# ADVANCED RACE CAR CHASSIS TECHNOLOGY

**Winning Chassis Design and Setup for Circle Track and Road Race Cars**

Previously published as *Stock Car Setup Secrets*

**Bob Bolles**

HPBooks

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# ACKNOWLEDGMENTS

The technology that forms a large part of this book was accumulated by working with a great many and varied race teams. As that work progressed, much knowledge was gained. I consider all who have asked for my help and paid my consulting fees partners in developing the information you will read in the following pages.

As with any serious, long-term endeavor, we got a lot of help along the way. It was once said by Martin Rutte, “You have to do it by yourself, and you can’t do it alone.” And the motto I mostly live by, from Zig Ziglar, “I believe you can get everything in life you want if you will just help enough other people get what they want.” In helping others, a lot came back to me in the form of financial assistance, knowledge of systems, suggestions, satisfaction and support.

This book is dedicated to: Wes Troup who gave me much support and my first important championship; Buddy Parrott and Nick Ollila for providing me with my first hands-on experience with a Cup car, which lit a fire in me; Dewayne Ragland for his friendship and ongoing support and for showing me around the Midwest; Brian Wheeler for use of his shop and resources as well as his continued support and concern; Brian Butler, who caught on early and who is always available for a “conference;” to Charley Miles; Jon, Jim and Jeff Craig; Jay Fogleman; Greg Marlowe; Jason Boyd; Robert Ham; Jack Cook; Brian Hoppe; Bob Garbarino; and all of the hundreds of other race car drivers who went out and won with this stuff.

I also want to thank certain car builders who helped me in various ways throughout my career. To Billy Hess, Harley Boeve, Wayne Lensing, Gene Coleman, Dick Anderson, Keith Masters and Steve Leavett, thanks for your valuable support. And to Bill Montagne, for divulging the secrets of the science of aerodynamics.

I gained a lot through my association with *Circle Track* magazine. I had always valued the publication and never thought I would be lucky enough to write for the racers. I gave my very first article to famed engine builder and CT contributor Smokey Yunick to read and critique. His comment was, “If it takes longer to read than it takes to take a crap, then it’s too long.” I loved Smokey. I have developed many valuable friendships as a result of my association with CT. My knowledge has grown over the years, and this book is an effort to share what I’ve learned with the racing community.

To everyone who bought my software and paid my consulting fees, you helped to fund this research and were truly a large part of making it happen. Thanks so much, and keep those cards and emails coming.

On a more personal level, my parents, children and my wonderful wife have all supported this effort. A project such as this one tends to consume a person and those who live around that person are affected most, but without close family support, this project would have been much more difficult or impossible to complete. To my immediate family—Grammy, Pa, Karen, Sonia, Mike, Christa and Tim—thanks for your continued patience and endurance.

And thank you, Harry Hyde. I’m still listening, man.

# INTRODUCTION

Around 1992 I decided to change careers and become a race car engineer. My early experience in racing was spending countless hours at Daytona International Speedway in the pits, in the stands and around the mechanics, drivers and owners listening and hearing about how the cars handled. I was always fascinated by the design and setup of race cars, be they stock cars, road racing cars, formula or weekend SCCA cars.

I attended many years of races at New Smyrna Speedway and Barberville, now known as Volusia Speedway Park. I was interested in the "race," but always fascinated by the way the cars handled and how all of that was accomplished. I watched Dick Trickle prepare his car in 1975 at a friend's garage in preparation for the Speed Weeks show at New Smyrna and thought, "I would like to be able to do that."

I am an engineer by education and nature and I knew someday I would have to get involved with racing. When that day came, I threw myself into the task of learning and inventing with more energy and determination than I ever had at any point in my life with anything. It was a passion combined with a purpose: *I would find the truth about chassis dynamics and race car setup.*

My work, and indeed my racing business, was born out of frustration and failure in trying to find really helpful information that I could use to set up a race car. So I set out on a journey that followed in no one's footsteps. Instead, I used one of my greatest personal assets, a profound and acutely developed ability to apply a commonsense approach to problem solving. That is exactly what you will find in this book, a commonsense approach to chassis setup, vehicle dynamics and race car design, together with solid engineering theory.

To a few in the industry, this is considered maybe the most controversial race car setup book ever written. To many more it has become their bible of racing knowledge. Much of the technology presented here has been more recently developed over the last fifteen years or so, and as such, it is often viewed with skepticism by established race engineers, authors and consultants, many who have come to believe that we had already pushed the envelope of vehicle dynamics about as far as it could go by the early 1990s. This book does not follow that line of thinking.

Regardless of what is on the pages, the proof is on the race track, and the methods in this book have been tested and proven to improve performance in race cars. They increase speed, improve basic stability and have already been used to win many races and championships in many classes of racing.

How, then, did this book come about? When I began my career working with race cars, I found plenty of information on chassis theory, but I couldn't find conclusive information that would tell me how to set up my race car in the shop, the right way, the first time. I had to read between the lines and keep trying different setups, working by trial and error. I personally don't like trial and error. I want to be able to know exactly how to set up my race car and know not only how something works, but why.

This book will help you avoid the trial-and-error approach to chassis setup. It will teach you sound, proven technology that is both easy to understand and easy to use, so you can set up your race car in the shop and see the positive results on the track immediately, with very little tweaking. What follows is a commonsense approach to chassis setup, vehicle dynamics and race car design, founded on solid engineering theory. However, you will need to have an open mind, and be willing to accept new ideas that may go against conventional chassis setup thinking.

Although many of the examples in this book center around stock or circle track race cars, the technology presented here applies to all race cars, from quarter midgets to Formula One and everything in between. This book is specifically written for stock car racing because it represents most of the world's automobile racing.

The theory of roll couple distribution was an early attempt to explain and quantify the dynamics of automobiles. It was a good start, but lacked a basic understanding of physics and made erroneous assumptions. In short, it was not complete. In this book, you will learn how subjects like roll couple distribution will no longer be used for chassis setup. I will explain a new method that more clearly and accurately defines what a race car wants and how to design it with that goal in mind.

## Weight Transfer and Other Myths

Load transfer and dynamic load distribution are a direct result of the design of the car and the setup that is in it. The lower the center of gravity, the less total load transfer takes place. But, do I really need to know how much transfer is going on in my car at my track? It won't really help me set up my car.

***Load Transfer Is Fixed***—The car will transfer X amount of load no matter what I do with the springs, and that's a hard-and-fast, proven dynamic—a fact of life. If you can't easily influence it, don't fret over it. We will learn the only way to accurately predict load transfer in a race car.

There are many examples of misconceptions in automotive dynamics that have been presented over the past fifty years and many more examples of correct thinking. What this book will do is separate the correct methods from the incorrect. It will provide you with a way to avoid the crutches that have been created over the course of time.

Success comes at all levels of endeavor, and we can't all be champions. But we can all get better at what we do. The goal of this book is to give good, solid information that has been tested and evaluated and found to be the truth. It is not, and will never be, complete as long as we continue to push the envelope in the search for better performance, but it will lay the foundation upon which future race engineers can build their programs.

# Chapter 1

## The Proper Approach to Chassis Setup

**The rules for making a stock car go fast even apply to road racing cars such as this Grand Am Pontiac GTO. Here the team prepares the setup in a controlled way to ensure a balanced setup.**

The approach to chassis setup and design is more mental than physical. You need to have a clear idea of what your goals are and how you intend to achieve those goals before you ever turn a wrench on your race car. Becoming educated and planning out your approach to design are the first things you need to do on the way to producing a winning race car.

The ultimate goal for all racers is to complete a lap in less time than their competitors consistently enough to win the race. It all comes down to that simple principle. But how do you do it? Exactly what are the steps to that end and where should you start? Here are some ideas that will help you answer those questions.

### Setting Goals

Basically, you want to achieve the maximum traction (or tractive capacity) possible with the equipment you have. Increased tractive capacity improves performance in the areas of braking, turn speed and allowing the increased use of available horsepower during exit acceleration.

The high performance we develop must last the entire race. Races are hard to win if the handling goes away before the end of the race. Most racers would rather be fast at the end than at any other point in the race. We can have a setup that is fast all of the time.

A good, fast setup is fairly easy to achieve if you know what the car needs, but oh so easy to lose if it is not maintained. Ask any racer, and he'll tell you that there were times, with certain cars, when they just flew. Nobody knew exactly how or why, but certain cars were fast. Then, the old car got crashed or new cars were built and in many cases, the performance just could not be duplicated. The components in the new car may be mounted in different places, the weight may not be arranged in the same way or the overall design might be much different. The point is, we can make any car work with the proper approach and knowledge.

In this book, we will learn how to make all cars fast by using a system of analysis that will allow us to change the geometry, springs, roll centers and weight distribution so that the chassis will work the way it desires.

### What Do We Really Want?

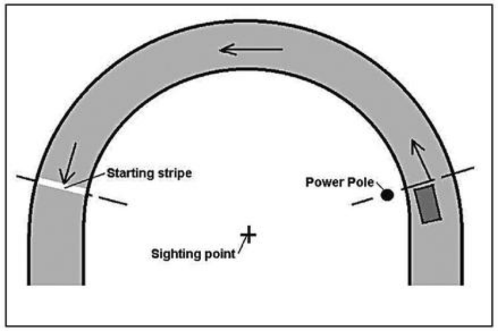
In the most basic terms: We want to make all four tires work to their highest capacity for a long period of time through the turns. Your overall goals should be:

- Balanced setup and consistent handling
- Maximized turn speeds
- Controlled entry combined with quick exit performance

***Corner Entry***—During braking and corner entry, we want all four tires to help to slow the car the best they possibly can and for the car to remain neutral in handling. The transition from acceleration to braking should be as smooth as possible.

***Midpoint Speed***—As we enter the midpoint of the turn, where the forward speed is the slowest, we want the car to be as fast as possible. Speed gained here will be carried throughout the lap.

Suppose my motor/gear combination will accelerate the car a total of sixty miles per hour from the time I pick up the throttle until I need to lift for the next turn. If I am able to start accelerating from a higher speed, then the average speed for the entire lap should increase by about the same amount. There is a combination of conditions that make this possible and all of them will be covered in later chapters.




**When taking turn segment times, position yourself near the radius of the turn if possible, and sight through poles or ends of walls and maintain the same position of those visual targets throughout the practice. Compare times with the other cars.**

**This motorsports reporter is trying to find out why this team's driver is the fastest in practice. He might say, "We have a really good motor in the car," or "The aero package is really good," but what is really working is the setup.**

**Tip:** To help set a baseline for how the car is performing in a turn, I recommend timing the car

**Even road racing cars such as this Grand Am Daytona Prototype car can benefit from a balanced setup. This car has been improved in its performance using the methods presented in this book.**

only in a predetermined section of the turn. You want to know how well the car is performing in the turns from the time the driver lets off the throttle until he straightens out the steering wheel.

I can't do much about the horsepower I have available at the track, except for the usual motor-tuning techniques. But we know that improving the mid-turn performance produces fast laps more easily. Straightaway gains in performance are raw horsepower/gear ratio influenced to a great extent and you can't buy enough legal horsepower to equal the gains found in improving your cornering performance.

***Exit Performance***—Exit speed and performance are very much dependent on being able to get on the gas early, and to convert the available horsepower into forward thrust. Gearing to the horsepower band, the handling balance while under power, control of wheel spin and the level of driver comfort all dictate how quickly a car can exit a turn.

***Working with All Areas of Performance***—All three of these turn segments—corner entry, midpoint speed, and exit performance—will be examined throughout the book, with initial emphasis on those areas of chassis setup that have the greatest effect on overall performance.

What we all need, in a nutshell, is a tool to tell us what the car wants and that we have selected the correct four springs to install in our race car in order to make all four tires work to their highest capacity. Bingo, the left-front spring should be an XXX, the right-front should be an XXX, etc. We want to know exactly what size sway bar we should use in combination with the springs and where we should locate the roll centers. We will be able to choose the right stagger that will be good for a certain race track and how much cross-weight the car will need. I want to know how to determine the correct caster/camber settings that will provide just the right tire temperatures for the best tire footprint.

I want to know how to read tire temperatures correctly and what to do if they are not right. I need to know what shocks do and what rate of shocks I will need at each corner of the car for best transition control to tune the entry and exit handling. I want good, solid advice on the best way to correct any handling problems I might encounter while racing my car. What we all want, in essence, is to know how to develop the total handling package (THP).

## The Total Package

What exactly is the total handling package? It is the perfect combination of settings and setup parameters that will lead to being the fastest car on the race track. Teaching you how to develop the THP is the ultimate goal of this book. In order to achieve that end, we may have to readjust our line of thinking. This means tossing out some old chassis setup conventions and embracing new ones. Much of the information that you have come across that has been presented in the past, in my opinion, does little to help the average racer understand how to set up his race car. Most published information deals with changes to pre-existing conditions and explains a lot of theory without making definitive statements on how to ultimately set up the car. "Detroit-generated" street car technology does not even begin to relate to race car setup as far as developing the THP.

***How Do We Achieve the THP?***—To achieve the THP, we must select the correct front roll center location 1) to give optimum dynamics and 2) to give us the best camber-change characteristics for the front wheels.

We will have to align the entire car so that the cambers are correct, the bump steer is near zero, the Ackermann steering effect is minimal, and the rear end is squared and aligned with the rear suspension being adjusted correctly for the desired roll steer.

We will have to develop a combination of spring rates, roll centers, and weight distribution so that when the car is in the turns, both ends of the car will be balanced in their desires and will want to work together to roll to the exact same angle.

We will have to select shock rates so that we have optimized entry and exit performance to suit the driver. We will have to ensure that the aerodynamic properties of the car complement the overall setup where neither end of the car is overly burdened with down-force. If all of these areas of chassis setup have been taken care of using the skills explained in this book, then you will have the THP you have been looking for. The rest is up to the driver and pit crew as to whether you will win a race.

**Inspection prior to the race should go smoothly. If the car was properly prepared before leaving the shop, there should be no problems.**

## New Methods for Achieving Balanced Handling

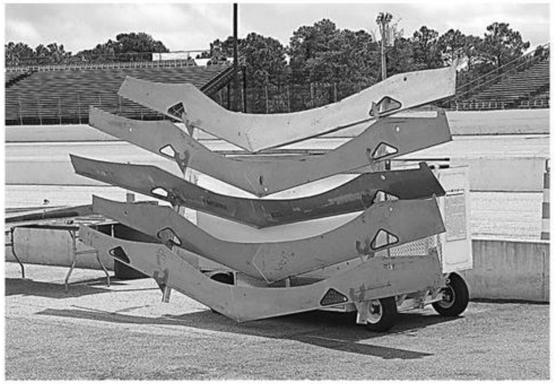
The secret to perfect handling is to develop a setup that will cause both ends of the car to want to do the same thing in the turns. That is exactly what the car wants. This is known as a dynamically balanced setup. But we need some information before we start to make that happen.

If a particular race car only likes one combination of wheel weights, roll center locations, springs and sway bar(s), then once we discover those correct elements, there should be no significant changes to make. If small changes are desired to suit driver preferences, the only way to further adjust the handling balance is to change the weight that is supported by each wheel. The way to accomplish this is to adjust the cross-weight percent. Traditionally, adjusting handling balance was achieved by experimentation—by changing one or more spring rates, raising or lowering the rear roll center and by changing the sway bar diameters.

In order to use the new technology I am proposing, you must believe that the traditional trial-and-error methods are only temporary solutions. Many of the adjustment techniques just mentioned have been used for years, but they may not be the best way to adjust the handling balance of the car. They can sometimes serve only as crutches while you properly address the chassis problems.

**Special attention should be paid to the heights of the body parts. Here a car is rolled under a device used to measure the roof height. Many touring series are very tight on the rules concerning roof and fender heights in order to maintain even competition.**

**Many racing series require the cars to fit stock dimensioned templates. Here is a stack of templates that represent all of the possible brands and styles of bodies that are legal in this series.**



You can make any car neutral in handling if you play around enough, but the setup we want in our race car is the one that will also make it faster and most of all, consistent.

If you are like most racers and believe that it is impossible to select the perfect combination of roll center locations, springs and sway bar diameter that will be just right for your car before you go to the track, then think again.

## Getting Started

There are many things we need to know before we begin working toward achieving the total handling package.

**This is an example of a dirt car that has been set up properly. The car looks very balanced and the angle of the front tires shows that the car is very neutral in handling. The driver doesn't need to throw the car sideways to get it to turn.**

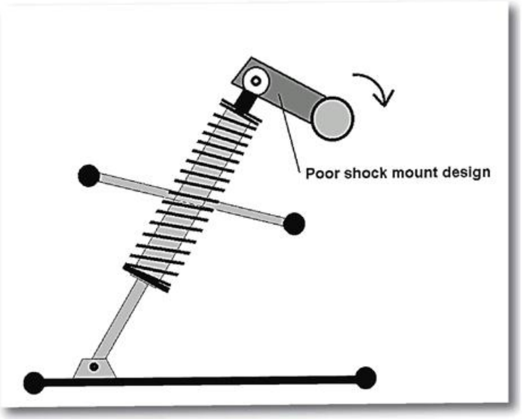
***Car Construction***—The first step is to make sure the car is built correctly. A lot of hands have probably been involved with the original fabrication, not to mention the rebuilding after the inevitable collisions. Even if the chassis builder is the best in the business, he cannot control who works on the car or what happens to the chassis after it leaves his shop. You need to really analyze how the car is put together. We'll tell you what to look for.

***Obvious Problem Areas***—Look for signs of cracks in the welded joints or control arms. Make sure there are no bent components and that all ball joints and pivot points are free of binding and well lubricated. Check for excess play in the steering system and trailing arm bushings. Get to know the overall condition of your race car.

***Understanding Dynamics***—The next step is to study and understand the basic dynamic forces and how they will influence the handling of the car as well as what the chassis basics are. We will help you understand what all of this means in practical terms, beginning with the next chapter.

# Chapter 2

## The Basics of a Working Chassis




**This is a poorly designed shock mount. High forces put on the shock mount will cause the mount to twist around the roll bar tubing and the weld and/or the mount will eventually break.**

The quest for dynamically balanced handling begins with the chassis construction. Of course, we all know that a chassis must be built rigid, with quality materials and strong welds, but what else do we look for? Here are some tips on creating a better chassis.

### Front Springs

All spring angles should be set to a minimum. For coilover designs, the top of the front springs must be angled in, toward the centerline of the car in order to clear the insides of the upper control arms. It is difficult to get these angles under about eighteen degrees. Mount the lower end of the shock/spring as close to the lower ball joint as practical.

### Front Shock Mounts

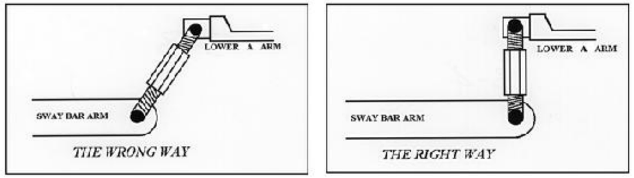
The upper end of the shock should not be mounted on any kind of perch or extension that extends to the side of the front loop bar. You might get away with it if the cross brace (between the right and left engine loop bars) is attached to the same structure to which the shock is attached. This bracing of the shock mount is necessary to minimize torsional twist in the loop bar. If this area flexes, and it will without proper bracing, the mount will eventually break.

### Rear Springs

The rear springs should be mounted as far out as possible from the centerline of the car without interfering with other components and both should be nearly equidistant from the centerline between the two tires. This provides a wider spring base that is better for resisting roll.

**This is the correct design for the shock mount. The bracket used to attach the shock must also be in line with the bracket used for the cross brace connected to the opposite shock mount. That way there is sufficient resistance to torsional loads applied to the chassis tubing.**

The benefit of the wider spring base will be discussed further in later chapters. Cars using the truck-arm type of suspension as well as other stock designs can suffer here because some rules state that the springs are to be mounted on the arms or in their stock original location. This results in a narrow spring base and therefore the rear has less resistance to roll effect.




**Shown here are the incorrect and correct angles for mounting the sway bar arm.**

## Rear Coil-Over Springs

For coil-over designs, the rear springs should be angled slightly with the tops positioned in toward the middle of the car at approximately a 5-degree angle and angled at no more than 10 degrees.

## Sway Bar Arm Design

Sway bar arms should be of equal lengths and the attachment between the sway bar arm and the lower control arm must be perpendicular to both the sway bar arm and the control arm. This is very important. If this attachment is mounted at an angle, there will be a binding problem that you will chase forever and never find. You need to understand this effect (see the illustrations above).

***How This Is Detrimental***—To quickly describe how this is detrimental, imagine trying to push a car forward using a bar that is attached at a 45-degree angle off the side of the car. As you push forward, you will have to resist the effect of the bar wanting to go to the side too.

***No Direct Force***—You will have to use a sideways force to resist the side motion as well as effort to push forward. This is a difficult thing for you to do and it is equally difficult for the sway bar to do. The end result is that the link will bind up and the actual "felt" rate of resistance for the sway bar will be very high. A one-inch diameter bar will resist roll like a one and one-half-inch bar in some cases. This will obviously throw a kink in your whole setup.

## Front Roll Moment Center Design

The front roll center design is the basic starting point for all setups. There are two roll centers, the *kinetic* roll center and the *dynamic* roll center. The roll center we are interested in is a geometric point, which is not necessarily the point about which a vehicle's sprung mass will roll, the kinetic roll center. Rather, it is a dynamic point that represents the bottom of the *moment arm* (MA). It controls the moment arm length and should be referred to instead as the *moment center* (MC). There are two such moment center points, one at the front and one at the rear of the vehicle.

The front moment center location is determined by the angles of the upper and lower control arms. The correct upper and lower A-arm angles are determined according to the intended use, and the desired location and migration of the geometric roll center. This sounds very complicated to the average racer, but we cannot ignore the importance of this part of the setup.

The moment center design, be it good or bad, can make all the difference in the world as to how your car performs, as we will see in the next chapter. Have you ever heard a driver say after a poor performance that his car was junk and he never wants to drive it again? If the truth were known, the front moment center was probably poorly located.

## Know Your Roll Center

Knowing your race car also means knowing where the front moment center is located on your car. I want to strongly stress this. Moment center location in the front end is very critical to the dynamics of the chassis. The reasons will be discussed in more detail in the next chapter, but it is important to know where it is located. There are computer programs available, such as the software manufactured by Chassis R&D, that will tell you where your moment center is. If you are racing as a hobby, say in the Late Model division, don't buy a complicated three-dimensional geometry program. You'll just get frustrated with all of the intense measurements that are required because most of these software programs are extremely complicated and produce much more accuracy than you will ever need. If you can find your moment center to about +1/2" in each direction, that will be good enough to know if you will have any real problem with the moment center. Again, we will discuss this in greater detail in the next chapter.

## Track the Location of Your Moment Center

Your team will need to closely track the location and migration of the moment center. Use a two-dimensional moment center computer program such as the one available from Chassis R&D (see ordering info at the back of this book) to analyze the roll center location and migration. The more advanced programs will also show the camber changes after dive and roll and allow the user to adjust arm angles and arm lengths as part of the redesign process.

Most of the racers who do not own roll center software will be forced to trust that the car builder knows what he is doing and has properly designed the car. From my experience, many car builders are not really sure where the moment center is located nor are they convinced that it is even that important. Remember that the technology that shows us why the moment center is important is relatively new. Many racers have not been exposed to this information.

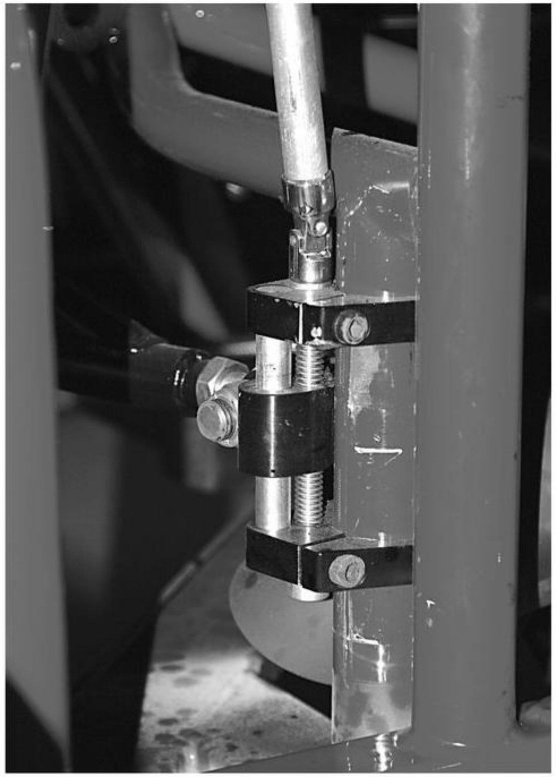
The other problem is one of changes to the original design. Anyone who has had their hands on the car could have made changes that made the car a different design. New spindles of different dimensions, new upper control arms of different length and a new clip are all examples of the ways that a car can be redesigned unintentionally.

Ask your chassis builder if he knows, and if he does not know or won't tell you, measure it for yourself or find someone who can measure it for you. A lot of chassis problems can be traced directly to improper moment center location. This is a very important part of having the correct total handling package.

## Freedom of Movement

There must be freedom of movement in all suspension components. Periodically check the pivot points to detect any difficulty in movement. If there is, you have friction shock at work that you don't need.

Bent-ball joint shafts and lower control arm mounting tabs are prime areas where a bump during a race can cause a bind in your suspension.



**This car has the panhard bar/track bar mounted to an adjustable chassis mount system. Note the screw and extension that makes small adjustments possible. Always mark a reference point for height.**

## The Panhard Bar

For cars that turn left and use a rear panhard, J or track bar as a lateral locating device, always mount the left end of the panhard bar to the rear end housing and the right end to the frame for an asphalt car and sometimes for a dirt car. There are other ways to mount a panhard bar, but I do not recommend other designs. They may work fine for some applications, but for consistency, I prefer to mount to the frame on the right side, even on dirt cars.

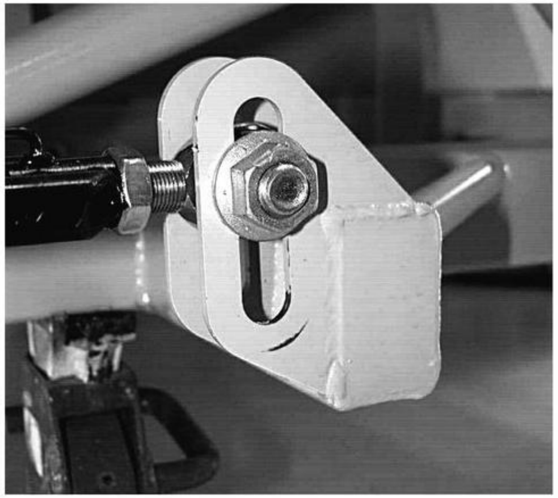
Mounting to the left side of the chassis on any car will make the car looser in the corners, which in the past has helped a car that would not turn well. Now that we know more about ways to properly design the front suspension, along with better ways to set up the car, we don't need this crutch.

## Track Bar Split

Always mount the left end of the panhard bar lower than the right end on an asphalt car. As a starting point, note the total amount of travel the frame mount end experiences in mid-turn. Divide the total travel by two and mount the frame mount one-half of the total higher than the other end of the bar.

On a dirt car, the trend has been to mount the left side much higher than the right side for added sidebite on dry slick tracks. This is okay as long as it is really needed. We have experimented with running a more level bar mounted to the right side of the chassis and had good results.

**The angle of the trailing arms is adjusted by moving the front mount up or down. The greatest effect caused by changing these angles is the creation of rear steer as the car rolls, dives and squats on exit off the corners.**



A long panhard bar is mechanically and dynamically better to use. There will be less effect of rear steer and roll resistance with a longer bar. Short bars seem to work with soft rear springs, but this is only an artificial fix to a problem the soft springs cause. There are other ways to make soft rear springs work.

## Short Rear Trailing Arms

In the case of a car built with short trailing arms (a three-link system), the right trailing arm should be mounted with the leading edge higher than the rear mount. The amount is dictated by the amount of rear steer you desire and the distance the front mount will travel at the point of mid-turn. To calculate, start by dividing the total distance the front end of the arm will travel by three, and raise the front mount by that distance above the rear mount. That should be the maximum height for the front of the trailing arm. This will produce a slight amount of net rear steer to the left.

For the left-side trailing arm, the front mount can be located level, or above the rear mount. The amount of angle will determine how much rear steer the car has related to the car squatting while accelerating off the corners. As the rear end squats when load transfers to the rear, the left-rear tire will be forced back causing the rear end to steer slightly to the left. The greater the angle of the trailing arm, the more the rear will steer to the left, which will increase forward bite if that is the goal.

## Angle Affects Rear Steer

The angling of the trailing arms in this manner serves to enhance or reduce the effects of rear steer in the turns and may improve the effects of dynamic thrust upon acceleration. What we need to be aware of is that too much rear steer can make the car too tight.

## Truck-Arm-Type Rear Trailing Arms

Many stock cars are built with rear truck arm systems, including all of the Cup cars (by rule) as well as the Busch-type cars, Craftsman Trucks and even certain short-track Late Model cars. Some teams think it is an advantage to run this type of system. Let's analyze how truck-arm systems work.

***Truck-Arm Rear Steer***—The truck-arm rear trailing arm system produces very little rear steer during cornering and only to the left, never to the right. The forward thrust upon acceleration is concentrated at the center of the frame about midway between the axles. There is some anti-squat inherent in this system, but it is not adjustable. The rear unsprung weight is also higher with this system.

The above characteristics can be viewed as overall positive or negative aspects of this system. There are two subtle differences that truly separate the truck-arm system from all others.

***Less Roll Resistance***—First, if the springs are mounted on top of the truck arms—as in the case with Cup-type cars with big springs—the spring base (i.e. the distance between the centerline of the springs) will be much narrower than the other systems where the springs can be mounted further out near the wheels. The narrower the spring base a system has, the greater the tendency for that end of the car to roll over for a given set of spring rates. This leads to an unbalanced setup.

Example: A coil-over system with the springs mounted out near the wheels will only need a pair of 175-lb springs to achieve the same roll angle as a truck-arm spring-mounted system with 250-lb springs. The system with the springs mounted on the truck arms must always be sprung heavier to resist roll and to be equal to a system whose springs are mounted further out from the centerline of the car.

***Torsion Bar Effect***—Second, the truck arms act somewhat like a torsional sway bar. This means that the arms themselves resist roll to some extent, just as if you had a rear sway bar mounted in the car. The wider the front mounting points of the truck arms, the more this sway bar effect must be taken into account when designing the spring layout and panhard bar height.

Because it would be difficult to predict the true amount of anti-roll rate, the front mounts of the truck arms should be as close together as possible, to minimize this effect.

## Rear Leaf Springs

Another rear suspension system that warrants close analysis is the leaf spring system. The following characteristics are inherent in the design and construction of leaf spring suspensions:

1. The spring base is very wide in this system; the moment center, being the average height of the two ends of the spring, at the point of attachment to the chassis, is very high; the rear moment center is not easily adjusted.

2. There is inherent friction between the leafs in multi-leaf springs; there can be a considerable amount of rear steer depending on the height at which the front of the springs are mounted.
3. The most significant negative characteristics of this system are the extreme effect of anti-roll caused by the springs being solidly mounted to the rigid rear end housing, and the changing rate of the springs as the car rolls through the turns.

***Roll Resistance***—If the two ends of the leaf spring differ in distances from the axle (as in a production car), then as the car rolls, the two leaf springs will assume different vertical angles at the axle. The rear end cannot twist, so there is a considerable resistance to roll created by the uneven leaf springs.

The amount of roll resistance created from axle twist increases as the spring rates increase. As is the case of roll resistance in the truck-arm system, the exact amount of resistance created by leaf springs is very difficult to predict.

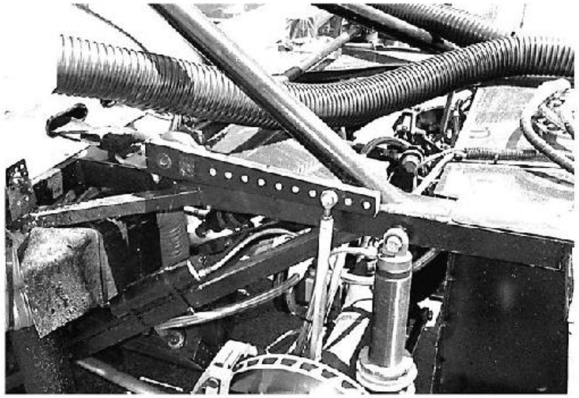
The only way to eliminate this resistance-to-roll effect would be to join the leaf spring to the rear end with a bird cage pivotal mount and add a third link or lift arm, much the same as a coil-over design system. This may not be permitted within the rules of your sanctioning body.

The other negative effect is that leaf springs have a tendency to change the effective spring rate as the car rolls. As the shackles move, they assume different angles to the chassis and spring. If the shackle is not at right angles to the chassis and spring, then a binding effect is created which causes a stiffer suspension.

The amount varies depending on what angle the shackles are mounted. This condition alone would make them very unpredictable for design of the overall spring rates.

Resistance to roll in the rear suspension system is created by:

- spring rates/splits
- rear sway bars



**The use of a rear sway bar is an advantage in this GT road-racing car. These cars have a very low rear roll center and need all of the roll resistance they can get. They are usually sprung very highly and roll to a minimum degree.**

- truck arm/leaf spring bind
- rear moment center height

***Negative Effects***—With the exception of the springs and rear moment center height, the other two in the list above are negative effects. The reason they are negative is because in order for a sway bar or truck arm/leaf spring to resist roll, they must all, to a certain extent, try to lift the left-rear tire and use the resistance of the weight of the rear end and wheel assembly to keep from doing that.

The springs cannot act independently and the suspension will be bound up. The car will not handle the normal bumps that are found in most race tracks when the suspension system is effectively locked up.

If a car works better with a rear sway bar installed (it is more neutral in handling), then something else is probably wrong and should be fixed instead. Torsional resistance to roll in the rear suspension is only an artificial fix for a car that is otherwise not designed correctly.

The problem may be that the combined overall setup is not correct and the two ends of the car want to do different things. In that case, the moment center locations, spring rates or other settings are definitely wrong and need to be changed.

## Avoid Rear Sway Bars

I personally do not recommend the use of rear sway bars in most stock cars. The effect of roll resistance in a truck-arm system can be made minimal so that this system can become one of the preferred rear suspension systems.

**This team has placed the battery in the middle of the car for proper weight distribution. It is advantageous on asphalt tracks to put as much weight to the**

**middle of the car as possible and still maintain as much left side weight as is legal. On dirt tracks, it is sometimes better to shift weight to the right side for better traction on slick surfaces.**

## Moving Weight Around

Any moveable weight should be placed low, left and between the axles for asphalt stock cars. For dirt cars, weight can be moved left or right in order to change the side-to-side percent distribution or up and down to raise or lower the center of gravity to compensate for slick conditions. Never mount moveable weight behind the rear axle.

## Cantilever Effect

Never, ever, put weight ballast either behind the rear axle or in front of the front axle. This will create a very negative cantilever effect that would wreck your setup and possibly the car as well. As much as you think it might work, it won't.

## Dirt Weight Placement

On dirt, it is sometimes an advantage to move weight to the right side and higher up for dry slick conditions. This is explained in Chapter 15.

## Front-End Geometry Settings

Bump steer, steer-steer and camber change characteristics should be taken care of when the car is built. The bump steer should be measured and zeroed with the control arms moving in the range and direction as they would move on the race track.

Unequal steering angles between the two front spindles is called Ackermann or reverse Ackermann and is explained in Chapter 6.

## Bump Steer Considerations

I know, everybody checks bump steer with the car at normal static ride heights and the wheel pointed straight ahead, but does that make sense? Where do we want zero bump steer—down the straightaway or in the turns where we are on the ragged edge? We really do not want the car to steer as it encounters bumps in the turns. If the car steers here, it should be the driver who is doing the steering.

***Bump Steer Affected by Geometric Changes—*** The whole geometric layout changes when the car dives and rolls and is steered. The bump steer characteristics can be very different in the mid-turn attitude from what we may see at ride height.

If you don't have a three-dimensional geometry program and someone who knows how to use it, then set the car on the floor at the turn attitude with the steering wheel turned to simulate the car at mid-turn. Once all of the turn attitude settings have been duplicated, then check the amount of bump steer in each front wheel. This is where you need the least bump steer. See pages 60-62 for more information on bump steer.

***Toe Settings—***Your toe settings don't mean much either if the car loses or gains toe-out when the wheels are turned. *Ackermann* is an effect that causes a change in toe that increases toe out. *Reverse Ackermann* causes a reduction in toe-out. If the car gains or loses toe as it is steered, the steering system will need to be adjusted. It's okay to have different length steering arms when only steering to the left, but it doesn't take much difference in length to produce a big effect. For cars that steer both ways, other design changes must be made to reduce Ackermann.

If you have two holes in your steering arm, DO NOT use a different hole for the tie rod mount on each steering arm. That is not what these holes are for. They are intended to quicken or slow the steering, and approximately the same length holes are to be used on each side. The great difference in distance between the holes (one inch or more) would produce far too much steer-steer (Ackermann or reverse-Ackermann) effect.

Most cars today have one or more steering arms on the spindles with slotted holes for Ackermann adjustments. On asphalt cars the arms can be different lengths. On dirt, we need the Ackermann to be consistent with right and left turns of the wheels.

**This spindle has a slot for adjusting the length of the steering arm on the left side. This allows us to adjust the amount of Ackermann we have in our steering system.**

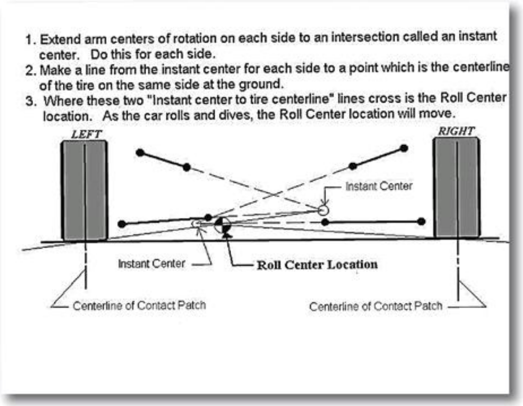
## Adjustable Length Spindles

If the system gains or loses toe when it is steered, the best way to adjust it is to buy spindles that have steering arms with slots or with the interchangeable offset inserts. These adjusting slots are located where the ends of the tie rods attach to the steering arms.

These inserts have the holes that are drilled at different offsets so that the distance between the outer end of the tie rod and the lower ball joint can be adjusted. Several racing parts distributors sell these items.

# Chapter 3

## The Importance of Front Moment Center




**The front moment center location is the intersection of the lines joining the instant centers with the tire contact patch center on the same side as the arms. These intersect to form the instant center. When the arm angles change as the car dives and rolls, the location of the instant centers changes, and so the moment center location will change.**

The growth of information about the front moment center (sometimes referred to as the MC) during the last ten years has helped us to understand the way in which this invisible point controls the front dynamics of our race car. I first published information about the moment center in the May, 1998 issue of *Circle Track*. At that time, much of the industry did not understand exactly how the moment center worked and many thought that it was just not important.

Since then, we have defined exactly what the moment center does and where it should be located based on research and input from racers across the globe. We have also discovered there are several roll centers in our race cars, including the kinematic roll center, which is based on the motion of the chassis, and the dynamic roll center, which is the bottom of the moment arm in every double A-arm suspension. Because the moment center is seldom the point upon which the chassis rolls, we should stop referring to it that way.

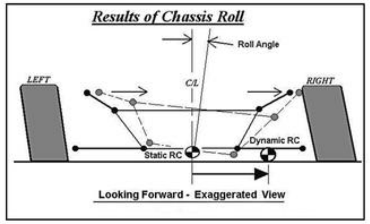
***Myths about Moment Centers***—Here are some popular myths concerning the moment centers that have now been disproved:

1. *The front moment center is at the center of the car.*
**Wrong**. The front moment center is rarely at the centerline of the race car. It also moves laterally as the car dives and rolls, some designs moving to the left and some to the right.

2. *The front moment center location is not important to the dynamics of the chassis.*
**Wrong**. The front moment center location is critical to the dynamics as we will show. Because it is the bottom of the moment arm, its location dictates the length of the moment arm and therefore the amount of force that will initiate roll in the chassis.

3. *When we change front control arm angles, we are really affecting the camber change characteristics and/or the jacking forces on the instant centers and the changes to the handling of the car are related to that, not the new moment center location.*
**Wrong**. We can move the moment center while affecting the camber change characteristics and the jacking very little and see a drastic change in the handling. This serves to disprove those notions.

4. *I can draw out my moment center on the garage floor or on paper to find its location.*
**Wrong**. The reason the static location, the one you draw out, is not really important is because the moment center moves as the chassis dives and rolls going into and through the turns. Where it ends up is the most important aspect of moment center design because it affects the turn dynamics where we desire our performance. It is very difficult to draw this dynamic location without a seriously complicated drafting software program.




**In this example, as the chassis rolls, the left instant center will move to the right and the right instant center will move to the right also. If both instant centers move to the right, then the moment center will also move to the right. In most cases, this is what happens when the chassis dives and rolls in a left hand turn.**

## Defining the Front Moment Center

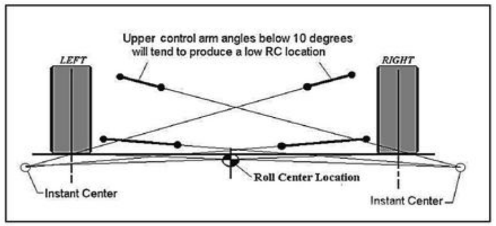
As mentioned in the last chapter, the moment center is a geometric point which is not the point on which a vehicle's sprung mass will roll, but a dynamic point that controls the moment arm length. The front moment center point in a double A-arm suspension is a very misunderstood part of the race car. Many still think that this geometric point does nothing and therefore is not important. That could not be further from the truth. A lot of research has been done over the last 15 years that has proven that the moment center is the most important aspect related to the dynamics of the front suspension on your stock car.

Where the front moment center is located will determine how well the front suspension will function and ultimately how your car will handle and how fast you will be able to go through the turns. Many times it is the front moment center location that dictates whether a car has the potential to win or instead be one that always finishes at the rear.

This chapter will explain how to find out where the front moment center is located, and how changes can be made to the chassis to relocate the front moment center. You will learn how the front moment center affects how the front end will want to work and offer some suggestions on the proper front moment center location for different types of stock cars for different race tracks.

## Locating the Front Moment Center

First, let's examine how you locate the front moment center. The front moment center is a geometric point that you cannot see. Its location is determined by the angles of the upper and lower control arms. The dynamic location (where it winds up after dive and roll) is determined by the way the angles are arranged in combination and by how they move after the car dives and rolls through the corner.



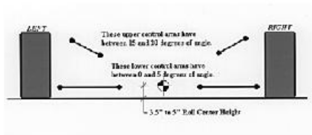

**Flat upper control arm angles will tend to produce a low moment center location because the instant centers are located outside the opposite tire and below the ground. The intersection that produces the moment center location will be below ground zero.**

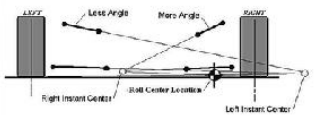
We are most interested in where the moment center ends up after the car enters the turn and is in a steady state, mid-turn configuration. It is here where the moment center does its work. The dynamics of the front suspension are influenced in a large part by the moment center location. If this design is wrong for your application, then nothing can be done to compensate for it. No spring change, load distribution change or other setup change can overcome a poorly designed MC.

***Instant Centers***—The lines formed by extending straight lines through the centers of rotation of the pivot points in the upper and lower control arms, at each side of the chassis, cross to create intersection points called instant centers. There is one instant center for each side of the suspension. A line is projected from the instant center of the right side of the suspension to the point where the right-side tire centerline meets the ground. The same is done for the left side of the suspension. The point where these two instant centerlines cross is the *front moment center location.*

***The Roll Center Moves After Chassis Dive and Roll***—If the chassis rolls and dives, then the control-arm angles will obviously change. Because the instant centers and the front moment center are located using the control arm angles, the moment center must move as the chassis dives and rolls and the arm angles change.

The angles of the upper control arms will largely determine the height and width of the moment center. More level upper control arm angles will tend to produce a lower moment center location.




**When the right upper control arm has more angle than the left upper control arm, the moment center is usually located more to the right of**

It is generally considered a good design when the movement of the moment center from static to dynamic location is less. We don't want the moment center to be moving 10, 20 or 30 inches. This is because such a radical movement changes the dynamics of the front end so much that the car will feel very differently from entry to the middle of the turns. One of the primary design goals is to create a consistent dynamic and therefore a more predictable handling characteristic.

## Upper Arm Angles

Upper arms with more angle to them will tend to produce a higher moment center.

More upper control arm angle produces a higher moment center as long as the lower control arm angles are not angled down too much from the lower ball joints to the inner mounts. Excess angle in the lower control arms produces a greater amount of movement of the moment center as the car dives and rolls in the turns.

The upper control arm angles, especially the right upper, controls camber change too and we need to think about how the angle affects camber change as we design our moment center location and migration. A low upper control arm angle results in a high amount of camber change for most race cars that roll and dive. The less roll a car has, the less camber change that is associated with shallow upper arm angles.

***Difference in Arm Angles***—When the upper arm angle on one side of the chassis is more than the opposite side upper control arm angle, the moment center location is usually toward the side with the most angle. That is not always true because the moment center location is determined by the combination of the upper and lower arm angles, but in most cases it is true.

We usually determine a proper right upper arm angle for camber change efficiency and then locate the moment center laterally with the left upper arm angle. The left side of the suspension tends to lose a lot of camber and that cannot be improved. So, the left upper arm angle is less critical and that is why we use that arm angle to locate the MC.

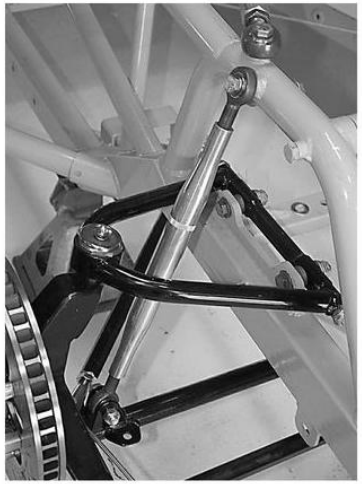
***Upper Arm Angles Control Moment Center Lateral Location***—A change in one upper control arm angle will move the moment center. If you increase the right upper control arm angle, the moment center will usually move to the right. If you decrease the left upper control arm angle, the moment center will also move to the right. If you look at the diagram on the right above, you can see that both of those changes moved the corresponding instant center to the right, and so you also moved the moment center to the right in the same direction that the instant center moved.

The lines that intersect to produce the instant centers are extensions of the lines that cross through the centers of rotation of the ball joint and the inner chassis mount for both the upper and lower control arms. These points must be located and measured accurately so that the true moment center location can be determined.

***Don't Measure the Control Arm Angles***—You never want to trust the angles of the structure of the control arms. The tubing, etc., may not be in line with the line between the two centers of rotation. Some teams try to save time by measuring the tubing thinking that they represent the arm angle. They do not. The arm angle is not really the structural arm angle, but really the angle formed by the two instant centers of the ball joint and inner mounts.

## Using a Computer Program to Locate Moment Center

When you measure the points to determine the moment center location, you will want to enter the measurements into a moment center software program. The easiest software programs to use are the 2-D programs. The 3-D programs will need a third measurement for each point in a fore/aft direction. These 3-D programs are very accurate, but at the same time, very difficult for the average racer to use.



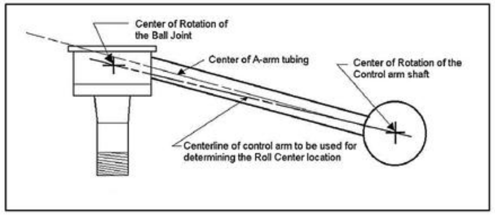
**When measuring the front ball joints for moment center location, always install a solid link in place of the shock so that you can remove the wheel and tire. That makes taking the measurements easier. The car is supported on blocks or jack stands and the wheels are removed. The link is adjusted to be the exact same length as the shock was at ride height with all weight in the car, including driver, fuel, engine fluids, etc. Then the spindle is at the same relative height and the arm angles are the same as when the car was on the ground.**

Satisfactory results can be obtained using the 2-D program, such as the one used in this book (see page 152 for ordering information). The moment center location will be accurate enough in 2-D analysis considering the limited amount of wheel travel you will encounter. The program also allows you to enter new arm angles and arm lengths to help with the redesign of the chassis if that is necessary.

***Evaluate Dive and Roll***—The program you use should allow you to enter dive and roll so you can simulate the attitude of the car in the turns. Because the moment center moves after dive and roll, you must be able to determine where it moves to in your car.

The reason why we cannot draw the moment center location is because we need the location of the moment center as the car goes through the turns. It would be very difficult to recreate the dynamic location in a drawing. And, there is no provision for redesign when drawing the layout.

***Tips for Measurements***—If you use a two-dimensional program, here are some tips on how to measure your points. If your car has anti-dive or pro-dive (i.e. the front of the upper control arm shaft is higher or lower than the rear of the shaft) then use a number for height that is the average of the heights of the two mounting bolts. On a strut type car, for the upper and lower control arm measurements, use the link that is mounted at right angles to the centerline of the car.



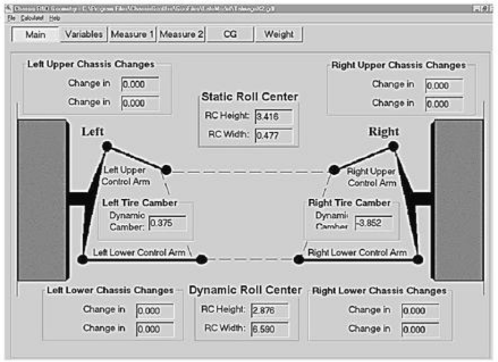

**The centerline of the control arm, for the purpose of determining the moment center location is a line between the centers of rotation of the ball joint and the control arm shaft at the chassis mount. This line may not be parallel to the centerline of the tubing that connects the ball joint and the control arm shaft. Measuring the angle of the control arm by placing an angle finder on the control arm tubing will not find the angle we are looking for to determine the front moment center.**

**A stock upper ball joint has a center of rotation that is usually not in line with the tubing that connects it to the chassis. Never measure to the grease fitting to locate the center of the ball joint when measuring the width of the point of rotation from the centerline of the car. The ball joint housing is almost always tilted in two directions, from camber and from anti-dive or pro-dive.**

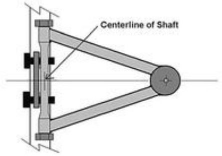
**Installing mono-ball-type ball joints will provide you with the opportunity to change the heights of the ball joints in order to change the moment center location. This team drilled and threaded the spindle and used a large machine head bolt the same size as the mono-ball hole. This design is strong and effective and allows more range of adjustment.**

For stock-type (GM, etc.) lower control arms that are mounted at roughly a 25-degree angle to the centerline of the car, measure to the front chassis pivot only. In the range of motion you are working in for a stock car, using just this point will produce a roll center location accurate enough for your purpose.

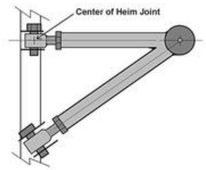
***Locate Centers of Rotation***—Be very sure to accurately measure the center of rotation of each ball joint. If you need to, place a ball joint in a vise and rotate the shaft from one side to the other and note where the two alignments cross on the side of the ball joint housing. Measure to this point and use that measurement to locate the center of rotation of each similar ball joint in the car.



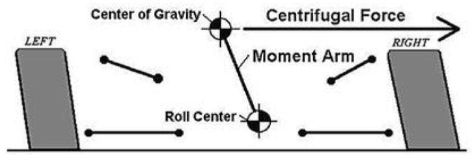

**A good 2-D geometry program, such as this one from Chassis R&D, will show the moment center location in both the static and dynamic locations. It will also show the wheel cambers after the amounts of dive and roll are entered. This is important information to know.**



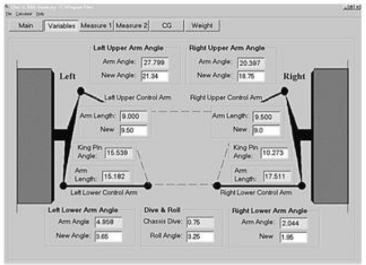

**When measuring the upper chassis mount for a symmetrical upper control arm, measure height and width to the center of the shaft.**



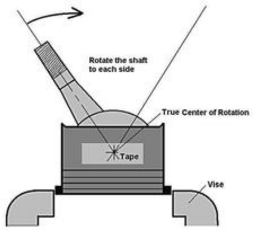

**The measurement for height and width for the strut type of control arm, when used for the upper or lower control arm, should be measured at the center of the forward Heim joint as shown.**



**The centrifugal force is not the only force acting on the car. There is always the force of gravity at work and these two combine into a resultant force, as seen in the illustrations on page 17.**

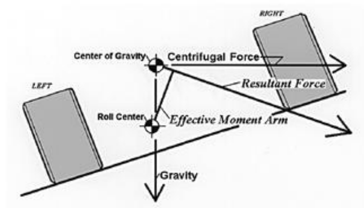


**Chassis R&D's software program also shows you the existing arm angles and arm lengths. It gives you the capability of allowing the user to change the arm angles and/or arm lengths in order to change the roll center location and camber change characteristics. This makes redesign very fast and easy.**

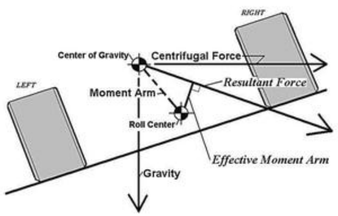



**To find the true centerline of rotation of a ball joint, place the balljoint in a vise with the shaft pointing up. Then rotate the shaft all of the way to the left and mark the centerline on the housing over a piece of masking tape. Then rotate the shaft all the way over to the other side of the housing and mark the centerline again. The intersection is the true center of rotation.**

Never use the grease fitting or guess at the center of rotation. The measurements are critical to getting the right information on your moment center location. All measurements should be +/- 1/16". Remeasure to make sure of not only the small increments of the measurement, but also the whole inch number. You can concentrate too much on the 16ths and miss the inch mark.




**The Effective Moment Arm is the right angle distance between the Moment Center and the Resultant Force vector.**



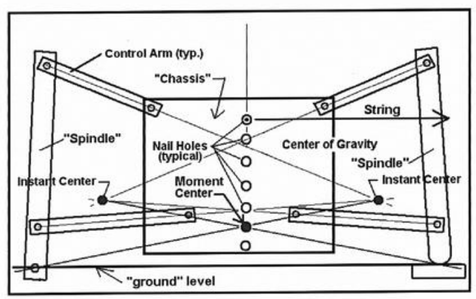

**In these two illustrations above, you can see that as the moment center moves to the right, the Effective Moment Arm becomes much shorter.**

## How the Moment Center Affects Chassis Setup

Now that you have a basic understanding of what the front moment center is, you need to know something about what it does. Many racers have experienced a change in handling when they make changes to the control arm lengths and/or angles. These handling changes have, in the past, been mistakenly connected to changes to the camber change characteristics.

While the handling is affected by changes in camber design, you can design two cars with very similar camber change designs and radically different moment center locations and feel a distinct difference in handling. That is directly attributed to the effect of moment center location.

As mentioned in the beginning of this chapter, the moment center is an invisible point formed by the control arms and the angles at which they are mounted. This point acts just like a rod end with a bolt through it as if it were attached to the chassis. What the front moment center is, in reality, is the bottom of the moment arm for the front end of the car.



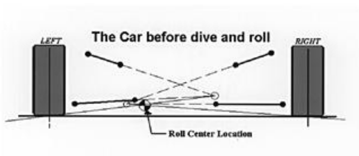
**A model was constructed and control arms were mounted on spindles and a chassis. This was a 2-D representation of a stock car front suspension. The result was a better understanding of how the imaginary moment center related to the dynamics of the front of our cars.**

***Defining Moment Arm***—The moment arm in your car is just like a jack handle or shovel handle. The top of the jack handle is the center of gravity (CG) and the bottom of the jack handle is the moment center. The longer or shorter the bar is, the more or less efficient the moment arm is, too. The g-force created when you drive through the turns pulls on the top of the moment arm at the center of gravity. The pulling effect is resisted by the moment center at the bottom of the moment arm and the suspension's roll resistance.

***A Simple Experiment***—It is very difficult for us to understand the importance of an invisible point and how it could possibly be important to the dynamics of the front suspension. We generally think in terms of hard points that we can put a bolt through and that are attached to the chassis. The moment center is not directly connected to the chassis and has no bolt through it. So, some years ago while I was trying to understand how the moment center really worked, I decided to build a model to find out exactly what influence the moment center had on a double A-arm suspension.

I built a 2-D model of a double A-arm suspension on a board, with spindles, upper and lower control arms and the chassis portion was weighted and supported by springs. I drilled a series of holes vertically along the centerline of the chassis between the control arm mounts to simulate several locations of the CG of the car. I also had the ability to change the arm angles so that I could create different locations for the moment center.

**The moment center at static location.**




I began at the top CG hole and attached a string and pulled laterally to the right on the string. The chassis would roll to the right each time as I moved down from hole to hole. When I reached the hole that represented the moment center, my suspension would lock up and would not roll. As I proceeded down below the moment center, the "chassis" would then roll to the left because the moment arm was now inverted.

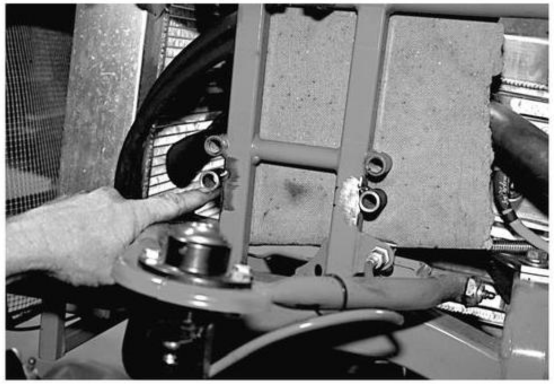
I changed the moment center location several times and each time when I put the CG nail in the hole that represented the moment center, the suspension locked up. That told me that the moment center was indeed the bottom of the moment arm and when the moment center is in the same location as the CG, there is no moment arm and therefore no lever arm to roll the chassis.

## Two Forces Acting on the Chassis

The actual force that pulls at the center of gravity is in reality a combination of two forces. The first is gravity, which is always present, and the other is the g-force that is correctly called the centrifugal force caused by the car wanting to go straight as you drive through the turns. When these two forces combine, like two people pulling on ropes at different angles, there is what is called a *resultant force*.

The direction and magnitude of the resultant force is determined by the amount of gravitational force (what the sprung portion of the car weighs) and the amount of centrifugal force, or what we call *g-force*. G-force is the lateral force divided by the sprung mass weight. If twice the sprung weight were the lateral force, then the g-force would be 2.0.

We also have a true moment arm, or the direct distance between the CG and the moment center and we have the effective moment arm, or the resulting arm that is a corrected length due to the angle of the true moment arm to the resultant force.



**Don't be afraid to alter your chassis attachment points to improve your moment center design. On a dirt late model, the fix is easy. Just determine where your upper control arms need to be mounted and then weld on new bungs to the uprights. You can add several different locations for different tracks you may run from low, flat and dry tracks to high-banked and fast ones.**

As you can see in the diagram on the left side of page 17, what the car feels for a true moment arm is the length of the *effective moment arm* that is at right angles to the resultant force. If the moment center is located more to the right, then the effective moment arm will be shorter.

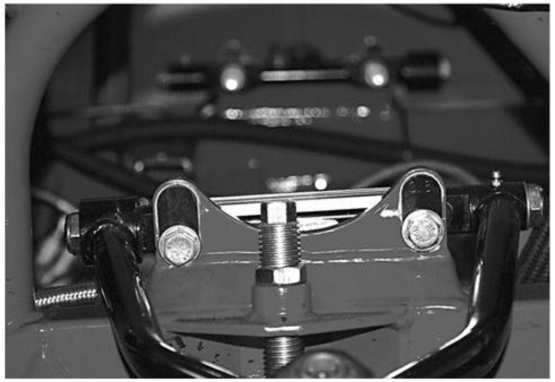
## Moment Arm Changes Length as Moment Center Moves

As you redesign and move the moment center location to the left, the effective moment arm becomes longer and more efficient, causing the front end to want to roll to a greater angle. Just like the jack handle, the longer you make the bar, the more efficiently you can move things. This makes the suspension softer, like installing softer spring rates. Conversely, moving the moment center to the right stiffens the front suspension just like installing higher spring rates.

This is an accurate and true description of how the moment center location affects what the front end of your race car wants to do. In the next chapter on race car dynamics, you will learn how the car is affected by how much the front and rear want to roll individually. But simply put, if the length of the moment arm determines how much the front end will want to roll, then if the moment center was too far right or left of the centerline of the car, you will have a difficult time finding a balance in your setup.

## The Wrong Front Moment Center Location

The most common situation is when the front moment center is too far right of the centerline of the car. This creates a very short moment arm, a very stiff dynamic and the front end will not want to roll very much. The result is just like running very stiff front springs. The front end will not want to roll and a lot of excess weight will be transferred to the right-front tire in the turns. In extreme cases, the car will actually lift the left-front tire off the racing surface.



**This car has slotted upper control arm plates that have offset slugs installed. This makes changing the upper control arm angles very easy to do by installing slugs with different offset holes. The range of offset is usually 3/8“ either way in increments of 1/16” from the center of the slot.**

Many times, a pushy car is the result of a poorly positioned front moment center. The front moment center location moves as the car dives and rolls in the turns. It is the excess movement of some designs that causes the moment center to move too far to the right and produce a very still suspension. This is never a good situation for any race car.

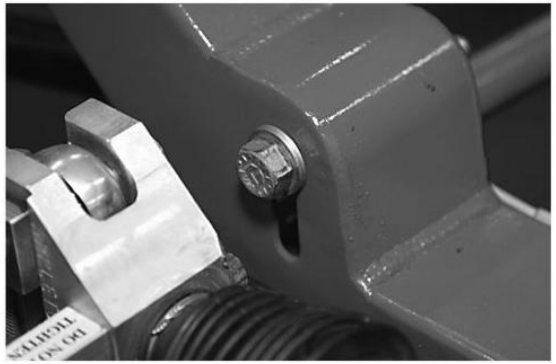
## Moment Center Movement

The moment center movement affects the car by how far it moves from static to dynamic location, and where the dynamic moment center is located in relation to the centerline of the car.

The moment center starts at the static location, which is where it is located with the car at ride height, and moves to the dynamic location as the car rolls through the turns. As a general rule, the shorter the movement of the moment center from static to dynamic locations, the better the design. A race car will be more consistent and the handling through the transitions will be more predictable when the movement is reduced.

## Dirt Car Moment Center Location

Generally speaking, a moment center located in a range just to the left of the centerline is much more efficient and works well for most dirt applications where the g-forces are relatively low and you need all of the help you can get to cause the front end to want to roll.



**Most newer cars have slotted lower arm mounts so that the lower arm angle can be adjusted to accommodate the conventional setups as well as the soft spring setups. This makes knowing the moment center location even more important as we now have another variable to deal with.**

This efficiency causes less load transfer and a result is that the left-front tire will retain more loading, maintain more grip and help turn the car better on entry and through the middle of the turns. This always improves turn speed and overall performance.

## Asphalt Car Moment Center Location

The best design for asphalt race cars running a more conventional setup is a little different. Because of the higher g-forces these cars experience, the moment center must be located in a range to the right of the centerline of the car, but not too far right.

For the softer setups we have seen in the recent past, the desire is for the front of the car to be as low as possible in the turns and a softer suspension is desirable. So, a location to the left of centerline is considered appropriate for those softer setups.

In each application, dirt or asphalt, what determines the exact point where the moment center should be located dynamically depends on the center of gravity height of the car, the track banking angle and the lateral force the car will experience related to turn speeds and track grip.

## The Best Moment Center Location

We now know that the front moment center location is critical for all stock cars and the correct location is different for the various kinds of racing. Through research and development, certain truths have become evident and can now be counted upon.

***Dynamic Moment Center Locations For Asphalt Cars***

| | Track Banking Angle | | | | | |
|---|---|---|---|---|---|---|
| *Type of Car* | 0 - 4 | 4 - 6 | 6 - 8 | 8 - 12 | 12 - 16 | 16 + |
| Street Stock | 4-6 | 6-8 | 8-10 | 10-12 | 12-14 | 14-18 |
| Limited Late Model | 2-4 | 4-6 | 6-8 | 8-10 | 10-12 | 12-14 |
| Hooters Pro Cup | 0-2 | 2-4 | 4-6 | 6-8 | 8-10 | 10-12 |
| Nascar LM | (-)2-0 | 0-2 | 2-4 | 4-6 | 6-8 | 8-10 |
| Super LM | (-)4-(-)2 | (-)2-0 | 0-2 | 2-4 | 4-6 | 6-8 |
| Outlaw LM | (-)6-(-)4 | (-)4-(-)2 | (-)2-0 | 0-2 | 2-4 | 4-6 |
| IMCA type Mod | (-)4-(-)2 | (-)2-0 | 0-2 | 2-4 | 4-6 | 6-8 |
| Touring Mod | (-)6-(-)4 | (-)4-(-)2 | (-)2-0 | 0-2 | 2-4 | 4-6 |

***Dynamic Moment Center Locations For Dirt Cars***

| | Track Banking Angle | | | | | |
|---|---|---|---|---|---|---|
| *Track Conditions* | 0 - 4 | 4 - 6 | 6 - 8 | 8 - 12 | 12 - 16 | 16 + |
| Muddy Wet | 4-6 | 6-8 | 8-10 | 10-12 | 12-14 | 14-18 |
| Packed Mud Wet | 2-4 | 4-6 | 6-8 | 8-10 | 10-12 | 12-14 |
| Packed Semi-wet | 0-2 | 2-4 | 4-6 | 6-8 | 8-10 | 10-12 |
| Black Tacky | (-)2-0 | 0-2 | 2-4 | 4-6 | 6-8 | 8-10 |
| Black Slick | (-)4-(-)2 | (-)2-0 | 0-2 | 2-4 | 4-6 | 6-8 |
| Semi-dry Slick | (-)6-(-)4 | (-)4-(-)2 | (-)2-0 | 0-2 | 2-4 | 4-6 |
| Dry Slick | (-)8-(-)6 | (-)6-(-)4 | (-)4-(-)2 | (-)2-0 | 0-2 | 2-4 |
| Super Dry Slick | (-)10-(-)8 | (-)8-(-)6 | (-)6-(-)4 | (-)4-(-)2 | (-)2-0 | 0-2 |

## Sample Locations

The following samples offer a suggestion where the moment center needs to be located for each specific application. This information is presented specifically for stock cars that race on oval tracks and that only turn left.

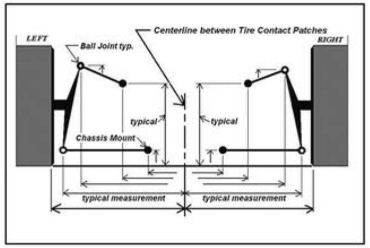
Please keep in mind that this technology is relatively new. Most of what you read here has only been discovered and developed in the last fifteen years. We continue to learn more and more about the effects of the front moment center on the dynamics of the race car as time goes on.

The information presented here is the product of having worked with many different types of stock cars and having seen the results in testing and under racing conditions. Anytime information such as this is presented, it is considered somewhat subjective and as such, open to different interpretations. As we continued to work with the different classes of cars, certain truths became evident and can now be verified. The research is ongoing as we work with more and more teams. Here is what we know as of this writing:

- A higher moment center with more upper control arm angles is best for the tracks with a lower banking angle. There is less camber change after dive and roll where dive is less and the car rolls more.
- A lower moment center with less upper control arm angles is best for the tracks with a higher banking angle. There is less camber change after dive and roll where the dive is substantial and the car rolls less.
- The higher the center of gravity the car has, the farther to the right the moment center should be located. This is to reduce the overturning moment caused by the high CG.
- The lower the center of gravity the car has, the farther left you can locate the moment center. Modifieds with their low CG can design their moment center farther to the left to improve the dynamics of the front suspension.
- If you run at a track with a long and flat entry, the moment center can start further left and move a greater distance from the static location to the dynamic location.
- If your race track has a fair amount of banking on the straightaways and mid to high banking in the turns, the moment center should not move more than 3" to 4" from static to dynamic width from the centerline of the car.
- Dirt car moment center locations will range from 4" to 5 1/2" off the ground and 6" left of centerline to 4" right of centerline, depending on the track banking angle. On flat and slick tracks (4 to 8 degrees of banking) the moment center should start at 6" to12" left of centerline and move to 2" to 4" left of centerline after dive and roll.

On medium-banked tracks, it should start at between 4" to 6" left of centerline and end up at centerline to 2" right of centerline. At the very high banked dirt tracks having 16 or more degrees of banking, the moment center can start at around the centerline and move to 4" to 6" right of centerline after dive and roll.

- For asphalt stock cars, the range should be from 2" to 3 1/2" off the ground and from 8" left of centerline to 4" right of centerline. For flat tracks (4 to 6 degrees of banking) with little traction, the moment center can start at between 4" to 8" left of centerline and move to 2" to 4" left of the centerline. For medium banked tracks (10 to 12 degrees of banking) the moment center should start at 2" to 4" left of centerline and move to 2" to 4" right of centerline after dive and roll. For high-banked tracks (14 to 24 degrees of banking) the moment center should start at around centerline and move to 8" to 10" right of centerline after dive and roll.




**When we establish the centerline of the car for the purpose of moment center measurement and evaluation, we use the center between the two front tire contact patches. The moment center "feels" the effect of its location in relation to the front tire contact patches.**

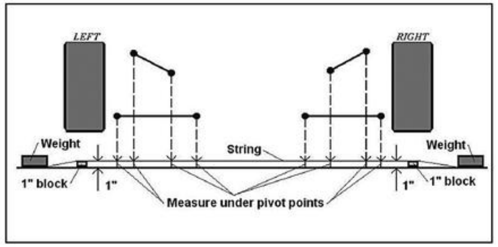
## Adjust Range for Center of Gravity

In each range for both dirt and asphalt stock cars, consider the center of gravity height and use the numbers to the left of the range for cars with a low center of gravity (CG),and use the numbers to the right of the range for the higher CG cars.

Higher CG asphalt cars such as the Cup-type cars and some of the strictly stock classes should have the moment centers at a dynamic location of 2" to 4" right of centerline for most low to medium (6 to 12 degrees of banking) banked race tracks. For cars that race on the very high-banked race tracks such as Daytona, Bristol and Dover, the moment center should be located up to 16" to 18" right of centerline.

## Moment Center Height

Work with the height of your moment center by observing the camber change for each front wheel on an individual basis. Concentrate mostly on the right-front wheel and look at the camber amount after dive and roll. The best and most consistent cars will keep the same camber after dive and roll.




**Check the floor where you will be taking measurements. A good way to check for flatness if you don't have a builders level is to pull a string over 1"[11] (or whatever works) blocks and measure from the string to the floor at the points where the height measurements for the pivot points will be taken. If the gap between the string and the floor varies more than 1/16", then find a new spot, or note the difference at each point and adjust the height measurement as you go along.**

The exception to that rule is when the car is setup with what we call the Big Bar and Soft Spring (BBSS) setups. For the BBSS setups, the camber changes for both front wheels will be high. You cannot eliminate the camber change at the right-front wheel without ruining the moment center design, so don't try.

## Camber Should Stay the Same

For the conventional setups only, if you start at negative three degrees of camber in the static location, you should have negative three degrees of camber after dive and roll, as the car would be in the turns. Gaining or losing camber in the right front tire can have a negative effect on the front grip. The left-front tire will always lose several degrees of positive camber after dive and roll. There is nothing you can do about that as we said without ruining the moment center location. Set your static camber in the left-front wheel so that you end up with about one-half to one degree of positive camber after dive and roll. Never let that wheel go into negative camber.

Remember, this is not theory or something you should try. These moment center locations have been used on winning dirt and asphalt race cars and the performance has increased substantially for many teams. The front moment center is not only a part of the total setup package, it is the absolute starting point. Therefore, you should know the moment center locations on your race car just like you know your stagger or rear gear ratio. If you don't, you are just rolling the dice when it comes to setting up your car. There is no way to compensate for a bad moment center location. It is a crucial part of a winning setup.

**To record the spindle position, you can measure from a point on the lower control arm (such as the top of the lower ball joint stud) to a place on the roll bar engine hoop. Record these measurements.**

## How to Measure the Front Moment Center

Because we have presented the fact that the front roll center, or moment center as we like to call it, is so important, it would be nice if we explained how to measure your car for moment center location. These measurements are best put into a geometry software program. It doesn't take too long and the results could be substantial.

Taking the measurements to determine the moment center location is not that difficult. Racers in general will always do what is needed to perform, from making last minute engine changes to staying up all night to prepare for an important race. We are showing the process for taking measurements for a 2-D software program. The process of measuring the front end takes from two to four hours, depending on how organized you are and how much help you have. This is considering that you will take your time and do it right by checking every measurement and verifying the data. If you want to use a 3-D program, you will need to take front and rear measurements from a datum line, and this will add about an hour or two to your process.

The following are the steps and methods you can use to measure the eight pivot points used in a 2-D software program in order to determine the static and dynamic locations of the front moment center. For most types of stock cars, the information we desire to know about the front moment center location can be found accurately enough by taking two-dimensional measurements and using a two-dimensional geometry software program.

***Step 1***—One of the most important steps is to locate a level portion of the garage floor on which to measure your car. The most important area that should be smooth and level is that area in between the front tires and extended fore and aft 10" + from the "axle" line. So, roughly a rectangular area that is about 20" x 70" will do.

Pull a string over 1" blocks set at the outside and under where each tire will sit and across the area to be used and measure along the string to see if the floor varies more than 1/16" in the exact spots you will be measuring to. If it does, move and find another area. Get this part right and you will be able to trust your numbers.

| Corner | Ride Ht. | | Offset | | Total Ht. |
|---|---|---|---|---|---|
| Left Front Corner | 4.0" | + | 10.0" | = | 14.0" |
| Right Front Corner | 4.25" | + | 10.0" | = | 14.25" |
| Left Rear Corner | 4.50" | + | 10.0" | = | 14.50" |
| Right Rear Corner | 5.0" | + | 10.0" | = | 15.0" |

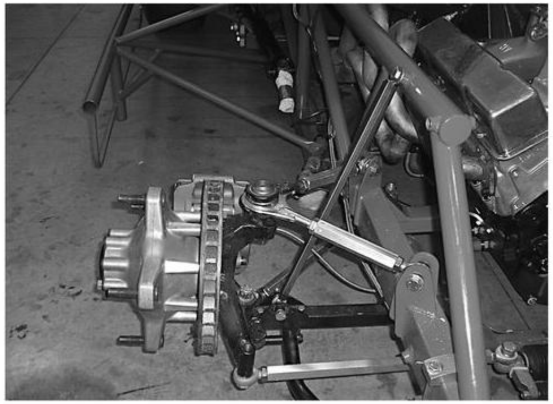
**Here is a sample offset chart. The offset to which the car was raised must be the same at all four corners of the chassis. Add the constant offset number to each of the four ride heights and make sure that each corner is at the proper offset height.**

***Step 2***—Remove the string and blocks and position the car over the level spot with all of the weights in the car including the driver. Make sure to have the correct cambers set, and the tires aired up to race pressures.

If the engine has been removed, support the car under the frame rails at ride height and remove the springs and shocks. Reduce the air pressures in the front tires until the left-front (LF) lower ball joint flange drops 3/8" closer to the floor and then the right-front (RF) ball joint flange drops 1/2" closer to the floor. Dropping the spindles this way will closely simulate the amount that the tire squashes when all of the weight is on the tires with the engine, springs and shocks installed.

***Step 3***—Take a measurement at each front wheel so that we can later return the wheel assemblies to their same positions in relation to the chassis. We can measure at the outside of the tires from the bottom rim of the wheel to a mark on the fender or on the inside of the tire from the top of the ball joint stud to a point on the engine hoop bar. Some teams will measure the length of the shock. Whichever way, the idea is to have a way to accurately reposition the wheel assembly later on after we have raised the car and removed the wheels.

***Step 4***—Jack the car up and support the chassis at the four corners on jack stands. Keep the stands away from the actual area where we will be taking the measurements in order to be able to access and measure to the pickup points under the front suspension without the stands being in the way. We want to raise the car the exact same amount at each corner. A good distance to raise the car is 10.0", but any dimension will do. As we eventually measure the height of each chassis pivot point, the offset (amount we raised the car) will have to be subtracted from each distance and ten is an easy number to subtract.



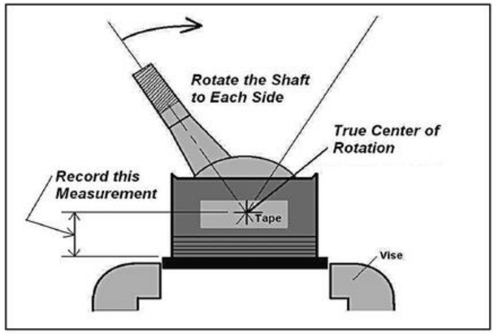
**The best way to support the spindle while taking moment center measurements is by using a spare control rod or lower strut rod. Both of these usually have opposite rotational threads and therefore are easy to use to fine tune the spindle height. The spindle must be positioned in relation to the inner pivot points exactly as it would be with the spring installed and the car at ride height with all of the weight in it. Shown is a new unit from Coleman Racing Products.**

Start by measuring the LF corner, then move around the car clockwise to adjust the other three corners to a dimension equal to their ride height plus the offset amount. Then make sure that the chassis is fully supported at all fours corners and does not rock and roll. You can shim one of the rear corners to stabilize the car, usually the right-rear (RR). As long as the two front corners are set to ride height plus the constant offset and tight on the jack stands, then you will be okay.

***Step 5***—Remove the front springs and shocks and jack the LF and RF wheel assemblies up until they are positioned so that you have the same measurements as we took in step 3. Install a link in place of the shock at each side so that the wheel assembly is supported in the same position as if it were at normal ride height with all of the weight on the tires (step 3 measurements used).

The link can be a strut rod or tubular control arm with opposite threaded Heim joints of a usable length. This type of temporary link is easy to install and adjust for length.

If those are not available, then a piece of 1" x 1/8" iron or aluminum strap metal can be used. Drill a one-piece link the exact length of the installed height of the shocks for each side. Or, you can cut a piece in two so that they are long enough to overlap when installed in the shock mounts, drill a hole in one end of each piece and bolt the two to the shock mounts.




**If you do not know the exact location of the center of rotation of your ball joints, this simple method will allow you to establish the true center. Place the ball joint in a vise with the shaft pointing up. Rotate the shaft all of the way to the left and mark the centerline on the housing over a piece of masking tape. Then rotate the shaft all the way over to the other side of the housing and mark the centerline again. The intersection is the true center of rotation.**

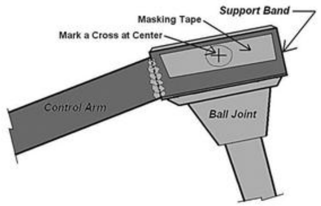
With the wheel assembly positioned correctly, overlap the straps and lock them together with a pair of vice grip pliers. Drill another hole through both pieces and bolt the two together. Label each set of straps, i.e. LF, RF so that you can reuse them if you need to remeasure later on. Once the two wheel assemblies are secured in their proper positions, remove the tires and wheels.

***Step 6***—Establish and mark the center of rotation of each ball joint. It is important to know the exact location of the pivot point of the ball joint so that we can mark that point on the ball joint support band on the control arms and measure to it.

To find the center of each different type of ball joint, we can quickly locate it using a simple method of placing the ball joint in a vise with the stud pointed up and then lining up the shaft as it moves from side to side.

Now that we know where the center of rotation is located in relation to the band, we can mark a point on each ball joint on the car. Remember to allow for anti-dive angle in the control arms as well as the control arm angle. These angles will affect where you place the point to measure to.

Use 3/4" or 1" wide masking tape and place a piece over the ball joint band. Clean the surface first to remove all grease and dirt. Use a fine tip black marker and a small straightedge to make a cross on the tape to represent the center of the ball joint for height and width measurements. Do this for the upper and lower ball joints.



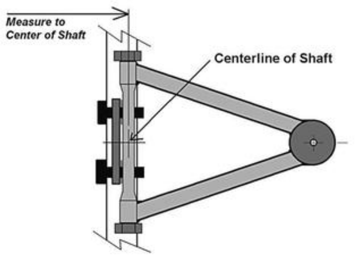

**Mark the center of rotation of the ball joint on a piece of masking tape affixed to the control arm band. You will need to project the center point out to the tape taking into account the control arm angle and direction of the ball joint shaft (due to king pin inclination in the spindle).**

***Step 7***—Take all of the height measurements first. If a direct vertical measurement cannot be taken, then use a level to project the height out from each point or construct a fixture to use to represent the distance so that a measurement can be taken away from the car.

When measuring the lower chassis points, use the pivot that is closest to a line lying at right angles from the ball joint to the centerline of the car. For the stock GM lower control arms, use the center of the front bushing. For a strut-type of lower control arm, use the center of the bushing or center of the Heim joint that is on a line lying 90 degrees off the centerline of the car projected through the center of the ball joint.

The upper chassis mounts often have anti-dive. To measure the chassis pivot point, average the heights of the centers of the two mounting bolts and measure the width to the center of the control arm shaft. In the case of an upper control arm that uses Heim joints, measure to the pivot that is closest to a line that would be lying perpendicular to the centerline of the car from the center of the ball joint. If the two mounts are equidistant from the perpendicular line, measure to both and average the measurements for height and width.

Measure and record the heights to the centers of rotation and remember to subtract the offset amount that we raised the car. Make sure that the tape is vertical for all measurements. It's easy to concentrate on the numbers and forget to line up the tape.




**For standard A-arms, the pivot point will be at the center of the control arm shaft. This point represents the average height of the two mounting bolts (when anti-dive is present) as well as the width of the rotational axis.**

***Step 8***—Establish a centerline for the purpose of moment center location. This will not be the true centerline of the chassis, but rather a point half way between the front tire contact patches. The reason for this is that we want to know where the moment center is located in relation to the tires because that is what is important to the car. The car feels the effect of moment center location in relation to the two contact patches irregardless of where the frame rails or other components are located.

After placing the wheels and tires back on the car, mark a point on the floor at each outside edge of the front tires. I often hang a plumb bob over the bulge in the tire to the floor. Measure between these points and divide that measurement by two. Place a mark on the floor between the front tires that represents half the distance between the tires. Using that same half-distance, measure from the outside of the RR tire in toward the middle of the car and place a mark for the rear centerline point.

The right-side tires are supposed to be in line or very close to it, and so our points will be parallel to the right-side tire patches and centered between the front contact patches. Pull a string over these two centerline points, pull tight and hold each end with blocks of lead or a concrete block.

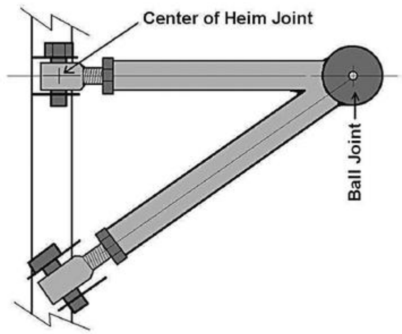
***Step 9***—Drop a plumb line down from each center of rotation for the four ball joints and the four chassis pickup points and place a mark on the floor. The frame rail and lower control arms may prevent you from dropping straight down from some of these points. In that case, measure out beyond the spindle at a right angle to the centerline and plumb down and mark an offset point on the floor. Write the offset amount (use 20, 30 etc., inches) on the masking tape beside the point.

The point we will measure from at each ball joint must be either at the front or rear of the ball joint so the measurement will be an accurate width dimension. When marking these points on the side of the ball joint, make sure you are looking either directly to the front or rear of the car.

***Step 10***—Measure from each point on the floor to the centerline string and don't forget to subtract the offsets if you have used them. Once all measurements have been taken and recorded, enter all of the height and width measurements into a racing geometry software program.

We are interested in the location of the moment center in both static and dynamic positions. Static represents where the moment center is located when the car is at static ride height and the dynamic position is where the moment center migrates to as the car dives and rolls in the turns.

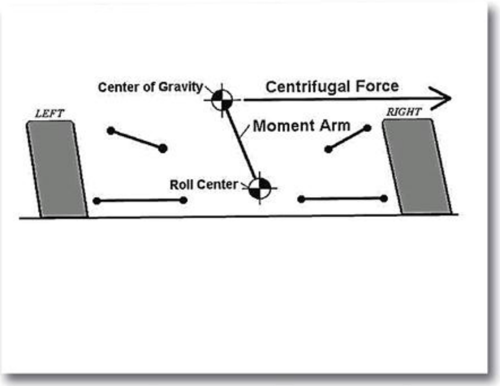
The dive and roll numbers you will enter into the geometry program are very dependant upon the type of car, track banking angle and setup stiffness. Try to use numbers that make sense and simulate the attitude of the car at mid-turn. Shock travels may include additional shock travel from hard braking on entry into the turns and may not accurately represent the mid-turn attitude.




**In the case of a strut-type upper control arm, measure to the center of the H Heim joint that is along a perpendicular line between the ball joint and the centerline of the car.**

# Chapter 4

## Race Car Dynamics and Load Transfer




**The front of this race car, with its own design of moment center and position of the center of gravity, will want to roll to a certain angle in relation to the race track surface depending on the g-forces it experiences.**

This is a very important chapter because the overall handling principles discussed here can present the single greatest obstacle to obtaining best chassis performance. When the dynamics work the way they are supposed to, the car gets faster in the turns, it becomes more stable and the setup stays consistent. This is called a *balanced setup*.

The balanced setup has noticeable results in performance. That is why I am so adamant about getting racers to fully understand the concept. I ran across the following description of the balanced setup on a web forum called 4M.com. It was written by Mr. Larry Bendele in a post there. We have his permission to reprint. It says it all.

*"A balanced setup for asphalt has the following characteristics:*

*"A perfect handling car allows the driver to have full confidence that he can drive it into the turn as hard as he wants without the slightest worry if it is going to spin out or head for the outside wall. For corner entry, the steering wheel movement is made one time, and doesn't need to be corrected when you approach the corner apex.*

*"Just prior to the center of the turn, the car rotates slightly (points) without getting loose and begs the driver to give it full throttle.*

*"You are able to give it full throttle at the corner apex and keep the hammer down, and the car is willing to run the lower groove on corner exit. However, you can reduce front tire drag (and accelerate more) by purposely steering the car to exit near the outside wall.*

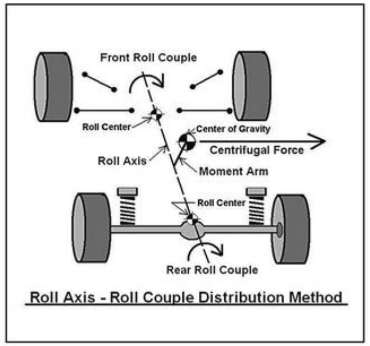
*"It does the above for 90% of the laps of the feature and you are able to win by several car lengths. Late in the race, you think about taking it easy because of your big lead, however, the car is handling so perfectly and comfortably that it wouldn't be as much fun to drive if you backed it down a notch. So you smoke the competition."*

For those of you that have experienced a race car that handled like that, you probably have come in touch with a balanced setup. Early pioneers of stock car dynamic research include individuals such as Maurice Olley and his group whose work represented much of the early progress that had been made in vehicle dynamic research. Among many other notable accomplishments, his work in the early 1930s led the industry to adapt the double A-arm suspension system, or short long-arm suspensions (SLA).

In 1952, Bob Schilling, the head of the Mechanical Engineering Department in the GM Research Laboratory Division, and his group met with a group of aircraft engineers that included Bill and Doug Milliken. The aero engineers were then contracted by GM to attempt to apply techniques that had been used in aircraft design to the study of land vehicle dynamics.

A compilation of that work, as well as other research, is contained in a book published by the Society of Automotive Engineers (SAE) entitled *Race Car Vehicle Dynamics*.

As the designs of exotic race cars developed, the engineers began to incorporate aero downforce into the structures of the cars. They added airfoils (wings) to the front and rear of the cars to enhance traction and to facilitate adjustments to the handling balance of the car.



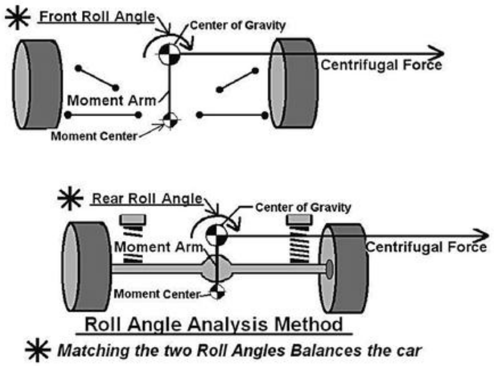

**Roll couple distribution technology was primarily developed for symmetrical suspension systems such as those found in production automobiles. This method involves calculating the resistance to roll of each suspension system. It does not take into account all of the dynamic effects associated with a race vehicle.**

Development related to chassis setup balance tended to get lost in the process. As stock car racing grew in number, and the designs became less stock and more complex, racers renewed the quest for more complete information related to chassis dynamics.

What has been refined in most top racing series is the hit-or-miss art of trial and error. Advanced data acquisition systems are used today that not only record movements, pressures and temperatures but also the forces exerted on components. These systems have become useful and necessary tools of the modern day chassis tuner and developer. As the teams compile and study all of this information, the fact still remains that they tend to react to, and not necessarily predict, the handling nature of their cars.

Technology has now evolved related to the ability to predict the handling characteristics of your car. It is a continuation of the work that early vehicle dynamics pioneers such as Olley started. Without their efforts, none of what comes next could possibly exist.

The primary thread of their early analysis of vehicle dynamics involved a model of a vehicle that treated the body and frame as a single unit with a single center of gravity for the sprung mass. The roll (moment) centers at the front and rear were connected by an invisible line, or axis, and a right angle line between the CG and the "roll" axis was the vehicles moment arm.

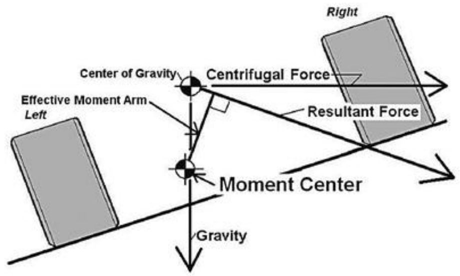



**The new roll angle analysis method allows us to understand that each end of the car wants to react independently to the force created by cornering. Knowing this, we can alter the suspension components such as spring rates and moment center locations to achieve a more balanced setup. This is exactly what we shoot for by trial-and-error guessing. This method saves the racer a lot of time and frustration.**

A moment arm is much like a pry bar or shovel handle. The CG is equivalent to the end of the bar we hold on to, and the roll centers and axis is the opposite end, which is the object we are trying to move. The longer the bar (moment arm) the more leverage we have and the easier we can move the object, or in this case, roll the car.

In the roll axis thread of technology, each end of the car was calculated to have a given roll resistance percentage based on the spring rates and other pertinent information. In subsequent skid pad testing, a neutral handling car was found to have significantly different roll couple numbers at the front and rear.

The handling characteristics of the car could be altered by changing the couple at each end, but, the handling still could not be predicted. The cars were dialed in through trial and error methods. The roll couple distribution thread of vehicle dynamic analysis did not present a complete model that would by itself accurately predict a stock car's handling performance.




**This simple diagram shows the two ends of the moment arm. The front roll angle is a product of the height and magnitude of the center of gravity/centrifugal force. The moment center resists this force. The length of the effective moment arm influences the amount the front wants to roll. The centrifugal force combines with the gravitational force, which exists all of the time, to produce a resultant force. It is the magnitude and direction of the resultant force that we use to determine the effective moment arm length.**

Because technology is, for the most part, universally shared among race car engineers around the world, we can be fairly sure that up until the early 1990s, there did not exist a method that could be used to accurately predict the handling of either an F1 car or a stock car. In my personal discussions with motorsports engineers, I was led to the conclusion that a definitive method and associated software did not exist at that time to accurately predict a stock car's handling characteristics in advance of going to a test or to a race.

In the early 1990s a method was developed that represented an advancement related to vehicle dynamic modeling. It involved treating the vehicle as two separate masses, each with its own separate suspension system.

This method made a lot of practical sense because in a stock car we have two axles, each supporting the weight of each end of the car, with each resisting the lateral forces created by cornering. In physics, we are taught that everything is fluid, or somewhat flexible, and dividing the car into separate halves allows us to analyze each one independently to determine its desire.

The review of early notes kept by a select few of the top stock car crew chiefs of the 1980s and early '90s indicate that they were then, too, thinking in the context of a balanced setup. The goal was to arrange the setup so that the two ends of the car would be balanced independently, thereby providing a perfectly balanced handling car.

There are several critical reasons why a balanced setup is essential to optimum chassis performance. First of all, we can accurately predict load transfer if the setup in the car is balanced. An unbalanced setup redistributes the load on the four tires in a very unpredictable way. If we cannot match the desires of each end of the car, we then cannot accurately predict the exact amount of load transfer and ultimately how much load ends up on each tire at mid-turn.

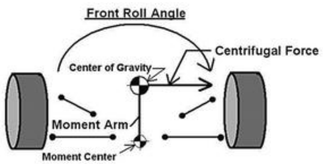
We need to have two sets of tires that are each doing equal amounts of work at mid-turn. Which two are paired depends on the static weight distribution. In stock car racing, we will almost never have all four tires doing equal work (having equal weight on each tire) under most current left-side weight rules. If we can setup the car so that after the weight transfers in the corners, we have equal working pairs of tires, then we will have a truly balanced setup.

Secondly, we will have less (almost non-existent) chassis flex with a balanced setup. Compliance, or flexing of the chassis, cannot occur if we remove the forces that cause this to happen. In 1995, I was asked by a race engineer what I thought of compliance. I asked if he meant chassis flexing between the axles, and he replied yes. I told him that if we could remove the forces that ultimately try to twist the chassis, we could mostly eliminate chassis flex.

Last and most importantly, a balanced setup is much more forgiving when the track conditions change or the driver runs different grooves. The speed of the car does not fall of as much, either, as the race goes on and the tires wear. It is the tendency of the balanced setup to help maintain a neutral handling characteristic and retained speed after a long run that helps win races.

***Primary Influences on Front Roll***—There are six primary things that combine to influence the amount of roll angle in the front suspension. They are:

1. The weight of the sprung mass of the car supported by the front suspension. This is represented by the weight of the front end measured on the scales under the left-front and right-front tires minus the unsprung weight of the wheels, tires, etc.
2. The magnitude and location of the lateral force measured in *g*'s. A one *g* lateral force would equal the sprung weight of the front end.
3. The moment center location, both in height and width after the car dives and rolls in the turns.



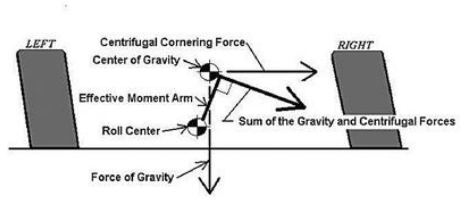

**This simple sketch shows us how the cornering forces react through the center of gravity and are resisted by the moment center to cause chassis to roll at the front of the car. Further study of those forces helps us to better understand what does influence the chassis to roll and to what degree.**

4. The overall spring stiffness translated to wheel rate as well as the relationship of the two spring rates side-to-side (i.e., softer right-front vs. left-front spring).
5. The front sway bar has an effect of anti-roll and must be taken into account. The larger the bar, obviously the more resistance to roll.
6. The track banking angle.

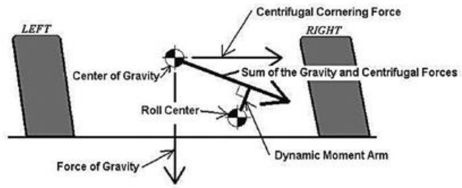
***The Double A-Arm Suspension***—A double A-arm suspension has a moment center that represents the bottom of the moment arm at the front end. The top of the moment arm is the center of gravity of the sprung mass of the car. As the center of gravity/center of mass tries to continue in a straight line as we turn the corner, a lateral force (centrifugal force) is exerted on the chassis and that force is resisted by the moment center. If you stick a shovel blade firmly into the ground and then pull on the end of the handle, your arms represent the lateral g-forces, the end of the shovel handle is the center of gravity, and the blade at the ground is the moment center.

***Two Forces at Work***—In a stock car we really have two forces at work being applied to the top end of the moment arm/center of gravity. One is the lateral force of cornering known as centrifugal force, and the other is gravity. These two forces combine into one resultant force for which we can calculate a magnitude and direction.

By looking at the direction of the resultant force, we can see the true picture of how a combination of the two forces will react in the front suspension through the center of gravity and resisted by the moment center. The effective moment arm length is the result of the direction of the combined force and the location of the moment center.




**When the moment center is located to the left of the centerline between the front tires, the effective moment arm is relatively long. This promotes a larger roll angle at the front and makes the front more efficient.**

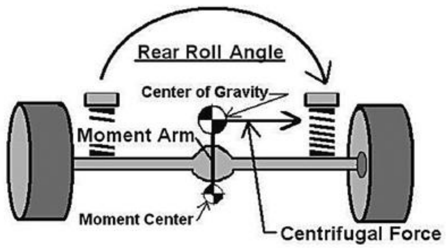



**Many stock cars have a front geometry design that puts the moment center to the right of the centerline between the front tires. As the MC is designed further to the right, the front suspension becomes much stiffer due to the diminishing length of the moment arm.**

***Effective Moment Arm***—The effective moment arm is the right angle distance between the resultant force line and the moment center. This is very important because we can see that when the moment center is moved to the right or left, the effective moment arm length changes significantly. As in the shovel handle analogy, a longer handle can apply more force to the blade end, just as a longer effective moment arm applies more roll force to our stock car.

The amount of lateral force and the length of the effective moment arm are contributing factors that help determine exactly what angle the front of our car desires roll to. If the front end of our car was not rigidly connected to the rear it would roll to a certain angle and a predictable amount of load would transfer from the left-front tire onto the right-front tire. But that is not the case. The two are connected and unless we know for sure that their desire are matched, then we cannot accurately predict the weight transfer at each end of the car.

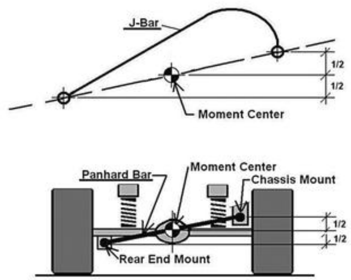
***A Rigid Chassis***—Both suspension systems of the car are connected by a rigid chassis. What each system desires to do is influenced by what the other wants to do as the car negotiates turns. I have used an analogy in the past that helps to explain this concept. Have you ever seen a circus act where two people are in a horse costume? The horse moves around fine as long as each end is in sync with the other. When the rear wants to go left and the front wants to go right, it gets comical. In our stockcar, when the front moves/rolls differently from the rear, it is not so funny and performance suffers.




**The rear suspension is much different from the front suspension. The car "feels" the spring base at the top of the springs. The moment center resists the lateral centrifugal force that causes the suspension to roll. Changing the MC height is the primary method used to control rear roll.**

***The Rear Suspension Dynamics***—The rear suspension is a much different system from the front and we look at it differently. At the front with the double A-arm suspensions, the spring base is felt at the wheels, but a rear solid axle system (and this relates also to a front straight axle car) has a spring base felt on top of the actual springs. This dynamic model is not a new concept, but was developed and published some 60 years ago. It is also described and illustrated in the popular book *Tune to Win* by the late race engineer Carroll Smith.

The rear suspension has a center of gravity of the sprung weight of the car that represents the top of the moment arm just like at the front. The bottom of the moment arm is the moment center created by the lateral locating device known to us by the terms *Panhard/J-bar*, *metric 4-link*, *leaf springs*, or *Watts link*. These four devices comprise the majority of lateral restraint systems used for straight axle suspensions in stock cars. Each restraint system has its own moment center that is the bottom of the rear moment arm.



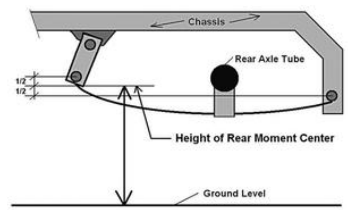

**The rear moment center height of a Panhard/J-bar system is the average height of the two ends of the bar. For the purpose of roll angle prediction, the MC is located laterally half way between the top of the springs.**

***The Rear Moment Center***—The height of the rear moment center is fairly easy to determine, but there have been varying theories on both the height and lateral location. Again, going back to early writings on the subject, the car "feels" the rear moment center laterally halfway between the two springs. Subsequent experiments have proven that regardless of the lateral location of the locating devices, the rolling force remains the same, thus proving the early theories.

***Primary Influences on Rear Roll***—There are seven primary things that affect the magnitude of the rear roll angle. These are:

1. The sprung mass of the portion of the car supported by the rear suspension (scale weights at the LR and RR tires minus unsprung components)
2. The height of the rear moment center
3. The magnitude of the lateral force
4. The overall spring stiffness as well as side-to-side spring split (i.e., LR stiffer than the RR spring)
5. The width of the spring base, which is the distance between the centers of the top of the springs;
6. The rear sway bar (if used) has an effect of anti-roll and must be taken into account. The larger the diameter of the bar in this system, the more resistance there is to roll
7. The track banking angle

Now that we know how to influence the desires of each suspension system, the key to creating a balanced setup is to change springs and moment center locations so that each end of the car will want to roll to the same angle. We can detect when our car is balanced by observing tire temperatures as well as tire wear.




**The leaf-spring type of rear locating device is unique in that the tops of the springs are also the lateral locating devices. Therefore, the average heights of**

**the ends are the height of the rear moment center. This system provides a wide spring base and is superior to other suspension systems in some cases.**

In order to set up our cars, we would need to be able to change components, if necessary, to balance the desired roll angles of the front and rear of the car. These changeable components include the spring rates, the moment center locations front and rear, the sway bar sizes and arm lengths, and the static weight distribution.

A balanced chassis—where both ends are working together—is what we always tried to find by using trial and error setup techniques. In the past, when we happened to find a really good setup, we probably didn't know how we got there or why it worked so well. Often the performance could not be duplicated when we built, bought or otherwise acquired a new car because of differences in moment arm locations or other differences that affect the roll angles.

All race teams need to know certain basic information about their cars so that the foundation of a balanced setup can be laid. Learn to recognize the tendencies that make a car's suspension want to roll, more or less, and try to match the two ends of the car for a more balanced setup. Know your front geometry settings, especially the moment center location and camber change characteristics. Be prepared to adjust the weight distribution (cross-weight distribution) as you make changes in the direction of a balanced setup.

If you can learn to do these things, finding that sweet spot related to a winning chassis setup will be a much easier process. Above all, be willing to take control of your chassis and do not be afraid to make changes to improve the geometry, the alignment and the balance of your setup.

**This car is well balanced and is able to drive right on the white line at the bottom of the race track. The consistency that balanced setups provide creates the opportunity for winning.**

## Chassis R&D's Computer Program

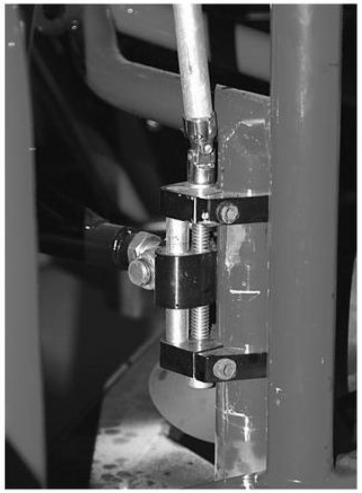
A computer program has been developed by Chassis R&D that uses this patented information, and it contains all of the formulas (algorithms for engineering students) necessary to accurately predict these two roll angles. This program is manufactured exclusively under license and is only available from Chassis R&D (see ordering information on page 153).

***Use it Like Any Other Tool***—Just like a timing light or a set of scales, you can measure what the two suspensions in your race car are wanting to do and then match them up. That is a major step forward in chassis setup. Although the internal calculations are very complicated, the entry methods in the program are very easy to perform and the results are incredible.

Just imagine trying to set the timing for your engine by ear, or torque the head bolts by feel. You wouldn't even think of doing that. Well, this is just what you have been doing with your chassis through the use of trial and error to try to find the right setup. It's time to move on to a better way.

## Calculating Roll Angles and Understanding Their Effect

With this new tool, you can now calculate the exact angle at which each suspension system would roll to if it were in fact independent and not attached to the other system by means of the chassis. In most cases, because you didn't know any better when you set up the car, the roll angles would probably be much different. In a well-designed chassis they would be the same. It is very detrimental to overall performance and handling when the roll angles are different. There are several reasons why.



**An adjustable screw-type panhard bar mount, shown here, is mounted to the frame and is infinitely adjustable. The entire mount can be moved vertically to adjust the range for a particular application. This makes tuning the balance of the car more efficient.**

***The Negative Effects of Unequal Roll Angles***—For a conventional setup or a dirt setup, here is what happens with an unbalanced setup. First of all, let's say the rear suspension system wants to roll more than the front. The rear suspension will never reach its desired roll angle, because the chassis connects the two systems and the front won't let it.

The front suspension will be forced to roll to a greater angle than it is designed to, because the rear is forcing it to. The net roll angle for the car will usually be the average that both systems are trying to achieve and neither will be where it wants to be. An unbalanced and unstable situation will be the result and the setup will be very inconsistent.

***Excess Weight Transfer***—Another negative effect of unequal roll angles is this: The left-front corner of the car will be lifted somewhat by the action of the front system being forced to roll more than it desires and excess weight will be transferred to the right-front corner. The right-front wheel will be forced to support more of the front vehicle total weight than it really wants to and the cross-weight percentage will obviously increase during cornering.

***Low Cross-Weight Needed***—The car will be very tight if the static cross-weight percentage is not reduced. If the car would have been neutral at say 51% cross, this car will need to start with about 48% to 49% or less static cross-weight to be neutral. If you need to de-wedge a car like this to make it handle, it is a noticeable indication that something is wrong.

***Left-Front Tire Not Working***—With the left-front carrying less load in the turns, it will work less and show less heat buildup. It will be the coolest tire on the car. Does this sound familiar to you? I've seen hundreds of cars with this problem in all classes of stock car racing.

For the BBSS setups, the opposite might be true. The high rate of the large sway bar reduces the front roll angle and the teams usually install a high right-rear spring rate to go along with that. If the rear-spring split is too great, then the front might end up out-rolling the rear. We might see a front desired roll angle of 1.0 degrees where the rear might not want to roll at all or even achieve a negative roll angle. This causes excess load transfer to the right-rear and leaves the left-rear tire cool and not working as hard.


**This computer program uses the patented method and is manufactured exclusively under license by Chassis R&D. It accurately calculates the roll angles that each end of the car wants to roll to. By changing springs, sway bar or panhard bar heights and weights, the two ends can be designed to work together for a more balanced setup.**

***Balance Is Now Easy to Predict***—Until recently, there was no way to predict this condition or to design a car so that this would not occur. There is now this new method and computer program that will analyze the suspension systems and predict the roll angles, so that the user can adjust the components in order to match the roll angles.

The result is a chassis with two balanced suspension systems that will work together and where all four tires will do their job and therefore generate maximum traction. The setup will be balanced and therefore faster, safer and much more consistent.

## True Load Transfer

The effect of load transfer during cornering is subject to a lot of misinterpretation and myths. In all cars, even a go-kart with no suspension, there is load transfer during cornering. The myth is that different rates of springs will transfer different amounts of load.

This is true only to the extent that by changing the springs, you inadvertently force the suspension systems to work against each other, and that redistributes the loads. The total amount of load transfer remains the same, but the distribution among the tires changes. That is why we get handling changes along with changes to the spring rates.


**In order to provide more moveable weight, this team used a smaller fuel tank and ran less fuel for the shorter races. This removes weight from behind the rear axle and allows the team to move it to the center of the car for a 50/50 load distribution.**

***Springs Don't Affect Weight Transfer, Setup Does***—The truth is that the spring rates in and of themselves do not significantly affect the total amount of load transfer in your race cars. If I generate a lateral force on a front or rear suspension system, without any restriction, the total amount of load transfer that system experiences will be the same for a set of 200-lb springs as it is for a set of 300-lb springs. The only difference between the two setups is that the system with 200-lb springs will roll to a greater angle.

***The Same Load Transfer***—Once each system stops rolling, and the springs have resisted the lateral force all they can, the exact same amount of load transfer occurs as dictated solely by the total weight of the vehicle (sprung mass plus rear unsprung mass), track width (supporting base), height of the vehicle center of gravity and the lateral g-force exerted on the car.

***Racing Karts Transfer Weight Too***—Essentially, a kart with the exact same total weight, track width, center of gravity height and lateral g-force would transfer the same amount of load.

So why would someone believe that by putting softer springs in the rear suspension system, the car will transfer less load? Or if you stiffen the front springs, more load will be transferred? The answer is in the redistribution of the loads on the four tires that causes handling changes that appear to be more or less load transfer.

***Load Transfer and Distribution Affects Handling***—The persistent theory (myth) is that by causing more load transfer at one end of the car, that system will provide less traction if you need that condition to balance the handling of the car. That is true only because that end of the car is forced to roll to a greater angle than it desires and transfers more load due to the attitude of the chassis, not the different spring rates.

**This view from beneath the car shows how the fuel tank is built around the quick-change rear end, moving the weight of the fuel forward. Note that there is still enough room to remove the rear cover and change gears.**

A set of laterally opposed tires will generate the most traction when they are equally loaded. When we move load from one to the other and they become unequally loaded, the amount of traction available from the pair of tires decreases.

***The Two Ends of the Car Are Attached***—While it is true that more load transfer means less traction at that end of the car, what is often forgotten is that the system you are talking about changing the springs in is connected to the opposite suspension system by a rigid chassis. Therefore it affects that other end too. What happens at one end of the car will cause an opposite reaction at the other end of the car.

So, we can never only change one suspension system and expect the results to be limited to that suspension system. We always influence the opposite system, either in a positive or negative way. In the same way, load transfer at both ends of the car is affected by changes to one or more spring rates or other dynamic changes.

## Shocks and Load Transfer

Shocks do not regulate the rate at which the loads are transfers. Using different rates of shocks on each corner will serve to redistribute the loads during the time it takes for the corners to settle in to a new attitude, when the car is braking into the corner, rolling through the turns, or accelerating off the corner.

The loads are transferred immediately from the left to the right side of the car. The different shock rates that might be present will only serve to redistribute those new loads onto each tire while the shocks are in motion.

**Example:** "A softer right-front shock will slow load transfer to that corner." This is wrong. A softer right-front shock will speed up the time it takes for that corner to assume its attitude, and if that is on entry to the corner, then the left-front and right-rear corners will momentarily gain some of the load distribution. This will loosen the car on entry while the attitude of the car is in a transition.

## The Way the Chassis Really Works

Here is what really happens during cornering. What follows is the big secret to adjusting the handling of a stock car the right way, so please read it carefully.

***Two Ends of the Chassis Influence Each Other***—Spring rates, along with the sway bar affect the amount of roll angle for each end of the car and the net combined roll angle of the chassis. The softer the springs, the more roll angle is produced, and the stiffer the springs, the less roll angle. If I soften the spring rates at one end of the car it will want to roll more. I said "want" to roll more but it can't go all the way to what it desires. Why? Because it is connected to the other suspension system and that system still wants to roll to its same designed roll angle.

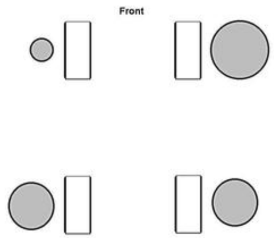
***Result of More Rear Roll Angle***—All you do when, for example, you soften the rear springs is to increase the desired roll angle in the rear. This will cause the rear system to struggle to achieve that new angle but it can't go all the way there. It does actually roll more, taking the front with it to some new angle that is usually nearly an average of the front and rear desired roll angles.

So now the rear does not reach its desired angle and the result is that the left-rear spring has not released all of the load it would have if the rear were allowed to roll to its desired angle.

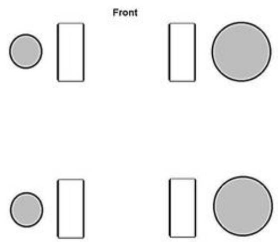
This leaves more load on the left-rear tire. This end of the car will have more traction than it would have (more equally loaded tires generate more traction).

Then, as a result of the changes to the rear spring rates, the front will roll to a greater angle than it desires, causing the left-front spring to unload more load than it should or wants to, which is then dumped on the right-front corner. This causes less equally loaded tires in the front and therefore less traction.

***Uneven Roll Angles Make for a Tight Car***—More traction in the rear and less in the front equals a tighter car. You have tightened the car at the expense of the left-front tire by causing it to do less work. Many of us interpret this to mean the car is working better. In reality, the rear gains while the front loses. At the front, the left-front tire has lost traction and the right-front tire is doing too much work. The whole car now has less traction and goes slower.



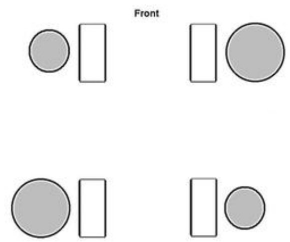

**The darker circles represent weight on each wheel—the larger the circle, the more weight. When the rear wants to out-roll the front, excess weight will be transferred to the right-front tire. So we must decrease the cross-weight percentage to compensate.**




**If the circles represent amount of traction based on the size of the circle, then this would be the ideal weight distribution for a high-banked race track when the car is in the turns. Left-side total weight compared to right-side total weight is dependant upon allowable left-side weight percentages according to the track rules. If we could use more left-side weight, then the circles might be more even in weight, left to right.**

I don't want to cause any tire to do less work, and I don't want to overwork a tire. Common sense dictates that this cannot be good for my race car. You can change the cross-weight distribution to effect a change to make the car neutral, but in doing so, you overwork some of the tires.

So, if you find a combination of springs, sway bar and panhard bar location that will produce equal predicted roll angles at the front and rear, you will have a much better race car! Of all the things you can do to increase chassis related performance, this is the most critical.




**This is an example of redistributing the loads on the four tires so that we have a neutral handling car for the flat tracks. As we can see, the right-front and left-rear tires are doing more equal work, as are the other pair of tires. The result will be a neutral handling car that offers better bite off the corners by loading the left-rear tire.**

## The Best Load Distribution Design

You may have found that for a circle track stock car, there are several ranges of cross-weight that will produce a neutral handling balance. One is in the range of around 50% and another is higher, in the range of much the same as the left-side weight percentage (if the left side supported 56% of the total vehicle weight, then the cross-weight percentage would be near 56%). If there are two to choose from, which one do you want? That depends on the type of race track and the banking angle.

We recently tested this principle with dirt cars and have found that some teams are finding success using a high amount of left-rear loading (high cross-weight percent) on flat and dry slick tracks to get more bite off the corners.

***High-Banked Tracks***—The best and most consistent range for the higher-banked race tracks (say 10 degrees or more) is around 48% to 52%, depending on the front-to-rear-weight percent. The higher the rear-weight percentage is, the higher the cross-weight percentage that will be needed to balance the car. If you make a weight distribution change to your car that changes the front to rear percent, then the cross-weight must change too in order to maintain a handling balance.

***Flat Tracks***—For the flatter race tracks, using the higher range of cross-weight percentage will provide better bite off the corners on exit. It should not affect the mid-turn balance if set correctly.

A high cross-weight forces more load onto the right-front and the left-rear tires. This causes the right-front to produce more turning force and the left-rear to deliver more traction during acceleration.

I think it is the increased left-rear loading that causes the increase in traction off the corners. If the right-rear tire is biting more on acceleration, then the car will be driven left and feel loose. When the left-rear tire is biting more, the car is driven to the right and the car feels tighter.

## Balanced Load Distribution

The primary objective is to end up with a more equal loading on each of two sets of tires, either sides or diagonal sets. That means that when the car is in the turns in the low cross-weight range, the left-side tires would have the same load on each of them and the right-side tires would have the same load on each. When the car is in the turns in the high cross-weight range, the right-front and left-rear tire loading would be equal and the left-front and right-rear tires would have the same load.

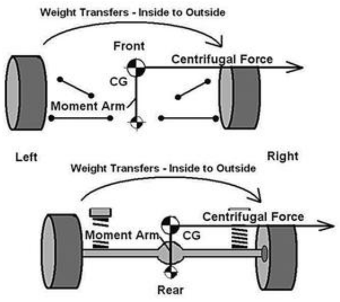
If you could calculate exactly how much load transferred at each end of the car for a particular setup, you could back out just how much load should be on each tire when the car is at rest in order to end up that way. Then as the car goes into the turn, and the load transfers, then you would have the ideal load distribution. The software program mentioned earlier does this for you.

## About Load Transfer

In order to really understand race car handling, we must know something about the load distribution on the four tires and how those loads change through the course of a typical lap. When we fully understand the principles of weight distribution and load transfer, we can better plan out our setup so that our car will have a better load distribution when cornering. After all, setup is all about how our loads end up on the tires, period. Many professionals will tell you that race car chassis performance all relates to being able to produce the maximum amount of traction from the four tires.

In this discussion, we are going to be using the terms *weight* as a physical measurement and *load* as a measurement of tire traction. In a static condition, when the car is motionless and on the scales, weight and load are identical. The difference is that weight is the measurement of the physical weight of the actual parts when the car is in a static motionless, condition.

**When we are cornering, a lateral acceleration force commonly called a g-force tries to overturn the car. This forces the right-side tires to carry more of the overall load than the left-side tires did before the car started to turn. This force is resisted by the two tire sets for each axle.**



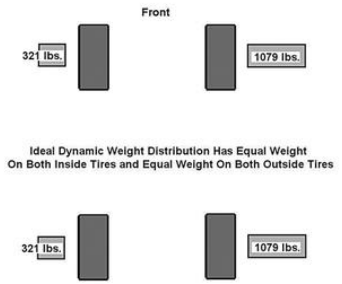

Load is the measurement we would record if we could scale the car dynamically in the turns. Load is partially artificial in a sense because part of it comes as a result of the forces we encounter during cornering, trying to roll the car over and compress it into the track surface. As a result, this causes changes to the distribution of the loads supported by each of the four tires.

***Understanding Load Transfer***—As load transfers, weight does not physically move within the car, but the lateral centrifugal force causes the distribution of loads on the four tires to change. Since the overall distribution of load on the four tires determines the amount of traction a set of tires will provide, we should be concerned with where load ends up when planning out setups.

The relationship between the two suspension systems will dictate how that transferred load ends up being distributed upon the four tires. A balanced setup will be very predictable for load transfer and an unbalanced setup will be almost impossible to predict, leading to trial-and-error searching for the right static weight distribution that matches the setup.

Extensive studies of the properties of tires all came to the conclusion that a pair of tires will produce more combined traction when they are evenly supporting the weight upon an axle. The term *axle* is used here to mean any two opposing tires in a suspension system. That could be either the front or rear pair of tires. If we could end up with an equal load on both tires in each pair at mid-turn, then each axle pair of tires would be giving us the most traction it is capable of.

In the real world, equal loading is never the case. We are not allowed enough static left side weight to compensate for the amount of load transfer that occurs during cornering, so we always end up with more overall load on the right-side tires than on the left-side tires at mid-turn. If we cannot end up with equal weight on an axle pair of tires, then we need to be sure they are as close to equal as can be.

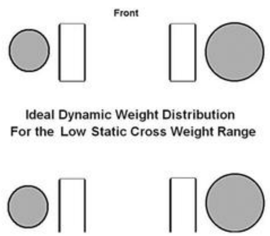



**If everything goes well, at mid-turn, the weights on the outside tires will be equal and the weights on the inside tires will also be equal. This is how a car should be setup for a banked track for the best traction and the most consistency.**

Cross-weight is a setup variable, and little is understood about where it should be and why. For asphalt cars, the percentage number for cross-weight is used, and for dirt cars, the terminology is a little different. Most dirt teams refer to the amount of "bite" or "left-rear weight" in the car, which is the number of pounds of weight that the LR tire supports over the RR tire. By subtracting the amount of weight that the RR tire supports from the LR tire weight, we arrive at a number and call that the amount of bite in the car, i.e. "100 lb of bite or left-rear."

***Stuck on One Number***—Over the years, many teams feel the need to adhere to a certain static cross-weight distribution, or bite number because that has always worked in the past, or because everyone else is using that number. The range could be anything from say 48% to an amount equal to the left side percentage, which is very common among some circles of stock car racing. The need to hold to a fixed weight distribution or bite number can only lead to a lot of frustration when your setups don't work out. With every change in setup, a corresponding change to weight distribution is usually necessary, if that involves a change to the balance of the car.

Setup is not the only variable involved with cross-weight distribution. If we change the front-to-rear percentage of weight distribution by physically moving weight in the car, the required cross-weight percentage changes too. Let's consider that we have a balanced setup in our car. If we move weight front-to-rear or the reverse, the cross-weight must change in order for the dynamic load distribution to be correct. The general rule is the more rear percentage we have, the more cross-weight we will need to be neutral.



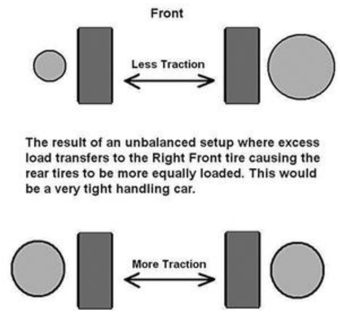

**If we could use circles to represent the amount of traction for each tire, the ideal layout would resemble this sketch. As we go through the turns, after the loads have transferred, the circle would resemble those above. The right-side tires would carry most of the vehicle weight.**

***Weight Distribution Must Change with Setup***—What we have learned is that the weight distribution that will balance the handling will change along with our changes to spring rates, panhard bar heights, sway bar sizes, etc. What we are changing when we make basic setup changes is the relationship between the front and rear desires of the suspension system. This used to be called suspension stiffness, but we have learned over the past ten years that more goes into roll resistance than just the stiffness of the suspension system.

The important goal here is for the difference between opposing tire loads to be the same for the front and rear tire sets.

We see a more equal loading in the rear tires and a very unequal loading in the front tires. This car will have much more traction in the rear than the front and will be very tight. This is the car that everyone notices with the RF tire squealing, steering wheel cranked to the left, and the front end pushing up, big time.

We talk continually about chassis balance being the real goal in race car setup. As we make changes to bring our car closer to a balanced condition, the cross-weight, or weight distribution, must also change. That is because with every change to the base setup, we are also changing the amount of load transfer at the front and rear of the car.



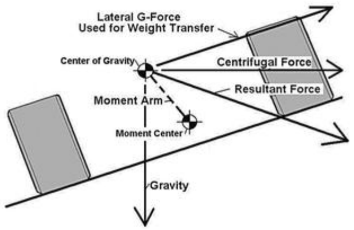
**When we have an unbalanced setup, the one end will usually desire to roll more so than the other end. The common Big Bar and Soft Spring setups are famous for this condition. We used to see this with conventional setups in the mid-'90s; now we see it again with BBSS setups by teams who are not doing what it takes to balance the setup.**

This can further redistribute the loads carried by the tires. A split in spring rates, and more specifically wheel rates, will affect the chassis balance and therefore affect load distribution. That is one of the reasons we need to have a balanced setup that takes into account the true forces and their directions.

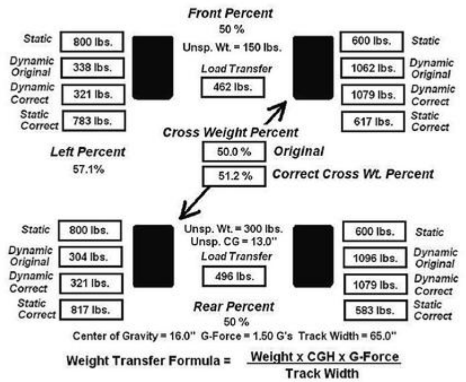
There is a set amount of total load transfer that occurs for every car that is determined by:

1. The weight of the car, both sprung and unsprung
2. The height of the center of gravity
3. The track width
4. The lateral g-force
5. The track banking angle

How the dynamic loads are distributed among the four tires is solely determined by the balance between the two suspension systems.

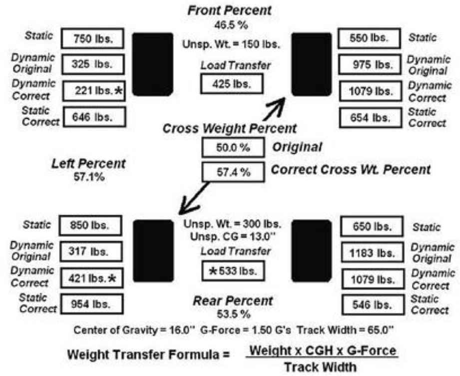



**The translated force line that is parallel to the track surface is the net force magnitude that must be used to determine lateral load transfer. The true force and the direction that force takes is called the resultant force. On very high-banked tracks, the direction this force takes in may well be between the tires at each axle.**




**Here we see a situation where the original static weight distribution did not work to produce equal loading at each side during cornering. When we changed the static distribution (i.e. the cross-weight percentage) we achieved the goal of equal loading as shown by the dynamic correct numbers.**






**As we increase the rear-weight percentage, we must also increase the cross-weight percentage in order for the load transfer amounts to produce equal loading on the side pairs of tires. We need the differential between pairs of tires at the same axle to be the same ideally.**

***Exactly How It Works***—Using a common formula for calculating weight or load transfer, we can predict the exact amount of load transfer that occurs at each end of the car. This is only accurate if the setup is truly balanced to where both ends are attempting to do the exact same thing in the turns. Then, and only then, are these numbers correct.

Let's look at a 2800-lb car (weighed with the driver and all fluids) with a CG height of 16.0" off the ground, a track width of 65.0", a front-to-rear percentage of weight distribution of 50-50, a left-side weight percentage of 57.1, and unsprung weights of 150-lb front and 300 lb rear. The car will experience a lateral g-force of 1.50 g's. Using the formula:

**[W (weight) x CGH (center of gravity height) x G-force] ÷ track width = load transfer**

we separate the weight into front and rear and do separate calculations for each end of the car.

In front, the sprung weight is used to calculate the total load transfer because the independent suspension parts do not transfer weight. The total weight of the tires, wheels and spindles plus roughly half the weight of the control arms and other connecting components remain just where they are. In the rear it is a little different. We have both the sprung weight that is used for load transfer plus the load transfer of the rear end assembly which has its own CG associated with its mass.

The load transfer up front equals 462 lb and the load transfer combined in the rear equals 496 lb. If we started out with a static cross-weight distribution of 50% and then add and subtract the load transfer, then the dynamic loads on the tires will produce neither equally loaded tires on each side nor an equal difference from side to side.

If we redistribute the static weights upon the four tires (without moving weight around in the car) to a cross-weight percentage of 51.2%, then when we add and subtract the load transfer, our weights come out much better. We see in the sketch that the dynamic loads on each right-side tire are equal and it is the same for the left-side tires. This is truly a perfect dynamic load distribution. Combined with a balanced setup, this car will not only be very fast it will also be very consistent.

If we increase the rear percentage in the car by physically moving weight to the rear to 53.5% rear, then in order for the dynamic loads to come out as above, we need to increase the static cross-weight distribution. The sketch shows the change to static tire loads needed to accomplish this. The correct cross-weight percentage goes up quite a bit, to 57.4%.

This tells us in part that when we move weight front to rear, we are changing what the car wants for cross-weight if no other changes are made to the setup. Moving weight to the rear while maintaining the same cross-weight percentage will loosen the car. Whoa there, a lot of racers will tell you that adding rear weight gave them better bite off the corners. That is probably because the car was originally tight/loose and by reducing the cross-weight, the car became more neutral in handling and less loose off the corner when there was excessive steering input at mid-turn.

Once we balance the two systems so that each end wants to do the same thing, or in effect desiring to achieve the same roll attitude, at mid-turn and hopefully on entry and exit off the turns, the load transfer is very predictable. We can then maintain a static weight distribution whereby at mid-turn the load will be distributed so that a minimum difference between the inside and outside tire loads will result.

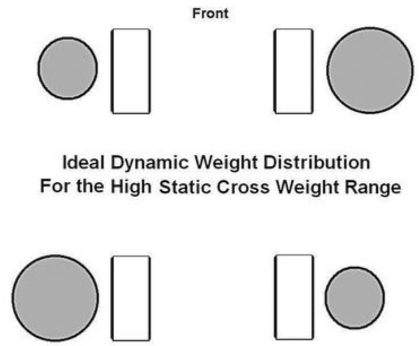
That will give us the most overall traction we can have under the left side weight restrictions dictated by the rules. There are exceptions to this rule. One exception is when we need more bite off the corners on flat tracks. We then need to deviate from the plan to end up with less difference and move toward having a more equal distribution of load on the rear tires.

The only reason we would deviate from a more equal overall distribution is that the small loss we would experience from having less equally loaded distribution causes less performance loss than if we could not motor off the corners without excess rear tire spin. So, we compromise our static weight distribution while still maintaining a balanced setup.

***High-Traction Weight Distribution***—If we need more bite off the corners, we can change our static weight distribution from the 50% to 52% range for a 50-50 front-to-rear weight distribution car, to running close to a static weight percentage being equal or greater from the left-side percentage. Racers have been doing this in the Midwest and Northeast for years.

This arrangement of static weight works great for the low banked tracks with minimal traction, but in order for it to really work, the car must be well designed for front moment center location and the setup must be balanced. The RF tire will be doing a lot of work, but it will have lots of load on it to make it stick. When we go to the higher-banked tracks, the cross-weight should change to the lower range to be most effective.

The tracks where this works best is where the driver must park the car at mid-turn and then motor off as best he can under conditions that provide little traction. The amount of time spent at the middle of the turn is less and the overall gain in lap times is all due to the improved acceleration starting just past the midway point of the turns. In this situation, we must compromise with the static weight distribution and therefore lose some midturn traction.




**This may well be what the final load distribution looks like with a high cross-weight static weight distribution. We still see equal differences in the loads carried by tires in each axle set. To achieve this, more redistribution of the loads must take place than just load transfer. The use of spring split causes additional load distribution changes to occur.**

The key points to remember are that the weight distribution the car needs will change when we make setup changes like a spring change or a panhard bar height change. Even making changes to the front moment center location changes the desire of the front end, which in turn changes the dynamic balance of the car.

As we make positive changes to bring our car to a more balanced setup, we will need to make corresponding changes to the cross-weight percentage. Reducing front roll stiffness causes more front traction and the cross-weight percentage must be increased to keep the car from becoming loose. Increasing the rear roll stiffness will also cause the same effect, so too is the need to up the cross-weight percentage.

Don't get stuck on a particular cross-weight percentage number. Be flexible and understand what is happening when you make those spring changes or panhard bar movements or when you move weight around in the car. If you understand the influence of weight distribution and load transfer, you can then make more intelligent chassis setup decisions.

## Difference between High and Low Banking

On the higher-banked tracks, you don't need the added traction off the corners because the downforce from the banking will usually equal or exceed the high cross-weight effect. If you try to use the higher cross-weight at the high-banked tracks, with the right-front working harder, it will generate more heat and wear. It will most likely give up at some point in the race depending on the length of the event, and will gain and then ultimately lose traction as the race proceeds. The car will get tight, the front end will eventually push, and the lap times will suffer.

We recommend running the low cross-weight range for high-banked race tracks. The setup will stay very consistent and the lap times will drop off less with tire wear and heat buildup.

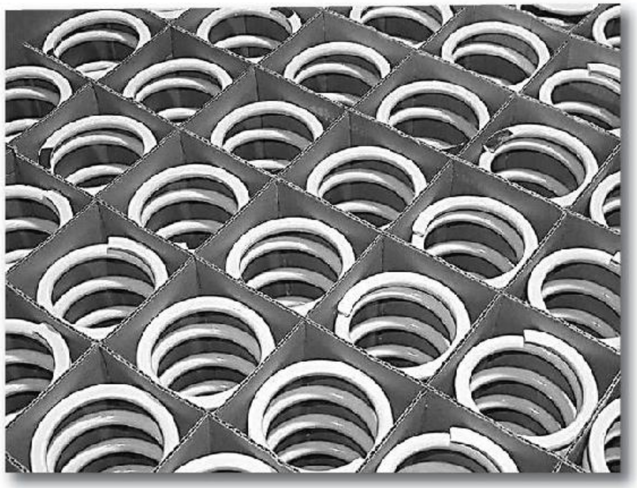
## Putting Everything Together for a Balanced Setup

If you select the proper spring rates, moment center locations, weight distribution and shock rates for the track banking angle, you will enjoy a well balanced and fast race car. Many teams have already discovered how easy this is to accomplish if they have the right tools and knowledge of what they are trying to achieve.

We can now accurately predict the desires of our race cars suspensions and design a setup that will make the car happy. We will achieve the goals we always desired when working with trial and error methods of experimentation. Only now, we will be able to know when we have a truly balanced setup BEFORE we go to the race track.

# Chapter 5

## A Study of Springs



Historically there has been very little written about how springs affect the chassis setup. Even in the most comprehensive racing chassis books, only a few words are offered on the subject of springs. What you have been taught in the past is that you can use springs to adjust the handling balance of the car. That represents the trial and error setup methods that you will no longer use if you follow the technology presented in this book.

Spring stiffness, wheel rate, installation ratio are all threads of discussion previously presented, which offer no real direction or conclusion. Here we will take a comprehensive look at how springs affect the setup, and how the combination of springs at the four corners of the car can be arranged to provide a more balanced setup for speed and consistency.

### How Spring Combination Affects Chassis Setup

As you have learned and can deduct easily, the springs basically help support the weight of the car and dictate the load distribution in the dynamic state when traveling through a turn. The relationship of the four spring rates is the most important aspect of chassis design. Average lap speeds are mostly influenced by the maximum speed the car can attain at the point of mid-turn.

To carry this further, when we have the correct combination of spring for the desired spring stiffness, we can negotiate the turn faster. That speed is then carried throughout the lap and here's why. If your engine horsepower/torque and gear combination will accelerate the car, say, 25 mph from throttle application to the point of lifting, going into the next corner, then if we increase the mid-turn speed by 1 mph, then the average lap speed will increase by 1 mph.

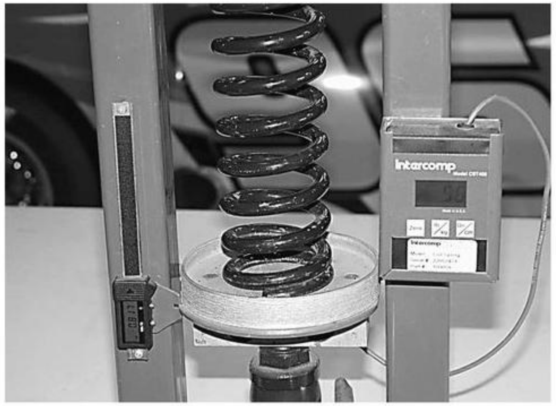
Translated, that equals an increase in distance traveled of 1,320 feet for a fifty-lap race on a half-mile track, or about 0.20 seconds reduction in lap time per lap. Most racers will agree that that is a significant gain and it is well within reach.

### Springs Are Used to Balance the Setup

The dynamic balance of the car determines the mid-turn traction capacity that translates directly into speed. The more traction you have at mid-turn, the faster you can execute the turn. The faster you can execute the turn, the faster speed you will have when you accelerate out of the turn. The spring rates, along with the moment center design, determine the attitude of the car at mid-turn.

Therefore, because springs have the greatest effect on how fast the car will travel through the turns, they have a much greater influence on lap times than anything else. The steady-state condition of the car is defined as the car in a position where there is no acceleration and no deceleration running at a steady speed. It is this point on the race track where we need to improve performance the most.

There are several things you definitely need to know about springs. First, you need to know exactly what the rates are for the springs you have in stock in pounds of resistance per inch of travel. This is not as simple as reading the stamped number on the spring. Those numbers are not always reliable. Spring companies often rate their springs differently and can sometimes make mistakes labeling the springs. Also, the rate of the springs can change after they have been used, due to abuse or spring sag.




**A good quality spring rate tester is essential to finding your correct spring rates. Find the rate of the spring in the range it will be working in and not the first few inches. The spring will never be working at the first inch. A spring rated at 200-lb per inch will be compressed three inches with 600-lb of load**

**on it. This machine has a digital readout for accurately measuring the amount of travel as you rate the spring. Measure your spring length at ride height and compress it to that length before starting to rate the spring.**

## Proper Spring Selection

As you can see, spring selection is very important. But how do you know what combinations of springs will work for your car to provide the best attitude for maximum traction in the turns? There are an almost infinite combination of springs to use for your car. You need to pick the spring stiffness you want to work with.

The location of the components and the moment centers, the height of the sprung center of gravity, the amount of sprung mass, and the lateral force and track banking angle all need to be considered in order for you to determine the angle to which a suspension system should roll in a given turn. Each end of the car is a separate and much different suspension system. Although a rigid chassis connects them, they still desire to reach their own individual roll angle depending on the arrangement of the components.

On low-banked tracks, it is desirable to allow more roll in the car so that the suspension is more compliant and give the tires more time to adjust to changes in direction and braking and accelerating. We need to stiffen the suspension for higher banked tracks for several reasons. First, the increased downforce we have from the high banking is used to help provide bite for accelerating off the turns. Plus we will have more of the lateral force concentrated down rather than to the side, which will cause more dive and less roll. So, we will need to stiffen the overall spring rates on the four corners.

## Choose Spring Rates to Balance the Roll Angles

Since computer technology now makes it possible to accurately predict the roll angles that each system desires (see Chapter 4), you could change spring rates until both ends would desire to roll to the same angle. Then both systems would roll together to the same roll angle and all four tires would work at their highest capacity. The car would be fast and the handling would be consistent.

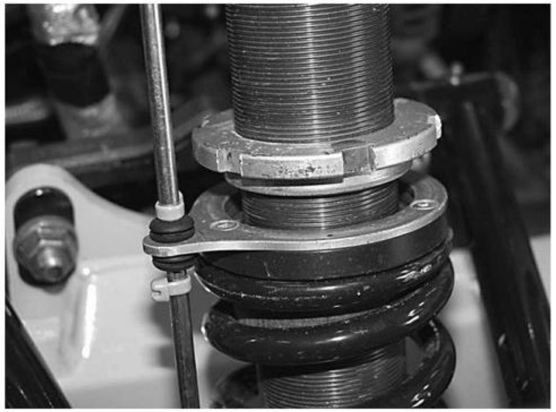
We do this by combining the effects of spring rate plus a measured amount of spring split, along with adjustments to the panhard bar (rear roll center height) heights, and sway bar size. On a typical pavement late model car, a change from running a pair of 200 ppi (lb per inch) springs to a 150 ppi left-rear (LR) and a 250 ppi right-rear (RR) spring has the same roll reducing affect as raising the panhard bar about 3 1/2". That is a huge change as most of us know. Matching roll angles will balance your race car and give it maximum cornering power.

## How to Rate and Check Your Springs

Use top quality springs. They are all that is holding up your car. Always measure the rate of your springs. Do not trust the markings on the springs. Even new springs have been found to actually have a different rate from what is marked on them. Check your spring testing equipment before rating the springs. Make sure it is strong enough to handle the high loads generated by compressing the springs. Never rate a bent spring. It may eject from the tool and cause serious bodily injury. Throw bent springs away.

The proper way to rate a spring is to preload the spring until the spring is at the same compressed height as it would be when it is installed in the car. Make sure you use the height it goes to with all of the load on it. Then think about which corner the spring will be installed in.

For the left-front spring, the travel might be up and down one inch or so, for conventional setups and for asphalt BBSS, down up to four inches. A spring mounted on the right-front (RF) will usually travel in compression only and move from between two and three inches or more. So it would be useless to rate it at a greater height than it ever would be in the turns where it is doing its job and working to balance the car.



**This type of shock travel indicator will tell the crew how much movement, in both directions, a corner of the car experiences. It is important on the left side where a wheel might possibly be in rebound or compression at mid-turn. Excess wheel travel indicates a setup that is too soft, which causes excessive camber change.**

If you don't have a spring rate tester, use someone else's. And recheck them periodically. Sometimes a spring may develop a weak spot, and the rate will change. Almost all springs will slowly lose their height and get shorter during repeated use. This can change the rate due to more of the end coils making contract with the second coil and eliminating part of a coil. Weigh the car and check ride heights frequently.

## Why Spring Rates Change

Although the spring rate may change due to steel fatigue, I believe a more common reason is the collapse of the spring. The following is why:

***Spring Height Changes***—We have learned that when springs are subjected to extreme racing conditions, they will slowly lose their height, or collapse. The steel may retain the same resistance to the mass placed upon it, but the very ends of the spring seem to lose height and will contact the next coil. With less coils available, the rate increases.

**Note:** Spring rate is based on the diameter of the wire, the diameter of the coils and the length (number of coils) of the wire. Larger diameter wire and/or less coils means more resistance to bending and a higher rate. This loss of coil is the primary reason why the spring changes rate and they usually get higher in rate.

***Loss of Coils = Higher Spring Rate***—Once the end makes contact with the next coil, that portion of the spring from the end to the contact area is no longer in use. It's like cutting off a section of the spring. Once this happens, and it happens a lot at big fast tracks such as Daytona and Talladega, throw the spring away. Admittedly, this occurs more in large rate, open-end coil springs than in the flat-ground, closed-end, coil-over type springs. But once it happens, the spring will be fairly unpredictable and higher in actual spring rate.

## Use Straight Springs

Check to make sure the springs are straight. Roll the springs across the floor to detect any curvature in the spring. You can noticeably see the wobble if it is bent. This is a bad condition, and if a spring is curved do not use it. This is especially true for coilover springs, for obvious reasons. The spring would rub on the shock.

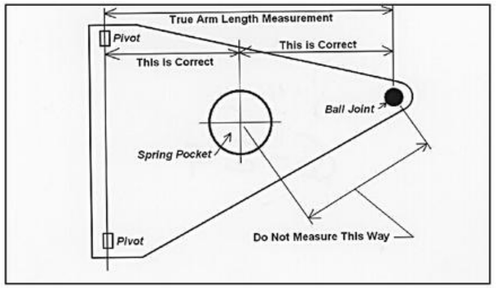
Reasons for a bent spring might be the installation angle of the top or bottom mounts in the case of a large coil, stock type of spring. We need to make sure the bottom bucket and top cap are seated perpendicular to the spring when the car is both at ride height and when it is at the turn attitude. With the BBSS setups on asphalt, the front is traveling much more and the springs might no longer be mounted properly for travel.

Most top car builders work with the newer designs so that this is not a problem. But, if you are converting an older car, look for this problem before it ruins your springs. Simply evaluate the system and make corrections to the lower control arm and/or the upper mount to make them seat properly. You can use a very low rate of spring, and then compress the suspension to check for alignment of the spring to the mounts.

## How to Change Springs Correctly

When changing springs, you want to make sure you don't alter other settings such as load distribution. When you change the spring at any corner of your car to a different rate, you will also change the overall load distribution if you don't also change the height of the top of the spring. This is basic chassis setup procedure, but there are many teams who will bring the car in to the pits, and change from a 200-lb spring to a 225-lb spring without moving the adjusting ring (on a coil-over design), or the jack bolt height (in the case of the big spring car).

You should take a measurement or weigh the corner and then make the change. After installing the new spring, bring the car back to the original ride height with the adjuster or reweigh the corner and reset the weight to the original weight.




**When measuring the length of the lower control arm, the distances from the ball joint to the center of the spring, and spring center to lower chassis mounts, use this sketch to make sure you measure correctly. We always want the rotational radius for control arm length and along a perpendicular line from the alignment of the center of the chassis mounts for measurements between the spring and ball joint/pivots or to the sway bar mounts.**

## How It Can Go Wrong

Here is what might happen: A 200 ppi spring will compress 4 1/2" with 900 lb on it (900 lb ÷ 200 lb rate = 4.5"). You've already set your ride height with that spring in the left-rear corner and now want to install a larger rate spring.

You now decide to go up in rate to a 225 ppi spring. This spring will still have 900 lb resting on it, but will now compress only four inches (900 lb ÷ 225 lb = 4.0"). If you don't raise the seat at the top of the spring by 1/2", then when you install the new spring, your cross-weight percentage will change. You will have made two very significant changes to your setup at the same time and both of these changes will tend to tighten the car.

Before you install a new spring, compare the freestanding height to one another. Stand the springs side by side and note if the new spring is longer or shorter. If it is, note the amount and adjust the spring height accordingly. If the new spring were 1/4" longer in the above example, we would have adjusted the ring up by 1/2" minus the 1/4" the new spring was longer by for a net change of 1/4".

Again, this sounds very basic, but too many teams do not understand the concept. In keeping with the rule to only change one thing at a time, you would want to see the effect of the spring rate change only and not that of a new cross-weight percentage.

Reweigh the car or recheck the ride heights after each spring change to make sure the percentage of cross-weight is the same as before the change. A good idea is to make up combinations of springs and shocks and install them in the car at the race shop. Make a note of the positions of the adjusting ring (or bolt). Then if you decide to make a change at the track, you will know where to put the adjusters for that particular spring so the spring change will not affect the original weight distribution.

## Wheel Rate

Wheel rate is defined as the spring rate calculated at the wheel in a double A-arm front suspension. The rate, position and angle of the spring dictate what the wheel rate will be for your car. If you try to set up a big spring car to handle the same as a coil-over car, you will need to know the wheel rate that is best for your track in order to maintain the same wheel rate, and therefore the same roll angle.

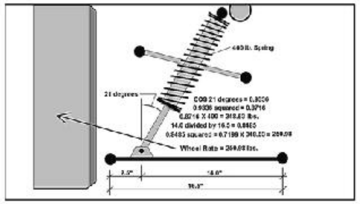
The idea is to find the wheel rate and then reverse engineer to find the rate of the new spring so that the wheel rate remains the same. Many times a team will have great success with a stock coil car and then build a new coil-over car and struggle to find the best combination of springs. With the following method, you can duplicate the old cars wheel rate.

***Calculate Wheel Rate***—Let's say you are using a 400-lb RF spring in a coil-over car with good results. You have a backup car that is a big spring design, and you want to install a spring that will give the same wheel rate. If you use the following equation, you can calculate the wheel rate for the coil-over car with a 400-lb spring. See the figures on page 45 for an illustrated example.

Be sure to measure your spring rate first to make sure what you have been running. Also measure the new spring for the same reason. We need to know the exact spring rate for each spring. This function is for front spring changes only. There is no way to duplicate the wheel rate for rear springs installed on a straight axle car. This is a much different system and does not act dynamically like the springs in a double A-arm system.

**WR = Cos (SA)$^2$ x (CAL - BJ-SP ÷ CAL)$^2$ x SPR**
**Cos = the Cosine function of the angle in degrees**
**SA = shock angle in degrees**
**BJ-SP = ball joint to spring distance**
**CAL = control arm length**
**SPR = spring rate in lb per inch**
**WR = wheel rate**

$$\text{SPR} = \frac{\text{WR}}{\text{Cos (SA)}^2 \times \left(\dfrac{\text{CAL minus BJ-SP}}{\text{CAL}}\right)^2}$$




**The wheel rate is calculated to be 250.98 lb-in of travel at the wheel. If we want to find the correct spring to install in our big spring car, we can use the formula above.**

The illustrations above demonstrate that you can go from the wheel rate calculated for a coil-over car to an equivalent spring rate in order to find the correct spring rate in a big spring, so that this car will handle the same as the one with coil-over springs. This method only matches one component that makes up the whole setup. Weight distribution and moment centers will also affect the way each car handles and must be evaluated also.

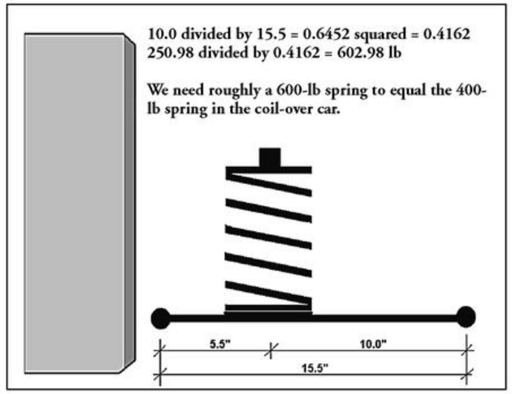
We are not saying that this alone will duplicate the setup for the new car. This is only one component, but a very important one. Measure your moment center and load distribution and use the setup software to find the correct rear spring rates and weight distribution.

## Spring Bind and How to Avoid It

One effect that can ruin an otherwise great setup is spring bind. That is when one or more coils of the spring contact each other or a part of the car's suspension or shock body. This will effectively eliminate some length of the spring from compressing. With less length of spring able to bend, the spring rate will increase. The balance we thought we had will no longer be true.

When the car goes tight or loose due to the binding of one or more springs, we usually read this as a setup problem. The bind should be found before the car goes to the track. Look the entire car over with an eye for these kinds of problems. Look at the shock body to note any rubbing of the paint or other indications.

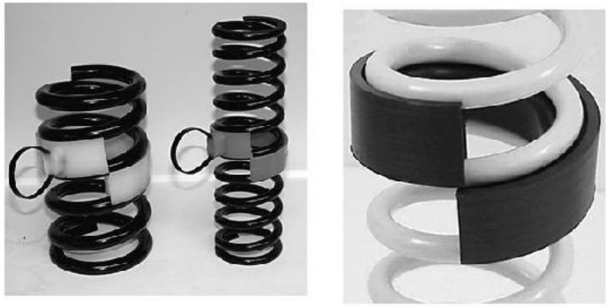
***Spring Bind Affects Setup***—A very common problem happens when the spring contacts part of the top or bottom retainer that locates and holds the spring. The retainers should be tapered so that the only part of the spring that touches it is at the base or the very top of the spring. Taking one coil away from a 1000-lb big spring can increase the spring rate several hundred lb. That has a huge effect on the setup.



**Using the spring rate formula knowing the wheel rate, we calculate a correct spring rate to install that is 602.98 lb-in. So, if we install a 600-lb spring in our big spring car, we will be very close to the same wheel rate and performance as our coil-over car. We would do this for each of the front corners of the car to match springs to wheel rate.**

Straight spring buckets are fairly common. If the bucket is sized large enough and has an inner ring for the spring to sit on and keep it centered, then it will be okay. But, if the spring bucket is too small, the spring will make contact with the sides, and problems will occur.

**In this example, the top retainer is conical in shape and has no effect on spring bind. The bottom retainer is tubular and is large enough that there is no chance of it contacting the spring coils and causing an increase in spring rate. Make sure your spring is aligned with the upper and lower mounts when it is compressed at mid-turn height.**



**Spring rubbers come in different rates, or hardness, and styles. They can be used with the large stock type of coil springs or the coil-over sizes. The longer coil-over springs have more room to place multiple rubbers.**

## Coil-Over Spring Bind

In a coil-over shock setup, spring bind can occur if the spring contacts the shock. Look for obvious signs of wear on the insides of the spring and on the shock body or threaded portion at the height adjustment end. Always make sure the spring caps on the coil-over shock are seated when you take the car off the jackstands. These caps have a tendency to unseat and hang up when the car is jacked up.

There are special seating springs available to keep tension on the spring when the car is jacked up. These are beneficial for short spring installations. A hung spring cap can alter the weight distribution and dramatically change the handling of the car.

## Incorrect Spring Seats

Inspect the spring seats on a big spring car to make sure the open-end wire angle is the same as the angle in the seat in the lower control arm. A mismatch here can cause spring bind by misaligning the spring and causing the coils on one side of the spring to contact each other. Different springs are made with different coil angles. So, the bucket must be built to the design of the spring. Some manufacturers use a flat bottom spring bucket and then offer aluminum inserts that are made to different angles to fit your particular spring.

Different spring manufacturers may build springs with different wire angles, depending on the rate and number of coils. Lower control arms vary as to the bucket design related to spring coil angle. If a stock Cup car was designed to run 1000-lb springs and you race with 600-lb springs, then there is a very good chance the bucket angle in your car is different from the spring you are using. Try to find a brand of spring that is designed to match the bucket angle of your car.

## Spring Rubbers

We preach having a balanced setup, and whether you dial your car in by trial and error or with the use of computer software, changing spring rates is all part of the process. The truth is, we can balance the setup in the car through the use of many different combinations of spring rates. The middle of the turns must remain balanced, but what we might need to improve is the entry and exit. Various front and rear spring split combinations will feel different to the driver and may result in a change in performance.

One way to quickly enact a spring rate change in our cars is by the use of spring rubbers that increase the rate of the spring. This is useful with asphalt stock cars, and almost essential with dirt stock cars. The spring rubber causes an increase in the rate of the spring by eliminating the effectiveness of one coil in the spring. We can even use multiple spring rubbers in a spring if that will provide us with the necessary change we seek.

***How to Rate a Rubber—***The success we will have using spring rubbers is only as good as our knowledge of how much the spring rate changes. The rate change for a particular size and hardness of spring rubber is different for each different rate and design of spring and for different amounts of preload on a certain rate of spring.

If I install a 25 ppi spring rubber in a 200-lb spring, the amount of rate change will be different as the magnitude of preload on the spring changes. That is because a 200 lb-in rated spring that holds up 950 lb will be compressed 4 3/4" where as a 200-lb spring that holds up 500 lb will only compress 2 1/2". That means there is a different gap between the coils for each application and the spring rubber will be compressed more in the spring that supports 950 lb than the one that supports 500 lb.

It is also true that if we change to a 150 lb-in rated spring in place of the 200-lb spring, the compressed height on the corner holding 950 lb will be 6 1/3" and the spring rubber will be compressed even more yielding a greater spring rate of its own.

The correct way to rate a spring rubber for a particular use is to do it like we rate a spring, in a spring tester. We first install the spring without the rubber in the tester. We need to compress the spring to the same compressed length as when it is installed in the car with all of the competition related weight in the car. Then we rate the spring in the next inch or two. This establishes the actual installed rate of the spring itself.

Next we relieve the pressure on the spring and install the spring rubber. We then repeat the process and compress the spring to its competition height and go another inch or two and record the rate. Whatever the increase is over the spring-only rate is the rate of that spring rubber for that corner of the car and that particular spring.

We can have several springs that are rated the same in lb-in, but have a different number of coils and/or diameter of wire. This difference in construction means they will be different in the size of the gap between coils and therefore a difference in how much a particular spring rubber will affect the spring rate.

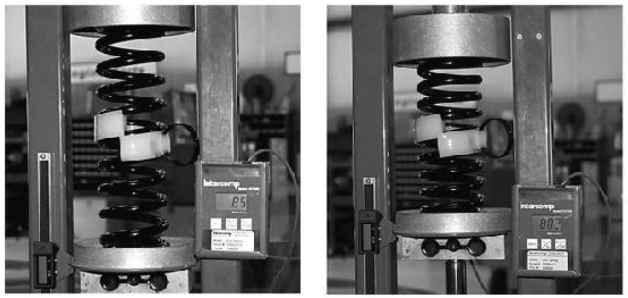
***Uses for Spring Rubbers***—The times we might need to use spring rubbers are for compensating for changes in the race track surface grip as on dirt throughout the day and night and to effect changes in handling for entry and exit to and from the corners.

Many dirt tracks start out wet and tight and usually transition to a more slick condition as the event goes through the stages of practice, qualifying, heat races and the main events. The spring rates must change as the track loses grip and we can utilize the spring rubbers to adjust to the conditions.

We would install the best spring combination for the slick conditions as our original setup and then install spring rubbers at one or more corners to get the car setup for the tighter track condition early on in the event. Then as the track dries out, we can remove the spring rubbers.

## Changes in Flight

We can install several rubbers of a softer compound at one corner so that we can make two changes as conditions deteriorate. An example would be to install a 150-lb spring in the RR corner that would be great for a dry slick track. Then we could add two 25-lb spring rubbers to that spring and start out the day practicing and maybe qualifying with the equivalent of a 200-lb RR spring.



**The space between the coils is greatly diminished when we have the full preload on the spring. The view on the left is an unloaded spring and on the right a spring with average pre-load. The space difference affects the rate and effectiveness of the spring rubber.**

**Spring Rubber Test w/ a 250 lb. Spring**

**The 250 spring rated @ 250.8 lbs. per inch at 4 inches**

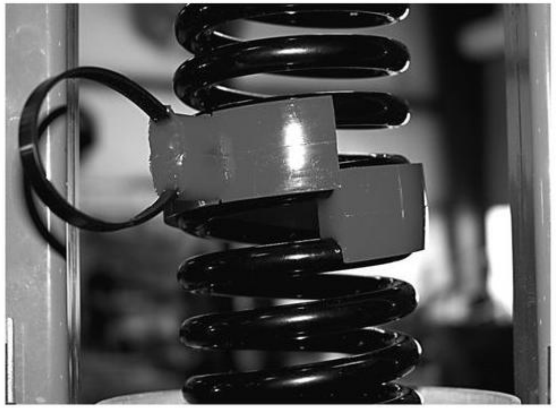
| | Total Pre-load @ 4" | Total Spring Rate | Spring Rubber Rate |
|---|---|---|---|
| Soft | 1052.5 | 263.1 | 12.3 |
| Medium | 1086.9 | 271.7 | 20.9 |
| Hard | 1098.3 | 274.5 | 23.7 |

**We can see by this chart how the spring rate increases with the use of different hardness of spring rubbers. We should always rate the spring at or near its installed height to get accurate results. Then we will know exactly how much our spring rates are with the use of each spring rubber.**

When the track has begun to dry out somewhat, but is not yet dry slick, we can run our heat races with only one spring rubber for a combined 175-lb rate. Then if the track becomes dryer and more slick, we can yank the remaining rubber out and be set for the main event.

For asphalt, we might want to experiment with various amounts of spring split in the front and rear. Spring split up front usually does not greatly affect the middle handling, but can help our entry into the corner on some types of track. If we run an equal rate of springs across the front, we can experiment with a reverse spring split up front by installing a 50-lb pre-rated spring rubber in the left-front to see if having a 50-lb split helps corner entry. Many times it will help the transition into the corners on the flatter race tracks.

**Note the difference in space between the coils outside the spring rubber and the space inside the rubber. At full preload, the rubber effectively takes almost 100% of one coil out of the spring equation.**

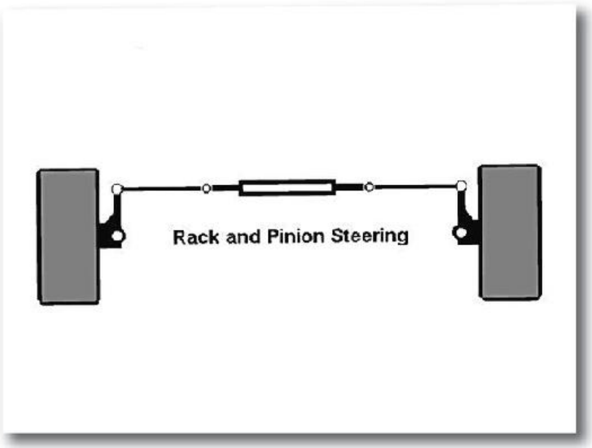


Changing the spring split in the rear greatly affects the mid-turn handling, so we need to be careful when making changes to the rear springs in order to affect corner exit performance. An example is when we are using a 25-lb spring split (RR softer than the LR) in the rear to help bite off the corner, we can install a 10-lb rated spring rubber in the RR spring to see if only a 15-lb split will suffice. The panhard bar height will need to be lowered along with this spring change in order to remain neutral through the middle of the corner.

The advantage in using spring rubbers to change our spring rate on each corner of the car is the speed and ease of making those changes. We just need to be sure not to guess at the resulting rate change when we throw in the rubbers. Use a spring tester and rate your spring rubbers for each corner and each spring that will be used in that corner. Then the change in rate will be predictable and we will be able to see the true results.

## Chapter 6

### The Steering System




**A simple rack-and-pinion system. We can see that this system is pretty straightforward. The rack goes back and forth (side to side) and it moves the tie rods and steering arms back and forth to turn the wheels. Both wheels will turn about the same amount of degrees with small amounts of steering input. The offset of the rack fore and aft, as well as the steering arm angles from a top view, will determine if this system has any Ackermann effect.**

The steering system is a very important component of a race car, and it is very important that you understand its function and how important it is to handling. Historically, car builders and racers have altered stock steering systems and substituted steering components for various reasons. The most common reason is to save weight by substituing lighter, compact-car spindles on larger-model stock cars. For this reason, you need to be aware of how the steering system works and be able to recognize if your steering system has any problems.

The stock-type, heavy spindles usually come with older model full-sized cars, just the kind of chassis that modified and stock-clip stock cars are made from. The lightweight spindles that a lot of racers use to save weight on those same cars come from compact and subcompact cars that sometimes use a steering system different from that used on bigger cars.

There are two basic steering systems found in stock cars today: the rack-and-pinion system and the drag link system. Each system works differently from the other, so it is important to understand how each one is designed and intended to work, and to make sure that parts belonging to one are not mixed with the other.

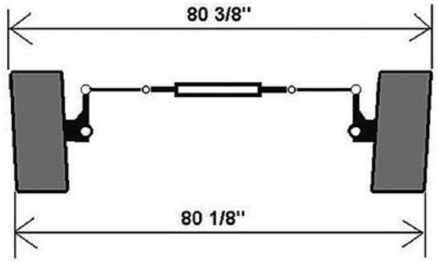
### The Rack-and-Pinion System & Ackermann

In a front-steer car (where the steering mechanism is in front of the axle), if the rack is mounted behind (to the rear of) the outer ends of the tie rods, then as the steering wheel is turned, the outer ends of the tie rods will move toward the rear of the car and the tie rods will straighten out, causing the distance between the outer ends of the tie rods to increase. This would create the *Ackermann Effect* that would cause the front wheels to toe-out more and more as the steering wheel is turned until the tie rods formed a straight line. The reverse would begin to happen (loss of toe) if you continued to turn the steering wheel.

***Ackermann Effect Overview***—For both the dirt racers and the asphalt teams, modern setups dictate a closer look at many areas of chassis geometry and alignment. If we prioritize the various areas of concern, Ackermann would rank right up there near the top. Modern setup trends dictate that we need to take a closer look at our Ackermann situation.

Years ago it was fairly common to see a dirt car with the LF tire up off the track in the turns or see tire temperatures on an asphalt car's LF tire that were the coolest of the four. These were the result of unbalanced setups where the rear suspension desired to roll much more than the front suspension. In those days, Ackermann could be desirable, or at least less harmful to our handling (if the LF is off the racing surface it can do no harm).

The Ackermann Effect is a mechanical phenomenon that is associated with an automobile's steering system. A steering design that incorporates Ackermann causes the inside (closest to the radius of the turn) wheel to turn a greater amount than the outside wheel. We do need a slight difference in steering angle between the front tires because the inside wheel runs on a smaller circle or arc than the outside wheel. The key word here is "slight."




**Ackermann Effect is actually the addition of toe-out to the car when the wheels are turned. To measure toe, we measure between the front of the tires and the rear of the tires and subtract. This car has toe-out, meaning the front of the tires are wider than the rear. If we subtract the rear (80 1/8") from the front (80 3/8") we see that this car has 1/4" toe-out.**

Ackermann is named after the man who did extensive research and development on the subject. Early on in basic automotive design and development, engineers discovered the need to design a system for steering a production car so that each wheel tracked correctly when the car was negotiating a turn. The ideal system would compensate for large radius turns as well as for tight, "turn right at the stop sign," type of smaller radii turns.

Zoeken

An early story offers that many of the very first owners of automobiles were concerned about tearing up their circular, gravel driveways, and the Ackermann helped keep the wheels tracking correctly and reduced the primary cause of rutting in the driveways. Modern racing stock cars have little in common with production cars, so we need to readdress the issue of Ackermann.

***Do We Need Ackermann in Our Race Cars?***— There have been many opinions about the use of Ackermann in our race cars and whether it really helps. Numerous older books and articles on the subject extol the benefits of Ackermann to help the car to turn. Were these articles correct about this subject? The answer is Yes and No. Here is why.

In our past, going back some thirty years, the suspension and steering systems in oval track stock cars were strictly stock units that exhibited characteristics of the original intended use, driving around the neighborhood, primarily. Converting the car to circle track racing was beyond its original intended use. So, it is easy to understand why some of the stock systems may not work very well on the race track.

Early crew chiefs did not understand, nor had the technical knowledge to develop what we now know as a balanced setup. This is where both of the suspension systems are working together and doing the same thing when the car is in the turns. This balance makes a lot of good things happen including helping all four tires work harder, and providing consistency in the handling balance between tight and loose.

Since many cars in the past were not properly balanced, the left front tire usually carried less weight and did little work. This was evidenced by several indicators:

1. Cool LF tire temperatures compared to the LR tire
2. A need for a very stiff RF spring as the RF corner took most of the front load of the car in the turns
3. Excess RF tire wear and heat, and for dirt, a LF tire that had no contact with the racing surface much of the time. If the LF tire had little or no weight on it in the turns, then teams discovered that excess Ackermann actually helped the tire to generate more heat and turning effort when it was in contact with the track.

***Modern Day Trends in Setup***—In today's racing world, the dirt cars are more balanced in concept and the LF tire does much more work. This trend has made the dirt cars more consistent and faster under most conditions. With the asphalt teams, we see a move towards larger sway bars and softer springs. This arrangement causes the LF tire to be much more in contact with the racing surface and to work harder than ever before. If the front tires don't track exactly where they should, there will be problems getting the car to turn.

When we have Ackermann Effect present in our steering design, it means that the toe-out is increased and with reverse Ackermann, toe is reduced when we turn the steering wheel. There are different static settings for front-end toe that are dependent on the size of the race track, the banking angle and the type of tire used. Most short track stock car teams use toe-out to stabilize the front end and keep it from wandering back and forth across the track. Conventional wisdom tells us that the car will need more static toe-out for the smaller radius tracks. At big race tracks of more than a half-mile, less toe-out is required. The amount of toe-out used typically ranges from one-sixteenth to one-quarter of an inch.

The truth is, we need very little Ackermann Effect in most situations when racing on an oval track, be it dirt or asphalt racing. Even on very tight quarter mile tracks, the LF wheel will only need an additional 1/16" of toe over the RF wheel to correctly follow its smaller radius arc. That is 0.112 degrees or a little over one tenth of a degree. You can imagine my reaction when a racer tells me that they only have a couple of degrees of Ackermann in the car. A degree of Ackermann equals 1/2" of toe for an 85" circumference tire. So, if we have two degrees of Ackermann in our steering systems that would equal an additional inch of toe when we turn the steering wheel. We would never think of setting an inch of static toe in our cars and then go racing.

While this all points to the fact that we all need a correctly designed steering system, many racers and car builders may not fully understand the steering systems in their cars and how they work to produce or cancel Ackermann.

***What Causes Ackermann?***—There are several different ways that your car could be producing Ackermann effect. The most common is when we install the wrong spindles or other steering system components on our car.

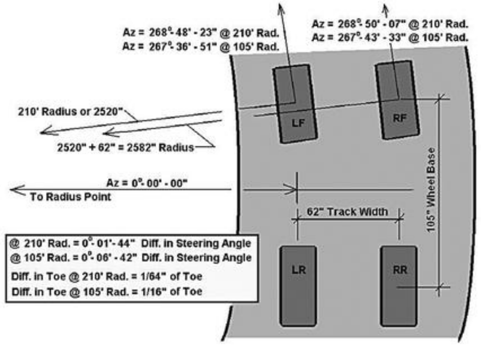
Over the last few years, teams and car builders have worked hard to reduce unsprung weight—the weight of the wheel/spindle assembly. One way to accomplish this was to install a lighter spindle.

The stock type spindles with top view angled steering arms were intended to be used on the stock based drag-link steering systems. When racers started using the lightweight rack steering arms on the drag-link system, it produced a considerable amount of Ackermann effect and caused a considerable gain in toe when the steering wheel was turned.

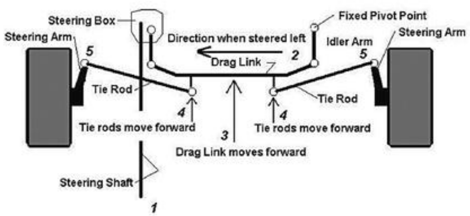
At first, car builders began using smaller, compact car spindles on the full-sized cars stock front ends that were designed with the drag-link steering system. At the same time, custom spindles were being fabricated for the newer design and very popular rack-and-pinion steering system. These later spindles were different in design from the stock spindles because they had steering arms that were pointed straight ahead from the ball joint instead of being angled in from a top view at the tie rod end like the ones used on the drag-link steering systems.

In the mid-1990s, some car builders swapped the heavy cast iron stock car spindles that had been used with their stock based drag-link systems for the lighter rack spindles that were intended to be used on the rack system. The result was a steering system that produced excess Ackermann effect. This hurt the turning performance on those cars.

A very few racers figured out what the problem was, corrected it with different length steering arms and dominated racing during that period because their cars turned better than the competition. Today, with our better understanding of how Ackermann works, and what amounts our cars really need, we can measure our Ackermann and correctly adjust out any excess toe-steering quickly and easily. Remember, no amount of chassis setup adjustment will overcome excess Ackermann effect and the loss of front grip associated with it.




**Here are some very accurate calculations that were made using a commercial civil engineering coordinate geometry software program to see just how much Ackermann is really needed. The results indicate that we do not need whole degrees of Ackermann, but decimals of degrees.**




**A drag-link system is correctly designed with angled steering arms. The system inside the steering arms will produce unwanted Ackermann effect which needs to be canceled. The result of turning the steering wheel is as follows:**

1. **The driver turns the steering wheel left.**
2. **The drag link moves to the left.**
3. **The drag link moves forward as the Pitman arm and the Idler arm rotate around fixed points.**
4. **The inner tie rod ends move forward with the drag link.**
5. **The outer tie rod ends (at the forward ends of the steering arms) are forced wider apart as both tie rods become less angled from a top view creating additional toe-out. The angled steering arms produce a Reverse-Ackermann Effect which serves to cancel the system's attempt to spread out the wheels. So, the system shown can produce very little Ackermann Effect.**

**By using a precise laser alignment system, such as this one from True Laser Track, we can measure the amount of steering in each front wheel to determine if we have either Ackermann or Reverse Ackermann. The movement in inches of the laser dot on the target is translated into exact toe gain or loss. No method is more accurate than this.**

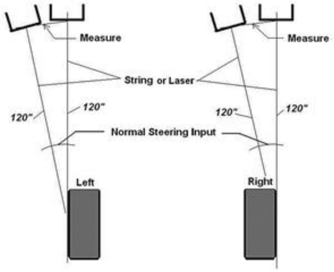
***How to Check for Ackermann Effect*****—**There are a few ways to check for excess Ackermann in our race cars. The best way is to use a laser alignment system to measure how much each front wheel turns and compare the two. The laser system can also be used for rear end alignment, right-side tire alignment and bump steer.

A less expensive, but adequately accurate method is to use strings to measure your Ackermann. I have used this method and if done carefully, it will yield the results we are looking for. Almost everyone has used strings to align a race car. A string pulled tight is always straight, we can count on that. So, if we pull a tight string across the outside of each front wheel and extend the string to the front ten feet, we can take the measurements necessary to see how much Ackermann we have.

**Ackermann Toe Chart**

| Difference @ 10 feet | Average Tire Circumference 80" | 82" | 84" | 85" | 86" | 87" | 88" |
|---|---|---|---|---|---|---|---|
| 0.25" | 0.053 | 0.054 | 0.056 | 0.056 | 0.057 | 0.058 | 0.058 |
| 0.50" | 0.106 | 0.109 | 0.111 | 0.113 | 0.114 | 0.115 | 0.117 |
| 1.0" | 0.212 | 0.218 | 0.223 | 0.226 | 0.228 | 0.231 | 0.233 |
| 1.5" | 0.318 | 0.326 | 0.334 | 0.338 | 0.342 | 0.346 | 0.350 |
| 2.0" | 0.424 | 0.435 | 0.446 | 0.451 | 0.456 | 0.462 | 0.467 |
| 2.5" | 0.530 | 0.544 | 0.557 | 0.564 | 0.570 | 0.577 | 0.584 |
| 3.0" | 0.637 | 0.652 | 0.669 | 0.677 | 0.684 | 0.692 | 0.700 |

**This chart shows how much difference in turning distance at 10 feet relates to toe. For an 86" circumference tire, a 1 1/2" difference between wheel movement at 10 feet out results in 0.342" of additional toe. When doing this test, take note which side turns more. If the left wheel turns more than the right wheel, you have Ackermann. If the right turns more, you have reverse Ackermann, and the car is losing toe.**




**A very simple yet accurate way to measure Ackermann is to use a laser or string to project the alignment of the wheel/tire out in front of the car. If you place targets in front of the tires at a distance of exactly 10 feet from the center of the hub, you can mark where the tires point at straight ahead and then at wheels-turned positions.**

The procedure is as follows:

1. Put the front wheels straight ahead.
2. Pull a string across the outside of each front wheel and place a mark on the floor (on a piece of masking tape) where straight ahead is.
3. Turn the steering wheel approximately the same amount the driver would in the turns where you race.
4. Pull a string extending from the outside of each front tire and place a mark on the floor at ten feet.
5. Measure between each set of marks for each wheel and compare the left wheel with the right wheel.

The Ackermann toe chart at left shows how much toe gain relates to differences in the left and right wheels for different size tires. We can average the left and right tire sizes and look at that number when finding our Ackermann on the chart. Remember that if the left wheel moves farther than the right wheel, then we have Ackermann, or toe gain. If the right wheel moves more than the left wheel then you have Reverse Ackermann or loss of toe.

***Solving the Excess Ackermann Problem***—If your car gains or loses toe, there are a couple of ways to correct the situation. You can adjust the length of your steering arms to compensate for Ackermann Effect. This works best for a car that always turns left as opposed to a dirt car that sometimes has the wheels turned to the right. Lengthening the left steering arm will reduce the amount that wheel turns, which reduces Ackermann Effect. The opposite being true for the right steering arm—we would need to shorten it in order to reduce Ackermann. We can also change our drag link to move the inner ends of the tie rods forward to reduce Ackermann or rearward to reduce reverse Ackermann Effect.

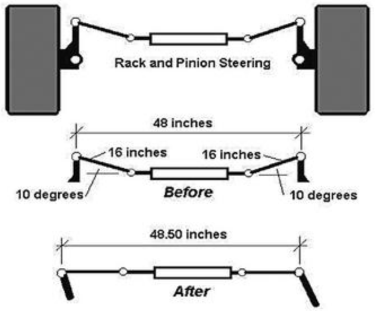
**This spindle has a slotted hole where the tie rod end mounts to the steering arm. This allows the team to adjust the length of the steering arm to control the amount of Ackermann effect.**

If your spindles were not designed for your steering system, change to the correct spindle design and possibly have some light weight ones fabricated to the exact specifications as the correct ones.

For a rack-and-pinion steering system, moving the rack forward in relation to the outer tie rod ends will reduce Ackermann. This works well for turning left or right. The same effect can be had by moving the drag link forward in a drag-link steering system and again the effect is the same for steering left or right.

**Caution**: Do not make spindle changes without knowing how the change will affect your moment center location. You may be making a positive change in your steering system and a negative change in the moment center design. This problem relates to spindle height differences where the upper and/or lower ball joints will change height with a spindle change. This changes the upper and/or lower arm angles and along with that, the moment center location.

Make sure you know how much each of your tires is steering and reduce the Ackermann effect if needed. Then, when you balance your setup, both front tires will be working in perfect alignment to steer your car. A good steering race car is one that will have more turning power and is therefore more capable of running up front and winning races.

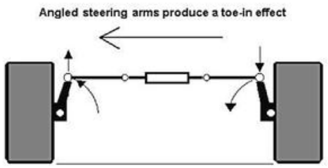



**Angled tie rods will produce Ackermann Effect (toe-out) as the wheels are turned because the outer tie rod ends move to the rear as the wheels are turned, causing the distance between the outer ends of the tie rods to increase.**

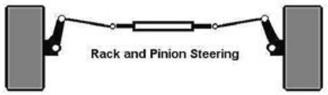
***Straight-Ahead Steering Arms***—Rack-and-pinion steering systems with straight-ahead steering arms will need the rack to be mounted a small distance to the rear of the outer ends of the tie rods so that as the steering arms move, the outer ends of the tie rods will never be behind the inner ends of the tie rods. That would create a condition where the wheels would begin to toe-in. There will be a slight amount of Ackermann, but not so much as to be detrimental to performance.

***Angled Steering Arms***—When you use spindles that have angled steering arms (angled in the top view in relation to the centerline of the car, with the tie rod ends closer to the centerline than the ball joints), along with parallel tie rods, you can expect them to produce a certain amount of toe-in, or Reverse Ackermann, as the steering wheel is turned.

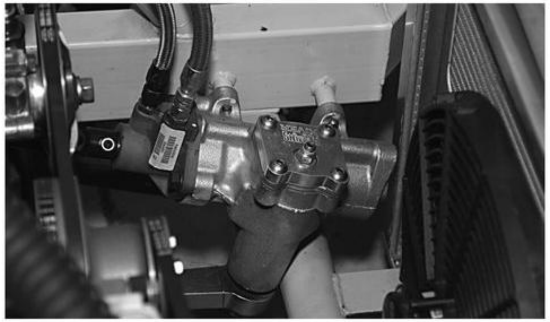
That is because, as the car is steered to the left, the left steering arm turns a lesser number of degrees than the right steering arm. Since the right steering arm turns more (along with the wheel) than the left steering arm (and wheel), then you will lose toe and the front wheels can end up with some amount of toe-in. **With each inch of lateral movement of the ends of the steering arms, the left wheel will turn less degrees than the right wheel. Example: With the first inch of tie rod movement, the left wheel turns 9.88 degrees while the right wheel turns 10.53 degrees. At two inches of tie rod movement, the left wheel urns 19.47 degrees and the right wheel turns 22.34 degrees creating quite a lot of toe-in. This represents Reverse Ackermann.**




**In this system, there will be very little Ackermann or Reverse Ackermann Effect because the tie rod ends will move in opposite directions when the car is steered. This cancels any Ackermann effect. Note that the tie rods are at approximately 90 degrees to the steering arms. The zero Ackermann Effect is the same for left or right hand turns and this makes this system ideal for road racing.**




**The drag link system is one where the steering box is located in front of the crossmember and the steering arm is attached to the drag link. The tie rod is attached to the drag link and is sometimes bolted through a slug that provides some adjustment for bump steer, or the drag link can be spaced vertically to adjust bump-steer.**



The middle illustration on this page shows what the system would look like to produce approximate parallel steering with zero Ackermann Effect.

## The Drag Link Steering System

The other common type of steering system is the drag link system. It is so named because the Pitman arm on the steering box rotates to "drag" a link side to side to which the tie rods are attached. This link then pushes the tie rods in the direction you want to turn in a front steer car. Front steer, where the steering box is located in front of the ball joints, is the most common type drag link system being used today.

There are two important things to remember about the drag link system. First of all, as the drag link moves to the side, it also moves toward the front of the car. The tie rods are angled from a top view with the outer ends more forward than the inner ends. Since the drag link moves forward, the tie rods will become more parallel, causing the distance between the outer tie rod ends to increase when the steering wheel is turned. This could cause Ackermann.

***This System Works to Cancel Ackermann Effect***—Since the increase in distance between the outer tie rod ends creates additional toe-out, you would end up with way too much Ackermann in the turns. The element of the system that cancels that tendency is what we have just talked about, and that is the angled steering arms.

As the drag link is moving the inner tie rod ends forward, causing the outer tie rod ends to want to move farther apart, the angled steering arms are steering a different angle from left to right causing an opposite reverse Ackermann, or toe-in, effect. If the system is designed correctly, the two effects cancel each other out.

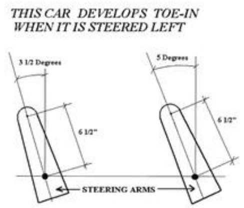
***How Steering Can Go Wrong***—Here is a situation where the car builder or team can upset the whole system. Suppose you take either system and substitute spindles from the other system. Teams do this to reduce the unsprung weight on the car. You can see where it can create a lot of problems from what you have just learned. When spindles with angled steering arms that were designed for the drag-link system are used with a rack-and-pinion system, they will create a good deal of toe-in when the steering wheel is turned.

## Rack Spindles on Drag Link Cars

If you put the spindles designed for the rack-and-pinion system, which uses more straight-ahead steering arms on a drag link system, you would end up with too much toe-out, or Ackermann, when you steered the car. This has been done a lot in the past and most car builders understand the problems this has created and are now wise to the effect. But many teams might mix and match parts and get this wrong.

## Check Steer Toe to Make Sure

Since these two steering systems are so complicated in design, the easiest way to check your car is to use either a string or laser system (toe plates are not accurate enough for this important check). The wheels need to be checked in both the straight ahead and turned positions.




First point the wheels straight ahead and measure, either by running a string along the sidewall of the tire or by using a laser system, ten feet out in front of the center of the hub, and make a mark on the floor. Then turn the steering wheel approximately the same amount as you would at your speedway in the middle of the turns and make another mark for each side.

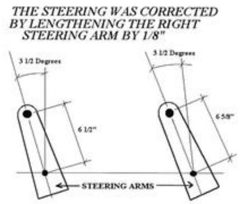
Measure the distance between the two marks for each wheel. The two should be equal if there is zero Ackermann. If the left marks are wider, then the car has Ackermann and if the left marks are less than the right ones, the car has Reverse Ackermann.

## Correcting Ackermann with Steering Arm Lengths

The easiest fix, but not the best one, to correct Ackermann problems is to change the lengths of one or both of the steering arms. Hopefully you will have adjustable steering arms for length. If so, shorten the right steering arm and lengthen the left steering arm to reduce toe-out Ackermann effect (usually caused by putting a straight steering arm spindle on a drag link system). Do the opposite to take out Reverse Ackermann Effect.

## Swapping Spindles

It is always best to use the correct spindles that were designed for your system. As mentioned in the beginning of this chapter, the drive to reduce unsprung weight in our race cars that has become prevalent over the last ten years or so has led racers and car builders to swap spindles around for the purpose of saving weight. What has happened to our steering systems because of that tendency is a lot worse than the added unsprung weight.




**Correcting Ackermann with steering arm lengths.**

We can have the best of both worlds by fabricating spindles that are light weight and still maintain the correct dimensions for our steering systems. Many car builders are doing just that. I had a team request a car builder to fabricate a lightweight set of spindles that matched the heavier stock cast spindles for a drag link late model stock car years ago. The car builder duplicated what we did and started putting the new spindles on his new chassis.

## Use Custom Spindles

When you change spindles, you might create a steering system that won't work to turn the car. It is a bad trade-off. The best idea is to find a manufacturer who can duplicate the correct spindles for overall height, pin height and steering arm angle, etc. and build those spindles with lightweight materials. Then you will have the best of both worlds: lower unsprung weight and a well designed steering system.

## New Spindles and Moment Center

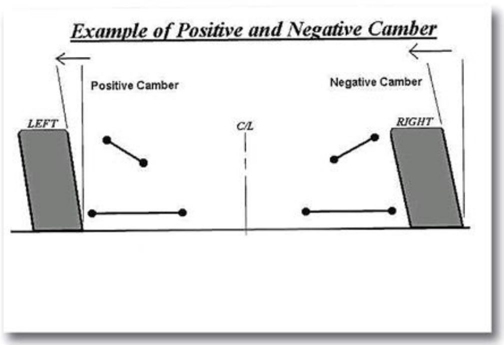
When thinking of ordering new spindles, keep in mind where your moment center is located. Don't change the spindle height or pin offset or you will inadvertently be changing your moment center location.

If you have been wanting to change your moment center location, now is the time to do it. Custom spindles can help solve the problem of changing the moment center location. If you need to take angle out of the lower control arms, a larger offset spindle (from the bottom to the spindle pin) will do that.

If you need more angle in your upper control arms, a taller spindle will help you do that without needing to change the chassis mounts. Many car builders are changing to taller spindles now for just that reason.

# Chapter 7

## Front-End Geometry




**Looking forward, driver's view. Here is an illustrated example of positive camber (leaning out) and negative camber (leaning in).**

Camber change characteristics, caster split, bump steer, Ackermann Effect, and toe settings have a great deal to do with the stability of the car in the turns. Note that I said "in the turns." This is exactly where you want to analyze all of these. It is important to analyze how the caster and camber of the front wheels affect your race car, so you will look at how each is influenced by the other and what settings of caster and camber may be best for different applications.

## Camber Change

Research done over the past 10 years has yielded some interesting facts about camber change. More recently, we have discovered more about ideal camber change.

While I was at a big asphalt Late Model race a few years ago, I was walking among the cars that had qualified in the top ten. They were lined up on the front stretch just before the start of the race. I couldn't help but notice that each of the cars had very different right-front wheel cambers. Some had barely two degrees in the right-front and some had what appeared to be a lot more than four degrees.

I'm sure each team had set up their car with what they thought they needed according to the tire temperatures, but the differences I saw told me that the suspensions on each of those cars had to be very different from one another.

If you need to use excessive camber in either of the front wheels, it can be an indication of a problem in the front-end geometry of your race car. It usually means that the car has a combination of front geometry that is causing too much camber change during cornering or the setup is putting too much weight on the right-front tire.

One very important ingredient for the total handling package is a front end that is set up for proper camber change characteristics. The relationship between the upper and lower control arm angles and the amount of dive and roll your car will experience at a particular race track will, in part, determine the amount of camber change. Camber change is also somewhat dependant on the degree of spindle inclination (king pin inclination) and degree of caster.

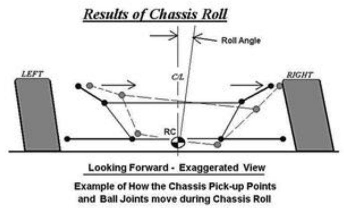
Most of us know that if the right-front tire is hot on the outside, you need more negative camber. You can usually adjust your front tire cambers so that the heat will be relatively even across the tire. But how do you know if you have the best design for camber change?

## True Camber Change Defined

True camber change is the number of degrees of camber that the front wheels lose or gain from static (down the straightaway) to dynamic (in the middle of the turns) chassis attitude. Remember that a car dives and rolls in the turns. There is an optimum amount of camber change for each of the front wheels. The amount of track banking is an important factor in determining the best design for your car. The camber change for your car can be very different between a flat track and one that is high banked.

Many racers try to determine the amount of camber change in their race cars by bumping the wheel with the car at static ride height. This procedure is an antiquated one and will not give you a true picture of your camber change characteristics.

The true camber change results from a combination of chassis roll, chassis dive, and to a lesser degree, steering input. You will need a geometry software program to correctly evaluate the true camber change in your race car. In a good program, you will be able to enter dive and roll numbers to simulate what the car is doing on the race track.




**Example of how the chassis pick-up points and ball joints move during chassis roll.**

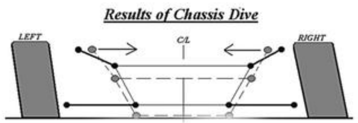
Before you get into the specifics of what makes up the best camber change design for a particular track, it is important to understand some basic information about how the cambers change in your race car. Just for clarification, negative camber is when the top of the wheel is closer to the centerline of the car than the bottom. Positive camber is when the opposite is true; the top is farther away from the centerline of the car than the bottom.

Here are the six most important components and effects that influence camber change: chassis roll, chassis dive, control arm lengths, control arm angles, king pin inclination/caster settings and spindle height. Let's look at each of these individually.

## Camber Changes as Chassis Rolls

As the car rolls in the turns, there are three things that happen to affect camber change. First the right-front wheel is in bump (moves up in relation to the chassis) and the left-front wheel is either in bump or in rebound (moving up or down in relation to the chassis). The next thing that is happening, and is often ignored, is that the chassis itself is rolling. As the chassis rolls, the upper chassis mounts are moving to the right (in a left hand turn).

If the chassis mounting points are moving, then so is the control arm and the upper ball joint as well. If the upper ball joint moves in relation to the lower ball joint, then you have a change of camber caused by chassis roll. Finally, as you turn the wheel, the caster and kingpin inclination affects the amount of camber change to some degree.




**Here you can see how the upper ball joints move inward during chassis dive.**

## Camber Change as the Car Dives

As the car dives, the upper ball joints are drawn in toward the center of the car. The lower ball joints are either drawn in or pushed out, depending on whether the chassis mounts are higher or lower than the lower ball joints. But because the lower control arms are longer and have less amount of angle than the uppers, the influence on camber change is much less. The upper arms have the greatest influence.

Both of the front wheels will gain negative camber (top moving inward toward the center of the car) as the car dives. At high-banked, high downforce tracks, close attention should be paid to the amount of camber change due to chassis dive.

## Arm Lengths and Camber Change

The lengths of the upper control arms will influence the amount of camber change that occurs in each front wheel. The correct arm lengths for your car will depend on the overall design of the front geometry relative to the race track you intend to compete on.

The best way to know how the arm lengths will affect the camber change in your car is to use a geometry software program that will allow you to install different length arms without changing the arm angles. Then you can see the camber change effects that different lengths have in order to decide which arm length is best for your car.

## Small Upper Control Arm Angles

The smaller the angle (from horizontal) that the upper control arms has, the less camber change that will result from chassis dive. A chassis with less upper control arm angle will also have more camber change resulting from chassis roll. The opposite is true of higher angled upper control arms.

So, the degree of angle you have in the upper control arms will influence the amount of camber change and the optimum control arm angles are determined by considering the degree of track banking angle. We will tell you more about this later.

## Camber Change Due to Degree of Spindle and Caster

The degree of spindle (or king pin inclination) and the amount of caster for each wheel will influence the amount of total camber change when the car is steered and both must be factored in when determining the exact total camber change that happens when you drive through the turns. There is a relatively small amount of effect from steering, but it must be included so that you can completely understand all of the effects.

## Camber Change from Steering Input

If you only look at camber change that results from steering input, you can come to some conclusions and learn the true amount of camber change associated with steering. Let's use, for example, a right-front spindle that has a 10-degree inclination and 5 degrees of positive caster.

If you turn the wheel left 90 degrees, the camber change from spindle inclination would be positive 10 degrees. The change associated with caster would be measured at full effect at 90 degrees of rotation. So the amount of camber change from caster would be a negative 5 degrees.

Since you work in the range of 5 to 10 degrees of steering input most of the time, let's look at how much camber change is associated with 5 degrees of steering input. If the spindle inclination produces a positive 10 degrees at 90 degrees of rotation, then it will produce 0.55 degrees of positive camber at 5 degrees of steering input. And, if the caster angle produces 5 degrees of negative camber in 90 degrees of steering input, then it will make 0.28 degrees of negative camber change in 5 degrees of steering input. If you subtract the two, the result is a camber change of positive 0.27 degrees of camber. That means you lose a quarter of a degree of our static camber from steering the wheel 5 degrees.

Then if you use the 10-degree right-front spindle and only 2 degrees of positive caster, the net change would be 0.44 degrees of positive camber or a loss of 0.44 degrees of camber from our usual setting of negative camber in the right-front wheel.

If you use a 5-degree spindle and 5 degrees of caster, the net change would be zero degrees of camber change. Because the change for both spindle inclination and caster are the same amount, one in the positive direction and one in the negative direction, they would cancel each other out.

For the left-front wheel, you can use the illustration on the next page (top right), but the difference is that the caster affects the camber in a positive direction, not negative as in the right-front wheel.

The spindle inclination still produces positive camber change at the left-front wheel. Therefore, because both are positive changes, you add the two numbers together instead of subtracting and since you need to reduce the loss of positive camber at the left-front wheel, the camber change associated with steering helps your left-front tire maintain the proper camber.

Therefore, a 10-degree spindle with 2 degrees of caster would produce 0.66 degrees of positive camber change in 5 degrees of steering input. This helps cancel the normal high degree of camber loss at the left-front wheel.

**Note:** A common combination for spindle inclination is to use a 10 to 12 degree spindle on the left and a 5 to 7 degree spindle on the right. This tendency makes more sense now.

## Camber Change Related to Spindle Heights

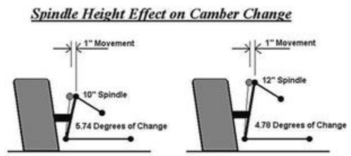
The height of the spindle is the measured vertical distance between the centers of the ball joints. Spindles come in many different lengths. But what is generally true is that the greater the spindle length, the less the amount the camber changes from dive and roll. It is reasonably easy to understand why.

***Longer Spindles Change Camber Less***—If the upper ball joint moves laterally one inch, the wheel will change its camber more with a 10-inch spindle than with a 12-inch spindle. The greater the distance between ball joints, the less degree of angle change that is produced with the same amount of upper ball joint movement, and, therefore, the less degree of camber change.

## Drawing Some Simple Conclusions

How do you put all of this information together into a design for a front end that you can use? Let's draw some simple conclusions from what has been presented.

***Track Banking and Camber Change***—As a rule, a flatter track will produce more of a chassis roll angle with less chassis dive. As the track banking angle increases, the amount of chassis roll decreases and the amount of chassis dive increases due to more downforce effect. The overall goal here is to produce the least combined camber change in each wheel, especially the right-front wheel, for each type of race track.




**The camber change for the 12" spindle is nearly one degree less than that of the 10" spindle with the same amount of ball joint movement.**

***Camber Change in the Right-Front Wheel***— The right-front wheel will either gain or lose negative camber, depending on the combination of control arm angles and lengths and the height of the spindles you use. What you really want is little or no gain in the negative direction, and you never want the right-front wheel to change camber in a positive direction.

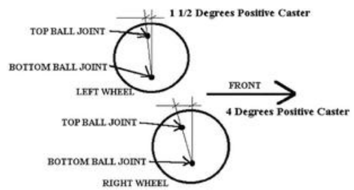
***Zero Camber Change at the Right-Front Wheel***—What the car wants is for the right-front tire to maintain the same camber as when the car first enters the turn and the tire first takes a set. If the camber changes after that tire takes a set, then it will give up traction and the front end will push.

The right-front tire takes a set fairly early on entry to the corner. Once that tire takes its set, it does not want any changes to the camber throughout the rest of the turn. What we once thought was ideal was for the right-front wheel to gain camber after entry. But through extensive testing and evaluation of hundreds of stock cars, we now know that the car wants zero camber change through dive and roll at the right-front wheel.

***Camber Loss at the Left-Front Wheel***—For stock cars that turn left, the left-front wheel will always lose much of its positive camber as the car negotiates the turn. At the left-front, you want to lose as little positive camber as possible so that you can start with the least amount of positive camber.

You will need to end up with about one-half to three-quarters of a degree of positive camber in the left-front wheel after the car dives and rolls and is steered. For both front wheels, the final tuning for the best static cambers is done by running the car and measuring the heat across the tires.

This is done only after the geometry has been correctly analyzed and designed. Be sure to also look at the tire wear to help determine the best static cambers.




**Caster stagger in a stock car.**

**The upper control arm bracket on this car is adjustable for height and the control arm shaft is slotted to adjust the amount of caster. The control arm is moved forward or backward to set the proper caster for each wheel.**

***Maintaining Correct Moment Center Location***—Throughout the whole process of perfecting camber change, don't forget to track where your moment center is located and be sure to keep it where it should be. The height and width of the moment center will change as you increase or decrease the upper control arm angles.

You can change arm angles and arm lengths and still keep your correct moment center location. Your moment center software will help you to make the correct changes to arm angles so that the moment center distance from centerline does not change.

As you have learned, the position of the moment center in relation to the centerline of the car is critical. Do not start changing arm angles and lengths to affect the camber change without tracking how each change affects your moment center location.

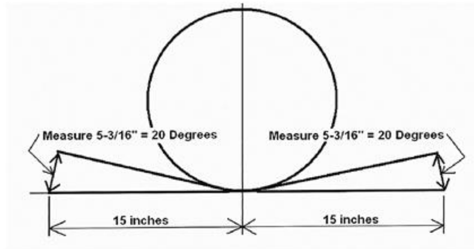
## Caster and Caster Stagger

Caster settings are primarily made in order to affect the amount of effort that goes into steering the car in the turns and to provide feedback to the driver. The amount of caster is often set according to driver preference.

***Caster Split***—For stock cars that turn left, the amount of positive caster used on the right-front spindle is more than what is used on the left-front spindle. This caster split (split is defined as the difference in the degree of caster angle between the right and left spindles) makes the car easier to turn.

**Use a caster/camber gauge to check the amount of caster in the wheel. Make sure to turn the wheel twenty degrees in each direction as designed into the etching on the bubble tubes. The SAE design criteria for checking the caster is based on that amount of steering and the equipment manufactured to measure caster is designed accordingly.**


**You may also want to use a newer design digital gauge that has a direct read-out. There are several brands available. These units must be tested and checked for accuracy before each use. There is a procedure for checking and zeroing these units, use it often.**

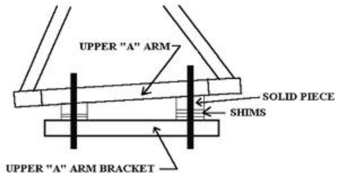



**This sketch shows how you must turn the wheels the correct number of degrees to check caster to come up with the correct number. Turning the wheel more or less than this will result in incorrect readings.**

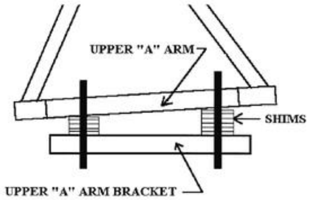
Too little caster split causes the driver to have to exert too much effort to steer the car and too much caster split will cause the driver to apply backpressure to keep the car off the bottom and in the groove in the turns.

The effect was much more important to drivers in years past when power steering was not as popular, and steering a stock car took a lot of effort.

***Caster Split Produces Neutral Steering***—The steering should be nearly neutral in the turn with just a small amount of left pressure needed to negotiate it. Always adjust the caster angle either by adjusting the position of the upper control arm frame mount bracket, or by having an offset upper control arm built that will position the upper ball joint where it will produce the desired amount of caster for each side.




**The right way to shim an A-arm.**




**The wrong way to shim an A-arm.**

## Shimming to Adjust Caster

Try not to use a different thickness of spacers in mounting the upper A-arm to the frame bracket to accomplish proper caster settings. This will torque the mounting bar and bend it, which will cause the upper arm pivots to bind. If you must adjust caster this way, use a solid spacer in addition to the shims and cut an angle in the face of the spacer so that the bar on the A-arm will seat flat without bending. See the illustrations at left.

***Caster Split at Big Tracks***—The caster split used on large and fast tracks such as Daytona or Charlotte is much less. Usually only 1 degree to 2 degrees of caster split is necessary.

## Bump Steer

Bump steer is undesirable anywhere on the track, but it is not acceptable at all when the car is in the turns. A common misconception is that if the car has zero bump steer when measured at static ride height, then it will be good to go all the way around the track. This may not be the case. In many cases, the car may have zero bump steer when measured at static ride height, and then when it is measured at the turn attitude, it will develop bump steer.

Using three-dimensional geometry software, we see the bump steer characteristics can change with some systems when the wheels move and the car attains the midturn attitude. This is where we least want bump steer to occur.

***Geometry Changes When the Car Is in the Turns***—When a car rolls, squats, and is steered, the whole front geometry layout changes. Every point of rotation is now in a different place and the chance that the bump steer is the same is very slim. It does happen, but not very often.

Bump steer can be one of those areas of race car setup that can mess up an otherwise good chassis. You should know how to check for bump steer, but let's examine how the components are supposed to be designed in order to achieve near-zero bump steer.

***Understanding Bump Steer***—First you need to understand a little about bump steer and what affects it. When the wheel moves up and down, most of the time you don't want the wheel to steer either way. There are different theories on this, but whatever you believe to be best as far as having some or no bump steer, if you know what affects the way a wheel steers when the wheel moves up and down, you will know better how to achieve the desired results.

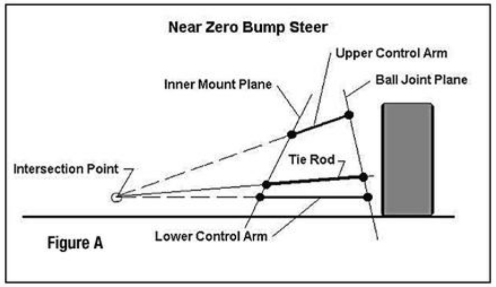
***What Causes Bump Steer***—Bump steer is influenced by the lengths and the angles of the tie rods and the position of the control arms. In the moment center chapter, you learned that when you extend a line through the centers of rotation of the upper and lower control arms toward the center of the car, the lines form an intersection at a point called an instant center.

## How to Achieve Zero Bump Steer

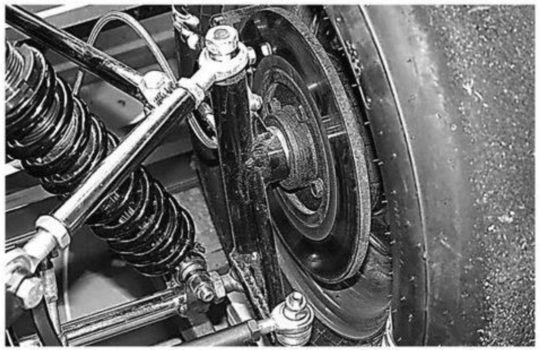
To have zero bump steer at a particular wheel, the tie rod needs to be at an angle so that a line extended through its centers of rotation toward the center of the car will intersect with the instant center formed by the upper and lower control arms. This is one of two elements that make up near zero bump steer. The other element is that the tie rod needs to be a specific length.

***Determining Correct Tie Rod Length***—Where the line through the centers of rotation of the tie rod intersects with two other lines or planes representing the inner pivot points for the upper and lower control arms (the chassis mounts), and the outer pivot points (the ball joints), that length or measurement of the distance between the intersection points between each plane should equal the length of the tie rod (see Figure A above).

***Tie Rod Lateral Position***—The tie rod does not necessarily have to be positioned exactly between the two planes, but it does need to be that same length as the intersection and it needs to be pointed in a direction so that its extended line intersects the instant center.




**The direction and length of the tie rods are critical to assure proper bump steer design**

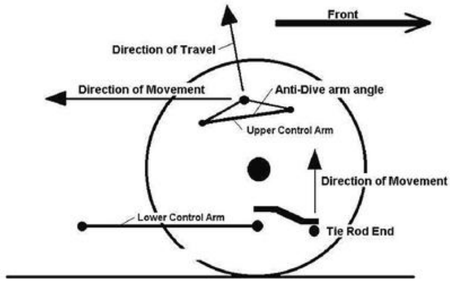


**The spindles built for this smaller-scale asphalt car are somewhat crude in comparison to the late model designs. Even so, they have proven to be sufficiently strong for the amount of weight and forces they will encounter. These types of spindles are very easy to modify for overall height, pin offset and kingpin inclination by a crafty crew. When manufacturers design and build cars that have faulty front-end geometry, correcting the situation should not be considered cheating as much as it is increasing the driveability, raceability and safety of the vehicle. Sanctioning bodies should welcome positive input about the way the cars are constructed if such input makes for more competitive and safer racing.**

On some cars, the tie rod is mounted at the same distance off the ground as the lower control arm. So, if you adjust the tie rod so that it is at the same angle as the lower control arm, you have achieved the objective of pointing it in the right direction. And if the tie rod is the same length as the lower control arm, then you should have near zero bump steer.

## Changes That Ruin Bump Steer

One way that bump steer can change, for the worse, is when you make changes in order to move the moment center. If you change the upper or lower control arm angles, which will affect the location and movement of the moment center, you also move the instant center point so that the tie rod may not be pointed toward it any more.

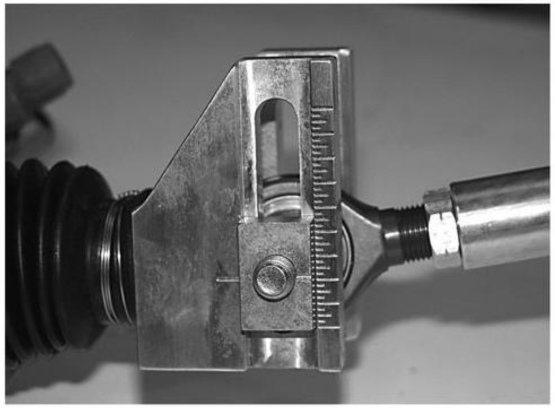



**You can see in this illustration that when the chassis dives during cornering or braking, with anti-dive, the upper ball joint moves rearward and that action rotates the spindle. As this rotation occurs, the outer end of the tie rod on that side will rise up and the tie rod angle will change, altering the bump steer characteristics. That is why we need to check bump steer when the wheel is in the position, relative to the chassis, that it will be at mid-turn.**

The greatest problem is when you make changes to the lower control arm angle by moving the lower ball joint or the inner chassis mounting point. Since the tie rod is usually mounted at nearly the same height as the lower control arm, the movement of either of these two points has a negative affect on bump steer. The tie rod angle must change along with the movement of these lower control arm points.

***Anti-Dive Affects Bump Steer***—Bump steer can be affected in another way. If you have anti-dive built into our front end, the caster for the wheel will change as the wheel moves vertically. If the caster changes, then the spindle will rotate from a side view and along with that rotation, the end of the steering arm moves vertically also. This means that the outer tie rod end will change its height and that will change the angle at which it is pointed in the direction of the instant center. If it was properly aligned when you were at ride height, it will probably not be properly aligned when the wheel moves vertically.

***Why Check Bump Steer at Turn Attitude?***— The above scenario is the primary reason to check bump steer at the turn attitude of the front end. Then factors such as caster change that affect bump steer can be taken into account.



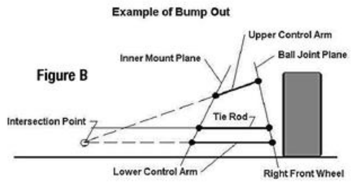
**The tie rod ends at the rack can be adjusted by using spacers to move the tie rod end vertically or by using the slotted ends shown here to adjust the angle of the tie rod for bump steer control.**

***Caster Change from Dive and Roll***—Dive and roll, as well as steering, affect all of the angles (control arms and tie rods). Sometimes a car that shows zero bump steer sitting at ride height may have an entirely different bump steer reading after the car is put in the attitude it will be in the turns.

***3-D Analysis***—Analysis with a three-dimensional software program has shown problems with some systems. The amount of bump steer sometimes changes after dive and roll and steering, but usually this is caused by an inherent problem with one of the basics components that affect bump steer, such as a tie rod that is too long or too short.

***Match the Attitude of the Car***—When checking bump steer, always consider what the wheel you are working on is going to do when the car goes through the turns. If you are bumping the left-front wheel, the range you should be looking at is from maybe one inche down (rebound) to one inch up (bump). If the wheel is located at the right-front, the range might be from zero (at ride height elevation) to maybe two or three inches up (bump). That is the range that wheel is going to be working in. The right-front wheel will not see two or three inches of rebound unless the car goes airborne. At that point, bump steer is the least of our concerns.

***New BBSS Setups***—The newer soft spring setups create a large amount of dive and very little roll. This excessive dive can really affect the bump steer and cause front-end toe problems if not checked and corrected. The tendency to put high anti-dive in the right front and high pro-dive in the left front will mean that both sides of the steering system will be affected in the changing of the bump steer characteristics from static to mid-turn ride heights.




**The inner tie rod mount needs to be lowered or the outer end needs to be raised in order to achieve the correct angle that will intersect the instant center and provide zero bump steer.**

***Check Bump Steer at Turn Attitude***—Position both wheels at the approximate attitude they will be when in the turns as you check bump steer. This includes the amount of wheel travel and the amount of steering input. You might be surprised at the numbers you see when the car is positioned this way.

Adjust the bump steer to zero at the mid-turn attitude. Recheck the bump at ride height and note the difference. If it is too great, then you might consider making changes to the system to reduce the difference. This could involve tie rod length changes and/or reducing the anti's in the control arms.

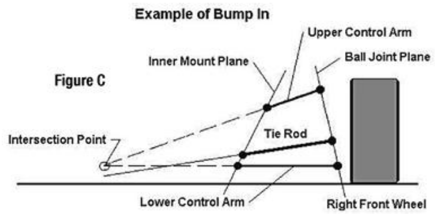
## Making Changes to Bump Steer

To make changes to bump steer, you need to know what direction to move the ends of the tie rod related to which way the wheel is moving. If, for example, the right-front wheel is bumping out (the front dial indicator is measuring less change than the rear dial indicator), then the tie rod is too high on the inside mount or too low at the outer end (see Figure B above). The opposite is true if the right-front wheel is bumping in (toeing in at the front of the tire). See Figure C above. Study the Figures to see how this works.

***How to Adjust Tie Rod Lengths***—If the lengths of your tie rods are wrong, you may be able to use a different length steering rack, if you use a rack-and-pinion system.

If your steering system is a drag-link type of steering system, then maybe a different drag link with the inner mounting holes positioned wider apart or narrower would be the answer.

Make sure your bump steer is correct to eliminate a potential steering problem.



**The inner tie rod mount needs to be raised or the outer end needs to be lowered in order to achieve the correct angle that will intersect the instant center and provide zero bump steer.**

## A Good Compromise

If you cannot get zero bump steer in both static and dynamic locations, where do you want the car to have zero bump steer? Take a wild guess. Down the straightaway where you don't really need it or in the turns where you are right on the ragged edge of adhesion, and running side by side with a guy who's never brought a race car home in one piece before.

This is not a hard choice to make. Set your car at the turn attitude with the wheels steered and then set the bump steer at zero.

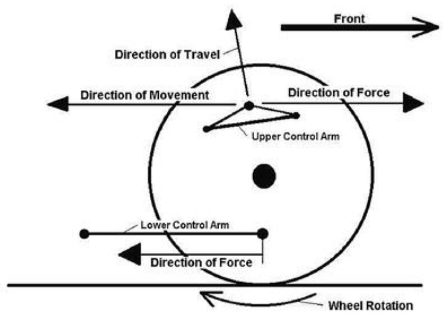
***Toe Settings***—Toe-out amounts vary with the track. The most common range used by many short track teams is 1/16" to 3/16" of toe-out. For short, short bull rings, it can go as high as 1/4" and at a track like Daytona, it is best set at near zero. Consider Ackermann Effect when planning out your initial toe settings. If you are gaining 1/8" of toe from Ackermann effect, then you might not need any toe setting at ride height with the wheels pointed straight ahead. The added toe caused by Ackermann will give you all of the mid-turn toe you need to track your wheels to match the inside and outside wheel radius.

## Anti-Dive

Anti-dive is a mechanical effect that resists the diving motion of the front end only when the brakes are applied. This effect uses the energy of the brakes trying to rotate the spindle and when there is no braking, has little affect on the front suspension other than the changes to bump-steer mentioned previously.

## Opposing Forces at Work

While the brakes are stopping the car, the brake pad and caliper are grabbing the brake rotor and trying to force it to rotate the spindle in a clockwise direction, looking at the right-front wheel from the side. As the car tries to dive, if you have angled the control arms so that as the car dives, the spindle is trying to rotate counter-clockwise, then these two motions are opposed. The force that the brakes are putting on the spindle, trying to rotate it clockwise resists the motion that diving generates in trying to rotate the spindle in the opposite direction.




**View of the right-front wheel showing how in dive, the upper ball joint wants to move in the opposite direction of the forces created by braking.**

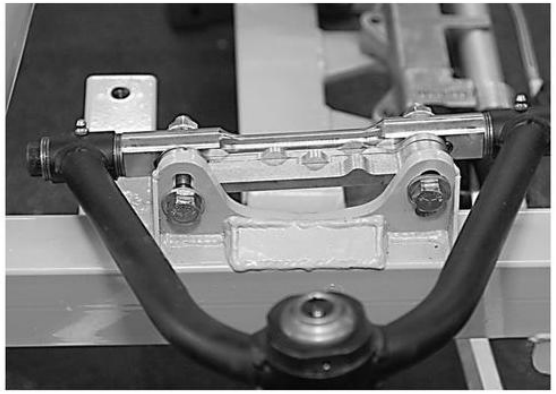
## Which Cars Use Anti-Dive?

Most touring cars don't use any anti-dive. Heavier Late Model cars and the Cup-type cars usually need some amount of anti-dive to control dive on entry. That is because of the higher weight of the cars and the higher center of gravity those cars have. Excessive and rapid dive is unwanted and creates rapid camber change that upsets the tire and causes it to lose grip (push on entry). Racing tires take a set and lose grip when a change in camber takes place.

Today, more and more tour-type Late Models are using anti-dive. The trend toward softer spring setups has forced many top teams to build anti-dive into the front suspension. Since anti-dive does not affect the car anywhere but on braking, there are no negative side effects associated with using it.

## How to Measure Anti-Dive

Anti-dive is usually measured in degrees of control arm mounting angle. Three to five degrees are the normal amounts generally used. For example, three degrees would be a difference of 0.314", or 5/16", in height between the mounts if the mounting holes are 6" apart. Five degrees would be a difference in height of 0.525" or a little over 1/2".



**Special slotted upper control arm brackets allow you to lower or raise the mounts. This team lowered the rear mount by 1/4" and raised the front mount by 1/4" to make a five-degree angle in the control arm shaft for anti-dive.**

There is usually more anti-dive built into the right-front than the left-front wheel. That is because as the car is braking, it is usually starting to turn left and more force and weight is put on the right-front, requiring more anti-dive effect.

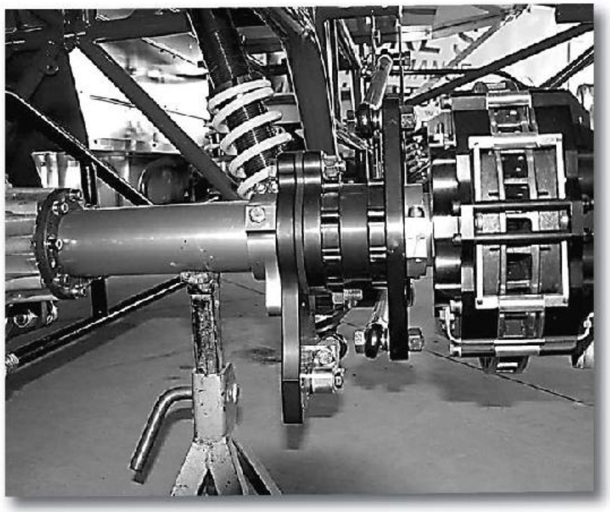
Smaller race tracks with tight corners require more anti-dive than larger tracks with long gradual entry to the corners. The more severe the application of the brakes, obviously the more anti-dive that is required.

## Anti-Dive Drawback

The one negative aspect of anti-dive is that it tends to lock up the front suspension as braking is taking place. If a particular track has a rough surface or a bump at the point of braking on entry to the turn, then just when you need a cushioning effect to get the tire over that part of the race track, the suspension would be locked and there would be no softening action. The tires might then skip and lose traction. The type of race track and the condition of the surface must be taken into account when deciding how much anti-dive you should design into your race car.

# Chapter 8

## The Rear Suspension



**There are many different designs of racing rear suspension systems and the adjustability is almost infinite for some of them. In this chapter we will discuss the most important aspects of rear alignment and the effects of rear steer.**

There are a variety of rear suspension designs used in circle track racing, both on dirt and on asphalt. We will cover the most common types and tell you about the most important aspects of rear suspension design and our goals for achieving the most performance. The information differs somewhat from dirt to asphalt application mostly because asphalt has so much grip and, well dirt doesn't. We sometimes must push the envelope on dirt, whereas pushing the limits on asphalt will only get us in trouble.

The first and foremost rule on rear suspensions is that the rear end should be square to the centerline of the chassis and it should usually be placed laterally where the right-side tires contact patches line up. Handling problems should not be fixed by moving the rear end to one side or the other, or out of square. The best and most accurate method to use to check square of the rear end is as follows:

### Checking Rear End for Square

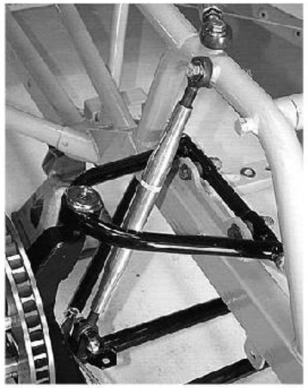
The best way to prepare the car for taking measurements is to put the car at ride height or some distance above ride height adding the same amount to each corner. Remove the springs and place links where the shocks usually mount that will position the rear end at the same attitude in relation to the chassis as they would reside when the car was sitting at static ride height on the ground. That way the rear end is positioned in the same place that it would be at ride height with the tires on and all weight on them.

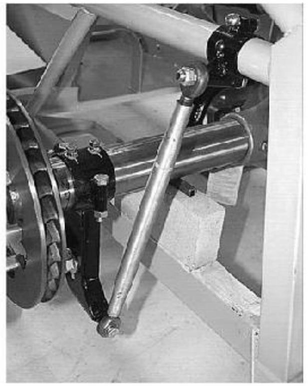
Using the diagram on page 66, follow the numbered steps to setup a line that is 90° to the centerline of the car and lies behind the rear end far enough to allow easy measurement. On a perimeter car, split the distance between the frame rails at the front and rear to establish the centerline. For offset chassis, you may be able to come off the straight rail along the right side to establish an offset to the centerline. The idea is to find a line that will be parallel to the centers of the right-side tire contact patches.

***Step 1***—If your car is a perimeter chassis (both sides of the frame are symmetrical), first measure between the inside frame rails at the front and rear and divide those numbers by two. Measure from one side of the frame at the front and rear using the half measurements and place a mark on the floor at each end of the car at centerline. (I mark on a piece of 2" or 3" wide masking tape placed on the floor) These marks now represent the centerline of the car.

If you are measuring a straight rail (offset chassis) type of car, measure the same distance (say 20") from the front end of the straight rail and the rear end, just in front of the rear axle and place marks on the floor to create a line that is parallel to the centerline of the car.

You will then have two points at each end of the car to use to develop a line that is at a right angle to the centerline of the car. Then, snap a chalk line or stretch a string over each of the two marks at each end of the car forming a line. Make the line long enough to extend past the rear of the car. If you use a string, you can hold the string in place with spare lead ballast weights. That way, you can stretch the string tight and the weight of the lead will hold it firm.

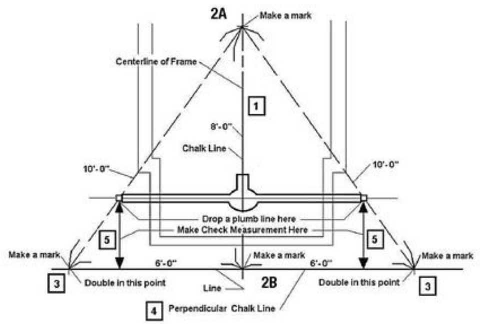




**When taking measurements, always use solid links in place of the shocks to locate the front wheel hubs and the rear end. Set them up in exactly the same position that it would be at ride height with the suspension supporting all of the weight.**

***Step 2***—Make a mark crossing the centerline somewhere behind the rear of the car. This will be used to establish a line that will be at right angles to the centerline.

***Step 3***—Measure from the mark up the line toward the front of the car 96 inches or 8 feet and make another mark crossing the line. Again you can use masking tape to mark on. I always cut a foot from the end of the tape so that I can make an accurate measurement using the one foot mark and the nine foot mark. From this line...




**Follow the steps to develop a centerline that is either the true centerline of the chassis or in the case of an offset chassis, a line that is parallel to the straight rail. We then use that line to mark a perpendicular line (one that is at 90 degrees to the centerline) behind the rear-end housing to measure to so we can check the rear for alignment. The rear wheel hubs should be equal distance from this perpendicular line.**

***Step 4***—Measure two distances to form an intersection, one ten feet from the front point (2A) and the other six feet from the rear point (2B) to establish a point on each side of the car. These intersection points will be used to mark a line (4) that is exactly at a right angle to the centerline of the car.

***Step 5***—Stretch a string, or pop a chalk line, over these two outer intersection points. The line that crosses the centerline should be directly over the rear eight-foot point on the centerline. If it is not, recheck all of your measurements and re-establish the intersecting points that form the perpendicular line. These triangles (if you haven't recognized it yet) are just 3-4-5 right triangles whose sides have been doubled. In geometry, coincidentally, if a triangle has sides that measure 3 units, 4 units and 5 units on each side, it is a right triangle. You just doubled the numbers. You still have a right triangle. This is the easiest way to layout a perpendicular line (Line 4).

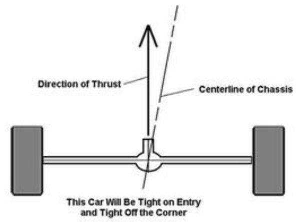
***Step 6—Lateral Rear End Location.*** In addition to making sure the rear end is perpendicular to the centerline of the car, you also want to make sure that it is positioned correctly between the rear frame rails.

One of the handling adjustment methods that have been passed down through the years involves moving the rear end to one side or the other to change the handling balance. This is another unreliable and temporary fix that should not be necessary if all of the other components are set up properly.

***Step 7—Line Up Right-Side Tire Contact Patches.*** I always recommend that the rear wheels be positioned so that the right-side tire contact patches line up. This is because in the turns, most of the load is on the right-side tires and the car will want to track inline with the right-side tires where they contact the ground.

This step must be performed first before you square the rear end. If you do this after squaring, then you will need to re-square the rear end because many rear suspension systems will steer the rear end as the rear moves from side to side.

***Step 8***—Next, drop a plumb line off the rear axle tube at each end and mark that point on the floor. You may use a level or plumb bob for this, but be sure to use the same point on each side of the rear end housing. The hubs are machined and are best to use. Don't use the axle tube if it is the original cast type.




**When the direction of thrust is pointed to the left of centerline, the car will be very tight on exit because the rear wheels will want to drive to the inside of the front wheels.**

From the Step 5 line, measure forward to each rear axle point making sure your measure tape is running at right angles to the rear line. These measurements should be the same. Adjust the lengths of the trailing arms to square the rear end keeping in mind to maintain the proper pinion angle.

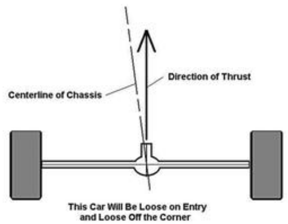
## Asphalt Rear Steer

The rear end may steer as the car rolls and squats/lifts in the turn. The amount of steer depends on the degree of roll, amount of squat/lift, and position of the arms. With long truck arms as found on NASCAR Cup, Nationwide Series, Trucks, USARacing and some Late Model cars, the steering effect is fairly small and these systems only steer to the left. Cars that are built with short trailing arms can steer quite a bit if the arms are not positioned correctly.

With the dirt cars, there are two primary systems in use, the four bar and Z-link. The four-bar system can, and usually is designed to, steer quite a bit. Many teams feel it necessary to steer the rear end to the right to help the car turn on entry and middle and this turn attitude continues sometimes all of the way down the straightaway. This is an old school fix for a car that will not turn well.

I believe a car should be designed with a correct front moment center location, and a balanced setup to where it will turn through the middle without having to rotate the car with a rear suspension that steers to the right. There are some very negative reasons why rear steer to the right is bad for your car.

On an asphalt car, we never want the rear to be steered to the right. This makes the car very loose on entry and through the middle and extremely loose off the corners. The rear tires must develop an angle of attack in order to generate side grip. We do this to the front tires by steering the car. If the rear end is pointed to the right, then we will never develop the needed angle to generate the grip needed to turn.




**If the rear end is aligned so that the direction of thrust is to the right of centerline, then the rear wheels will want to drive to the outside of the front wheels. This makes the car very loose on exit.**

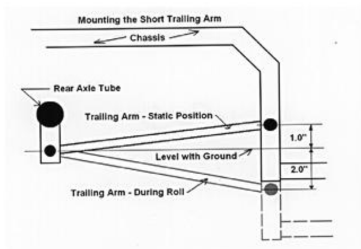
## Rear Steer to the Left

***The Three-Link System***—If the trailing arms are level at static ride height, then when the car rolls, the front of the right arm will move down, pulling the right side of the rear end forward. The front of the left arm will usually stay very close to the same height. This causes quite a bit of rear steer to the left, which can tighten the car.

The net steer is to the left because the right wheel moved more forward and the left wheel stayed in place. A car that steers left an excessive amount is going to end up a very tight car. The rear end should follow the front through the turn, but it is trying to take an inside line and pass the front end to the left side. It is very hard to steer against this tendency, and that will make the car push.

The best way to set up this type of rear trailing arm car is this: To compensate for the steering effect, the right-front mounts should be mounted higher than the right-rear mount. On the right-rear corner of the car, the front mounts should be positioned above the rear mount by a distance of about one-third of the vertical travel of that portion of the chassis at mid-turn. Shock travel indicators on the shocks will help you determine the amount of travel.

Keep in mind that the spring rate you will be running will dictate the distance that corner will travel. This angle will create a very small amount of rear steer to the left and actually produce more rear grip with a car that has a proper front end design and turns well. On the left side, position the front mounts either level or slightly above the rear mounts.




**For a slight amount of rear steer to the left, divide the total chassis travel on the right side by three and raise the forward end of the trailing arm up above level that amount. If you had 3.0" of travel, the amount to raise the front end of the arm would be 1.0".**

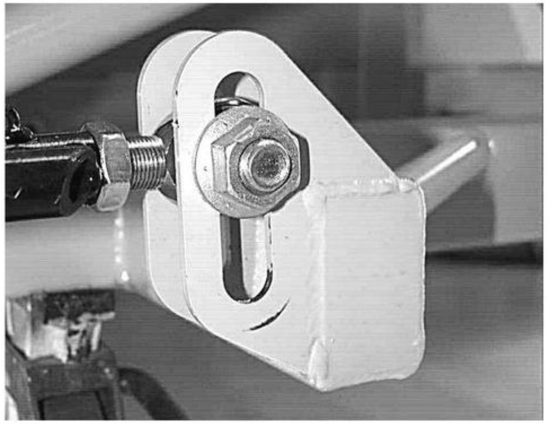
***Positioning the Trailing Arm According to Travel***—Let's say the chassis travel is 3.0" on the right side. The right-side forward arm mount should be positioned 1.0" above the rear mount. On the left side, the forward mount will be positioned in relation to the rear mount either level to it or up approximately one half of the amount used on the right side.

***Net Rear Steer to the Left***—With the trailing arms set this way, as the car first rolls into the corner, the right-rear wheel will move slightly to the rear, but then as the frame continues to travel due to roll, that wheel will move forward and end up slightly more forward than when it was at ride height. This produces a slight amount of rear steer to the left, which promotes rear traction without making the car excessively tight.

If you desire to have the rear end steer more so in the turns, mount the right-side trailing arm lower on the chassis end. You only want a net rear steer to the left of centerline. This has a tightening effect on exit and can help provide more forward bite. Excess rear steer can make your car too tight in the middle of the turns. Be careful to make small changes to the angle of the trailing arm. The driver will usually feel a quarter-degree change in trailing arm angle.

***Dirt Rear Steer***—There are four types of rear suspensions used in most dirt cars that are significant to study regarding rear steer: the Four-Bar, Z-link, three-link and the Metric four-link. Let's expand our discussion on these four systems.

Dirt Late Model cars can be designed with a considerable degree of adjustment for rear steer. Many teams use varying amounts of rear steer to adjust to constantly changing track conditions, a product of variations in moisture content that is so common in dirt racing. Other teams may just stick with a fixed location for the mounts in the rear end and adjust handling with other means.



**This team has positioned the front of the trailing arm slightly above the center of the adjusting slot by approximately 1/2“ so that as the car rolls in the turns, the rear end will steer left a small amount. This is a typical setting when using large right-rear spring rates. These high spring rates cause much less movement of the right-rear corner of the car.**

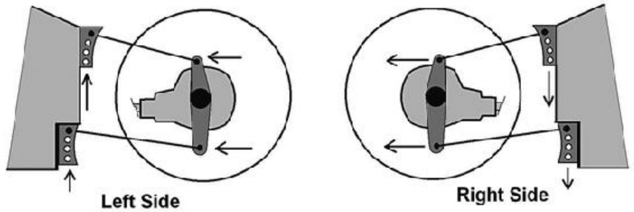
One of the reasons why a car will test fast in practice, qualifying and maybe the heat races, but then when the track changes be out to lunch come feature time, is a result of improper rear steer. Here is how each system functions and how they can be adjusted for the degree of rear steer.

***The Standard Four-Bar System***—The four-bar suspension is highly adjustable and can be made to steer both directions. The rule about never steering the rear end to the right on an asphalt car does not apply to a dirt car. There are times when we definitely want the rear to steer to the right.

Depending on the angles of the trailing arms or bars, each rear wheel can be made to move to the front or rear. The roll angles and vertical movement on a dirt car can be very pronounced. With so much movement, we can plan out our rear steer just about any way we need it.

The bars can be mounted on one side of the car so that only that wheel moves to create the rear steer. If both sides are configured to move in opposite directions, then rear steer can be extreme in magnitude.

On a tacky track, the team would do well to limit rear steer on both sides of the car. These conditions call for a driving line that is more straight ahead. When the track goes slick, especially dry slick, rear steer is needed. In the past, drivers would set the car up for exit off the corners, throwing the car sideways by breaking the rear tires loose. Now, in more recent years, teams have been setting the car up so that the left side rises up quite a bit.



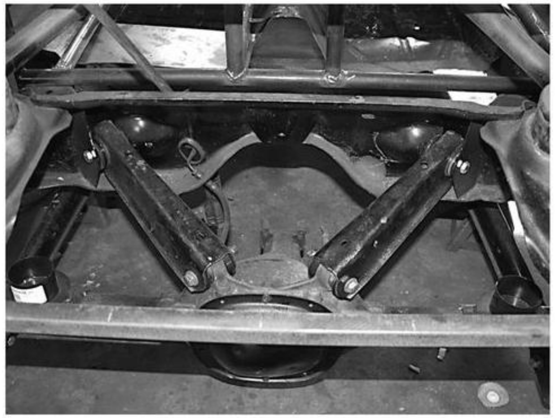

**If the bars on a four-bar car are set all of the way to the top of the mounts, then as the car rolls up on the left side and down on the right side, the rear end will steer to the right quite a bit. This helps the driver get the car turned to prepare to exit the corner and keeps the rear tires in contact with the track surface under extremely dry slick conditions.**

The left-rear suspension is designed so that when that corner rises up, the arms are angled so that the left-rear wheel is pulled forward toward the driver. This produces quite a bit of rear steer to the right and the rear of the car moves to the right, just like when we used to throw the car sideways. The difference is that now we can maintain rear traction having never broken loose and the car is angled somewhat sideways and pointed in the right direction to get off the corner.

***How Much Is Too Much?***—There are limits to how far we go in steering the car this way. One disadvantage is that high left-rear loading does not increase traction. As the left side of the car travels up, the front of both of the trailing arms are angled upwards so that the left-rear tire tries to drive up under the chassis loading the left-rear tire considerably.

We can have too much load end up on the left-rear tire and lose traction and/or cause the car to push off the corners because of all of the forward thrust is concentrated in the left-rear tire. In racing, we have the maximum amount of traction from a pair of tires on the same axle if they are equally loaded. Excess loading of either the left-rear or right-rear tires decreases traction in most cases.

***The Metric Four-Link System***—The metric four-link is a widely used system that comes with some models of stock automobiles. It uses four links as the name implies that are not parallel to the centerline of the car. The top links are angled from a top view with the front pivots wider than the rear pivots. The lower links are angled from a top view with the front pivots narrower than the rear pivots.

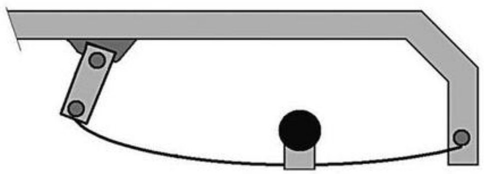


**The Metric four-link suspension has two links above the rear end and two links below the rear end. They are angled from a top view to prevent the rear end from moving side to side as the chassis rolls.**

With this system, the rear end stays located by virtue of the opposing angles of the upper and lower links. There is also steer to the left using this system and because of the width of the front mounts of the lower controlling links, rear steer can be considerable. Under most current rules, there is no adjustment for amounts of rear steer with these systems.

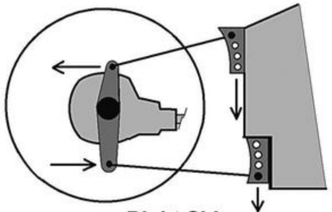
***Leaf-Spring Systems***—The leaf-spring rear suspension system locates the rear end fore and aft as well as laterally using the leafs. There can be a small amount of rear steer as the chassis rolls and squats, but it is both minimal and mostly fixed as far as adjustability. The advantage of this system is that it keeps the rear end squared up and the thrust under acceleration straight ahead, if that is what is needed.

**The leaf-spring suspension system usually has fixed mounts in the front and therefore no adjustment for amount of rear steer. The rear end stays mostly square in the car throughout the lap. The feedback we hear from the racers is that the leaf-spring rear suspension is good on tacky or wet tracks.**

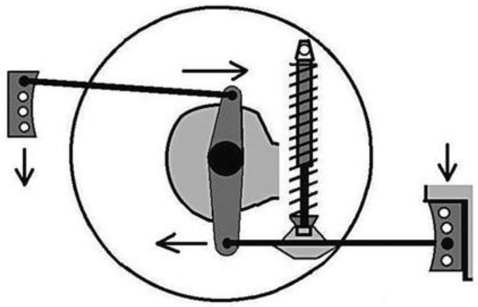


You can adjust the rear steer by moving the spring up and down in relation to the rear axle. This positions the front eye at an angle in relation to the rear pivot point, which is the center of the rear axle. Just as with the three link systems we have described, the position of the front mount and the angle it produces dictates the amount of rear steer.

**If the bars on a four-bar car are set in the correct holes, the movement of the top and bottom mounts at the rear end will compensate fore and aft resulting in zero rear steer. This is best for tight, wet tracks where we cannot use any rear steer and we need for the thrust to be pointed straight ahead.**




***The Z-link System***—The Z-link rear suspension, or swing arm as it is sometimes called, is another system used on dirt cars. Compared to the four-bar cars, it has somewhat limited adjustment for rear steer and historically has worked well on the tighter and more highly banked race tracks because the direction the rear end is pointed is more straight ahead. Some manufacturers have added multiple mounting points on the front and rear chassis mounts. This helps make the rear steer characteristics more adjustable for the changing conditions. Today, the Z-link or swing arm suspension can have nearly as much rear steer as the four-link without the excessive loading of the left-rear tire.



**A Z-link suspension system uses a link extending from the rear end forward to the chassis and one from the rear end rearward to a mount on the chassis there. Most designs use very few mounting holes that would enable the team to adjust for the amount of rear steer in those cars. Note that the spring is mounted directly on the front link.**

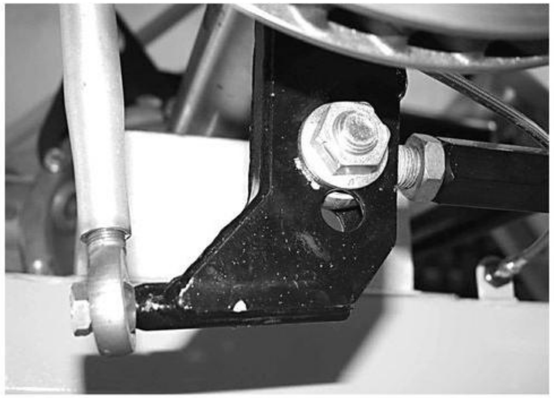
***Spring Motion Ratio***—Most of the Z-link systems utilize a spring mounting system that attaches the spring to the front link. This produces a motion ratio that causes the spring to move less than the chassis per degree of roll and/or inch of squat. Therefore, the rate that the car feels is much less, usually around 50%, than the actual installed spring rate. A 200-lb spring in a Z-link car feels more like a 100-lb spring installed in a four-link car where the coilover is mounted to a birdcage.

The significance of this is that the chassis travel in a Z-link is enhanced compared to the 4-link suspension when using the same installed spring rate and this causes quite a bit of chassis travel and related rear steer. So, teams need to take this rate difference into account.

There are reports from the past of a team winning a race using four 400-lb springs on a Z-link type of car. The front of the car felt the actual 400-lb rate while the rears felt like 200-lb springs. The track in this case was banked and had a lot of grip. So the car was setup and driven more like an asphalt car and it was fast. Those conditions rarely exist on dirt.

A more current trend, and one that has become popular among dirt late model teams, is the use of a larger right-rear spring rate than that used on the left-rear. This was first tried by a top team during Speedweeks back in 2005, when there had been a lot of rain that winter and East Bay and Volusia Speedway Park were loaded with moisture and had plenty of grip. When the conditions are right, this works very well.

***Dirt Track Aero***—One theory related to having the attitude of the car sideways involves the use of the aerodynamic aspects of the car. If you look at a modern dirt late model, the sides are made up of big, flat panels similar to the sides of a sprint car wing. We can see the effect of the sprint car wing in the turns as the cars actually roll left due to the pressure differential developed on the flat wing sides as the cars go sideways at a high speed.



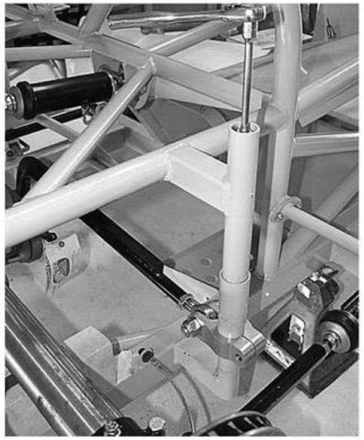
**Many rear brackets for mounting the trailing arm to the axle have several holes. This makes it possible to adjust the range for the trailing arm angles. This can also be used to develop rear steer upon acceleration only.**

On a late model, this air pressure difference may help keep the car on the track by virtue of having the car go through the air at an angle causing both a high pressure on the leading (right) side and a lower pressure on the trailing (left) side. Any time we can press air against the sides of the car we can help the car to turn. Some car builders have experimented with dirt track aero in the past with certain teams.

The reason that this type of aero side force might be important is because on dry slick surfaces, the tires do not grip very well. The sideways attitude of the car does two things, it helps to slow the car down on entry much like an air brake on a Lear Jet allowing deeper entry and it may also help to produce a lateral force that resists the opposite centrifugal force that tries to take the car to the fence.

***Tuning with Rear Steer***—We should learn to read the conditions of the track and tune the amount of rear steer, less for tacky and wet conditions and add more rear stter as the track gets slicker. On extreme dry slick conditions, use lots of rear steer to the right. This is accomplished by causing the right-rear wheel to move back and the left-rear wheel to move forward as the car rolls. Soft springs, a high center of gravity, a left chassis mounted track bar, and easy-up shocks on the left side all promote the body roll that produces rear steer to the right.

**This J-bar bracket is mounted to the pinion cap bolts and has numerous holes to adjust the height of the end of the J-bar. Mounts such as these, with holes that are up to 1" apart offer less fine-tuning of the J-bar height.**



**The J-bar adjuster shown here is infinitely adjustable and is an excellent tool used to tune the height of the rear moment center.**

## The Panhard Bar/J-bar Mount

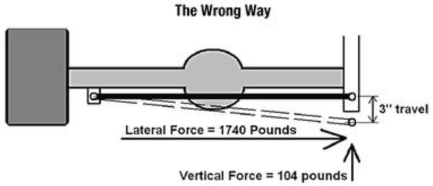
With top view parallel trailing arms, there is minimal steer as the rear end moves from side to side as the chassis moves during roll. With trailing arms that are not parallel to the centerline of the car, such as the truck-arm system and some three-link systems, the vertical movement of the panhard bar will cause some amount of rear steer. As the panhard bar moves vertically, it also moves the rear end laterally.

With trailing arms that are not parallel from a top view, there is a significant amount of rear steer. It is best to roughly split the difference of the travel measured at the end of the panhard bar that is attached to the chassis for all designs of rear trailing arms.

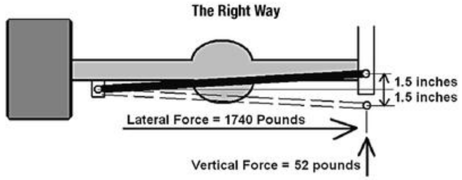
**Note:** It is highly recommended that for all pavement applications to mount the chassis end of the panhard/J-bar to the right side of the chassis. Years ago, some racers mounted the bar to the left side to loosen up a tight car. Now you have the tools to make the front end work, so you don't need to unhook the rear end on a tight car.

For many dirt applications, the panhard bar is mounted on the left side of the chassis. This does several things to change the dynamics of the rear suspension. It first assists in the lifting action of the rear when the car is in the turns. Lifting enhances rear steer. It also drives load onto the right-rear tire during side loading to help the tire bite through the dry and slick surface of the track.

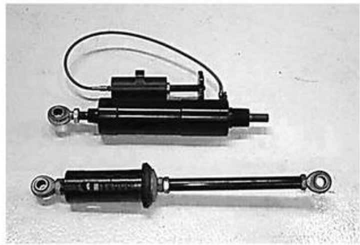
Experimentation has shown that a dirt car with a right side mounted panhard bar has a much flatter and lower attitude. This can be beneficial on a track that is higher banked and with more grip. The car becomes much more manageable for the driver too because there is much less steering input required than when the car is up on the bars.



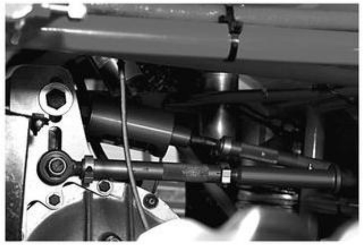

**As the car rolls, the end of the panhard bar that is attached to the frame travels down 3". As the lateral force pulls on the end of the bar, the bar wants to straighten out. A vertical force is then generated which tries to lift the right end of the panhard bar and which generates a sizable force of 104 lb. This is enough force to redistribute a substantial amount of weight on the four tires and negatively affect our handling balance.**




**As the car rolls, the frame-mounted end of the panhard bar travels 3" down. If that end of the panhard bar is mounted 1.5" above level at ride height, then the angle that the panhard bar will be at after the car rolls will be less and the resulting vertical force that will be generated will also be less. This is why we want to split the difference of the total amount of travel at the right-rear corner of the car that results from chassis roll, and try to split the heights of the ends of the panhard bar to compensate.**



**These are two examples of third links on a three-link rear suspension that extend to promote forward bite. The upper link is a dual spring pull bar with a hydraulic adjustable preload to regulate the amount of travel. The lower piece is a single spring unit.**



**A pull-bar-designed third link, when properly installed, will dampen the rotational forces that try to wrap up the rear end. A long spring allows rearward movement upon acceleration, and a rubber biscuit dampens deceleration forces. This unit from Coleman Racing dampens both acceleration and deceleration forces.**

To achieve zero rear steer on a right-side-chassis-mounted panhard/J-bar, position the right end higher than the left end of the panhard bar by one half of the amount of travel. Then as the chassis rolls, and the end moves, the rear end will move slightly to one side and at the point of mid-turn, it will move back to its original position, producing minimal steering effect. If some amount of rear steer is desired, lower the right-side chassis mount of the panhard/J-bar.

***Dynamic Influence of Panhard Bar Angle***— There is also a dynamic reason to minimize the angle of the panhard bar created by chassis roll. Looking at the figures at left, you will notice that with excess panhard bar angles, a vertical force is created that pushes up on the right end of the panhard bar during cornering.

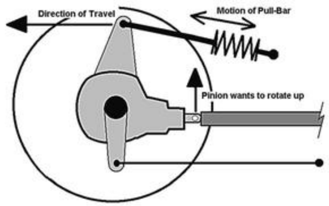
The end of the bar is trying to rise up to counter the effect of roll as the chassis executes a turn. This lifting force changes the weight distribution of the car and can be minimized through the proper installation of the panhard bar.

## Methods to Increase Bite

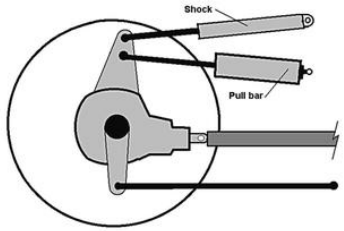
The single most sought-after goal for all racers is more traction for increased speed in the turns and for better forward "bite." The "traction control" spoken of here is about making the tires grip better while we are going through the turns and while under power off the turns and down the straightaway. We will provide some valuable information about how tires gain traction and then how we can design our cars so that we take advantage of that knowledge.

There has been a lot of talk over the past few years about illegal traction control being used in circle track racing. We know that it has been used and may have helped win some races, but there may be better ways to legally go about developing more traction, especially while under power. We know that many legal teams have been able to run faster than the ones that were known to be using illegal means.

Traction enhancing technology has grown in recent times. We have collectively learned what the tires want and somewhat how to give them the opportunity to maintain grip with the racing surface as much as the laws of physics will allow. Let's face it, there are limits to everything in this physical world, so our goal is to find the achievable limits. We need to learn to recognize when we get to that limit so we can stop looking lest we go backward.

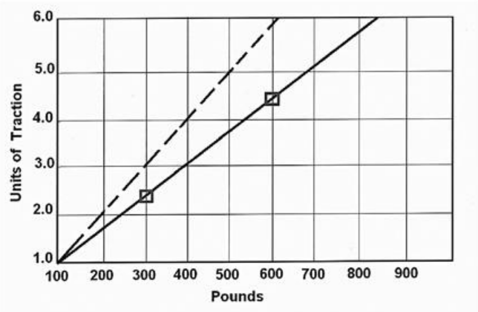



**As torque is applied to the pinion shaft and onto the ring gear, the pinion wants to rotate upward. If we use a moveable pull bar for the third link, then the rear housing will be able to rotate, and this action reduces the amount of torque shock that will be transmitted to the rear tires to help with maintaining traction while under acceleration.**




**When we install a pull bar only, we must also install a shock that will be mounted roughly parallel to the bar. This shock will dampen the movement of the pull bar, especially the return of the bar to static position as we get off the throttle and on the brakes on entry to the corners. Usually the rate of the shock has a much greater resistance to compression (return of the pull bar to static position) than rebound (direction of the pull bar movement on acceleration). Some designs provide dampening of both acceleration and deceleration forces without the need for a shock.**

The principle of stopping when you're ahead is true in developing a good handling package and remains true when developing the best traction package. Know when enough is enough. The word package is an important one, because we might well be using several different approaches at the same time to enhance traction. They rarely interfere with each other and each one will add a little to the package. Collectively, they can add up to a marked improvement in available traction.



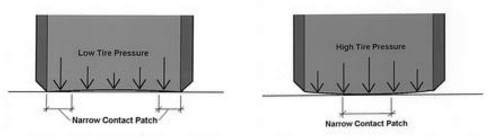

**If traction increased at the same rate as loading, then we would see a result indicated by the dashed line. It does not, so we see, as shown by the solid line, that as the number of pounds of loading on the tire increases, the units of traction do not increase at the same rate. At 300 lb of load, the units of traction are 2.4. If we double the load to 600 lb, the units of traction only increase to 4.4 instead of double which would be 4.8.**

Let's take a look at the various areas of influence that affect available traction and how we can maximize how our car reacts to those influences. Some are almost the same for dirt or asphalt and some of what we discuss is very different and will be talked about separately.

***Tires***—Tires, as most race car engineering books will tell you, are the ultimate connection between the car and the racing surface. That basic principle is a concept that has always been at the forefront when trying to understand ways to increase handling performance in a race car. It is also at the very top of the list when we discuss traction under power.

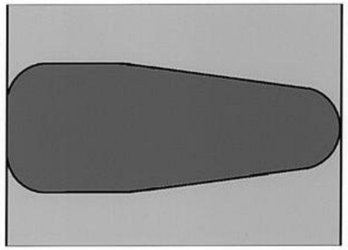
There are five basic effects that influence the amount of traction that a set of race tires will develop.

***Vertical Loading***—Increasing the amount of vertical loading on a tire increases the available traction, but in a non-linear way. This loading can be the result of static weight increase, lateral load transfer or aero downforce. As we increase the loading on a tire, it will gain traction, but not in an amount equal to the percentage of increase in load. If a tire has X amount of grip with 400 lb of load on it, the grip will be less than double if we apply double the loading of 800 lb. The amount of traction will be somewhat less than twice X.




**As the tire pressure is reduced from optimum, the pressure on the middle portion of the tire is reduced resulting in less traction. The same occurs as we over-inflate the tire. The outer edges of the tire lose pressure to the racing surface which results in less traction. At optimum pressure, the entire width of the tire contact patch will exert equal pressure on the racing surface.**

**If we could look down on the tire contact patch during cornering, we would want to see an even pattern across the width of the tire as shown.**



**If the tire had too much negative camber set into it, at mid-turn the contact patch might well look like this pattern and the tire would have less overall grip.**

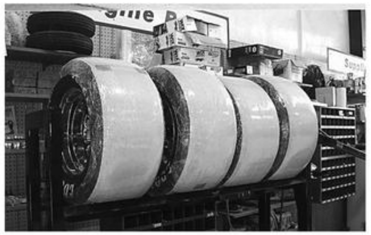
***Contact Patch***—The size and cross sectional loading of the contact patch helps determine how much grip we will have for a particular tire. An added effect related to the contact patch and traction involves grooving and siping with dirt tires.

Reducing the air pressure will usually increase the size of the tire contact patch which would seem to enhance traction, but excessively low or high pressures may reduce the loading on portions of the tire, so that the total grip of the tire is reduced, and we end up with less available traction for that tire. There is an optimum operating air pressure for each tire that will offer maximum contact patch area and equal loading across the width of the patch.

Camber also affects the size and cross sectional loading of the contact patch. The correct camber angle compensates for the deflection of the tire sidewalls as the lateral force is applied when we turn the car. More or less camber than what would be ideal means that one side of the tire will support more load than the other, and this also reduces traction.

***Chemical Makeup***—The chemical makeup of the compound of the rubber will help to determine how much traction is available from a tire. A softer tire will provide more grip, but the maximum amount of traction that can be utilized over a long period of time concerns how the tire holds up to increased heat and wear.

A tire that is a little harder may sometimes hold up better and be faster towards the end of the race when the tires have built up a lot of heat and are well worn after a number of laps.



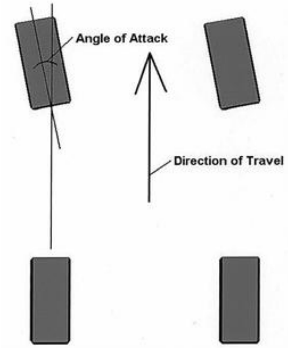
**Some tracks and sanctioning bodies allow the use of tire treatment, which softens the rubber compound. This can be a way to limit cost, allowing a team to run otherwise uncompetitive hard, old tires. Other tracks outlaw tire soaking but look the other way on this issue, and the teams must soak their tires in order to be competitive. Promoters should define and enforce tire rules either way.**

***Angle of Attack***—The amount of traction available from a tire can actually be enhanced simply by increasing its angle of attack relative to the direction of the car, but only up to a point. From traveling straight ahead, we can turn the wheel and with each degree of angle of deviation from the direction of travel, the traction in the tire increases.

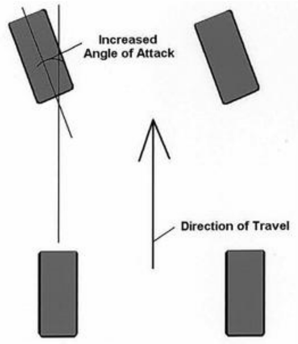
There is a point we reach where the gain is reduced and we approach the limit of the attack angle that the tire can handle. Once that point is reached, going beyond causes a sudden loss of grip and traction falls off drastically. This principle is true of all four of our tires.

***Equal Loading***—An opposing pair of tires (tires on the same axle or at the same end of the car) will develop maximum grip when they are equally loaded. That is a generally true statement that has been made many times in the past, in countless publications. Upon more careful examination of how we do things in circle track racing, there is a unique situation where this is not exactly true.

The situation is when we have a tire on one side of the car (usually the left side) that is built with a softer compound than the opposing tire whereby it may be able to develop more grip under the same loading as the opposing tire. So, increasing the vertical load on the inside tire with the goal of attaining equal loading for both tires, by whatever means, may not actually generate more traction because of the difference in grip per pound of vertical loading created by differences in compounds.




**As a driver turns the steering wheel, the front tires develop an angle of attack relative to the direction of travel of the car. The more the wheel is turned, the greater the angle of attack.**




**With increased angle of attack, the front end gains traction up to a point where the angle becomes excessive and the tire gives up most of its available traction resulting in a severe push.**

***Track Configuration***—The shape of the track for both dirt and asphalt can influence the available traction in several different ways. As we apply power, we need to know a little about how the track is banked, how the banking angle is changing coming off the corners, and how the radius of the turn might be changing.

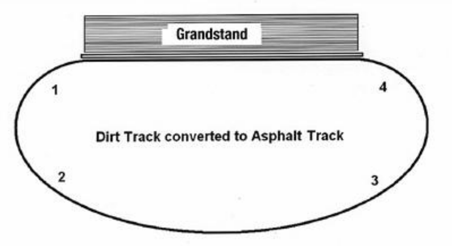
## Engine Torque Promotes Equal Loading

There is one effect that helps promote traction that every stock car has, but few realize, and that is the effect of engine torque. When we get back in the throttle the torque from the rotation of the engine, through the driveshaft, tries to rotate the whole rear end in a counterclockwise direction when viewed from the rear. This action, or force, loads the left-rear tire as well as the right-front. When those two corners are more loaded, the cross-weight percentage goes up and the car gets tighter. Also, if the right-rear tire was supporting more weight than the left-rear tire, then with this effect, the two rear tires would be more equally loaded providing more traction.

A question often asked is why the car does not get loose immediately when we gas it up if the rear tires are already providing all of their available traction keeping the car off the wall. The introduction of power would cause the tires to loose traction if it were not for the added affect of the engine torque. There is no way to enhance this effect, and the magnitude is dependent on the amount of torque the engine develops at a given rpm verses the width of the rear tires. The wider the rear track width, the less effect torque will have on adding load to the left-rear tire.

A highly banked race track is very forgiving when it comes to the need for bite off the corners. There is so much downforce due to the banking and associated lateral forces, that many times the tires are loaded to the extent that the power generated by the motor cannot break the tires loose. The tracks we are most concerned about getting off the corners are the ones that are flatter and with less surface grip.

***Pitch Angle***—The severity of change in banking angle of the racing surface in the portion of the track where we are initially accelerating can cause changes to the pitch angle of the chassis that works to unload one or more tires which can reduce traction. A track that goes from high banking in the turns to low banking on the straights fairly quickly can cause the left-rear tire to unload quickly making the car loose. There are two ways this can happen. One is when the outside edge of the track drops in elevation and the right-front tire follows the drop-off, which in turn lifts load off the left-rear tire causing loss of traction in that tire.




**Many current dirt tracks as well as some asphalt tracks that used to be dirt have developed a "D" shape. This is caused by having a wall along the grandstand side only and as the track gets raced on and groomed, the back side away from the grandstand gets pushed out. This makes turns 1 and 4 tighter than turns 2 and 3. More steering is required for the tighter turns and in turn 4 it is usually very difficult to get traction under power as opposed to exiting turn 2.**

The other problem occurs when the inside edge of the track rises up to match the elevation of the outside edge of the track. As the left front tire rises up, the left-front and right-rear pair of tires become more loaded momentarily causing loss of loading in the opposing pair of tires. The loss of cross-weight percentage (right-front to left-rear) makes the car lose traction in the rear.

A track that has a decreasing radius in the latter portion of one of the turns can cause a car to develop a loose condition at that point. Usually, older tracks that were originally dirt, and then paved, retain a straight front stretch and a rounded out back straightaway. This "D" shape causes turns 1 and 4 to be a smaller radius than turns 2 and 3 for that reason. So, turn 4 is difficult to accelerate off of due to the decreasing radius.

Remember we said that traction increases for a set of opposing tires when we increase the angle of attack as we turn the steering wheel. If the car is neutral in and through the middle of the turns, then as we approach the tightest portion of the turn past midway, where the radius is the least, we need to turn the steering wheel more and that produces more front traction than rear traction. The balance we enjoyed through the middle of the turn is now upset and the car becomes loose just when we are getting back in the throttle. This causes loss of rear traction. We will study ways to compensate for this later.

***The Racing Surface***—The surface we race on largely determines the amount of traction available under power and we will look at dirt and asphalt tracks separately. On dirt tracks, the amount of moisture dictates the amount of grip the track gives us. Bumps, grooves, banking angles, and the overall radius all help determine how much grip is available for traction in and off the corners. The setup related to cambers, shocks, springs and rear geometry helps determine how much traction will be available for a certain set of conditions.

On asphalt tracks, and even some dirt tracks that have been oiled to the point of almost being asphalt, the surface is more consistent and other than holes or bumps and rises in the surface, we can expect the grip to be the same over the course of the event. Flatter banking and older asphalt dictates the need for more traction control efforts.

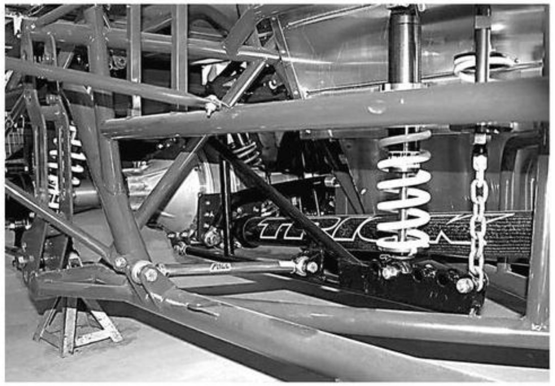
The path we need to take to developing more traction while under power is related to how our car is setup, how the suspension systems are designed and how the race track is shaped.

***The Setup Helps***—The way in which we set up the car can help us to get more traction off the corners on flatter race tracks. One thing teams did years ago was to split the rates of the rear springs so that the left-rear spring is a higher rate than the right-rear spring. When we accelerate, we transfer load to the rear of the car. As that weight is applied, the rear springs must compress to absorb the added load. If the left-rear spring is stiffer, then it will compress less than the right-rear spring and this will increase the amount of the total sprung weight supported by the right-rear and left-rear tires. This produces an increase in the cross-weight percentage, usually making the car tighter off the turns while under acceleration.

When the teams did this, they had to be sure to maintain a balanced setup. If you soften the right-rear spring rate, the rear of the car will want to roll more creating an unbalanced setup. We must raise the rear moment center to compensate so the car will not be overly tight in the middle of the turns.

Newer asphalt setups, and to a lesser extent dirt setups, utilize a stiffer right-rear spring rate over the left-rear rate. This is to enhance a more level attitude of the car to "square" it to the racing surface. It is thought that this helps the car turn better and provide a more efficient aerodynamic configuration.

***Setup Balance***—The setup package in the car can have an affect on how the tires adapt to the application of power. Most of the time, if we can keep the car from being overly tight on entry and through the middle of the turns, we can avoid the all too common tight/loose condition that causes a car to be loose off the corners. A balanced setup helps to prevent this condition.



**A torque arm is a device that absorbs some of the engine torque when we open the throttle on exit off the corners. Various rates of springs and shocks can be used to adjust the resistance to rotation of the rear end.**

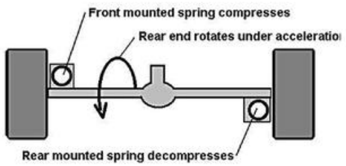
If a car is tight in the middle of the turns, we must add steering input to help increase the front traction to compensate. Then as we pass mid-turn, the added steering generates more than enough front traction to overcome the tight condition and the car begins to get loose. All of this usually happens right about the time we start to get into the throttle and as power is applied, the rear tires suddenly lose all traction.

Many drivers will swear that the car is loose. We need to learn to recognize this tight/loose condition so that proper adjustments can be made to the setup of the car for a more balanced mid-turn handling package. This condition is responsible for a major number of "loose off" problems.

***Shock Split Rates***—Splitting the rear shocks compression rates will accomplish a similiar effect for increased bite while the shocks are in motion and adjusting to the transfer of load upon initial acceleration. This effect is very short lived, but can help to reduce the shock to the tires that comes from the initial application of power. We would increase the compression rate in the left-rear shock over the right-rear shock to accomplish this effect.

***Sticker Shock***—We have learned that traction can be better maintained if we can decrease the amount of torque that reaches the rear tire contact patches that comes from the initial application of power. Doing this helps the tires adjust to the transition of forces from lateral to longitudinal.

When we are at mid-turn, the lateral forces will be resisted by the tires at the contact patch and all four tire contact patches will be at the limit of lateral adhesion if we are going as fast as we can go without sliding. In more simple terms, the tires at that point are about to give up and slide. If we can reduce the initial shock that is transferred to the rear tires through the driveline at that same time, we can help the rear tires maintain their attachment to the racing surface.



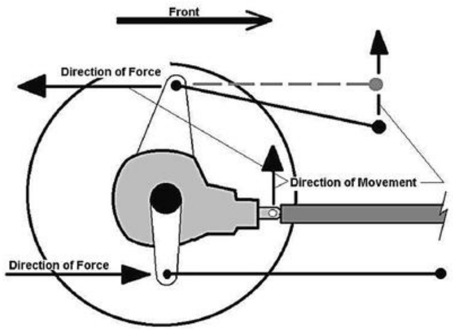

**The pull-bar third link acts much the same as the torque arm by extending under acceleration, which serves to soften the application of torque to the rear wheels. The rotation of the rear end can be utilized to produce several effects such as introducing rear steer and increasing the cross-weight percentage while under acceleration.**

***Traction Circles***—The traction circle theory of tire technology tells us that there is only so much traction available from a particular tire and its contact patch no matter what direction the forces are coming from. The actual number in pounds of resistance is based on the size of the tire contact patch, the adhesion properties of the compound itself, the amount of load on the tire and the tire slip angle, or angle of attack relative to the direction of travel of the car.

The tire needs to be able to transition from the one direction of resistance (lateral, which is the resisting of the centrifugal forces which are at right angles to the direction of travel) to the other (longitudinal or inline acceleration associated with application of power) over a longer period of time in order to maintain grip with the surface of the track.

If this transition happens too quickly, the tire is shocked and will most likely break loose. This is very detrimental to performance because in order to recover the grip in the rear tires, we must back off the throttle or slow down to allow the tires to reattach themselves to the track surface. This takes a lot of time and we lose a lot of ground in the process.

The pull bar or lift arm can absorb some of the torque going to the tires during initial application of power. By being able to move, these devices will absorb of some of the torque of the motor for a short period of time, usually long enough to allow the tire to adjust to the new direction of force.




**We can use the engine torque to our advantage by mounting the rear control arms in a certain way. As the driveshaft rotates, the pinion gear (attached to**

**the driveshaft through the universal joints) engages the ring gear (attached to the axles through the differential) and tries to climb it. This applies a force that will try to rotate the rear end in a counter-clockwise direction when viewed from the right side.**

We can experiment with different rates of springs and shocks in these systems to adjust to and perfect the traction enhancement for different conditions. Higher amounts of grip in the track surface mean more spring rate is needed in the devices. Slicker track conditions require less spring rate and more travel for increased torque absorption.

***Anti-Squat***—Anti-squat is a geometric suspension design that utilizes the torque that is transferred to the rear end and tries to rotate the differential. On a three link car, the third link (upper link mounted above the center of the rear end housing) can be mounted at an angle with the front mount lower than the rear mount so that when the car is accelerating, the force caused by the pinion gear trying to climb the ring gear causes the link to try to straighten out. Since the rear of the link that is mounted to the rear end cannot move vertically, the front mount can exert an upward vertical force that resists the squat that comes from weight being transferred to the rear under acceleration.

Anti-squat enhances rear traction in two ways, first by helping keep the rear of the car higher and with that the center of gravity and second by keeping the rear spoiler higher because the rear of the car is higher due to less squatting.

If the upper link, on a three-link rear suspension, is angled with the front end lower than the rear end, the force that tries to rotate the rear end will try to make the third link more horizontal. This applies an upward vertical force to the front of the link when accelerating that tries to lift the rear of the car. When decelerating, the opposite occurs and the braking forces try to lift the rear end causing the car to be loose. Anti-squat should be used in limited amounts.

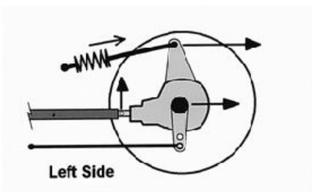
Load transfer is directly related to the height of the CG, and the higher it is, the more load transferred we have to the rear under acceleration. So, a higher CG promotes traction as more load is transferred while under acceleration. Along with that, a higher rear spoiler catches more air and produces more aero downforce for added grip at the rear tires.

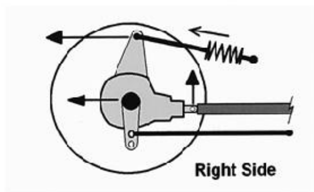
There is no truth to the theory that the third link produces additional mechanical downforce on the rear tires through the rear end. Any pressure put on the rear end by virtue of the link wanting to straighten out is offset by the reduced compression in the springs and the tradeoff is even. For every action, there is an equal and opposite reaction. We cannot pull weight from out of the sky, so as we stated, all added load comes from weight transfer and/or more aero downforce from a more efficient rear spoiler.

***Rear Geometry***—Asphalt cars merely need to maintain a straight ahead attitude when cornering, but dirt cars must steer the rear end to the right on dry slick tracks to develop a more sideways attitude that will point the car in the right direction to be better able to get off the corners. In past years, the drivers on dry slick tracks would need to throw the car sideways in the turns and in the process break the rear tires loose in order to point the car.

When it came time to get back into the throttle, the tires had already lost traction and all that happened was that the tires spun producing little forward bite. With the advent of radical rear steer geometry, the cars will now roll over, the rear end will steer to the right to point the car and the rear tires will maintain grip with the track surface and be ready to provide forward bite when the driver gets back into the throttle.

***Power Steer***—A fairly new concept for added bite on asphalt involves a geometric design that will produce rear steer upon application of power. We can utilize a certain type of rear suspension to create rear steer only under acceleration. In a three-link rear suspension system, if we use a pull bar, lift arm or other similar device that will allow the rear end to rotate under acceleration, we can steer the rear end to the left while the car is accelerating.




**We can cause the car to produce rear steer to the left to tighten the car while accelerating off the corners for more forward bite by staggering the heights of the trailing links. If the right trailing arm is mounted higher than the left-side arm, then as the rear end rotates, the left-rear tire will move to the rear more so than the right-rear tire resulting in rear steer to the left.**

As the rear end rotates under power with the pinion moving upward, the whole rear end will move rearward. If the lower control arms are mounted different distances from the axle, then one side of the rear end will move farther than the other. If the left-side trailing arm is mounted lower than the right-side trailing arm, then the left-rear wheel will move rearward more so than the right-rear wheel and this results in rear steer to the left, which will tighten a car off the corners.

***Pinion Angle***—It might be appropriate to mention another element related to geometry that affects traction off the corners and that is pinion angle. We know that excess pinion angle absorbs some of the engine force, which reduces power to the rear wheels. In the past we have heard racers say that they experienced better bite off the corners when they put more pinion angle in the car.

While it is probably believable that excess pinion angle reduces rear wheel tire spin, it is not because of any mechanical enhancement effect, but rather a reduction in the amount of power that reaches the rear wheels. If we reduce the amount of power that reaches the rear wheels, we also reduce the tendency for the rear wheels to spin. This is not a recommended procedure for adjusting power to the rear wheels.

***Reducing Power***—It is not widely known, but some top dirt racers have in the past adjusted their car's engines to produce less horsepower when slick track conditions would not allow great amounts of torque and horsepower to be put to full use. Using smaller carburetors, adding restrictor plates, unhooking the secondary butterflies, or using electronic traction control that changes the timing, breaks down the ignition on one or more cylinders, or applies the rear brakes are all ways that teams have of reducing rear wheel spin.

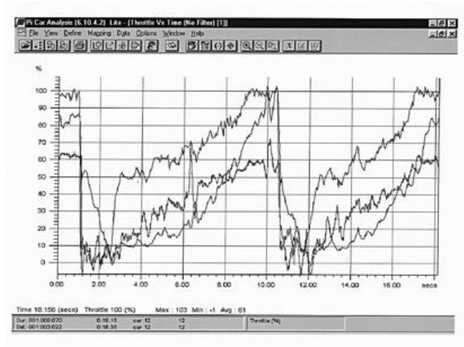
We have seen teams change to a smaller engine when they knew they were going to a traditionally dry slick track. Again, anything we can do to help the rear tires maintain grip at all times will give us a better chance to apply the power available to accelerate the car.

***Throttle Control***—When all available and useable methods of promoting traction control have been applied, the car may still be difficult to apply power to without losing rear traction. In that case, it comes down to the drivers using their skills to help prevent loss of rear traction coming off the corners.

Many top drivers have perfected the art of throttle control to help maintain traction. This means that if the driver knows he/she cannot apply full throttle without the rear tires spinning, then they will work to apply just enough power to accelerate without breaking the tires loose. This method applies to both dirt and asphalt racing and is much harder to master than most might think. Truth be known, many of our most successful drivers overcame less than perfect setups using this technique.

There is a story that the late and great Dale Earnhardt was at a test at the Richmond race track years ago along with member of many other teams, one in particular that was having unknown problems and going slow. The struggling team's owner knew Dale and asked him if he would take the car out and see if he could determine what might be the problem. The car had a data recording device installed and one of the functions that the system showed was throttle travel.

Dale promptly went out and ran a full second quicker than the usual driver. Later on, a close review of the throttle graph showed that Dale was rolling on and off the throttle and the graph looked much like a roller coaster. The other driver's throttle graph looked like a group of large square buildings, straight up and down, or quickly on and off the throttle. He was off the throttle much too quickly going into the corner and had to wait too long to get back into the throttle off the corners until the car was more straight to keep from spinning the tires as he mashed the gas. This example best defines driver induced traction control.

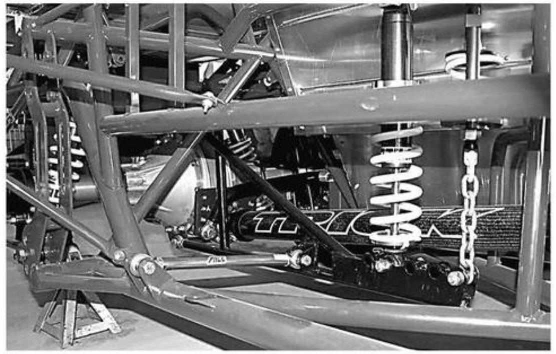


**Data acquisition not only tells us exactly how our drivers use the throttle, but also how the traction control devices are working. In this example, we see a graph from a dirt Late Model car at a test at Eldora. The driver is Kevin Weaver and we can see that as the throttle is applied the pull bar begins to extend. Kevin initially applies about 30% throttle and then gradually increases throttle all of the way down the straightaway to 100% near the end. The engine rpm never ran up meaning that the rear tires never break loose. The pull bar has controlled the engine torque and the driver used throttle control. This was a very fast lap.**

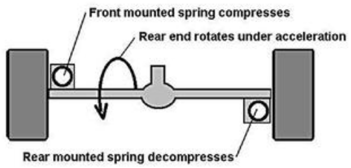
Improving traction off the corners is mostly about three things:

1. Balancing the setup and geometry so that the rear tires are always griping the race track so the car is not tight leading to the tight/loose syndrome;
2. Applying one or more traction methods to enhance weight distribution and overall mechanical grip off the corners as needed;
3. Learning to recognize the amount of traction that is available and help the driver to know when you have done all that is mechanically possible to enhance forward bite. At that point it is now up to the driver to operate the throttle correctly to help further maintain grip between the tires and the track surface.

Your driver may never be able to mash the gas and go, but as racer Scott Bloomquist once said, "My goal is to go wide open all of the way around the race track. I know that's not possible, but the closer I can get to doing that, the better I like it." Like Scott, learn to develop a legal traction control package that will maximize performance through enhanced traction off the corners. Not only will your lap times get better, the car will be more competitive when trying to get by lapped traffic or when passing for position.

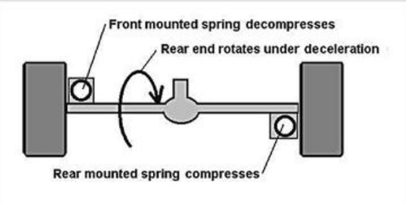


**This lift bar will allow the rear end to rotate in both directions, for entry and exit control of rear end torque.**



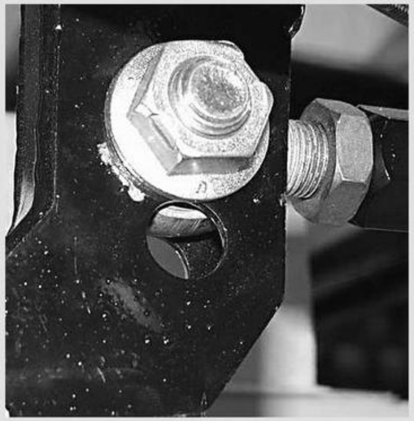

As we apply power to the rear differential, the rear housing will rotate in a counterclockwise direction (from a right-side view) with the use of a pull bar. If we mount our springs with the left-rear spring ahead of the rear housing and the right-rear spring behind, then the left-rear spring will compress and the right-rear spring will decompress. This increases the amount of left-rear and right-rear weight which increases the cross-weight percentage and the amount of bite in the car.

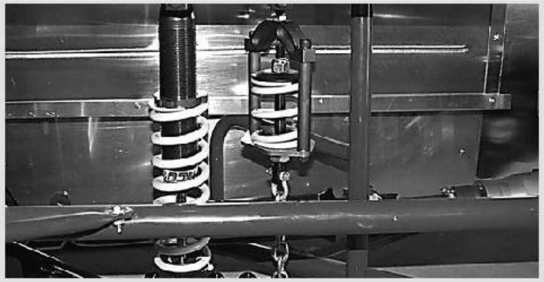
## Traction Tricks to Consider



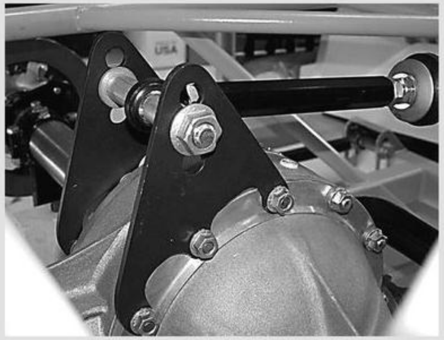

As we decelerate, the rear-end housing wants to rotate in a clockwise direction (from a right-side view) and if the rear end is allowed to rotate past the static position, then the car will be dewedged with the left-rear spring being decompressed and the right-rear spring being compressed. This reduces the left-rear and right-rear weight, which reduces the amount of cross-weight in the car and loosens the handling.

This trailing arm has two holes to mount the rear of the trailing arm. If we mount the right-side trailing arm in the top holes and the left side in the bottom holes, then as the rear end rotates, using a pull bar or lift arm, coming off the corner under acceleration, the left side axle tube will move more rearward due to the longer radius from the trailing arm to the center of the axle. Remember to keep the trailing arm angles the same as before.



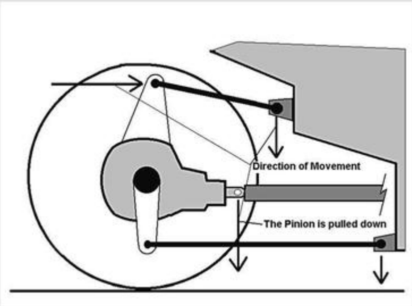


The spring and shock to the left in this photo controls the acceleration forces by compressing as the rear end rotates counterclockwise (from a right-side view) and the spring and chain on the right compresses as the end of the lift bar moves down upon deceleration and braking.



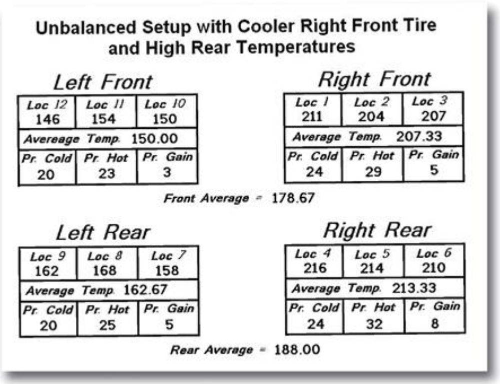
The distance from the center of the rear end/axle centerline where the third link is mounted has an effect on the amount of pull on the third link that the car will experience. The closer the link is mounted to the rear end, the greater the amount of pull and therefore, the more anti-squat the car will have if the third link angle remains the same.

The angle of the third link determines the degree change of the pinion angle as the car squats. If the car is allowed to squat in the rear, the attachment points for the trailing arms and the third link would drop. Because the third link is shorter and at an angle, this would pull the top mount on the rear end forward, rotating the differential. This drops the pinion and creates more pinion angle. The pull bar causes the pinion angle to change as the bar extends upon acceleration. Preplanning your pinion angle means that you might add static pinion angle to the car so that when the third link is extended, you will end up with the desired pinion angle when coming off the corners under full acceleration, where it counts the most.



# Chapter 9

## Tire Temps, Pressures and Stagger




**These temperatures show a typically unbalanced setup. Note that the left-front average tire temperatures are the lowest on the car. The difference between the LF and LR tires is 12 degrees. The average rear tire temperatures are also 10 degrees higher than the front temperatures. This is due to a loose condition caused either by being tight/loose or by loosening the car too much when it did not want to turn.**

Tires generate maximum traction when the surface is flat to the track as the car corners. This is after the sidewalls have flexed and the tire has rolled over due to the lateral forces generated from cornering. When this happens, the load distribution across the footprint of the tire is even. The heat buildup across the face of the tire can tell you a lot about how the tire is situated to the track surface while racing through the turns.

Remember that heat will migrate from a hot area to the cooler areas fairly quickly. So taking tire temperatures immediately after the car exits the race track is very important. In early real time tire temperature data for the right-front tire, the temperatures increased to over 300 degrees in the turns. It was noted too that as the tire was run down the straightaways, the inside of the tire cooled faster than the outside. That was because the inside portion was the more heavily compressed portion of the tire, due to the extreme camber of the right-front tire, and the cooler track surface drew more heat off that portion of the tire faster.

Because the tires represent the entire speed enhancing part of a race car's turn performance, we need to pay close attention to the way the tires are mounted, how they change attitude in the turns and how they are inflated and gain pressure as they are run. It is the setup that determines the load distribution on the four tires and that can definitely increase performance when it is done correctly, but it is the ultimate position of the tire to the race track surface that provides the benefit.

## Tire Temperatures

Always measure the tire temperature at three places on the tire—near the inside edge (about 1" in from the edge), in the middle, and near the outside edge (about 1" in from the edge). Where you start on the tire is often dictated by team preference and by the equipment you are using. Some electronic gauges will run in a certain order. Tire temperatures should be taken as soon as possible after the car comes off the track. Start with the right-front tire and proceed around the car in a clockwise direction.

## Get the Core Temperature

Insert the probe into the tire compound at a 45-degree angle to get the inner core temperature, which will stay hot longer and give a true reading of just what is happening. The surface of the tire cools very quickly and if you read that temperature it will not tell the true story. Let the numbers settle for each reading. Don't be in too much of a hurry. You can determine the optimum tire pressures and camber settings by studying the three temperatures on each tire. The temperatures also provide information about the overall handling of the car, so take your time and be accurate!

## Problems to Look For

You first want to look for any obvious camber or tire pressure problems. Temperatures that are hotter toward either edge of the tread would indicate camber or extreme pressure problems. The temperatures may look like those in the illustration on page 82.

**When inserting the probe on an electronic tire temperature gauge, always keep a 45-degree angle to the tread surface (left). Hold the probe inside the tire until the temperature stabilizes on the meter. Quickly move to another position once the reading has been recorded. That way, the probe will lose less**

**temperature and the next reading will take less time for the number to stabilize. Usually measure the inside (toward the centerline of the car) edge of the tire first and proceed toward the outside edge. This can be done the other way, too, according to team preference. Just be sure to enter the numbers correctly in the temperature gauge or on paper.**


**Taking tire depth measurements across the tire will tell you how the tire is wearing from pressures and camber settings. For dirt teams, this may be the only way you can judge if your tire pressures and cambers are set correctly. Dirt teams rarely take tire temperatures.**

***Excess Camber***—These temperatures indicate that the insides of the right-front and left-front tires are a little too hot, which means that there is too much negative camber on the right-front tire and too little positive camber in the left-front tire.

***Low Pressures***—If, for example, the right-front tire temperatures are something like 190-178-189 from the inside to outside, then the pressure is too low in the tire. Too high would look like 182-191-180. See the sketches on page 85 to see how this affects the tire contact patch size.

***Tire Roll Over***—If the right-front tire has temps like 185-175-195, then the camber is set with too little negative angle and/or the pressure is very low. This tire shows signs of *rolling over*. The outside edge of the tire is rolling over and picking up the middle of the tire. That is why the outer temperature is high and the middle temperature is so low.

***Improper Setup***—The temperatures in the chart on page 82 also show another problem. A car that is set up with the correct combination of springs, sway bar and panhard bar heights will show the average tire temperatures to be the same on each side of the car, front to rear.

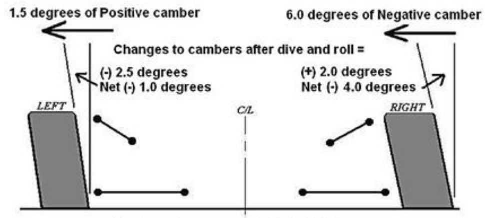
The difference between the right-side and the left-side pairs of tires will vary depending on the type of car, the amount of left-side weight and the banking angle and turn radius of the individual track. This car shows the left-front tire considerably cooler than the left-rear tire.

***Unequal Roll Angles***—If the left-front is the coolest tire on the car, there is a problem with the setup. This is a classic case of the rear suspension wanting to outroll the front. This condition makes the handling very inconsistent and causes the loss of performance.

## Determining Handling Balance

By averaging the temperatures for each pair of tires (fronts, rears, and cross pairs) you can determine the handling balance (loose or tight condition) even when the driver feels like the problem is something else.

***Tight or Loose Condition***—A hotter rear average suggests a loose condition. Hotter front temperatures for both the front tires over the rear averages suggest a push.




Looking Forward—Driver's View

**This diagram is an example of incorrect static camber settings. The left-front wheel will lose about 2.5 degrees of positive camber and so we need to start out with more than that so that we end up with some amount of positive camber in that wheel after the car dives and rolls. The right-front wheel may, with an improperly designed moment center, lose negative camber after dive and roll. This team compensated by putting excessive negative camber into the right-front wheel so that after the loss of camber, the car would have the correct amount of camber needed for this race track.**

**Balanced Setup - More Even Left Side Tire Temperatures**

*Left Front*

| Loc 12 | Loc 11 | Loc 10 |
|---|---|---|
| 163 | 163 | 162 |
| Average Temp. 162.66 | | |
| Pr. Cold | Pr. Hot | Pr. Gain |
| 17 | 21 | 4 |

*Right Front*

| Loc 1 | Loc 2 | Loc 3 |
|---|---|---|
| 204 | 204 | 203 |
| Average Temp. 203.66 | | |
| Pr. Cold | Pr. Hot | Pr. Gain |
| 25 | 32 | 7 |

Front Average = 183.16

*Left Rear*

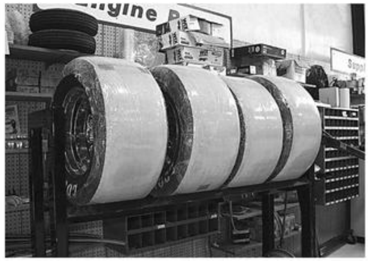
| Loc 9 | Loc 8 | Loc 7 |
|---|---|---|
| 164 | 163 | 159 |
| Average Temp. 162.00 | | |
| Pr. Cold | Pr. Hot | Pr. Gain |
| 17 | 21 | 4 |

*Right Rear*

| Loc 4 | Loc 5 | Loc 6 |
|---|---|---|
| 204 | 202 | 201 |
| Average Temp. 203.00 | | |
| Pr. Cold | Pr. Hot | Pr. Gain |
| 25 | 32 | 7 |

Rear Average = 182.50

**Typical balanced tire temperatures. Note that there is very little variation in temperature across the face of each tire, the pressures are equal for pairs of tires on the same side, and the average temperatures of the front pair and the rear pair are very close to the same—within less than one degree. And, the left-front is matched with the left-rear, showing a balanced setup.**



**It is always a good idea to keep new tires wrapped in plastic until they are ready to be used. As soon as the tires are exposed to air, they begin to deteriorate and harden. This team has applied tire treatment to the tread, a practice that is legal at some race tracks.**

## Tire Pressures

Optimum tire pressures are some-times very hard to predict. If you run with a lower pressure than the tire needs, the tire will roll over somewhat and lose traction because of a reduced footprint. The middle of the tread will not have sufficient pressure on it and that part of the tire won't grip as well as it normally would.

If we end up with too much pressure, the tire will expand and the middle of the tire will support most of the load with similar loss of tire footprint. The edges of the tire will not have enough pressure on them to get a good grip on the race track. It is as though that part of the tire was not even touching the track. Tire temperatures can tell us a lot about whether you have the right amount of tire pressure by showing us the amount of work the parts of the tire are doing.

## Predicting Pressure Buildup for Races

You must predict how much pressure build-up there will be during your race so you can start with a cold pressure for each tire that will compensate for this increase to produce optimum tire pressures during the race.

***Starting Pressure for Short Races***—For shorter races, especially ones where there might be several cautions, you can probably use more starting tire pressure because the tires won't have as much time to build up pressure. Short races are usually more like sprint races and if you are not right at the start, you won't have much of a chance to move up. It may even be better to be a little high on the starting pressures so that you can do some early passing while there are more opportunities.

**Use a large dial tire pressure gauge so you can read accurately. When you get the setup close, you might be adding or subtracting 1/2 lb of air pressure at a time.**

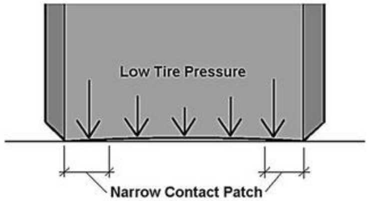
***Planning for Longer Races***—On longer runs, the tire heat and pressure will build continually. It may be an advantage to start a little low with the air pressures so that when the pressure builds towards the end of the race, the tire pressures will be closer to optimum. The longer races provide more opportunity for passing and advancement. A little preplanning goes a long way towards being fast at the end and having a chance at winning.

## Pressures for Qualifying

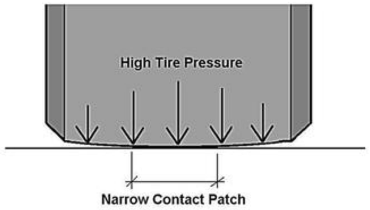
For qualifying, the one or two laps given for most short track qualifying are not enough to build to optimum pressures from pre-race pressures. Therefore, you must start higher than the pre-race pressures. Most tracks allow us to adjust tire pressures after qualifying even if you cannot change the setup.

If you start at optimum pressures, then as the tires heat up, the tires will grow beyond the optimum pressures. You need to determine how much lower than optimum we need to start out with, but more than the cold pressures, before your qualifying run.

***Anticipate Pressure Buildup for Qualifying***— Usually, for asphalt applications you only need to drop the pressures 15 to 20 percent below optimum. For the left-side tires, that would be starting pressures of from 20 lb if optimum hot pressure was 25 lb. For right-side tires, you need to drop the pressure about 20 to 25 percent. That would be a starting pressure range of between 26 lb if the optimum hot pressure was 34 lb.




**A tire that has low pressure will cup in the center and less load will be supported there than on the outside edges. As the car corners, the tire will have a tendency to roll over causing even less load to be supported on the center and a smaller tire footprint, meaning less traction.**



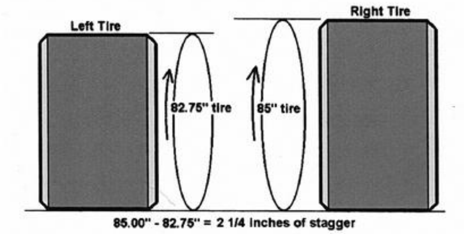

**A tire that is overinflated will cause the center of the tire to bulge out causing a smaller tire footprint, less average loading and less traction. This tire will probably overheat and wear the middle excessively.**

***Starting Pressures Based on Number of Laps and Track Surface***—The ultimate tire pressure to start out with for qualifying is largely determined by how many laps you are allowed to run, how hot the surface temperature of the track is at the time of qualifying and how much grip is in the track. Tracks that tend to be slick will build heat faster than tracks that have a lot of grip. The better the tires grip, the less heat buildup the tires will experience. Qualifying at 5:00 pm verses 7:30 pm could be a difference of 10 to 20 degrees of track temperature once the sun goes down below the horizon.

For some race tracks, the first lap is always the fastest; while at others it is the second lap. Take that into consideration when determining the starting the tire pressures for qualifying. Obviously, if the first lap is going to be the fastest lap, set the starting pressures higher.

**Safety Note**: There is a trend in circle track racing where teams inflate new tires to a high pressure to stretch the cords supposedly to provide a more consistent growth of the tire in order to maintain the correct staggers. This is extremely dangerous. Do not stretch your tires by inflating them to high pressures. Racers have been killed from tires exploding. The wheel can literally take off body parts when it separates from the tire. If you are set up correctly and not abusing your tires, they will grow evenly and not cause stagger problems.

**Critical tire information should be clearly marked on the tire, including which corner of the car the tire has been run on, the race track, the date of use and which set so that tires don't get mixed up. It is also a good idea to put the number of laps run on a tire once the event is over. Change the data when necessary such as to reflect corner changes (swapping the right-side tires) or after running more laps on a set.**


**Stagger is the difference in circumference of two tires on the same end of the car. Measure around each tire at the middle of the tread. Subtract the two measurements to find stagger or "roll out," as it is sometimes called. Always inflate to race pressures before measuring.**

## Tire Stagger

Tire stagger is the difference in circumference between a pair of tires on the same axle. This is a very important consideration due to the different radii the two tires must run. For a left-turning circle track stock car, the inside tire should always be smaller than the outside, even in the front. The idea is to create a difference in circumference so that each wheel will turn the same rpm, especially the rear tires.

**Tire stagger must be carefully measured before deciding which tires go on which corner of the car. One crewmember should be assigned to look after the tire staggers and set the order of placement on the car. This is a process best learned by doing.**

If you run a spool rear-end setup, the two wheels are locked together and will turn the same rpm. If the stagger is wrong and it does not fit the turn radius, then there will be a scrubbing effect that will reduce grip. Also, the car will want to track along a radius that fits the stagger rather than what is needed to negotiate the turn you are trying to run.

For locker rear end setups, the car will be okay into and through the turns, but once the locker engages and the wheels are locked together, the car will either be tight off with inadequate stagger or loose off with too much stagger. Many handling problems can be traced to incorrect rear tire stagger.

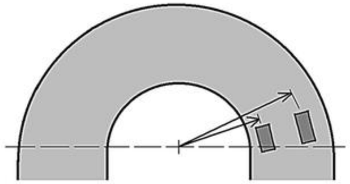
## Front Stagger Split

You may be able to run even sizes in the front, but a split in sizes does help in several ways. One is that with braking, a stagger split at the front help to turn the car. As the brakes are applied, the left-front generates more braking power with the smaller diameter tire and therefore help slightly to rotate the car upon entry braking.

The most benefit might just be from the sizes you run. If your rear stagger would require a change due to unanticipated growth of one or both tire, then if you run a front size that could be switched with the rears, then you could compensate with a swap of the left-sides, right-sides or both to gain proper rear stagger, which is most critical.

## Rear Stagger Split

The rear stagger split amount you will need is largely dependent on the size of the track. You want the car to roll around the turns with both of the axle speeds being the same.



Radius of inside tire = 200 feet or 2400 inches (12" x 200')
Radius of outside tire = 2465 inches (2400 + 65" track width)
Outside tire travels 2465 x 2 x PI (3.1416) ÷ 2 = 7744 inches
Inside tire travels 2400 x 2 x PI ÷ 2 = 7540 inches
Outside tire = 85 inches in circumference
Inside Tire = 85 x (7540 ÷ 7744) = 82.75
Correct Stagger = 85 minus 82.75 or 2 1/4 inches.

**If you are running the correct stagger split and still having problems, then look elsewhere. Your handling problem is not stagger related. Having to run excess stagger to correct a push problem is very detrimental to overall performance. Fix the push with other means, namely by correcting front geometry problems, or using the correct combination of springs, shocks or other components that will cause all of the tires to work together. It may be a simple case of too much or too little cross-weight percentage.**

To do this, the tires will need to be a different size left to right. One way to tell if the stagger is not right for the track radius is if the car is very tight or loose on exit. There may be too much or too little stagger split.

The chart above is a good starting point for selecting your rear stagger. If you are running an 88" right-front tire, then the left-front should be 85.34. or 85 and 5/16" for a 12 degree banked half-mile track where you run a 65" rear track width. For smaller and flatter tracks, increase the stagger a little. For higher banked and larger tracks, reduce the stagger as shown.

## Run the Correct Stagger

I never recommend fixing a mid-turn handling problem with stagger. A particular race track will require a certain rear stagger amount that will effectively roll the rear of the car around the track without wanting to steer toward the wall or inside of the race track.

## Cross-Weight vs. Stagger

Negative influences related to incorrect stagger are less apparent with the setups that use around a lower cross-weight of around 50%. With a high cross-weight percentage, say from 56% to 59%, the amount of stagger split becomes critical.

| | Right Rear Tire Circumference | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Turn Radius | 80" | 82" | 84" | 86" | 88" | 90" | 92" | 94" | 96" |
| 100' | 4.24 | 4.34 | 4.45 | 4.56 | 4.66 | 4.77 | 4.87 | 4.98 | 5.09 |
| 125' | 3.39 | 3.48 | 3.56 | 3.65 | 3.73 | 3.81 | 3.90 | 3.98 | 4.07 |
| 150' | 2.83 | 2.90 | 2.97 | 3.04 | 3.11 | 3.18 | 3.25 | 3.32 | 3.39 |
| 175' | 2.42 | 2.48 | 2.54 | 2.60 | 2.66 | 2.72 | 2.79 | 2.85 | 2.91 |
| 200' | 2.12 | 2.17 | 2.23 | 2.28 | 2.33 | 2.38 | 2.44 | 2.49 | 2.54 |
| 250' | 1.70 | 1.74 | 1.78 | 1.82 | 1.87 | 1.91 | 1.95 | 1.99 | 2.03 |
| 375' | 1.13 | 1.16 | 1.19 | 1.22 | 1.24 | 1.27 | 1.30 | 1.33 | 1.36 |
| 500' | 0.85 | 0.87 | 0.89 | 0.91 | 0.93 | 0.95 | 0.97 | 1.00 | 1.02 |
| 1250' Daytona | 0.34 | 0.35 | 0.36 | 0.36 | 0.37 | 0.38 | 0.39 | 0.40 | 0.41 |

Note: The sample car had a 65" track width and the sample race track was banked 12 degrees. Follow the rows and columns to find correct stagger.
Example: 2.66" = Correct Stagger for 88" tire at 175' radius.

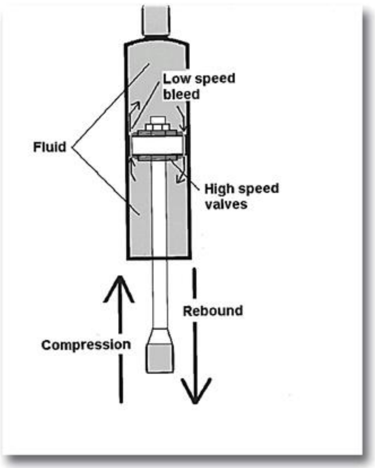
**To find the amount of stagger the easy way, follow this simple method and never subtract tire sizes again. Measure the larger tire first and remember the number. Then wrap the tape around the smaller tire and note where the larger tire size number falls from the end of the tape. That is the stagger difference between the two tires.**

This is because the greater amount of load on the left-rear tire will reduce the slipping that would be needed if the stagger split changed during a race. With both rear tires more equally loaded, stagger split will steer the car to a greater degree and must stay very close to optimum.

When using the high cross-weight percentage setups, the handling balance will be affected in a big way if the stagger changes considerably during the race. This must be taken into consideration when choosing a cross-weight range. Remember that on tracks banked higher than 10 degrees, you will be better off using the low range of cross-weight.

# Chapter 10

## Racing Shocks




**The anatomy of a typical racing shock.**

I once heard a wise and very successful crew chief say that you really need only to select your shock rates to control the transitional attitude of the race car, not to control the bumps. Shocks do not support the car, but they do affect the rate, or speed, at which the car will move vertically at each wheel.

Shocks are being used for much more than that today. Teams are trying to tie down corners of the car using very high rebound, which does severely restrict wheel movement, but does not prevent load transfer—which is the primary reason why the corner is tied down in the first place.

While bumps can be a concern, for the most part, the shock package for your race car should be designed for low-speed control to improve entry and exit performance. The shock times the movement of each of the corners of the car. It is this timing effect that redistributes the load on the four tires.

### The Modern Racing Shock

Shocks are a very important part of the overall setup package. While you can easily understand how spring rates and moment centers affect the setup, shocks can be very difficult to understand. Let's look at how shocks are designed, what racing shocks do and how they affect your setup, and how you can improve performance with shocks.

All the while, keep in mind that the shocks are tools to help enhance the overall setup platform, not setup components to be used to balance the car.

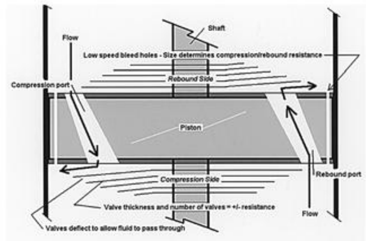
On both dirt and asphalt, shocks have come into their own as tuning tools. More and more teams and car builders are learning about how shocks can enhance their racing. Evidence of that is the sprouting up of new companies who specialize in designing shock packages and manufacturing the shock themselves.

### Shocks Are Speed Controllers

The racing shock is a device that controls how fast each corner of the car moves when a force is applied or removed. The two things that will cause a shock, or corner of the car, to move are bumps and changes in pitch and roll. Pitch is the change in attitude of the car on entry and exit and is caused by braking and acceleration. Roll is generated by the centrifugal force that affects the car in the turns that is trying to keep the car on a straight course and ultimately pulls on the center of gravity and creates a roll angle.

Different shock rates result in different speeds of movement for a given force. A stiff shock rate will move much slower when a measured force is applied to it in either compression or rebound. The force resistance for compression and rebound can and should be different for each shock. When we design the resistance forces we need to keep in mind our goals, the spring rates the shocks will be controlling and the motion ratios involved between the shocks and the wheel.

***Shocks Have Variable Resistance***—Shocks resist movement in various amounts depending on the speed at which the shocks are moving. The faster the shock is forced to move, the more resistance it provides. It is the speed of the fluid moving through the orifices of the shock that cause the change. As the speed of fluid movement increases, the pressures increase. Fluids are not compressible so the movement must slow as the volume increases.




**Shock piston showing ports and valves.**

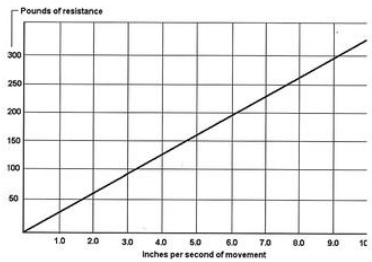
If the shaft is moving at three inches per second, the resistance (or shock rate) is much less than if it were moving 12" per second. The lower shaft speeds are typical of pitch and roll conditions, and the higher shaft speeds are typical of what happens when the tires run over bumps, brakes are applied or the car accelerates..

***Low-Speed Control***—Shocks contain a fluid that passes through tiny holes or jets for low-speed control, and larger ports with disc valves for higher speed control. The larger the low-speed hole in the shock piston, the less resistance there is to low-speed movement of the shock.

***Shock Valves and High-Speed Control***—The valves in shocks will deflect when the pressure within the shock increases along with faster movement of the shock shaft. There are different designs for these valves and for the ports within the pistons that the valves are attached to.

The valves are discs of thin stainless steel and come in different diameters and thickness. They are stacked with the largest diameter disc near the shock piston and the four or five additional discs per side are progressively smaller as they are stacked on top of the piston.

The thickness and arrangement of the different sizes of the valve discs determine the rate of resistance for each shock. Obviously, the thicker the discs are, the greater is the resistance to bending and the more restricted the flow of fluids.




**A linear shock.**

***Disc Preload***—Some valve discs can be preloaded so that they will begin to function at a higher pressure than normal. This is done by cutting a dish shape into the face of the piston. When the locking nut is tightened against the valve piston, the discs will be deflected tightly inside the dish recess. This creates a preload on the discs and more force will be required to open the disc than if the piston were flat.

## Rebuildable Shocks

Rebuildable shocks allow the racer to change the rates of their shocks themselves. With these types of shocks, you can open the shock body and remove the shaft and piston. Then the shaft is placed in a holder, and a nut holding the piston and valves is removed to allow the discs and/or piston to be changed.

More and more teams are learning the techniques for making shock valving changes. Kits are provided by the manufacturers with the different sizes of discs and various designs of pistons.

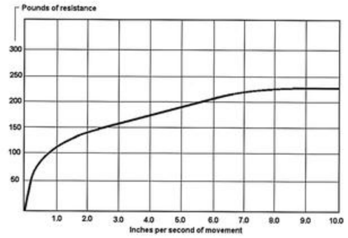
## Linear and Digressive Shocks

The two basic piston designs are called linear and digressive. Each type performs in a different way. While a linear shock will resist movement at a progressively higher rate as the speed increases and has less low speed resistance, the digressive shock offers more low-speed resistance and a more consistent high-speed control.

***Linear Shocks***—Linear shock pistons allow a greater flow at lower shock speeds. Therefore there is much less resistance to movement at the low speeds than that of a digressive shock. If high piston speeds are encountered, the resistance rate goes up significantly. If you hit a bump with a linear shock, the shock may not displace well and end up disturbing the handling.

The linear design of piston is most often preferred for the front shocks by drivers who are easy off the throttle and easier on the brakes. If a deeper entry is required in order to get under another car for a pass, the resistance will increase as the shock speed increases. The harder you go in, the more resistance, which makes the linear design a popular shock for the front of an asphalt stock car.

**A digressive shock.**




***Digressive Shocks***—A digressive shock will start out with a higher low speed resistance and increase resistance along with increased speed, but will digress in resistance (gradually offer less and less resistance) until at some point it does not build resistance and maintains a predetermined amount.

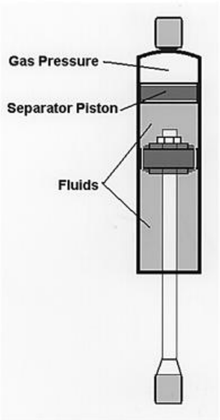
These types of shocks are usually preferred by drivers who are very aggressive and who will require a lot of "feel" to the car. These types of drivers will drive very deep into the corners and use a lot of brakes. In defense of this practice, there are some race tracks where this driving style is common and almost a necessity.

Some drivers prefer a linear shock to a digressive, and those drivers are usually smoother on entry and exit. The linear shocks have less low-speed control (see the illustration above).

If high levels of resistance are needed at various times during the race, the digressive types of shocks may not be able to provide adequate resistance once the shaft speed passes the point where the resistance no longer increases.

This is a common occurrence with front shocks. See the graph for digressive shocks. Above about 8" per second of shaft speed, the resistance does not increase past 230 lb What if you need 260 or 280 lb of resistance at this or greater shaft speeds?

If you look at the graph for the linear shock, at 8" per second you have 260 lb of resistance. If you drive harder and the shock moves faster, the resistance will increase to continue to provide sufficient control.




**All shocks need a volume of gas inside to compress when the shock shaft is pushed up into the body. This shaft displaces the fluid and fluid is not compressible. So, if we didn't have a gas present, then the shock shaft would not go into the body. And, the gas must not mix with the fluids or the rate and consistency of the motion and resistance will be negatively affected.**

## What Shocks on What End?

Because of the characteristics explained above, it is usually preferable to put linear shocks on the front of the car and digressive shocks on the rear of the car. The front could develop higher shaft speeds with hard braking and the linear shocks will provide the added resistance needed for those shaft speeds.

At the rear of the car, the shaft speeds are much lower and probably never will reach the high velocities experienced by the front shocks. For this reason, as well as others related to load manipulation to improve entry and exit characteristics, digressive shocks are preferred for the rear of the stock car.

A gas-pressurized shock is built so that you can add nitrogen gas under pressure. This helps keep the gas from mixing with the shock oil and causing cavitations inside the shock when in motion. There is a separator piston in addition to the valve piston and it seals and separates the fluid and gas compartments.

## Gas Shocks

Some racing shocks carry unpressurized gas and some carry gas under pressure with a piston separating the fluids from the gas. The reason for using gas under pressure is because it forces all of the air out of the fluid and works to prevent cavitations, or the mixing of the air with the fluids as the piston moves inside the shock tube.

Inside any shock, there must be some air space in order for the fluid area inside the shock to have room to expand in order to compensate for the volume of the shaft as it is pushed into the shock body. While the shock is being compressed, the shaft moves into the shock body and takes up space. With a gas space inside the shock, the gas will compress to allow room for the space occupied by the shaft. Fluid will not compress, so gas is required because it will compress.

The pressure of the gas can be changed to tune the characteristics of the gas pressure shock. This is a fine tuning tool and should be done within certain limits.

***Unpressurized Shocks***—With unpressurized shocks, the gas is usually contained in a bag that is placed inside the shock inside the fluid. As the shaft enters the shock body, the gas in the bag will compress providing room for the volume of the shock shaft. This type of shock tends to exhibit some of the tendencies of the pressure shocks as long as the bag remains intact and sealed. And, because the shock shaft is fully extended when the shock is assembled and partially inserted inside the shock body at ride height, there is some pressurization of the gas, but not to the extent of a pressurized gas shock.

***Pressurized Shocks***—In a gas pressure shock, the gas is separated from the fluid by a separator piston. This gas is then pressurized through a valve in the top of the shock body. This design keeps all of the gas inside of the shock from mixing with the fluid. If the gas were to come in contact with the shock fluid, then as the shock piston moved back and forth, the gas would mix with the fluid causing cavitations and would reduce the amount of resistance for the shock while making the movement very erratic.

***Mixing of Air and Fluid Lowers Shock Rate***—Fluid that is mixed with gas will move through the openings in the shock piston much more easily than pure fluid, so in order for the shock to maintain proper resistance, the gas cannot be allowed to mix with the fluid.

***Problems with Gas Pressure Shocks***—Gas pressure shocks are said to be more consistent, and many racers prefer them because of that trait. They resist cavitations and for that reason alone are more consistent.

The downside to gas pressure shocks is that if the gas pressure gets too high from heat buildup, they become too stiff and change their rating. When the shock is run and continuously moved, it heats up and the gas inside the shock expands. With the higher pressures, the shock has more resistance to accepting the area of the shaft on compression, the compression rate goes up and the rebound rate goes down.

If you are able to regulate the pressure of your shocks, do not start out with too much cold pressure in the shock. A starting pressure of between 75 and 100 lb is plenty. As the shock heats up from movement during practice or the race, the pressure will build to 120 to 150 lb. If you start at 120 lb or more, then the pressure you will have after the heat build-up will be excessive.

## Split-Valve Shocks

Every shock has a separate mechanism to resist high-speed and low-speed movements. Compression (when the shaft is pushed into the shock body) and rebound (when the shaft is pulled out of the body) resistance can be tuned to the conditions of the race track by changing the valving inside the shock. The shock can be built so that the amount of resistance is different for each of these motions.

These are called split-valve shocks, and the high-speed compression resistance can be designed to be more or less than the high-speed rebound resistance. The low-speed control would basically remain the same for both movements if a hole through the piston allows low-speed flow control.

## External Low-Speed Adjustment

Some shocks are designed to allow for low-speed flow adjustment through the use of a specially built hollow shock shaft. A needle valve regulates the flow of fluid through the hollow shaft and the flow rate can be regulated without taking apart the shock body by turning an external adjuster.

These adjustable shocks can be built to provide a wide or narrow range of adjustment and resistance depending on the design of the valve. Tuning with these types of shocks is fast and easy and almost a necessity for testing where entry and exit tuning can be enhanced.

## Tuning with Shocks

Because you can choose higher or lower resistance for high-speed or low-speed compression and rebound for each corner of the car, you then have the ability to change the transitional characteristics of the car to improve performance at certain parts of the race track.

Each change will redistribute the loads on the four tires momentarily while the shock is in motion. Remember that a change to one shock setting will affect the other four corners of the car related to load distribution.

***Shocks Can Influence Mid-Turn Handling—***

In this modern age, we have learned that shocks can affect the mid-turn handling of a circle track race car. The use of high-rebound resistance shocks, or tie-downs, can cause a jacking effect that essentially will hold a wheel in rebound longer than it wants to return to its neutral dynamic state for the load it is carrying.

Each corner of the car reacts to changes in the load it is carrying by compressing, rebounding or staying still if the load does not change. If we restrict the movement more than is necessary to allow the timely movement of the wheel to the new load, then we artificially add or remove load from that wheel.

This manipulation of load is hard to design and very difficult to tune for handling balance. The setup is best defined by the spring rates and moment center designs.

## Basic Shock Theory

Basic shock theory tells us that our springs help resist bump or compression (along with the shocks) and will promote rebound. The original job that all shocks were intended to do was to keep the spring bounce in check, so that automobiles would ride smoother. If you've ever seen an old car going down the road with completely worn-out shocks, you know why they are so important. Those cars seem to keep on bouncing forever.

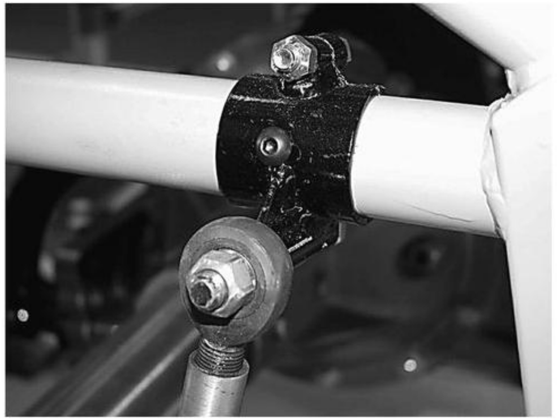
This theory should be carried over to racing shocks. As we make changes to our overall spring stiffness, the shock rates must change also.

***The True 50/50 Shock***—If the springs resist compression and promote rebound, it would seem like the perfect shock would have more rebound resistance than compression resistance in order for the resistance-to-wheel movement to be the same each way, or 50/50.

If you read a graph of a shock and the compression and rebound resistance are the same, then with the spring installed, it would seem that you would need a stiffer rebound number than compression because of the force of the spring. If you were to run even shock values for compression and rebound, then on the race track, you would have much more compression resistance than rebound resistance in your wheel assemblies.

So why don't you see a 50/50 shock that is rated at say four compression and six rebound? This arrangement is actually becoming more and more popular and works very well on flatter race tracks and on dirt.

Professional teams have started to rate their shocks in a fixture with the spring installed too. The resistance is measured not at the shock, but at the axle, or spindle pin. This gives us a much better picture of what we should be looking at.



**When using the clamp type of shock-mounting bracket, always through-bolt into the chassis tubing to keep the bracket from slipping around the tubing. The high amount of load and forces the shocks and/or shock-spring combination take will cause the clamps to shift.**

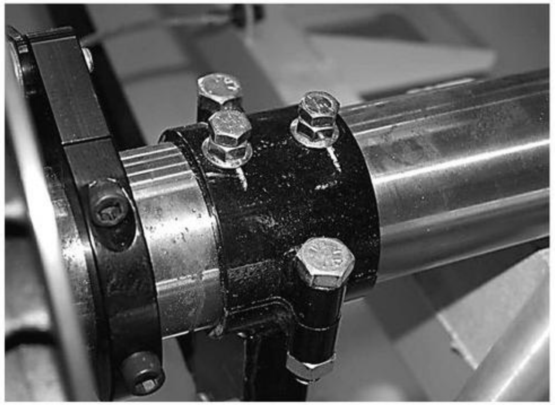
***High-Banked Tracks Require More Compression***—As the car enters the turns on higher-banked race tracks, the banking creates quite a bit of downforce as it rises up to create the banking. The suspension will want to compress into the banking on entry and so more compression resistance is usually required.

The continued downforce created by the banking offsets some of the rebound properties of the springs. With that help, you don't need to add more rebound resistance. The shock package for a high-banked race track might truly be a 50/50 shock, or one that has equal resistance for compression and rebound due to the down-force created by the banking.

## Shock Resistance Affected by Spring Rate

If shocks control the speed at which the corners of the car want to move, it would seem logical that a number 6 shock would move at different speeds when used with different rates of springs. This is because the spring adds resistance to the compression stroke of the shock and a softer spring would move faster than a stiffer one with the same force trying to move both. A stiffer spring will cause a shock to rebound faster than if the shock were installed with a softer spring for the same reason. A shock dyno tells us how much load a shock will resist for each "speed in" of movement per second. To know how fast a corner moves involves knowing what spring rates are installed in the car.

Under the same track conditions, if you change from a 600-lb spring to a 900-lb spring, the shock will react differently and have a different rate of resistance. Logically, shocks should be rated with the spring, but they aren't, so you are forced to make trial-and-error selections for your shocks.



**The rear trailing arm/shock bracket should also be pinned. This team drilled and tapped into the axle housing to locate the bracket and prevent the clamp from slipping.**

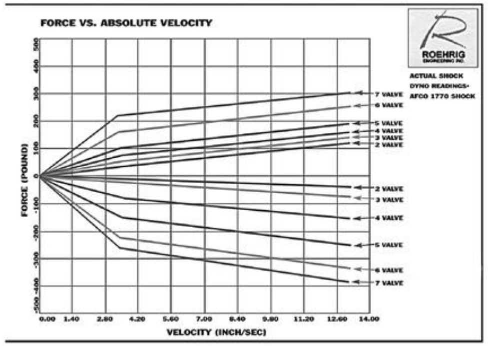
In the case of a high motion ratio installation such as a swing arm rear suspension, the shock will move at 66 to 75% of the speed of the wheel. If we install a shock that was designed for a 1:1 ratio of movement such as one clamped to the rear axle housing, then we won't have the rates we need. Both the rebound and compression rates will need to be increased accordingly.

## Use Split-Valve Shocks for Entry and Exit

Splitting the resistance of the shocks, side to side at each end of the car, will alter entry and exit performance and affect weight transfer momentarily. Let's examine the front first for entry performance.

If you put a pair of number 6 shocks on the front corners, as you brake into the corner, both the right-front and left-front corners will compress at the same rate when using equal springs. If the right-front spring is rated higher, then the right-front will compress more slowly. If you put a stiffer compression shock on the right-front also, then it will compress even slower.

What does this mean as far as performance is concerned? If the right-front compresses slower, then for the amount of time it takes the front end to complete its suspension travel, the car will be tighter. That is because with more resistance-to-compression at the right-front corner, there will be more weight jacked into that corner and the left-rear corner.




**A well-designed adjustable shock will provide a wide range of resistance to movement in rebound and compression. This allows you to find the best combination to tune your entry and exit for maximum performance.**

Insist on a shock graph with each shock build you buy. If the shock is an adjustable one, ask for a sweep graph showing the entire range of adjustment for both rebound and compression.

## Weight Jacking Using Shocks

As load is jacked into any corner, the diagonal corner will also support more load. In this example, let's assume it is the right-front corner that compresses on entry. If the right-front and left-rear now support more load, then the cross-weight percentage becomes higher. That equals more bite and the car will be tighter on entry.

Usually this is a confidence builder for the driver and allows him to drive into the corner deeper knowing the rear end is firmly under him.

In order for this to work the way it is supposed to, the left-rear shock must be low enough in rebound resistance to allow it to maintain contact and loading on the track surface. If a car is already tight on entry, decreasing the right-front compression and increasing the left-rear rebound resistance will make the car more neutral on entry. We should only correct an improper arrangement of settings doing these changes and not try to manipulate the setup using the shocks.

## Shock Combinations

There are an infinite number of combinations of shock rates that can be used for a particular application. You need to think practically about what you need to accomplish and have a shock specialist help you to design the best combination of rebound and compression for all four shocks. Here are some general guidelines for using shocks to solve transient handling problems:
**Problem:** Push on entry
**Cause:** RF shock too stiff on compression.
**Solution:** Soften compression in RF shock.

**Problem:** Loose on entry
**Cause:** RF shock is too soft in compression or LR shock is too stiff in rebound.
**Solution:** Stiffen compression in RF shock or soften rebound in LR depending on which is the cause from above.
**Problem:** Push on exit
**Cause:** LF shock is too stiff in rebound or LR is too soft in compression or RR too soft in compression.
Solution: Soften LF in rebound or stiffen compression in LR or soften compression in RR.

**Problem:** Loose on exit:
**Cause:** RR is stiff in compression or LF is soft in rebound.
**Solution:** Soften compression in RR or stiffen rebound in LF.

**Note:** If you are experiencing a push or loose condition in the middle of the turn, this could be any number of things—a wrong combination of cross-weight, springs, sway bar, panhard bar heights, moment center locations or a combination of two or more of these. This is not usually a shock-related problem, but could be if you are trying to tie down one or more corners of the car.

**Note:** Never attempt to solve a spring problem with shocks. Balance the roll angles first to eliminate spring related handling problems. Remember, shocks do not support the car, they only control the speed at which the wheels move vertically and therefore the timing of the load transfer to each corner.

## Using Shocks for More Bite

In the rear, if you want more bite coming off the corners, you can split the compression resistance between the sides by increasing the left-rear compression and/or decreasing the right-rear compression. This adds load to the left-rear tire momentarily while the shocks are moving.

When the car squats on exit, more load will be forced onto the left-rear corner, as well as the right-front corner, providing a higher cross-weight percentage and a tighter car during initial acceleration. Again, this effect only lasts as long as the rear is moving downward, or squatting. But momentary effects like this can help prevent the tires from breaking loose when you first apply the throttle. The effect does not have to last long to be helpful.

## Brand Differences

It would be nice to be able to tell you exactly what rate and brand shocks to run on your race car for all conditions, but no one can do that. There are too many variables. One good reason is because all shock brands are different in their low- and high-speed designs. A #6 Carrera will not behave like a #6 Bilstein or a #6 Afco.

***Rating Shocks at a Certain Speed***—Besides, the obvious differences in piston and valve design, one of the primary reasons for brand mismatch is because most of the major shock companies rate their shocks at different speeds. Look again at the shock graphs and you will see that if Company X rates their shocks at 12" per second, and Company Y rates their shocks at 8" per second, then there is no way to relate between the two brands and a #6 shock for each brand might behave much differently on the race track. That is the best reason not to mix brands of shocks on your race car.

The gas pressure shock brands use very similar designs of discs and valves, but there are so many different variations of each that it is hard to tell what each will use for a particular application. So, even with a relatively similar shock design, there can be differences in the rates and characteristics.

***Different Designs of Resistance***—Different brands have different resistance curves and different amounts of low-speed control. No matter what claims are made, races and championships can be won with most of the better brands of pure racing shocks, whether they are gas pressure or unpressurized, as long as the quality is there. Shocks should be checked often for leaks, bad seals and bent shafts. Most shocks should be rebuilt or replaced at least once a season.

## Test Your Shocks Often

Doing the hand-push test is a good way to tell if the seals are blown out in a shock, but a dyno test is much more accurate. If it is within your budget, locate a good shock maintenance facility and let them rebuild and dyno each of your shocks. That way you know exactly what you have.

Ask them to provide you with a printout of the graph showing the rates versus speeds for each shock for each setting. Keep these for future reference in you notebook.

## Do Your Setup Before Selecting Shocks

Find the right combination of shock rates that suits your driver's style and stick with it. Above all, get your setup right before you try to tune with shocks. When you have good, consistent mid-turn performance, tune entry and exit with your shocks.

The first rule of setup is to find the balance with the springs and moment centers before tuning with the shocks.

## Corner Entry Control

On entry, there is a transfer of load forward and to the right. The right-front corner of the car wants to quickly dive as you apply the brakes and turn left. This motion will in turn cause the left-rear corner to try to rise up and unload the left-rear tire. The car may get loose because of the decreased traction in the rear from less overall load and less equal side-to-side loading.

***Solving Loose Handling on Corner Entry***—To solve this problem, you may want to stiffen the compression on the right-front to slow it down and at the same time decrease the rebound resistance in the left-rear in order to release it more quickly to help it stay down and maintain loading and traction.

Doing this will help eliminate both a front push condition (the right-front gaining camber too fast yielding too much negative camber too quickly), or a possible loose condition that would be caused by the left-rear being unloaded too quickly.

## Corner Exit Control

On exit, the transfer of load is to the right and to the rear. The right-rear shock should be softer in compression for increased bite off the corner. If it is too stiff in compression, the transfer of the loads will loosen the car upon acceleration. The rear tires will spin if they do not have enough weight-induced traction. The correct distribution of this load transfer may help this situation.

The left front shock should have reduced rate of rebound to allow it to maintain contact with the track surface. As the load is transferred to the right-rear, the left front will have a tendency to rise up quickly. That tire must stay down to prevent a push condition.

If the car happens to be loose on exit, the compression on the left-rear can be increased to create a higher cross-weight percentage while the car is squatting.

## Aerodynamic Control Using Shocks

On faster, high-banked tracks such as Daytona and Talladega, the shocks serve a different purpose. Because of the restrictions on horsepower, the importance of aerodynamics is increased at these tracks and the shocks, more than anything else, help improve the aero efficiency. This is not to be confused with aero efficiency at the short tracks and the principles noted here may not apply to your type of racing.

***Lower Is Better***—The lower the car rides to the track, the less aero drag it produces because of less frontal area, less airflow under the dirty underside of the car and less wind striking the rear spoiler (which is often called an air dam). A low attitude will also enhance aero downforce to help increase overall grip.

***Tie-Down Shocks***—The shocks used at these tracks are generally built to compress quickly and rebound slowly, more so during qualifying than in the race. As the cars enter the turns a great amount of dynamic downforce pushes the car down and the soft compression allows this to happen fairly quickly.

Then as the car exits the turn onto the straightaway, it would normally return to the static ride height. The stiff rebound that is designed into the shocks holds the car down longer so that the aero advantage of being low that was making the car faster in the turns continues down the straightaway.

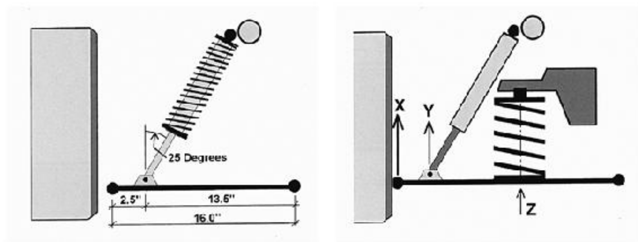
## Aero Push

You may have heard the term *aero push*. This condition is created when a change in the pitch attitude of the car causes loss of grip at the front of the car. For whatever reason, the front is made to rise up and airflows under the front of the car. The low pressure that is the cause of aero downforce is reduced and the downforce is also reduced and the front end loses grip quickly.

***Entry Humps Cause Aero-Push***—On some longer tracks, usually three quarters to one and a half mile in length, and with medium banking, there will be a slight crest in the track surface located just at the point where the car enters the corner. If the front end is allowed to rise up as the car moves over this hill, then a blast of air is allowed to flow under the front spoiler and front downforce is reduced.

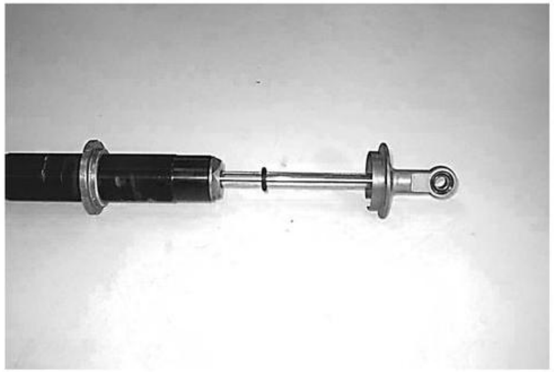
All of this happens just when you start to turn in, and the result is a push on entry. This can cause a driver to lift early on entry and ruin the lap times. Chapter 12 explains how front downforce works and how the condition explained here might reduce the amount of downforce.

To prevent this condition, you need to install shocks that have a much higher rebound rating than compression. This will allow the front to absorb the bump with the reduced compression resistance while controlling the tendency to rebound excessively with the increased rebound resistance. The car will follow the track surface over the bump, maintain or reduce the front spoiler height and eliminate the loss of front downforce.




**The effectiveness of the shock rate is influenced by the installation ratio of the suspension. The shock usually moves less than the wheel due to installation**

**motion ratios, or shock angles. So if movement speed affects the rate of resistance, then the shock might be wrong for the application if the ratio isn't taken into consideration.**



**Shocks usually come with a rubber O-ring placed over the shaft. When we push this ring up to the shock body before the car leaves the pit, we can measure the distance it has traveled from the body after the run to determine how far the shock moved. This method only measures the amount of compression or bump that has taken place and includes movement associated with braking and going over bumps.**

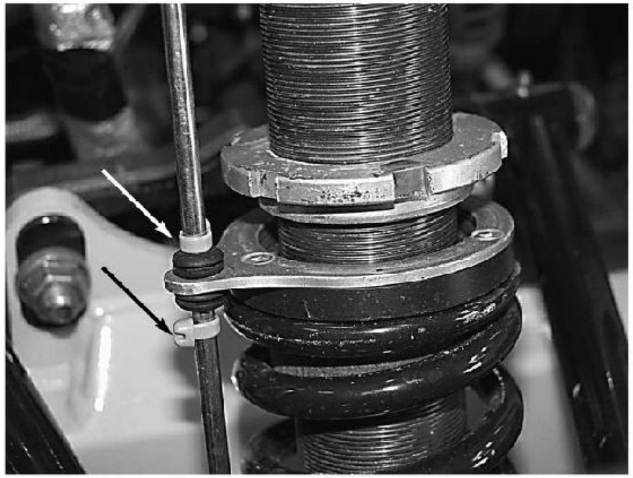
## Shock Travel

Shock travel is a good indicator of your spring stiffness related to how much you need for a particular track. It can also tell us a little about how far your wheels are moving in bump and rebound. If there is excessive shock travel, then we need to increase the spring rate. If there is insufficient travel, we can soften the spring rate.

The most accurate way to measure shock travel is with data acquisition. Then we can read the shock position and travel at any point on the race track. We can also read and compute the speed of the shock at the transition portions. This helps us know the resistance rate when we have a graph of the shock to compare the speed to .

Most shock experts agree with certain basics, such as:

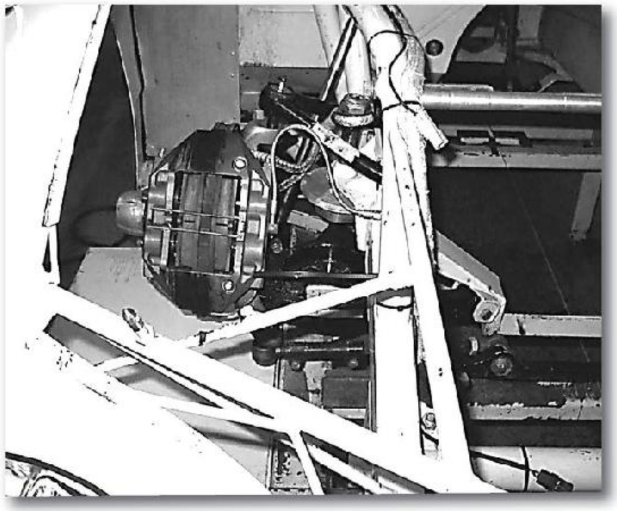
1. The shock package should be softer overall when racing on dirt and when the track is flatter when on asphalt.
2. Get your basic setup close to being balanced before trying to tune with shocks. Shocks cannot solve basic handling balance problems.
3. Higher banked tracks require a higher overall rate of shock as opposed to flat tracks. This is because of the higher speeds and the extreme amount of downforce.
4. Shocks that are mounted farther from the ball joint should be stiffer than if they were mounted close to the ball joint. That is because with each inch of travel of the wheel, the shock mounted farther away will move at a lesser speed which means less resistance to both rebound and compression.
5. Tune entry performance first. If there are no entry problems, make small changes if you want to experiment to see if entry can be improved. Entry problems include a tight car or a loose car. By far the worst problem would be the loose-in condition. Nine times out of ten this is an alignment problem and not shock related.
6. Tune exit performance last. If there are no exit problems, don't make any significant changes. Exit problems can include a car that pushes under acceleration or one that goes loose under power. Be sure that you do not have a tight/loose condition where the car is basically tight and goes loose just past mid-turn.
7. On dirt race tracks, reduce rebound settings on the left side and decrease the compression rates on the right side for dry slick surfaces to promote more chassis roll. This helps to maintain grip as the car goes through the transitional phases of entry and exit. The slower movement of the chassis allows the tires to better maintain contact and grip with the track surface.
8. On asphalt tracks, once the car has been tuned with shocks for optimum entry and exit performance, increase the overall rebound rates a small step at a time, especially on the left side, to possibly increase overall performance. This is especially good for low to medium banked race tracks. For highly banked tracks, the added rebound is not necessary or advisable.



**A couple of tie wraps placed tight to the rod on each side of the ring will record the amount of travel in each direction giving us a record of both compression and rebound travel.**

Chapter 11

## Brake Control Methods



**Stock cars need large brakes in order to slow the car from the high entry speeds. Large, vented rotors and brake pads with special compounds that withstand ultra-high heat are common and necessary. These brake systems must be tuned in order to gain the most performance from them. Just as we tune the suspension for balance, there needs to be a balance in the brake system so that we can attain maximum braking power and longevity.**

Tractive capacity is largely determined by how much load is put on a tire. As you brake, load will transfer from the back of the car to the front and the front tires will then support more load and with that, gain traction, which provides more ability to grip the race track. The more grip, the harder you can use the brakes when you are entering the corner.

With the increased traction on the front tires, the brakes can develop greater stopping power and you may need to use all of that stopping power. You will then be able to slow the car down in a shorter distance and brake later. The driver can go into the turn deeper, stay on the throttle a little longer and the average lap times should decrease. While this may not be the best practice for every lap of the race, it will get us under someone you are trying to pass.

Driving instructors tell us that the fastest and most consistent laps are experienced with the driver getting off the throttle a little early and applying the brakes smoothly. Then he/she can get back on the throttle earlier and accelerate out of the turn.

This is all well and good and works just fine if you're not racing with anyone. But in the real world, you will be racing with other cars. They may not slow down when you get off the throttle early. In fact, they may just pass you on the inside or outside while you are being easy on the brakes.

For passing other cars or protecting your lead, you need all of the braking power you can get. When you can gain a couple of car lengths lead over you competitor, then you can relax into the easy off, hard on entry technique.

So you need to know how your brakes will react to diving in deep and applying a lot of brakes. This is where brake bias adjustment is so critical.

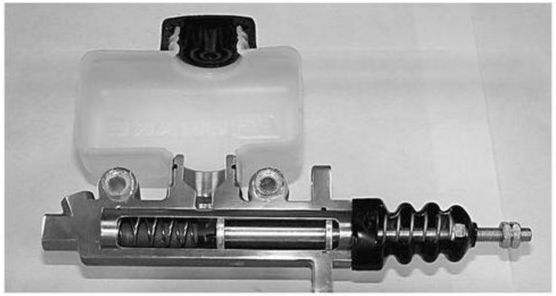
## Selecting Components for Bias

The perfect brake bias would have both the front and rear brakes lock up simultaneously, or very nearly so. When one end or the other has more or less braking power for the available traction the tires have available, then that end will lock up. If one end locks up well before the other, then we have a brake bias problem and we will not be able to slow the car as quickly as possible.

The selection of components is foremost in the process of establishing your brake bias. The size of the master cylinders versus the caliper piston size will establish the initial range of bias. The bias can be tuned with the balance bar in the pedal assembly once the correct combination of the above has been selected.

## Master Cylinders

In choosing the correct master cylinders, remember that the smaller the piston in the master, the more pressure in lb per square inch it will generate. This is because the force you place on the pedal in lb is transferred to the fluid through the face of the piston. You divide the force by the surface area of the piston to get the line pressure.



**The size of the master cylinder bore and piston determines how much line pressure you can generate. We have more braking power in the front brakes due to the larger load the tires carry, so the front can stand more line pressure and braking force before the tires break loose.**

If a one square inch piston were moved with 100 lb of force, then the line pressure would be 100 psi (lb per square inch). If we reduce the piston size to a

3/4 square inch surface area, then the line pressure would be 100 divided by 0.75, or 133 psi. We gain line pressure from the smaller master cylinder bore and piston size.

## Brake Calipers

The caliper size will determine how much force the line pressure will generate in clamping the brake pads against the brake rotor. The theory is somewhat reversed from the explanation of the master cylinders.

We have generated a certain line pressure related to the amount of force put on the brake pedal and the size of the master cylinder. Now we need to determine the caliper size we need to complete the brake system for the end of the car we are working on.

If we apply a line pressure of 133 psi to a 1.76 square inch caliper piston, we can generate 235 lb of force onto the brake pad.

A larger piston will generate more pounds of force because the surface area increases and the line pressure is distributed over more square inches.

## Balance Front to Rear

Now we need to know how to balance the front to rear bias from the selection of the master cylinder sizes and the caliper size for the front and rear. If we use a smaller diameter front master cylinder in relation to the rear master, then we will have more line pressure available to the front calipers.

If we install larger front calipers versus the rear calipers, then we will generate more brake pad pressure if the front and rear masters were the same size. So, there are two ways to set brake bias. We don't want to overdo this process and end up with a front bias that overwhelms the rear, or vice versa, too much rear bias. But we do need to get the system in a range where when the balance bar is centered, we have nearly perfect front-to-rear brake bias.

**The size of the piston in the brake caliper determines how much pressure will be exerted on the brake pads. A larger piston will generate more pressure. We need to find the correct size caliper for the front and rear to help establish the correct bias.**

**When selecting the front and rear master cylinders, take into account the bias difference you will need. The front master size is usually smaller than the rear to generate more line pressure to the front. It is the caliper size that ultimately determines the final pressures exerted on the brake pads.**

## Brake Bias

You need to know how much line pressure is being applied to each set of front and rear calipers. This can be measured with a set of line pressure gauges. They show the pressure in pound per square inch (psi) for the front and rear brake lines with the same brake pedal pressure. These gauges are very important to have installed in your car if you want to maintain and tune to the best front-to-rear brake bias ratio. An added advantage is being able to detect any sudden changes to brake line pressures that may occur for any reason. Damaged components, and brake line and piston seal leaks all attribute to changes in line pressure.

## Increase Total Braking Power

If you run a 50/50 split of line pressure front to rear, you may not be getting the most out of your brakes. Let's say for example that at each end of the car you are generating a total of 500 lb of brake pad pressure at the front and rear (250 lb front and 250 lb rear) when the pedal is pushed. The front tires might be able to withstand 300 or more psi of pad pressure because of the added traction available from higher loading to the front upon braking.

The rear brakes might only be able to withstand 200 psi of pad because of the loss of load on the tires due to load transfer. So, the driver will have to limit his braking to 200 lb of line pressure in order to keep the rear brakes from locking up. He may never know that there is more braking power available to him. Drivers are very sensitive to how the car feels, and in this case, the car would feel like it could only enter with 200 lb of brake pad pressure, causing him to let off earlier and brake longer.

## Brakes Can Change Amount of Grip

There are several reasons why braking bias might change. As the car is run, the brake pads will wear, and the surface area will increase. This is because many pads have a bevel that is cut into the leading edge of the pad. As the pad wears out, the pad surface area increases, which increases gripping power. Since the front pads wear much faster than the rear, the front will gain bias over the rear. The front-to-rear bias may have to be changed periodically to compensate for this effect.

## Brake Failure

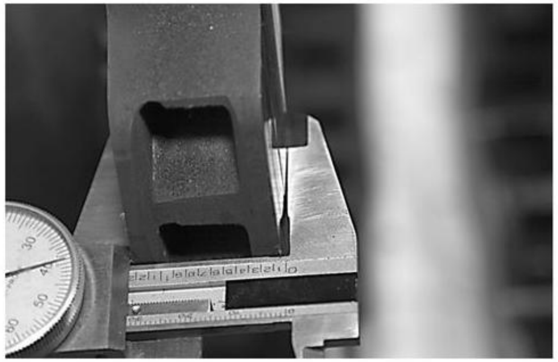
It doesn't matter how fast your car is in the race. If your brakes don't last, you will eventually slow down. There are several factors that lead to brake failure. We need to know these possibilities so we can focus attention on these areas and possibly prevent the failures. Installation and maintenance procedures can go a long way towards preventing brake problems.

***Brake Fluid Failure***—The most common cause of brake fluid failure is moisture getting into the fluid. As soon as the brake fluid bottle is opened and the fluid is exposed to the air, moisture from the air will mix with the fluid and contaminate it. Always use fresh, unopened brake fluid and never store an opened bottle for future use.

High fluid temperatures will boil the water that contaminates brake fluid. The temperatures inside the caliper can reach well over 300 degrees. Water boils at 212 degrees. The moisture inside the brake fluid will boil causing gas (steam) to mix with the brake fluid. The brakes get mushy and the car becomes very hard to stop. Never reuse brake fluid. A good way to prevent problems is to replace the brake fluid often.

***Rotor Failure***—Rotors can fail or become less efficient. Excessive heat cycles can fatigue the metal and cause cracks to appear. There are basically two kinds of cracks we see in racing rotors. The small surface cracks are a normal occurrence and if they are not too deep and near the edge of the rotor, they are not a problem.

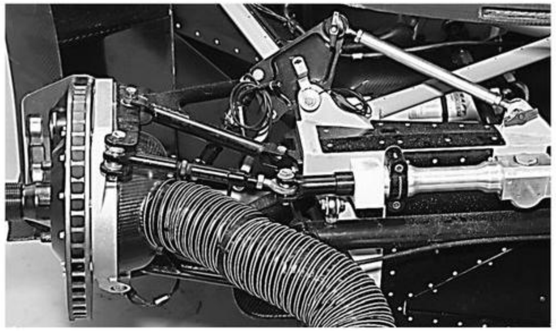
**If your rotor develops deep cracks that extend to the edge of the rotor, it is time to replace it. These types of cracks can cause the rotor to break apart with very bad results. Small surface cracks that are shallow and don't extend to the edge of the rotor are acceptable and normal for racing brake rotors.**



**Rotors can develop tapered wear. If the calipers flex under braking pressure, then the pad will be pressed at an angle to the rotor face. Eventually this uneven pressure will wear the outer edge of the rotor and we can see here where the material has been worn more so at the outer edge to form a taper. It is time to replace the rotor and possibly the caliper.**

Larger cracks that extend to the edge of the rotor are a failure waiting to happen. When you see these kinds of cracks, you need to replace the rotor.

***Cooling the Brakes***—Another problem that can reduce brake power is insufficient cooling of the brake rotor. A brake rotor is built like a centrifugal fan. As it rotates, air is forced out of the vent ducts that are cast into the center of the rotor. Therefore, air enters at the center of the rotor and exits at the outer edge. Always direct the ducted cooling air to the center of the rotor to get the maximum effect of cooling. Air that is directed to the face of the rotor will not have nearly as much cooling effect and really only cools one side of the rotor. Make sure the rotor vanes are pointed in the correct direction on angled vane rotors. The correct direction is toward the rear of the car when looking at the top of the rotor.



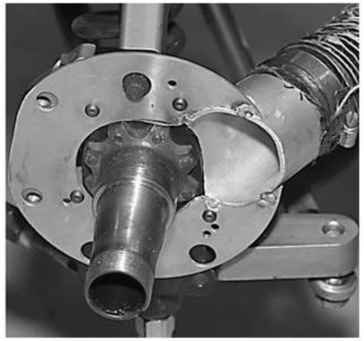
**This brake duct is well made and installed correctly. The rotor end of the hose assembly is made of metal and is fitted to deliver the most air directly to the center of the brake rotor. Note that the rotor vanes are correctly angled to the rear at the top of the rotor. This system is installed on a Grand Am Daytona Prototype. The cooling air is collected at the front of the splitter assembly. Carbon fiber is used where possible to reduce weight.**

***Wheel to Rotor Clearance***—Make sure there is sufficient clearance between the wheel and the outer edge of the rotor. There should be enough room for the hot gases from the brakes to escape. Using too large a rotor diameter for your wheel size will cause cooling problems when the hot air cannot escape from the rotor vanes.

***Wheel Offset***—Wheel offset can also affect brake cooling. A deeper offset (from the inside part of the wheel) will place the brake rotor more to the inside of the wheel and will reduce the cooling efficiency.

***Rotational Direction for Brake Rotors***—Also, make sure the cooling vanes in your brake rotors are facing the right direction. More than one team has installed the rotors backwards. Looking down on the rotor, the vanes should be angled to the rear of the car. When the rotor spins, air is vented out to the rear at the top of the rotor. If the vanes are backward (rotors reversed from side to side), then air will be jammed up in the vanes and the rotors will not cool properly.

**When mounting the brake rotors, make sure the venting ports are angled to the rear from a top view on each side. The rotation of the rotor forces the hot air to exit at the outside edge of the disk and causes cooler air to be sucked in at the middle of the rotor. Air vents should be directed at the center of the rotor for this reason.**



**This is a very good example of proper brake cooling procedure because the air is directed at the center of the rotor where it can flow through the vents evenly. It does little good to move cooler air onto the surface of the rotor. Cooling one side of the rotor will only cause uneven temperatures side to side and may cause rotor failure.**

## Brake Pads

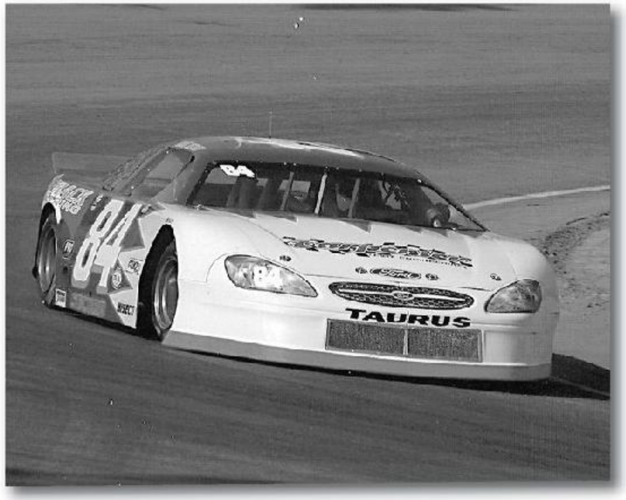
There are many new brake pad materials available now as compared ten years ago. The quality of brake rotor has improved too, which relates to being able to run higher pad/rotor temperatures than ever before without experiencing brake fade.

***Seek Help from a Professional***—Select brake pad material carefully. Consult a brake company representative and seek advice on the correct hardness and type of material for the brake pad for your application. Pick his brain concerning the best pads and rotors to run for your type of racing. Take brake rotor temperatures after a hard run. These temperatures will tell the representative a lot about how your system needs to be designed. Don't be afraid to ask questions. The representative will be interested in improving your performance because it helps him sell the product if you are successful.

This is free help, so use it. A little improvement here goes a long way towards top performance.

Chapter 12

# Aerodynamics



**A low and flat attitude is especially useful for developing the best aero package. While working on your aero package, you need to be careful not to get away from the dynamic balance that was so hard to perfect. This car won numerous races and championships yet still showed some degree of chassis roll.**

Aerodynamics is the study of how an object is affected by moving through air. Since our race car is an object that moves very quickly through the air, the stability and loading is affected by the shape of its body and the attitude of the car. Performance can be gained by designing the car to be more aerodynamically efficient.

It takes a lot of horsepower to push a car through air and more horsepower is required the faster you go. It helps to produce more speed if the body of our race car is more efficient to let the air pass easily around it. The force needed to propel the car is compounded exponentially as the speed increases. This means that if we want to double our speed, we would need much more than double the power to push the car through air at the increased speed.

## Basic Aerodynamic Principles

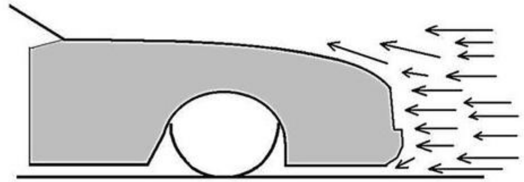
As air passes over, under and around your race car, it has an effect on how much traction you have and how difficult it is for your engine to push the car through the air. Traction is gained by having more downforce. Speed is gained by having less drag. The car will move through the air more easily if there is less drag. Downforce creates more loading which makes the tires grip better, increasing cornering speeds. Here is how these effects work.

***Drag***—Drag is defined as the resistance to forward speed caused by the car pushing through the air. The variables that determine how much drag there is are:

- air density (how thick the air is that you are trying to push the car through)
- frontal area (how big the object is you are trying to push through the air)
- aero efficiency (how slick and how easily air flows over the surface of the race car).

It's hard to believe a substance as thin as air can create such resistance. But it is the velocity that makes the difference. The faster an object travels through the air, the more resistance is generated, and the drag increases exponentially. That means that for twice the speed, the drag might increase 2 1/2 times. At three times the speed, the drag might increase four times or more. That is why a car with 600 horsepower does not go twice as fast as a car with 300 horsepower. A good Late Model stock car with 350 or so horsepower can manage to run 160 miles per hour at a big race track. But if you put a 700 horsepower motor in it, it will not run 320 miles per hour.

***Stick Your Hand Out the Window***—Think back to when you were a kid, or for those of you that never grew up like me, maybe last week. Traveling down the road at 60-plus miles per hour, you stick your hand out the window and feel the resistance of the air. If you hold your palm flat to the oncoming air, it pushes your arm back. If you turn your palm down, suddenly there is less resistance and your hand is easy to hold against the wind.



**A blunt front end will not help air to get up and over the hood area of the car. It will jam up the air at the front to create a pressure front, or bow wave, as it is referred to.**

***Shape Matters***—What you felt was aerodynamic drag. Drag is caused by the shape and size of the car and the shape of its components. A "rocket" is an efficient aerodynamic shape and causes less aerodynamic drag, so it is easier to push through the air. A flat, square shape is much harder to push through the air.

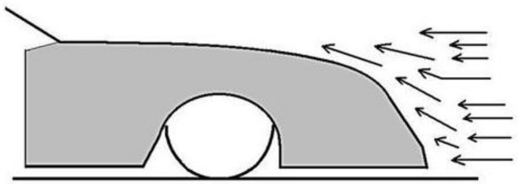
***Downforce***—Downforce is caused by a differential of air pressure between the two sides of an object with the lower pressure being on the underside. Thus the effect of pull is in the down direction. In the case of front downforce, the area under the hood is under less atmospheric pressure than at the top of the hood. With more psi pressure on the top, a force pushing down is created.

## Short Track Aerodynamics

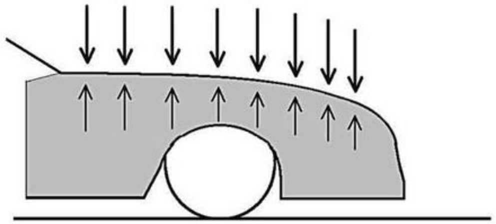
In the study of a short-track race car, drag is not as significant a factor as in the case of a modern Cup car at Daytona. That much is obvious. But, if downforce can increase traction, then we may be able to utilize some added downforce at the front and rear of the car to help with corner speeds and wheel slip caused by sudden acceleration.

***Better Traction Overrides Increased Drag***—A rear spoiler with increased area and vertical angle will help provide more traction on exit off the corner at the expense of increased high-speed drag. Even though the high-speed drag is more, a bigger gain in speed will be experienced with the higher traction on exit than will be lost in aero drag for most short track situations.

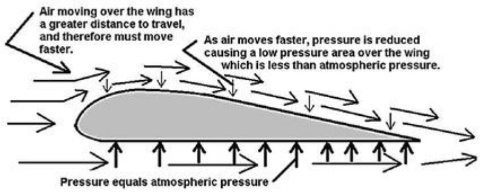
***Rear Downforce Changes Weight Distribution***—Keep in mind that two things happen with spoiler-induced down-force. First, and most obvious, it increases the load on the rear tires, which increases traction. This is a very good thing. It also creates a cantilever effect that redistributes the weight of the car because the force is applied well behind the rear axle. This tends to lift the front end robbing it of some amount of load. Both the effect of increased rear downforce and weight transfer to the rear will serve to "tighten" the car.



**A sloped front end is a more efficient design that allows the air coming at the front of the car to begin to move up and over the hood, creating less drag.**



**If the pressure under the hood is reduced from 14.7 to 14.5 psi, then the force pushing down on the hood would be 300 lb. That is only a difference of 0.20 psi of pressure needed to create a lot of downforce.**




## How Aero Forces Work

A wing on an airplane is not pushed up by air striking the bottom of the wing, but as the result of a low-pressure area on the top of the wing and higher pressure on the bottom. Look out the window of a commercial jet on your next trip somewhere and you can see the sections of the wing between the rivets bulging out from this low-pressure effect. The airplane is being pushed up into the sky by the higher pressure beneath the wing.

**This is an example of a 70-degree spoiler. There is not much horizontal area behind the spoiler to create effective downforce. This spoiler will produce a lot of drag.**

**This shows what a 55-degree spoiler looks like. It will produce more downforce than the 70-degree spoiler with less drag. This is probably the most angle you should use and optimum is between 50 and 55 degrees from horizontal.**

***Aero Forces in a Stock Car***—A similar effect is taking place with your spoiler. As airflows over the spoiler, air is being sucked out of the space behind it and that creates a low-pressure area under and behind the spoiler. That low-pressure area pulls down on the spoiler and creates the downforce.

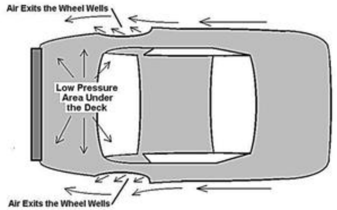
## Rear Downforce

The angle of the rear spoiler is critical to the amount of downforce that is created. A spoiler creates two forces, drag and downforce. A basic study and understanding of aero-dynamics tells us that differences in air pressure are what create the pulling, or downforce effect.

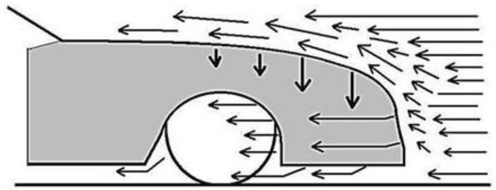
***Increased Rear Downforce***—Rear downforce can also be produced by the movement of air around the sides of the rear wheel wells of the car. This fast-moving air flows out and to the side of the wheel wells, creating a low-pressure area immediately outside the wheels that pulls air from inside the rear deck compartment. Once this happens, a low-pressure area is then created under the rear deck and this is what creates the additional rear downforce.

## Front Downforce

Front downforce is produced mostly by the movement of air around the sides of the nose of the car. This fast-moving air flows out and to the side of the wheel wells creating a low-pressure area immediately outside the wheels that pulls air from inside the engine compartment. Once this happens, a low-pressure area is then created under the hood and this is what creates the downforce.




**The above illustration shows how, as the air is routed down the sides of the car, the shape of the side panels causes the air to be directed away from the sides of the car to create a low pressure area outside of the wheel wells. As a result of this low-pressure area, air is sucked out of the wheel wells, and a low-pressure area is formed under the rear deck.**



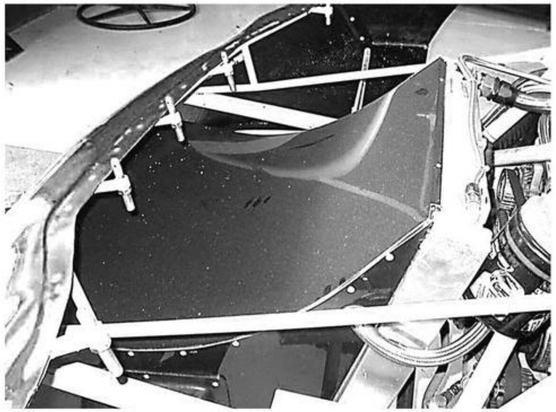
**Front downforce is created by air being sucked out from the engine compartment through the wheel wells. As air flows over the hood, there is little effect from pushing down on the top of the hood.**

***Long Noses Create More Downforce***—The longer the nose, the more the downforce affects the setup. This is the result of the cantilever effect of the downforce working ahead of the front axle.

***The Effect of a Nose Pan***—If the nose area is closed off underneath and in front of the wheels, then the downforce effect is increased. That is because air usually flows under the front spoiler at the front and sides of the nose and replaces the air being sucked out of the wheel wells. By preventing this flow of air from reaching the area of negative pressure, more downforce is created.

***It Doesn't Take Much***—A small amount of low pressure creates a large amount of downforce. For example, a difference in pressure of less than a 1/4 psi creates a total downforce of 300 lb.

Regulating the size of the wheel wells and the shape of the skirts does affect the amount of downforce created. That is why a car that has been hit in the front corner begins to push. Without the air being blown out and away from the wheel well, there is less suction effect.



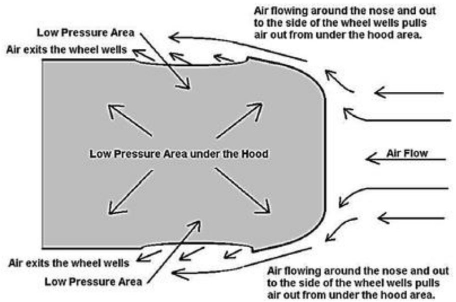
**In this photo you can see how building a curved air box can allow more space between the top of the box and the hood, increasing aero downforce on the front end. The radiator still gets plenty of air with this shape, and so cooling is not affected.**

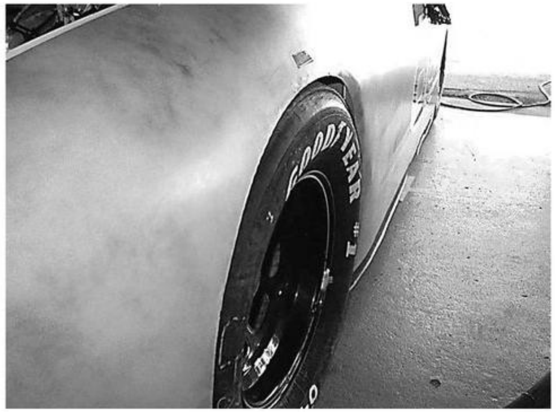
Another technique that will enhance the amount of downforce at the front end is to enlarge the area that is affected by the low pressure. If the top of the air box (from the nose to the radiator) is flat on top and close to the hood, then there is very little space available to create a low pressure in that area. If you design the air box so that it allows more space between the hood and the top of the air box, it has been proven that more downforce will be developed.

***Aerodynamics for Qualifying***—During the qualifying run, some teams will tape off the front air intakes to the radiator and brake duct openings in order to increase downforce, and in turn, increase the front traction. This actually creates more airflow around the sides of the car and better airflow over the hood creating more front downforce and less drag.

***More Front Downforce Allows More Bite***— With more front downforce, you can use more cross-weight percentage, which will provide more traction to tighten the car and allow the driver to be quicker on the throttle on exit. This is only good for a couple of laps because of the obvious heat buildup in the motor due to the lack of air passing through the radiator.

***No Cantilever Effect at the Front***—The negative cantilever effect of the added downforce in the front is not as pronounced as in the spoiler-induced rear downforce because the force at the front is applied over the top of the axle and the cantilever effect is minimal.



**The fender well on this car is built tight to the tire. On fast, high-speed tracks like Daytona, this provides less resistance from turbulence. The front of the wheel well is cut straight and the rear is angled to provide the exit of air from under the hood and fender to produce more downforce.**

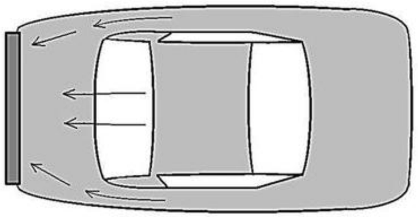
## Superspeedway Aerodynamics

On superspeedways, aerodynamics play the most important role when it comes to speed. The aerodynamic speed is largely determined by how slick a car is and how small the profile is.

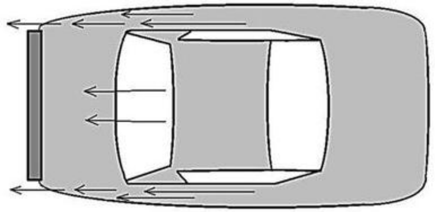
***High-Speed Objectives***—The objectives are decreased frontal area, a low front spoiler, and a lowered rear deck that will serve to get the rear spoiler out of the wind stream. Some of this is made possible through the selection of a proper set of shocks and springs that will help to create and maintain a low attitude in the turns and keep that attitude down the straightaways as well.

Another way to increase aero efficiency and reduce drag is to reshape the body. If you reposition the area where the roof support meets the fender, you can get the air away from the rear spoiler. On short tracks, you need to get more air to the spoiler for downforce effect. On superspeedways, however, the air flowing over the spoiler can produce a large amount of drag. If you can redirect the air to bypass the spoiler, then drag will be reduced, increasing speed.

**This is a good short-track design that allows more air to flow around the sides of the roof supports and onto the spoiler for more downforce and more rear traction.**



**A speedway car might be designed like this car. The roof support section is shaped to be more parallel to the centerline of the car, which will direct the air past the spoiler. There is less rear downforce, but much less drag. This has been proven to create higher speeds.**



## Low Front Spoiler

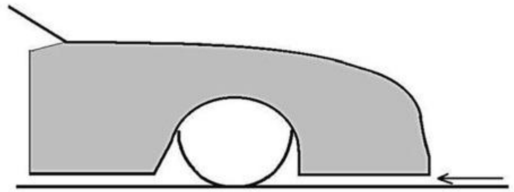
A low front spoiler, or valance, will reduce the amount of air that gets under the car. The bottom of the car has many irregular surfaces for the air to flow over and around and this produces a large amount of drag. Low spoilers help to create more downforce which further lowers the front of the car.

***Lower Spoiler Due to Setup Configuration***—A lower front that is more parallel to the race track can be produced through the setup of the car. By selecting the right combination of springs, you can mostly eliminate the roll effect and cause the car to dive on high-banked race tracks. Then there will be a low-level front spoiler with less airflowing underneath the car when cornering.

## Pitch Control Enhances Aero Efficiency

Many teams strive for pitch control at a superspeedway. The car will assume a certain pitch, which is the front-to-rear angle of the car to the race track, while in the turns. As the car comes off the banking onto the straightaway, it should maintain the same pitch angle for best aero efficiency.

***Springs and Shocks Help Pitch Control***—The proper selection of springs will allow the car to get lower and to be square to the track in the turns. The correct combination of shocks will let it get down quickly on turn entry, keep it lower down the straightaways and help maintain the same pitch after the car exits the turns and resumes the normal ride height.



**A major objective of teams at superspeedways is to try to lower the nose to reduce the gap under the nose of the car. Certain setups promote a lower attitude as the car negotiates the turns. Air traveling under the chassis will be more disturbed (dirty air) and cause more drag than any other air traveling around the car.**

## Aero Push

An aero push is often caused by a setup that allows an excessive amount of air to flow under the front spoiler. The air that flows under the front skirt will replace the air that is being suctioned out of the wheel wells. This creates less downforce. This can be due to the wrong setup or a problem that is a direct result of how the race track is shaped.

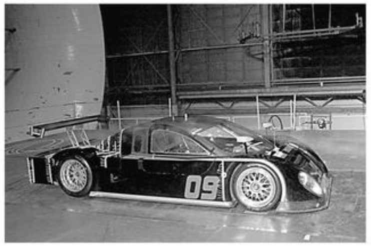
If the track has a rise or a long and low bump right before entry to the turns, then the front end will lift allowing a greater volume of air to flow under the front spoiler.

This momentary "gulp" of air replaces the suctioned air and reduces the amount of front downforce. This upsets the balance of the race car and will make it push. With less front downforce, there will be less traction up front and the car won't want to turn.

Although this usually happens quickly and is over in a fairly short amount of time, once the push starts, it will stay with the car through the entire turn, unless the driver backs off to regain control. The solution is to decrease compression and increase front shock rebound settings. At these types of tracks, you want to use a fairly high amount of rebound settings on all four shocks.

## Setup Creates Aero Problems

In the case of a setup problem, the car may be sprung so that there is excessive right-rear shock travel, causing the left-front corner of the car to be higher in the turns than it should be. This allows excess air to come under that part of the nose, which then replaces the air that has been suctioned out. Less suction equals less downforce. Using a setup that will reduce the height of the left-front corner will increase the downforce effect and help the car turn better.




**Many professional teams have the funding to spend time in the wind tunnel. We need to understand the properties of air, moving and still, to be able to properly utilize the data we acquire from wind tunnel tests.**

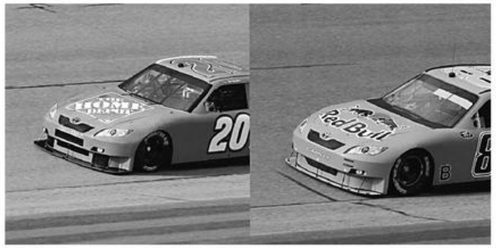
## Wind Tunnel Testing

The wind tunnel is designed to move air into and around a stationary vehicle. Keep in mind that we don't race in 120-185 mph winds, we actually race at 120-185 mph through relatively still air. It is a different set of dynamics between the two conditions. The only thing we can hope for in a wind tunnel, a NASA engineer once alluded to, is to find tendencies, not exact data.

***The Energy Level of Moving Air***—Air moving through a wind tunnel has a significant amount of energy, whereas still air on a race track or on the road has virtually none. One pound of air displaces about 13.07 cubic feet of volume at sea level. If one pound of air is traveling 75 mph in a wind tunnel, it would have 110 lb of inertia. There is approximately 20 lb of air contained in the volume of the race car. That equates to 2,200 lb of total inertia.

Each molecule of air has a lot of force trying to keep it going in the flow direction. It will take a lot of force to change its direction and once you do change its direction, it will carry a lot of force trying to keep it going in the new direction. Compress that high energy air between the car and the walls of the wind tunnel and you introduce more variables than you can account for.

***The Influence of Aero Beyond the Car***—When you are racing in still air, each pound of air would have one pound of inertia keeping it there. It is therefore easy to deflect that air, and it compresses easily. A car drives through still air at a high speed and disturbs the air in several directions. Then the rear of the car sucks the air back towards where it was to begin with. The perfect shape for a race car would move the air out of the way with the least amount of force, and then allow the air to flow back gently undisturbed. This can't be done realistically, but it is still your goal.




**We can see that the current trend is to develop setups that will provide a low and level attitude to the race track, especially at tracks like Daytona.**


**The older redesign of the Cup cars incorporates a front splitter, much like a Grand Am DP car, and also had a wing mounted to the rear deck. It was not much of a wing, however, due to the lack of space under it. This was to allow a free flow of air in order to develop downforce. This design created a lot of drag instead. Now these cars have gone back to the spoiler design.**

If the walls of a wind tunnel are too close, they will negatively affect your wind tunnel data. The closer they are to the car, the more inaccurate the data is. If you put a vehicle in a wind tunnel, you restrain airflow disturbance and actually artificially reattach the airflow back onto the vehicle.

The data will show a higher down force and higher drag, because you are compressing the air between the vehicle and the walls of the wind tunnel. This can also lower drag in some areas because you artificially reattached the flow onto the vehicle. One does not cancel out the other. You must manipulate all of the numbers from the wind tunnel data to have it make sense. Because you are putting a lot of inertia and energy into the air in a wind tunnel, the air does not behave the same way as it does in the real world. If it did, we wouldn't need test pilots.

**The wing on this sprint car could be very efficient in providing downforce. The problem comes when teams mount the wing with too much angle of attack to the direction of the air. The wing will stall and produce a lot of drag and little downforce.**

When you see a smoke wand used in a wind tunnel, you see smoke roughly following the contour of the vehicle. The further the smoke trail is off the surface of the vehicle when the wand is placed near the surface, the more airflow separation exists. This indicates more drag and less down force. You want the smoke to lay on the vehicle from front to rear. The further the smoke is off the car, the greater the flow separation and the greater the problem.

Changes to the rear flow of air will change the front flow characteristics and changes to the front flow will change the rear flow. Both drag and downforce are affected in this way. Any device you install across the airflow at the front of the car will separate the flow and significantly reduce good aerodynamic affects on the rear as well as add drag. NEVER disturb the airflow at the front of the car.

***Different Types of Airflow***—Turbulent flow is where airflow boils and rolls in many different directions as it flows over the surface. This may be over the entire surface, or part of it. The less turbulent flow you have, the less drag you will have. Most any current race car has turbulent airflow around it. The worst turbulence I have ever seen was in flight-testing a certain low wing aircraft. There was some airflow actually going in the opposite direction of the aircraft. That means going forward.

**In a test for aerodynamic properties, attaching yarn tufts can give us a visual reference for the flow of air over the body and how it is attached and reacting with the shape changes. You can observe this effect either in a wind tunnel where air is moved over a stationary vehicle or in a more realistic scenario by running the car through the air and recording the movement of the air as the car passes through it.**

Attached flow will significantly reduce drag and increase downforce or lift. If you get it attached over the entire surface, the drag reduction will really shock you. Usually attached flow occurs over less than 10% to 25 % of the front surface area. The more you get, the better you are. Attached flow is typically misinterpreted as Laminar flow. The two are different.

If anyone talks to you about achieving laminar flow on a race car, they are misinformed. The only exception is with a very few Formula car wings. Those cars only achieve laminar flow over a very small part of the surface. Laminar flow is a very small, as in a few thousandths of an inch, layer of airflow that acts like ball bearings, further reducing drag.

When you look up a laminar air foil from say NASA to use it on a race car, odds are about 99 %, you won't actually achieve the laminar flow. You really don't want a laminar flow air foil on a race car, because slight imperfections, dirt, rain, humidity can dramatically and suddenly reduce their performance. The surface must be clean, smooth and exceptionally accurate. If you put a pin stripe on some laminar air foils, they will not make any lift or down force. Laminar flow does not exist on any race cars in the U.S.

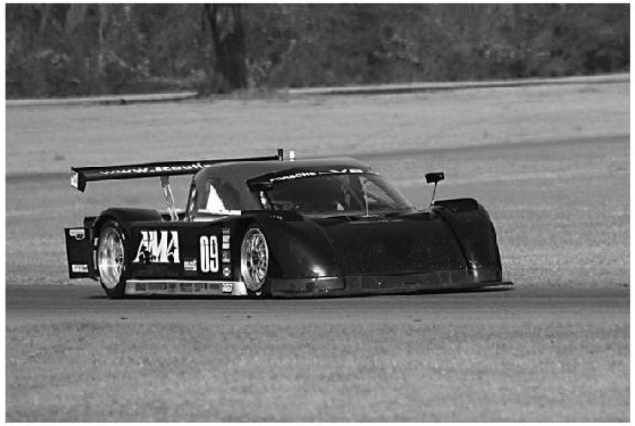
***Bow Wave***—As a vehicle pushes through air, it creates an area of high pressure in front of it. This is called a bow wave. The bow wave on a race car will be somewhere between 10 and 20 feet in front of the car. This means that the car is affecting and changing the airflow that is far in front of the car. The steeper the angle of the front of the car to the ground, the further out in front of the car the bow wave will be. The further out in front it is, the more drag the car will have.

**When testing either in a wind tunnel or on track, sensors are mounted along the body to record air pressure. This is recorded in data collection systems and can be evaluated later on to see the effects of changes to the shape of the body.**

If the bow wave is strong enough, it will detach the flow completely over the rest of the car, at the point where the hood blends in to a more horizontal surface. As it detaches higher, the airflow is actually causing suction or lift, counteracting the down force you thought you were creating. The two probably can't cancel each other completely, but it can significantly reduce down force and increase drag.

Separation of flow at the front of the car will also reduce the down force created at the rear. This is because the air of normal pressure can't get back down to the level of the rear spoiler. Now, up to a certain point, increasing the angle of the spoiler will reattach some of the flow in front of it. If a car is sliding at some angle to its actual direction of travel as in a dirt car, the sides of the car will detach some or all of the downforce flow. This is due to the abrupt change in direction of the oncoming air up over the side of the vehicle and it cannot reattach to the top of the car. You will also reduce some down force because high pressure air on the side of the car will get under it causing lift, unless you can seal the side to the ground.

***Drag and Moment Arm***—Surfaces of the car that create down force also have a moment arm. That is the distance from the wheel to the force. With a spoiler far back on the car, you could change down force on the rear and it WILL affect the down force on the front in the opposite direction. The height of the spoiler or air foil affects the length of the moment arm. A sprint car wing has the most radical moment arm of any aerodynamic surface used in racing.



**On-track testing provides the most realistic data about drag and downforce. By noting the loading of the suspension, a team can measure the downforce created by various settings of the wings, pitch of the car and height of the splitter. A balance is desired between the total front loading and the rear loading to attain the desired handling balance.**

The bottom of the car is also important. Air does flow under there and it is usually under some suction force, so it has much less affect, but things can be done here to gain speed. Lining everything up will give you an improvement over certain designs, but more yet can be had. Look at how flows are detached under the car. You have to know what to look for and not everyone sees it. There are ways of obtaining more downforce and less drag under the car. Look also at what the underside is doing under roll, squat and dive. Look at how these conditions disturb the airflow and downforce. The more suction you produce, the more air wants to go under the car.

***Homemade Wind Tunnel***—You can make your own wind tunnel to get real data. It takes a good camera, some small diameter yarn, and tape. Ideally, paint your car white, and do a good job with minimal overspray or orange peel. A bad paint job will have a negative effect on airflow. Tape a 2"-3" length of black yarn every 6" or so all over the car, including the sides. Just eyeball it. Make sure the tape is put down smoothly so it doesn't disturb the airflow over the yarn.

Drive the car at different speeds and take video or high-speed still shots as the car goes by, or from inside the car. Don't put the camera where it will disturb the flow. Maintain a clean surface free of dirt. You can video from other cars along side, both close to and farther away. Look at how the yarn changes with another car in certain positions relative to your car. Different cars will affect your airflow a little differently, but generally in the same way.

**The front car in this drafting formation develops a bow wave that pushes the air out of the way and up and over not only that car, but well over the two cars behind it. This is how drafting works to reduce drag on not only the front car, but back several car lengths behind. The bow wave can extend some 20 to 30 feet in front of the lead car.**

Ideally every yarn will lay flat on the surface and point straight back to the rear of the car. Highpressure areas will do one or all of the following; lift the yarn, flutter the yarn violently, point it off to one side. If you see these characteristics, you may be making more drag and less down force than optimal.

Low pressure may do one or all of the following: lift the yarn in a more limp action, cause more of a limp flutter, and/or keep the yarn moving all over the place. These could be areas of lift. These indicators show more drag than optimal.

How much affect do you get from getting it right? From what we see on a dirt late model, you may be able to cut the drag in half.

# Chapter 13

## Gear Selection and Rear Differentials

**Gear selection is an area where we need to think out our setup for the specific track we will be running. There are some interesting lines of thought presented in this chapter that might make the difference in how well you can race with other cars.**

Gear selection is one of the most difficult things to determine when working out your setup. There seems to always be conflicting thoughts between selecting a lower gear that will get off the turns faster and produce more rpm or one that may stay closer within the powerband and not run out of power at the end of the straightaway. Everything is a tradeoff.

## Gear Selection

Finding the right gear ratio for a particular track in a certain class of circle track racing may be as easy as asking your competitors. Most racers who regularly run the same race track each week will settle on the same gear and run it the entire season. But is the gear you are using producing the fastest lap?

Differences in the track, tire sizes, class rules, and other factors can cause us to rethink our selection of gears, possibly from week to week and even beginning to end of an event in the case of dirt track racing. The reasons for this may become more apparent as we study the whole concept of gear selection.

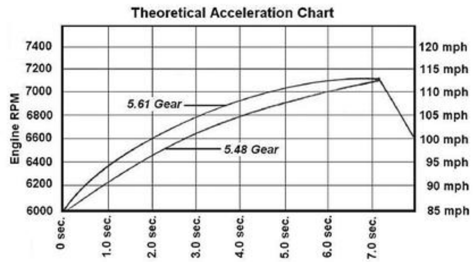
***Basic Gear Primer***—There are two basic rear ends that are used in circle track racing. There is the OEM-type ring and pinion in a pumpkin case where gear changes are rather difficult and racers are less likely to make week-to-week changes. The other is the quick-change rear end, and is designed to be much easier to access the drive gears and therefore facilitate quick changes to your gear ratio. The reasons why we would make these changes are varied, but can be necessary in order to maintain performance levels.

To say that the quick change is superior would not be exactly accurate. It is in fact less durable than the OEM-type rear end, but for most short track racing, holds up fine with regular maintenance. For larger cars that run long and fast race tracks and with high horsepower engines at high rpm, the Ford 9" based rear end is almost mandatory.

For our discussion, we will use as an example the quick-change rear end. Some of the discussion will also relate to the OEM rear ends as we talk about reasons for gear change, not necessarily the process of making changes that are as involved with each type.

***Choosing the Correct Gear Ratio***—We should always consider the highest and lowest rpm in our powerband when choosing the gear for our cars. You need to know where the engine powerband starts and ends for your motor. Then look at what the engine rpm is at each point around the track for the gear you are currently running. You don't want to begin to accelerate off a turn below the rpm where the power starts to build.

Likewise, it may not be the best thing to run out of the powerband somewhere down the straightaway. A bigger mistake might be to begin to hit peak horsepower just as you are getting ready to brake into the corner. There is a compromise that may produce a faster lap.




**In this chart we see where two different gear ratios start out at the same speed and end up at the same speed, but the lower gear will gain speed faster through the acceleration zone and yield a faster average speed with less time between points.**

There may be two or more gear ratios that will produce the same rpm at the lift point at the end of the straightaway. Each will begin at the same rpm off the turns and each will end at the same rpm at the lift point going into the next turn, but one will be faster. How so? Here's how.

If we chose a gear that will pull from say 6000 rpm just past mid-turn to 7100 rpm at the end of the straightaway, we might feel we have the right gear if the horsepower curve goals are met. That means our engine horsepower curve comes on at 6000 rpm and it peaks at 7100 rpm. It sounds like we have the right gear, but maybe not.

On some tracks where acceleration off the corners is critical for passing, a lower gear might help us get off the turns better, while not necessarily hurting us at the other end. The lower gear will accelerate the car quicker and if we don't loose traction with the switch, at least to the flag stand we will be better off.

For the last half of the straightaway, if we have gained a half a car length by now, our speed will be mostly peaked while our competitor will still be accelerating. We will still be pulling away from the other car because the other car has not yet reached top speed/rpm.

Our turn entry will be much smoother because we will have slowed our acceleration before we lift to brake while the other car is still accelerating when the transition to braking occurs. It is very disruptive to make the change from hard acceleration to hard braking. It is much smoother to transition from steady speed to hard braking. Just ask any high-performance driving instructor and they will agree.

So, we might be better off to install a lower gear, beat our competition off the corner and have a better corner entry all by doing a little experimentation. All it takes is a little effort and testing with a stopwatch and the results can be evaluated. Most teams don't know what areas to test at a test session. This is one of those areas that may well improve your performance.

***Let the Stopwatch Decide***—The best rule is to let the stop watch determine the best gear. The fastest gear on the watch may not look or feel fast, but the lap times will tell the true story.

Divide the track into segments and time the car from the points on the track where the driver starts to accelerate to where the driver lifts going into the next turn. Use the exact same point on the race track for every measurement of elapsed time. Compare your times to your competitor's times to judge how each change stands up.

## Power vs. Wheel Spin

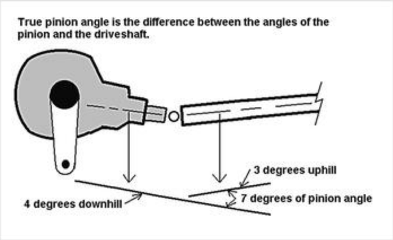
Many racers mistake rpm for horsepower. A lower gear will pull much better, but only if the engine is putting out sufficient horsepower, and if you can get the power to the race track. The advantage of being able to exit strongly from a corner is lost if the wheels start spinning.

## Pinion Angle Controls Rear Wheel Horsepower

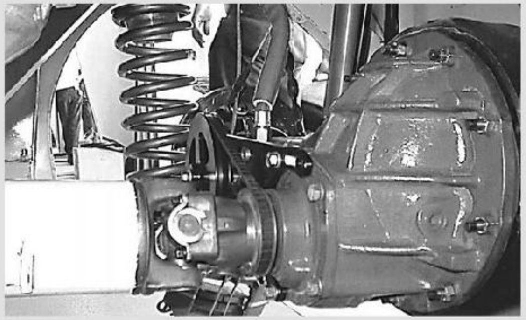
There is a mechanical loss of force (horsepower) in the U-joints, rear end bearings, pinion and ring gears and the rear axle wheel bearings. Most losses are not controllable, except pinion angle power loss. Pinion angle (more correctly known as U-joint angle) has erroneously been measured as the angle between the pinion shaft and the ground. That angle tells us nothing. What you really need to know is the angle between the driveshaft and the pinion shaft as well as the driveshaft and the transmission output shaft. The degree of those angles determines the amount of power loss you will have through the drivetrain.

A U-joint needs to have some angle between the two connecting shafts in order to load the needle bearings in the caps of the U-joint. This loading forces the bearings to rotate under load, which facilitates lubrication. If the needle bearings did not rotate, they would quickly loose lubrication and flat spot, causing a failure of the bearing. It is widely understood that two-to-four degrees of driveshaft angle will be sufficient to adequately load the bearings and provide the needed lubrication. Remember that the front and rear angles must be close to equal and opposite in direction.

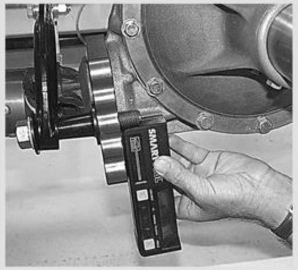
### DETERMINING PINION ANGLE




**1. To find true pinion angle we are looking to measure the difference between the angle of the driveshaft and the angle of the pinion shaft. There is also an angle at the front of the driveshaft where it is attached to the transmission output shaft that must be measured too. The two angles at each end of the driveshaft should be nearly equal and opposite.**

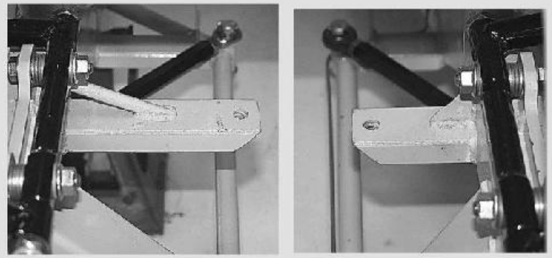


**2. The pinion angle is critical in order to prevent loss of horsepower and for reduction in vibration. True pinion angle is the difference in angle between the driveshaft and both the pinion shaft and the tranny output shaft. Many teams only measure the pinion shaft angle relative to the ground. This will not tell you the true pinion angle that matters. The greater the angle between the driveshaft and the pinion shaft/tranny shaft, the more horsepower that will be lost through mechanical inefficiency. A difference in angles in the front and rear can be very hard on the driveline.**



**3. First check the pinion angle relative to the ground by placing a digital level on a flat surface parallel to the face of the pinion casting on the rear housing (in this case you use the J-bar bracket which is bolted directly to the pinion plate). Subtract the number from 90 degrees (the pinion angle measured 87.50 degrees off vertical, so 90 minus 87.50 = 2.50 degrees of angle). Now do the same with the transmission output shaft.**


**4. Then measure the angle of the driveshaft and note which direction the shaft is angled. If the pinion is angled with the pinion shaft down in front and the driveshaft is angled with the rear end lower (typically the most common situation with stock cars), then add the two angles to find true pinion angle. Do the same at the front end.**



**5. In these two photos, you see how the engine can be offset. The right-side mount, shown on the left is longer than the left-side mount, shown on the right. Because of this offset, the driveshaft may be angled from a top view. This creates additional driveshaft angle (pinion angle) relative to the pinion shaft, as well as the transmission output shaft, which may be enough for mechanical loading of the bearings and where no sideview angle is needed.**

Differences in shaft angles (pinion angles) that exceed four degrees cause excess power loss and should be avoided. Take into consideration the top view angle of the driveshaft in relation to the transmission and the rear end. Some cars have offset pinion shafts at the rear ends so that there is an angle created (from a top view) that may be sufficient for bearing lubrication to where a team might not need to even run any side view pinion angle. Remember, pinion angle in any direction is sufficient to load the bearings in order to provide proper lubrication.

## Power Loss Due to Universal Joint Angle

Universal joints need some angle in order to load the needle bearings to facilitate lubrication. If the bearings are loaded, then they will rotate and the grease will be distributed evenly around the bearings and the race. This angle design needs to be employed at each end of the driveshaft, at the front where it connects to the transmission tail shaft and at the rear end where it attaches to the pinion shaft at the rear differential.

Pinion angle also robs us of some amount of rear wheel horsepower due to two effects. One is mechanical loss, meaning the forces put into loading the bearings never reaches the rear wheels (the exact amount of loss is dependant on the degree of angle between the driveshaft and the pinion/transmission output shaft) and the other is loss due to friction with the increased loading on the U-joint bearings, pinion bearings and transmission shaft bearings. Pinion angle can occur in any direction. Some cars are designed so that the driveshaft is not lined up from a top view between the transmission and the pinion shaft. This creates additional U-joint angle that robs rear wheel horsepower.

## How to Measure Pinion Angle

It is a common practice for racers to only measure the angle of the pinion shaft intending to measure pinion angle. The true angle you should be concerned with is really the U-joint angle, both at the pinion and at the transmission. Most engines are mounted with the crankshaft/output shaft level in relation to the ground. So, by measuring the driveshaft angle, you then can know the angle created at the transmission output shaft.

To correctly measure the U-joint angle at the pinion end of the driveshaft, you need to measure both the driveshaft angle and the pinion angle. The difference in these angles is the U-joint angle. Two-to-four degrees is plenty of angle to design into your driveline in order to make sure there are sufficient forces applied to the bearings to help them rotate and stay lubricated, without causing excessive loss of rear wheel horsepower.

## Running Past the Powerband

If you go to a lower gear and put yourself beyond the point where the motor produces good horsepower half way down the straightaway, you've gone backwards. Restricted motors are especially known for a dramatic drop in horsepower at the end of the powerband. Not only is the power-band running out, but also the restricted intake won't suck any more air at the higher rpm.

## Calculating Final Drive Ratio

Always keep a record of your final drive ratio. This is the ratio that includes tire circumference information. You may have found the right gear ratio for your track and then lose the advantage when you are forced to run different sized tires. If the tire sizes change, so must the gear. A new gear ratio can be easily determined using the final drive ratio that worked with the previous tire size. The formula for final drive ratio is:

**FDR = CIR ÷ RGR**

where: RGR = rear gear ratio; CIR = tire circumference; FDR = final drive ratio

Example: Suppose you have a tire circumference of 80" and a rear gear ratio of 5.88. When you divide the CIR by the RGR, you would have an FDR of 13.605.

If you switch to an 85" tire, you only need to divide your FDR of the 13.605 into the new CIR to determine that you need a 6.25 rear gear.

If you change tire sizes, divide the new tire circumference by the final drive ratio that works and you have the new gear ratio number. It's very simple, but a lot of people lose their good gear setups when they change tire sizes.

## Rear Differential Selection

There are many different types of rear differentials on the market today, from a typical stock Open differential (not used for racing), to the "locked-up" types (called a spool), a Detroit Locker, and various types of limited slip and traction transferring types. Each one has different characteristics.

**The gears should be kept in individual boxes and the ratio clearly marked on the outside of the box.**

## The Locked Rear End (Spool)

The spool is basically a stock, open rear end that has been modified so that it is locked up all of the time. This provides continuous power to both wheels, even when decelerating into the turns. These types of rear differentials are very reliable because there are no moving parts to break or wear out.

***Stagger Is Crucial***—The main thing to remember about using a spool is that stagger is crucial to control entry and exit. As the car brakes into the corner, the rear stagger will help turn the car. Too much stagger will cause a loose-in condition. Even before you get into the throttle, the rear stagger will be influencing the mid-turn handling characteristics.

The trade-off for reliability is control of the stagger amount. If one of the rear tires grows more than the other and the stagger changes, the handling will suffer throughout the turn.

***Entry Braking Effect***—There is also a braking effect from the engine when using a locked rear differential. Because the wheels are locked to the driveshaft all of the time, once you come off the throttle, the engine will help brake the car. This means that you can use less rear brake pressure to balance out the front-to-rear braking bias. Going from one type of differential to another can require a change to the brake bias.

## The Detroit Locker

The Detroit Locker is a type of differential that is locked when power is applied, but unlocks when you let off the throttle. This is an advantage, because if the stagger does change, the handling is only affected as the car comes off the corner under power when the rear end locks back up. The entry and mid-turn performance will not be greatly affected.

***What Can Go Wrong***—These types of rear end differentials often use springs in the mechanism that lock and unlock the axles. These springs can become overheated and lose rate and become ineffective. They can also break from overheating and fatigue.

If one of these springs goes away during a race, only one wheel will have power with obvious results. If only the inside wheel is locked up, then the car will drive toward the outside wall. If the outside wheel is the only one locked up, then the car will be loose from both having only one wheel/tire controlling the power, and from the torque of the thrust causing the car to want to turn left more so than needed.

***A Quick Check***—You can quickly check to see if one or more of the springs is bad by jacking the car up and turning each wheel. A distinct click should be heard coming from the differential. If the clicking sound is low, then a spring is probably weak.

Braking bias can be more easily regulated when using a Detroit Locker. There is no stagger effect that would steer the car on braking and usually entry into the corner is smooth and fast. You can eliminate stagger influences and concentrate on brake bias adjustment to tune entry characteristics.

***Maintenance Is Essential***—Maintenance of the Detroit Locker is essential. These units should be inspected and parts replaced on a regular basis. Of most interest are the springs that control the locking and unlocking of the axles. A good idea is to replace these on a periodic basis.

A professional who has worked for many Cup teams over the years told me that the springs should be replaced every three races on a Late Model. Don't wait until one fails. Anticipate the life of the springs and replace before they cost you a race.

***Rear End Oil Cooler***—A rear end oil cooler is a good idea for longer races. The heat buildup can be the primary factor in rear end failure. As the bearings and springs heat up to excessive temperatures, they can fail. The springs are especially sensitive to heat. They can lose temper and rate or break from prolonged exposure to high heat. If the rules allow, use a rear end cooler all of the time.

## Traction-Sensing Differentials

A popular type of differential used today is one that senses a loss of traction in one of the wheels and transmits most of the power to the other wheel. This can be especially useful if the stagger has gone away and the left-rear wheel is slipping.

With the weight transfer happening in the turns, the right-rear wheel will usually have most of the weight on it in the turns. If stagger closes up, the right-rear tire will maintain grip over the left-rear wheel because it has more weight on it.

***Compensating for Stagger Loss***—That means that the left-rear wheel must slip in order for the car to execute the turn. If the traction-sensing differential notices this slip, and transfers the power to the outside wheel, then the effect of reduced stagger is eliminated.

Many times a loss of stagger will cause both wheels to "slip," or not rotate at the same speed as they should to match the speed of the car. The right-rear wheel will be rotating less than is necessary and the left-rear wheel will be rotating more than is necessary.

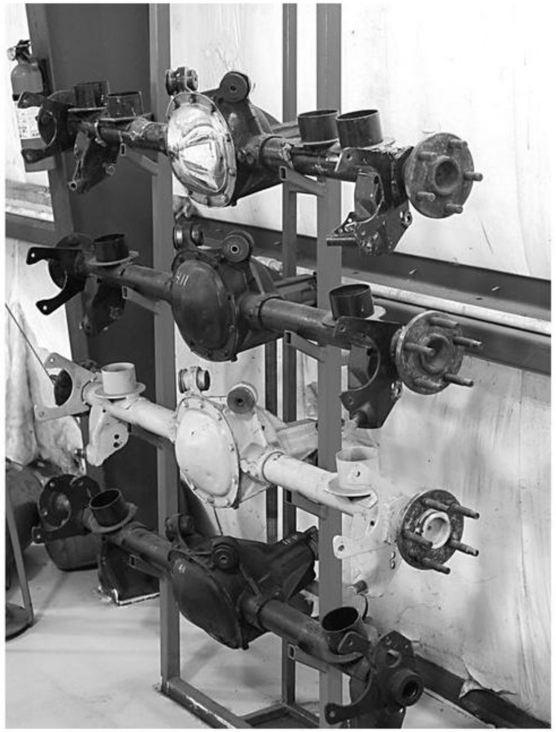
Because neither wheel is rotating at the correct speed, both lose traction and the car goes loose. Essentially both rear tires are fighting each other in order to try to rotate the correct speed. If the differential can adjust to this struggle for equality, then traction can be maintained off the turns.

Traction sensing can also eliminate one wheel from spinning and losing all of its traction instantly because of the transfer of the power to the wheel with traction. That way, you lose less traction in the wheel that wants to spin, but not all of the traction.

The only drawback I can see from using the traction-sensing differentials is reliability. The ones that might use springs or clutches can go away and stop working to transfer power without regular maintenance.

On some tracks, these units will overwork themselves and cause a different handling feel each lap that goes by. That is the report I get from users. I personally think that each race team should evaluate their needs and where they are going to be racing and then select the proper differential. Talk to the manufacturer to make sure you are using the product the right way.

When coupled with a good, balanced setup and a well-maintained car, the Detroit Locker cannot be beat for race-to-race reliability. Even so, there may be certain situations where a traction-sensing differential will provide better performance.



**Well-prepared teams carry extra parts, including these complete rear-end assemblies that are ready to be installed should a gear change be necessary. This kind of preparation pays off when traveling to different race tracks.**

# Chapter 14

## Asphalt Car Setup and Handling

**The trend in recent years toward setting up a car for asphalt has been toward aero efficiency and BBSS (big bar, soft springs), but it has been proven that a more conventional balanced setup is just as fast.**

The setup of an asphalt stock car involves all of what we have covered about working to achieve a balanced setup where all four tires are working to their highest capacity and where both ends of the car are in harmony with their desires. That will never change.

The industry has taken a quite different road in some series and types of racing on asphalt where they have put more value in aero efficiency than in working to develop a truly balanced setup. In fact, many of the newer trend setups have seriously unbalanced setups. It seems like the industry has gone back some ten or fifteen years to a time where trial and error ruled and the monkey see, monkey do mentality has again taken over.

It has been proven that a setup that is more toward what we call conventional is fast and does win races over the newer setups using very big sway bars and very soft springs (BBSS) setups. In back-to-back testing, comparisons in many actual races, and in reports I have received from racers all over the country, a well-balanced soft-conventional setup will be every bit as fast, or even faster as the race goes on, as the very best of the BBSS setups.

Because it is of such interest, we will report on the technical aspects of the BBSS setups and how you might go about setting up your car that way. We do not, and never will, endorse the extreme setups that run on bump stops or in coil bind. Those cars are large Karts and not stock cars in my opinion.

Big bar and soft spring setups are the rage in asphalt racing circles right now. Many teams are going the setup route that uses a large sway bar combined with soft front springs and a very stiff right-rear (RR) spring. The problem is that you cannot just bolt those parts onto your car and go racing and expect to be successful.

We have talked to teams and component manufacturers about the transition and we have run those setups in back to back tests against conventional setups. In short, we have a lot of information to share.

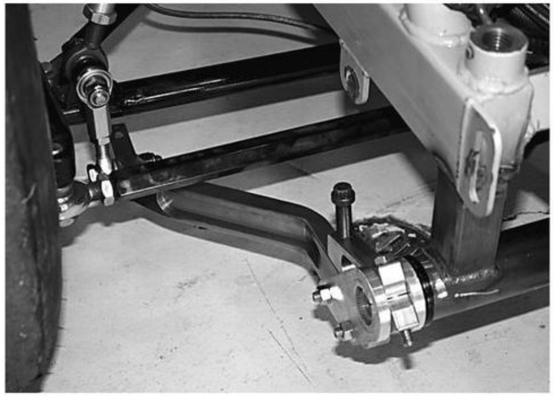
The very first thing to know is that the BBSS setups are not good for all race tracks. There are some tracks where the gains are significant, others where there is no gain at all, and some where the conventional setups are just plain faster. We'll explain why.

***Goals***—Let's take a look at what our goals might be in going the BBSS route. Most ill-handling cars are traditionally tight and will not turn well. The BBSS setups do help the car to turn better by forcing additional load onto the left-front (LF) tire.

Handling balance can be accomplished with adjustments to the weight distribution meaning a change in cross-weight percentage. So, making the car neutral is not a problem.

**Prepare your car in the shop before you go to the track. Setup the car with your old setup first and record all of the information. Then put in the BBSS setup with changes as needed.**

**Many teams opt to install the Nascar-style sway bar mounts instead of the one-piece type. These mounts are much stronger and offer less friction between the bar and the housing. This one even has a fine adjustment built into the steel arm.**

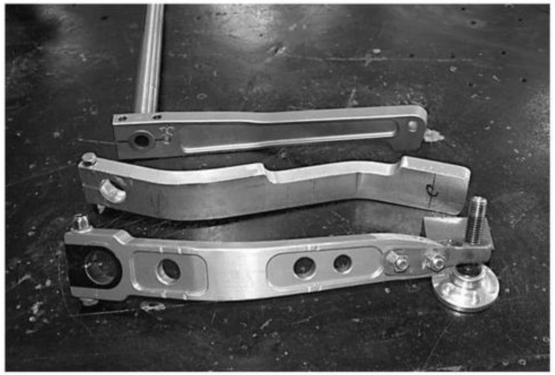


Aero efficiency is improved, sometimes greatly improved on longer tracks, due to the front valence being lower and the rear spoiler being higher. The soft front springs compress more and the stiff LR spring forces the LF corner down to where the front of the car is low and parallel to the track in the turns.

***Results of the Setup***—There are some interesting results that come from the transition. First of all, if the car is setup right, meaning all of the way to BBSS, and we'll explain what that means later, the dynamic balance is way off. The front wants to roll to say 1 to 1.5 degrees and the rear wants to achieve a negative roll angle of from 0.5 to 1.0 degrees.

This difference in desires means that a lot of extra load is being put on the RR tire. In older traditional setups that were unbalanced, the rear outrolled the front and a lot of extra load ended up on the RF tire. That tire soon began to overheat and loose grip. The car either pushed badly or the driver could overcome the tight condition with extra steering input until the car went to a tight-loose condition.

The final result was either a worn out RF tire or a burned out RR tire. One of the two was sure to go. So, the big question is, why doesn't the RR tire give up similar to the RF tire that was overloaded with an unbalanced conventional setup? Glad you asked.



**When running a large-diameter sway bar, always try to use steel arms. The aluminum arms will bend more than the bar when using 1.5" and larger sway bars.**

We pondered the very same question and finally came to a conclusion. When the car is unbalanced with the rear out-rolling the front, the RF tire has to carry extra load, do extra work keeping the car on the track through the turns, and it has to turn the car. It is this extra duty that overloads the tire and causes it to give up.

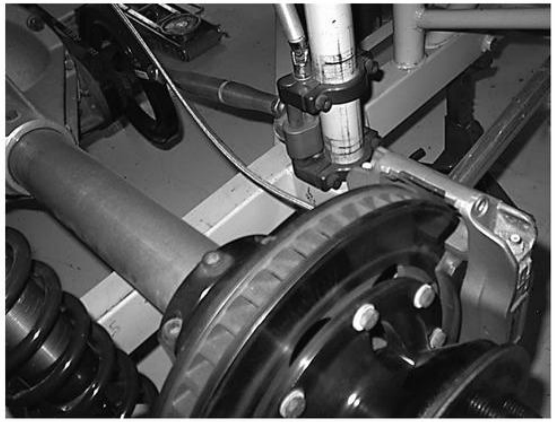
Contrary to the conventional unbalanced situation, with the BBSS unbalanced syndrome, the RR tire does not have to turn the car. It only needs to keep the rear of the car on the track and it carries a heavier load to help it.

Since the setup is unbalanced with the front tires being more equally loaded side-to-side than the rear, the front develops more grip. So, we see the need to increase the cross-weight percentage to tighten up the car. And that is exactly what we found when we did a back to back test at Florence Speedway in the ASA Late Model Series South division.

***BBSS Components***—Keeping in mind that there are many variations of the BBSS setups, let's take a look at a common configuration for the straight rail Late Model cars that usually run a touring series. We will offer general directions, so don't run out and put this in your car. Every car is a little different and a slow approach to the transition will keep you from getting into trouble.

The sway bar size runs from a low of 1 3/8" (1.375") diameter heavy wall thickness through a 1.50" bar all of the way to 2.0" and more. For most Late Model cars, 1.50 to 1.75 is common. Some teams think the 1.375 is a large bar, but it is not when going with the BBSS setup.

Front spring rates vary from a pair of 150-lb springs up to 225- and 250-lb springs. Again, if you are in the 200-lb range, you are too stiff. The RR spring is usually increased over conventional rates by 100- to 300-lb. This means you would run a minimum of a 250-lb spring all of the way up to and beyond a 400-lb spring.



**The panhard/J-bar mounts will need to be lowered with the BBSS setups. This one is all of the way down on the frame rail.**

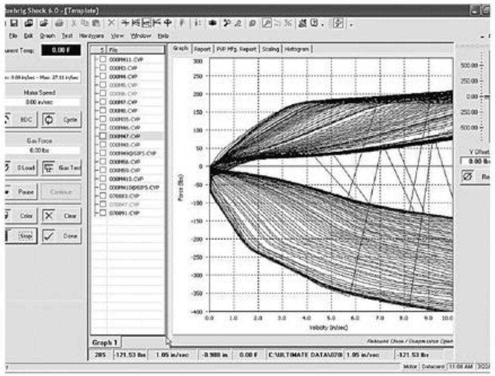
The cross-weight must be increased along with these changes. Typical increases are from 2% to 4% of total weight. It is often better to begin with the lower cross-weight range (for a 50% front percent car it is around 51.5% cross with a conventional setup) normally used with stiffer springs and smaller sway bars, and then add 3% or so until the car is neutral in handling.

Since the rear roll angle is a lot less than the front, we also want to lower the panhard/J-bar about as low as it will go. With most chassis designs, we are limited to going down to 8-9" off the ground. Go there!

The RR shock will travel about half as much with the BBSS stiff spring in the car, so adjust your trailing arm angle so that there won't be any rear steer to the right in the turns. With normal travel of 3.5" to 4", we usually use around 1.5-2 degrees of trailing arm angle in the right trailing arm. With the BBSS spring in the RR, reduce that to half, or 0.75 to 1 degree of angle—front high of course.

***Shock Changes for BBSS***—One of the biggest changes that must accompany the BBSS setups is to your shock rates. The compression settings generally go up at the RF with the LF compression going down.

The RR might need a little more rebound to control that stiff spring. It is very helpful in the tuning stages of the conversion to BBSS that you use adjustable shocks, preferably double adjustable.



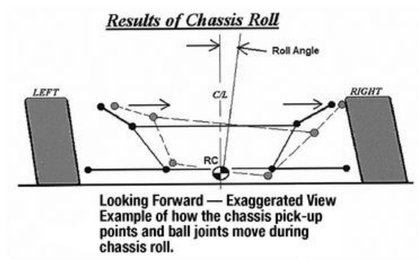
**This shock graph shows how much adjustment is available from a double adjustable shock like the Pro shock that this represents. You should be able to completely tune the shocks to the different BBSS setup.**

The amount of increase and decrease in rebound and compression varies as to the track size. Long, smooth and flatter tracks can use much more rebound control than on shorter tracks that might be rough. Rough tracks also have a negative effect on the RR when using a very stiff spring. The car tends to bounce at that corner instead of negotiating the bumps smoothly. A reduction in the RR spring rate along with changes to the cross-weight percentage to bring the car back to neutral handling is necessary.

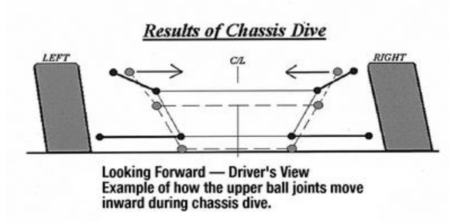
Most of the high-end racing shock companies make shocks that are double adjustable. Afco has released a new canister shock that can be used without the can and Pro Shocks is very active with the asphalt racers that are using its highly adjustable shocks. Similar designs are available from QA1, Ohlins, Penske and Bilstein companies.

***Problems Associated with BBSS Setups***—We're not done yet folks. There are other areas where we need to make changes to accommodate the BBSS setups. The front geometry must be redesigned in order to properly gain the advantages of the BBSS setups. Moment center location is still very important, and camber change characteristics are totally different with these setups.

The car will dive more and roll less with the BBSS setup. That means out camber changes at the front are entirely different than we saw with the conventional setups. Both front tires will lose lots of camber due to the high dive numbers, 3 to 4" in most cases and low roll angles that normally would counter camber loss in more conventional setups.




**With conventional setups, the dive and roll actions tend to cancel each other out as to camber change in the RF and produce less camber loss in the LF.**



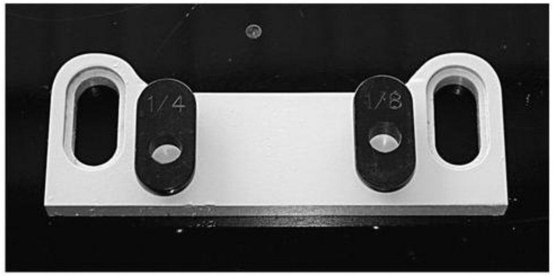
**The BBSS setups have little roll and a lot of dive associated with them. Here we see lots of camber loss in both the RF and LF wheels.**

The bottom line is that the upper control arm angles will need to be reduced. If you had say 18 to 24 degrees of upper control arm angle with your conventional setup, you will now need to reduce those to 12 to 16 degrees, all the while maintaining a decent moment center location.

The static cambers themselves must be altered with the transition. The RF must be reduced from the normal (-) 3.5 to (-) 4.0 degrees to under (-) 2 degrees in most cases depending on the type of tire you run.

The LF tire camber must be increased from a normal 2.5 to 3.0 degrees to 4.0 degrees and more. This tire will loose some 3.5 degrees of camber in the turns.

Ackermann Effect is very detrimental to the BBSS setups. If you are used to using some amount of Ackermann in your conventional setups, you cannot run it with the BBSS setups. The reasoning is this, with the BBSS setup, the LF corner is forced down and a lot of the front load is carried by that tire. Since it is doing a lot of work, it will compete with the RF tire.




**Changes to the upper control arm angles are made easier with these slotted and slugged upper mounts. The angles will have to change in order to help control the camber loss associated with the BBSS setups.**

These two tires must track along their proper arcs tangent to the radius. We have computed and proven that a car running on a short quarter-mile track needs around 0.100" of added toe, or about 0.2 (1/5th) of a degree. On half-mile tracks, that number goes down to 0.040" of added toe or less than 0.10 (1/10th) degrees of toe.

***Where to Run BBSS and Where Not To***—We have made the statement in the past that we don't see track records falling from the use of the BBSS setups. About a couple of months ago I had a guy call to tell me they had switched to the BBSS stuff and indeed had broken the record at their track. So, I take it back. That doesn't mean it works everywhere.

We have proven that the BBSS setups are not meant for all race tracks. In general, the higher the banking at the track, above 10 degrees or so, the less effective the BBSS setups will be. If your track is above 16 degrees of banking don't even think about it.

Tracks with a rough surface and/or large transitions in banking angle from the straightaways to the turns are hard to manage with the BBSS setups and you might be better off and more consistent running more conventional.

The tracks where these setups shine are the flatter and smoother tracks and the longer speedways like Kentucky or Nashville (not the Fairgrounds). Gateway International Raceway is another good one.

Out west we might see the BBSS setups at tracks like Phoenix or Evergreen Speedway. The longer and faster tracks will benefit from the added aero effect to provide more overall grip adhesion for faster turn speeds. On three-quarter to one-mile tracks, that added speed can add up to several tenths lower lap times.

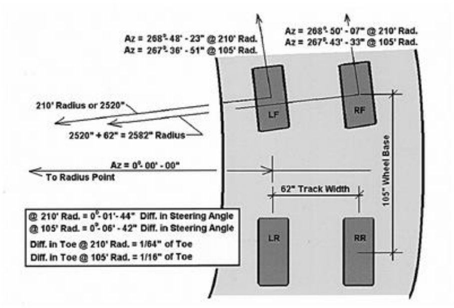
**Slotted steering arms allow us to dial in or out, the Ackermann in our front end. This works as long as we only turn left as in asphalt racing. Dirt Ackermann adjustment is done differently.**

The choice of setup is entirely yours so chose your asphalt setup based on need. If you are winning a lot with conventional setups, you can experiment during a test session like we did, but not at the event. There's not enough time to tune and properly evaluate the difference.

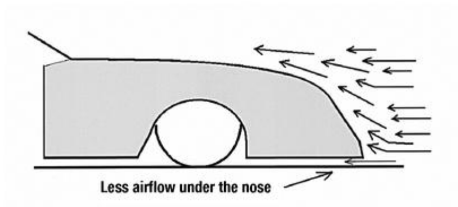
Watch your shock travel at the RF when using very soft springs. If the frame contacts the track, the car will move quickly to the wall. Make spring changes in a progression rather than a one step change. Adjust the shocks to fit the transition. Add a little cross-weight with each change to maintain the neutral handling.

Once the car is neutral, get good lap times up to 15 to 20 laps and then immediately switch back to the conventional setup and make another run. See which one feels better to the driver and which one is faster. Compare those times with the usual lap times everyone runs. Make a choice and go with it.

If you decide to go with the BBSS setup, you don't necessarily have to go all the way. The softer conventional setups are working very well for a lot of teams. The idea is to reduce the spring rates and go with a larger sway bar, but stay on the springs and use the suspension system the way it was designed. That includes the function of the moment center and steering geometry technology we have covered.




**This graphic illustration demonstrates the small amount of Ackermann needed in order for the front wheel to track correctly.**




**The BBSS setups allow a much more efficient front aero package by causing the front end to be lowertother ace ack. This mostly eliminates air form entering the engine compartment and allows the downforce producing low**

## Chapter 15

### Dirt Car Setup and Handling

**Dirt racing involves many varied types of cars. The dirt Late Model and the IMCA Modified are very popular classes. Much of what we discuss here will relate to these cars.**

The information presented in the previous chapters relates to all dirt as well as asphalt stock cars. Nearly every word written in those chapters has an effect on dirt car setup. But the fact is, dirt cars are much more complicated and sophisticated to set up than asphalt cars.

### How Dirt Cars Are Different

There are many reasons why dirt car setups are more difficult to develop than asphalt setups. We are still racing on four tires with four springs controlling the ride and with a double A-arm front suspension and a straight axle rear suspension. Both cars race on a hard surface, but that surface can be much different on dirt, depending on the time of day. Surface material is the major difference between dirt and asphalt racing.

### Track Surface Changes

The track surface on dirt can change by the minute. Asphalt racers enjoy a relatively consistent surface to race on. Temperature is the primary factor in changes to grip on a particular race day when racing on asphalt. The track surface on dirt tracks is constantly changing. The dirt racer is always trying to judge what the track is going to do next.

### G-Forces Are Constantly Changing

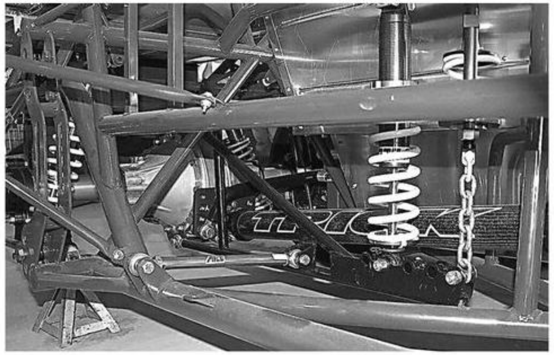
The g-forces the dirt cars will experience are directly related to the surface conditions and the tires. The choice of setup is directly dependent on the amount of grip that the track is giving at any particular moment. Springs, J-bar heights, bite and rear steer have to be constantly changed to compensate for a track that has gone from one condition to another, sometimes in less than an hour. Smart racers are constantly checking other heat races and time trials to keep up with how the track is changing and to allow time to make adjustments to their car.

### Large Choice of Tire Hardness and Tread Design

The dirt racer has a choice of tire compounds and tread designs. Asphalt racers usually do not. Tires are extremely important to the dirt racer. There is a choice of hardness and tread design available to enable the crew to adjust to changing conditions. But that gets tricky.

Tires intended for wet conditions won't work on dry surfaces. Dry-slick tires won't work on a track that goes black and turns into an asphalt surface. Soft tires will burn up on a slick track and hard tires won't get a grip on dry slick.

**How a track is prepared has everything to do with how much traction will be available and how much the track will change with time. Critical elements to consider are banking angles, type of material, smoothness of the surface, and moisture content. Proper selection of setup and tire tread patterns determines how fast your car will go.**



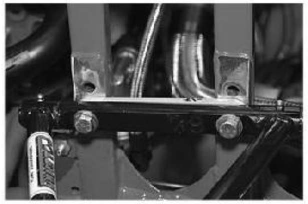
**The lift bar is a device used to control the torque that is transmitted to the rear end and ultimately the tires. It is adjustable for the amount of control during acceleration and deceleration.**

## Horsepower to Grip Ratio

Dirt Super Late Model teams also run much more horsepower than most asphalt Late Model teams. Controlling all of that horsepower is hard on the setup and the driver.

## Setting Up for Dirt

You will need a balanced setup that includes a good moment center design, correct selection of springs, J-bar height, weight distribution and steering design. All of those items help us get through the corners and use all four tires like we're supposed to. The two most critical factors that relate to performance on dirt are: a) making the car turn well, and b) getting sufficient bite off the corners.



**Do not be afraid to make moment center changes to your dirt late model. There is a location that works best to cause the front end to work to turn the car. If your car is not properly designed for moment center location, then change it. You might need to provide new mounting holes for the upper control arms or install mono-ball joints so that you can adjust the angles of the upper and lower control arms.**

**Most dirt cars have rear suspensions with highly adjustable arm angles. There are multiple holes in the chassis to mount the link ends into, as well as birdcages that are adjustable for link mounting location. Check your rear steer and know how much and where the wheel on each side is moving for your wheel travel.**

## Making the Car Turn

To make the dirt car turn, you need to do all of the things discussed in earlier chapters. Design the geometry correctly and place the moment center left of centerline to make the front end more efficient. Correct any steering problems you might find in the front end and eliminate Ackermann Effect.

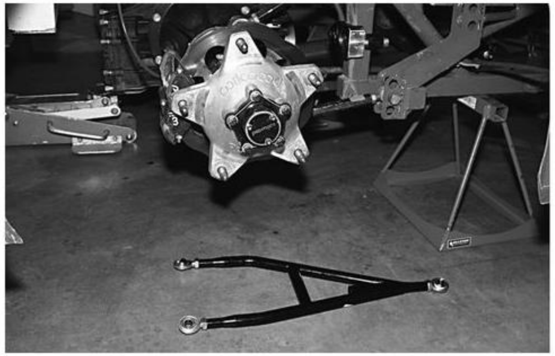
You need to develop setups that will help the car use all four tires and stay consistent. These setups will have to match the g-forces that the track is providing. With setup software, the g-forces can be entered and setups developed that will match the existing track conditions.

## Configure Rear Geometry for Correct Rear Steer

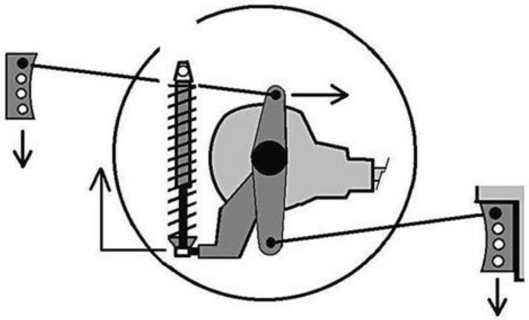
Rear steer, more than any other adjustment, will help the dirt car get more forward bite off the corners. The direction of the thrust is important for helping keep the car in the groove. A dirt car is put sideways for a reason. When the car is pointed toward the inside of the race track, putting power to the rear wheels will force the car toward the inside of the track and help the car get around the corner.

If we can set the rear bars and trailing arms so that the rear end is pointed to the left of centerline, then the thrust will be directed where we need it. The car must be well designed so that it turns well or else it will be too tight and push.

**Dirt rear suspension designs include the four link, the Z-link and a newer design called the Spear Rod that makes the car more like a three-link design.**



**This is an example of a long-arm spring mount. As the birdcage rotates when the chassis moves down, the bottom of the spring will move slightly up, taking bite out of the car.**



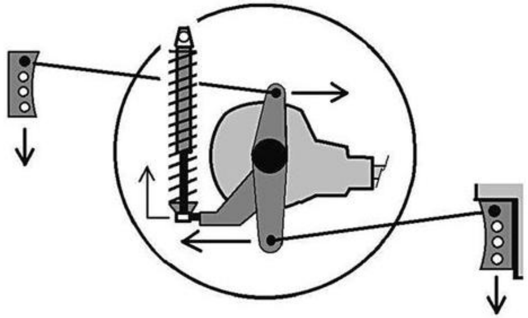
***Traction Control Devices Help Provide Bite***—Pull bars, lift bars, and pushrods all help to promote forward bite. A dirt car is super sensitive to quick application of power to the rear tires. That is why these cars must run devices that will absorb some of the torque. If we can cushion the forces directed at the tires, then the car will maintain grip and forward bite will improve.

***Main Ingredients for Bite Devices***—Any device that is made to improve forward bite should be adjustable to existing conditions. A lift bar should be made so that the springs can be changed quickly. A pull bar should be adjustable for preload.

The device should have plenty of room for travel so that it does not bottom out anywhere on the race track. Many pull bars don't have stiff enough springs in them and they bottom out quickly on exit off the corners. These units can be helpful in preventing wheel spin even when the car is going down the straightaway and running over bumps in the track. If they are fully extended and bottomed out, they won't help.

## Front Moment Center Location

The front moment center for a dirt car will need to be positioned farther left than that of an asphalt Late Model car. Except for very high banked tracks like Eldora, the moment center can be set so that it



**A birdcage with a shorter spring mounting arm will move farther when the assembly rotates, affecting weight distribution more.**

starts left of centerline and then moves right after the chassis dives and rolls to end up between 6" left of centerline to right around centerline. This makes the front end want to roll over even with small amounts of g-forces as the track gets dry slick.

## Weight Distribution

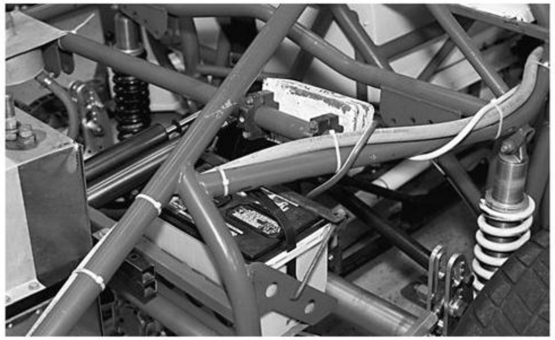
While it is generally accepted that more left-side weight will make a race car faster, this isn't necessarily true on dirt tracks. Some dirt tracks are more like asphalt tracks and have been oiled and prepared so that the dirt is packed tight and the surface resembles an asphalt track.

For these kinds of tracks, yes, more left-side weight is better. But on tracks that can go to a dry slick condition very quickly, we need to be able to get weight on at least some of the tires to help them cut through the slick layer of sand on the track surface.

***Two Tires Are Better Than Four?***—In a deviation from normal theory and practice, there may be a better way to get traction on a dry-slick race track. If you move weight from the left side to the right side, then the right-side tires will have more weight on them to help the tires cut through the slick layer of sand. There is a lot less g-force in the turns when the track goes slick, and therefore less weight transfer (weight transfer is dependant on g-forces). If the weight won't transfer, then you need to put the weight there to begin with.

***Even Weight Distribution May Make It Worse***—If the weight in the car was more evenly distributed, then maybe none of the four tires would have enough weight on them to be able to bite the surface. Two tires biting are always better than four tires that are sliding across the surface.

***Changing to a Higher Center of Gravity***—We can also raise weight up in the car so that the center of gravity is higher. A higher center of gravity will transfer more weight in the turns and put more weight on the right-side tires to provide even more bite.



**Keep your added weight in front of the rear end and high in the car for more load transfer on dry and slick tracks. This team mounted the battery to the right and the ballast to the front of the rear differential. This provides a more balanced polar moment and a more compliant chassis roll that benefits the setups for slick tracks.**

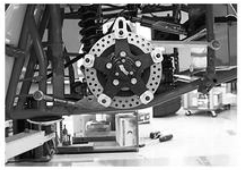
***Adjustment of Trailing Arms Allows Control of Steering and Thrust***—By being able to adjust the angle of the trailing arms, you are able to tune the handling and control the thrust off the corner. The examples show the extremes of adjustment. Holes that are in between are for adjusting the amount of steer you think you will need.

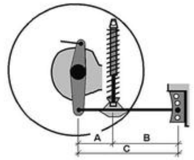
## Birdcage Indexing

The bracket that the trailing arms are attached to at the axle is called a *birdcage*. This bracket is loosely bolted around the rear end axle tubes and allowed to rotate freely. The bracket is located laterally by pins or locking clamps so that it cannot move side to side.

The rear end is located to prevent rotation by either a third link or a lift bar mechanism. The springs (coil-over assembly) are usually mounted on the birdcage, and as the bracket might move or rotate when the car rolls into the turns, the ends of the springs will rise or fall, depending on which way the birdcage rotates.

***Length of Arm Affects the Amount of Indexing***—The length of the spring mounting arms off the birdcage will affect the amount of vertical movement that takes place. This vertical movement has the effect of altering the weight distribution of the car. If the left-rear spring mount moves lower and the right-rear spring mount moves higher, then cross-weight percentage, or bite, will be reduced, loosening the car at mid-turn.






**A swing-arm rear suspension is much different from a standard four-bar type. The swing arm is located with a Z-link and the shock/spring combination is mounted directly on the front trailing link. Because it is mounted on the link, as the chassis and rear end move vertically, the spring moves at a different speed from each of the two. This means that with every inch of movement of the chassis, the spring moves less and the rate of the suspension per inch of movement is much less than the installed spring rate.**

SPR = Installed Spring Rate
NSPR = Net Spring Rate

$$NSPR = \left(\frac{C - A}{C}\right)^2 x\ SPR$$

Typical Example:

$$NSPR = \left(\frac{14.25 - 4.25}{14.25}\right)^2 x\ 375\ \#\ spring = 184.67\ \#\ net\ rate$$

**Use this formula for true spring rate of a swing-arm mounted spring.**

## The Swing-Arm Trailing Arm

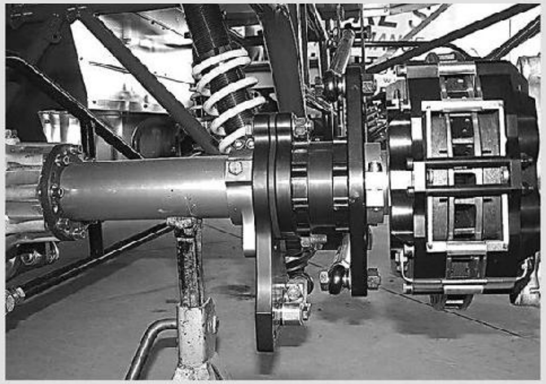
Some dirt cars have their rear springs (coil-over assembly) mounted directly on the rear trailing arm. Because there is a motion ratio with this type of mount, the car "feels" much less spring rate than the rate of the spring that is installed.

### Use the Net Spring Rate for Setup Calculations

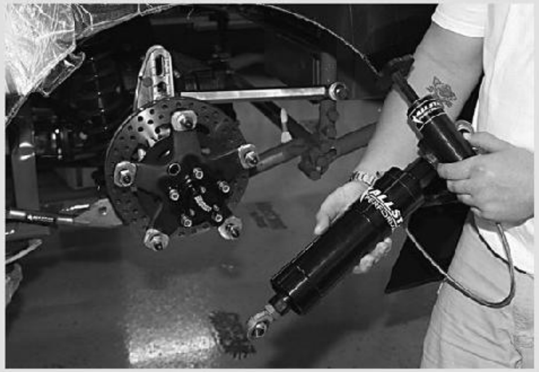
When setting up the car, use the net spring rate calculations, as if the spring were mounted to the birdcage or to the rear-end housing.

### DIRT CAR REAR STEERING SYSTEMS

The rear trailing arms can be adjusted on most dirt cars in order to cause the rear end to steer when the car rolls over in the turns.

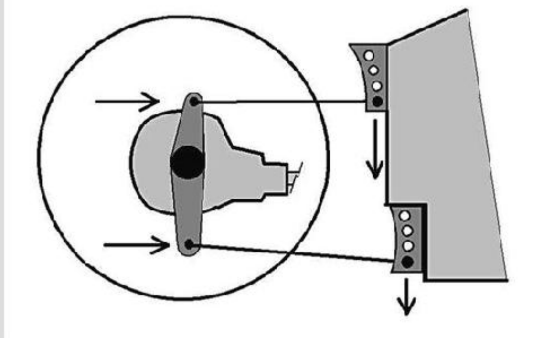


**The rear springs can be mounted on the birdcage or on a separate clamp attached to the rear end axle tubing. When clamped, the spring is either compressed or decompressed as the axle rotates under acceleration or deceleration. This movement of the spring mount allows the team to adjust the amount of bite caused by weight distribution on the rear tires. As the rear end rotates, each tire will either gain or lose weight, depending on the desired effect.**

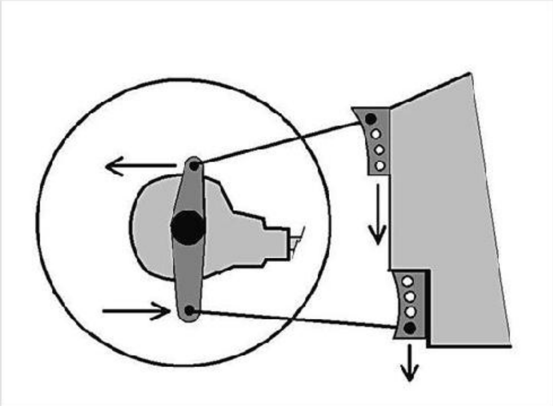


**A newer device for controlling axle wrap-up and providing anti-squat is the adjustable pull bar that has multiple springs for dampening the engine torque allowing the rear tires to maintain contact with the track surface. This unit has been proven to control wheel spin all of the way down the straightaway and not bottom out.**

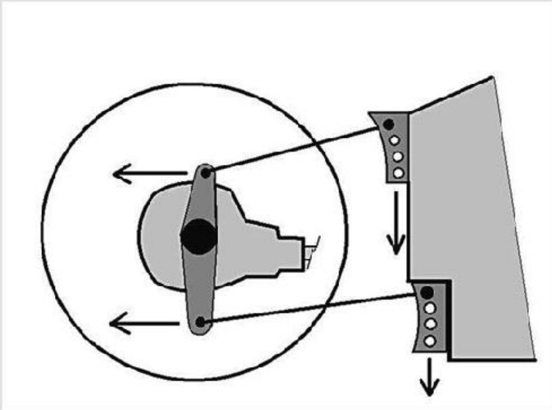
**A Four-Bar Car**



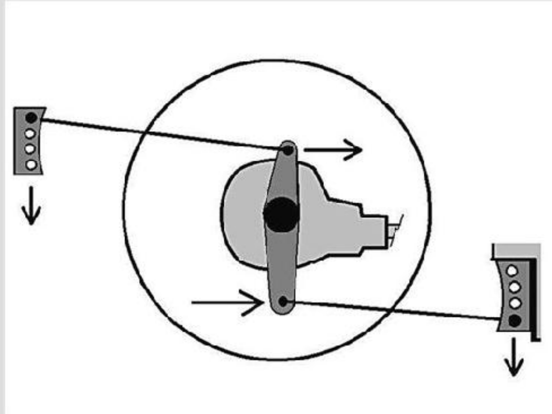
**RIGHT-SIDE VIEW. When we mount the trailing arms in the bottom holes, as the chassis rolls and the chassis mounts move down, the rear end will be pulled forward on the right side causing rear steer to the left of centerline. This will tighten a loose car.**



RIGHT-SIDE VIEW. When we mount the trailing arms to the top hole for the upper trailing arm and the bottom hole for the bottom trailing arm, then as the chassis rolls and the chassis mounts move down, the rear end will have very little rear steer because the two mounts on the rear axle bracket move in opposite directions.

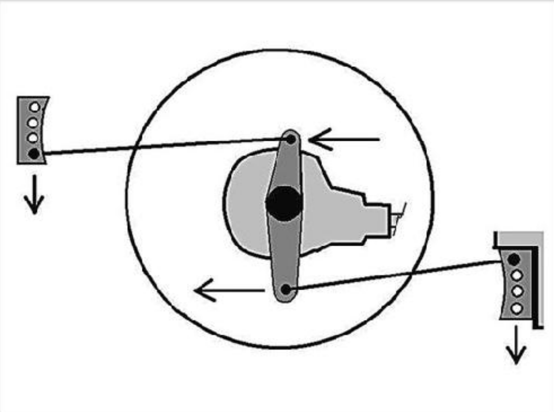


RIGHT-SIDE VIEW. When we mount the trailing arms in the top holes for both of the trailing arms, as the chassis rolls and the chassis mounts move down, the rear end will be pushed to the rear on the right side causing rear steer to the right of centerline. This will loosen an otherwise tight car.

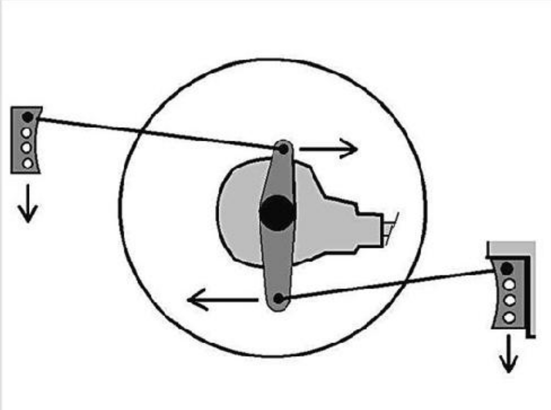


RIGHT-SIDE VIEW. When we mount the trailing arms in the top hole in the rear mount and the bottom hole of the front mount, then as the chassis rolls and the chassis mounts move down, the rear end will be pushed to the front on the right side causing rear steer to the left of centerline. This will tighten an otherwise loose car.

## A Z-Link or Swing-Arm Car



RIGHT-SIDE VIEW. When we mount the trailing arms in the bottom hole in the rear chassis mount and the top hole of the front mount, then as the chassis rolls and the chassis mounts move down, the rear end will be pushed to the rear on the right side causing rear steer to the right of centerline. This will loosen an otherwise tight car.



RIGHT-SIDE VIEW. When we mount the trailing arms in the top holes for the both of the trailing arm chassis mounts, then as the chassis rolls and the chassis mounts move down, the rear end will have very little rear steer because the two mounts on the rear axle bracket move in opposite directions.

Chapter 16

## Stock Car Class Setup


**The stock class race cars can be made to handle in much the same way as any other race car. If the rules makers will relax on a few key points, we can turn these monsters into respectable racing machines. This reduces costs by helping the racer to build cars that handle well enough to race side by side and not crash, something we see all too much of in stock classes.**

It is a basic premise in circle track racing that in a perfect world devoid of cheaters, the horsepower output of your motor is strictly regulated as opposed to the old saw "run what ya brung" and that most of the performance enhancement should be done with the chassis and through improved driver skills. We know all about illegal high dollar "stock" engines and that is another subject altogether. The problem with chassis rules in many stock class divisions is that the racer is restricted to what they can do to make the car handle better. Let's examine this situation and evaluate how we might be able to influence the governing bodies, so that stock class racing can improve as a whole.

The cars we are talking about are known by various names such as Street Stock, Hobby Stock, Pure Stock, Grand Stock and Chargers among other more localized names. The rules among race tracks vary, but most call for the suspension components to remain OEM stock. That's okay as far as it goes in holding down costs, versus the racer buying aftermarket upper and lower control arms and spindles. Nonetheless, a lot can be done to make these cars handle better and be more competitive by allowing changes to the control arm mounting points.

***Unreasonable Restrictions***—Many restrictions are placed on the circle track racers in the name of cost savings. While most will agree that racing needs to be cheaper overall, there are certain areas where a small outlay of cash will reap huge benefits for not only the race teams, but for the spectators and the track owners as well. Better competition, combined with fewer wrecks and caution periods, means happier race teams and spectators. How many times have we sat through a ten-lap, street stock-type race and seen a dozen cautions that produced a pile of bent fenders and suspensions? What we hope to demonstrate is that allowing the teams to spend a small amount of money may well yield huge benefits.

Cost is relative . Let's examine how the area of cost relates to stock class circle track racing. The biggest cost in terms of time and money (excluding tires) is in replacing parts such as fenders, spindles, control arms, etc. after the car is wrecked.

It is safe to say that a typical stocker will be involved in many wrecks during the course of a year. If we can reduce the amount of crashes, we can also reduce the cost to the racer. Allowing the teams to setup the car properly will improve performance to the point where there will be fewer incidents caused by ill-handling race cars. Many accidents I have seen involve one car pushing up into another car and causing a multi-car pileup.

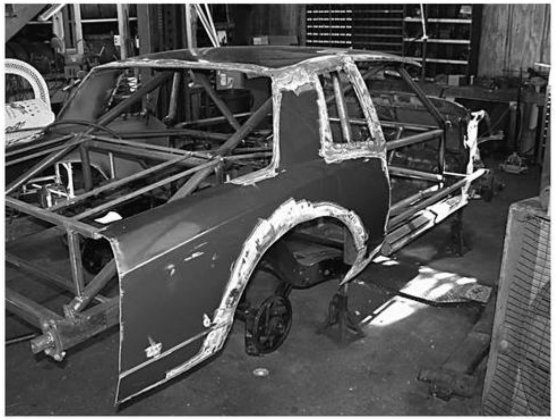
***What We Hear***—One of the most popular chassis of choice now is the GM metric cars made from 1979 to 1986 because they are so plentiful. We estimate that over 90% of all stock class cars are GM cars with many being the metric chassis. Although the rear suspension in those cars is not ideal, the front is where we see the most potential for improvement.

**There is a movement afoot to enact changes to many current stock class rules that now prohibit the changing of stock components. The need for better handling cars supercedes the small outlay of cash required to do the job.**

**Regardless of class, safety needs to be the top priority in your race car. This high school racing program street stock car has all of the important safety equipment installed.**

The front geometry design on the stock class cars is terrible. The moment center is not where it should be, the camber change (severe loss) is far from ideal and the steering usually has lots of Ackermann. The front of the chassis is the most important area we can work on in order to improve overall handling and chassis related performance. If only the rules would allow us to make those changes.

All we would need to do to improve the front geometry is to change the angles of the upper and lower control arms. We can easily do this, if allowed to, by installing aftermarket upper control arms, aftermarket adjustable inner mounts and adjustable mono-ball ball joints. These parts are not very expensive, and from our experience, would do wonders for the handling of the cars if properly mounted.



**The car we are mostly concerned with is similar to this early '80s GM Monte Carlo. This is a Hobby Stock dirt car under construction earlier this year.**

**The problems associated with the stock upper control arms are evident in these photos. The upper arms actually have reverse angle to them with the inner mounts being higher than the ball joints.**

Another area where the stock class racer needs to make adjustments is in weight distribution. If the teams were allowed to install weight jackers, the weight distribution would be easy to adjust. We all know that some racers install spacers above the springs to dial in the cross-weight, so why not just let them make it a little easier by using screw weight jackers.

In the grand scheme of things, the stock class is often a training ground for inexperienced teams to learn how to set up a race car. Why not provide the tools they need to make the necessary setup changes to those cars so that when the time comes to move up in class, the learning curve will be much shorter.

***What We Preach***—We preach the importance of proper moment center design, camber change characteristics and steering that does not produce excess or deficient toe in the turns. We tell the racers how to accomplish those ends in a very detailed way. The problem we have is that all of that knowledge makes for a very frustrated stock class racer who cannot do anything about how his car is designed.

**If the racers were allowed to install weight jackers, a lot of time and effort would be saved. The team could dial in the handling balance more easily as track conditions change.**

**When installing adjustable spacers, you might need to weld the rings together once you have established your intended ride height and weight distribution in order to meet the rules outlawing spring adjusters.**

It was far easier when the guy didn't know any better and just went along with the way it was. Unfortunately, that has all changed. Imagine knowing that there is a cure for a certain illness that you can afford to buy, but then not be allowed to use it. This is what the stock class racers are going through right now.

In many cases, the racers take it upon themselves to bend the rules in their favor. I know of one team that made what seemed like minor changes to the front suspension, and it made a world of difference in how the car handled. They simply cut off the upper mounts and lowered them. In the process they repositioned them so that they had a caster split and the proper cambers on each side of the car. They also installed ball joints with longer shafts to raise the upper ball joints and take angle out of the lower ball joints. The upper arms were cut and re-welded to provide more clearance for the ball joint shaft. This work involved mostly labor, and the only cost in dollars was for new ball joints. The old ball joints needed replacement anyhow, so there was really NO additional costs, only labor and some welding.

The result of those changes was a better moment center location that made the front end more efficient and allowed the car to turn better. The steering felt better, due to the caster split, and the tires had more grip, due to the cambers being correct. The driver, a veteran of more than 20 years on the dirt, said it was the best handling car he had ever driven. The whole process took less than four hours.

***Promoters, Please Wake Up***—I really believe that the majority of promoters want better competition and more car count for each division that races at their tracks. Therefore, it shouldn't be hard to convince them that allowing these simple changes would benefit everyone involved, racers, fans and owners. Sometimes the resistance we see is just a matter of the officials not knowing exactly what the racer is up to when they see a deviation from the rules.

I had an experience at a touring race when the officials saw that some of the teams, ours included, had changed the shape of the radiator inlet boxes. The reshaping of the top of the box allowed more space for low pressure under the hood and the car produced more aero downforce as a result. This helped the car to turn better which is always helpful.

The officials were leaning toward outlawing this modification since none of the current rules covered that part of the car. I had a talk with the top official and explained in detail what was being done and why. I told him that rather than ban the practice, he would do much better allowing all of the teams to make the modification. The cars would then turn better, and he would have a better show as a result.

He was actually glad I came by, and said he had been confused at why the teams were doing that. Now that he understood, he agreed to allow the teams to go ahead and modify the air boxes without restrictions.

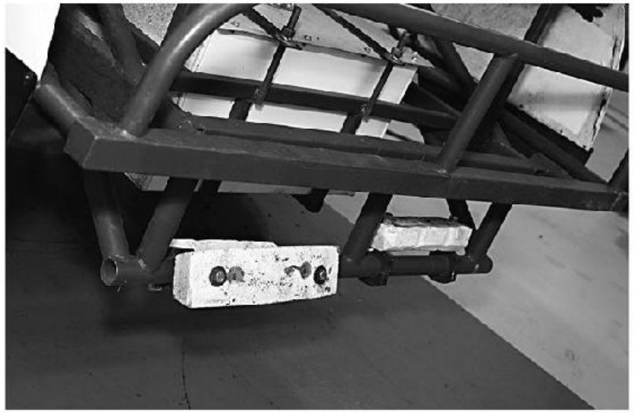
Most track officials and owners are in need of this kind of information so that they can make intelligent decisions regarding suspension rules. If everyone in a particular class at your race track met with the officials and explained why they needed a change in the rules and how it would benefit all, they would be hard pressed to say no without appearing unreasonable.

***What Specifically Needs to Change***—The following are areas where the racer should be allowed to make changes. The costs are relatively low and most of the work involves labor, a commodity that is readily available with most racers. The building of the car requires a lot of labor involving cutting and welding, so a few more hours is not too much to ask.

- Modify the upper control arm mounts. This can be described as lowering the existing mounts or allowing aftermarket adjustable upper mounts to be welded onto the chassis.
- Allow the use of aftermarket upper control arms of various lengths so that the racer can modify the cambers and moment center location more easily.
- Allow aftermarket mono-ball-joints and/or extended shaft ball joints to help reposition the moment centers and reduce camber change. A step further here would be to allow aftermarket spindles.
- Allow modifications to the upper control arm if it is to remain stock. This is required to eliminate binding when increasing the upper control arm angles.
- Allow the teams to install weight-jacking systems in the front and/or rear end of the car so that the cross-weight (bite or left-rear weight) can be adjusted for handling balance.

These desired modifications seem so simple when we really take a look at it. I am often of the opinion that if all of the racers went ahead and made the changes, the track officials would be hard pressed to throw everyone out. Call it civil disobedience or call it standing up for what is right, but by all means, let your officials, and especially the track owner and promoter know how you feel.

We need the entry-level classes and when these cars are designed right, it can be very good racing both from inside the car as well as when viewed from the grandstands. Then the cars will compete based on superior setups and the drivers skill level. And isn't that the way it is supposed to be?



**Lead ballast placed far to the rear in a stock car is not recommended. This placement causes a lot of polar moment influence to the rear where it will make the car loose. Put rear ballast in front of the rear end and high in the car.**

# Chapter 17

## Practice and Testing


**Be ready for tech inspection. The car should be well prepared in the shop before leaving for the races so that tech inspection goes well. This allows more time for practice. All of your alignment, front-end geometry, rear alignment, and engine preparation should have been done at the shop. The test and/or practice day is not the time to finish building and setting up the car.**

### Practice Sessions

A winning team seems to always be ready to take part in the first practice session. That is very important, because if anything does go wrong, it can be quickly evaluated and fixed in time for final practice. We've all had unexplained ignition problems, brake fluid leaks, oil leaks, and other problems that seem to come out of nowhere. These things cannot be anticipated, but can be fixed if you allow a sufficient amount of time to solve the problem. If you can fix the car early, it leaves more time for practice.

***Don't Rush Out onto the Race Track***—Being ready does not mean you have to be the first one on the race track. Sometimes there is debris on the track such as dirt, rocks, or bolts and other scrap metal. Let someone else puncture a tire or slip in the dirt (assuming an asphalt track). It is not a bad idea to wait five or ten laps into the first practice to go out.

Initially do a short three or four lap session and then come in to check things over. Look for obvious leaks in the radiator, fuel lines, and oil lines. Recheck the tire pressures and then go back out and do several ten lap runs.

Don't start evaluating the tire temperatures until the temps are close to race levels. Cool tires will tell you nothing about how the car is handling or how close the tire pressures and cambers are to optimum.

### Driver Input During Practice

Everything you do to the race car is for the benefit of the driver. If you're the owner/crew chief, then you will always need a warm body to steer, brake, and push on the throttle. It's a given that when the driver feels good about the setup, he will feel confident about pushing the car to its limits. In order to set up the car the way he wants it, you need to interpret what he is saying about how it is handling on the track. This is especially true during practice sessions on race weekends. Testing is something altogether different.

Evaluate clean laps for lap times. Look for consistency in the times even if you are off a few tenths from another car. Take into account the wear of the tires. If you are off three tenths from the fastest car, but running on 80-lap tires versus his 20-lap tire, you could well be as fast were it not for the difference in the age of the tires.

Don't chase a loose car in the heat of the day. With some tracks, the heat of the afternoon will draw out the oils that are a part of the asphalt and liquids that have been spilled on the track from previous races. If you adjust for these conditions, then you will be very tight when the cool evening conditions come at race time.

Make the driver communicate what he/she feels. If a driver tells you something is wrong with the car, then something is wrong. Many of us who have the job of setting up these cars have experienced times when the driver's comments don't match our idea of what is happening on the track. You need to decipher the comments against what you see and then take the appropriate action. A driver who says the car is loose may not realize the car is very tight and going tight/loose on exit because he had to crank the steering wheel so much to get the car through the middle of the turn.

**Be early through the tech line so that you can utilize as much practice as possible. This means that the car should have been properly prepped at the shop and no major work needs to be done at the track. The long shadows indicate a very early trip to the tech station.**


**Mark your tires with the set number, date, where the tires were run and which corner of the car they were run on. After the test, you might even write the number of laps run on the tires for future reference.**

Try to be a good listener, carefully analyze the information coming back from the driver and assume something needs to be changed. When you make changes that will increase driver confidence, but not necessarily recognizable performance changes, the car will get faster.


**Testing a stock car at Daytona is always exciting. This car has been properly prepared for performance before it ever reached the track. All that is necessary now is to fine-tune the setup and tweak the aero package.**

**Communication between driver and crew is critical for sorting out handling problems and setting up the car. Teams must properly evaluate the comments from the driver in order to understand what the car is doing.**

***Feedback from Observation***—You should observe how deep in the corners the driver is going and how soon he gets back on the throttle. If your driver is letting off the throttle earlier and braking sooner than the competition, then he must feel that the car won't let him push those limits. Once the handling balance has been established and the car is fast through the middle, you need to work on entry and exit, which is greatly influenced by the confidence of the driver.

## Common Driver Complaints

***Entry***—If a driver complains that if he goes in deeper into the corner, the rear end feels as if it will break loose, then it probably will. What you need to change first is brake bias, then look at the shock package or spring split in order to make the driver more confident that the car will stick on entry.

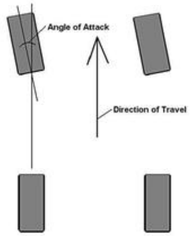
Rear alignment problems are the single most common cause of a car that is loose on entry. You will never solve this problem with setup changes. The rear end must be squared correctly. A simple stringing of the right-side tires will tell you if the rear end is running square to the right-side tires. The right-rear tire alignment should be parallel to the right-front tire when it is pointed straight ahead.

**Drivers need to fully understand how the officials intend to run the race event. Here a top driver discusses weekend rules and by talking directly to the official, gains his respect and understanding if there is a problem.**

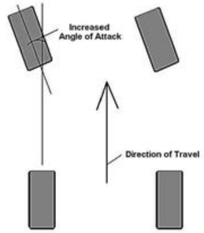
**The crew chief takes a personal interest in lap times while practice is going on. From this vantage point, he can observe how the car looks as it takes the turns. Driver comments can be noted on the radio and he can instruct the crew on possible changes to be made when the car returns to the pits.**

Some other causes of loose entry are: The left-rear tire is unloading on entry and losing traction. The harder the driver goes in, the more it unloads. Go back to Chapter 10 to understand how to make this situation better by using different shock rates at the corners. If the driver says that the car is very loose on entry and at mid-turn, the problem may be a rear steer in the rear end, usually with the right-rear wheel moving back farther than the left-rear wheel. Loose entry is a fairly rare problem and can usually be traced to alignment problems and rear steer shows all of the way through the turns as well.

The other probable cause of loose entry is too much rear brake bias. This problem can be evaluated by having the driver enter the turn using less brake pressure to see if the loose feeling is still there. With a misaligned rear end, the car will still feel loose at any speed, but the brake bias problem will only show up with more braking.




**With this much steering input, this car is handling tight. Note the angle of the front tires in relation to the direction the car is going.**




**As you increase the steering input to get the car to turn, the angle of attack increases until the car becomes loose. The front tires have gained more traction than the rears.**

***Rear Differential Problems*—**If a driver complains, "If I barely touch the throttle, the car breaks loose,"then there may be a problem with the rear differential, causing loss of traction in one of the wheels. With only one wheel taking the power of the engine, the car will either give up and spin very quickly or push like a dump truck.

If the left wheel is the only one hooked up on exit, then the car will push. If the right-rear is the only one driving the car, then it will likely break loose and lose traction since it cannot provide enough bite to turn the car and accelerate it.

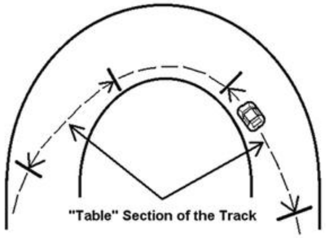
***The Tight/Loose Condition***—A driver will sometimes find it hard to distinguish between a tight car and a loose car. Why? Because the basic characteristics of racing tires can cause an otherwise tight car to go loose just as the car is exiting the turn and just as the drive is applying power. Here's how that works.

**In this photo, it is easy to see the driver's right hand to know how far he is turning the wheel. Remember, always wear gloves!**

**The position of the driver's right hand, below the door bars, tells us that the car is very tight in the middle of the turn.**

***Angle of Attack Produces More Traction***—A tire will gain traction as its angle of attack relative to the direction that the car is traveling is increased. In simple terms, as you turn the steering wheel of a tight car more and more into the turn, the front tires will be gaining more and more traction. This continues up until the angle of attack reaches a point where the tires break loose and give up all of their traction and the front end skates. Up until the front tires skate, the front end will be gaining more traction.

If the rear wheels started out having more traction than the front wheels (the car is tight), then as we turn the steering wheel the front starts gaining more traction (the front tires are gaining angle of attack). At some point the front will have gained enough traction from turning the wheel so that the balance of traction moves past neutral and onto being in favor of the front wheels. It is at this point that the car goes loose and the driver will only feel the looseness of the car.




**This sketch shows the area where we can gain both entry and exit speed. Some new drivers think that as the car enters the turn the car should be as slowed down as is needed at the middle of the turn. Delayed or diminished braking and gradually rolling off the throttle will gain speed in these portions of the race track.**

A visual inspection of the car at mid-turn from outside the car can tell you that the driver has to turn the steering wheel too much for the radius of the turn and that translates to a tight car that might well end up loose off.

Similarly, deep braking will cost the car speed in the middle and delayed application of power. An early lifting of the throttle, maintaining speed into the entry and early throttle application all result in faster average speeds and lower lap times. It takes practice and discipline to conquer the tendency to brake late. Late entry braking might feel fast and is exciting, but it is not the fastest way to run a lap.

***Loose Off the Corner***—Once you have made it through the middle with a tight car, it is about to go loose and this is usually just about the time the driver is getting back into the throttle. Bam, the car snaps loose and the driver reports that the car is loose. NOT SO. The car is tight/loose and you need to make it more neutral. By adjusting the handling balance to the free or loose side, we can actually gain bite off the corner. If you wrongly tighten the car (because the driver insists the car is loose), you will be making the situation worse.

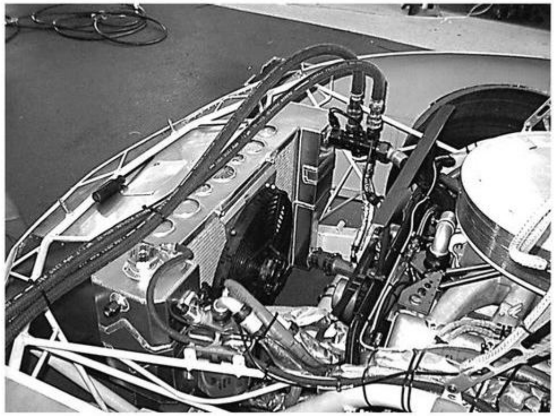
***Learn to Recognize Tight/Loose***—Learn to recognize this situation. Look at how far the driver is turning the steering wheel and how far the front wheels are turned. There is an exercise you can run where the driver goes around the turns at a slower speed and notes how far the steering wheel is turned just to roll through the groove.

Then he speeds up and at the higher speed, he notes where the steering wheel is turned in order to get the car to follow the same groove. If the wheel is turned more at the higher speed than at slow speed, then the car is tight.

This may be one of the only times we need to ignore the driver comments and do what is right, in order to correct the loose-off condition that is caused by a tight/loose condition.

**The panhard bar height is a critical measurement and should be noted. The mount should have a reference line to indicate a certain height off the ground at ride height so the crewmember can easily ascertain the correct height for note keeping.**

**When testing at the big, fast tracks, teams will simulate a "cold" run by circulating cool water through the engine and radiator between each run. Note the two water hoses attached to the inlet hose between the engine and the radiator. Very little air is allowed to pass through the radiator opening in the front of the car in order to improve the aero efficiency, so the engines will heat up very quickly in only a couple of laps.**



## Evaluate Quickly

Quickly evaluate the handling balance of your car. If you have run the car before and are fairly certain that the setup is close, look for a mechanical problem if the car acts weird. It just might be a bad set of tires (if using old tires, one might have heated up more than the others and has a different hardness) that is causing the difference. Before you chase a mysterious handling problem, rule out the tires. Put on a different set and see if the problem still exists.

Nine times out of ten, a car that suddenly changes its handling characteristics has a mechanical problem. The shocks might have changed, the rear might have become loose and not square, a spring might not be seated properly or the toe might be set too wide or there might be toe-in.

**All changes made during a test session or practice for a race should be carefully noted and kept for future reference.**

Sometimes the car will experience an incident at the last race that bends a part away from an area of damage. This happens all of the time. Be sure to look the entire car over for damage when involved in an on-track incident.

## Make Responsible Changes

If you get the car good in the middle, don't make changes to improve the entry and exit performance that will ruin the mid-turn handling balance. When the car is good through the middle segment (as fast as the competition), make a note of all of the setup parameters.

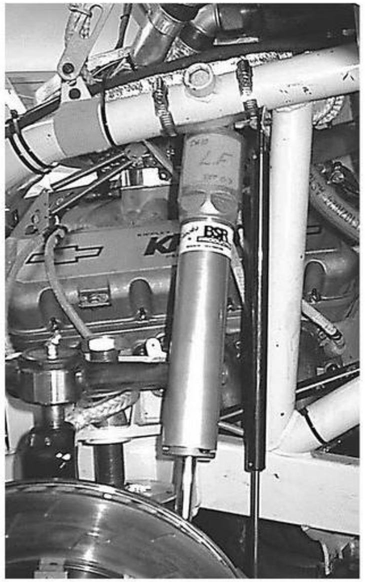
It is vitally important to note segment times to see if your deficiency in lap times is caused by handling or lack of power. Have someone note times of the turn segments as well as the straightaway segments. If you are as fast or faster in the turns, then look to the motor to find more speed.

***Know When to Stop Fiddling with the Setup—*** The chances are very good that when you start getting fast laps consistently, it's as good as it will get. When you are the fastest car on the race track, you have a 99% chance of going slower with each change you make.

## Keep Good Records

Record all of the setup parameters including, but not limited to: spring rates, wheel weights, shock rates, ride heights (wheel rim to fender well will do for track measurements), panhard bar heights, tire pressures, tire sizes, sway bar size and preload, gear ratio, final ratio, lap times, number of laps on tires, driver's comments, setup changes and any other information you think will adequately tell you how the test or practice went and how you ended up. Always be prepared to go back to the setup settings that were the fastest and most consistent if you decided to make further changes.

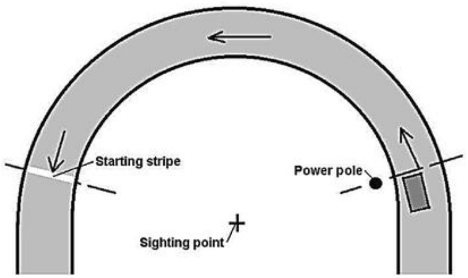
**When testing, it is a good idea to use a data acquisition system to record functions of the car, such as shock travel, engine rpm, fluid temperatures, steering input, braking, speeds, etc. There are numerous systems available for the short track market and the prices have become very reasonable.**



**Pick a high point at the track to observe the car and to take segment times. These observers can note other information such as track conditions, warnings about other cars with problems, driving lines and handling issues.**

Designate one team member to take the notes. Keep him informed of any and all comments, changes and other pertinent information that you will find useful later on. There are few people who do not need good notes.

**One crew member may be assigned the task of taking and recording tire temperatures and pressures. This must be done immediately after the car comes off the track after a session.**

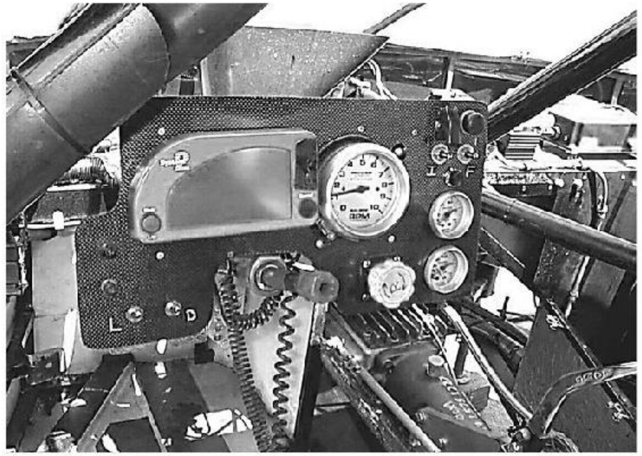



**When taking turn segment times, position yourself near the radius of the turn, if possible, and sight through poles or ends of walls and maintain the same position and visual targets throughout the practice. Compare times with other cars.**

## Lap Times Are Important

Take lap times for each and every lap. Monitor your competition's lap times as well. Compare your performance with that of other teams. Take into consideration your tires and your competitors'. Don't be alarmed if another car goes out on stickers and beats your time by five tenths if you've been practicing on old tires.

***Segment Times Tell a Lot about Setup***—The turn segment times are important to take in order to determine how well you are getting through the turns. These are the most important times to take. Other than figuring out if the engine has gone south on horsepower, the straightaway times are of little use. Total lap times will tell you if you are competitive. But if you are off the pace a little, these times won't tell you where you are losing the speed. It may be that in one of the turns is where you need to improve, not both turns.



**As in practice, a good addition to a test session would be a data acquisition system such as the one above. This is a system with a dash display. The driver can see critical information while the car is underway. The other data can be downloaded for later review.**

## Consider Tires vs. Lap Times

When comparing your lap times with a competitor, make sure you factor in tire wear. If your tires have 100 practice laps on them, and your competitor puts on stickers and runs three tenths faster, don't panic. Remember what you gain in time between old tires and stickers, and subtract it from your lap time to tell how you will qualify.

Whatever you do, do not chase a competitor who is going too fast for your class. Teams don't just show up and run five tenths faster than they did last week for no reason. Chances are they are cheating, hopefully only in practice, where there is no penalty. They just want to get you to change your good setup to try to match their times. Usually, if you fall for this, you'll end up all messed up and slower.

One team I knew once bolted on a 500cfm carburetor for practice when the legal one was a 350cfm. They had every team in their class scrambling to go faster to match their lap times. Before qualifying, they changed to a legal carb and went on to qualify on the pole and win the race. Don't let anyone do this to you.

**Spring rubbers can be used to temporarily change the spring rates to judge the effect. Remember that spring rubber rate changes are not consistent and entirely dependent upon the spring rate they are installed in, the compressed height at both ride height and at mid-turn and the density of the material used to make the spring rubber.**

## Track Testing

Testing is different from practice. With testing, you have much more time to try new setups and combinations. You can take big risks without worrying about making the race. Take advantage of any available testing dates at your track or any nearby track. This is the perfect time to try those different spring setups or to experiment with different gear ratios, rear ends, shocks, etc. Practice sessions during a race weekend are not the best time.

***Plan Your Test Session***—The sessions should be planned out well in advance. Know what you want to try and do those changes in an orderly way. Keep accurate notes on what changes you made and how the car was affected.

***Different Spring Combinations***—Create new spring combinations by weighing the car in the shop with each set installed and record the positions of the spring adjusters (either the ring on a coil-over or the screw jack bolt on a big spring car) so that the changes can be made quickly and efficiently. You probably won't have to get the scales out at the track if you do it right.

***Park in a Good Spot***—When you get to the track, find a fairly flat spot to park the car. Once you have your car positioned in your pit, mark the tire spots, and then get ride heights by measuring from the bottom rim on each wheel to the edge of the wheel well, and record this distance. For Modified or dirt cars, measure from a point on the lower control arm near the ball joint to a point on the engine hoop bars. Put a piece of masking tape on the fender/bar and mark an even inch.

**Keep a list of things to do to complete the preparation of the car and post that list on the car for all to see. When a task has been completed, check it off. These lists are very important in keeping track of all the things needed to complete a build or preparation of the car. If you don't currently use a list, start now.**

***Easy and Quick Way to Get Ride Heights Back***—This method will help to make the job easier if you need to get ride heights back after a spring change. These measurements are more accurate and a whole lot easier to take than trying to measure the chassis heights off the ground. Only change one spring at a time and readjust that corner back to its original ride height.

Spring rubbers are an excellent way to make changes to a car between sessions quickly without having to remove a spring.

## Making Setup Changes

When you make changes to your setup, make one change at a time. You've heard this before, but it is one of the most important principals of testing. That way when a change causes an effect, either positive or negative, you'll know exactly what caused it.

Change two or more things at once and you will spend much of your time trying to sort out which one had the effect or whether it was a combination of each. This is a waste of valuable testing time. You do not go faster by doing several changes at one time.

Don't, for instance, change stagger and cross-weight at the same time, or tire pressure and camber, etc. To correctly analyze the effect of a change, it has to be evaluated on its own.

***Find Handling Balance First***—When testing, find the handling balance first. Do this by rolling the car into the turn without any heavy braking or acceleration. Come down the straightaway at or slightly above the mid-turn speed and slow to the maximum speed at which the car will stick. Then, if the car is tight, it will push up in the front and if it is loose, the rear will drift up.


**When the car is running laps, watch closely how well it is able to stay down on the bottom of the turns and how much the front wheels are tuned. A lot can be learned about the cars handling by observing the attitude while it is going through the turns.**

Without the influence of heavy braking on entry and power application on exit, the car should merely show you if it is neutral or not. Once you find neutral handling at mid-turn, you can then evaluate entry and exit handling characteristics.

***How to Quickly Find the Balance***—One way for the driver to correctly evaluate whether the car is tight or loose is to roll through the turns slowly and note how far the steering wheel is turned. Then speed up and note again how far the wheel needs to be turned. Tight will require more turning of the steering wheel and loose will require less.

**Note:** If a car is set up properly with the correct springs, sway bar diameter and panhard bar heights, the only adjustment left for mid-turn handling balance is the cross-weight. The amount of cross-weight for most cars will fall in the range of 50%-52% for banked race tracks and 56%-60% for flat race tracks. The exact amount within each range will depend upon the amount of front to rear weight bias. The more front-weight percentage, the less cross you will need.

***Work on Mid-Turn First***—Make adjustments to suit the driver's preference for mid-turn handling, and then work on entry and exit performance.

## Establish the Correct Setup in the Shop

Earlier in this book, you learned how to balance the setup before the car is driven, so that the handling balance is established with the changing wheel loads (cross-weight).

## Maintain Ride Heights

If you change the cross-weight percentages, always maintain the original ride height. Adjust the spring heights at all four corners when making changes. The front adjustment will be less than that of the rear. This is because with the motion ratio at the front, each round of adjusting ring or jack bolt will effect weight change at the wheel.

Example: I want to increase the cross-weight percentage. I put 2 rounds in the LR and take 2 rounds out of the RR. I also put 1 1/2 rounds in the RF and take 1 1/2 rounds out of the LF. By changing cross-weight in this way, the ride heights will remain the same.

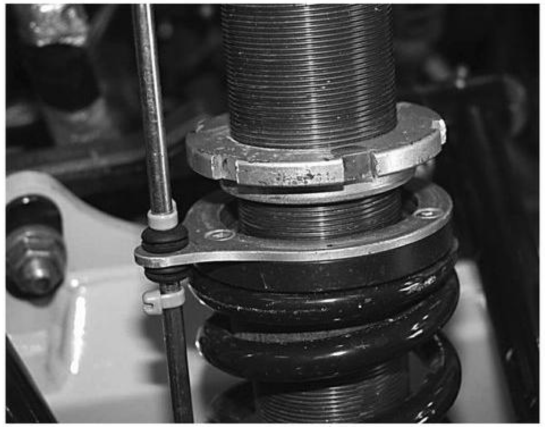
## Don't Chase Old Tires

Usually we practice on old tires that have between 35 and 100 laps on them. If you start the day off and keep getting the car better and better through the turns, but the lap times stay the same, in reality you are probably going faster. Consider that the car, if you keep the same setup, slows down the more you run it on the same tires. So, if you aren't losing speed and your lap times are staying the same, you must be getting better. When you put stickers on the car, the improvements will show with lower lap times.

## Maintain Good Notes on Practice and Races

Delegate someone on your team to take and maintain good notes on your setup and on any changes you make. Record lap times of all cars including yours. Record the tire temperatures, pressures, wheel weights, springs, panhard bar heights, moment center locations, shocks, shock travels, sway bar diameter and pre-load and any other pertinent information. This information will be of critical value during your test sessions.

***Post-Practice Evaluation***—The information you record can be studied later, back at the shop, and decisions can be made more effectively when the pressure is off. In the comfort and quiet of your shop, you might see something that will help your setup.



**Shock travel indicators mounted on the shock can be a simple way to determine the stiffness of your spring package related to the track and conditions you**

**are competing in. Excess travel might indicate a shock that has too little resistance or a spring that is too soft allowing unwanted movement.**

# Chapter 18

## Stock Car Safety

**A modern helmet and attached Hans device sit atop this Hooters Pro Cup car ready to protect the driver who is wearing a multi-layered fire suit. The use of head and neck restraints has become more commonplace as more and more rules require its use. Make sure your tethers are adjusted correctly. Many lives have been saved from the use of these products.**

From 1999 through the 2001 season, there was an unusually high number of racing-related fatalities, especially in stock car racing. This increase brought the issue of safety to the forefront of all types of racing. Everyone involved in motorsports generally agrees that something had to be done to make the sport safer for drivers and for the fans. Much has been done over the past ten years to improve driver safety.

In the years since Dale Sr. died, we have come to see that most drivers wear head and neck restraints, better helmets, more fire protection, better designed seats with side support for the head, and track safety personnel improvements. I have witnessed crashes that would have seriously injured or killed the driver, but the proper safety equipment was used, and the driver walked away.

## Soft Walls

Most of the discussion on racing safety used to be centered on designing so-called soft walls, that could absorb the energy from a high impact crash. Today we do see more and more tracks installing the Safer-Barrier walls and a 2009 crash at Indy supported the importance when a driver hit at over 210 mph and the wall absorbed much of the energy. He too survived when ten years ago, his would have been a fatal encounter.

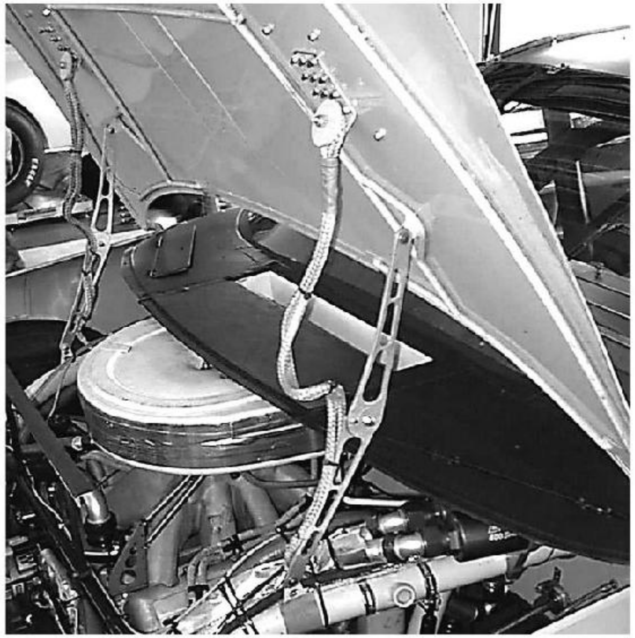
## The Soft Car Solution

We have advocated building softer cars that would absorb energy in a crash, but little has been done on that front. The articles written shortly after the Dale Earnhardt crash at Daytona suggested that we might need soft cars instead, and told how the construction of stock cars has evolved over the years. Today's stock cars are built so rigid that they no longer crush sufficiently in order to absorb the impact of hitting a concrete wall. But unfortunately, little has been done to correct the situation.

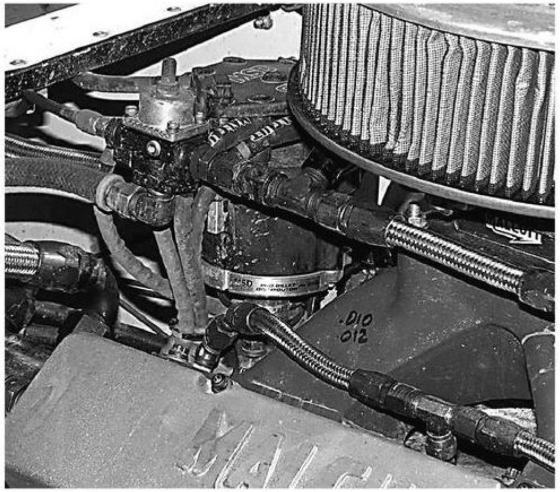
***Problems in All Stock Car Divisions***—This wasn't just a Cup problem, it was a stock car racing problem on all levels of the sport. In past years, several short track drivers lost their lives from either basal skull fractures or massive head injuries, as described in news accounts of those events. The injuries seemed to point to a chassis that was too stiff combined with inadequate and/or unavailable safety equipment.

## The Evolution of the Stock Car Chassis

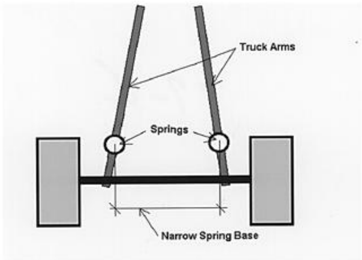
The stiffness associated with the construction of cars and trucks in all stock car divisions evolved over a period of more than fifteen years. In the mid-'80s, Winston Cup stock car teams were allowed the use of a rear suspension system called the truck-arm system. It is essentially a copy of a mid-'60s Chevrolet pickup truck rear suspension. It was strong, it had some good performance characteristics, but this system basically upset the balance of race cars so that the setups were harder to develop and driving the cars was more difficult than even some of the older designs.



Restraints, such as this double rope design that secures the hood to the chassis, help prevent parts of the car from flying into the grandstand or pits when the cars are involved in an accident.



As a matter of fire safety, fuel lines and especially the fuel pressure pop-off valve should not be placed near ignition wires and the distributor.




**The truck arm suspension used on NASCAR trucks, Busch cars and NASCAR Cup cars are designed and set by rules so that the springs are mounted on top of the arms. Because the arms are narrower than the frame rails, the distance between the springs is somewhat narrow and makes for a smaller spring base. The smaller the spring base, the easier it is for the rear to roll when the lateral forces are put on the suspension in the turns.**

## The Balanced Setup

In order for a stock car to handle correctly through the turns, it must have a balanced setup. We know now, due to recent technological advancements, that the term balanced means that both ends of the car will want to roll to the same angle in the turns, at high speeds. The setup in a stock car is correct when both ends are made to do the same thing.

## Leaf Spring Suspension

The leaf spring rear suspension system was very popular in the '60s through to the mid-'80s. Because of its design, this suspension, when used with the front suspension system still used today, came very close to the ideal balance needed for optimum performance. That was because a leaf spring suspension had a wide spring base and a high moment center, both of which resist roll in the rear of the car. The popular coil-over spring suspension used on some Late Model race cars is similar to the leaf spring system, in that it also has a wide spring base.

## The Old Days Were Better

If you ask some of the older drivers, they will tell you that is seems that these newer cars (from around the late 1980s till now) are harder to drive than those of the late 1970s to mid 1980s. Just watch some of the old races at Darlington and see where the cars just ride up the banking in a four-wheel drift when the drivers go in too deep. That does not happen today. The cars aren't nearly as well balanced. The BBSS setups are partially to blame.

The truck-arm system used in Cup racing has a narrow spring base and lower moment center, so cars are thrown off balance and do not handle nearly as well. It has been a struggle to try to make these cars handle properly.

## Top Engineers Couldn't Help

In the early '90s, engineers were asked to help the teams and they attempted to use Detroit technology that was originally intended for the passenger cars of the day, to try to solve the problem. Their efforts produced little or no success. The reasoning given for the failure was that the cars were too compliant, meaning that the chassis flexed too much. The engineers told the teams that the setups would never be consistent as long as the chassis flexed.

## The Chassis Becomes Stiffer

From approximately 1995 on, the teams and car builders continued to make changes to reduce the amount of flex in the chassis. The primary part of the cars that presented the biggest flex problems was the right-front corner. As time went on, the right-front corner became stiffer. The problem we are faced with is that in many cases, the first part of the car to contact the concrete wall is the right front of the car.

In the period between 1997 and 1999, several well-known drivers suffered serious brain-related injuries. The problems with the stiff chassis were beginning to show up. Then in 1999, chassis builders increased the wall thickness in the tubing used in the front of the chassis. This further increased the stiffness of the front ends. The theory is that the cars became much less energy absorbing and more crush resistant, increasing the magnitude of the force sustained by the driver during impact with the wall.

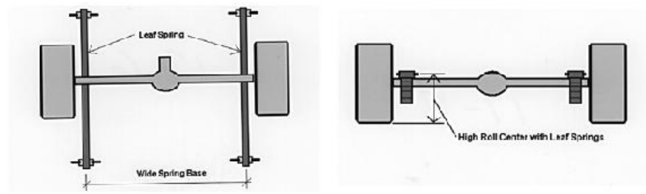
The Hans device (above left) has been one of the most influential products to come along to improve safety since the fire suit was promoted by Bill Simpson. We are positive that it has and will save lives for those who care enough to purchase and wear these units. We urge all governing bodies in racing to mandate the use of head and neck restraints.


**The use of full-support seats, multilayered fire suits, head and neck restraints, five- and six-point harnesses, window nets and improved fire control systems has made today's driver much more able to survive a serious crash.**

Despite the focus on improving safety, the governing bodies have historically been cautious in their approach to enact new rules that would change the chassis design. If rules are suddenly implemented that might make the cars handle worse, then they might become even more unsafe.

Fortunately, the head and neck restraint device, more specifically the Hans, came along and revolutionized how we can survive a high-speed frontal crash. The Hans was designed, in my opinion, to specifically address the problem and offer a perfectly engineered solution. The design goal is to restrict and slow the movement of the head forward as the car and driver come to an abrupt stop. It is this sudden forward motion of an unrestrained head that severs the connecting tissue between the vertebrae.

**A modern racing crew member is equipped with a fireproof suit and radio with headset that keeps him in touch with the crew chief and driver. Good communication and fire prevention can help prevent unnecessary injuries on pit road.**




**A leaf spring rear suspension provides a wider spring base than other suspension systems. The rear moment center is also much higher with this system, and both of these design characteristics provide more resistance to roll as the car negotiates the turns.**

The Hans provides the needed restraint that helps absorb this energy and keep the head attached to the body. More and more tracks and sanctioning bodies are requiring or suggesting the use of head and neck restraints. And it has saved lives.

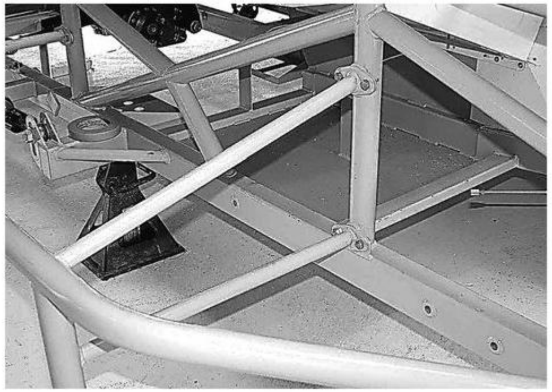
## Considering the Effect of Changes

Many factors need to be addressed when considering the redesign of cars. As we add structure and components to cars in order to assist in dissipation of energy on impact, we need to also consider the effects each change has on the way cars are set up and how those changes will affect the performance of cars. For example, adding weight to the front of the car affects the weight distribution, which directly affects handling and the way we set up cars.

***Raised Frame Rails Disturb Front Geometry***— If we decide to raise the frame rail on the front of cars to increase the angles formed by the tubing, we might alter the geometric layout that is so critical for camber control and moment center location. These two effects play a significant role in allowing the front tires to work the way they should. Correct designs for front geometry have evolved over many years and we don't need to destroy all of that work by overreacting.

***Compromises That Won't Hurt Performance***— As compromises to the above, it may be possible to move the engine back a little farther, in order to compensate for the increase in weight to the front of the car to offset the effect of the added weight of the crush components.

We could angle the tubing at the front of the car in such a way that the geometry we have carefully designed into the cars, remains the same. These are good examples of considerations that could be made. Each proposed change must be carefully examined before implementation.

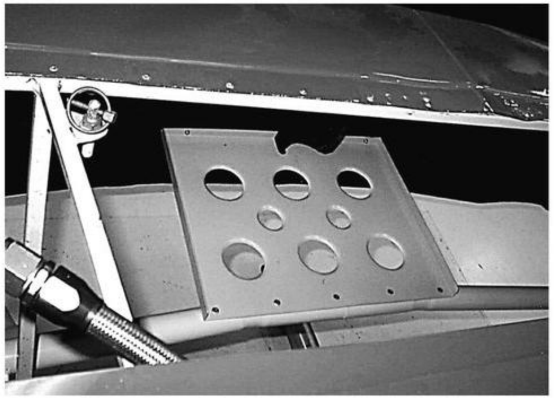


**This car has been constructed with detachable side bars so that after an accident, the sides can be replaced quickly and easily. Time is a valuable commodity to many teams who run a series and must travel. Attention to details such as this make the turn-around time shorter between races.**

***Making Changes***—More changes may be needed and we don't know exactly how far away we are, or can be from a total solution to the issue of driver safety. It is fairly safe to say that the more input the sanctioning bodies get from places like Detroit and other safety industry sources familiar with these kinds of problems, the sooner we will come to some conclusions.

A lot of people are curious as to exactly what is wrong with the cars, how difficult it can possibly be to change them and exactly what some of the proposed changes could be. Here are some thoughts and a bit of information that might help in understanding this complex predicament.

**This is a properly installed seat belt. Note how the belt runs straight from the mounting tab at the floor up through the seat and around the driver. This provides little chance that the belt will dump, or bunch up at one side of the slot in the mounting plate.**



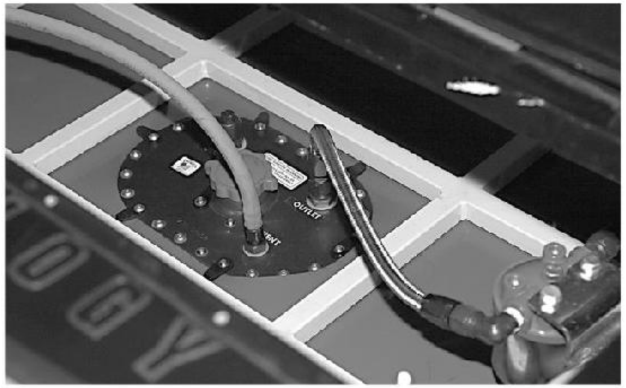
**Looking down through the opening in the rear deck, we can see where this team has mounted a support plate between the rear bumper and the rear tubing that protects the fuel cell. This provides a lightweight cushion that will absorb some shock if the car is rear-ended. It may well save the rear clip from damage and it is easy to replace.**

## Crush Zones

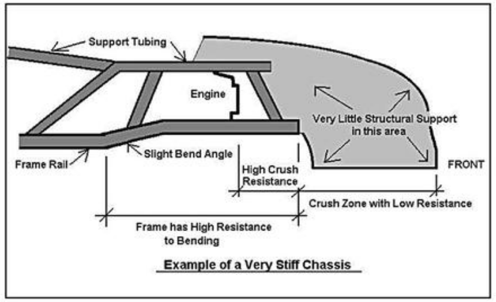
Stock cars need crush zones, period. Stock cars have traditionally not been designed with distinct crush zones. The crush zones should be built into areas of the car that have a good chance of coming in high-speed contact with the wall or other obstructions. The crush zones should collapse in a controlled way in order to slow the car and extend the time it takes to stop.

The crush zones could be spaces where prefabricated units could be installed and replaced in the event of a crash. This would serve two purposes; to soften the impact and dissipate energy, and to save the chassis of the car from damage in order to save the team repair money.

***Example of Energy Absorption***—It is important to understand what we mean with we refer to energy absorption. When we watch how movies are made, we sometimes see a stunt person jump off of a 10-story building onto a large bag filled with air vents. That person hits the top of the bag and then sinks slowly, as air flows out, through the vents. This is a great example of the dissipation of energy. The stunt person walks away because the sudden stop at the bottom becomes less sudden, because the time it takes to go from fall speed to zero is increased.

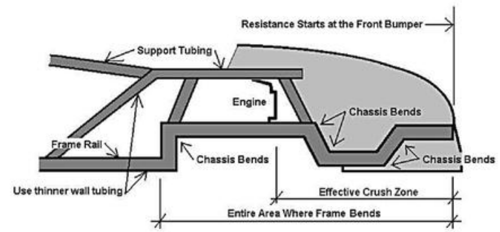


**This fuel tank bladder is surrounded by a strong metal enclosure. Should this car experience a rear end impact, the fuel tank will stay in the car and the bladder will prevent fuel from spilling and igniting.**



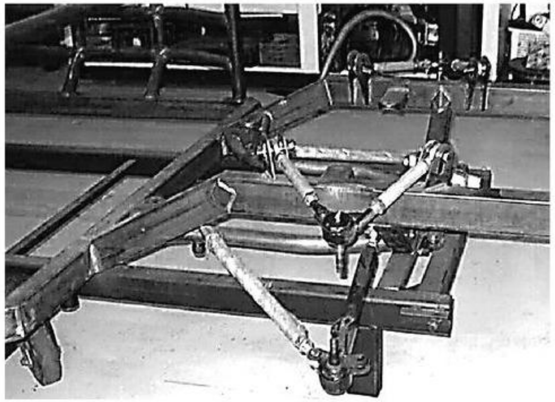

**This is an example of a typical front end on a modern stock car. We can see that there is very little structure built into the front area behind the nose to provide resistance to frontal impact. Once the nose has crushed back to the frame rail, there will be a great deal of resistance from the frame and engine.**

The same principle can apply to a stock car when it hits the wall. With a little cushion, or crumple zone in the front end of the car, the car will be slowed over a longer period of time. If we design the crush zone correctly, the driver will absorb much less force from the impact.




**Example of a More Crushable Design**

**This is an example of how a car might be constructed to provide crush resistance all of the way from the front of the bumper to the engine. The bends in the frame rails allow the frame to crush and resist the impact.**
**Ultra-straight front frame rails such as these will be a thing of the past in the near future as chassis designers move to design a more crush-friendly chassis. These current designs provide little protection for frontal impact.**



***Current Stock Car Crush Design***—The way some stock cars collapse (or don't collapse, as the case may be) now makes it easy to understand why drivers can get hurt. The nose area of the car is supported with minimal structure and will provide little resistance when the car crashes into a concrete wall. As the nose is pushed back, the wall contacts the end of the front clip, or frame of the car. This is where it gets ugly.

***Stiff Frames Are the Problem***—The front clip, or frame portion of the front end is the part that has become overly stiff over the years. The speed the car is traveling when the frame reaches the wall is much the same as before the nose contacted the wall.


**Even drivers running on dirt now understand the need for head and neck protection. This driver steps into his Modified wearing a Hans device that could possibly save his life.**

Therefore the car stops in a very short distance and transmits excessive g-forces to the driver, just like what would happen to the stunt person if we were to take away the air bag and he were to land on the concrete sidewalk.

***Proper Crush Design***—What we know from past research is that the cars need to crush with a constant resistance over a predetermined distance. That distance is directly dependent on the speed at which impact is made and the amount of g-force the human body, or in our case, a driver's body with helmet attached, can withstand without serious injury.

***Defining the Crush Zone Amount***—Using the g-force limits and the maximum vector speeds (not necessarily forward speed, but speed perpendicular to the wall), it has been found that we need a crush zone distance of between 2.2 and 3.0 feet. Coincidentally, in most race cars, there is almost exactly three feet between the front of the bumper and the front of the engine. The engine is considered by many to be the ultimate limit for how far the car will crush, as it will move very little on impact.

***Two Crush Zones***—Within the overall crush zone there are two distinctly different areas of design. The first is the area from the front edge of the bumper to the front of the frame rail. Within this area, we could design a collapsible steel or aluminum structure similar to those that many production cars have.

***Production Cars Have Crush Zones***—Many production cars are designed to crush like an accordion and they offer constant and equal resistance throughout the entire range of the crush zone. This reduces the g-forces transmitted to the occupants of the car.

**Head restraints for super speedway cars have evolved into much stronger and efficient designs. This design utilizes extended range of protection while en-**

abling the driver to see to the side of the car. Limitation of head movement is a safety goal of those who manufacture racing seats.**

## Use Foam Material to Cushion Impact

Another design would be to place some material, similar to foam, between the front bumper and the frame rails to absorb the impact. Either system must provide adequate and constant resistance.

Once the car crushes back to the point to where the ends of the frame rail are, then the frame must take over and continue the resistance until the required crush zone design distance is used up.

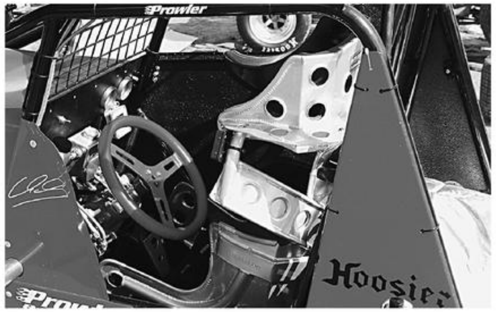
## Critical Elements for Crush Zones

The most important elements in crush zone design are the amount of resistance of the crush zone structure and the ability of the structure to provide constant and equal resistance all during the crash, just like the stunt air bag.

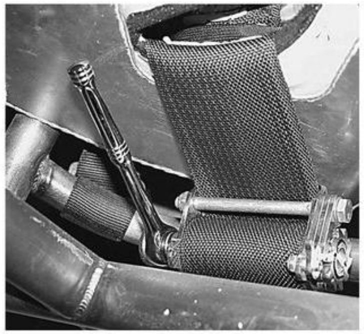
***Moving the Engine Creates More Crush Zone—*** If we could move the engine back further from the front bumper, then we would have more room for the crush zone with an additional safety margin.

## Governing Bodies Need to Act

Today, the governing bodies of all forms of stock car racing need to fully understand how we have come to this point, how important it is to quickly make these changes and then put together a list of changes that are responsible and effective. If they can do that, all the losses we have all suffered will not be in vain.




**The design of sprint car seats has evolved with the addition of improved support systems. A seat deflection limitation is a very important factor in helping keep the driver in the seat and protected during a crash.**



**Improper seat belt adjustment and tightening can be a contributing factor in roll-over injuries, especially in sprint cars. This new innovation allows the driver to adjust the belt with an easy-to-reach ratchet tightener.**

**Newer and more heat and flame resistant fabrics are being utilized in support of the fire suit. This under garment called CarbonX is designed to withstand high temperatures with thin layers.**

# CONCLUSION

I realize that in writing this book I may have taken much of the fun out of chassis setup. If you follow the suggestions given throughout this book, you won't need to constantly search for handling balance by frequently changing springs at the track, wondering each time how the car is going to react, or changing the sway bar, or moving that panhard bar up and down, up and down . . . things might just get a little boring.

But think about it. You get to the track, the tire guys get a new set of tires and air them up to the usual pressures and stagger. You roll the car out, top off the fuel tank, warm the motor and give a final check to the float level in the carb. You take in the first practice on last week's tires and notice the car is a little loose in the heat of the day. A slight adjustment to the cross-weight fixes the problem. The tire temperatures are perfect, lap times are good and it's time to scuff-in the new tires.

Now, you take a few quick laps at moderate speed, a few hot laps, and then a cool-down period. The first thing you notice is that the handling balance you had with the used tires is the same with the new ones. Oh yeah, you're quicker with the new tires but the handling stays the same.

All of those expensive springs and shocks you bought to help you find the handling balance at the track week in and week out are there just to experiment with. The car has the springs and weight distribution it wants, and no change is going to make it any better.

So the only thing left to do is maybe play with gear ratios, carb jetting, tire pressures, brake bias adjustments or other minor performance-related settings. In an ideal racing world, this is how easy a race weekend should be. Sound unrealistic? Perhaps. But by following the steps outlined in this book, your quest for the balanced, perfect race car setup that remains consistent throughout the race is that much easier to attain. Racing is, above all else, supposed to be safe and fun. This is exactly how racing is for many short-track racers. Many hundreds of teams have used these very same methods to win races and championships during the late '90s and into the twenty-first century. You can take control of your chassis and setup and make your racing efforts more fun. All it takes is a little effort; and the rewards are many.

Enjoy less stress and start enjoying your racing. Improve your performance and chances of winning. Drop the old habits and get on with the new technology. Good luck and I wish all of you much success and continued enjoyment of this great sport of stock car auto racing.

## ABOUT THE AUTHOR

Bob Bolles is an inventor, author, tech editor, publisher, consultant, speaker, manufacturer, and most important, a hands-on motorsports engineer. Although he holds a degree in mechanical engineering, his skill and experience with race cars come from working directly on the chassis and with the teams. Like the late Smokey Yunick, a former friend, Bob isn't afraid to get his hands dirty in the never-ending quest for speed.

The nice thing about racing is that you cannot BS what you know or what you develop. It either works or it doesn't. Proof is just a few laps away. Before Bob started his research on race car dynamics and engineering, he struggled with the very same problems that most race teams continue to struggle with today. He was determined to find a better way.

Over the years, Bob has worked with a high degree of success on virtually every type of stock car raced in the United States as well as with sprint cars and Grand Am AGT class and Daytona Prototypes. His cars have gone on to win championships in asphalt Late Model, Touring, Modified, road racing, Dirt Late Model, the famed Eldora World 100 and the Dream races.

Such a broad level of experience has helped him to develop new technology and methods that many racers around the world use today. Through his company, Chassis R&D, Bob has developed computer software programs that have been used by championship-winning teams throughout the United States, Canada, Australia, New Zealand and Europe since the mid-'90s. Today, he continues to test, develop and refine this technology, and help racers throughout the world apply it to their cars.

# METRIC CUSTOMARY UNIT EQUIVALENTS

| Multiply: | by: | to get: | Multiply by: | to get: |
|---|---|---|---|---|
| **LINEAR** | | | | |
| inches | x 25.4 | = millimeters (mm) | x 0.03937 | = inches |
| feet | x 0.3048 | = meters (m) | x 3.281 | = feet |
| yards | x 0.9144 | = meters (m) | x 1.0936 | = yards |
| **AREA** | | | | |
| inches² | x 645.16 | = millimeters² (mm²) | x 0.00155 | = inches² |
| feet² | x 0.0929 | = meters² (m²) | x 10.764 | = feet² |
| **VOLUME** | | | | |
| inch³ | x0.01639 | = liters (l) | x 61.023 | = liters |
| feet³ | x 28.317 | = liters (l) | x 0.03531 | = feet³ |
| feet³ | x 0.02832 | = meters³ (m³) | x 35.315 | = feet³ |
| fluid oz | x 29.57 | = milliliters (ml) | x 0.03381 | = fluid oz |
| quarts | x 0.94635 | = liters (l) | x 1.0567 | = quarts |
| gallons | x 3.7854 | = liters (l) | x 0.2642 | = gallons |
| **MASS** | | | | |
| ounces (av) | x 28.35 | = grams (g) | x 0.03527 | = ounces (av) |
| pounds (av) | x 0.4536 | = kilograms (kg) | x 2.2046 | = pounds (av) |
| **FORCE** | | | | |
| ounces-f (av) | x 0.278 | = newtons (N) | x 3.597 | = ounces-f (av) |
| pounds-f (av) | x 4.448 | = newtons (N) | x 0.2248 | = pounds-f (av) |
| **TEMPERATURE** | | | | |
| Degrees Celsius (C) = 0.556 (F – 32) Degree Fahrenheit (F) = (1.8C) + 32 | | | | |
| **ENERGY OR WORK (Watt-second = joule= newton-meter)** | | | | |
| foot-pounds | x 1.3558 | = joules (J) | x 0.7376 | = foot-pounds |
| Btu | x 1055 | = joules (J) | x 0.000948 | = Btu |
| **PRESSURE OR STRESS** | | | | |
| pounds/sq in. | x 6.895 | = kilopascals (kPa) | x 0.145 | = pounds/sq in |
| **TORQUE** | | | | |
| pound-inches | x 0.11298 | = newton-meters (N-m) | x 8.851 | = pound-inches |
| pound-feet | x 1.3558 | = newton-meters (N-m) | x 0.7376 | = pound-feet |
| pound-inches | x 0.0115 | = kilogram-meters (Kg-M) | x 87 | = pound-feet |
| pound-feet | x 0.138 | = kilogram-meters (Kg-M) | x 7.25 | = pound-feet |
| **POWER** | | | | |
| horsepower | x 0.74570 | = kilowatts (kW) | x 1.34102 | = horsepower |
| **COMMON METRIC PREFIXES** | | | | |
| mega (M) | = 1,000,000 or 106 centi (c) = 0.01 or 10-2 | | | |
| kilo (k) | = 1,000 or 103 milli (m) = 0.001 or 10-3 | | | |
| hecto (h) | = 100 or 102 micro (u) = (u)0.000,001 or 10-6 | | | |

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