
Weight tries to rotate the bike counter-clockwise _relative to the rider_ in a left bend

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

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