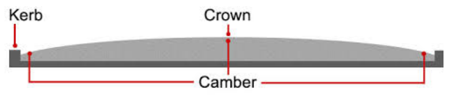
Camber gives an advantage in a left bend: True or False?

UK roads are generally 'Crown Cambered'; that is, they are high in the centre and lower towards the edges, as this helps water to drain from the road surface.



Note: Motorways are 'Super Elevated'. Look at the Blog on Super Elevation for more information on the advantages this presents.

Camber is said to give an advantage to drivers and riders in a left bend, but a disadvantage in a right bend.

In this blog I will explore this statement to see if there really is an advantage when driving or riding through a left bend on a UK road; and if so, why?

Diagram 1

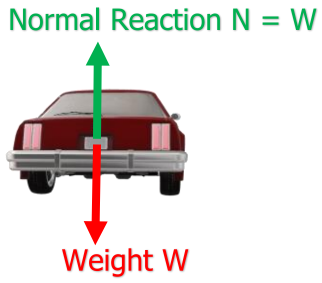


Diagram 1 shows the back of a car travelling away from you, on a level, straight road. The Weight (W) is shown by the red arrow and the Newton's 3rd Law equal and opposite force to the Weight, known as the Normal Reaction Force (N), is shown by the green arrow. Think of the Normal Reaction as the force with which the road pushes back on the car, to stop it disappearing down to the centre of the Earth!

What is Acceleration?

Acceleration is the rate at which Velocity changes with time.

Velocity is one of those physical quantities that has both size and direction, unlike Speed, which is fully defined by stating its size. For example, 30mph is a Speed but 30mph due North is a Velocity. Consider two drivers on a perfectly flat road that goes on for miles. If one sets off and travels with a Velocity of 30mph due North and the other sets off at the same time from the same place and travels with a Velocity of 30mph due South, then after an hour they are both 30 miles away from the starting point, because they travelled at the same Speed; but they are not in the same place, because the 'direction' of travel was different: this shows the difference between Speed and Velocity.

If Acceleration is the rate at which Velocity changes with time, then a car which is increasing Speed from stationary to 30mph is said to be accelerating, as the 'Speed' element of its Velocity is changing with time; and this is how we normally think of Acceleration; more correctly referred to as Linear Acceleration, because the car is accelerating in a straight line as shown below in Diagram 2.

Diagram 2

This car Accelerates along a straight road owing to the rate of change of Speed, as the driver presses on the gas pedal.

What is Centripetal Acceleration?

If a car is being driven around a circular track at a constant Speed, it is still Accelerating because the 'direction' element of its Velocity is constantly changing as it follows the track!

The direction of this Acceleration is always towards the centre of the track or bend and the car is said to **Accelerate Centripetally**, as shown by the yellow arrow in Diagram 3 below.

Diagram 3

This car Accelerates through a right bend at ***constant Speed***, owing to the rate of change of direction in the bend.

What is Corner Force?

Newton's Second Law tells us that an unbalanced Force (F) acting on a Mass (m), will cause the Mass to Accelerate in the direction of the unbalanced Force. (**Note:** by 'unbalanced, we simply mean that although there may be several Forces acting on the Mass all pushing or pulling it in different directions at the same time, if you add all the Forces together and they don't cancel out, you are left with an 'unbalanced' Force.)

Weight = mass x Gravitational Acceleration is a good example of Newton's Second law: I.E.

$$\mathbf{W = mg}$$

Diagram 4

Linear Force (I.E. the driving Force that makes the car move in a straight line) results in Linear Acceleration.

Diagram 5

Centripetal Force (I.E. Corner Force) results in Centripetal Acceleration

In Diagram 4 above, the unbalanced Linear Force results in Linear Acceleration; and in Diagram 5, the Force responsible for the **Centripetal Acceleration** is know as **Centripetal Force**. In driving terms, another name for Centripetal Force is **Corner Force**, because it only acts when the car is in a corner or bend, that is when it Accelerates Centripetally: it does not act when the car is travelling in a straight line, because when travelling in a straight line there is no Centripetal Acceleration!

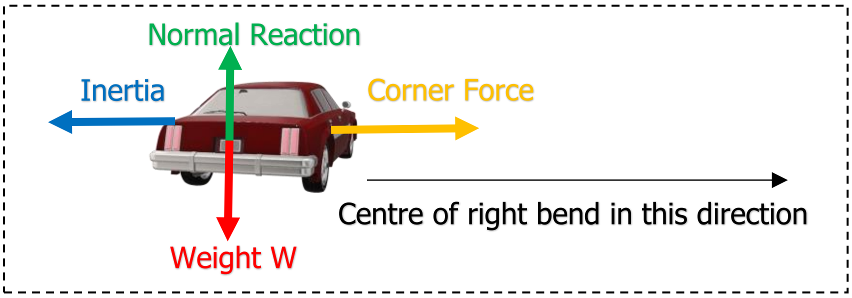
Force and Acceleration are also physical quantities that have both size and direction and in each case, the Acceleration and the Force responsible for the Acceleration both act in the same direction!

What is Inertia?

Newton's Third Law tells us that every Action (I.E. Force) has an equal and opposite Reaction. Diagram 1 above shows how Weight (an Action Force) has an equal and opposite Reaction Force, which we call the 'Normal Reaction Force'.

According to Newton, there should be an equal opposite Force to the Corner Force, which a car experiences when in a bend; and there is, we call it the **Inertia Force**, or simply **Inertia**, as shown in Diagram 6 below for this car in a right bend.

Diagram 6



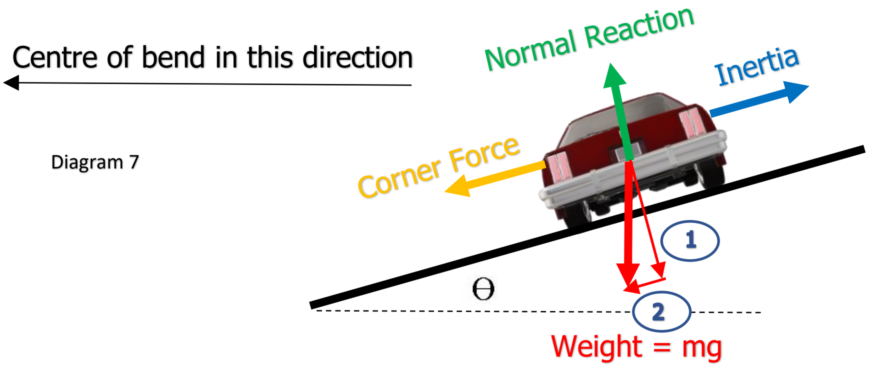
Note that Inertia is ***NOT*** Centrifugal Force! To find out more about Centrifugal Force, read the Blog that explains the myth of Centrifugal Force!

The effect of Camber

We have considered the Forces and associated Accelerations acting on a car, whether in a straight line or when negotiating a bend; so, we are now ready to see what effect Camber has and whether it offers any advantage in a bend.

Let's consider the car in a left bend, which has a good camber, as shown (exaggerated) in Diagram 7 below.

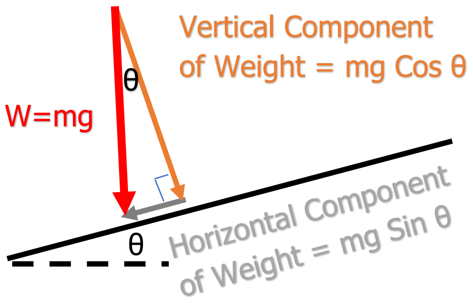
Diagram 7



The Angle of Slope is given by the Greek letter Theta (θ). The Weight of the car can be shown to have two components: one at right angles to the road surface and equal in size to the Normal Reaction Force (Component (1) above); the other acting along the road surface, pointing towards the centre of the bend, which in this case is off to the left: (Weight Component (2) above). Splitting quantities such as Force, Velocity and Acceleration into their Horizontal and Vertical Component parts, is a common analysis technique in Physics, allowing easy comparison of all such components.

It can also be shown that the Angle of Slope of the road (θ) is the same as the angle between the Weight and the Vertical Component of the Weight; this can be seen better in Diagram 8 below, where the Force Triangle has been enlarged for ease of viewing.

Diagram 8



The right-angled Weight triangle in the diagram above, shows one of the two Weight Components acting down the slope towards the centre of the left bend, and if familiar with Trigonometry, you will see that this component is (mg Sin θ)

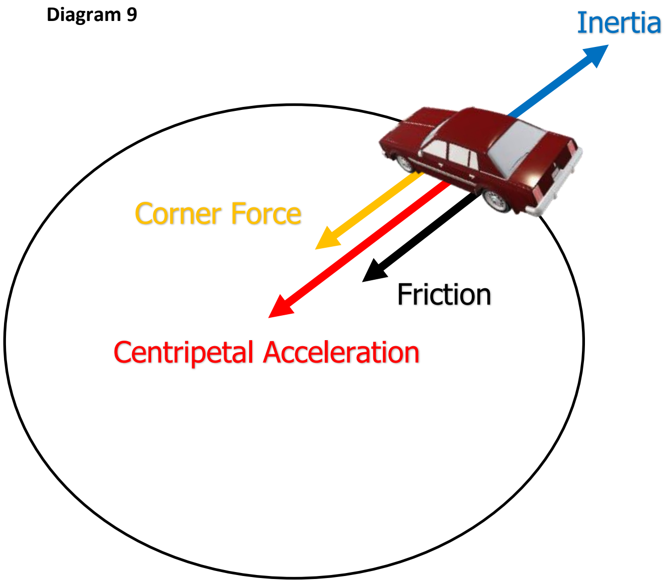
If 'Trig' is not your strong point, look upon this as a bit of the car's Weight that's trying to pull it down the slope; and if the road surface was very icy, and the car was at rest on the slope, that's exactly what it would do!

So, in a left bend, with the slope of the road running up hill from left to right, some of the car's Weight acts down the slope; the question is: does this give an advantage, or not?

Corner Force is a ***demand*** on the car and this demand must be met by the **Force of Friction** between the tyres and the road. I.E. by the **Grip** between the tyres and the road surface.

Inertia opposes Centripetal Acceleration and tries to pull the car away from the centre of the bend: in other words, Inertia tries to make the car Understeer. Inertia is opposed by Corner Force, the force required to keep the car Accelerating Centripetally, which we have said is provided by Friction between the tyres and the road surface.

Diagram 9



Corner Force causes Centripetal Acceleration and the Corner Force is provided by Friction, between the tyres and the road surface.

Corner Force = **Friction**

Inertia is seen to oppose **Centripetal Acceleration**

(I.E. to act in the opposite direction to Centripetal Acceleration.)

Inertia will increase with the square of the car's Velocity. I.E. if the Speed component of Velocity doubles by driving faster into the bend, Inertia increases by a factor of four! Friction between the tyres and the road surface is finite, it has a maximum value.

Normally, you don't use all the available Friction; if you only use 40% there will be 60% in reserve; if you only use 20%, there will be 80% in reserve: and so on.

However, it is quite possible that if the Speed into the bend is sufficiently large, there is insufficient Friction to meet the demand of rapidly increasing Inertia and the car understeers, running dangerously wide in the bend.

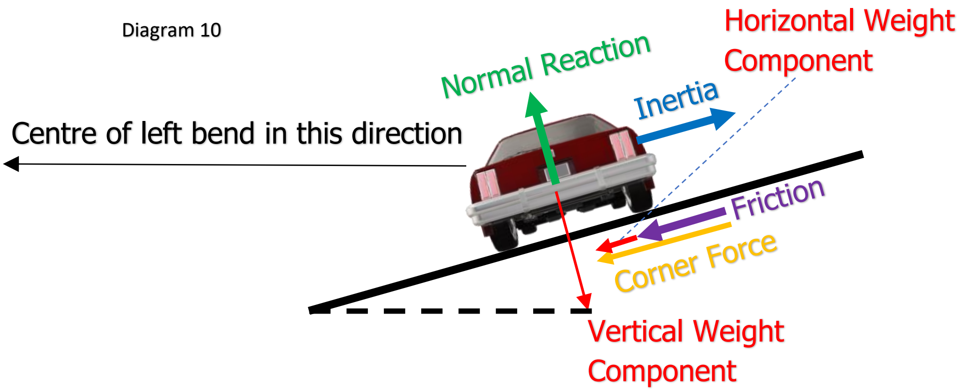
The slope of the road does not change whether the bend is to the left or the right, it still runs from left kerb, up to the road crown, and then down to the right kerb, relative to the direction of travel.

Left Bend:
In Diagram 10 below for a left bend, some of the car's Weight acts down the slope in the same direction as Friction, and this Horizontal Weight Component helps the car meet the demand of Corner Force, which opposes Inertia.

Road camber introduces a slope from left to right, therefore in a left bend on a UK road, **LESS** Friction is needed to meet the demand of Inertia, leaving **MORE** Friction in reserve: this is an advantage, as the added Friction in reserve can meet the effect of increased Inertia, which would result if speed into the bend was increased!

Whereas the slope can't increase Grip, it can reduce the demand for Grip: which amounts to the same thing!

Diagram 10



Inertia, which opposes **Corner Force** and Centripetal Acceleration, tries to pull the car to the right, in this left bend.

Friction (I.E. '**Grip**') opposes this motion and therefore acts down the slope towards the centre of the bend. **Grip** is ***assisted*** by the **Horizontal Weight Component** when meeting the **Corner Force** Demand.

Corner Force = Grip + Horizontal Weight Conponent

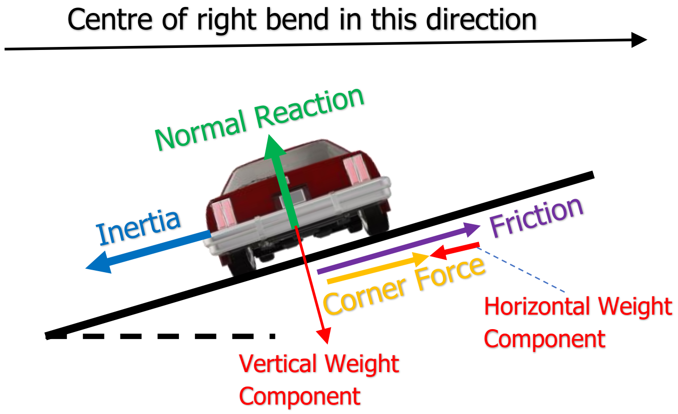
In a left bend, Centripetal Acceleration and Corner Force point to the left, in the same direction as the Horizontal Weight Component (mg Sin θ); whilst Inertia, which opposes Centripetal Acceleration and Corner Force Demand, points to the right.

Inertia tries to pull the car wide in the bend (I.E. tries to generate Understeer) but is opposed by the Friction Force between the tyres and the road surface; therefore, Friction acts down the slope, in the same direction as the Horizontal Weight Component.

Hence, in a left bend, the Horizontal Weight Component reduces the amount of Friction required to meet the Corner Force Demand: leaving more Friction (I.E. 'Grip') in reserve.

Right Bend:
In Diagram 11 below for a right bend, some of the car's Weight acts down the slope as before, but this time this Horizontal Weight Component ***opposes*** Friction, making Friction less able to meet the Corner Force demand and oppose the tendency of Inertia to generate Understeer. In other words, more of the Friction reserve must be used to meet the Corner Force Demand, leaving less in reserve: or worse still, having insufficient Friction to meet the Corner Force Demand altogether. The car is therefore more likely to Understeer in a right bend!

Diagram 11



Inertia tries to pull the car to the left in this right bend; **Friction** (I.E. '**Grip**') opposes this motion and therefore acts up the slope towards the centre of the bend. This time, **Grip** is ***opposed*** by the **Horizontal Weight Component** when meeting the **Corner Force** Demand.

Corner Force = Grip - Horizontal Weight Conponent

In a right bend, Centripetal Acceleration and Corner Force point to the right, in the opposite direction to the Horizontal Weight Component (mg Sin θ); whilst Inertia, which opposes Centripetal Acceleration and Corner Force Demand, points to the left.

Inertia tries to pull the car wide in the bend but is opposed by the Friction Force between the tyres and the road surface; therefore, Friction acts up the slope, in the opposite direction to the Horizontal Weight Component.

Hence, in a right bend, the Horizontal Weight Component reduces the effect of Friction, in trying to meet the Corner Force Demand; as such, more of the reserve Friction is required to meet the Corner Force Demand.

Conclusion

Camber makes the car more likely to Understeer in a right bend.
Inertia tries to generate Understeer, but it is held in check by the opposing Corner Force, which in turn is provided by the Grip between the tyres and the road surface.

However, if some of the available Grip is used up overcoming the car's Horizontal Weight Component, there is **LESS** Grip available to provide Corner Force.

Both Inertia and Corner Force Demand increase with the square of the car's Velocity into the bend, as such, if there is less Grip available to meet this increasing demand, the conditions that generate Understeer will be achieved sooner, than they would in a left bend.

I.E. to generate Understeer in a right bend: (Note: > is the symbol for 'is greater than')

Corner Force Demand > Grip – Horizontal Weight Component

Camber makes the car less likely to Understeer in a left bend.

To generate Understeer in a left bend:

Corner Force Demand > Grip + Horizontal Weight Component

Comparing the two conditions for Understeer, more Corner Force Demand can be tolerated in a left bend, than in a right bend before Understeer occurs. I.E. a left bend could be taken at greater speed before Understeer occurs. Hence why some racing tracks are banked with the slope running down from the outside to the centre of the bend.

Alternatively, for the same speed into both a right and a left bend, there is less demand for Grip in the left bend, leaving more Grip in reserve. I.E. there is a greater margin for safety against Understeer in a left bend, than in a right bend taken at the same speed, with the same radius of track through the bend.

On UK roads, the camber assists vehicles to resist Understeer in left bends but makes Understeer more likely in right bends.

This is opposite in countries where they drive on the right-hand side of the road; in those countries, the camber assists vehicles to resist Understeer in right bends but makes Understeer more likely in left bends!

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