Centrifugal Force: fact or fiction?

Why do Physicists refer to Centrifugal Force as a 'Pseudo Force' or a 'Fake Force'? Afterall, if I'm sat on a moving train going through a bend, I can feel myself being pulled out away from the centre of the bend: is that not Centrifugal Force? Like most things to do with Physics, the answer is not always as straight forward as it may appear; so, read on.

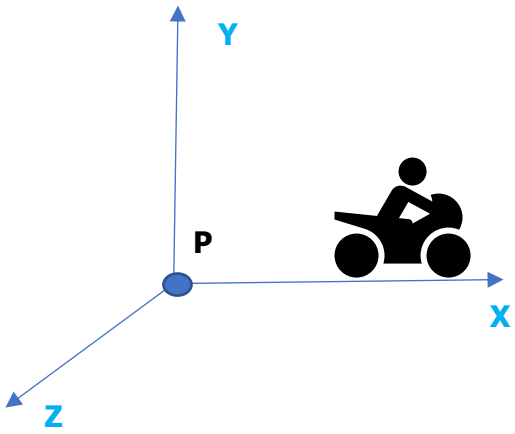
Most people are familiar with the term 'Centrifugal Force' and if asked to describe it they would probably say: 'it's the **Force** that pulls you **outwards** away from the centre, when going through a bend'.

Whenever there is non-linear motion (I.E. rotation about some point), Centrifugal Force appears to apply, but to appreciate the meaning of Centrifugal Force, we need to look at non-linear motion from two different **Frames of Reference**, so let's start by explaining what we mean by this.

Frames of Reference

A Frame of Reference is a simple X, Y, Z set of axes, which we use when measuring quantities such as Length; Speed; Velocity and Acceleration. These quantities are measured ***relative*** to the Frame of Reference, which defines a starting point for the measurements. The most convenient Frame of Reference we have is the Earth's surface, which always appears to us to be at rest, relative to the person making the measurements, although the Earth is spinning on its axis and hurtling through space-time at about 26,000 mph! However, everything we see around us is doing the same, as such, there is no ***relative motion*** between us and the Earth's surface, making it a convenient 'Frame of Reference' for measurements.

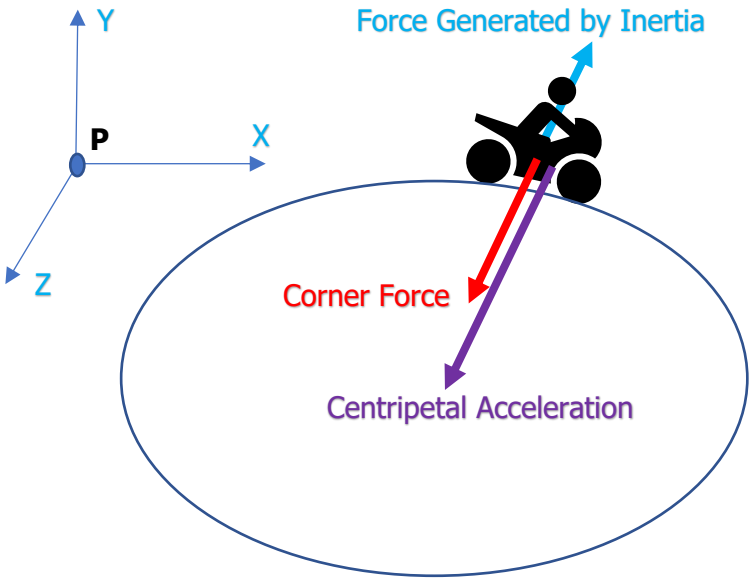
Consider a motorcycle starting from rest and accelerating up to 30mph in the X-direction. Acceleration is measured from some starting point P, in terms of the bike's rate of change of Velocity relative to P; that is, relative to the 'stationary' surface of the Earth. Average Speed is found by measuring how far the bike moves from P in a given period of time and Velocity is in the direction of the X Axis.



Consider the rider now going around a circular track.

Relative to our preferred, convenient X, Y, Z Frame of Reference on the Earth's surface, the Rider is seen to be **Accelerating Centripetally** towards the centre of the track.

The Force needed to keep the bike Accelerating Centripetally is the **Centripetal Force**, or **Corner Force** as it is referred to in driving and riding terms. Newton's Third Law states that to every action (I.E. Force) there is an equal and opposite reaction; and the Force that is 'equal and opposite' to the Corner Force is the **Force Generated by Inertia**.



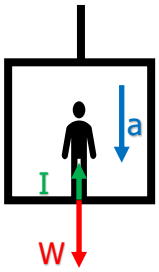
Inertia is that property which resists any change in a body's state of rest or uniform motion; Mass is a measure of Inertia. The more massive a body is, the more Inertia it has and the harder it is to get it moving; or to stop it moving once it has started. ***Inertia always opposes Acceleration by generating a Force in the opposite direction to the Acceleration***.

In the diagram above, Inertia points away from the centre of the track, opposing the Centripetal Acceleration that points towards the centre.

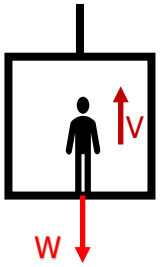
Inertia is **NOT** Centrifugal Force, although some publications cloud the issue, in my opinion, by referring to Inertia as the 'Reactive Centrifugal Force'. To get a better understanding of Inertia and its relationship to acceleration, look at the three diagrams opposite, showing a man travelling up in a lift from the ground to the 8th floor. The man and the lift both have Mass and therefore they both have Inertia.

The Inertia Generated Force (I) acts in the opposite direction to Acceleration.

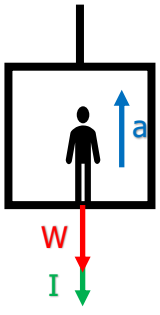
3. On approaching the 8th floor, the lift decelerates. Inertia opposes the deceleration and the Inertia Generated Force acts in the opposite direction to the man's weight, which makes him feel lighter, with an apparent weight of (W-I), as the lift slows.



2. Between floors there is no acceleration and the lift travels upwards at constant velocity, as shown by the brown arrow. If there is no acceleration, there is no Inertia Generated Force and the man feels his correct weight (W).



1. When the lift begins to move from the ground floor, it accelerates upwards, as shown by the blue arrow. The Inertia Generated Force (green arrow) opposes the acceleration and acts in the same direction as the man's weight (red arrow), which makes him feel heavier, with an apparent weight of (W+I) during the acceleration phase.



Our preferred Frame of Reference is referred to as an **Inertial Frame of Reference**.
I.E. a Frame of Reference in which a body at rest will remain at rest, and one travelling with uniform motion (I.E. constant Velocity) will remain travelling with uniform motion, unless acted on by an unbalanced force: this is Newton's First Law of Motion.
The unbalanced force will result in Acceleration (Newton's Second Law of Motion) and Inertia is the resistance a mass shows to any change in its state of rest or uniform motion, because of the Acceleration. The Inertia Generated Force opposes the acceleration responsible for it.

Centripetal Force

In the case of a car or bike in a bend, Centripetal Force is referred to as Corner Force. Think of Corner Force as a ***demand*** on the car or bike; a demand that must be met by real forces; in this case the force of Friction between the tyres and the road surface. If there is not enough Friction to meet the Corner Force demand, the car or bike will understeer in the bend as the Inertia Generated Force overcomes the opposing Friction and pulls it outwards, away from the centre of rotation. When this happens, the Corner Force demand reduces, as it is inversely proportional to the distance from the centre of rotation; once the reducing Corner Force demand can be met by the available Friction, the car or bike stops understeering: but by then it may already have run off the road in a right bend and hit a tree; or crossed over the centre line in a left bend, into the path of an oncoming vehicle.

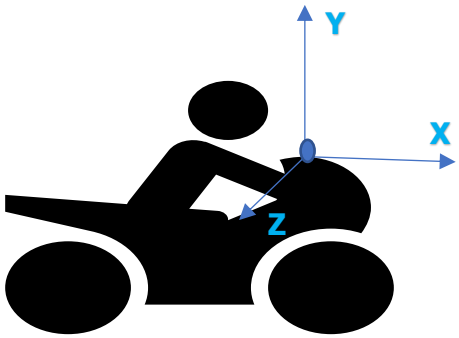
Consider the situation where you are standing still on a train going through a bend.
In this case, the Corner Force demand is met by the Friction Force between your shoes and the floor of the carriage; and because this Friction Force opposes the force generated by your Inertia, you remain stationary relative to the floor. However, if you were to jump up in the air and disconnect yourself from the floor, you would not follow the train around the curve, but would continue to travel in the same direction you were going when you disconnected. I.E. if the linear speed of the train is 100mph relative to our stationary (on the Earth's surface) Frame of Reference, when you jump up and disconnect yourself from the floor, you will continue to travel in a straight line at 100mph by moving along a tangent to the train's path, while the train turns under you. This is because once disconnected from the floor, there is no Corner Force; no Friction (assuming negligible air resistance to your motion) and no Inertia Generated Force acting on you. Your straight-line, tangential motion is fully explained by Newton's First Law of Motion, without invoking a Centrifugal Force.

Centrifugal Force

Now that we know what is meant by a Frame of Reference and we have discussed Corner Force demand; Centripetal Acceleration; Inertia and the Force Generated by Inertia when you try and change the state of rest or uniform motion of a body with Mass, we are better placed to discuss Centrifugal Force.

Special Relativity tells us that the Laws of Physics are equally valid in ***all*** Frames of Reference and the rider can decide which Frame of Reference to use, so let's say our rider wants to attach the Frame of Reference ***to the bike.*** I.E. think of the Frame of Reference as being 'glued' to the bike, so that they always move together as one.

With the Frame of Reference attached to the bike, instead of to the Earth's surface, the bike ***never Accelerates relative to this new Frame of Reference***, because the X, Y & Z axes are doing exactly what the bike does and ***there is no relative motion between them***.



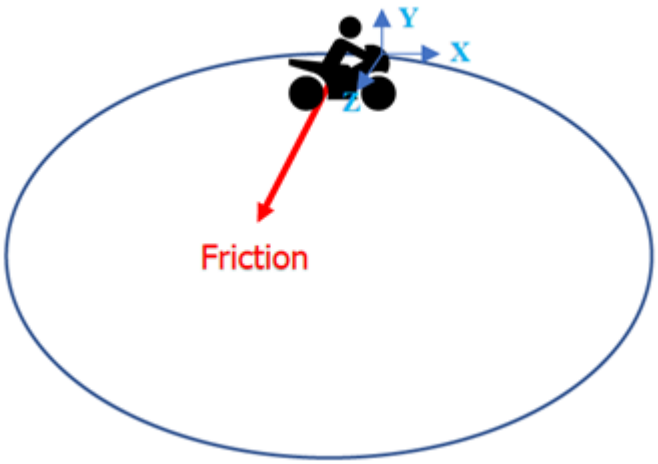
This time when we consider the Rider going around a circular track there is no Centripetal Acceleration therefore there is no Centripetal Force (I.E. Corner Force) and no Inertia Generated Force ***relative*** to the new Frame of Reference attached to the bike.

This new Frame of Reference is referred to as a **Non-Inertial Frame of Reference**.

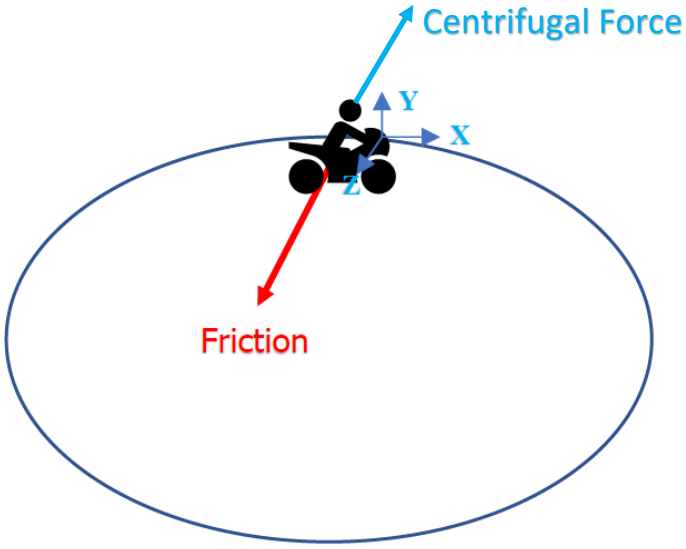
It is also referred to as a Rotational Frame of Reference, because it 'rotates' around the centre of the curved path along with the bike.

According to Special Relativity, the Laws of Physics are equally valid in all Frames of Reference and logic suggests that the bike behaves the same, irrespective of which Frame of Reference we use to view it in.

The bike therefore follows the circular track, because there is Friction between the tyres and the road surface, allowing it to steer.



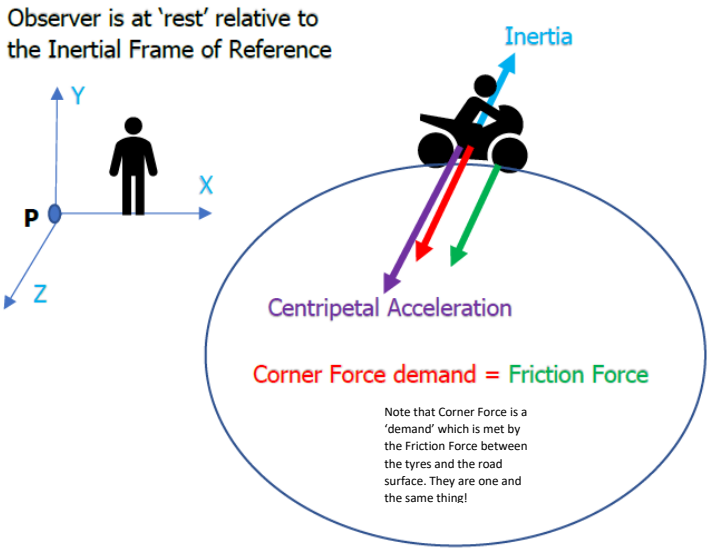
This Friction is the only thing stopping the bike from running wide and coming off the track. If the rider accelerates, speed increases and there will come a point at which Friction alone cannot keep the bike on the track. When viewed from the Non-Inertial Frame of Reference attached to the bike, there is no Force acting outwards away from the centre of the track causing it to do this.



That is, there is no Newton's Third Law 'equal and opposite' Force to partner the Friction Force. To get around this anomaly we introduce a 'Fake Force' acting outwards away from the centre of the turn to ensure we do not violate Newton's Third Law and Special Relativity, and we call it **Centrifugal Force.**

Conclusion

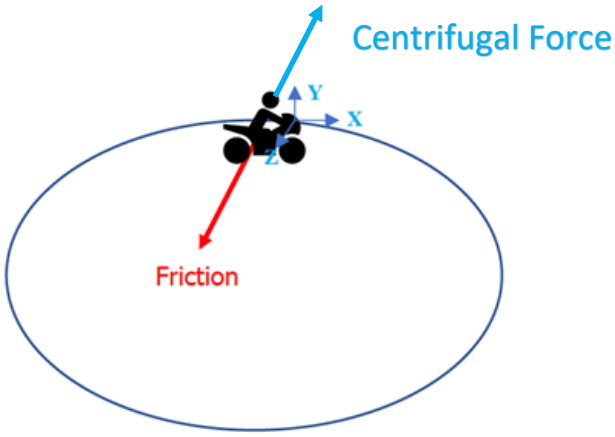
An Inertial Frame of Reference attached to the surface of the Earth is the most convenient and natural Frame of Reference we have, and it does not require the need to invoke a Centrifugal Force acting on the bike in a bend, because the Force Generated by Inertia exists and opposes the Centripetal Acceleration.



However, the Frame of Reference choice is up to the individual observer, who may decide to view things from a Non-Inertial Frame of Reference attached to the bike.

If so we are obliged to introduce a **Fake Force**, known as **Centrifugal Force**, to avoid violation of Newton's Third Law of Motion and Special Relativity, which states that no Frame

of Reference is any more valid than another: we simply choose the one that is most convenient.



It is not wrong to talk about Centrifugal Force and it is perfectly legitimate to use it in calculations, provided the chosen Frame of Reference is assumed to be ***attached*** to the body upon which the Centrifugal Force acts.

It all comes down to choice and convenience and quite often engineers and scientists will find it convenient to work with a Non-Inertial Frame of Reference, whereas at other times, they may well choose to work with an Inertial Frame of Reference.

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