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Definition of Terms and Concepts

Before we can get into the specifics of the myths we need to establish a common ground of understanding of terms and concepts. The misuse of terms or the use of the wrong term to explain motorcycle motion is one of the author's pet peeves. The terms and concepts needed cover basic physics, inertia and gravitational forces and dynamics of motion as related to motorcycles. Without getting into a major physics class we will use layman's language and simple diagrams to explain.

The specific terms we need to know are:

1. Center Of Gravity
2. Centrifugal Force
3. Inertia
4. Force Vector
5. Torque
6. Gyroscopic Forces
7. Physical limits of a motorcycle chassis

1. Center of Gravity

For this writing we will refer to the center of gravity as CG (or resulting Center of Gravity, RCG), often referred to a center of mass. All objects with mass will have a center of gravity or CG. The CG is not always at the physical center of the object but it is always at the center of mass of the object. In some circles of study it is often referred to it as the center of mass instead of center of gravity. Simply put the CG is a point in an object the all forces of gravity and inertia will be focused on. If you could suspend an object at its CG it would remain in whatever position you placed it.

For example, consider a perfectly balanced wheel. The CG would theoretically be at the center of the wheel's axle. If you suspended the wheel by its axle, it would not have a tendency to rotate. It would stay in whatever position you placed it. If the wheel was not in balance then the CG would not be at the dead center and the wheel would rotate until the heavy spot was at the bottom.

(Figure1) Another example of a position of the CG is a hammer. The head of the hammer is heavier than the handle, so the resulting CG is not in the center of the object but will actually be closer to the head of the hammer. If you suspended the hammer at the CG, it would hang level. Note the position of the CG in the photo.

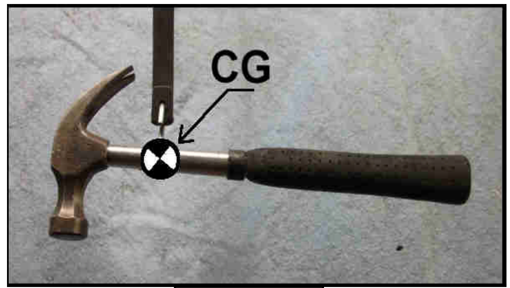


Figure 1

(Figure 2) A motorcycle will have a CG and the rider will also have his own CG. The combined mass of a motorcycle and rider will have what I like to call the "Resulting CG" (RCG). The body position that the rider takes will have a small affect on the position of the RCG, relative to the chassis of the motorcycle.

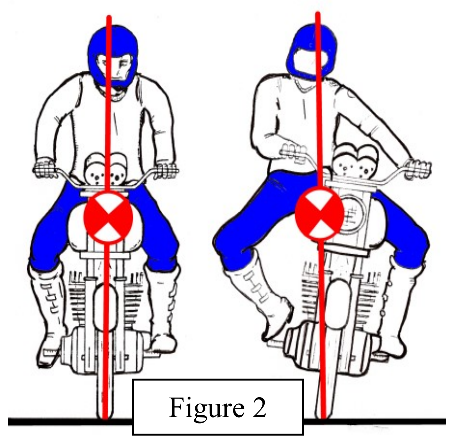


Figure 2

Confusion about the RCG is the biggest reason for the myriad of conflicting theories about body position. Body position will be discussed in detail in Myth #1.

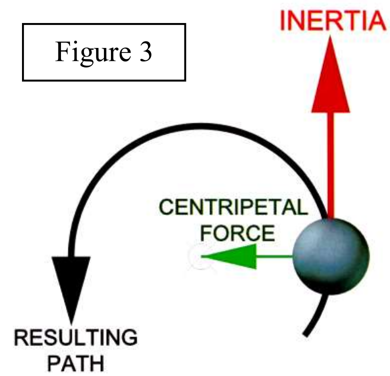
2. Centrifugal Force vs. Centripetal Force

(Figure 3) Centrifugal is from the Latin word for *"center fleeing"*. Centrifugal Force is an often misused phrase. It is used to describe why objects are pushed outward while spinning or turning. For example, when talking about the force pushing the passengers of a car outward in a hard turn, the term centrifugal force will be used. In reality the force pushing objects outward is simply inertia.

3. Inertia as Applied to a Spinning Object

Inertia has two components, simply stated, the first is, a body at rest tends to stay at rest and the second is, a body in motion tends to stay in motion. It is this second aspect of inertia that is what we are concerned with when talking about centrifugal force.

Figure 3



A body in motion will tend to stay in motion in a straight line, *unless* acted on by an outside force. (*Refer to Appendix "A" for Newton's first law of motion*). The people in the car are trying to go straight due to inertia but, the seatbelts and seats of the car are applying a centripetal force to the occupants. The centripetal force generated by the tires is what acts against the inertia and causes the car to go in a circular path and take the people with it. The result is the people feel an outward push of inertia as the car turns.

Another example of inertia and centripetal force is the good ole ball on a string. If you spin the ball and string, it is inertia that pushes the ball outward. It is the string that provides the centripetal force that makes the ball travel in a circle. If the string broke, the ball would continue in a straight line. The same is true for the familiar water in a pail. If you swing the pail fast enough, you a can even swing it over your head without the water coming out. Once again, it is the inertia holding the water in the pail.

When talking about spinning object most scientists/engineers, that I have worked with, don't use the term centrifugal force, we just use the term inertia.

The body at rest will tend to stay at rest concept is important factor to use when trying to understand the forces on a motorcycle in a stable and balanced condition. That will be discussed in a later chapter.

4. <u>Force Vector</u>

(Figure 4) A force vector is a combination of two or more forces on a single mass with a resulting combined single force. For example if you have a mass with one force pushing to the West and a second force pushing equally as hard to the South the resulting force vector and/or movement will be the Southwest. (*Refer to Appendix "A" for detailed formula for a force vector*)

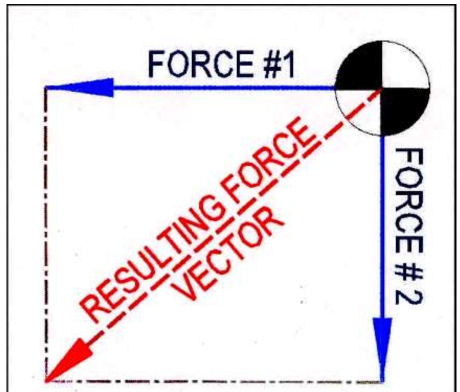


Figure 4

Force Vector

"Applying the concept of force vectors to motorcycle motion"

(Figure 5) Notice the force vector from the RCG to the tire contact patch. As mentioned above there are two main forces acting on the chassis of the bike while cornering, gravity and inertia. The forces work perpendicular to each other. The combination of these two forces will result in a force vector. On a motorcycle this force vector will work from the RCG straight to the tire contact patch. Gravity is pulling the weight of the bike and rider down on the tire and the inertia is pushing laterally on the tire. The resulting force vector is drawn in green. No matter how you sit on the bike, the force vector will always work through the RCG and straight to the contact patch.

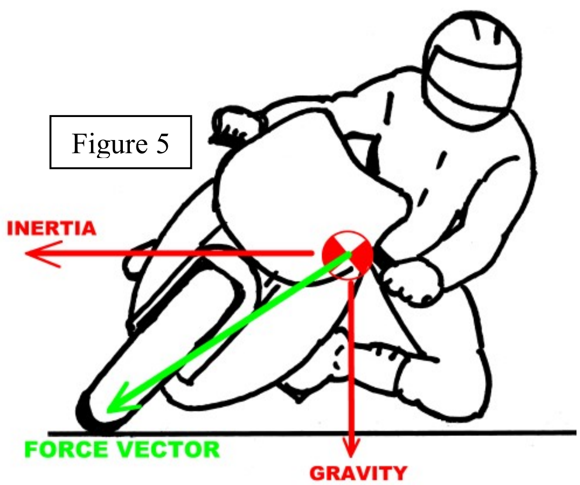


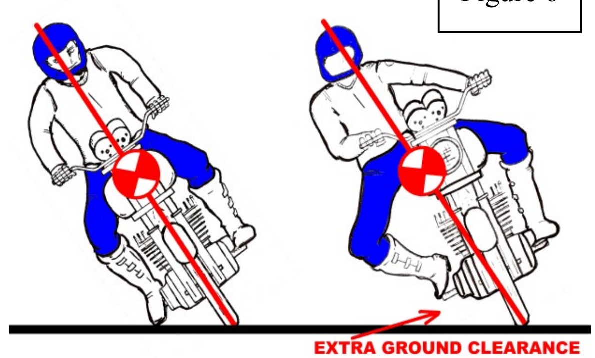
Figure 5

Because the rider cannot change his weight or the bikes weight, the force of gravity pushing down on the tire is always one (1) g thus the resulting friction will remain constant. The only thing the rider can change is the force of inertia by changing speed or radius.

(Figure 6) In this drawing, notice the angle of both force vectors.

In this example we will assume that both riders are at the exact same speed and on the exact same radius turn. With both bikes at the same speed and radius, the resulting force vectors (*drawn in red*) from the RCG to the tire contact patch will scribe the exact same angle relative to vertical for both bikes. The force vector is not dependant on how the rider sits on the bike. The angle of the force vector is strictly a function of the speed and radius.

Figure 6

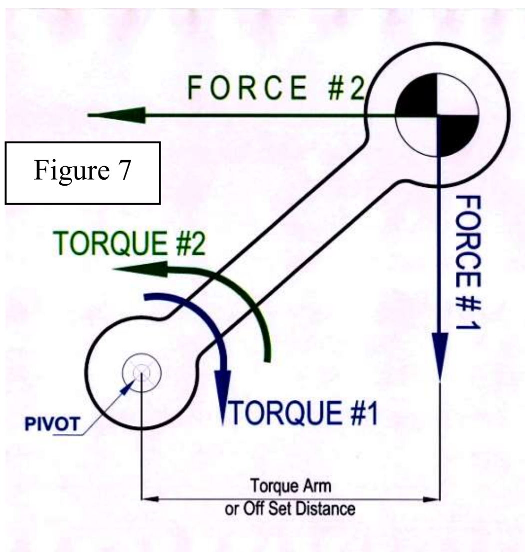


In other words, the only thing the rider is doing by hanging off is just replacing some of the motorcycles weight with his own body weight by moving the motorcycle up and putting his body in its place. The force vector that the tire and chassis feel will remain unchanged. By hanging off the rider has not changed any of the cornering forces acting on the tire contact patch.

5. Torque

Torque is the result of a force that will cause a body or lever to try to rotate around a central fulcrum point such as an axle or pivot point. A motorcycle in motion is subject to several sources of torque such as the wheels, the engine and transmission output etc. As applied to motorcycling, torque and the reaction to it is often confused with or misinterpreted as gyroscopic forces.

Figure 7



(Figure 7) In the diagram, you can see a lever with two forces applied. Force # 1 is pushing straight down. We can think of this as the force of gravity acting on the CG. The pull of gravity will cause the lever to rotate around the pivot point in a clockwise motion. Notice the distance measured horizontally from the pivot point to a point directly under the Force #1. This distance can be called the torque arm length or off set distance or even the moment arm length. The greater this length, the greater the resulting torque on the lever will be, even with the same amount of weight or downward force applied. If Force#1 was the only force acting on the lever it would move clockwise.

Notice the Force # 2. It is applying a force on the CG, perpendicular to Force #1. This force will also generate a torque on the lever but, this torque will be in a counterclockwise direction. Depending and the amount of force #2 and its torque arm length; it may be developing a greater or lesser torque as compared to torque #1. If both are the same derived value, the lever will not rotate. But, if one torque is greater than the other, it will try to rotate the lever in that direction.

"Applying the Concept of Torque to Motorcycle Motion."

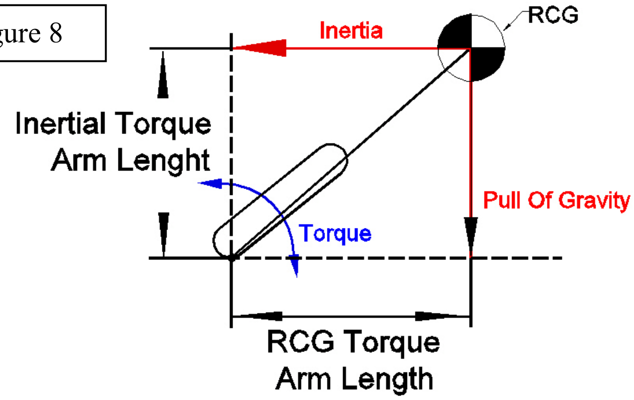
The torque we are concerned with in this chapter is the torque that will have an affect the leaning of a motorcycle in motion.

One way to think about the forces acting on a motorcycle while it is cornering is to look at the torques generated on the chassis. For this concept of torque we will use the tire contact patch as the fulcrum or pivot point. When a bike is traveling in a straight line the downward force of gravity is directly above the tire contact patch. Also there is no lateral inertia developing a torque either. The result is no torque applied to the bike and it remains upright.

(Figure 8) A cornering motorcycle, on the other hand, has two main points of interest. These are the RCG and the tire contact point. The first torque to look at is the downward gravitational pull on the RCG. Notice that when the bike is leaned over the RCG is off set to one side of the contact patch. The further the bike leans over the more the RCG is offset to one side. It is this offset distance which represents a torque arm or moment arm, and is the crucial distance. With the downward pull of gravity as a constant at one (1) g the only way to increase the torque pulling the bike down is to lean over more or hang off further. So the result is, the further the RCG is offset to one side, for whatever reason, the higher the torque pulling the bike down will be.

The second torque to look at is one generated by the outward push on the RCG. This force is called inertia and is often mislabeled as centrifugal force. This inertia acts on the RCG of the motorcycle. It will try to push the RCG outward. This force is perpendicular to the gravitational pull on the RCG. The vertical distance between the RCG and the tire contact patch can be thought of as the vertical inertial torque arm. The inertial force times the torque length will develop a torque around the contact patch and try to pull the bike back up.

Figure 8



It is these two toques generated by inertia and gravity which has the biggest affect on the lean or change in lean angle of the bike. It is the difference between these two opposing torques which will result in the bike to either lean over or to straighten up. So you can see that a higher speed generates a higher inertial force and the bike must then be leaned further over to compensate.

When the torques are in equilibrium, a balanced condition exists. The bike can be either at a stable unchanging lean angle and turning or going in a straight line.

The resulting torque controls the lean angle of the bike but will have very little effect on the forces acting on the contact patch itself. The force the tire contact patch feels comes from the resulting force vector generated while cornering, as described above.

6. <u>Gyroscopic Forces</u>

Gyroscopic forces are actually a result of “angular momentum” of a spinning body. The term gyroscope is seldom used in science. Generally, when the term gyroscope is used, it is referring to the actual spinning device that is causing the angular momentum.

7. <u>Physical limits to a motorcycle</u>

There are several forces acting on the chassis of a motorcycle when it is in motion. Before we can discuss the theory of motorcycle motion we needed to understand the physical limits of the bike and tire plus the basic concepts of forces acting on the bike. All motorcycles have several physical limits to how fast it can ultimately corner. There are two main physical limits we are concerned with when discussing performance.

These limits are.

1) Traction
    a) Co-efficient of fraction
    b) Total weight on tire contact patch
    c) Size of contact patch
2) The Lean Angle
    a) Ground clearance
    b) Edge of tire tread.

1. <u>Traction</u>

Traction is the topic where riders have been exposed to several misconceptions and myths. The myth that I often overhear is “I hang off in this corner to get better traction by standing the bike up and putting it on the fatter part of the tire for more traction”. Once again it sounds logical and easy to visualize. Sounding logical and easy doesn’t necessarily make it right or wrong.

Traction is a function of the interaction between the tire, the pavement and weight of the bike. In physics we use the formula, friction = Mu x normal ($f = \mu Y$) Where Mu = the coefficient of friction multiplied by “Y” the normal weight applied along the vertical axis. For a motorcycle Mu is developed by the tire and pavement. The “Y” is the total weight of the motorcycle and rider. The complete formula for friction is shown in appendix “A”.