HANDLING!

What It Is And How To Get it

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FOREWORD

Learning is the way we have advanced since our hunting and gathering days, but what many lose sight of in the worlds of Modern Academia is that, regardless of the diplomas you may earn, if you only learn what others teach there can he no progress.

Too often impressive titles, corporate logos, and academic recognition make the individual feel he must only follow, as his mind surely cannot create beyond what the great established institutions that surround him have done. But while they exchange, copy, and formalize knowledge, it is the individual's ability to think that creates and pushes forward the frontiers of man's knowledge.

I trust that the following work will give you the will and encouragement to use your mind to add to our wisdom and accomplishments.

"If I have seen further than others, it is because I have stood on the shoulder of giants." - Sir Isaac Newton

INTRODUCTION

HANDLING

What It Is – And How To Get It

Handling is control, and the more control you have of your vehicle, especially in adverse conditions, the better the "handling." If run slowly enough, any vehicle will negotiate almost any adverse conditions whether it be bumps, curves, or what have you; for this reason SPEED must be a basic assumption in discussing handling. Thus, if car "A" does any given maneuver quicker than car "B," it will be credited with having better handling. Inversely – at any given speed, the better handling car is the safer – frequently much safer. This is undeniable. Although engine power is definitely a part of handling, it is such a separate and distinctive part of a car's nature that it is not treated herein except where it relates directly to its effect on chassis performance, due to its weight, or to its effect on driven wheel adhesion.

The popular, yet much maligned, "soft ride," is also a part or handling. Although taken to an extreme in many cars, one can visualize a situation in which a softly sprung car could be driven at a higher speed across an extremely rough road than a hard sprung sports car, which would not only bounce out of control, but would be more likely to damage itself or put an unacceptable strain on the driver.

A Firebird owner called me once and said he had done "everything" he could to his car; stiffer springs, extra large swaybars, stiffer shocks, big tires with 30 some lbs. Of pressure, but his wife's Buick could still beat him into town and on a winding old country road. I explained that if the car's suspension resiliency is greatly reduced, the car can no longer absorb rough or uneven surfaces, thus greatly reducing the ability of the tires to stick to the road.

Obviously, handling must be a compromise among many facets of automobile behavior; and no two people, given their exact choice, would choose the same combination of virtues and weaknesses in their own car. For this reason, we will outline the most important areas of handling and show the effects of the various modifications available on the market. In this way owners can weigh their personal preference in modifying their car so as to have it perform just the way they want it to.

CHAPTER I

Where Is The Problem?

ON THE STRAIGHT-AWAY

This is one time when you want nothing new to happen; you want to just go on zipping straight down the freeway steadily and comfortably. With our ever increasing freeway system, this is becoming increasingly Important to many people, even though it may not be too much fun. Unfortunately, many cars don't just keep zipping down the freeway. They wander, float up and down, pitch fore and aft like a see-saw, vibrate, or need constant corrections to keep them in their lane. Perhaps the most unfortunate aspects of modern cars is the false sense of security they give, when in actuality their high speed maneuverability in an emergency is extremely low.

PASSING

We list this separately, as it is a unique type of maneuver; from a fairly high constant speed; you open the throttle as you execute a tight "S" curve. In many of today's cars, this can be an unnerving event; just as you establish overlap on the other car, your vehicle seems to want to continue its pivoting effect set up in the "S" curve. You must apply a little correction, then quickly correct so you will not leave the road or hit the passed car. Many highway accidents are caused by loss of control when trying to pass.

CORNERING

This is the first thing most enthusiasts think of when you mention "HANDLING." Poor cornering is always unpleasant and, not infrequently, dangerous. When you steer the wheels, you would like the car to follow them with no fuss. Only a few of the special-order performance cars sold today will do this. For this reason, salesmen on demonstration rides will seek out railroad tracks to show the soft. Ride, straight-aways to show off power, but never a sharp corner to push it through! Body lean, tire squeal, understeer, wheel spin, etc., are so much a part of today's cars that most of the population simply consider them due to "driving too fast." Thus, there is little incentive to invest the extra few dollars to correct it. Things have improved somewhat since 1974-75. They include extra stable suspensions with better shocks and anti-sway bars on their top-of-the-line models. Regrettably, these are installed only on luxury models.

Since the early 80's handling has become worse with most cars going to front-wheel-drive. The problem is more insidious as many of these cars handle relatively flat, and accelerating in a curve no longer spins a wheel, and the newer tires do not start to sing as you approach the adhesion point. If pushed too hard though, there is suddenly massive understeer, as the front tires slide. If the brakes are hit, the light rear comes around, and it's gone.

If you look at the skid marks on the interstate, you will now see many marks made by small cars where the tire marks cross one another, indicating the car was spinning, all wheels on the pavement and no other marks in the area. Indicating a sudden braking or passing maneuver caused the driver to simply lose it.

Statistically most interstate deaths are single car accidents. Many accidents that start as single car accidents, involve others as they cross the median. There is no excuse for any car to lose control on an interstate at any speed (except for drivers that fall asleep), but it happens more and more often, simply because the cars are not stable enough to retain control after a sudden swerve or braking maneuver. Mini-vans, one would expect to be handier and more nimble, than the older larger vans, but the handling is not any better, but a great deal worse. Some are out right dangerous even in everyday driving, due to its lack of stability.

ACCELERATION

Because the car body is accelerated, not by the engine, but by the suspension, it causes some strange effects. On corners, the car body is being acted on by the weight of the car, the thrust of the tires, the lateral side thrust of the cornering force and the torque of the engine. On rough pavement, the wheels can hop, break traction, grip again and hop, and so on, giving a hammering effect; and on corners can cause the rear end to slide.

BRAKING

Here we have the same problems as in accelerating, except that the drive axles want to drag and rotate with the wheels instead of against them. As one usually has less choice about whether to continue braking or not, than to continue accelerating, the consequences can be worse. Dive, an unpleasant feeling puts more weight than ever on the front tires, thereby, reducing braking and steering efficiency.

RIDE

Many people feel that the stiffer the springs, the better the handling. Not so. In the extreme case in which the frames are welded to the axles (like in many Dragsters), everything will be fine if the track is perfectly smooth (as for Dragsters); but if you drove such a car on the road, every little bump would break the tires loose from the pavement, breaking the adhesion. In effect, your whole car is "unsprung weight." Furthermore, on uneven pavement only three tires would ever be on the ground. This explains the expensive and carefully built independent suspensions on the all-out racers, such as the Formula cars.

ROAD FEEL

Basically, this is experiencing the sensations of driving. Naturally, the enthusiasts like it, and the family man {and especially women} who think a good car should feel like his favorite TV armchair, dislike it. As the enthusiasts are outnumbered (what is the ratio – 50 to 1?), manufacturers go to great lengths to do away with road feel. This is tragic, for one can feel impending danger long before one sees it start to happen – if you are allowed to sense what is happening, as well as just sit there and look out of the windshield. Slicker pavement, a failing tire, uneven drift, poor surface, failing brakes, or poor steering, the safety margin on curves – all are sensed by way of the steering response, the brake sensitivity, the seat itself, and the visual awareness of small, but telltale movements, of the front of the car. (This is the purpose of racing stripes in front of the driver on the hood. So now, they put them on the roof, or even worse, on the rocker panels, or around the trunk.) In most of today's cars, there is so much irrelevant movement in he car body on its mushy suspension, and so little feel in the power steering and power brakes, that only the sudden movement of the countryside tells one that something bad has already started to happen.

It matters not if you own a large luxury sedan or a sports car; any of the foregoing problems exist to one degree or another. And they can all be improved a little, or a great deal, with a little ingenuity and a few dollars. I said a few dollars. If you go buying all the most expensive accessories, tires, etc., available without carefully weighing your initial problems, the most direct cure, and your own goals and compromises, hen the sky is the limit. Production cars are not that bad; they are just built for people that neither, know nor care about handling. Of course, the builders are reluctant to spend any money on things that will not help the cars sell, and which, even in a small way, might detract from the ultra-soft "sitting in a tin cloud" ride that sells so many cars to the intrepid.

Remember, that an extra dollar spent on building a car would cost the producer $1,000,000 or more per year. In an earlier edition of this book I said, "If handling were less nebulous, and could be measured on a machine like horsepower, and then advertised in a neat competitive number, things might change." This has actually come to pass, and most car reviews now give the "G" factor of skid pad tests. Many of these are in the 80's. These tell you that it stuck up to that reading but does not tell how out of shape and difficult to control, or how uncomfortable it was, but at least it gives some indication what to expect. A year or two ago, some well set up, low priced sedans were raced against a number of big engine Corvettes on a well known West Coast race track. It was a toss-up. The sedans cornered "at least as well" and had almost as much acceleration. So, there it is. That's what you can do by knowing what to do and what equipment to use.

So much for what you wish would happen and what, on the other hand, usually does happen. The next step is to honestly evaluate how good or bad your car is in these various areas of handling. Despite the ads, the different suspensions used, and what the respective fans say, cars are all built to compete in the same markets, and must sell at competitive prices; it is no surprise that they have the same handling weaknesses. In varying degrees to be sure, but the difference is not as great as you might think. A little work on the worst would make it handle much better than the best.

CHAPTER II

Your Goal

Now decide what kind of a machine you want. More specifically, how do you want to be able to use it? There are a number of car types, one of which represents an enthusiast's objective. Frequently, it is a blend-compromise if you will – of two or more kinds. Detroit merchandisers have a field day every year dreaming up what they feel are exciting new image names that relate to one type or another – and their penchant for putting the wrong name on the wrong car is uncanny. A Cadillac is a comfortable car for long distance trips; so, why do they call it a "Coupe de Ville" (French for town coupe)? Try driving one in a French town! I can think of more suitable cars to name after the French road race, Le Mans, than a middle of the line Tempest and now a bottom-of-the-line, entry-level oriental import. But to most knowledgeable car buffs, cars do fall into some common sense categories that are good to think about in the light of one's own taste. Most cars will fall into one of these groups – Highway Sedan, Town Car, Grand Touring, Hot Street Car, RaIly, Sports Road Racer, Slalom, High-powered Race Cars, Oval Track Cars, and the like, are not discussed here, due to their special left-hand-only turns, they are never set up to be all-round good handling cars, which is our goal.

HIGHWAY SEDAN

This is the intermediate to large size cars used primarily for long distance driving. This is the type of car that Detroit has prided itself in until the gas shortage came on the scene. They do their job very well, and yet, many show up with obvious handling problems. For this type of driving there are a number of important requirements. Directional stability is the most important due to the fact that nearly all one's life is spent riding at high speed on straight or gently curving highways. Resistance to cross winds is essential.

Powerful engines are not as important as they used to be, as the time of two-lane highways full of underpowered trucks that had to be constantly passed, is now seldom encountered. Sufficient power for acceleration ramps and good gas mileage is the best compromise now. Anti-sway bars and shocks are the most important here.

TOWN CAR

A comfortable and usually an intermediate size vehicle in which I good acceleration and handling are the sought after elements. An unstable car becomes very tiring to drive in urban areas, as the constant corners require slowing to as little as 8 m.p.h. to avoid uncomfortable lurch and tire squeal. The accompanying front tire wear is another important problem. There are other factors also if the car's poor handling requires slowing from 30 to 10 m.p.h. for a typical city block turn instead of being able to take it at 20 m.p.h. You will use twice the gas accelerating back to 30 m.p.h. as you would if your car handled well-and in so doing, you will, thus, cause twice the pollution also! Another little asset is that you look like you're in control. I saw a young driver make a turn onto State Street in Chicago's downtown Loop district. He was not going fast – 10 or 12 m.p.h. at most – but he cranked the wheel over especially fast to give clearance to an oncoming wall of pedestrians. His Rambler, equipped with light duty tires and no anti- sway bars, lurched precariously and looked so out of shape, a traffic cop signaled him over for "reckless driving." It helps your case a great deal if an officer must admit that he did not hear your tires squeal. The section on anti-sway bars is the most pertinent for the city driver.

THE HOT STREET CARS

Perhaps those are the most sought after type of car by the young enthusiast. These small or intermediate size cars are set up to be as powerful as possible with numerically high rear end ratios to give the fastest acceleration possible. These drivers frequently did not care about handling, but with cars like the Olds 442 introduced in 1965, the trend was set to power-plus-handling capabilities. In the 70's the finest example of this type was the highly successful Firebird and Camaro. Available with a full range of engines and special suspensions, it offered the best sport chassis for the enthusiast to work with. Regrettably, it was destined to fall victim to the down-sizing program required by the gasoline mileage goals of the government. For this type vehicle, special attention should be paid to the section on traction bars and anti-sway bars. In the case of engine swaps where heavy engines have been put into light chassis, rear anti-sway bars, front shocks, and springs are where there one's attention should be given.

RALLY

Whether it is a small sedan or sports car, no exceptional demands are placed on the vehicle itself, but if it is not fun and rewarding to drive, it has failed. Your personal driving taste should be the guide here.

GRAND TOURING

One visualizes a fast, extremely good handling car used for high speed cross-country touring; a car that must maintain speed comfortably on narrow, rough, and winding roads. Spreading suburbia, super highways, speed traps and the 55 m.p.h. limit on back roads, have relegated this – perhaps the most thoroughly rewarding type of driving – to those fortunate enough to afford insurance that escalates with every new speeding citation.

The grand touring type car would be set up similarly to the next classification.

SPORTS ROAD RACER

These are sports cars or intermediate sports-sedans. Set up primarily for racing on road courses. Typical of these are the SCCA production racer. As they are highly competitive and safety oriented, they become ill-suited for street driving due to the elimination of lights, etc. Of only moderate power the winning cars are the cars that handle the best and that have the needed endurance. As these races are frequently long, engines, tires and drive-trains must stand up to all-out racing for hours at a time. Tires, anti-away bars, shocks, and other suspension components, must be delicately balanced.

SLALOMS

The competition of cars against the clock in a short tight circuit is not only challenging for the driver but quickly separates the good handling cars from the bad. Usually laid out about pylons in an unused airstrip or parking lot, the cars' suspensions are wrung out more thoroughly in a good slalom course than on many road courses. As cars are run usually only one at a time and comers are marked by plastic pylons instead of the trees, gullies, and other "natural hazards" of a road course, cars are frequently pushed to and past their adhesion points. As a misjudgment means only lost points, rather then a demolished car or personal injury, even the neophyte can push his car to its limit; thus, the demand for handling is perhaps more pertinent in a good slalom contest then in a sports road course where engine power, endurance, and the interference of other contestants all become factors.

An unusual set up for these cars favored by some drivers is extra firm rear anti-sway bars. The purpose is to cause oversteer and the ability to slide the rear out. Thus, pylons may be passed close by with the front wheel, and the rear will oversteer clear of it. Thus, part of the steering is done with the rear of the car.

One important feature of slalom cars is that most can and are driven on the street also. Shock absorbers are less important than in the sports road racers, as speeds are never as high; the surface is usually regular. Panhard-rods and anti-sway bars are more important in this case.

HIGHER POWERED SPORTS CLASSES

These are sports road course racers. With the reworked or special engines, these cars are light with a lot of power and are set up differently from the lower sports classes. With a lot of power fed consistently to the drive wheels, oversteer would be a constant problem; so, the trend here is to put more and more of the cornering effort on the front wheel. For these cars the importance is for front anti-sway bars, Z-bars, and Panhard-rods. This set up would make a clumsy streetcar at best.

VAN AND MOTOR HOME

Less exciting, maybe, but more important from a practical point of view are these everyday workhorses. As their drivers use them for long periods traveling on the highway, it is important that they not be unpleasant or tiring to drive. Their large size and higher C.G. give these vehicles inherently inferior handling characteristics; thus, extra care must be taken to make them handle well. Poor highway tracking and clumsy cornering are their problems. Anti-sway bars and good shocks are what they need the most.

AMBULANCE

Although usually based on van and small truck chassis, they are listed separately, as they are used so differently – usually heavily loaded with extra body and equipment. They are driven as fast and as hard as possible – well above legal speeds most of the time. The best handling possible is an absolute essential: It not only increases safety, but also increases the possible speed that it can be driven. A reasonably good ride must be retained for the comfort of the patient being transported.

With the foregoing groups in mind, as you read on pay particular attention to the section that applies the most directly to the type of car in which you are interested. Even if you are setting up an H production sports car, you will still want to make your go-to-work sedan a pleasant car to drive. So first, we will see what can be done with a typical car as it comes from the showroom.

CHAPTER III

Dynamics Of Cornering

Before one can understand why a car handles badly, or before one can understand what will improve it, one must be able to visualize in one's mind every force that is developed and how every part of the car reacts to it. Thus, as one experiences certain undesirable characteristics of the car's behavior, one can easily reason out both the cause and the cure. The reason that there is so much misinformation and, to be frank, ignorance, on the subject even among people in the parts and mechanics business, is that they have never bothered to think through the mechanics of the thing; and thus, they can only repeat the rumors, tales, and erroneous ideas they hear from others or that are pushed by car merchants or specialty equipment salesmen. Think it through step-by-step and come to your own logical solutions and act on them: you will develop a better car for less money than your competition that relies on grease-monkey hearsay.

The terms "Understeer" and "Over steer" and "Drift" must be completely understood and visualized in order to understand any discussion of automobile handling. The terms deal with the phenomenon of a tire creeping sideways as it rolls if there is a lateral force pushing it from the side. The speed of this creep or "drift" as it is called, depends on the amount of lateral force, the type of tire carcass and its rigidity, the tread compound, the air pressure, and the load bearing down on the tire. The greater the load the more the distortion and, therefore, drift. This all assumes one has not reached the adhesion point. The adhesion point is the point at which the lateral force pushing the tire is equal to the friction between the tread and the road surface. If more lateral force is added, then in addition to the drift, you have slide. The more weight you have on the tire, the higher the friction and, therefore, the higher the adhesion point. Extra weight on any given tire will increase both drift and adhesion force.

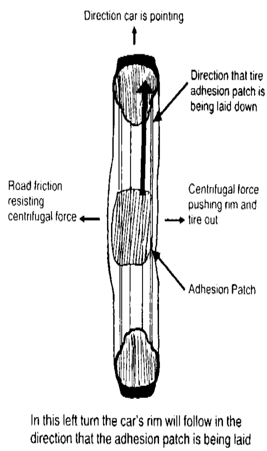


Figure 1

Obviously the tire adhesion patch is motionless on the pavement, anyway, up to the adhesion point at which time it slides. But obviously also, the rear end of the patch is constantly being picked up and the front is constantly being laid down. This is more visually evident when one watches a tank-tread in motion. The principle is the same, but in corner the rim and thus most of the tire is pushed outward of the adhesion patch. As the tire rolls the adhesion patch is laid down, not in front of the previous location of the adhesion patch, but a little further out more in line with the forward part of the tire which is centered on the rim. This is where the new tread that is being laid down is coming from. A gust of wind that pushes the front of a car to one side, although acting just briefly, causes the same effect and requires steering correction. Waggle the rear of a sedan with your hands as you watch the rim over the adhesion patch; see how much the rim can move.

Figure No. 1 shows the various forces working to distort the portion of the tire near the adhesion patch. The rim, and thus the car, will follow the direction in which the patch is being laid down just as your body follows the direction in which you place your next step when you walk.

Flexy sidewall radials will have greater drift, sometimes referred to as slip angles, than will hard multi-ply bias tires. More air pressure makes the tire less distortable and thus the rim can move out away from the adhesion patch less. This extra air pressure reduces tire drift.

Understeer and oversteer refer to the relationship of front versus rear drift. If the front tires have a higher drift speed than the rear tires, the front of the car is led out of the turn; therefore, making the car describe a larger radius curve than was steered by the driver and indicated by the angle of the front wheels, this is understeer. If the rear tires drift faster than the front tires, thereby bringing the rear of the car out and pointing the front of it in toward the center of the curve, one has an oversteer condition which will make the car describe a smaller radius curve than was steered. The foregoing assumes the tires were not sliding, but only drifting. If the front had started sliding, it would e referred to as "mushing out" or some other such term, or to "spin-out" if the rear tires had slid. The terms give the idea that the front slide is more gradual than the rear slide. It is, and for an obvious reason: as the front slides out, it increases the radius described by the car, thus, decreasing the lateral centrifugal force; thus, reducing the slide tendency so it can teeter along just beyond the adhesion point in a kind of equilibrium. Whereas, when the rear starts to slide out, it decreases the radius of the path of the car throwing it into an even tighter turn. Thus, greatly increasing lateral G forces that cause it to slide even faster. Only fast steering out of the front end by the driver will avoid the car from spinning out. It is this fact that the Detroit designers use (in the name of safety) to justify building of the clumsy, nose-heavy vehicles for which they have been known. The black marks of sliding front tires over the outer curbs of almost every clover leaf is ample evidence of the foolishness of this philosophy when carried to some of the present extremes.

In the case of a sudden turn, the front tires can easily be heard to squeal as they become temporarily overloaded as they try to snap the front of the vehicle around. As this docs not happen without some additional drift outward from the direction in which the front tires are pointed, understeer is experienced until the pivoting speed of the chassis has caught up with the function of the speed and angle of the front tires. At this point, the car will continue to circle around and around at a given number of circles per minute; and, incidentally, it will be doing the same number of pivots per minute. To better visualize this, imagine this circling car in space. It would be referred to as a "tumbling in orbit." The orbit is the circles it is doing on the parking lot, and the tumbling is the constant pivoting of the car necessary to keep its front end leading. In this case, the car "orbits" in the same manner as the moon with its orbits coinciding with its rotational speed. Thus, both the moon and the car keep the same side toward the center of the circle all the time.

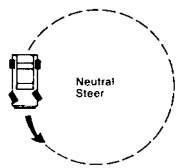
On coming out of the curve, the reverse happens. The front tires are steered out of the curve, and the pivotal inertia of the chassis tries to push them sideways into the turn. As this force is in opposition to the centrifugal force of curve, front tire drift is suddenly reduced, and an effect called terminal oversteer occurs. These effects are not the fault of tires, or other aspects of the suspension, and cannot be cured by them, but they are magnified or minimized by the dynamic weight distribution discussed later. These ill effects can, though, be absorbed by a well set up car through large capacity, low-drift tires, etc. Let's study dynamic weight distribution, or more correctly, the mass distribution and how it affects initial understeer and terminal oversteer.

As can be seen from the fact that vehicle weight increases a tire's drift and decreases its sliding, drift and sliding; and therefore, oversteer and spin-out (and understeer and mush-out) are caused by different effects and have different cures. Remember though, that as weight is increased, so is the mass of the vehicle; so, it develops more centrifugal force for any given radius and speed. Theoretically, this will increase at the same rate as the increased adhesion; but other things enter into it, such as the weight-to-unsprung-weight ratio, etc., that will effect the result.

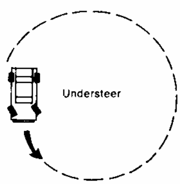
EXPERIMENT

In the middle of an empty parking lot, crank in a one-half turn on the steering wheel. Put the car in gear, and drive it five miles an hour and when car completes the circle, you will have returned to your original position. Have someone measure the approximate diameter of the circle. Try it again with the same amount or steering turn at 20 m.p.h. and 30 m.p.h. being sure to use a steady gentle throttle. If your car describes a larger circle as you increase the speed, it understeer; if it describes a smaller circle, and you end up closer to the center than where you started, it is oversteering. If it is set up to steer neutral, you will still end up slightly further out than you started because the car still drifted, but it drifted evenly front and rear; thus, the difference was not magnified by the car being pointed inward or outward by the drift. If it is set up to oversteer slightly – just enough to offset the drift- you will end up just where you started. This slight oversteer condition is what most drivers seek; it means that the car goes exactly where it is steered. Try this experiment again in the rain; at slow speeds the results will be the same due to the fact that the slicker pavement is reducing the adhesion, but not the drift in the tire. At high speeds you will easily pass the adhesion point, mush-out, or spinout, or slide out-sideways.

Neutral Steer
Front and rear drift are equal. Car will end up close to start point. (A little further out since both ends are drifting but still pointed in the same direction.) A little oversteer would compensate for drift of both ends and result in a perfect circle.



Understeer
Front tire drift causes car to refuse to turn as sharply as the direction in which the front wheels are pointed. Car can fail to "negotiate" curve. If wheel is held at given turn and throttle held constant, car will not make a true circle because front wheel drift changes its direction outward.



Oversteer
Rear tire drift is greater than that of the front and rear end tends to "spin out". Car in circle will end up closer to center of the circle because rear wheel drift changes its direction inward.

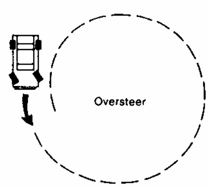


Figure 2

People are always concerned about their car's weight ratio in relation to cornering: a 50/50 weight ratio being considered ideal. Actually it is only an advantage in that the same tires and pressures can be used front and rear which, of course, simplifies the tire rotation. Furthermore, many racing clubs require equal size tires on all wheels in the sports car classes. If a car is engineered out completely (and very few are it seems), and the weight distribution, track width, roll stiffness, tire size and pressures, spring rates and other factors are all taken into consideration and are proportioned correctly, then weight distribution need not be balanced, and in itself is not important.

An early example of this is the Citroen DS with engine, transmission and drive train weight all over the front wheels and no rear overhang. The percentage of weight on the front wheels is far greater than on any domestic car, and yet, it is a beautifully balanced car in a really hard, high-speed turn. This has been done by wider front track than rear, heavy proportioned, front and rear anti-sway bars, hydraulically proportioned "Spring Rates" (It is an entirely hydro-pneumatic system.), and increased front tire pressures (although the tire size is the same).

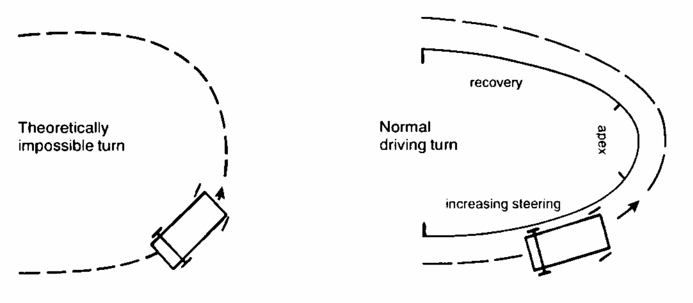
The EI Dorados of the time on the other hand, had the extra front-end weight of the front-wheel drive layout. A heavy front anti-sway bar, similar track and tires (front and rear), and at speed in sharp corners, develops what even broad-minded magazine test drivers refer to as "massive" understeer. This is an excellent example of two similar types cars, one engineered out for handling performance and the other built with no special regard given to its control capability. The heavier a car, or end of a car, the greater is the centrifugal force generated on any given radius corner at any given speed, but so is the weight of the car forcing the tread compound against the road surface. Thus, weight -or lack of it – in itself is not harmful to cornering provided all parts of the car, or that end of the car, are proportioned properly.

The Delorean that has 65% of its weight on its rear wheels was equipped with 15" X 8" wide rear rims. Its front had 13" X 6" rims. This gave it excellent balance. The Lotus Elise, which is mid-engine, had less weight bias than the Delorean, but nonetheless, had larger tires fitted to the rear to balance it. The balance is so good you just can't "lose it." These cars are not only more fun, but safer then any Ho-Hum Sedan.

In the foregoing, we are speaking of weight as ascertained by placing first the front wheels and then the rear wheels on a truck scale. As the car runs in a circle, this weight, acting as mass, develops the same ratio of lateral thrust pushing the tires sideways as it pushes them downward against the pavement; thus, other things being equal, front and rear, equal drift and adhesion are attained, front and rear. In this instance, it matters not if the weight is located over each axle or between them. Regrettably, cars are not driven in continuous circles; they go into curves and then come out of them again. This is where the trouble begins and where dynamic weight distribution becomes so important.

As a car is steered into a curve, the front tires are placed at an angle to the chassis, and they thus derive energy from the forward motion of the car to start the chassis pivoting about the rear axles and in so doing, change the path of motion of the car into a new direction. Tire and bearing friction aside, running a car in a circle requires no extra energy (on the same principle that a perfectly elastic ball will bounce forever or that an orbiting satellite will orbit forever, even though constantly changing direction), but pivoting the car to face toward the new direction does require a considerable amount of energy, as it absorbs energy to acquire a rotational speed in addition to its forward speed. If no extra gas is fed to the engine, energy is taken instead from part of its forward speed. This is often referred to as "scrubbing off speed."

As the car is steered into the curve, the front tires are given an extra load. As the front of the car is pushed into the turn, and the whole car is accelerated rotationally until the car reaches its fastest rate of turn. This extra load, which is in addition to the centrifugal force developed during the curve, is placed on the front tires at the beginning of the curve and is never experienced by the rear tires – it causes what is known as initial understeer. To appreciate the effort the front tires must put out to start the car turning; think of a sports car on a skid-pad 100 feet in diameter at about 50 m.p.h.; sufficient speed so that it makes a complete circle every eight seconds. The car, in addition to its forward speed of 50 m.p.h. must have been given a rotational speed of one revolution about its rear axle every eight seconds (or at about 7.5 r.p.m.). If the car is well balanced with an adequate tire adhesion/force ratio, the car will continue to turn its circle without further steering input.

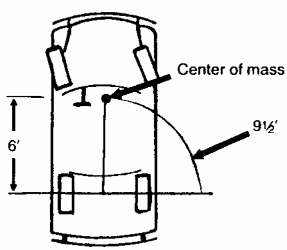


Figures 3 & 4

Figure 3 represents the track a car would have to make if it were to execute a continuous-radius 180° curve from a straight line course and then return to a straight line path, such as if a driver tried to follow exactly the wall of an oval track. Actually this would be impossible for the person or the vehicle to do for two reasons:

1) At the moment he decided to start the turn, he would have to instantaneously crank-in his full steering angle for the radius involved which he could not do instantaneously; and
2) If he did so, his front tires could not accelerate the front of his car into the turn instantaneously anyway, and they would start to slide.

Figure 4 shows a more realistic turn that would be executed in everyday driving or on a road course. To negotiate the same 180° turn (in this example in four seconds), one would be turning the steering wheel sharper and sharper for maybe two seconds and then straightening out the wheels for another two seconds. Thus, in two seconds one must accelerate the center of mass of the car through 90° in two seconds. For a car of 12-foot length, with center of mass 6' from rear axle, this would equal 2,500 pounds accelerated through 9.5' in two seconds, or a little over 21 horsepower. See Figure 5.



In a 180° turn that takes 4 seconds to complete, the center of mass must be accelerated through a 9½' arc in 2 seconds.

$$\frac{2500 \text{ lbs.} \times 9.5'}{2 \text{ seconds}} = 11875 \text{ ft/lbs/sec} \qquad \frac{712500 \text{ ft/lbs/min}}{33000} = 21.6 \text{ horsepower}$$

Figure 5

If this had been a mid-engine car with perhaps a 2' center of mass to pivot distance, it would have taken a one third less horsepower (7) from the forward speed. Actually the reduction in pivotal inertia are somewhat less than the indicated above as the car has width also. Thus the left side of the car must be pivoted backwards and the right side pivoted forward 90°, but if this factor is regarded as a constant the advantages or shortening the mass-to-pivot distance is obvious. Naturally, if you decrease it toward zero you would have no weight left on the front wheels to grip the road and start the pivoted movement to begin with. To actually feel the forgoing, take a well balanced, stable car and coast at 30 m.p.h. into a 90° street corner keeping just below the tire squeal point (the start of tire slide point), as the car emerges from the corner it will only be traveling about 15 m.p.h. Most of this speed was lost due to its kinetic energy being used up in pivoting and then stopping the pivoting motion. Of course, some was lost in tire and air friction losses, etc.

To better visualize the foregoing, note Figure 6. Assume the car is mounted on a pivot placed under the center of the rear axle, which is the pivot point of a four-wheel vehicle. Imagine instead of the front tire's action to pull the car's front around, that a man is doing the work. As the car is pivoted around toward its new direction, the man must push against the front end. As the car nears its half-way point towards its new direction (thus, it has moved through 90°), he must then pull on it to slow down this pivoting action; so, by the time the car is facing in its newly desired direction (180°), the pivoting action will have halted.

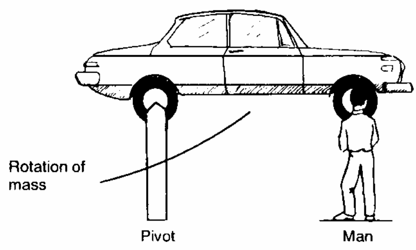


Figure 6

A. It will be far easier for the man if he accelerates the front of the car around at a steady acceleration rate until the half-way point and then de-accelerates the front end at a comparable rate. Thus, smooth steering prevents sudden lateral loads that may momentarily overcome front tire adhesion throwing the car out of control.

B. There is, though, no lateral thrust on the pivot (i.e., rear tires) regardless of how suddenly the front is pulled around. Now consider the mass distribution of the vehicle. Referring to the mass distribution diagrams, Figure 7:

C. Front drive cars have the most Polar inertia due to the concentration of weight of both the cross-wise engine and the transmission, and differential gears and drive trains. They will show the most initial and overall understeer.

D. Front-engined rear drive cars, such as a Corvette or the traditional sedans with less weight in the nose than front drive cars, will show less understeer. Initial understeer and terminal oversteer will always be noticeable.

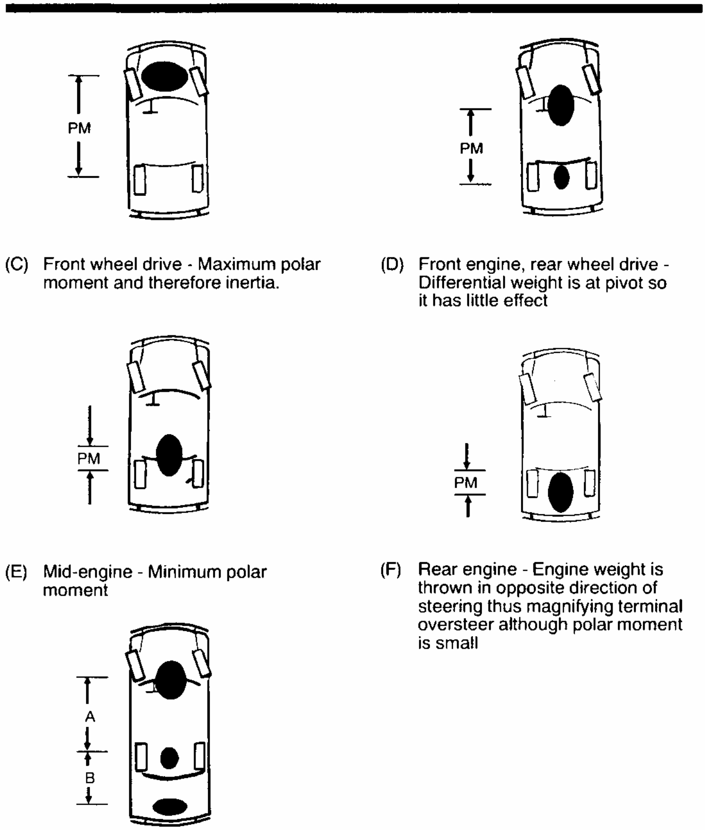
E. Mid-engined cars (Lotus Elise, Celica, etc.) will experience only mild effects of this phenomenon.

F. Rear-engined cars (Porsche 911, Delorean, V.W. Bug, etc.) develop slightly different effect. As the front wheels (or the man in Figure 6.) push the front into the corner the engine mass that is to the rear of the pivot point is accelerated to the outside and thus, the opposing force is to push the rear wheel toward the inside of the curve. More on this following the paragraph below.

G. Assuming the same wheel base in the above cars, the mechanical leverage of the front tires pulling the front around is the same although the inertial mass to be rotated about the rear axle; i.e. Polar inertia or P.M. (as measured in foot pounds) decreases as the dimension between the mass and rear axle decreases. Therefore quicker response and less initial understeer or terminal oversteer.

H. As the mass, therefore weight, of the car is moved to the rear, there is less weight on the front tires also. This reduces the tire's ability to adhere to the pavement and pull the front around. This phenomenon was most obviously demonstrated once when I watched a Volkswagen in a road course race. At one end of the track was a sweeping 200-foot radius, 180° curve. The front wheels had to be turned in at full-lock on the turn to keep this rear-engined car on the track as the front tires had insufficient bite to pull it around.

I. Moving some weight (batteries, ballast, gas tanks, etc.) out to the rear of the rear axle in an attempt to balance out a nose-heavy car will balance it out, but it will also have another effect. As the front tires pull the forward mass into the turn through distance A, it must also throw the rear mass outward through distance B. This car may have the same weight distribution as the rnid-engined car, and it may be 50/50, but its polar inertia may well be twice as great (A plus B) compared to a mid-engined car, even for two cars of the same weight. See figure 7(1).



(C) Front wheel drive - Maximum polar moment and therefore inertia.

(D) Front engine, rear wheel drive - Differential weight is at pivot so it has little effect

(E) Mid-engine - Minimum polar moment

(F) Rear engine - Engine weight is thrown in opposite direction of steering thus magnifying terminal oversteer although polar moment is small

(I) A typical sedan with rear overhang (or weight added to the rear)

PM = Polar Moment

Figure 7

The popular patrol-car chases staged on television show how easy it is for the typical domestic long-overhang sedan to spin out.

Keep it clear in your mind the difference in the case of initial over and understeer and what you might encounter on a skid pad. On a skid pad polar moment or polar inertia means nothing, as the car is not being accelerated or decelerated pivotally. Remember too that we are speaking of concentrated weight such as engines and transmissions, but all the same principles apply to any weight, such as bumpers, coach work, etc.

Cars with rear overhang, whether they be rear-engined or front-engined, with a large sedan style trunk hanging out at the back will have greatly magnified initial understeer and terminal oversteer for still another reason. Returning for a moment to our example of the man pushing the front of the car around with the rear on a pivot: When the man accelerates the front of the car into a rotational speed, the inertia of the rear weight will cause a lateral thrust on the pivot (i.e., rear tires); it will push them inward toward the direction of the turn, thereby, counteracting part of the centrifugal force of the turn causing less rear tire drift and increasing the effect of initial understeer. More serious though is the reverse effect that develops as the car is steered out of the curve. As the front of the car is steered out of the curve, the inertia of the rear overhang continues to try to pivot outward, and this force working together with the centerfugal corning force, both pull the rear tires outward adding to their drift and not infrequently causing them to slide. This rear weight will cause oversteer even in a steady state (skid pad) curve as it is pushing the front-tires inward and rear outward and at the same time it is lightening the load on the front tires and increasing the load on the rear tires by more than its actual weight due to its canterleavered position. These are good reasons for avoiding rear overhang in a race or sports car. In a sedan it is the poorest place for load carrying, as it is the location of the car that causes the greatest detriment to handling and load support capability pound carried. Its only justification is to reduce wheelbase on very long vehicles so as to increase low speed maneuverability.

For rear-engined cars this effect must be considered in balancing the car. The 911 & 912's always had the oversteer problem as did the Corvair. The light air cooled engine of the VW lessened its effect, and on the Delorean, the much larger rear tires and rims on the rear, overcame most of the problem.

Go back to the sketch of the man pushing around the front of the pivoted car that has the weight out behind. Once he has it pivoting fast, and he suddenly holds onto the front and stops it, the rear weight will try to pull off the pivot and come around and hit him in the back. If he does this with the car with no weight to the rear, it has absolutely no tendency to swing around off the pivot. Look at the average intermediate sedan, and add up the weight to the rear of the rear axle: frames, sheet metal, tank full of gas, spare tire and rear bumper, (especially the 2.25 m.p.h. crash bumpers, as it is heavy and being far to the rear has a more damaging effect), and you can see a good percentage of the chassis weight is doing its best to spin you out as you come out of a turn.

Adding overhang to the front will not counteract it but will increase the pivotal inertia and its attendant initial understeer and terminal oversteer problem.

Thus, it can be seen that the basic layout of a car's chassis determines its inherent handling characteristics. But surprisingly, these inherent characteristics can be balanced, compensated, and overcome by other factors to the point that the different types may all be equally fun to drive and on the racetrack, may be truly competitive with one another.

GEOMETRIC STEERING EFFECT

The foregoing discussion of a car's basic design tendencies when steered into a curve was assuming the driver was actually steering the vehicle into a turn. The car's suspension design also will affect its sensitivity to cross winds, truck suction, and uneven or crowned roads, all of which cause most cars to develop suspension geometry-induced steering effect. This is usually most noticeable on straight highways and causes needless steering corrections and driver fatigue. The effect is sometimes used intentionally in some chassis set ups, though. The phenomenon of steering effect is when one of the above-mentioned conditions causes body roll or the road (i.e. bump steer) to actually deflect the front or rear wheels away from the direction of travel.

One common cause for a car's wandering in its lane is lack of toe-in. Normally; the front wheels of a car are adjusted so that they point slightly inward. This sets up a balance of pressure between the front tires for steadier tracking by preventing minor road ridges, etc., from causing wheel deflections. When steered into a corner, though. The outside tires take on more than half the load and will, thus, drift more easily and "lose" its balance with the inner tire; therefore, a slight increase in understeer results. Excessive toe-in causes, not only more understeer, but also excessive tire wear. Suspension steering effect is more noticeable and more troublesome when it is caused by the rear suspension, particularly on straight highways; and regrettably it is built into many rear suspensions.

In the case of the "live" or solid axle rear suspension, cross winds, pavement undulations, truck-wash, or maybe just a driver's normal slight steering correction causes the body to roll on its suspension slightly. Assume that the suspension strut (or the forward part of a leaf spring suspension - the principle is the same) slopes up at 15° from the axle to the frame and is 20 inches long.

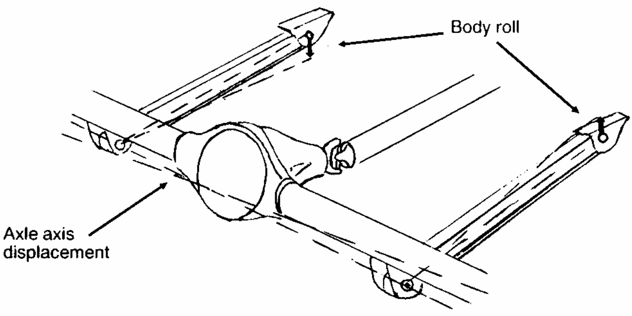


Figure 8

If the frame moves down one inch on one side and up one inch on the other due to a pavement undulation (or gust of wind, etc.), we have the following happen:

The resulting arcs made by the struts (or springs) will cause the low aide of the car to push the axle back 2/10 of an inch and the high side of the car to pull the axle forward about 3/10 of an inch. On a 40" wide suspension this gives a trigonometric function resulting in 35 minutes or a little over 1/2 of a degree. After the car has run its length, of say 100 inches, it results in the rear axle running off to the side an inch.

This is more than enough to require a quick steering correction. In practice, the shock absorbers will slow down this action helping it to blend in with the next undulation which may well be the opposite direction; so, the whole steering effect blurs together in just a rather mushy, uncertain control sensation. Watch the wheel well against the wheel of a car at 65 m.p.h. in the next lane; you will see one inch of vertical movement is common even on good expressways.

An example of rear steering effect was that of a friend who had a Cadillac that always pulled to one side of the highway. Unable to locate the cause, an enterprising mechanic offset it by putting rubber spacers between the coils in one of the rear springs; thus, introducing a constant steering effect that offset the tendency to pull to one side.

Later he installed an ADDCO Industries' rear sway bar. He was very pleased with the improved stability and control but said that some or the pulling tendency had returned. The rear anti-sway bar was reducing the rear steering effect by offsetting the mechanic's improvisation. He finally traded the Cadillac for a newer model and

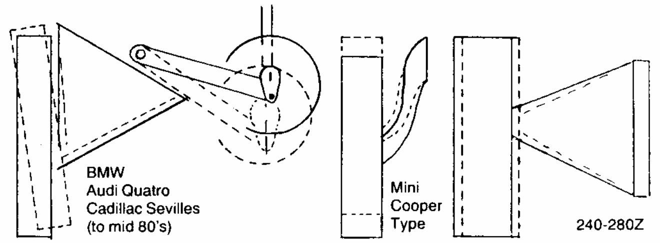


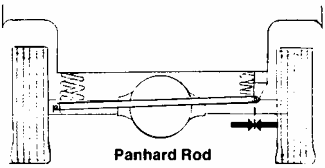
Figure 9

transferred the rear sway bar to the new car!

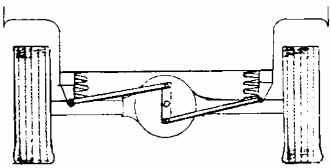
Independent rear suspensions also can cause rear steering effect. In fact, most do. The rear suspensions that do not cause rear geometric steering effect are those that pivot on either longitudinal arms or longitudinally mounted A-arms. An example of the first would be a Mini-Cooper which has a pivoted tubular arm that leads back to the rear wheel. Thus, the wheel remains true toward the front of the car no matter how high or low it moves on its arc. Furthermore, there is no lateral pull either. That is to say, the tire does not try to move inward or outward against the pavement as it drops or rises. An example of the longitudinally mounted A-arms type would be the 260Z; although this type will pull laterally as the A-arm makes its arc, it does not steer the tire to one side.

A rear suspension, such as the BMWs, the Audi Quatro, many Datsuns or TR-6s, uses a rear A-arm that is mounted to a cross-member that runs at an angle across the bottom of the car. If you visualize pivoted all the way down (as if you removed the spring and shock absorber, and let the wheel hang straight down), you can see that it will "toe-out" as it moves down. This effect will cause only mild steering effect, as unlike the solid axle car described earlier, as one side goes up it effects only one rear wheel, as far as steering effect is concerned.

Another cause of rear steering effect is the Panhard-rod. This device at is used on the full-sized Fords, Chevrolets (until 1970), Fiats, Opels, Volvos and a number of other makes is in reality a lateral locator link. It is pivoted at one end of the axle and crosses the car, and the other end pivots on the opposite frame. This keeps the car body laterally located over the rear axle. The problem is that as the car moves up and down, it makes an arc, thus, pulling the rear of the car body sideways. This is most obvious if you follow a large Ford or older Chevrolet driven slowly across railroad tracks (or if you just ride in the back seat). The rear of the car is actually shaken sideways as the wheel near the axle-end of the pivoted Panhard-rod moves up and down. Making the rod as long as possible and as horizontal as possible minimizes this effect. This reduces the side thrust between



You can see lateral thrust generated by the panhard rod when the left wheel rises or drops or the body moves vertically.



Note that this watts link allows vertical movement of either wheel but locks out any lateral movement of the body and it generates no side thrust.

Figures 10 & 11

the body and axle, and, thus, reduces the resulting rear tire drift but does not eliminate it. The same effect is caused by upper struts that are angled sharply to act as lateral locator links as on most GM rear drive cars.

Panhard-rods are often added to regular leaf spring rear suspensions on hard-raced sports cars to prevent lateral flexing of the leaf springs on very hard cornering. Any steering effect induced is negligible due to the short suspension travel of most modified sports cars. See Figure 10.

An improvement of the Panhard-rod is the type of locator link used on the later Alfas called Watts links. In this linkage there is a vertical link about four inches long, pivoted at its center on a pivot attached to the differential housing. The top of the link is connected by a rod and pivots to one frame, and the bottom is connected to the opposite frame via pivots. Thus, as the frames rise and fall relative to the axle, the extra reach of the rods is provided for by the vertical link by simply being pulled out of the vertical. In the case of lateral force, though, as one frame rod is pushing on the top and the other is pulling on the bottom, the vertical link locks up, and no movement results. This type of linkage gives the lateral location without the drawbacks of rear shake and deflection of the simpler Panhard-rod. It is, though, more complex to build. See Figure 11.

Rear suspension steering effect is especially noticeable and troublesome on large sedans and vans. On the large sedan, any rear steering is greatly magnified by the rear overhang as outlined earlier in the discussion on cornering dynamics. Vans are the most vulnerable for three reasons: The first is their especially large "sail area" making them rock in cross winds and truck-wash. Secondly, their high center of gravity causes more body roll on pavement undulations; and thirdly, most are built on virtually straight frames, without the "kick-up" over the axle. Although the springs are usually mounted on top of the axle instead of below it, the spring still must lead up at a steeper angle from the axle to the forward frame attaching point than on a car. Thus, the arcs made by the springs holding the axle develop larger thrust forward and back on the axle as the body rolls, particularly when not

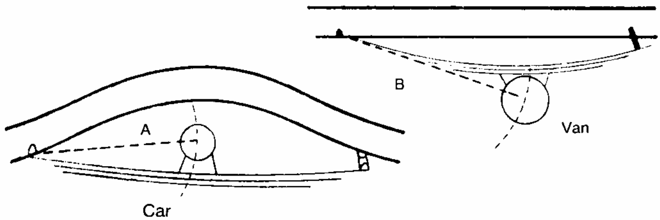


Figure 12

carrying a load. The slope of arc-producing spring A is more horizontal than slope of B on the van; thus, the steering effect is less pronounced. The most direct and most used cure is the addition of anti-sway bars, but this must be carefully done if the car in question has a steep roll axis.

ROLL AXIS

There is a point about which suspension geometry will allow a car body assembly to rotate as it leans under centrifugal force on a corner. This is the roll center. It can be thought of as the point of the car structure that does not move up, down or sideways when the body is rolled. On most front suspensions this is at a point between the oil pan and the pavement. On a solid axle car this point is about midway between the rear springs – that is to say, at a height, which is approximately averaged between the front end and rear end of the spring or about a point above the differential.

Naturally, the body is a fairly rigid unit; therefore, front and rear rolls together, pivoting on an axis that passes through the rear and front suspension roll centers. On an old type rigid front axle van or early 30's coupe, the roll points are about the same height; therefore, the body roll axis is horizontal, and the car will roll purely sideways like a boat in a beam sea. With the lower front roll point and high rear roll point of the typical independent front/rigid rear axle car, the roll axis is steeply inclined down to the front. The rear roll center height may be one foot higher than the front giving a roll axis of seven or more degrees inclination on a 90" wheel base sedan. A typical car of this type is illustrated. On a 120" wheel base sedan with the roll height kept approximately the same, the roll axis angle is considerably less, due to the long wheelbase.

The drawback of steep roll axis is that as the body roll develops, weight is thrown not only outward, but also forward like a tipping tricycle. This aggravates understeer, particularly on a front-engined small car. The shorter the wheelbase and the higher the center of gravity of the car, the worse this becomes. Frequently this body mass movement away from the inner rear wheel causes rear wheel spin (under power) or lift.

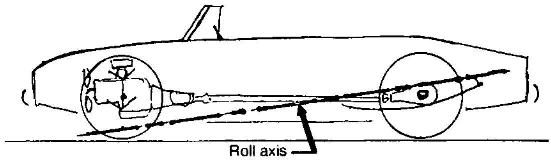


Figure 13

Some of the worst examples of this are the small imported sedans, Datsuns, Toyotas, and similar cars. Mini-Coopers and some rear-engined cars have the reverse problem – front wheel lift. As any one thing that is done to prevent understeer, which usually plagues these small sedans, will also aggravate rear wheel lift, both ends of the car must be worked on for a balanced, tractable vehicle.

Another unnerving phenomenon is a surge of oversteer when one lets up off the throttle. This is unnoticeable in an ordinary sedan, but with a large high compression engine, straight transmission and high (numerically) rear end gears, the breaking action of the engine can produce enough resistance to the rear wheel's rotation to cause highly increased rear tire drift as though one were accelerating hard. In addition, worn suspension bushings, especially in independent rear suspensions, can allow rear steering effect to develop when forward thrust of the wheel suddenly becomes a hard drag.

To summarize, handling is affected by numerous factors that contribute to over or understeer, breakaway, slide or drift, body roll, wheel hop, loss of adhesion, etc. The following list summarizes the major problems:

UNDERSTEER

- Too heavy front vs. rear anti-sway bar
- Too small front tires and/or rims
- Heavy front weight bias
- Too narrow front track
- Too stiff front springs
- Too low pressure in front tires
- Steep roll axis
- Oversize rear tires

OVERSTEER

· Too heavy a rear vs. front sway bar
· Raised rear end
· Rear weight bias
· Undersized tires, rims, or too low tire pressure at rear
· Rear overhang
· Too stiff rear springs

REAR BREAK-AWAY

· Stiff springs and/or shocks on rough corners
· Rear overhang
· Lack of rear anti-sway bar to "coordinate" road shock between both rear wheels
· Too high tire pressure

SLIDE (Four-wheel)

· Wrong tire compound or tire design
· Excessive speed for conditions

EXCESSIVE BODY ROLL

· High C.G.
· Undersized anti-sway bars
· Narrow suspension base
· Overloaded springs and tires

WHEEL HOP

· Lack of rear bar to coordinate rear wheel control on bumps
· Lack of traction bars or worn link bushings
· Poor shocks

WHEEL LIFT

· Poor weight distribution
· Steep roll axis
· Too light of an anti-sway bar on opposite end of car

ADHESION LOSS

· Too rigid springs
· Too narrow a tire patch
· Too high a tire pressure
· Too stiff or incorrectly calibrated shock absorbers

HIGHWAY WANDER

- Play in steering
- Incorrect toe-in or alignment
- Large “sail area”
- Rear Steering effect
- Worn shocks and suspension bushings
- Insufficient sway bars

BOTTOMING

- Worn shocks
- Overloaded springs
- Lack of travel distance due to lowering

HIGH SPEED INSTABILITY

- Aerodynamic lift
- Too mild shocks
- Too mild anti-sway bars

CORNERING SHAKE (racing)

- Panhard-rod needed
- Too rigid suspension

ACCELERATION SHAKE

- Traction Bars
- Firmer rear shocks

SWERVING ON DE-ACCELERATION

- High engine drag
- Worn suspension bushings

In order to work to correct these problems, you should pick out the worst trait of your car and correct that first. In correcting this, it may correct other problems as well. For instance, correcting body roll will eliminate undesirable geometric steering effect also. Keep in mind that if you eliminate all these problems almost completely, you would have a grand prix racer except for the blueprinted 500 h.p. engine. This may not be your goal, of course, but your taste can be your guide to know how far to go to get the car you want.

Two words of caution:

1) A chain is only as strong as its weakest link; tires and rims that can develop .75 G-cornering force are a waste of money if at .50 G, your rocker panels are dragging the ground
2) If your original shocks (or tires) are still good. Work on other things while they wear out; no use throwing away equipment with good miles left.

CHAPTER IV

The Equipment

As the final path of a driven car is determined by the relationship between the tires and the pavement, we will start by discussing tires.

TIRES

Until 1968, unless you ordered special tires, your car came with two-ply bias rayon tires. Three main reasons were: They are cheap, they have more flexible walls, and they can be run at lower pressures without overheating (because the wall is more flexible). The first is self-explanatory, the second and third are to give an even smoother ride. Unfortunately, these tires are marginal as far as the weight that they can carry. They are not suitable for more than a three-passenger load. Furthermore, the thin constructions that give a good ride are too flexible to retain their shape in hard cornering. The "slip angles" (i.e., the creep or sideways drift) of these tires is very large especially if inflated only to the recommended pressures. This accounts, in part, for some of the wander and unsteady feel of the cars so equipped. With the lawmakers in Washington finally becoming aware of this, things have improved. By the 90's the buyers were flooded with alternatives and a great array of tires of every description. Enough public awareness has been developed so that really good tires can be ordered and are now part or the sales approach.

When buying a new vehicle check the tires that come with it. I have noticed some of the '92 mini vans come with single ply polyester sidewalls. These are very flexy and even the most stable chassis will wobble around on them, and blowout resistance must be marginal.

If you request better tires the dealers will install them at a reasonable price as they sell the originals as new "take-offs".

The "belted" tires, that were basically the old "bias" two-ply with an extra two-plies running around the circumference under the tread were somewhat of a compromise between the radial and the bias cord tire. By the 90's they had been replaced by radials.

In both the regular bias cord and the belted tires, the bias cord carcass tries to distort the tread as the cord passes through the adhesion patch area. As the sidewalls bend outward on either side of the adhesion area, their bias running cords pull in the sidewall ahead and to the rear of the patch causing an "S" curve in the sidewall. At high speed this generates a "standing wave" to the rear of the patch similar to the lateral waves that follow the stern of a motorboat. This causes heat build-up and great stress inside the fabric. In the belted version of these tires, the two plies running around the circumference of the tire are supposed to "fight" this wave or "squirm" as the manufacturers like to call it. Undoubtedly, it does, but the stress is still there.

With the true radial tire, the cords run at right angles to the tire, instead of at an angle to it. This makes a great difference in how the tires flex at the adhesion patch. As the cords cannot pull the tire wall in forward and to the rear of the patch, it flexes more easily and only the cords directly alongside the patch flex. This means there is less of a tendency for the standing wave to follow the patch, and thus, tire stress and fatigue is reduced. It also means that the tire looks under inflated compared to a bias cord tire as the more localized tire flex is more obvious. Around the circumference of the radial tire are additional plies of either synthetic cord or steel plies that also protect from tire cuts.

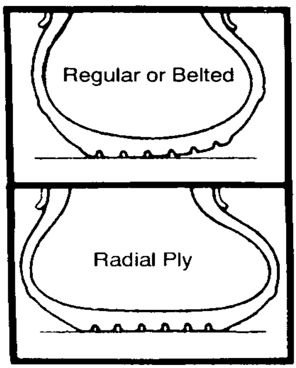


Figure 14

Radial ply tires' greatest virtue, though, is in their behavior under lateral stress during hard cornering

In a hard corner, the rim of the wheel moves outward so that it is no longer directly over the adhesion patch. How far it moves in any given cornering situation depends on the firmness of the tire wall, the inflation pressure, and the type of tire construction. In the case of a bias cord tire as it moves out, the inner sidewall tends to roll the tread up off the road. This throws more of the weight and cornering force onto the outer side of the tire as it greatly distorts the shape of the adhesion patch. This not only increases tire drift and lowers the breakaway point, but also greatly increases tire squeal.

A radial cord tire, on the other hand, may allow the rim to move out a little further than a comparable bias tire but in the case of the radial, the sidewall does not tend to pull the inner edge of the tire tread up off of the road as can be seen in the diagram.

It is for this reason that radials give very little warning as one approaches the point of maximum adhesion. As there is little tire noise, an inexperienced driver not used to the radial tire's characteristics can easily exceed the adhesion point by cornering too fast. Then, as the centrifugal force of the car exceeds the friction of the tread on the road surface, the car "lets go" and slides with far less warning than one would get from bias tires; although the speed at which this would take place, would most likely be higher in the case of the radial tire.

If your car is about evenly balanced, you can put 32 lbs. or other recommenced maximum pressures all around. If it is not very evenly distributed (and if you have an intermediate with a big mill, or a front wheel drive car, you know it isn't), you will need either more pressure or larger capacity tires in front or at whichever end has the most weight. Although this can be partially compensated, as far as cornering is concerned by juggling roll stiffness, as we will discuss later, the thing is, tire slip angles (drift in corners) depends on the load it is supporting and the pressure it is running. Thus, the greater the load, the higher the pressure must be to give the same drift angle (or drift speed.) Our goal is, of course, to have approximately the same drift in front as in rear. If the front drifts faster, you have an UNDERSTEER situation in which you could eventually go off the outside of the curve. If the rear drifts faster than the front, you have an OVERSTEER situation in which you wind up running off the inside of the curve – unless it is corrected via the steering wheel.

Increasing tire size above what was recommended or installed by the manufacturer will usually prove beneficial. Naturally, rim diameter cannot be altered unless larger diameter wheels are installed. A moderately larger tire cross-section, though, can be used without other alterations. The larger cross-section will increase the carrying and cornering capacity as well as longevity of the tire. Even more effective is installing wide-rim wheels. This gives the tire a wider base and increases its geometric resistance to cornering distortion. A tire can be installed on a slightly wider rim than what was originally intended, but for the extra wide rims now on the market, you need the specially designed wide-tread tires.

To further complicate matters, on rear-drive cars the rear tires must have a margin of adhesion to supply forward thrust. Whereas, the front tires must also have a margin of adhesion as they are being pushed sideways by the thrust of the drive wheels. On front-drive cars, the front tires must do both. Thus, this must all be worked out experimentally for your car and your driving technique. This all assumes the car remains almost flat during the cornering maneuver. In stock form, most cars lean a great deal, including those with "heavy duty" suspension packages. Street sports cars also suffer from this. This would throw all our calculations off unless we first reduce this body lean by 80 percent or better. This will be taken up under the section on anti-sway bars.

The old "6.55-14" or "8.55-15" designations had become so confused with the addition of "low profiles," "super-low profiles," and the old cotton-cord-ply, numbers had given way to rayon and nylon and polyesters. Thus, "three-ply" meant little as to the strength of a tire. This led manufacturers using such terminology as "four-ply rating" for a strong "two-ply tire."

The whole system was changed to a more logical order where tires were given a "Load Rating" in pounds, as determined by the

Department of Transportation (DOT); thus, "Load Rating," A, B, C, D, etc.,: A-Light Duty; B-Average Good; C-Heavy Duty Tire; D-Truck Type, etc. The letters represent a weight maximum for each class.

Furthermore, the size description was changed to better describe the cross-section. Thus, H-70 gives the cross-section size group by the letter and the number (60 or 70, etc.); the percent of the tire's tread width compared to its height (bead to tread). Thus, a G-60 will be higher in profile than a G-70. For truck and some van sizes the old higher "7.50-17" size terminology is still used. Many tires are now "metric" to fit metric size rims, thus further confusing the size & proportion comparisons.

One has only to look at some of the cars on the street to realize that there are many drivers who will put on the widest tire they can find, even if it means jacking up the rear end several inches or cutting up the fenders. A 500 hp. car will need wide low pressure tires for traction on the drag strip, but you often see these 10-inch treads on Volkswagens and Pintos that could not brake traction on their factory originals.

One must choose between the type of structures, bias, bias-belted, radial (always belted), and a number of new materials in addition to rayon and nylon (Polyester and trade names for Polyester), rayon and steel and nylon combinations and mixtures.

The most expensive top-of-the-line tires are not necessarily the best or the toughest. The famous "Firestone 500" scandal of the 70's, an example of a large old-line tire companies "best" tire, was dangerously inferior to its cheaper tires.

Of course, the main thing some people look for in tires is tread width - the more the merrier, and this is their attitude even if it means cutting off sheet metal, jacking the rear up, or using reversed wheels.

As to wide tires, if you ever see writers make comments, as I have seen, such as, "It comes with nine-inch wide tires which put plenty of rubber on the road," you might as well quit reading, as he knows nothing of tires; let alone the laws of physics. No matter what diameter, width, or style is on the car, the "rubber on the road" will remain identica1 providing the vehicle weight and tire pressure are the same. Archimedes' law stated that a floating body will immerse itself in a liquid until it displaces a volume of water equal to its own weight. There is a corollary here, which 1 am sure Archimedes would have stated if he had been concerned with pneumatic tires in his day: A tire adhesion patch will continue to enlarge (as the vehicle sinks down) until the adhesion patches are large enough so that the internal tire pressure against the patch(s) equals the weight of the vehicle.

This is not because of the pressure in the tire pressing down against the patch; no way could this downward pressure hold up the car. It is the equal and opposite reaction (as stated in Newton's Law) that is holding up the car.

Imagine an inflated tire lying on the floor.

You push against one side, and the wheel and tire skids away from you. Why? As it lies on the floor, the internal pressure is balanced all around the rim, sidewalls, and tread. As you push on the tread, you relieve the tire in the area where you are pushing of the internal pressure as this force is now taken by your foot or hand. Therefore, the area of the tire on the opposite side is no longer balanced; and the tire is, therefore, pushed away by this unbalanced pressure on the inside of the tire tread on the opposite side from you.

Therefore: A vehicle will sink down until the force pushing up in the TOP of the tire which is no longer balanced by the pressure in the bottom of the tire (because the pavement is taking the pressure force through the tread and the sidewalls are no longer pulling down) is equal to the vehicle weight. Thus, it makes no difference if the tires are wide, narrow, large diameter or small, high or low profile: The tire patch size in square inches will be the same for any given vehicle weight and tire pressure.

Why wide tires then?

You may recall a demonstration in Physics class where a brick is pulled along a board with a tension (fish) scale: It made no difference if the brick were on its wide side, narrow side or standing on end; it took the same effort to pull it. The explanation was that as the coefficient of friction of the board and the brick remains the same, and the brick remained the same weight – on end more weight per square inch, on its side less weight per square inch, but more square inches; and as the area and weight per square inch varied proportionately, there was no change in friction.

Thus, theoretically, any given tire tread compound on any given pavement will give the same adhesion regardless of tire design. But there are some other considerations that come into it.

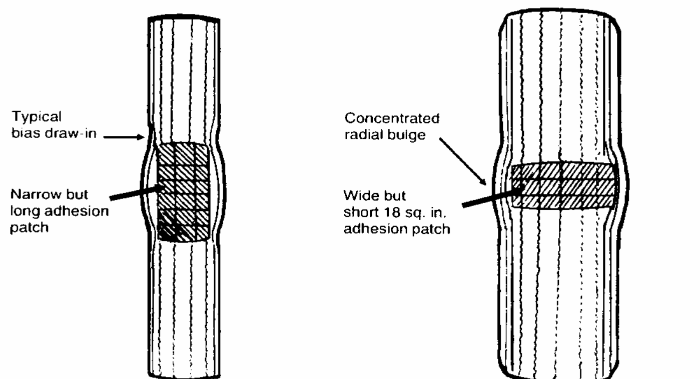


Figure 15

The above illustrates the tire patches of 18 square inches each: One on a four-inch wide tread and the other on an eight-inch wide tread.

Consider:

- Tire "A" hits a four-inch-wide hole; its adhesion (or traction) will be momentarily lost; while tire "B" still has four inches of tread left on the road.
- Tire "A" hits a four-inch-wide bump; it will be completely affected while only half of tire "B" will and, therefore, is more likely to absorb the object than to bounce up on it.
- Tire "A" in an emergency braking situation (or under hard acceleration) has the same rubber in contact twice as long as with tire "B" resulting in more heated compound and less friction.

A narrow tire must have high side-walls (or extra large diameter) in order to have a large patch (or the rim will have insufficient clearance above the road). High sidewalls generate more sidewall flex and cornering distortion.

- Tire "B" can develop its 18 square inch of patch area with far less side-wall flex; thus, far less hear built up.
- Tire "B" will have less tendency to dig itself into sand; is, therefore, universally used on dune buggies.
-Tire "B" will encounter twice as much water film in wet weather and unless carefully compensated for in the tread design, will have a definitely higher tendency to hydroplane, as the edges where the water escapes to the sides are further apart.

Many wide tires are bought simply to look sporty by those who have no idea of what they are really doing. I have often seen streetcars with 10-inch wide tires running only 10 pounds of air in them – with about an eight-inch-long patch giving them the 800 pounds support needed. It is hard to visualize a little bump or washboard effect surface breaking it loose though. It is also hard to visualize being able to mount this tire on the front, also, without greatly reduced turning radius and heavier and rougher steering. Thus, with such different tires on the front and rear, one may have a real problem juggling other factors to get a car to really corner well. It can be done though, as nearly all the open wheel racers use larger and wider rear tires.

In choosing tires, buy what you feel your driving and your car needs, and forget the latest fads and status brands – so what if your tires don't have "TIGER – CLAWS" in white letters on them!

Light duty two-ply are not recommended for highway use; four-ply bias are strong and firm and give top directional stability but are hard to find nowadays; radials will give the best cornering, and best gas mileage, but may give less steady steering on the highway; belted bias have not proven to offer

advantages over the other types; and some have proven dangerous due to
sudden disintegration caused by the bias trying to flex diagonally and the belt trying to flex laterally. Check with publications such as Consumer Reports. In a recent article they tested various makes of tires for tire wear. One well-known brand of steel belted radials fell apart consistently to the point they were unable to give it a mileage figure!

A WORD OF CAUTION

After many perplexing experiences with high-speed vibrations, and low speed "limping" on new, expertly balanced tires, I started to make investigations. I was totally surprised, - shocked actually, to find out that many of the tires sold by the leading, best-known tire companies are in reality seconds! We have all been offered "seconds" at tire stores and then been assured that the only thing wrong with them is a slightly marred whitewall or lettering; and that is probably true, but if it is a defect that you cannot see, like being hopelessly out-of round or are beyond balance tolerance, are thrown into the aftermarket, and the good ones are sent to the O.E.M. accounts and are mounted on the new cars.

As a businessman I cannot understand a company putting its name on merchandise it knows to be defective, but this is done by many, if not, most of the large manufacturers.

The symptoms are a limping sensation at 15 m.p.h. and a vibration or shimmy at 45 to 50 m.p.h. The high-speed vibration feels like a balance problem, but the low speed limp is distinctive. Out-of-round tires can also be easily spotted simply by turning the mounted tire with a quick push of the hand and looking at the tread surface against a fixed spot. If the tread surface rises and falls visibly, then it should be rejected. The cure for out-of-round tires is to "true" them. This consists of turning the tire with a slow running electric motor and the approaching the tire tread with a spinning razor-sharp disc. It simply shaves off the larger side of the tire tread. As one-eighth or more of the out-of-round is common, you end up with half your tread lost. In any case, very few dealers even have truing equipment.

The only real solution is to get an agreement that they will change any out-of-round tire before you buy. Remember: a lope, waddling, or limp at slow speeds; a tread surface that moves ever so slightly when the tire is spun, or a vibration in a balanced tire at 45 to 55 m.p.h. will tell you that you have been sold a second. As one tire official told me, "…and if it is out-of-round, it means it has other problems too…"

Look also for pull-ins in the sidewall. These are depressions that follow the radial fibers and run from the bead to the shoulder. These are caused by poorly laid radial fibers that are shorter than those next to them. They are visible when the tire is mounted and inflated. They too should be cause for rejection, as they are not only visually objectionable but cause stress points in the tire wall.

WHEELS

One of the best-merchandised fads to hit the auto aftermarket since the steering wheel knobs of the 30's was the "Mag" wheel. The idea of magnesium wheels is sound enough, but once again, the facts were soon lost in the dust raised by the "image makers" and the outright distortions that the sales efforts led to. What had sprung up as a profitable innovation soon became a very competitive selling conflict.

Lightness in any vehicle is important, particularly if acceleration is an important factor. Lightness in wheels, tires, and unsprung drive train parts is important when accelerating, as these parts must be accelerated, not only forward with the rest of the car, but also rotationally accelerated. Therefore, the saving of 10 pounds in the rim of a wheel is equal to many times this figure in ordinary chassis weight. Thus, magnesium or even aluminum wheels are advantageous, particularly for the drag racer.

But, it was very soon that "Mags" were not magnesium, or even aluminum alloy, but were steel – often weighing more than original equipment wheels; or they had aluminum centers and steel rims – and of course, it is at the rim that the weight should be saved to attain the greatest advantage. But, so well and competitively merchandised were these "Mags," that almost everyone felt that they had to buy a set – at between $120 to $300 – although most of them were no better, and many were less safe than the original wheels. Many of them failed to even include the inner "safety rim" ridge that prevents blown-out tires from leaving the rim that is standard on many Detroit original wheels. Others were found to fail due to lack of strength at the hub or rim.

Their one advantage – on most of them – was additional rim width giving the tire a more stable configuration when cornering and enabling wider tires to be fitted. Some of these special wheels were simply stock type wheels with wider rims – probably a good investment. The inner fender wall, springs, steering gear or other parts often prohibited the rim from being much wider than stock, so the "reversed" or "dished" wheel was developed. This, in effect, moved the whole wheel and tire centerline outward. Sometimes, the same was accomplished by using spacers or adapters that would go between the wheel center and the brake drum. A minor drawback on most cars was the need to either flair the fenders, cut them out, or raise the car to prevent fenders from hitting the tires. But a far greater drawback from a serious view is the fact that a wheel is designed so that the load is proportionately distributed between the wheel bearings. A dished or reversed wheel moves the load center outward; thus, placing more load on the outer bearing and less on the inner bearing as well as more leverage on the axle. As most cars' wheel bearings are only just sufficient for normal service (heavy loads or trailer towing are enough to burn many out), these reversed wheels can easily cause bearing failure.

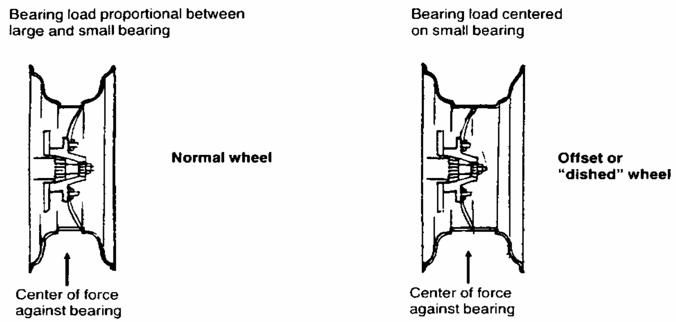


Figure 16

Our recommendation is to use the widest rim your car can take – font and rear – without going to the reversed type, and to keep the same width front and rear, unless you purposely use a rim width difference to balance your drift. A difference between front and rear rim width will require different size tires, front and rear, which complicates tire rotation.

SPOILERS

These were originally designed for high-speed sports cars. The object is to combat aerodynamic lift of the front end, introduce downward pressure to increase adhesion, or to decrease turbulence. In specially built all-out racers, these features are simply built-in to the body shape, frequently with a "wing" that can be controlled like a wing-flap so as to give either negative lift or an air brake effect. Most of these do, though, introduce wind drag, so they should not be hung on unless their beneficial effects are positively known. As most of these "spoilers" are only effective at speeds well above those normally driven on highways, they should be used only on road-course cars where speeds are high – a possible exception to this is the "air-dam" that is placed across the front of the car to prevent air pressure build up under the front end. The design of your car will determine whether this is a tendency with your car, and if not, the dam will do more harm than good. Don't just put them on "for looks." The knowledgeable enthusiasts will think you're pretty dumb if you hang a rear spoiler on the tail of a car used only in slalom courses where speeds seldom go over 50 m.p.h.

ANTI-SWAY BARS

These are sometimes referred to as "Stabilizer Bars," "Anti-Roll Bars," or just "Sway Bars." They should not be confused with reinforcements to protect the driver in case of a rollover, nor should they be confused with "Panhard-rods", "Watt's links" or "Lateral Locator Links", nor with "Track Bars" which will be discussed later. Panhard-rods and Track bars are often referred to by article writers as "stabilizers" or "sway-bars," but they cannot in anyway reduce the body lean.

The basic principle of anti-sway bars is that they allow the axle (or wheel assemblies) to move up or down together over dips, etc., but do not let one wheel go up by itself unless it twists the bar. For one wheel to go up and the other down – as they try to do, relative to the body, on a hard corner – the bar must be twisted a great deal. These bars are made in various thicknesses of high-grade spring steel and can take this torsional force; but in so doing, they eliminate a large portion of the body roll, thus, giving stability without harshness. Ferdinand Porsche was credited with first using anti-sway bars, and from the thirties through the fifties, nearly all cars came from the factory with meld front bars and no rear bars. The first notable exception to this was the very popular '55 to '57 Chevrolet that came with no sway-bars whatsoever except for their "Police Package." The next exception was the '65 Olds 442 and the Avanti – the first production cars to come stock with front and rear anti-sway bars. Regrettably, it was in the Mid-Sixties that many of the cheaper intermediates – Chevy II, Dart, Barracuda, etc., - started to come without even a front bar; later followed by the Pinto, Ventura, and other small cars. Even though the front, and even rear, bars are available when ordered on the expensive version of these cars, it is not as simple as just ordering the parts and putting them on. On many makes the welded-on brackets are missing, and the dealers will tell you that you have an additional cost of $200 or so to replace the whole A-arm. Welding on brackets may damage ball joints or other parts or cause A-arms to warp.

The bars are available for almost all cars from ADDCO (and for a few models, other aftermarket manufacturers) complete with the needed clamps and brackets, etc., that enable an easy and effective installation to be made without welding.

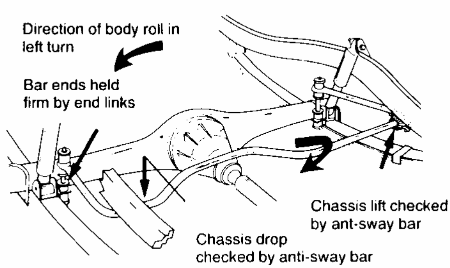


Figure 17

On the "hot" cars from Detroit, the manufacturers often add an extra thick, sometimes good and thick, front bar. This can be a mixed blessing even to the point of being treacherous. The addition of an extra heavy motor and the extra firm front bar to a chassis that originally had a small V-8, light front bar (or none at all, as in the case of some of the Dodge Darts and Barracudas) end up giving a very seriously "understeering" car. It is treacherous because the extra heavy front bar holds the car reasonably flat. If the car has good radials or other firm tires, the driver is not aware of the extra load the heavy engine and extra thick front bar is throwing on the outer front tire. Only when the adhesion point is passed, and the car mushes off the road, does the uneven tire without being aware of how the car will "let go" when the hairy edge is approached.

So much for what the manufacturer did or did not do. What can we do to improve the handling of our car?

When we were discussing tires, you will recall, we mentioned the relationship of roll stiffness – in front versus in rear – to tire drift; and also the tilting effect the body roll has on the front wheels and the resulting loss of adhesion and difficult steering. Now all theses effects must be weighed, along with steering and riding considerations. Our biggest and most serious problem with body roll is not just that it's unpleasant, but it literally plays havoc with the front suspension geometry. The illustration shows the front suspension geometry of the average car, and what happens to it as the roll angle of the body increases. In the case of a solid rear axle, as the car rolls on its suspension, the rear tires continue to bite the road in normal fashion with only a moderate weight shift to the outer tire. But, as the body roll increases, the front tires are tilted further outward, and the tires grip even less. Furthermore, because the roll axis of the car is on a slant down toward the front, the weight of the car is actually tilted forward onto the already heavily loaded front outer tire. The rear tires continue to bite fairly well as they remain upright, whereas the front tires "mush out" as they become overloaded and tilted toward. Thus, heavy understeer builds up. This requires even more steering into the turn, and this results in accelerating the process described above.

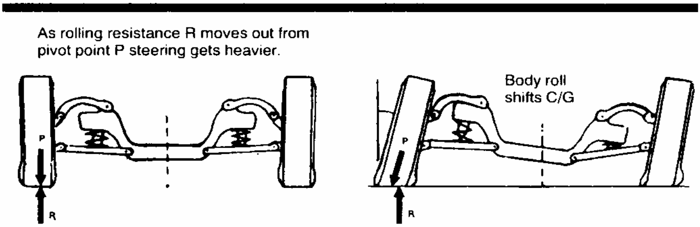


Illustration of body roll

Figure 18

The foregoing is just the opposite in some rear-engined cars. In the VW, for example, particularly up through the '68 models, as the body roll causes the rear suspension to tilt the rear tires, the front tires remain upright; thus the process accelerates and oversteer condition. In an old car from the 30's where the front suspension was a beam axle, the front and rear suspensions acted similarly under hard cornering. It is for this reason that many of the best "Sportsman" racers used these old chassis.

Recently, some of the sports car builders have been improving independent rear geometry, that will react similar to the front independent geometry so that they will get the adhesion and riding qualities of the independent suspension principle with the balanced and predictable cornering characteristics of the old beam axle set up.

To get a good idea of why a car can be such a handful when pushed in a corner, consider these points:

A. It has a big engine that puts more load on the front tires than the back, although all the tires are the same size and have equal pressure. This is even worse on front wheel drive cars.

B. It has a front stabilizer that throws extra load on the outer front tire.

C. The large degree of body roll is tilting the front wheels 15 to 20 degrees OUTWARD toward the outer side of the curve.

D. The rolling motion of the body has moved the center of gravity outward, there by putting even more load on the outer tires.

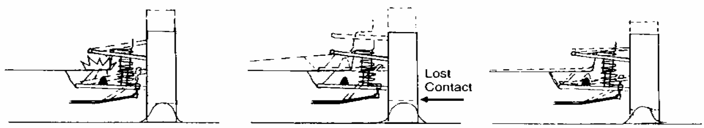
E. Due to the front wheel tilt, steering, unless assisted, becomes heavy.

The most unfortunate thing is that the first three points ALL work with one another to INCREASE the understeer. It is little wonder that most cars feel clumsy and hard to handle on a hard corner. All these points must be corrected in order to make your car handle.

If it is a front wheel drive car, things are even worse because the weight of the transmission is also all on the front and any engine induced traction or drag further taxes the front tires.

We will assume that A, above, has been corrected through the installation of the correct tires, properly inflated. As to B, C, C, and E, these must be corrected through the use of anti-sway bars or stiffer springs.

The first impulse of many drivers is to beef the springs to get rid of the soft ride. They have ridden in sports cars that ride harshly and have seen cars offer optional "stiffer springs,' and they feel that the stiffer the springs, the better she will handle. But, wait a minute: springs do more than just make the driver comfortable. It is the resiliency of the suspension that keeps the four wheels on the ground, gripping. A car that has very stiff springs will tend to support itself on three wheels should one wheel be over a dip in the pavement. Let's think a moment of the much discussed and



Too soft of a suspension - tire absorbs little, snubber bottoms hard

Too firm of a suspension - the whole car acts like "unsprung weight", chassis rises with bump, wheel cannot return to pavement, adhesion is lost

A resilient suspension - moderate firmness: body rises slightly, tire absorbs part of bump, suspension takes up the rest

Figure 19

little understood subject of sprung versus unsprung weight. The idea here is that the more weight you have leaping up and down with the wheels, the harder it will be to keep it moving exactly with the road surface; thereby, maintaining adhesion; and obviously, the more it will bump the body up and down via the springs and shocks.

Now imagine stiffening the springs more and more. In effect as the spring resiliency disappears, your whole car becomes unsprung weight, bouncing up and down with every bump. This had become a problem with many stock car racers; they are fine on smooth pavement, but they simply bounce off the pavement if they hit a bump. See Figure 19.

The softer the suspension, the better the adhesion, provided body roll and rebound are controlled via anti-sway bars and shocks. This, let's only stiffen the springs as a last resort – it should not be necessary. This leaves us with anti-sway bars as the best source for body stability. Although anti-sway bars do cut down on single wheel suspension resiliency (They have no effect on simultaneous movement – up or down – of both wheels.), they offer many times the body toll resistance of stiffer springs in relation to the loss of resiliency.

If we install a heavier front anti-sway bar, we will increase the load on the outer front tire and, thereby, increase understeer in this manner. It will, though, decrease the body roll, thus, reducing the front tire tilt, thus, decreasing understeer. Whether it will end up increasing or decreasing total understeer will depend on the car in question.

By the addition of a firm rear bar, we effectively balance the drift and eliminate 50 to 70 percent of the body roll. For a car to be set up for slaloms, ovals, or road racing, or enthusiastic street use, the front bar diameter should be increased as well as the addition of the firm rear bar.

On the old Sting Ray, for instance, if it is ordered with the heavy 427 or 454 cubic inch engine, it comes equipped with an extra thick front bar and a rear anti-sway bar as part of the package. This is to offset the extra understeering effect caused by the heavier than standard engine. The rear bar takes some of the cornering inertia roll force in the body rather than leaving it all up to the front stabilizer bar to counteract it. Although in the case of the Sting Ray, the rear bar they supplied was very light. Many hot rodders forget that the stability must be added at the opposite end from

Percentage of increased strength
with ADDCO anti-sway bar

ADDCO bar diameter					
1-1/4	1601%	779%	418%	224%	152%
1-1/8	1051%	511%	274%	160%	
1	655%	319%	171%		
7/8	382%	186%			
3/4	205%				
	5/8	3/4	7/8	1	1-1/8

Your car's original bar diameter

Figure 20

where the extra load is added to keep things balanced on the bends.

It is for this reason ADDCO discourages 1.5" diameter front bars some drivers ask for. A firm front bar and firm rear bar will give, not only flatter cornering, but balanced cornering as well, with near equal front and rear drift. When a car is balanced and held flat in a corner, which a good front and rear bar combination will do, there is nothing more to be gained from increasing the stiffness further. In fact, after this point, a thicker front bar simply reduces the resiliency and adhesion; to say nothing of riding comfort.

How heavy a rear bar should we use? The amount of added roll stiffness we need depends on the weight of the car; how softly it is sprung; and how much understeer we have to overcome. One often reads in toad test "technical data," the diameter of anti-sway bar. Unless you are comparing it to another diameter bar mounted on the same model car in the same manner, it is practically meaningless. The anti-roll properties that any given sway bar will deliver depend, not only on its diameter, but also on the length of the torsional portion between the bends, as well as the length of the lever arms working on it. Naturally, the longer the torsional part (the width across the car) or the bar, the less the stiffness it can deliver. How far out the end-links attached on the suspension, also, indicates the firmness of the car's action.

Small cars with independent front suspension and solid rear axles usually have a steep roll axis, and particularly with the driver aboard, a front weight bias. These cars – the smaller Toyotas, Datsuns, Colts, Pintos, etc. – are particularly hard to balance. Although they suffer from understeer, which the addition of the rear bar will help, it will at the same time aggravate rear wheel lift to which they are prone due to their forward pitch on corners. As one cannot change the angle of the roll axis, the only solution is to eliminate the roll. The front wheel drive versions are often more stable but usually have even more understeer even after rear bars are added. Thus, on these cars the replacement of the front factory bar with a firmer bar, and balancing it out with a good rear bar is the only way to overcome the worst of the problem. Once most of the roll is gone, one has eliminated the largest cause of wheel lift and balanced out most of the understeer. As mentioned earlier, when discussing basic automobile designs, one is not correcting the inherent flaw in the design, simply compensating for it and therefore, reducing it as much as possible. Thus, one can see photographs of these small cars, although professionally set up and driven, showing mild signs of simultaneous rear wheel lift and understeer.

As far as riding qualities are concerned, the addition of a moderate rear bar to a car with a front bar actually improves the ride. With only the front bar, the car's chassis has to follow the irregularities in the road as encountered by the front suspension, whereas if a rear bar is added, the chassis movement is averaged out between what the front wheels are running over and what the rear wheels are running over. Thus, the car has a much more gentle motion entering driveways and similar surfaces. In highway use, no ride difference will be noticed, but the directional stability will be greatly improved as described in the section on Geometric Steering Effect.

The installation of a fairly firm rear bar will make itself known on single-wheel bumps in the form of a little extra thump, although not what could be called harsh. The exchange of the front bar for an extra firm diameter bar is a little more noticeable due to the more sensitive independent front suspension. It will, though, prevent some of the shock of a pothole by preventing the wheel from falling into it as hard.

There are other advantages to cornering on an even keel in addition to better control and higher speeds; front tire wear is completely different, as they are no longer run on their sides on curves, they wear flat in a similar manner to the rear tires, provided adequate air is kept in them. The high-pitched squeal from the front tires is gone. Instead, there comes an even growl front and rear, and this only at a much higher speed on the some corner. Steering is lighter as the rolling resistance of the front tires now remains under the steering pivot point of the wheels instead of moving towards the outside on the curve, thus pulling against the steering effort. See Figure 18.

On the rear, there are two similar problems that can be overcome by the judicious use of anti-sway bars; wheel hop and wheel lift. These two problems have two completely different causes and the cure is the exact reverse of one another. Both of these, wheel lift and wheel hop, are most frequent under acceleration and affect the inner rear wheel on turns. In the case of wheel hop, the addition of a rear anti-sway bar will prevent it as the wheel cannot hop as it would have to twist the bar to do it. Wheel lift is not caused by the road but by the car's unbalanced roll stiffness and roll axis. If there is a lot more roll stiffness on the rear of a car than on the front, the rear wheel will tend to lift off the road on a hard turn. This would happen if a heavy bar were installed on the rear of a car that had no front bar. If the front has a great deal more roll stiffness than on the rear, then the front wheel will lift on a hard turn. This is the case with the Mini-Cooper or Porsche and some of other rear engine cars that are given a lot of front stiffness to try and compensate for inadequate rear suspensions.

Thus, it is important to find out the exact cause when wheel spin is encountered on hard turns. Wheel lift is only obvious under racing conditions but is noticed on the street when accelerating on sharp turns. The cure is to add anti-sway stiffness to the OPPOSITE end of the car. Wheel hop, noticeable at the rear under bumpy street conditions is overcome best by a firm rear anti-sway bar. While adequate shock absorbers will prevent wheel hop – shock absorbers will not help wheel lift.

Now, specifically what anti-sway bars should you get for your car?

FIRST

Decide on the projected use for your car. Is it for primarily street use, street and an occasional slalom, or is it to be used solely to race in slaloms, road courses, etc?

SECOND

What is your car now equipped with – no bars, front or rear, a light diameter front bar, a heavy front bar, or front and rear bars? With so many enthusiasts returning to the older cars, finding more potential and more fun than the models offered in the showrooms of the 90's, let's review some of them. Among domestic cars, Darts, Valiants, older Barracudas, Satellites, Coronets, older Chevy II's and Falcons, normally come with no bars. For these cars, one should add a heavy front and a heavy rear bar. On the other end of the scale, the special cars such as the Mustang Mach I, Dodge R/T, Super Bee, Road Runner, and the GM Intermediates, etc., usually come with a good heavy front bar and heavy front weight bias. Only a few come with a rear bar. For these cars further increasing of the front bar's diameter could do more harm than good unless a firm rear bar is added also. In the middle of the scale are the regular Mustangs, Cudas, older Camaros, Firebirds, etc. These cars should take a firmer front bar and an added rear bar to make them both fun and secure to drive. As to the smaller cars, the MGA, older MGB Sprites, Midgets, TR-3, TR-4, TR-4A, TR4-A independent rear suspension, Jenson Healey, Opel GT, Pintos, etc., unless specially ordered, come with no bars front or rear. Therefore, a front and rear bar should be added at the same time. These bars should be comparable in anti-roll stiffness after the difference in mounting geometry has been considered.

The Austin Healey, Alpine, Tiger, Datsuns, Spitfire, Toyotas, MGB(69-74), come with light front bars. These should be equipped with rear bars and an extra firm front bar. Recently, many people are racing or just improving the handling of imports that were built originally as plain passenger cars. The VW, Fiat, Volvo, BMW, and the like lend themselves to great improvements when equipped with the correct firmness of front and rear anti-sway bars. The older VW (pre-69) benefits especially from the addition of the bars as it not only reduces body roll but also eliminates most of the "tuck-under" of the outer rear wheel. By keeping the rear wheels square with the road, rear adhesion is greatly improved. This, according to many VW campaigners, more than compensates for the theoretical increase in rear tire drift. A thicker front bar improves control further. Volvo's and BMW's simply are too unstable for serious driving without the addition of a firmer front bar and a rear bar in suitable diameters depending on the anticipated use (many older BMW's have no stock front bar at all).

Despite the flood of nameplates and models, the later 80's and the 90's greatly reduced the variety of new car types one could buy. The only conventional front engine-rear drive models left were the Mustang and the Camaro/Firebird plus the held over LTD and Caprice types. Of the imports only the BMW and other luxury models are available. Most of the small or intermediate size cars now are front-wheel drive, and these all desperately need rear bars to reduce their inherent understeer. Most of them need heavier front bars also to prevent rear wheel lift, especially when fitted with the rear bars they need so badly. Some of them if they are the top-of-the-line performance models, come with heavy front bars. These can be made to handle well just with the addition of a firm rear bar.

Strangely, the only two front-wheel drive pick-ups, the Dodge Rampage and VW pick-up, sold poorly and were discontinued. Pick-ups need to have front and rear bars due to their inherent front weight bias. A firm rear bar without a beefed-up front bar will cause rear wheel lift if pushed hard.

Regardless of what type car you are setting up, remember: The correct anti-sway bars will make a far greater improvement in handling than any other improvement and at less cost. So, they should be the first modification made to the suspension of a car as no other handling improvement – shocks, tires, springs, or what have you – can be realistically evaluated and adjusted until the anti-sway bars have been installed and the car is reasonable steady on its suspension. Remember also: Anti-sway bars are extremely effective. If you have a passenger car for normal, though enthusiastic driving, do not be tempted to put on the stiffest anti-sway bars you can find. ADDCO has paired its front and rear sway bars carefully drawing upon many years of feedback and experience, and you can depend on this recommendation.

Now will your car have the much sought after "4-wheel drift?" Maybe and maybe not. But, at least you are close to it and with the car near-balanced and flat, you can start to fine-tune the chassis.

It is hard to have perfect handling in a passenger car, as varying weight distribution, due to passengers, etc., will change the relative drift on the front and rear. Don't forget the spare tire in the trunk. Leave it home, and your car will handle a little differently again, and even harder to keep track of is the gas load. Twenty gallons of gas way back under the trunk makes a lot of difference.

URETHANE BUSHING END-LINKS

End links serve three purposes:

A. Makes up for differences in arcs described by the suspension member and frame attachment point.
B. Makes up for the differences in arcs described by the suspension member and the anti-sway bar as the suspension works.
C. Insulate body from vibration and noise in the suspension member.

"A" should be modified by either lengthening or shortening the center bolt and tube spacer to accommodate any ride-height change due to lowering or rising of the chassis height relative to the suspension. Such replacement end-links (with urethane extra heavy duty bushings) are available at the ADDCO display in leading performance stores.

"B" must be allowed to happen to avoid stresses in the bar attachments or the suspension arm chassis attachments. The end-links must not be over tightened, as this will cause failure.

"C" Urethane (or even harder substances) will transmit more vibration, such as that caused by gravel roads, but they will also act quicker and more positively in stabilizing the chassis.

For instance, typical rubber end-link bushings have a compression rate of approximately 100 lbs./in. for the first inch. This cushions out vibrations and sudden movements to promote a comfortable ride. However, at about 190 lbs. They have collapsed 1.75". After this point they collapse very little and the bar then delivers close to its rated lbs./in. This appears to be more than a 2" roll further outboard as viewed at the fender. No matter whether the bar is stiff or mild, the end-link "give" is always added to the bar's "give" to detract from the initial crisp response and the "on rail" feeling that good anti-sway bars can deliver. Without modification, the urethane bushing end-links can be used on any sway bar installation that uses regular rubber bushed end-link. Under a typical heavy load, a standard GM rubber bushing would lose 53% of its height; whereas the similar standard urethane bushing would lose 33% of its height and the ADDCO heavy-duty type would lose 11% of its height. Vibration and noise transfer up from the wheels to the body is somewhat increased on gravel type surfaces. Eliminating the rubber from end-links doubles the effectiveness of the average heavy duty sway bar, not only mathematically, but also for the “seat-of-the-pants” driving feel. A study of the graph shows this clearly.

The graph (Figure 21) depicts “roll stiffness” of a sway bar with pounds of roll resistance plotted against the inches of “give.” Note the initial give of the rubber end-links. All installations eventually deliver the bar’s full force, but doing this before the body has rolled far is required for a top-handling car. The sway bar illustrated in the graph is rated at 200 lbs./in.

The graph shows the extra give in inches that can be eliminated by using urethane bushings. Note that at the 60 lb. Level the bushings will of course have crushed the same for both bars, but the total body roll will be 1” for the 200 lb. and 3” for the 30 lb. Bar. Note further that the body roll eliminated is less than .5” by using urethane on the 30 lb. Bar, but is over 1.5” for the 200 lb. Bar in a hard corner. From this one can see that on light original bars that do not crush the rubber bushings much anyway, replacing them with urethane does not help much. Heavy bars that can crush rubber an inch at only moderate degrees of roll show marked improvement when used with urethane.

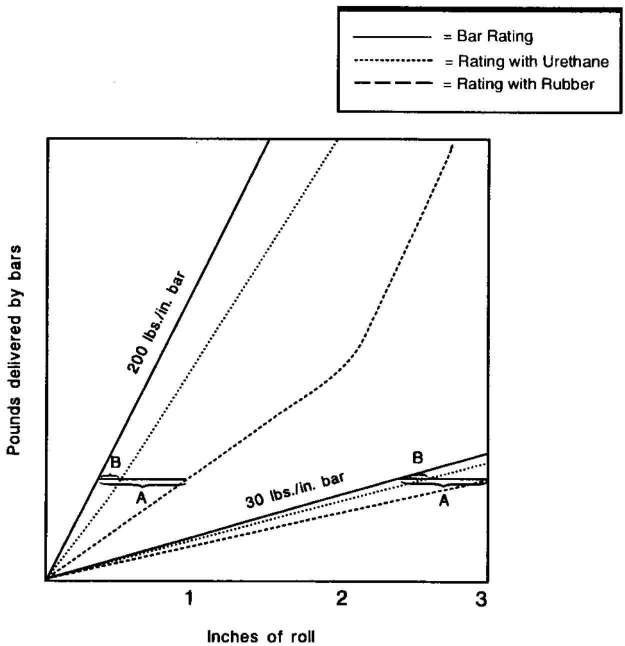


Figure 21

Urethane bushings can be used on the street on most applications. On applications where there is a great amount of suspension travel (such as on the rear suspension of cars, suspensions that are subject to extra load or for off-road use) rubber bushings should be retained at the bar eyes. One can mix rubber & urethane bushings for an intermediate effect.

ADJUSTABLE ANTI-SWAY BAR SYSTEMS

As anti-sway bars were found to be so pertinent to a car's handling, racers developed adjustable bars long before the idea of even adjustable shocks were toyed with. Once the correct stiffness of anti-sway bar had been selected they found that by adjusting the front against the rear or softening both, they could fine-tune the suspension to compensate for track surfaces, tire changes, driver technique and other little variations.

They accomplished this by one of two means: sliding attachments on the bar arms or multiple holes on the bar arm. See Figure 22. In both of these methods the lever arm of the bar could be lengthened to decrease the stiffness. Moving the attach point on the bar arm results in tilting of the end-links, and thus, requires multiple locations on the suspension ends also, unless the end-link is unusually tall and an inch or so of movement results in only a modest end-link inclinations out of vertical. As multiple suspension end-links locations are usually awkward and multiple holes in the sway bar arms must, for strength reasons, be small horizontal holes, both systems require the use of rod-ends or small steel pivots. These work well for racing where mileage is low and where vibration insulation is not important. These systems are not satisfactory when applied to street driven cars as the rod-ends last only 10 to 15 thousand miles, and the absence of any vibration insulation bring up unnecessary vibrations. For the driver that wants to be able to tune his car for weekend racing but wants a dependable and comfortable car for daily use the adjustable end-link is a good solution. These can be used with most sway bars that use conventional end-links. You can get the sway bars maximum strength by using the normal tube spacer and urethane bushings. To soften the system one can drop back to rubber bushings. To further soften the action, a 120 lb./in. spring can be substituted in place of the tube spacer. It can be further fine-tuned by pre-loading the spring. Thus any degree of initial bar effectiveness can be realized from soft to the bars maximum rating.

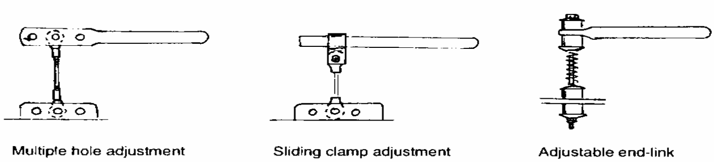


Figure 22

URETHANE MIDSECTION BUSHINGS

By substituting urethane bushings for the usual rubber, some improvement in crisp response of an anti-sway bar can be realized. The competitive driver will want these, especially when used on heavy-duty bars that can distort normal rubber bushings. They may also be used at the ends of some bars that use rubber "D" bushings such as in the rear of the '70 to '82 Camaro/Firebirds. Regrettably, there are engineers at GM, Chrysler, Audi, and VW, that either failed to understand the geometries they were working with or were over-ruled by cost-control types and as a result they came up with such poor geometry in their anti-sway bars that care must be taken in substituting urethane. Urethane "D" bushings are not recommended if the ends of the gars are mounted in "D" bushings where there is a prying action during chassis vertical motion, as they may not allow sufficient movement without causing damaging stresses on their brackets or on the suspension arm bushings where the arm attaches to the chassis.

The midsection urethane bushings will not, though, make as greater improvement as the urethane end-link bushings will due to the fact that the rubber wall is far thinner than the rubber in two end-link bushings, thus there is not much give to eliminate. For my own daily use cars I use the rubber bushings, but for that extra performance edge, go with urethane.

TRACTION BARS

These are primarily for use on leaf-spring cars that have poor bite when dragging. Leaf-spring rear suspensions normally have no locator links as do coil spring rear suspensions. The leaves keep the rear axle in place laterally and longitudinally. This works fine except for extreme conditions.

When the clutch is popped on a revving 300-cubic inch engine, there is a tremendous amount of torque generated on the axle housing. It tries to rotate in opposite direction to the wheels deforming the springs as in Figure 23. If the wheels break traction, the springs suddenly straighten out only to warp up again as soon as the wheels grab the pavement. This results in a harsh shaking sensation and poor traction. The same thing happens when the brakes are slammed on and the rear wheels try to lock. The rolling effect of the wheels takes the rear axle housing with it wrapping up the rear springs as it rotates. As the wheels grab and break traction, it produces the same shaking sensation as with hard acceleration.

Traction bars work similarly to the lower links or suspension arms on most coil spring cars. They run from the top or bottom of the axle housing forward (or in some cases back) to the car frame. Thus, it ends the shaking, grabbing action. Most manufacturers that use leaf springs rather than add traction bars have overcome most of these problems by two means. For one, they have moved the axle forward from the center of the spring and firmed up the shorter front portion as well. Thus, this front portion is fairly rigid and prevents the axle

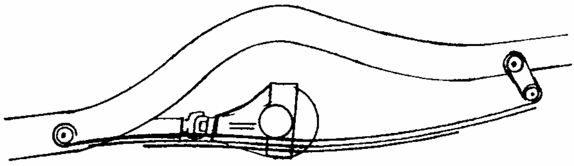


Figure 23

from winding up as much. The other point – and an excellent one – is to bolt an extension on the front of the differential housing, equipped with a rubber snubber. Thus, when heavy throttle is applied, this snubber contacts the bottom of the floor pan and prevents any serious spring windup. These developments, popularized in '57, have reduced the need for traction bars for most streetcars; now traction bars are more valuable in giving good traction when braking than when accelerating. Traction bars are used on cars strictly for dragging for another reason also. That is to keep as much weight on the rear wheels as possible. These are usually massive "lift" bars well below the rear axle housing and reach far forward so as to lift the front.

As the name implies, traction bars are used on leaf spring cars where the layout of the springs does not control axle wind-up effectively.

The first traction bars on the market were well made of steel rods with rubber-bushed pivots at both ends. Later, many companies got into the field and cane out with cheaper built units which simply clamped to the spring near the axle and had an extension leading forward with a rubber snubber just under the spring that upon acceleration raises up against the spring and prevents further wrap-up. Very effective on acceleration, but useless in the more important function of good braking traction as the spring can still wrap in the opposite direction. They are commonly referred to as "slap bars."

Cars set up for high speed driving would normally have a numerically low rear end ratio that will limit low speed torque, and thus, traction bars are not as needed on the typical "GT" or highway automobile

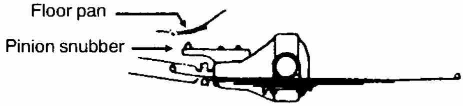


Figure 24

CAMBER COMPENSATORS

"Camber compensators" are leaf springs transversely mounted that can either push the wheel assemblies up against their springs or down extending the springs. Their most frequent use is on independent swing axle rear suspension. Actually, they are simply another spring and increase the rear spring rate of the car. This is a help when towing a trailer with heavy tongue weight, or when carrying a load. It will decrease adhesion as it increases ride harshness. They add only mild stability. They were once popular with the swing-axle pre-'69 VW's, to control tuck-under. The appearance on the market of rear anti-sway bars for the VW gave a more effective alternative to the tuck-under problem.

PANHARD-RODS

Traction bars must not be confused with "Panhard" rods, named after the French auto designer, that are actually lateral locator links. Some people confusedly refer to them as "Sway Bars" also. These are horizontal bars that run parallel and just in front or behind the rear axle. One end is pivoted to the axle housing and the other end to the frame. They serve simply to keep the body more or less above the rear axle. These are normally part of the suspension in coil spring cars that do not have four-link or other lateral locator control. Full size Fords, Mustangs and semi-rigid axle cars such as, Audi's and K-Cars use them, note Figure 10.

With cars now built with lower center of gravity and people expecting an even softer ride, designers have been able to soften the springs considerable. This has lead to the problem of the rear leaf springs not having sufficient lateral rigidity to deep the axle securely located in relation to the car. The leaf spring actually bends sideways under stress. Thus Panhard-rods are used on some leaf spring cars to relieve the side stresses on the springs.

SHOCK ABSORBERS

Many people are confused as to just what "shocks" are supposed to do. They do not affect spring rates (stiffness) nor do they effectively cut down on body lean, they simply slow down and damp the movement of the body on the wheels. Their basic construction consists of a piston in a cylinder full of oil with certain orifices supplied so that as the piston is moved, it has t force the oil through these orifices, thereby slowing up the motion and dissipating the energy. It will not, though, control how far the piston can move. Thus they cannot stop your car from squatting with a load or leaning on a corner, as these effects act on the car long enough to fully activate the shock absorbers, whether they be large heavy duty ones or small ones.

The real function of shock absorbers is to:

A) Prevent bottoming if high speed bumps are encountered by slowing down how fast the springs can compress and momentarily transmit the lifting force of the wheel directly to the frame.

B) Prevent the tire from bouncing the wheel violently up and down on little bumps. They in effect make the tire absorb pebbles, etc.

C) Dampen out rebound. If a car did not have shock absorbers, one bump on the highway would cause it to heave up and down on its springs five or six times before it settled down.

There has been a push by some of the manufacturers of H.D. Shocks to offer manually adjustable shocks. These are nice if one is experimenting on car set-up or if one has large variation in load such as a pick-up that is used with a heavy slide-in camper on summer trips – they can be unbolted at the bottom and turned up for the trip helping to prevent bottoming or some types can be adjusted with a screwdriver. Other than the above-mentioned situation, the adjustable feature is of little importance provided that the shock installed is properly calibrated for the weight of the vehicle in question.

Of more importance is the nitrogen gas hi-pressure shock. In these the fluid instead of passing into a reservoir (usually in an outer part of the double-walled tube) on shock compression, it compresses compressed nitrogen. As the fluid is thus constantly under compression (even on the extension stroke), it cannot either suck in air bubbles at the shaft seal or cause vapor bubbles within the fluid. Thus, nitrogen shocks don't become mush on rough roads as result of the fluid becoming emulsified with bubbles.

Most shock absorbers have one or more small passages for low intensity movements and a spring-loaded valve that unseats for high intensity movements. If they are "Heavy Duty" shocks, the passages are smaller and the case larger for added cooling. To give a "firm action" feel, the spring controlling the value is stiffer so the resistance "tops out" at a firmer level. This system works, but it only roughly approximates the damping action ideally required. The problem of shock absorber valving is magnified by the fact that the resistance to the flow of fluid through a passage or orifice increases the square of its velocity. Thus, unless one has an infinitely self-adjusting orifice, any orifice small enough to give suitable damping action on low intensity movements becomes much too harsh on faster movements.

To solve this problem, a patent was obtained by Dr. deCarbon. The Dr. deCarbon system uses flexing spring-discs that deflect further and further under increasing pressures under the compression stroke of the shock. As they deflect away from the piston rim on which they are located, more and more fluid can escape in a continuously increasing rate but only in a carefully calculated ratio to the PSI of the fluid. Thus, one has a shock that controls the suspension with damping pressures that are near ideal for almost any shock impact instead of ideal at only three impact speeds as dictated by the fixed orifice, valve spring, and top out rate of the ordinary shocks.

The extension resistance of the deCarbon shock is controlled by two orifices of fixed size. This may be fixed as the force extending the shock (when the axle moves down) can never by greater than that dictated by the weight of the axle and wheel accelerated downward by the car's springs. Thus, the "ratio" of this type of shock is not fixed, such as 50/50 or 60/40. It is 50/50 on gentle conditions but under harder use progressively changes to almost an infinite relationship. These shocks have the exceptional characteristics of optimum damping action for boulevard surfaces so as to prevent rhythmic wheel oscillations due to minor balance or out-of-round problems as well as the capacity to open up its valving on a continuous basis as needed to accommodate the roughest surface and highest speed so as to retain control that would otherwise suffer due to unnecessary harshness.

Makes that incorporate this disc valve and nitrogen gas combination are the types sold by BILSTEIN, KYB and GIRLING.

Another type shock on the market features a piston that's orifice slides on a stationary pin that is formed with a waist like a coke bottle. Thus, more fluid can pass at the normal or static ride height, but as the suspension compresses (or extends), the flow is more restricted. This type of arrangement gives a "soft" ride, but it does tighten up to prevent bottoming. The problem is it cannot adjust itself to the piston rod stroke speed (only the stroke length) and thus, does not adapt itself as well to a broad range of driving conditions. Furthermore, if a car has been raised an inch, or lowered, it will upset the shock's calibration.

In addition to the design and operating principles of a shock, the actual quality of the materials and workmanship is more important than most people would think. One has only to go to a new car dealer lot and look under new unsold cars to find shock absorber shaft rods already rusting. A rough, rusty shaft passing repeatedly through the seal will soon cause loss of fluid and the introduction of dirt and grit to the interior mechanism. I have had the end rings on shocks actually come off after only 15,000 miles.

Another type of shock is the Air-Shock. These are for the most part a standard type shock that has internal rubber air chambers that may be inflated as desired. These are discussed in detail under "Spring Boosters" below.

Now, do we need new or larger capacity shocks on our car?

Test No. 1

Push you weight down on the front fender and quickly release it. The car should bounce up, and then settle down in its normal position. If it bounces three or four times by itself when released, the shocks are worn out and should be replaced.

Test No. 2

Drive it about 20 m.p.h. over a one to two inch high bump of earth with one front wheel. The car should lift slightly to it, but you should not hear the wheel bottom with a thud on its rubber snubber. As the front wheel has two inches or so of rebound distance, a well-controlled wheel should not bottom on a one to two inch bump.

Test No. 3

Note the motion of the car on a secondary highway. At 60 m.p.h. the car should rise and fall quickly over or into a dip but should stabilize itself after two rebounds. If it does not, it will retain a floating motion from one bump to the next, which makes it uncomfortable and hard to steer accurately. It is this motion that often leads to carsickness.

Test No. 4

On rough stretches of highway does your car seem to vibrate and shake worse after the first few bumps? If so, this is caused by the emulsification (aeration) of the shock fluid that allows bubbles to mix in the fluid – a definite sign that you need a nitrogen gas pressured shock absorber.

If your car fails any of these tests, your shocks are either worn out or are mismatched to your car or to your use of it. Good shock absorbers are not the cure-all that some advertisers would like you to think, but if they are incorrect for your car, or your use, they can spoil the handling of an otherwise well set-up car.

SPRING BOOSTERS

The value of these is to enable your car to carry more load. If they are to be effective though, most of them will make the car sit high on its rear wheels, which is not desirable from a handling viewpoint due to the increased height of the center of gravity. They also, of course, add harshness to the ride. Some of them can be adjusted in such a manner that hey only come into action after the car is partially loaded. If you carry heavy loads, these would be the ones to get if they add enough boost for your needs. The air-inflated type can be filled and emptied as needed. Avoid the type that insert between coils from the side, as they tend to put uneven stress on the springs and could cause breakage.

There are "overload" springs that usually come attached to a shock absorber. These too have the drawback of making the rear end sit higher and add ride harshness. Furthermore, one may not be getting the best shocks with them, which adds another drawback.

Another version of the booster springs is the "4 way" spring booster. It is similar to regular boosters except that it is attached so that it exerts force on extension also, so it in effect, increases your car's overall spring rate, changing it from purely linear (in the case of coil) to a progressive rate.

Having to compromise on the shock that comes with the booster is also a problem with air shocks. The inflatable feature to get added support when needed is a good feature, but a better arrangement that does not make a compromise on the shocks is to use top quality shocks and add air bladder supports. Air bags lift directly between the axle or suspension arm and the frame, whereas many shocks are angled inward or forward and back, and thus, the lifting force exerts lateral thrust on the suspension and is less efficient than if it lifted vertically. As air shocks are small in diameter compared to an air bladder, the pressure in them must be very high to give effective support which not only leads to the shock bowing out. But the high pressure required means it cannot be hand inflated. Air bladders are large in cross-section and thus, operate effectively on low pressure. Another advantage of the air bladder over the air shock is that moisture than can be introduced in the air from the service station tank can cause corrosion in the shock absorber. This is not the case with the bladder, which has no metal internal parts.

Although shocks and air bladders may be a little more expensive initially, the cost is saved later when the shocks are replaced – as air shocks or booster shocks are not usually sold with a life of ownership guarantee, and replacing the whole unit, as in the case of air-shocks, is expensive.

The air bladder is fitted either inside the suspension's regular coil or spring or, in the case of leaf spring suspension, inside a light coil spring that is included in the kit. They are easily inflated for more carrying capacity and deflated afterwards.

BALLAST

Basically, don't. People refer to the rear end or what have you, as "feeling light." It is not that it is physically light that causes it to be unsteady. It is that the stability, tires, or suspension itself is of inadequate capacity. Remember, the last time you drove a big load in the back –

handling on corners was worse than ever, not better. Ballast will only overload already marginal springs and tires. You never hear of ballast in a racer. These terrific handling cars weigh about one-half as much as a passenger car.

SPRINGS & LOWERING

When up grading of a suspension is planned, often the OEM springs are questioned. Either they are thought of as too light (too low rate) or it is desired to lower the car for handling or appearance reasons. Often times older cars, 12-15 years old, for instance, have lowered themselves as the springs have sagged. In these cases sometimes it suffices to simply balance it out by lowering the end that sagged the least. Contrary to what is sometimes thought, springs do not lose their stiffness. As steel is "worked" it will, if anything, become harder. This is the principle of cold-drawn rods. Have you ever tried to break a piece of light wire by twisting it around and around with your hands? Notice how stiff the wire gets at the ends where it finally breaks. You broke it by work hardening it to the point where it could break. Springs will settle some over time as the crystals of the steel eventually offset themselves against one another, but that does not make them slide against one another more (leading to faster sag) or disturb more easily (leading to softer spring rate). If you have swapped a 6-cylinder engine for an 8-cylinder, it is simple to swap the 6-cylinder spring for the 8, or sometimes station wagon springs were firmer than the sedan's springs. These though will not lower the car in most cases and may even raise it. Thus one would have to resort to cutting of coils which can be done on non-taper wound springs. Heating the spring with an acetylene torch until it settles a little is another technique used but it can leave you with a spring that may settle too far over a little more time or could break.

These steps are non-reversible, short of buying new springs, and depending on the chassis type may cause difficult to cure alignment problems if overdone.

After-market "lowering springs" have problems of their own. ADDCO has received many complaints of after market springs sagging after only six months. Furthermore, in tests that ADDCO has conducted, many of these springs vary in rate from on to another as much as 10%. Thus a successful installation on one car may not be as successful on another similar car. The large OEM producers can test, categorize and code production batches and use them appropriately, but small aftermarket producers can't do this.

Perhaps the greatest problem in buying aftermarket springs is the fact that cars vary in weight depending on engines, transmissions, A.C., and other options. The'84 Mustang had five different front springs, the Camaro had four. Despite the ads promising a specific lowering amount, unless they offer four or five stock numbers per name plate/year, you might be disappointed.

Another problem is that many of these springs are a lot firmer – a nice way to make the customer feel he got something for his hefty investment. In reality these stiffer springs can, as often as not, actually harm the handling of the car on anything but smooth pavement.

Another method that is used is spring clamps. These are notched stampings that go over one coil and under another and are squeezed together by two bolts one inside and one outside the spring. The advantage is that you can pull together the spring to varying degrees giving a fine ride-height adjustment. This also increases the initial spring rate proportionately. The drawback is that these notched stampings' sharp edges can cause stress points on the spring and breakage. Another problem is that they can't be used on coils that have the shock or struts inside them, unless it is a very wide diameter spring.

For most suspension upgrades, where a moderate lowering (and proportional increase in firmness to prevent more frequent bottoming) is desired, these spring tuners should be considered due to their fine adjustability, ease of installation, economy, and reversibility should the car have to be returned to near stock height for any reason.

On leaf spring suspensions, lowering blocks are easy to use and they do not change the roll-steer relationship, whereas changing the shackle length, or forward frame mounting height, will alter slightly the roll steer. Due to their progressive nature, stiffening the rate will most likely be undesirable.

CHAPTER V

How stiff?

All too often, the resiliency of a suspension is regarded as something to be eliminated. But this characteristic should be regarded as the most valuable attribute to be preserved. It is this resiliency that enables a four-wheeled vehicle to remain under control on a typical roadway. Anti-sway bars are important because they are very effective in controlling instability with a minimum loss of resiliency. Correctly sized anti-sway bars should, therefore, make possible the use of more resilient (softer) springs in the suspension.

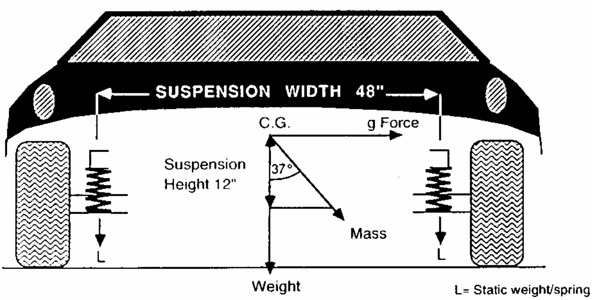
The most commonly perceived use of anti-sway bars is to increase a car's cornering stability. Cornering instability, or body roll, is the result of centrifugal force acting on the vehicle's body mass so that the mass is no longer evenly distributed on the springs.

The following formula can be used to measure body roll:

Body roll = 2 x g x (susp.height/susp.width) x (spring load/spring rate)

Body roll = 2 x .75 x (12"/48") x (800/100) = 3"

In this formula, the suspension height is the distance between the axle and the center of gravity, and the suspension width is the distance between the spring centers (see Figure 25). Note the importance of keeping the center of gravity low and the suspension width wide. The above car would actually seem to have 4" of body roll as seen at the fender rather than the spring center. Usually anti-sway bars, shocks and springs have similar suspension widths on an axle, but the effectiveness of each should be individually calculated. The above assumes .75 G. cornering force.



Suspension height and width are used to calculate body roll.

Figure 25

In the foregoing example, the body rolled until the compressing outer spring and the decompressing inner spring were finally able to neutralize the centrifugally displaced mass.

This body roll (3" on a width of 48") is 3.5° or so (3 x 48 = .0625 = sin 3.5°). This body roll will additionally induce a little more body roll:

tan 3.5° x (12/48) x 2 x (800/100) = .246"

This formula shown that body roll itself – at least in a car with a reasonable low center of gravity – contributes to weight transfer less than one would expect. To better realize this effect, park you car across a 3.5° slope and measure from the two sides of the bumper to the ground; a quarter of an inch of difference should be about all you find.

The far greater harm to cornering performance is caused by the effect of the body roll on suspension geometry. Now, the height above the road has no effect on the foregoing: if 16" wheels were substituted for 13" wheels, nothing would have changed in the equation. Tire loading would be affected, but not body roll.

But suppose that 100 lbs./in. anti-sway bars are added to the car used in the preceding example:

Body roll = 2 x .75 x (12/48) x (800/100 +(100 x 2)) = 1"

Note: The initial numeral 2 is to divide the stabilizing effect of the spring in half (as the unloaded inner spring pushes up). The second 2 cancels this out as far as the anti-sway bar rate goes, as the entire amount of body roll tries to torque the bar.

The formula demonstrates that the addition of a fairly mild bar of 100 lbs./in. will reduce the body roll from three inches to one. This clearly shows the effectiveness of anti-sway bars in stabilizing body roll.

Just where this body roll, or loading, is directed is even more important than the amount of the load. The sway bar very effectively dumps its load on the outer tire to which it is connected, unloading the inner tire. Not only does a bar connected to the front dump no load on the rear tire; it also actually relieves the load on the rear by limiting the body roll that would have caused additional spring compression (loading) of the rear spring. One need go no further than this to understand the inadvisability of installing a sway bar on only one end of a car.

Since we have now established the effectiveness of anti-sway bars, the next question might well be "why not do more good with a 200 or a 400 lb./in. bar?" Well, if we installed the 200 lb./in. bar, we would have:

Body roll = 2 x .75 x (12/48) x (800/100 + (200 x 2)) = .6"

or, for the 400 lb./in. bar:

Body roll = 2 x .75 x (12/48) x (800/100 + (400 x 2)) = .33"

Note: one must add body roll due to tire distortion and bushing compression to the above figures.

These equations show that as we increased roll stiffness from 50 lb./in. (with just the springs) to 150, 250, and 450 lb./in., we progressed from 3.25" of body roll to approximately one inch, to .6" and then to .33" of body roll. It is easy to see the pattern of diminishing returns.

Three inches of roll will seriously distort most of the independent suspensions used today, causing longitudinal weight shift (tipping forward like a tricycle), radical camber changes and resulting degradation of tire adhesion, heavy steering, and steering deflection (similar to bump steer). Since many of these problems will affect front and rear suspensions differently due to dissimilar geometries, their ill effects are magnified as far as directional control is concerned.

If we reduce the body roll from three inches to one inch, we will reduce these ill effects by a lot more than one-third. This is because most suspensions operate through arcs, as you can see in the illustration of unequal length upper and lower A-arm suspensions. See Figure 26.

When we moved from the 100 lb./in. bar to the 200 lb./in. unit, we reduced the body roll by an additional .4", but this reduction would not make an important reduction in the amount of geometric distortion; there was already very little distortion left at one inch of body roll, and the difference in mass displacement between 1" and .6" of body roll would be inconsequential.

But while it would not significantly reduce suspension distortion, the heavier bar would materially reduce the independent resiliency of each wheel. The result would be an increased possibility of tire overloading and its opposite, sliding. On even pavement, these effects would be unimportant. The car might perform very well on an oval, or on a flat track similar to those used in autocrosses and magazine testing sessions. The problems would arise on road courses or in driving on secondary roads.

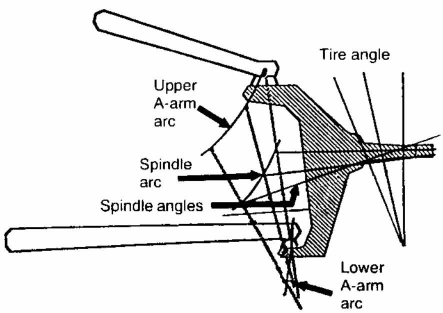


Illustration of wheel tilt induced by geometry of suspension accelerating at extreme deflection. This is added to body roll deflection.

Figure 26

The drawing below shows bow a car negotiates a curve on a road that has a crown at the side. If the car has 100 lb./in. springs and no anti-sway bar, centrifugal loading will add 150 lbs. to both front and rear outside tires (not 300 lbs., because the 3" body roll is 50% the result of the inner springs pushing up). To this we must add 200 lbs. – since we'll assume that the crown pushes up 2" – plus the body roll loading of .25" or 12.5 lbs. (one eighth of the 100 lb. spring rate). So the front tire (A in the drawing) would have then been loaded to 1162.5 lbs. (800 + 150 + 200 + 12.5).

However – and this is where things get more complex – the 2" lift caused by the crown is not fully absorbed by that front right suspension assembly. The 2" lift will also tip the chassis in a diagonal direction, compressing the suspension at wheel D. Thus, leaving out the effects of shocks and inertial delays, the 362 lbs. of loading will be shared between the spring A compressing and spring D compressing. Spring C & B will decompress proportionally (all spring/tire loads must still equal the 3,200 lbs. weight of the car). The unloading ratio between C & B will depend on the proportion of length to width of the car; the wheel closest to the lift will unload more.

But if we add anti-sway bars to this car, things will change. The centrifugal loading will not change, since it remains the same regardless of roll stability. But two other things will happen: The increased roll stiffness will increase the loading of A as it goes over the crown, and since anti-sway bars unite two specific wheels, the loading and unloading ratios will be altered.

What if, in the foregoing example, a 100 lb./in. sway bar is added to the front of our car? The 2" crown still pushes A up 2"; but the 200 lbs. of torque that this puts into the bar will lift B an extra 1" (since the bar will deflect 1" and the spring will compress 1"). This will result in an extra 100 lbs. of load on the outer tire, or 1,250 and 100 lbs. less on the inner tire, which is not on the crown. The sway bar also affects the rear tire loading: The body will now be tipped away from the crown by one inch less, the inner rear spring D will be compressed less, and the outer spring C will decompress less.

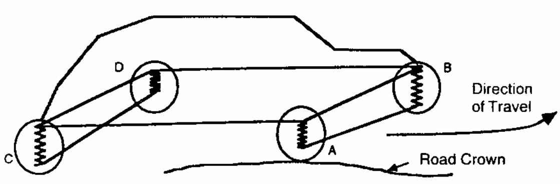


Figure 27

Thus the addition of the front bar reduces body roll, but increases the uneven loading of the tires as the car moves over the side crown of the road. The addition of a front bar only would also crease the loading of the front outer tire due to centrifugal mass shift resulting from the higher roll resistance.

Putting a rear bar on this car will also make the tire loading more acute. As the wheel A rises over the crown, the body can't be tipped away from the crown by 1" as before, because it would have to torque the rear bar. It can now tip away by only .5". That means more tire load at A, more lift at B, less lift at C, and less compression at D. Now we're up to 1,300 lbs. of load on A, and 300 lbs. at B (1,600-1,300 lbs.). The uneven loading of the tires is clearly magnified.

What if we added 200 lb./in. anti-sway bars, instead of 100 lb./in. units? Tire A would then carry 1,475 lbs. of load and B would be at 125 lbs. Obviously, at 1,475 lbs. the overloaded outer tire A will be drifting fast under the centrifugal force of the corner, and inner tire B will have so little weight on it that it will be easily dragged, sliding as A drifts. A moment later, the front of the car will have passed the crown and the rear outer wheel will climb onto it. Now the front will track the curve as the rear is drifting out. The driver, having steered more sharply to maintain his line, must steer out of the curve momentarily, then resume his original steering input. The car will feel twitchy.

Firm shock absorber would have increased the tire loading and unloading rates greatly, making the car feel even worse. High speeds would have introduced and additional inertial loading over the crown of the side road. To accurately compute tire loading rather than suspension loading, we would have to re-input our formula, eliminating the spring rate and using the center of gravity height divided by the width of the track, and adding in the static tire load. Thus:

Tire load = (Center of Gravity/2 x g x Track Width) x (Height/Tire Static Load) + T.S. load

Keep in mind the example of a four-legged stool: It will rock on two logs unless the floor is perfectly flat. Driving on only two of four tires is equally unnerving.

So what can we learn from studying all these figures? The best way to go is to have a car that is designed with a low center of gravity and a wide suspension, with a reasonably soft spring rate that doesn't permit too much body roll.

One problem we must consider in choosing spring, anti-sway bar and shock absorber rates is that if the rates are too low, the wheel can be easily thrown. If the rates are too high, then the whole car will be thrown up from the pavement and adhesion will again be lost. Thus adhesion will be best somewhere in between the two extremes. The sprung-to-unsprung weight ratio is critical in this balance. See Figure

19.

If you are thinking of preparing a car for autocross or just for some fast, fun driving, you must come up with a concept of the type of driving you plan to do. Smooth or rough pavement, high speed or tight turns? Your driving style should be also be considered, since the balance of understeer or oversteer should be tailored to it.

To be competitive, even these high-priced, limited production sports cars need the chassis tuning and stability of moderate anti-sway bars. Cars with narrower, higher chassis need anti-sway bars even more, particularly since their suspension geometries work reasonably well under only small body roll angles.

Since increasing suspension stiffness can create as many handling problems as it cures, sway bar selection should be made with knowledge and deliberation. The difference between the cost of making .75" diameter bar and 1.25" diameter bar is only about $6.00, so manufacturers can offer hopelessly rigid bars for about the same price as well-engineered units. One manufacturer offers bars that are rated at 5,600 lbs./in. – for a car that weighs only 3,500 lbs.! It is easy for the ill informed to fall prey to the hype from these companies.

But choosing the correct sway bar is no easy matter. In our preceding calculations, we used a hypothetical car that carried 800 lbs. on each tire, had a level roll axis, and had similar suspension and chassis design at the front and rear. A chassis like the one used in our formulas would be similar to the axle cars of the early thirties, long prized for use in some of the "sportsman" modified classes. Those formulas looked complex, but were actually much simpler than appropriate formulas for today's more complex cars.

Today's cars are more of a challenge. The manufacturers frequently include anti-sway bars that are added on as an afterthought in an attempt to correct handling problems that emerged somewhere on the early prototypes. These bars are snaked in around tail pipes, as filler pipes, spare tire wells, and all kinds of other non-dynamic stuff. I can't recall seeing a tail pipe that has been bent to avoid a sway bar; it seems that it is always the other way around.

So, short of becoming a mathematical genius, how are you to know how to choose the proper sway bar? Here are some points to consider regarding the firmness of different anti-sway bars.

- A typical front A-arm suspension, compared to a solid axle, needs twice the firmness of bar for the same result (tire loading/anti-roll effect) due to the rapid loss of "action" as one moves in from the wheel hub on the A-arm to avoid turning interference, and other factors.

- If the frame mounts on the front bar are closer together than those of the rear bar, the bar must be proportionally thicker to obtain the same result.

- As the torsional length (distance between the bends) increases, the firmness of the bar decreases proportionately.

- As the angle of the bar arm widens from 90° towards 180°, the firmness will decrease as the sway bar's arms become partially torsional.

- Although bends in the arms to avoid interference have little effect, bends in the torsional part reduce the firmness.

- A bar's firmness increases as the square of its cross-section. Thus a ¾" 100lb./in. bar would put out 185 lbs./in. if diameter was increased to 7/8".

One should also consider how the car handles before deciding how to use sway bars to locate firmness:

- On a well-balanced car, add the same firmness to both ends.

- On an understeering car, add more firmness to the rear than the front.

- On an oversteering car, add more firmness to the front than the rear.

- On vehicles with a high center of gravity, sufficient firmness is more important than where it is placed.

- On cars with a steep roll-axis (short wheelbase, independent front, solid axle rear) add extra firmness to both ends to stop the steep axis from developing.

- On front wheel drive cars, add firm front and rear bars (since the rear wheel will lift anyway) and balance the heavy understeer with the highest capacity front tires that will fit. If adding only one bar to a front-wheel drive car, add the rear bar.

- On vehicles that will be run on smooth tracks you may install firmer bars. Vehicles that will run on rougher or more uneven surfaces must be fitted with moderate anti-sway bars (like high performance street bars).

- Off-road vehicles should be fitted with moderate sway bars only – otherwise, you might be thrown from the car!

- Pick-up trucks that are normally run empty (nothing in the bed) should be fitted with moderate rear bars.

These are only rough guidelines. Since aftermarket anti-sway bars are available for over 300 chassis types representing a thousand-plus nameplates, the only way to get the correct bars for your particular car and your particular driving style is to consult with a manufacturer who designs anti-sway bars. The manufacturer should be as interested in cars as you, and willing to spend the time on your handling problem. Then his experience and knowledge can prove invaluable.

CHAPTER VI

Choosing a Chassis

The foregoing discussions have outlined the steps one can take to get the best out of whatever chassis one has – whether it be a classic sports car or a mother's hand-me-down. If though, one has the opportunity to go out looking for a car, sports car, van, four-wheel drive, or R.V., one can save oneself a lot of hassle, expense, and end up with a far nicer vehicle if one knows what to look for and what to avoid.

Although there are many various attributes that one looks for in a vehicle; looks, comfort, size, price, mileage, safety and so on, everyone appreciates good handling and good power, as that is what makes a car fun to drive. The power can usually be supplied by an engine option, a turbo or super charger or an engine swap, but handling is more evasive. Although as we have seen, dramatic improvements in handling can be made in almost any vehicle, it makes sense to look for a vehicle that has the basics needed for a really fine handling chassis, or at least one that will be easy to work on.

WEIGHT DISTRIBUTION

Very little can be done in this department once the chassis has been chosen; so obviously this is the first consideration to be made before buying.

1. Mid-engined. This is the best, of course. Unfortunately this engine location uses up the prime space in the car limiting its use to all-out, two-sear sports cars. All the mid-engined sports cars available as of this writing have excellent handling and can be made outstanding with very little effort.
2. Rear-engined. These also have been sports cars except for the Corvair and the VW bug. The rear engine weight bias must be catered to as outlined previously, but they have the advantage of better lay out of trunk and passenger areas, and they have the lightest steering. Their traction in snow and mud is unsurpassed, but the relatively lightweight on the front tires can cause the front to slide out in poor conditions.
3. Front-Wheel Drive. These are probably the best, next to four-wheel drive, for snow traction; anyway at low speeds where front-end inertia is not important. As the drive wheels pull in the direction steered and there is plenty of weight on them, they can pull you out of icy parking spots better than any rear driver can. The layout is excellent as far as passenger and luggage space goes, and it has no driveline hump. If you are looking for serious

driving though, the mass of engine and transmission weight concentrated so far forward will create an inertia load that will always make it slower and clumsier for the front tires to throw it into a corner. Industry hucksters, undaunted by the laws of physics, promise "front-wheel drive handling." Yeah! Right! Don't rule them out all together though. With all aluminum alloy blocks, turbos, and multi-valve cylinder heads, some engines are putting out an awful lot of power for their weight, despite emission controls; thus, making their front weight bias less condemning. Another front-wheel drive problem than can be downright dangerous in the higher-powered front-wheel cars is the phenomenon of torque-steer. This can produce near violent steering pull to one side under full throttle starts. This was particularly bad in the Dodge Colt (read as Mitsubishi); while it is unnoticeable in the heavier front-wheel drive Cadillac, despite generous torque.

4. Front-engine, Rear-drive. When Henry Ford was asked why he put the engine in the front of his cars, he replied, "… because that is where the horse was." In reality, it is illogical. It is particularly impractical when carried to the extreme in 40-foot motor homes with the engine at one end and the drive wheels 30 feet back; and the space, friction and rotating inertia of the long drive train is all waste. These chassis coast at half the speed of a rear-engined version and as you would expect, they use a good 12% more fuel.

   The traditional front-engined, rear-drive sports car can be made to handle well quite easily; good anti-sway bars, wider rims, and upgraded tires and better shocks and you have it! – a car that can be driven at its adhesion point quite securely. Where the front-engine/rear-drive becomes a compromise is when one gets into either the little sedans or the muscle cars.

   In the case of a small import coupe, they come with a steep roll-axis. This is true of both the older solid-axle rear type or the independent type. With a relatively high C.G. and narrow track, they rolled badly when pushed. They roll not like a boat, but tip forward as they go like a tricycle. Adding a heavy font anti-sway bar increases an already heavy understeer. Adding a heavy rear bar would cause wheel lift and spin at the rear. The only solution is to add both and reduce the body roll by, say 80 percent; and thus, the ill effects of the inclined roll-axis. Although the car will feel, perform, and corner a great deal better, the underlying drawbacks of its mismatched suspension lay-out are still there. Thus, you can see photographs of these cars, albeit professionally set up, cornering hard; and you can see the rear wheel light, or off the pavement altogether, while the car is obviously still understeering. The old Datsun 510, (circa 1968-73) was an exception. Its excellent independent rear suspension makes it sought after for sedan racing events even today.

5. Four-Wheel Drive. There are a number of four-wheel drive Coupes, sedans, and wagons being offered now; all following the lead of the American Motors Eagle, which originated the idea of a sedan-type car with four-wheel drive capabilities in the late 70's. It is a great idea if one lives in snowfall areas or even on muddy farms, and one does not want to drive a high boxy utility vehicle.

   Unfortunately the auto promoters are now making claims for the advantages of their "four-wheel handling." On the Eagle, the front wheels only cut in when it senses traction loss at the rear. It was a nice, smooth system. Some, such as the Subaru Legacy, advertise "full-time," four-wheel drive. If you have ever driven a real four-wheel drive, you would know the jerky awkward motion it gives during sharp turns. For full time 4WD to work smoothly and not force traction loss in tight turns, there must be either a fluid coupling or regular free turning differentials, and thus, no great difference between 2WD handling. I would avoid anything where there is talk of a "computer controlled" anything. That sounds too much like getting stuck down the road in more ways than one.

   Where 4WD could be a help, as far as dry weather handling goes, is in very high powered cars where high torque can break loose two tires. There have been some experimental racecars set up this way. Compared to 2WD drive cars though, they have the disadvantage of more drive line friction and a great deal more rotational inertia. During acceleration, a typical driveline has enough rotational inertia that a shift into the next gear is the equivalent of throwing 500 pounds out the window. None of the 4WD cars now offered comes even close to the power range where the 4WD feature could be needed to spread the torque in dry conditions, except for some of the 4WD new turbo pick ups that due to their light rear ends can use the four wheel traction effectively. One of the most expensive and most promoted for its 4WD handing is the Audi Quatro. Its owners complain that its handling is really bad, and it desperately "needs something." Once again, the image-makers masquerading as engineers. One look under the rear end explains everything; rear A-arms mounted on 45° pivot axis's promising bump-roll steer problems.

   So much for where the engine is and where it is sending its power. There are some other items that the promoters are pushing that are more hype than mechanics. "Active suspensions" – a term given to shocks that can have their valving adjusted from the dash, or even a computer that "senses the road ahead" and adjusts the suspension "automatically." I put these gimmicks in the same category as the expensive Japanese import "that is so advanced it uses the wind." They must be referring to the promoter's breath.

When considering the pros and cons of various chassis types that you may be interested in, keep alert as you watch cars in everyday traffic. Check the rear camber next time you see a BMW with four adults in it. One can almost see the bump-steer. Notice the amazing front camber changes as you cruise next to a Ford van – even on a smooth interstate. Watch its front wheel angles at steering lock. This is a good check for any chassis; crank the wheels all the way over and look at what happens to the toe-in and camber angles. Look especially to compare the angles of the wheels. Many of the best handling cars are going to "Anti-Ackerman" steering. This refers to little toe-in change when wheels are steered. A mild amount has been traditionally used so that the outer tire that is describing an arc with five feet more radius than the inner tire will steer the larger arc. The more parallel tire alignment develops less understeer. This "Anti-Ackerman" steering is achieved by having the arm on the wheel assembly aligned front-to-rear, parallel to the wheel rather than canting it in at an angle to the for-and-aft of the car. A moment's thought on this, and it will become apparent how this works.

Watch cars turning sharply in parking lots or cul-de-sacs. Many of them look "out of shape" at five m.p.h. Is the top of the rear fender-well hovering up and down over the rear tire? Do the front tire angles look awkward? Does it leave heavy tire tracks on concrete driveways? Watch and analyze. You learn a lot. Notice cars up on frame hoists in garages. Are their tires hanging plumb? Are the front tires in line with the rear? If not, you can expect wander on the highway, needless tire wear, and inferior cornering.

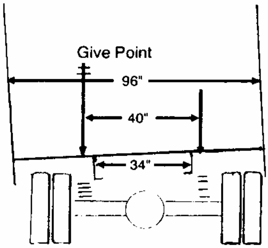
Don't be fooled by the styling. The Mitsubishi 300 (also known as the Dodge Stealth) is about as sleek and dramatic looking as a sports car can be. It is wide and powerful – available with up to 300+ horsepower and 2WD or 4WD drive. Dodge sent a racing team down to run a small stock-prepared race in Florida. ADDCO received a call two days before the race asking for help. The car was so unstable that they were not even going to be able to qualify it. ADDCO made up a 1 1/8" front and 1" rear, replacing the ¾" and 3/8" bars that were o the car. They not only qualified but placed 11th and 13th, and they were more than happy. The message here is – don't assume a high powered, sleek little car is a sports car just because it looks like one and the salesman says that it is. Before buying, drive the car and push it till it tells you something. In the case of the Stealth/3000, $300.00 worth of sway bars would have cured the problem, and you would end up with a real car. Other supposed sports cars may have needed anti-sway bars would have cured the problem, and you would end up with a real car. Other supposed sports cars may have needed anti-sway bars, wider rims, new tires, performance brake pads, shocks, etc., and you would have to add $2,000 or more to its total cost. Worst yet, what if it needed all the above, but the struts are so close to the stock wheels that they could not accept wider rims? What if performance shocks were not available? I have had many a call from shrewd buyers that inquire as to if we have anti-sway bars for a new model before they even buy the car. The first step though is the road test; it is better to scare a salesman than to get stuck with a dog you can't fix.

Just looking under a car in a showroom can tell you a lot. Regrettably, very few people do it before signing for a $20,000 - $30,000 investment. So few in fact that on many occasions, I have been asked, "Is anything wrong?" and even, "Are you feeling all right?" when looking under a new car in a showroom. They would rather you only gaze through the window at the upholstery.

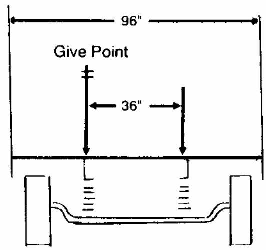
Things to look for: Are the steering rod-ends horizontal? Are the rear axle locators horizontal? If independent suspension, are the suspension arms pivoted or hinged along an axis that is 90° to the direction of travel or aligned front-to-rear? If not, any of the above can cause the car to wander on the highway.

One of the most important items to note is the suspension width – not the track width – but the suspension width. Visualize it thus: if the body is pushed down an inch, it will compress the springs an inch; but if the body is rolled an inch, will it still compress one spring one-half an inch and stretch one-half an inch? If it has a wide suspension width, it will. If it has a narrow suspension width, it will not. What you must look for is how far out the "give point" of the springs are and does this give point apply equally to roll and load? A load-to-roll rate of one-to-one is excellent. The most striking example of this comparison is found in looking at different motor home suspensions, as this type of vehicle demands a lot of stability due to its high C.G., and the suspensions vary widely.

The old Dodge and new Ford motor home chassis and some of the other manufacturers of large chassis, (Class A's) are built on the 1920's truck technology involving the use of simple longitudinal leaf springs. The popular P-30 Chevy chassis also uses this outdated system on the rear. The problem stems from the fact that the springs are mounted on the sides of the frames that are only three feet apart; the spring centers are only about 44 inches apart. On the front to make room for the inset wheels turning



This typical truck/motorhome Suspension has only a stability to support ratio of 1:2.18

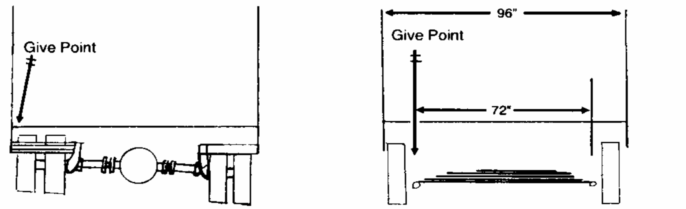


Common front leaf-spring motorhome suspension; it has a poor 1:2.6 ratio

Figure 28

space, they are set under the frames on 36" centers. The ratio of suspension width to body width is 2.18+.1; or in other words, only 45.8% of the springing applies itself to stability. This is referred to as the stability to support ratio. This means that if the body is rolled an inch down at the side, it will only bend the spring less than one-half inch; whereas, a one-inch bump will till bend both springs on inch! Thus, the inherent stability that one would normally get from the springs at any given spring rate, is divided by 2.18. Thus, the spring rates are increased a great deal more than needed for support, and a jarring ride results. On the P-30 chassis they put on an 1 ¾" diameter rear anti-sway bar so they could reduce the spring rate, but this also tends to negate the advantage of the softer spring. Some of the manufacturers on their higher priced units substitute air bags for the leaf springs (and add locator rods), but as they do not move them further out from the vehicle centerline, the problem remains and is actually made a little worse due to the fact that the leaf springs are progressive rate while air bags are not. Another disadvantage of solid axle/leaf spring type suspensions is that they have a lot of unsprung weight leaping up and down under the chassis, which further deteriorates the ride and adhesion.

In the early 70's the Food Machinery Corporation (FMC) designed a motor home chassis that combined great stability, very good ride, and it was very simple. The dual rear wheels were simply mounted on an arm that lead forward, where it attached to a transverse tube with a torsion bar mounted inside it and anchored in the chassis at the rocker panel. Obviously the torsion bar is twisted a given amount as the chassis is pressed down an inch, but if you study the diagram, you can see that if the body rolls an inch, the torsion bar is twisted just as much. See Figures 29 & 30. Thus, a one-to-one stability to support ratio. An added benefit was the fact that the massive differential was sprung weight, its torque fed to the wheels via half shafts. On the front it had a transverse leaf spring that had its give-point three inches from the



The FMC motorhome suspension has a 1:1 stability to support ratio

FMC, by using a Single Transverse front spring gave it a 1:1.3 ratio

Figures 29 & 30

brake backing plat. All simple enough, but it gave a real sports car feel and super-flat handling to a 30-foot motor home as well as a super smooth ride. It did not even have anti-sway bars. This shows the spectacular combination of stability and ride that one can get if good engineers are given clean paper, and no marketing committees are trying to do their work for them. This exceptional chassis was later stretched to 35 feet and used as the MCC and Barth Regency motor homes until the late 80's, when it was found to be "simpler" to just use the commonly available mass produced leaf spring or air bag chassis.

The GMC Motorhome that was built during the 70's also had a well thought out rear suspension. It had two rear tires a side, but in tandem, one behind the other. The rear one pivoted on an arm leading to the rear, and the front wheel was on an arm leading forward. An air bag was fitted on two uprights from the arms. The force from the air bag pushed apart the uprights causing the wheels to push down and raising the coach. It had a number of good points: each wheel could react independently as they encountered bumps; by inflating the bag on one side more than the other one could level the motorhome when parked across a slope or by inflating them above or below normal, one could level the vehicle front to rear. The drawbacks were that they needed more maintenance, and as it was an air system the spring rate was not progressive, making the addition of rear anti-sway bars desirable.

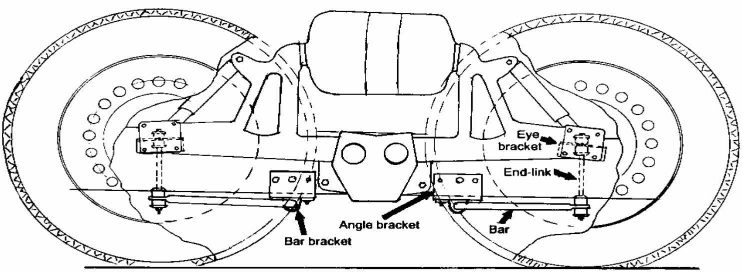


Figure 31

Another example of using a wide suspension width can be seen in the newer 2000-2005 Monoco motorcoaches. The air springs are located just in front and rear of the wheels gaining stability at the full width of the coach thus giving great stability even at mild air pressure, and thus assuring a soft ride. The un-sprung weight is increased by the large framework but the increase stability is worth the slight decrease of ride quality.

Then some "engineers" come up with excellent systems, and they do not even know how they got there, A well known manufacturer of a rubber-block suspension that substitutes for the leaf springs on motor homes advertises that it gives better stability and ride because, unlike a leaf spring that is progressive, its resistance is a straight line function (They even show a little graph depicting a curved and a straight line.). Well, a rubber-block in sheer is VERY progressive due to the fact that the rubber cells swing in an arc, thus, compressing themselves at an ever increasing rate; and progressive rate suspensions are far better for stability/ride combinations (hence, the new "progressive coil" wound coil springs.) The real reason that these rubber block suspensions give better stability/ride results is that, THEY ARE OUT IN FRONT AND IN BACK OF THE DUALS, out near the rocker panels, not jammed between the duals on 36" centers. Furthermore, they are lighter than the multi-leaf springs. Study the illustrations if all of the above is not clear to you.

Once again, it is the wide suspension width that gets the results.

Independent suspensions, such as the typical A-arms, are in some ways inefficient. Due to their short length, much of the wheel vertical movement is lost as one moves in along the A-arm towards the chassis. As it is difficult to attach the springs, anti-sway bars or shocks out at the

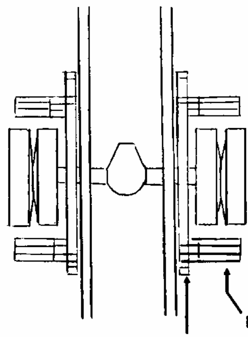


Figure 32

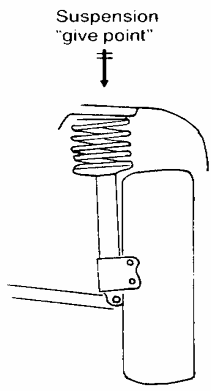
ball joint, they commonly attach half or two-thirds the way in towards the chassis pivot. Thus, the leverage against them is double or more the actual rate that would be needed if the spring or anti-sway bar were out at the wheel center. Thus, a live-axle rear suspension on a car with a typical "A-arm" front suspension is usually about a half or a third of the front spring rate, even if the car has a 50/50 weight distribution. As the same type of ratio affects the anti-sway bar and shock, these also will have to be at least twice the firmness of the rear bar and shock. This relationship effects both body-roll compression and load compression; thus, it does not enter into the "give-point"reasoning. The give-point in this type of suspension is the distance out toward the wheel of the upper spring seat.

As the sequence for designing a "platform", as Auto Execs like to refer to their chassis, seems to place anti-sway bars at the end of the layout process, if they are not just added on later when the prototype proves unsteady, they are often the worst designed part of the suspension.

Look at the anti-sway bar on the front of the Ford Aerostar mini-van of the early 90's Although the A-arms are well built and have reasonably good geometry, the anti-sway bar, which is hollow and contains needless bends and very out-of-plumb end-links, attaches to a part of the A-arm that moves very little when the van rolls. The Isuzu Trooper's anti-sway bar midsection is only 14" long, picking up very little relative movement, and it attaches only about 4" from the chassis end of the A-arm. The original hollow bar did virtually nothing, but even replaced with a thick 1 ¼" solid bar it does little, as there is so little movement even though the body may be rolling heavily.

In '92 the full size Ford eliminated this anti-sway bar efficiency loss by attaching the top of the bars end-links directly to the top of the spindle. It gives the bar near 100% efficiency but to it they had to lean the end-link sideways at about 60°. The stresses this generates are very high especially considering the light welded-rod end-links.

The typical "strut" suspension can be very efficient in regard to the give-point. The bottom of the "shock-tower" acts as the ball-joint and is far out next to the actual spindle base. The shock tower leans in slightly avoiding the upper inside wall of the tire. Above the tire is the flair for the bottom spring seat, and this puts the tip of the spring seat actually overlapping the tire. With the give-point this far out, the stability of these type of struts are very good and a lot better than the spring-sitting-on-an-A-arm type. Not also that as there is no leverage against the spring be the portion of an A-arm outboard of the spring; the spring rates are less. You can easily see that the wire gauge in these springs is smaller. It is this leverage effect that has surprised many a soul when they have mounted deep-dished wheels on their cars only to find they exhibit a negative camber stance when they jack them down onto their new wheels.



"Strut" suspensions can have very good "suspension width" giving approximate stability to support ratio of 1: 1.4

Figure 33

The drawback to these strut-type suspensions is that they are difficult to work with. What you see is what you get. When time comes to replace the shock absorber, on many, the whole strut must be replaced at a parts cost of over $200, and you have little choice of alternate shock rates. If the shock part can replaced with a cartridge, it is still more expensive, more work, and you have less choice of shock rates and characteristics than with a separate shock. Another drawback is that on many of these front suspensions, the front-to-back location of the wheel is achieved by using the anti-sway bar. Eliminating two strut rods could be a good idea, but again, it locks you into a hard-to-work-with situation. To get a long arc for smooth wheel movement over bumps, the strut rods, in this case the anti-sway bar arms, are relatively long. This reduces the effectiveness of a typically ¾" bar to the point of inadequacy. Replacing it with a heavier locator/sway bar is impractical as the hole in the suspension arm (that is usually a forging) that receives the bar end will not accommodate the larger bar. Thus, the bar end must be turned down on a lathe which will cause a stress concentration at that point. That is made more critical by the much higher vertical forces placed upon it by the thicker bar mid-section. Add to this the fact that an anti-sway bar must be made of hardened steel to give it its torsional springiness; if the end becomes overstressed, it is likely to break, rather than to bend, as it would if it were made of milder steel as a regular strut rod would be. The most workable solution is to simply add another complete anti-sway bar. Some strut front suspensions have separate anti-sway bars, such as many of the Mazdas. Some of these anti-sway bars are so buried behind the engine that they are difficult to remove and replace; on the Eclipse you must remove the transmission to remove the sway-bar. On some strut set-ups the strut tube only clears the top of the tire by an inch or less, ruling out much wider rims, unless you go to offset wheels with their attendant bearing problems. Another problem with struts is that is you lower the car, even moderately, the top of the strut does not have sufficient adjustability, and some modifications must be made to re-establish the camber.

Torsion bar suspensions of the type developed by Chrysler in the Mid-Fifties have some unique advantages. By simply having a longitudinal bar paralleling the frame, the bulky spring is gone; facilitating drive shafts, wider engine space, etc. Also, the car can be raised or lowered simply by adjusting the stationary end of the torsion bar via a handy adjustment screw. Visualizing the give-point in this type suspension is not easy. The depression of the car on its suspension does not progressively move down on the top of a spring at a fixed location on the car platform from which one could calculate the load-to-roll spring compression ratio. As the car is forced down, the A-arm changes the angle of the torsion bar-end. The same thing happens when the body rolls except it torques the bar from the stationary end, just as though you momentarily tightened up on the adjustment screw. To look at it another way, the "L" made by the torsion bar and A-arm all try to move with the body roll; thus, the give-point becomes the end of the A-arm, giving you a one-to-one-roll ratio.

As you check under these suspensions, you will notice that some are half-breeds. The Camaro/Firebird front end developed for the '82 models has a strut tower, but uses the A-arm at the bottom. You may well wonder why any one company, the Japanese companies in particular, design different suspensions for several similar sized cars, and then three years later re-design them all over again; and after many cycles of this, there seems to be no obvious improvement, and all the parts would almost interchange, but not quite. I have been told that there is a special tax put on over three year old chassis platform designs in Japan, thus forcing redesigns – it sounds unbelievable, but it could be. Maybe nobody knows.

As most of the manufacturers went to front-wheel drive in their smaller cars, it left them with the opportunity to simplify the rear suspensions, and simplify they did. Ford and GM went to independent suspensions using lower A-arms and struts, GM using a transverse fiber spring on their intermediate cars. It seems that they forgot about anti-sway bars and tacked them on later as an afterthought. You would have to see the Escort bars to appreciate the contortions they went through to tack one on. Honda and Toyota used dual suspension arms and a strut rod forward. Chrysler's K-car and the Audis and the Mitsubishi/Chrysler, Talon/Eclipse, GM's X-body and VW's Dasher and Jetta opted for a flexible axle set-up. The axle consists of an inverted U-shaped axle that looks like a half a split pipe. Inside it usually has a piece of tube welded in to give it additional stiffness. It is connected to the chassis by two long steel plates bolted rigidly to the axle (this has an approximate 4" dimension in the vertical plane) and pivoted at the frame near the rear of the rocker panel. As this arrangement has no lateral rigidity, a Panhard-rod is added, either behind it or in front. The spring is either in front on a welded-on seat or on top or the axle. The drawbacks are modest ground clearance, considerable unsprung weight, and the lateral shake caused by the Panhard-rod on the movement of the left wheel of chassis.

The Rabbit was the first out with a flexible cross-member, followed by such cars as the Pontiac 6000, Beretta, Cavalier, Horizon-Omni, and Golf. Basically, this is the same arrangement as the flexible axle described above, but it is the other way around. The cross-member is made of either a U- or V-shaped beam; or in the case of the Rabbit, a welded up T-section. This is pivoted in the rear of the rocker-panel area. From it the suspension arms lead back to the wheel spindle and shock/spring tower. On a corner the cross-member twists. It generally gives more rear-roll stiffness than the flexible axle type but are often beefed up with clamped on anti-sway bars (in the top-of-the-line models) that follow the contour of the welded-up assembly. These cross-member types are easier to work with; don't have the rather low-slung axle; don't have the drawback of a Panhard-rod (The whole assembly is welded together and has inherent lateral stability.) and has low unsprung weight. Neither of the above are in anyway "high-tech;" in fact, they look quite crude, but they get the job done with little or no alignment or maintenance problems.

Subaru's, Dodge Colt '79-'84, Porsche 924/944 and some others have a similar looking arrangement; except in place of the cross-member they have two slipped together tubes that house torsion bars. This gives true independent suspension action but also makes rear anti-sway bars more needed.

As to "clean" wheel movement with no steering effect on dips or corners, the last two are excellent. The flexible axle type can generate mild bump-steer or rear steering effect.

Rear-steering-effect, normally is something most drivers dislike, as it gives the same uncertain feel that a rear tire going flat gives one. But it was seized by the Japanese auto industry in the late 80's as a new angle to ballyhoo "high-tech engineering." It is nothing new; in fact, truck manufacturers have used it for 40 years or more. They sloped the springs that locate the rear axle down towards the front, as the truck was loaded, they bent down even more. Thus, as the body rolled in a corner, the outer spring draws the axle forward; while the inner spring would push its end of the axle back. This steers the axle into the turn and helps offset the high drift of the loaded rear tires. The old idea now has been glamorized.

The '86 Mazda RX-7 was the first to tout "4-wheel steering." This system used the centrifugal force to distort a bushing on the front of the suspension arm. Honda then came out with an actual rear steering hydraulic piston operated from the power steering system that activated the rear alignment tie-rods to steer the rear wheels in the opposite direction from the front; and at low speeds it reversed its action so one old theoretically crab-wise into parallel parking spots; not that one parallel parks much any more in this age of shopping malls. Personally I would rather steer the car as I see fit without strange and uncontrollable mechanisms moving the rear end around. If they were really so interested in making the car handle better, they and only to put on some decent anti-sway bars and tires that would have given them infinitely better handling than all that steering stuff. But of course, it would not have had the same potential for TV commercial graphics. I don't think that there in a serious future for this type of rear-steer in passenger cars.

Another trend of the late 80's was a movement towards hollow or tubular anti-sway bars. This concept is not new; they have been used for many years on racecars. Their advantage is that they can be made lighter. As the torsional stiffness of a bar increases, as the square of cross-section, 1 1/8" bar will put out about 65 percent of what an 1 ¼: bar will put out. If the bar is a hollow 1 ¼" bar with a 1/16: wall, then the ID is 1 1/8". Visualize that the 1 1/8" bar at the center of the hollow 1 ¼" bar is missing; thus, the 1 ¼" hollow bar will put out 65 percent less than if it were solid. Or, to put it in simple figures:

IF: a 1 ¼" bar puts out………..400 lbs./in.
a 1 1/8" puts out……………262 lbs./in.
a 1 ¼" hollow bar puts out….138 lbs./in.
a 1" solid bar puts out………164 lbs./in.

As a 1/16"-wall is realistic for most of these hollow bars, this gives you a rough idea of what to expect. As the eyes at the end of hollow bars are usually made by simply flattening the tube and punching a hole in it, one can easily find the wall thickness by measuring the eye thickness and dividing by two.

Keep in mind that although the torsion rate increases as the square of the cross-section, the weight only increases as the cross-section. Thus, the hollow 1 ¼: bar would weigh a little over a pound per foot, while the 1" solid bar would weigh about 2.68 lbs. per foot. The drawback to making heavy duty hollow bars is that they not only get very large in diameter, reducing all clearances and negating the use of the original tapped frame holes, but these large hollow bars cannot be bent on tight radii, thus, further increasing the clearance problem under congested front ends. Note also that many of the hollow bars are flattened at their ends in a vertical plane, because if they were flattened in the horizontal plane, the end would not be strong enough in the vertical direction to take the force without bending. This means further awkwardness in adapting an end-link.

I further question the engineering wisdom that was used in selecting these hollow bars. For instance, the '88 ford LTD had a solid bar in about 7/8" diameter. In '89 the same car came with a hollow bar of the same diameter. The '90 Camaro six-cylinder came with a 1 1/8: solid bar, but the V-8 came with a similar bar, except hollow.

In conclusion, take any opportunity you can to drive different cars. If you're looking for a sports car, mid-engine are the best balanced and most naturally nimble. Front wheel drives all feel secure initially, but will never handle well due to front-end inertia and understeer that suddenly becomes massive as the car is pushed harder in a curve. Front engine rear drives can be made to handle well and are by far the easiest to work on. The suspension of a car is what gives a car its personality and the driving it's fun. If you are considering a car, but it doesn't handle well, check under it and see if it can be easily upgraded. Can it take wider rims? Can the anti-sway bars and shocks be easily swapped out? Is the suspension geometry clean and simple? If not, it will be impossible to improve. If you plan to lower it (or raise it), will it be easy? Torsion bars and leaf springs are the easiest. Be sure to look under both ends and take the time to think out exactly how everything moves in a corner or on a bump. If it doesn't make sense to you it probably won't work to you satisfaction.

Chapter VII

HIGH SPEED DRIVING

All of us who appreciate good handling, high performance cars that can safely cruise at higher than average speeds, to put it mildly, like to feel our steeds do their thing on the highway, even if we are in no great hurry to get where we are going. Naturally when speed is mentioned, many good souls who do not understand cars, and who only use them for needed transportation, worry about the danger caused by "speeders" – and with some justification. All too many young bucks that have little experience, climb into their stock econo-boxes and take off on the interstates at full tilt, and yes, they are both a nuisance and a danger to others. The real car enthusiast, more than most drivers, wants to drive accident-free for he does not want to damage his prize possession nor lose the right to drive it. Fast and safe; yes you can have it both ways. Statistically, you are as likely to have an accident driving 20 mph below the speed limit, as you are 20 mph over. A good driver at 100 mph has 40% less time exposure to the klutzes out there, than the 60 mph driver on the same trip. A good road car at almost any speed could negotiate most of our interstates, with their broad lanes and mild curves, but the limiting factor is of course the behavior of the other drivers. This is where things get interesting!

The real car connoisseur not only selects a solid car with good handling and control, but then he goes to work on it: better rims, high speed rated tires, heavier anti-sway bars and up-graded shocks as a first step, and also very important, an engine and transmission that can still deliver good acceleration at 100 mph.

Having a sure-footed and powerful car is just the beginning. Secure high speed driving is more than just stepping on the gas: it takes experience, thought, knowledge, and concentration.

EXPERIENCE –

Our newspapers are all too full of accounts of young drivers involved in deadly crashes. Driving is not only more complex than it first appears to be, but it requires muscle-memory reaction. This is the same muscle-memory training that allows acrobats, skaters, dancers, and even piano virtuosos to perform, execute, and react far faster than the thought process ever could. Reaction time through the thought process is near a half second; muscle-memory is virtually instantaneous, the only delay is the actual time of foot or hand movement. To realize how long your thought-reaction time is, try playing the parlor game where one person dangles a dollar bill between thumb and forefinger. Directly below the dollar bill you place your thumb and forefinger ready to grab it as it falls. Although you know it is about to fall and you are ready, and watching it, it will fall through your fingers every time. An experienced driver will brake, get off the brake to steer evasively, get back on the brake and do it all before he has the time to think. And of course, these instantaneous reactions must be the correct ones for the situation. It only comes with training and repetition. I hear many people complain about "those dangerous trucks." Actually these drivers have the training and the experience that makes them very predictable. Despite their size, tendency to jack-knife and poor acceleration, 70% of truck/4-wheeler accidents are shown to be the fault of the 4-wheelers.

Even in non-emergency situations, such as changing lanes, checking your mirror MUST be fully automatic, so you never miss it. How often, this year, have people blown their horns as you started to change lanes? Are you ready?

There is a saying that "the two things all men think they are good at are driving and making love." You know that isn't true. Ask any woman.

THOUGHT

It is apparent that many drivers simply haven't the presence of mind to think rationally about what they are doing. Just this afternoon I was in a 45 mph zone running down a steep grade and a yuppie type in a new top-of-the-line beamer was on my tail following not more than twenty feet behind. I tapped my brake; I waved him back, nothing doing. At this point an old pick-up loaded with wood pulled out in front of me. I had to brake hard. He got himself stopped in time but then continued to tailgate. If he had observed the "two second rule" he would have got to town less than 2 seconds later and not risked his 50K car. I saw two young girls do the same behind a semi on the same hill, where they could see nothing, only to stop at the Holiday Inn. I wondered why they were in such a hurry to save 2 seconds. Young girls, it has been my observation, are the worst tail-gaters. See if you notice the same thing.

On the interstate this thoughtlessness is obvious when one is in a long line of traffic in the hammer lane with only marginal following distance behind the next vehicle, and some one passes one on the right and then tries to cut-in in front reducing one's following distance to a car length forcing one to brake back. Why do they think they should be there instead of you? Are they special? Or just a jerk that would cut in line at the checkout counter as well? These people may well be just jerks or may be nice guys that just are not THINKING.

Hammer lane dawdlers, without a doubt the greatest aggravation to the go-fast driver, are part of this absent-minded crowd. Even on an un-crowded interstate they will run next to a car in the right lane for miles as the traffic accumulates behind. Flashing you lights, even blowing your horn goes unheeded. These drivers are so out of it that they fear if they accelerate to 3 mph over the speed limit to pass the car next to them they might get a ticket! I do NOT recommend close tailgating to scare them over, as these types are too unpredictable, and may just hit their brakes in panic or belligerency. If there is a semi behind you, pull over to the right lane and let the semi tailgate him. Their size is very intimidating and they will clear the lane for you.

Another hazard that these non-thinkers present you with is their lack of understanding of merging principles. They fail to understand why the last part of an on-ramp is called an "acceleration lane." They will often accelerate all right, you see them and throttle back to give them space – and they hit the brakes despite having a clear shot on. Be ready to shift lanes or do a hard stop. Why do they think it is easier to merge with a 50 mph speed differential than 5 or 10 mph or zero mph if they have a car with good acceleration? No, they don't think that; they just don't think.

Confident high-speed drivers are often the cause of merging problems, though, in that they try to pass at on-ramps, thus blocking right lane traffic from shifting lanes to let on merging traffic. This can be serious when involving trucks that not only have to merge at lower speeds due to their lower power-to-weight ratio, but also are so much longer than cars that they block off more lanes to the merging traffic. Truck drivers are very good about moving over to allow on merging traffic; they will do it every time, so don't get in their way as they can not accelerate quickly or easily slow, to otherwise make room for mergers.

These mindless actions are bad enough for average drivers running errands, but the high-speed driver must reason out all his actions if he is to enjoy his drive, arrive at his destination, and not be regarded as rude half-wit.

KNOWLEDGE

It is scary to realize how little one need know to get a drivers license. This dismal fact helps account for the fact that 80% of new drivers have a wreck within two years. Experience will help, but statistics from the insurance industry show that experience in itself is not enough. Drivers who have never had a wreck, are most unlikely to have one in the next 10 years; those who have had one are slightly more likely to; but those who have had three or four wrecks in the last few years are almost certain to have another one. The government, never one to help, creates insurance pools that insurance companies are force to subsidize (at our expense) so as to keep these turkeys on the road.

First of all, know your car. The insurance industry has known for a long time that cars that are two years old or less are twice as likely to be wrecked than older cars. They have never been able to explain this fact, but I would suggest that the drivers of new cars do not know them yet and push them into situations they cannot handle. Any changes you make, such as new tires, should be followed up with a period of careful testing and experimental driving until you have satisfied yourself that you know your car's new capabilities.

Don't take car industry hype, or salesmen's assurances for granted. ABS brakes, for instance was hyped as being a real life-save as far back as the early 70's. Now mandated by government edict, these systems have not lived up to expectations, and for obvious reasons. I had the opportunity to observe a demonstration of ABS brakes in operation at the GM proving ground. Having wet down a large skid pad, a Suburban was brought up and it's ABS disconnected. It entered the pad at 40 mph and the brakes hit. It stopped in about 4 lengths having slewed 90 degrees. Next, the ABS was reconnected and the Suburban ran again. With much enthusiasm it was pointed out that it stopped in a straight line; but it was two lengths further down the pad! Obviously as ABS brakes interrupt the braking function the stopping distance is increased. This is the reason that recent insurance analysis showed that cars equipped with ABS brakes had a slightly HIGHER incidence of highway crashes. In 1968 I patented an all hydraulic anti-lock brake system which did not pump the brakes as the present ABS do, but would back off the brake line pressure to a point where the wheels could just not lock. This system would have maintained the shorter stopping distance, but would have been more expensive to build.

The faster one drives, the more aware one must be of one's stopping distance. The "two second rule" which says that two seconds must elapse before one passes a point just passed by the car in front, or the "one car length for every ten miles of speed" rule work well at regular urban speeds, but these are both straight line formulas that, for instance, simply double the distance needed if you double the speed. The laws of inertia that control acceleration and deceleration are not straight line but work on the square of the speed. Thus if a car has a 100 hp engine and can do the quarter in 16 seconds, swapping the engine for a 200 hp engine will not give you an 8 second time. At 5mph a car can stop in a foot or so; at 10 mph, about 4 feet, and so on. At 100 mph, you may need 500 feet or more especially considering that with that length of stopping distance you will have to momentarily back off the brake to maintain directional control, or with ABS even longer distances.

The "two second rule" will give you only 176 feet to stop at 60 mph, which may be enough to stop when you see brake lights come on the car ahead of you, as you will have your following distance plus his, but if the car in front suddenly loses control, or tangles with another vehicle or obstacle, you will have only your following distance to stop in. The "one car length per 10 mph" rule would only give you 102 feet at 60 mph! You no doubt have seen two cars cruising together at 100 or better, with only 3 or 4 car lengths apart. Not smart.

The reality is that often one will not be able to relax with 500 feet of clear highway ahead. For example, every over-pass limits your vision to 100 feet or so, so your muscle-memory must always be ready to take control. It can only do so correctly if as you drive you keep aware of all your surroundings. Is someone on your tail? Is the lane next to you clear? Is the shoulder sound? Is the pavement slick, muddy, or good? Were there some slowpokes ahead in the right lane that might suddenly shift over to your lane? As you pass these facts into your mind, they will be there for instantaneous use in an emergency, when you do not have the time for thought. The fast driver more than anyone must be conscious of his surroundings at all times. Ever look in your rear view mirror and see a car you were not aware of, especially if it is a highway trooper's cruiser, right behind you? You were goofing off! You should have been aware of him long before. Once, as I crested on an over-pass, doing about 70 mph towing a car, there, stopped in the hammer lane, was a line of cars! Only when the smoke and smell of rubber cleared did I realize what the situation had been.

A very important fact that every high-speed driver must be constantly aware of, is that if you are cruising a lot faster than the surrounding traffic, you will turn up in places that the other drivers are not expecting you to be in. For example, a driver in the right lane is contemplating passing the car in front of him: He checks his side mirror and sees you 400 feet back; he checks his speedometer to double check whether he should pass; he checks his rear mirror and sees the grill of a semi; yes he had better pass, and he starts to pull out. He assumed you were doing 75 mph like most of the fast-lane cars were doing and the 400 foot distance would have been ample, but if you were doing 120 mph and he is doing 60, you will be on him in 4.5 seconds and he had spent 3 seconds making up his mind to pass since he last checked on you. It would be hard to slow your car from 120 to 60 in 1.5 seconds. This is a very common scenario that the fast driver finds himself in and helps explain why the faster you drive the more unpredictable other drivers seem to be. You must expect other drivers to assume you are not driving faster than 10 mph over the speed limit, which is the norm for the fast lane.

As hazardous as other drivers are, 46% of interstate fatal wrecks are single car accidents. As many accidents start out as single car events that turn into multiple car accidents as the out of control car careens into on-coming or adjacent traffic, it is obvious that most accidents start out simply by someone losing control, unassisted. Why?

Drivers dozing off explains some, but it does not explain the black skid marks one sees every other mile or so on the interstates. Most of these only show one vehicle's marks and frequently their marks cross on another indicating a car that is doing a 180 or more as it slid. As higher speeds obviously make the end result of a loss-of-control wreck far worse, what can the high-speed driver do to better his odds? High speeds will reduce the likelihood of going to sleep at the wheel by reducing the time it takes to get where you are going, as well as by keeping your adrenalin pumping, and avoiding boredom. As mentioned earlier, drive a car intended and set up for high-speed driving. Needless to say, an SUV is not it. These vehicles have better than twice the rollover death rate compared to sedans. SUV should stand for "Shopping Utility Vehicle," not "sport" as in "sports car."

It is obvious that most of these single vehicle crashes start by a minor emergency that is mishandled. A moment of inattention and a wheel drops off the pavement edge; a sudden jerk reaction on the wheel and an unbalanced car can start a spin. The knowledgeable driver will have trained himself to calmly wait while watching for a smooth spot to regain the pavement. The shorter the wheel-base, the more likely the loss of control as any deflection of one end of the car inputs a larger degree of deflection over a short wheel-base distance, and a light rear-end is more easily deflected than a heavier one. If one cannot have the ideal car, at least be aware of its shortcomings. A minor emergency can often start as a reaction to another car's operation although no contact is made. This is particularly true as many of the drivers out there are uneasy already just being on the interstate. A semi, hounding behind such a driver, can cause them to cut in too quick causing them to lose control or cut off another vehicle. Remember that 90% of the cars out there with you are not designed for, and cannot execute, fast emergency maneuvers. An elderly relative of mine, who knows little of cars, (he was a banker) was doing 60 mph in the fast lane in a 65 zone. A driver, obviously frustrated, finally was able to pass him on the right, and then cut in short to "show him." The poor old guy reacted by jerking the wheel to the left, and the little rental car did a full 360! Somehow he stayed in lane and got it under control without even stopping. I trust that no one reading this book would be as crass and as heartless as to treat someone like that no matter how aggravating their driving.

Inclement weather changes everything. A snowstorm scares drivers and makes them cautious; rain does not for some reason and the ensuing crashes are blamed on “slick pavement” rather than driver ignorance. On a 500 mile run on the southern part of I-95 you may see one accident. I drove this as the remnants of a gulf storm blew across Georgia and South Carolina and I saw five wrecks – all single car crashes: A small sedan on its side that was headed north now pointing south; a small pick-up with a tree where its radiator had been, others hopelessly buried in the brush by the road or mired in the median. There were doubtless many others occupying the tow-trucks and police as these wrecks were left totally unattended. Once again these drivers simply did not have the necessary knowledge, or equipment to handle the situation to successfully get the most speed for the conditions.

If quizzed, all drivers will acknowledge that wet pavement is slicker than dry. But one must recognize that it is at least three times slicker; more on asphalt and a little less on concrete. Other factors make it worse; mud, or road film after a rainless period, and rough pavement all make sudden loss of control more likely. A rough paved country road and a still damp surface sent me into a 360 in my early driving days; it can make one a believer! Another frequent error of “cautious” drivers that one must be on guard for is their braking on turns. With the lower available adhesion on wet pavement, adding the stress of braking to that of the cornering force is dumb, but if you are too close they can force you to do the same.

Although these factors all effect traction and control to the same degree, regardless of speed, whereas hydroplaning is a danger that only presents itself at high speed. As one’s speed increases it takes more pressure to rapidly squeeze the water from between the road surface and the adhesion tire patch. When this required pressure becomes greater than one’s tire pressure, the tire floats off the pavement, thus losing all directional control. It can be sudden, unexpected and disastrous. I saw a small sedan that had reached the bottom of a grade where the rain water had concentrated on a recently redone five lane road, that had suddenly hydroplaned out of its lane, across the center turning lane, and into an oncoming semi-rig. It was crushed to nothing and in a 45 mph area at that.

Two of the factors that sales and marketing types use to sell “high performance” cars to the public are both dangerous for fast driving in the wet. One is “aggressive” looking wide tires, standard on Corvettes and such. Obviously a wider tire meets more water on the road and must squeeze it further to the side. Furthermore the wider the patch is the shorter it is (see page   in the handling section of this book) thus here is less time for water to be squeezed out. Don't think that because the semis are running 70 mph in a heavy rain that you can too; they carry 120 psi in their tires, compared to 35 psi in a road car. That's over three times the water squeezing power that you have. The other factor that makes these alleged high performance cars a go-slow in the rain are the extreme raked windshields. With rain drops falling at a speed about equal to a high-speed car, a windshield sloped at 45 degrees will catch the largest concentration of raindrops, but as you slow down it makes little improvement as the rain still hits the glass en-mass even if you are stopped. Whereas in a large truck or bus with a near vertical windshield the only rain that hits the glass are the drops you run into as they fall. It is a surprise when driving a bus, even towing a car trailer; one can easily maintain 60 mph in a heavy downpour, while all the streamlined sedans are on the shoulder with their hazards flashing. The most important aspect in successful high speed driving (i.e. getting where you are going) is wisdom of knowing when to speed and when not to.

Many drivers today, raised on interstates, seem never to have learned the art of passing on two lane roads. In their eagerness to pass they tailgate the cat in front. When their chance to pass comes they must accelerate from the speed of the car to be passed. Unless they have a very fast accelerating car, they will need a long stretch to complete the pass. In areas that passing is difficult you can pass faster, and thus sooner in many cases, if you hold back two to three hundred feet behind the slow car. As you see a possible passing opportunity coming up (cresting a hill, an approaching straight stretch, etc) accelerate up towards the slow car. If the straight is clear you can start your pass running 20 to 30 mph faster than the slowpoke, for a faster shorter pass. If an oncoming car appears, one can throttle back and await the next opportunity.

CONCENTRATION

The endless, needless crashes – I saw another one today – caused by other drivers not paying attention could easily involve you. Try to spot them. Five or six people in a car, doubtless all yacking with the driver: Drivers dangling their arms out of the window – or feet, drivers eating (truckers tend to do this), cars that wander in their lanes, cars with children, cars full of teenagers, cars that do not run at a steady speed, and of course, driver glued to cell phones. A study done in 2002 found that cell phones were bad but less distracting than other things such as tuning the radio. In fact the distraction of cell phones was little improved by hands free systems, as the deleterious effect of cell phone use was that the driver is thinking about his conversation, not his driving. The manufacturers have not helped the distraction factor by coming up with ever more cutesy instrumentation: the little "smart sticks" on the column that control the turn signals/washers/cruise control/and high beams, but ever model has a different combination and on a different side. With most families with four or more cars, and frequent use of rental cars, one's auto-reaction gets confused and one fumbles for the turn signal and one activates the high beam instead, and every radio has a different layout for its controls. None of us are immune to these problems, and we must all discipline ourselves. I read the account of a man following a woman ahead of him as she lit a cigarette. She did everything by feel: felt in her purse for the pack, shook out a cigarette, stuck it in her mouth, but she had to look down to find the dash lighter, and as she did so rear-ended a car in front. And of course, the faster you drive the more happens while you are distracted.

I trust these thoughts on fast driving, garnered from over 50 years of driving fast cars, will give you cause for further thoughts to safely get you there quick.

As technology advances, the influence on the automotive suspension industry is gaining strength. It began with anti-locking brake systems. ABS systems can add maneuverability during hard braking, but it comes as a compromise as braking distance is increased. As most of all "driver assistance" systems are intended to make most cars safer for most drivers, it can be a nuisance and hindrance to advanced drivers. You will not see many race prepared cars utilizing ABS however some vehicles such as Corvettes with the sport or touring switch on the console are common. The active systems on vehicles of today are basically executed by brake actuation or variable shock valving.

ABS systems are mandated by the government on new vehicles including cars, trucks, buses and motorhomes. This is because statistically it is safer as far as insurance institute statistics. While on a trip to Detroit, General Motor's engineers gave us a demonstration of ABS systems on a suburban on a wet skidpad. On the first pass, ABS disabled, the suburban came skidding to a stop and the driver could not avoid a cone and slid over it. The next pass, ABS enabled, the driver was able to maneuver around the cone, but the suburban took almost twice as much skidpad to stop. I will leave it up to you and your driving ability as to if you would keep ABS systems active on your car. If you think you have the nerve to ease up on the brake while skidding towards some obstacle and avoid it and still stop, you have to be comfortable with your car and your ability.

Active handling systems found today are basically controlled by applying individual wheel brakes, changing shock valving, or preloading the sway bar. The sensor in most of these systems works with a gyroscopic sensor that can sense if the G forces matches the direction angle change of the vehicle for the speed it is going. Therefore it can sense if the car is oversteering or understeering. If it senses oversteer, the vehicle will apply rear outside wheel brakes to induce the front to come around and vice versa. Some systems have steering sensors which sense steering direction and amount, then use a hydraulic pump and cylinders to preload the swaybars to increase handling. On cars that utilize a selector switch or even speed sensors to change handling characteristics for given speeds, sport, or touring, the only thing that is changed is the shock valve settings and usually, the increase in the rebound. These can be useful even when other suspension components are upgraded.

Four-wheel steering is found on a few models, been around since the 60's, but has never amounted to more than just a fad. The only useful application of four wheel steering is Delphi's steering system on the GMC trucks. It is noticeable only while maneuvering in parking lots or backing up trailers. As far as helping handling it is hardly noticeable. On Mitsubishi GT4 in the 90's and Hondas in the 80's, there were only loose bushings in the rear that allowed the caster to steer the cars. On the track, it felt as thought the car was over-steering dramatically. The rear steering really hurts handling quite a bit. This is due to the fact that when the car is put into a turn and the weight is transferred to the outside of the car in the direction of momentum, the rear steering allows the car to follow it. This makes the recovery of the turn (straightening) require more steering correction in the opposite direction. Next time you see four wheel steering advertised, you will notice it will not be offered on future models.

OFFROAD

Off-road driving setup is completely opposite of what you want to do to safely drive on-road. Off-road, especially for rock-climbing, requires a very soft suspension with tons of articulation and flexibility. Swaybars are not wanted anywhere near a rock crawler suspension unless you want to drive it to your favorite rock piles. This is why ADDCO developed and patented a disconnecting swaybar. A vehicle with a high center of gravity, soft springs, and short wheelbase needs a sway bar more than any other vehicle to make it tolerable and safe on the street. However, swaybars really limit a vehicles capability off road. Not only is a soft suspension needed offroad, it makes it far more comfortable offroad without the bars connected.

The myths about offroad suspensions and lift kits are that big, heavy, and stiff is the way to go. The truth is that nothing could be worse for offroading. The lighter, the better. There will be less mass to haul over the rocks, through the mud, or up a hill. The stiffness of the springs is often overlooked. The suspension on most truck lift kits are stiffer than stock, because they are designed to be driven on the road, while looking cool. They are stiffer to make it still feel stable with the added increase in center of gravity. However, the only benefit to most of these kits is clearance, but climbing over obstacles is limited due to lack of resiliency. If these kits were sprung to work well offroad, they would be unmanageable onroad. To properly setup a lift kit, it is important to know what you are going to be doing with your lifted truck:

Rock climbing, soft sprung, medium shocks with lots of travel Limiting straps etc. and disconnect bars if you still Drive on the road.

Mudding, Sand, medium sprung, heavy shocks and good swaybars. Most mudding trucks are driven fast off road, stability is important.

Highway, Stiffer suspension, heavy springs and swaybars.

IN SUMMARY

Going back to our goal:

We want to make a car handle swiftly and surely with sufficient stability to make it predictable, safe and FUN to drive. On rough or smooth pavement, it should be able to corner fast and effortlessly. If it is set up to race, it should be predictable right up to the adhesion point.

Step No. 1

Gear tire capacity to the weight of that end of the car. Buy tires for your projected use of the car, not for their looks. Large letters or stripes won't do a thing for the tire's performance.

Step No. 2

Eliminate as much of the body lean as possible via anti-sway bars. It should be kept down to 5°, at maximum point of cornering control, for a sports or competition car. For street, use your own judgment.

Step No. 3

Balance roll stiffness: If you have an anti-sway bar that is of marginal firmness, replace it with a firm replacement bar and balance the car with a rear bar kit. Of you have no bars, install firm front and rear kits.

Step No. 4

Match your shocks to your use and your car's new capabilities. Install the nitrogen, variable compression rate type.

Step No. 5

Keep the suspension as resilient as possible. It must absorb the bumps if you are to maintain adhesion.

These steps WILL WORK on your car. They are the principles to which every successful sports or racecar is built. Your car will look the same as it did before, but when you put it in gear – it will be a different machine entirely.