Lateral suspension

When we hit a bump whilst lent over in mid corner, the bump force will probably be approximately vertical. Therefore, only a component of this force will act in line with the suspension and the rest will act at right angles or laterally with respect to the bike. Fig. 6.35 shows the case for a 1 G. turn with a lean angle of 45 degrees. It’s not just single bumps that do this, of course, but a bike is always subject to a variety of disturbances, which when leant over will produce continuous variation in the tyre to road force. We have seen earlier that this load variation is detrimental to traction and so is of the utmost concern in racing circles.

As tyres and hence cornering speeds have improved over the years this problem has assumed greater importance, especially as power outputs have increased also. Transmitting this power effectively requires that the tyre maintains good contact with the ground, this is achieved by having the minimum possible variation in the tyre to road contact force. Ironically the gradual trend towards much stiffer chassis over the past two decades, to generally improve handling, has made this problem more obvious and we see experiments with “controlled flex” or lateral suspension as a counter-measure.

At the moment this seems to be a little understood and very controversial topic, without any real consensus about whether a chassis should be as stiff as possible or have some built in compliance designed to reduce the tyre force variation. Some laboratory and track testing has indicated a reduction in this variation, to the benefit of traction in general, by the introduction of some extra flexibility. However, races are not won by technical considerations alone, the rider has to be accounted for also. It’s a fact that some riders feel more at home on a bike with a rock solid feel to it, whereas others are happiest with a machine that appears to “give” a little. What is certain though, is that any deliberately introduced compliance must be below a level that would introduce other instability problems, such as wobbles or weaves. Prior to about the 1980s many chassis fell below that level and benefited greatly from increased chassis stiffness, however beyond a certain point it is doubtful if increased stiffness would be noticeable. It appears that some modern chassis may have exceeded that point possibly to the detriment of traction.

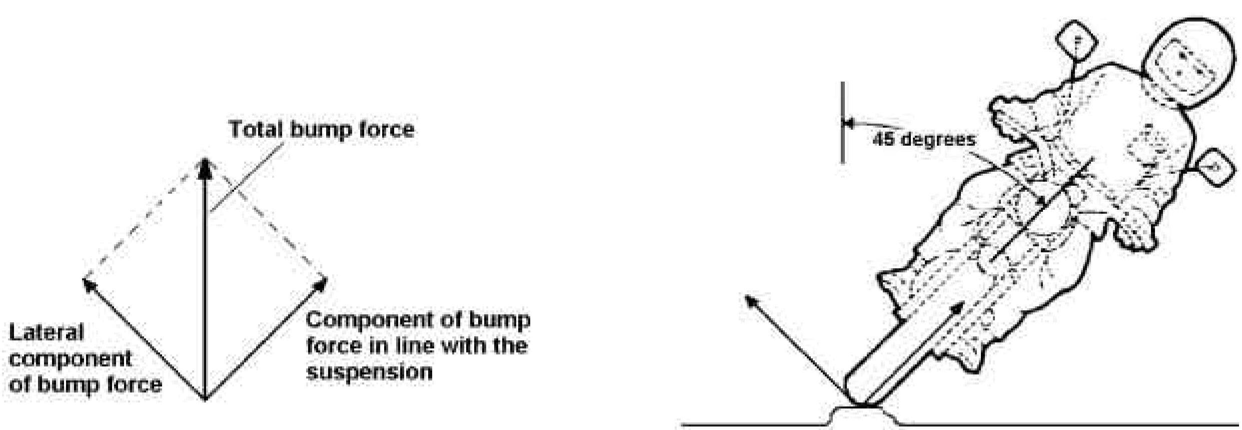

Fig. 6.35 **At 45 degrees lean a vertical bump force will create equal forces , one in line with the suspension movement and the other at right angles to it. These forces will each be 71% of the vertical bump force.**

Let’s look a little closer at this idea of lateral compliance and see if it has anything to offer.

At the 45 degree lean angle of the example in fig. 6.35, the extra force (due to a bump) in line with the suspension will also be equal to the lateral force, each being 71% of the total bump force. This fact leads us to the conclusion that the suspension will now compress by a lesser amount than that which would occur if the bike were upright when traversing the same bump, other factors being equal.

Other factors are not equal as fig. 6.36 shows. For a given vertical tyre displacement, if we introduce some lateral movement at the tyre then we will reduce the tyre motion in-line with the bike by an equal amount. The lateral motion primarily comes from a roll movement of the whole motorcycle, as shown, and lateral and torsional chassis compliance, which in practice depends on numerous factors.

Thus there are two factors which tend to reduce the displacement of the suspension unit, one being the reduction of the in-line component of the vertical force and the other due to the lateral displacement.

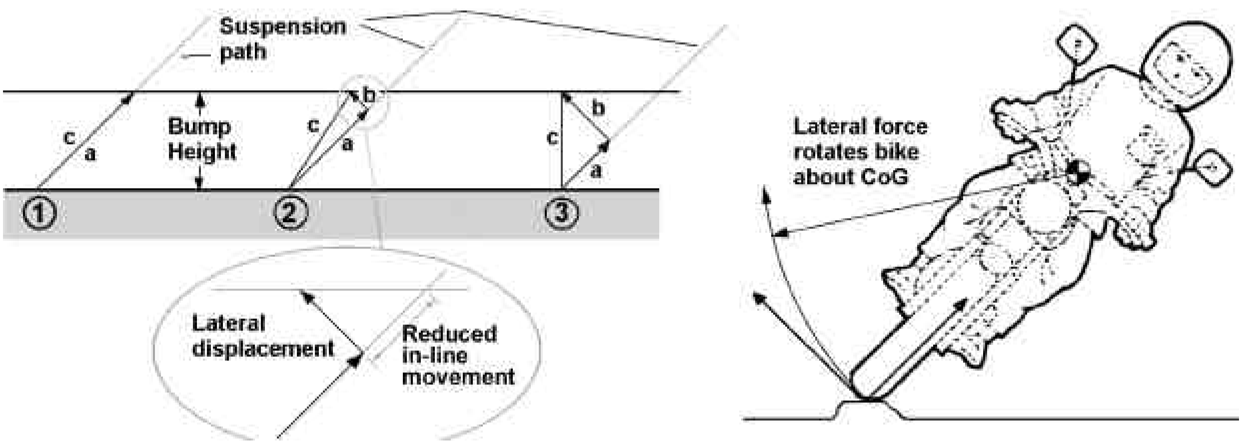

Fig. 6.36 **The sketches to the left show how the tyre movement needed to surmount a bump is changed by introducing lateral movement.**

1. Shows the case where all movement is along the path "c" which is colinear with "a" the suspension compression direction.

2. Shows how a small amount of lateral displacement "b" changes the tyre path, and the expanded view shows that the in-line movement reduces by the same amount.

3. When the lateral motion is equal to the in-line movement ("a" = "b") then the wheel path is vertical when at a lean angle of 45 degrees, .

Right. **The lateral impulse at the tyre tends to rotate the bike about its CoG, thereby giving some lateral displacement even without any lateral structural compliance.**

In fact calculations show that this roll response "absorbs" most of the bump disturbance when lent over in a curve. The lateral motion at the tyre due to this roll, and compliance, is extremely important to the whole suspension action when hitting a bump whilst leant over, as we shall see.

Fig. 6.37 shows the end view of an idealized simple model of a motorcycle at a lean angle of 45°. It has a mass of (**M**) centred at the CoG and a roll polar moment of inertia about the CoG of (**I**). The CoG is a fixed distance of (**r**) from the tyre (that is; there is no suspension movement). If this idealized machine is subject to a vertical bump force (**F**) then two types of motion are created;

A vertical movement of the CoG shown as (**v**).

An angular motion about the CoG shown as ($\boldsymbol{\theta}$) which leads to a lateral displacement at the tyre of (**l**)

Therefore the overall motion of the tyre will be as shown by the grey line in sub-sketch **(A).** The detail of this motion is controlled by the values of **M, I, r** and the angle of lean (This is just a standard physics problem and a full explanation can be found in many text books).

For our current purposes the ratio of the lateral displacement to the vertical is of interest and for a given angle of lean it can be shown that:

$$\frac{l}{v} \approx \frac{Mr^2}{I}$$

Substituting motorcycle values for these parameters we find that the lateral motion could typically be around five times that of the vertical, even more when chassis flex is accounted for.

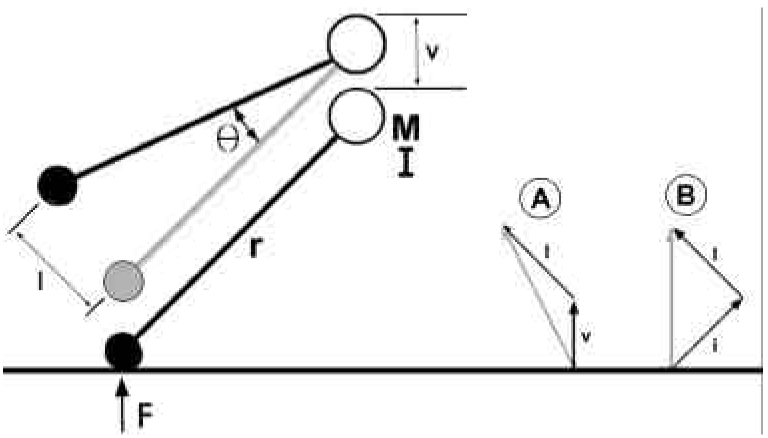

Fig. 6.37 **A motorcycle leaning at 45° is represented by a tyre connected by a rigid rod of length (r) connected to a mass (M) with a moment of inertia of (I). A bump is shown as a vertical force (F).**

The sketch at (A) shows the motion of the tyre, (v) is the vertical movement and (l) the lateral. (B) shows the motion if a sufficiently compliant suspension was introduced to give a totally vertical path, (l) being the lateral component and (i) the in-line component.

So it would seem that the problem is not so much one of needing to introduce more lateral displacement as often suggested, but one of restoring lost damping and thus in-line movement. **(B)** shows how enough in-line movement converts the wheel motion to purely vertical. This in-line motion is of course provided by the normal suspension system. The ratio of the suspension movement to lateral motion is affected by many parameters, e.g. **M, I, r** as before but also the unsprung mass and compliance of the suspension and chassis. In most practical cases, at high lean angles, the lateral motion will exceed that due to suspension movement. We have already seen that this lateral motion will reduce the suspension movement, for a given size of bump. If we consider the basic requirements of dissipating the effects of a bump it will become clear that reducing the suspension movement is highly detrimental.

At the most basic level, when we hit a bump some of the forward kinetic energy of the motorcycle is converted into energy acting in a vertical direction. Without any damping at all, this will cause a continuous oscillation on the tyre and suspension system, the introduction of damping will dissipate this vertical energy as heat and kill the oscillation. In practice this damping is mainly provided by tyre and suspension damping, although the suspension damping normally overwhelms that due to the tyres.

Fig. 6.38 shows the response to a small sinusoidal shaped single bump, in terms of tyre to road contact force, with three different values of damping. The bump is only 0.01 m. (10 mm.) high by 2 m. long and at 100 km/h. it takes approximately 0.07 seconds to pass over it. The physical parameters are fairly typically, a wheel load of 1250 N (127 kgf.), an unsprung mass of 20 kg., suspension frequency of 2.5 Hz. and a wheel hop frequency of 14 Hz. The damping values considered are:

- Some tyre damping only.

- Tyre damping plus a typical degree of suspension damping, with a rebound to bump ratio of about 4:1.
- Tyre damping with the suspension damping reduced to 0.25 of that above.

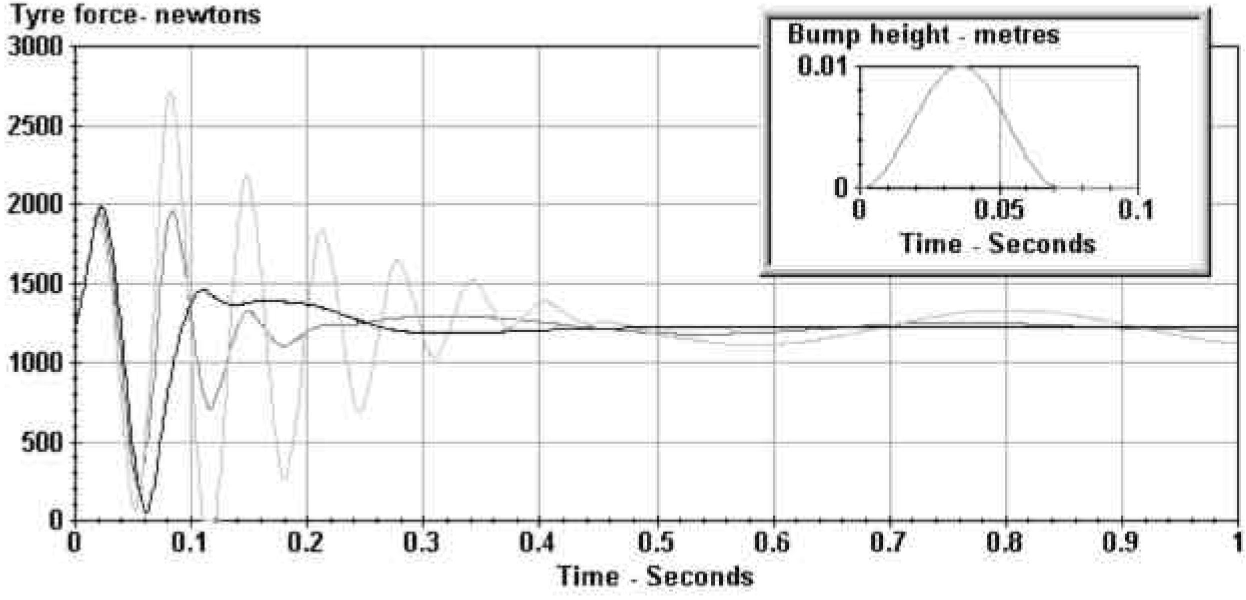

Fig. 6.38 **Tyre force response to a small sinusoidal bump (shown in the inset) for various values of damping. The light coloured curve is with tyre damping only, the darkest is with typical suspension damping and tyre damping, and the other is for a quarter of the previous suspension damping. The oscillation visible prior to 0.5 seconds is due to the unsprung mass bouncing on the tyre (wheel hop) and the much lower frequency motion after 0.5 seconds is due to the sprung mass moving on the suspension springs.**

We can see that the initial force peak is similar in all three cases, because, as we've seen in the tyre chapter, the initial impact of small bumps is mainly taken up by tyre deformation. However, there is considerable difference after the bump has passed. With the minimal damping due to the tyre alone there is considerable force variation at the wheel hop frequency lasting for close to 0.5 seconds. In the case of typical suspension damping this is almost smoothed out by about 0.1 seconds, and with a reduced suspension damping, by 0.25 seconds. This cyclic tyre force variation is bad for traction, and so it follows that reducing damping from an optimum level is also bad for traction.

Figs. 6.36 and 6.37 have shown that any lateral motion of the tyre, when leant over, will reduce the in-line or suspension movement. If the suspension movement is reduced then so too is the damping energy. In general the energy absorbed by a damper depends on the square of the displacement and so if the suspension movement is cut by half (not an unreasonable figure and probably very conservative) then the overall damping energy will be reduced to a quarter. So if the suspension system is adjusted for good traction when upright the damping is certain to be far too low when leant over on the same terrain. Allowing more lateral movement, for example by introducing lateral frame compliance would therefore seem to be counter-productive, as it would further reduce the in-line motion and damping along with it.

However, if by increasing chassis compliance we also introduced additional damping, then the overall effect would be beneficial provided that the chassis flexibility was still low enough to avoid instability problems. In fact, practical laboratory measurements show that a motorcycle chassis does not act as a simple elastic structure, but shows a hysteresis characteristic similar to that shown in the tyre chapter. That is; during a loading – unloading cycle there is a nett energy loss, or damping, as shown in fig. 6.39.

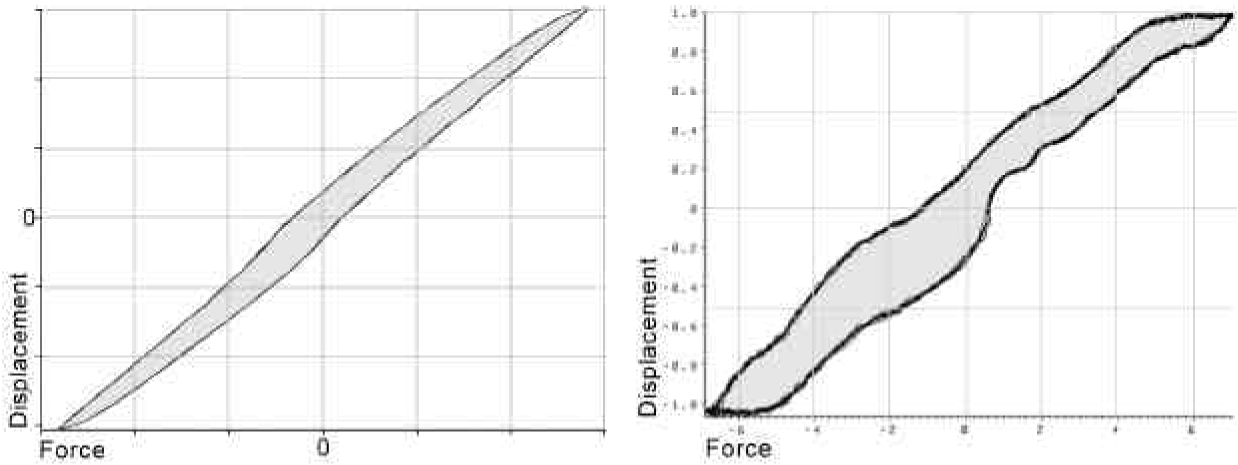

Fig. 6.39 **These force-displacement curves are measured from actual motorcycles. At left is a complete loading and unloading cycle covering positive and negative values. This shows the torsional characteristics from axle to axle. The second curves to the right show the stiffness of a complete wheel and swingarm assembly from a used sport bike. Despite the very irregular shape these characteristics are very repeatable from one loading cycle to the next. Slop and stiction etc. are causes of the strange shape. In both of these cases the main point to note in the current context is that they exhibit a hysteresis effect as explained in the tyre chapter. The shaded area represents a loss of energy that occurs during each complete loading cycle, damping in other words.** (data courtesy of Dr. Robin Tuluie and MTS)

This then, is where any benefit of increasing frame lateral flexibility comes from, an increase in the total system damping to help replace the lost damping in the suspension system. This will probably follow the same square law relationship mentioned above. If the chassis is allowed to dynamically flex twice as much then the damping energy dissipated will likely increase by a factor of four. Looking at it from the opposite perspective; if we increase chassis stiffness, beyond the value needed to avoid instabilities and any other poor handling traits, then we rapidly decrease the amount of damping from this source. Tyre grip when leant over will suffer as a result. Any practical chassis will have various sources of compliance and this can lead to various and different distributed resonances, the relationship between these resonances and the wheel hop frequency can cause interference effects which may increase or decrease the wheel hop. We are currently at the very early stages of beginning to understand this in suffient detail to apply it to actual designs, without a lot of testing of alternative frame configurations.

So if some lateral compliance is necessary we need to consider how best to achieve it. There are countless design possibilities for the manner in which lateral suspension could be implemented, but the easiest and most obvious are also probably the worst. For example, at the front end we could just introduce additional lateral flexibility to the forks, but as shown in fig. 7.1 this will introduce an additional camber angle to the tyre. Spurious and probably undesirable steering impulses would result with implications for handling and stability. At the rear some flexibility could be built in to the swinging arm mounting area, but as well as lateral movement at the rear we would get wheel yaw attitude changes, also leading to spurious steering inputs.

At the rear we also have the problem of the large chain forces waiting to take unfair advantage of any extra compliance. We really need to ensure that only true lateral motion is allowed. This could be done by just allowing the wheel or rim to move laterally, with the remaining chassis parts as rigid as possible, fig. 6.40.

We have seen that the fundamentals of dealing with bumps whilst cornering mean that the suspension units experience considerably less movement than would be the case if the bike remained in an upright position. This greatly reduces the rate of energy dissipation in the dampers. To counter this effect we need to take steps that will maximize suspension displacement, these include:

- Soft suspension springs – but this is compromised by all the other demands on the suspension, such as handling bumps when upright, braking and driving dive and squat etc.
- Low sprung mass – this is beneficial in general for most suspension demands.
- Increased rider lean-in – this will keep the bike and suspension travel more vertical.
- Lower the CoG height – the formula on page 6-45 shows that this has a squared effect. As shown throughout this book there are many conflicting demands on whether the CoG should be high or low and this one is just another in the mix.
- Use active suspension – this would be the ultimate way of reducing tyre force variation, and the subject is covered in more detail in chapter 18.

Once we've tuned the above parameters to ensure the maximum suspension movement and damping from the suspension units, there are a few more methods to increase the overall damping.

- Increase tyre damping – an obvious suggestion but it means higher tyre temperatures.
- Dynamically adjustable dampers – a low power alternative to full active suspension, also explored in chapter 18.
- Introduce lateral damping – as explained above this can be a result of allowing an optimum degree of lateral structural compliance. We need to consider how to construct the structural elements to maximize the inherent damping.

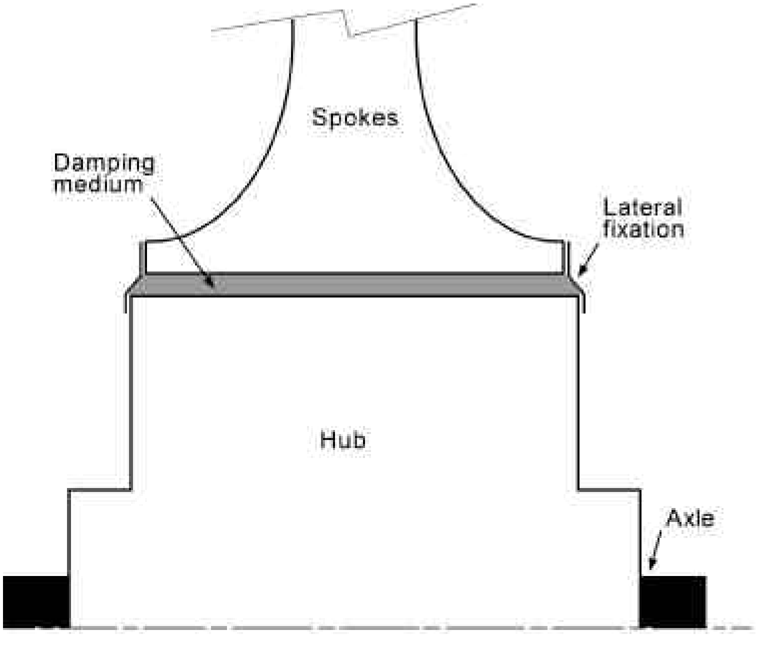

Fig. 6.40 **A preliminary proposal by the author for a two piece wheel with built-in lateral damping, which may be worth some consideration.**

This cross section shows a central hub which contains the bearings and provides disk and sprocket mounting in the normal fashion. The outer part of the wheel consists of the rim, spokes and a central ring with an inner diameter slightly larger than the inner hub. These two parts are joined together by some fixation method which allows some lateral compliance but gives a rigid radial and torsional support. The annular gap is filled with some form of damping medium. This manner of providing lateral compliance and damping only entails a small weight penalty, but on the other hand gives a minimal effective lateral unsprung mass, which is important to the reduction of dynamic tyre loads.

Such lateral damping may also have beneficial effects on weave stability, but analysis and testing would be needed to confirm it's worth.

In this section we have been considering the problem of suspension under cornering conditions as being one of tyre grip, obtaining the maximum traction. There is also the issue of ride comfort and as we have seen earlier in this chapter, ride comfort and the need to reduce tyre force variation are sometimes at odds with each other. Ride comfort requires a slow response from the wheel so as to pass the minimum possible accelerations through the suspension to the sprung mass of bike and rider. On the other hand, we need a rapid wheel response to reduce the dynamic loading on the tyre.

Summary

Motorcycle suspension is a coupled (back and front) dynamic system comprising springs, dampers and so-called sprung and unsprung masses. Whilst the basic layout is quite simple the dynamic interactions with the overall handling, stability and comfort of the machine are extremely complex. As shown in a previous chapter, tyres are the most important element in the suspension system.

In general we benefit from softer suspension but this must be balanced against the available movement and geometry changes. The need for appropriate behaviour under braking, acceleration and cornering has to be taken into account also. The many diverse requirements make it impossible to design a “perfect” setup for any particular bike, compromise is inevitable. The ideal for comfort may for example lead to weaving under rapid corner lean-in or perhaps excessive dive under braking.

Even though suspension movement takes place in the centre plane, the tight integration of motorcycle dynamics can lead to responses about other axis, yaw and roll. Poorly set suspension can reduce roadholding and/or allow these responses to become dangerous instabilities.

The necessity to lean when cornering introduces bump forces at right angles to the plane of suspension movement, which conventional suspension is ill equipped to handle. Damping is thereby reduced leading to increased wheel hop. Some attempts have been made to introduce a degree of lateral structural compliance to address this issue, but as yet there is no generally accepted solution to this problem. Realizing that the basic problem is one of insufficient damping, and not one of insufficient lateral motion might help point the search for improvement in the right direction.