TRACTION

The Formula

The subject of traction can be a confusing one, especially to those without a technical background. In general terms it really boils down to a simple basic relationship:

$$F = C_f N$$

This expression is engineer shorthand for saying that the maximum **Friction (F)** between any two materials is the product of two major factors: the first is what engineers call **coefficient of friction (C_f)**; the second is the force pressing the materials together, which is called the **normal force (N).**

The relationship is a general one that can be used to talk about clutches and brakes as well as tires. To make it relevant to tires, we will simply substitute the words "traction" for "friction" and "tire loading" for "force."

However, as with any general relationship, it is too simplistic to adequately explain everything about what happens where the rubber meets the road. Nonetheless, it is a good place to start this discussion, because it establishes the basis for understanding most of what the word "traction" means to us. We'll cover its limitations as we go.

Coefficient of Friction

You can think of a coefficient of friction as simply a measure of the potential for traction. It really describes the nature of the tire (its design, compound, temperature, and age), the nature of the road surface (its material, roughness, condition, etc.), and the degree to which the tire is being stressed (the load on the tire, whether it is rolling or sliding, etc.). Let's look at the most important factors affecting the potential for traction.

Tire Compound: Generally, the softer the rubber, the greater the potential for traction. However, there is another truth about rubber: the softer it is, the more rapidly it wears and the more it will flex under stress. So, to make a realistic street tire, there must be some compromises. Ongoing improvements in carcass design, rubber compounding, etc., have significantly reduced the effects of such compromises. For example, the traditional belief that high mileage means low grip or vice versa is far less true today than it once was. Modern motorcycle tires perform amazingly well. Nonetheless, even the best of them sacrifice ultimate traction for other considerations, such as long life and stability.

It is also wise to remember that rubber hardens with age and as the result of flexing. So all tires, including those intended for sport riding, lose traction potential with age.

Tire Temperature: Rubber is not as soft and pliable when it is cold as when it is warm. Each compound functions best at some design temperature, so it is important to get the tires to that temperature before expecting maximum traction potential. The natural flexing of the tire produces the heat necessary to warm the tire, so riding moderately for a few miles is all that's necessary to get the tires into their design temperature range. There is a limit, however, to the benefits of warming the tires. If they get too hot, they wear rapidly and lose traction potential. Maintaining proper tire pressure and remaining within their load/speed ratings are the keys to preventing overheating. These two factors limit the amount of flexing that occurs as the tire rolls.

Tire Tread: The purpose of the tread pattern is to give better traction on wet surfaces. It does this by providing channels for water to escape from the contact patch (the area of the tire touching the road) and, thus, delay the onset of hydroplaning.

Hydroplaning occurs when the water can't get out of the way of the advancing tire. It literally lifts the tire from the road surface. It is similar to what happens when a speed boat (a hydroplane) or a water ski is moving fast enough to skim along on the surface of the water. One reason why tire manufacturers recommend that a tire be replaced while there is still $^1/_{16}$" to $^3/_{32}$" of tread remaining is that tires worn beyond this point are not safe in the rain — even though the tread pattern remains visible. The grooves are not deep enough to channel away sufficient water to prevent hydroplaning at even moderate speeds.

The tread pattern has very little to do with dry traction directly, but it can affect heating rate, wear rate, stability, and control. In general, the larger the tread blocks (the greater the space between the grooves) and the narrower the grooves, the greater the tread life and stability — at the expense of wet traction. The wider the grooves and the smaller the tread blocks, the greater the wet traction — at the expense of tread life and stability. As with compound, though, technical advances within the tire have lessened the effects of tread pattern as a compromise between conflicting goals.

Before leaving the subject of the tread, we must address the size of the contact patch and how it relates to the traction available. Notice that our general traction formula does not mention anything about the size of the contact patch. Does this mean that the amount of rubber on the road has no effect on the amount of traction available? Unfortunately, there is no simple answer to this question, except to say, "It depends."

First, consider the friction between two sliding, hard, dry surfaces (metals, plastics, etc.). Such materials exhibit what is known as "plastic" deformation. For such materials, even highly polished, "perfectly" smooth surfaces are microscopically irregular. Their real area of contact is between these minute irregularities and is essentially independent of the size of the apparent "contact" patch. Instead, it is proportional to the ratio between the load on the surfaces and the yield strength of the materials. This friction mechanism is commonly called "adhesive friction"or simply "adhesion." But tires are made of rubber, a material that exhibits "elastic" deformation. What happens to the coefficient of friction when one of the surfaces is rubber?

As with harder materials, adhesion is a major contributor to the friction between rubber and the road surface. In fact, so long as there is no significant sliding between the rubber and the surface, adhesion remains the dominant factor. On the street, the normal condition is for the tires to roll without sliding. Therefore, the dominant friction mechanism is adhesion, and the size of the contact patch has little to do with the maximum traction available.

But once a tire begins to slide relative to the surface, the situation becomes more complex. The sliding coefficient of friction is dependent on three factors in addition to the adhesive component we've already described: deformation under stress, viscous behavior, and resistance to tearing. These factors are interrelated, and, unlike adhesion, they depend strongly on the size of the contact patch.

The **adhesive friction** component varies with sliding speed and temperature. In practice, sliding friction often decreases as sliding speed increases. The effect is complicated, however, by the fact that the tire-road slip causes heating.

Since rubber can be readily **deformed** under high loads, the **actual contact area** is no longer proportional to the load but to the $^{2/3}$ power of the load. This means that the coefficient of friction is not constant, but is proportional to

$$(\text{average contact pressure})^{2/3}.$$

This is also reflected in the well-known experimental relationship that the coefficient of friction μ is proportional to

$$\left(\frac{1}{\text{rubber hardness}}\right)^{2/3}$$

on dry surfaces.

The **viscous behavior** of the rubber manifests itself in the friction process as a retardation force (or damping loss) as the rubber slides over the bumps or protuberances of an uneven surface. The bumps produce vibrations in the rubber at frequencies that are related to the sliding speed and the texture of the road surface. A well-known manifestation is the high-frequency squeal of sliding tires.

Finally, the **tear** component of rubber friction involves the tearing of minute particles from the rubber surface by high traction and contact stresses, causing fracture in the rubber. Very high values of μ can be explained by this process.

Typical μ values in this respect would be 0.8 μ for truck tires and 2.0 μ for drag-racing tires.

Rubber is an elastic solid, so the sliding friction on dry surfaces involves processes whose effectiveness is related to the "amount of rubber on the road." This explanation on the traction of tires is not intended to create the belief that a larger contact patch will always provide a higher traction level, only that it is a factor to consider.

For example, the area of contact affects heating rates, stability, resistance to hydroplaning and the importance of small defects or spots of lubrication on the surface. In some cases (like with a small patch of oil), a large contact patch can have a beneficial effect on traction. In others (like with hyroplaning), it can be harmful.

There is a popular belief that fitting a larger tire will always provide a larger footprint, and therefore higher traction. That is not necessarily so because other factors, such as size of the rim, need to be considered. Rim size has a direct influence on the resulting size of footprint.

In racing, a big, fat tire with a large contact patch provides a high level of traction. The large contact patch permits the use of a soft, sticky tread compound. Such a compound in a smaller contact patch under the high stresses of racing would cause the rubber to overheat, tear and degrade to a level that would significantly lower traction.

Tires are designed as a total unit. Their size, carcass configuration, compounds, size of contact patch, etc., are blended to provide the optimum balance of performance and intended use. Traction is a key consideration in this performance package.

Road Surface: The surface material (asphalt, concrete, dirt, paint, ice) and the presence of lubricating materials (water, oil, antifreeze, leaves, sand, mud) combine to affect the potential for traction. It is difficult to make many valid general statements when there are so many variables involved. Dry, coarse concrete is better than wet, smooth ice; but between these extremes you must rely on common sense and trial-and-error experience to estimate the surface's traction potential. Here is where an effective riding strategy like SEARCH—PREDICT—ACT comes into the traction management concept.

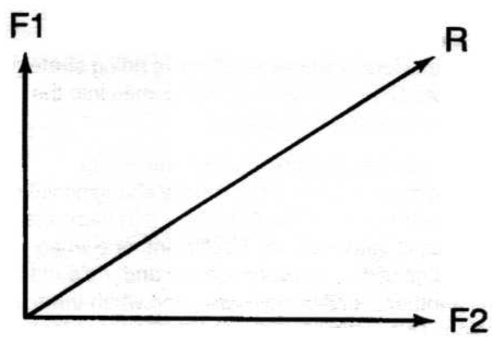
As you can see, the potential for traction or coefficient of friction is a continually changing value that is difficult to predict. Note also that there are two distinct values for the coefficient: one when there is no sliding between the tire and the surface and another, significantly lower, one when there is sliding. This is why a skidding tire produces less traction than a rolling one. Maintaining properly inflated tires in good condition and using proper visual habits to detect surface problems early to avoid skids are the rider's principal means of controlling or managing this aspect of traction.

Tire Loading: This brings us to normal tire loading, the other principal factor in the amount of traction available. Tire loading is what determines just how much of the potential traction discussed above is actually achieved. It's also the one over which the rider has the most control from one moment to the next, because it is affected by speed, turning radius, the rider's throttle and brake techniques, etc.

Tire loading is the term engineers use for the total force that the tires exert on the road surface. Normal tire loading is the component of total tire loading that acts to push the contact patch into the surface. (Normal in this sense is technical jargon meaning perpendicular, or at 90°, to the surface.) Notice the word *component* in the earlier sentence. It is an important word. We need to ensure that we understand the concepts of "component" and "resultant forces."

Diagram 1 illustrates this concept. The arrows in this diagram represent forces acting on or through a point on some physical object. The length of the arrows is proportional to the magnitude of the forces. Their orientation represents the direction in which the forces are acting.

Diagram 1: Component and Resultant Forces

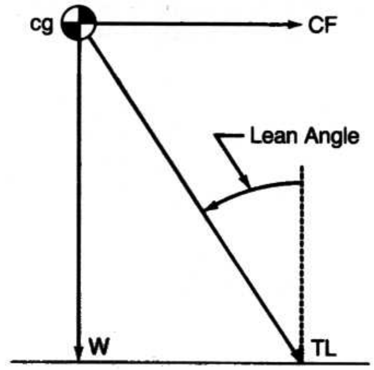


Forces F1 and F2 are two components, of the single resultant force, R. The resultant alone would affect the object exactly as the two components acting simultaneously. In other words, the resultant is the equivalent of its components and vice versa. At times it is easier to see what's going on by thinking of the components; at other times it is simpler to think of the single resultant force. The important idea here is that any set of forces acting through a single point can be represented by a single resultant force, and any single force can be broken down into a set of component forces that are equivalent in overall effect. With this idea in mind, we can now get back to our subject.

Tire loading is the resultant force produced by several components (weight, centrifugal force, etc.). To understand its relationship to traction, we must break this resultant force down into two components. One acts perpendicular or at 90° to the road surface, and the other acts parallel to the road surface. Remember, only the component of tire loading that acts perpendicular to the surface produces traction.

The other, parallel, component of total tire loading represents a need for traction. **Diagram 2** (following) illustrates this relationship in a turn on a level surface.

Diagram 2: Turning on a Level Surface



The weight **(W)** acts vertically downward and the centrifugal force **(CF)** acts horizontally to the right. Both forces act through what is known as the center of gravity **(cg)**. The resultant of these two components, tire loading **(TL)**, also acts through the cg at an angle (measured from vertical) known to us riders as the lean angle. In this situation, only the weight acts perpendicular to the surface, so it is the only factor that acts to produce traction. Notice also that since the weight doesn't change simply because the bike is leaning, the total traction remains exactly the same as it would be if the bike were going straight (at zero lean angle). Many riders believe that there is less traction when the bike is leaned over, so this may be news to them.

Level Surfaces

Of course, remember that we are dealing with an absolutely level surface here, and there aren't many such places out on actual streets and highways. What happens if the surface slopes or inclines? That's a very good question, and we'll get into that in a few minutes. But, for now, let's stay with the level or nearly-level aspect to discuss some factors that affect total tire loading and its distribution between the tires:

- When the bike is at rest on a level surface, the tire loading is simply the weight of the bike, rider(s), and cargo. The proportion of the total weight supported by each tire is determined by the center of gravity relative to the contact patches. Think of this as the basic tire-loading distribution, say 50:50 or 48:52, front to rear.

■ Accelerations that produce an increase in speed cause the distribution of the tire loading to shift toward the rear. The load on the rear tire increases, while the load on the front tire decreases. The effect is proportional to the magnitude of the acceleration; the harder you accelerate, the greater the transfer. The extreme case is known as a "wheelie." Note: The total tire loading doesn't change, just the distribution. If there is no wheel spin due to excess power, then total traction also remains the same, because the weight and the friction coefficient do not change.

■ Similarly, accelerations that produce a decrease in speed (known as "decelerations" in non-technical conversation) cause the distribution of tire loading to shift toward the front. Again, the harder you "decelerate," the greater the transfer. The extreme case is known as a "brakie," "stoppie," "nose stand," etc. Total tire loading doesn't change, and if there is no skidding due to overbraking, total traction is unchanged.

■ Vertical accelerations due to dips and bumps in the road result in momentary changes (both increases and decreases) in the tire loading and traction. It is the job of the bike's suspension to minimize these effects by absorbing part of the energy and by damping any bouncing tendencies. These effects are more severe in turns, because the suspension is designed to absorb such disturbances only in the plane of the wheels.

■ So long as the motorcycle is under enough power to at least maintain speed, aerodynamic drag force and the driving force necessary to overcome it act together to shift the distribution of tire loading from the front to the rear. Total tire loading and traction are not affected by this factor, but they can be if there is any net aerodynamic lift or downforce. These aerodynamic effects increase as the square of the speed: at 60 mph they're four times what they are at 30 mph.

■ The brakes and the power train produce torque-reaction forces. The forces produce accelerations of the suspension components, which result in momentary changes in the loading of the affected tire. Perhaps the best known and most obvious of these is the so-called "shaft-drive effect" in which the rear suspension extends or retracts as engine power is added or removed. The brakes can produce similar effects, depending on the design of the brakes and how they are mounted relative to the suspension components. These effects are generally rather small and very brief, but they can sometimes make the difference between a rolling tire and a skidding tire in the manner of the "last straw." Smooth throttle and brake techniques virtually eliminate them as significant factors.

Non-Level Surfaces

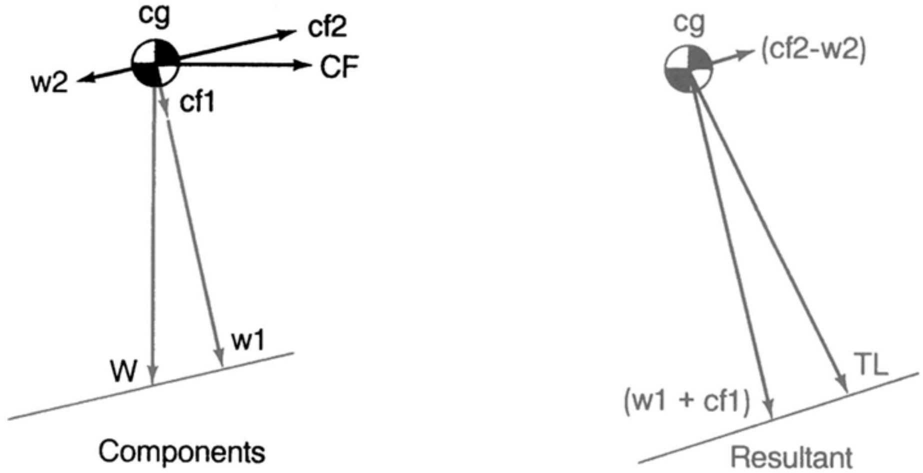
Now we can get back to our earlier question. What happens if the surface slopes or inclines? The answer to that one is a bit involved, because each case is different, depending on the orientation of the surface to the direction of travel.

To begin, let's look at a turn on a "banked" or positive-slope surface. Let's assume that we have the same bike making the same turn (speed and radius) as before. The weight is the same, and since the speed and radius are the same, the centrifugal force is the same. Therefore, the resultant total tire loading is the same. But what about the traction?

In **Diagram 3** (following page), each of the two major components — weight **(W)** and centrifugal force **(CF)** — is broken down into subcomponents that act perpendicular to the surface **(w1 and cf1)** and parallel to the surface **(w2 and cf2)**. These subcomponents must be added (or subtracted if they act in opposite directions) to come up with the net perpendicular and parallel components of tire loading. This result is shown on the right, where the resultant tire loading **(TL)** is shown with the net perpendicular component **(w1 + cf1)** and the net parallel component **(cf2 - w2)**.

On any non-level surface, the perpendicular component due to weight alone is reduced. This includes going directly up, down, and across hills. The steeper the slope, the greater the loss of total traction due to the weight. But in a turn

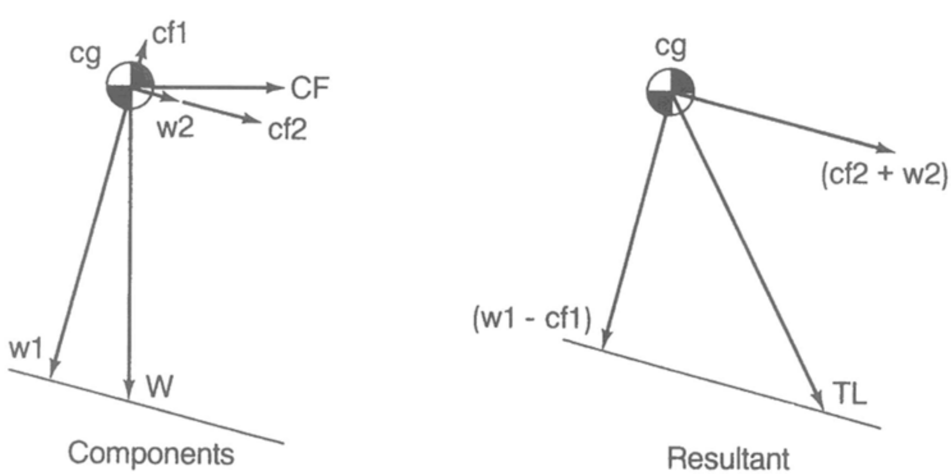
Diagram 3: Turning on a Surface with a Positive Slope



with positive slope, there is a component of centrifugal force that compensates for this loss in traction by adding a perpendicular component of its own. Also, notice that the parallel components **(cf2 & w2)** act in opposing directions so that the demand for traction is reduced. Therefore, the banked turn is good for two reasons related to traction.

With negative slope, shown below in **Diagram 4**, the situation is not so good. The weight is still producing less traction, but now the centrifugal force makes things even worse by subtracting from the traction. Its perpendicular component **(cf1)** acts away from the surface rather than toward it, so the net traction-producing component **(w1 - cf1)** is significantly smaller than in the previous case. Note also that the parallel components **(cf2 & w2)** both act downhill. Therefore, when traction is relatively low, the demand for traction is even higher.

Diagram 4: Turning on a Surface with a Negative Slope



We can make similar analyses for each specific case, but these examples are sufficient to demonstrate the principles and the ideas. It is easy to see the importance of looking well ahead and being alert to changes in road slope, camber, and surface condition, etc., when selecting a line and speed through any corner.

Summary/Bottom Line

Well, that's about it as far as traction goes. It depends on the potential for traction as expressed by the coefficient of friction and on the net force acting to press the contact patch of each tire into the road surface.

The rider's task is to keep both factors as high as possible when the demand for traction is high or to keep the demand for traction at a minimum when traction is likely to be low.