Suspension Evolution and Design

In this "information era" why is it that most manufacturers of various products offer lavish and expensive catalogues with fancy pictures and graphics yet still supply no information as to product design or to allow for any customer education. Could it be because they're afraid that the information might scare away more customers than it would attract? This information would allow their customers to make better-informed decisions as to what or whose product would be best suited for their application (and we're not just talking about street rod chassis here).

At Chassis Tech, we believe in customer education so that our customers can determine what suspension system is best for their application and why. If we don't have what they need, at least they can take this information along with them to help with their search and then possibly even know what questions to ask along the way. We have learned over the years that an educated customer is a satisfied customer and the best customer we could have. This way they not only appreciate our products more but also know what questions to ask us and others to help them with their project. One of our main goals is to promote street rodding and helping fellow rodders build and own the safest and best performing street rods possible with more emphasis on function and drivability and less on glitz and glamour.

Front suspensions have evolved a long way since the inception of the automobile over one hundred years ago. The first autos were nothing more than horse-drawn buggies converted to engine-powered vehicles. These first autos had exactly the same suspensions as those early horse-drawn carriages only with an engine and some type of primitive steering mechanism added. These early vehicles had straight axle suspensions and the same "buggy" springs used by their predecessors. With the slow speeds that these early vehicles attained, this type of suspension and steering was more than adequate.

As time elapsed and the automobile evolved so did the streets and highways they were driven on. Instead of 5 or 10 miles per hour these new vehicles were soon speeding along at 30 to 40 miles per hour. These new speeds required much better suspension and steering designs than the earlier vehicles and thus the first independent suspensions were born. With the bias-ply tires and the less than perfect roadways that these vehicles ran upon, the early independent suspensions worked just fine.

But as roads improved and horsepower (speed) increased, these early type suspensions became quickly outdated, as did the steering, brakes, and almost virtually every single component of the chassis including sometimes even the frame itself. Chassis designers were constantly playing catch-up with the engine builders who were supplying more and more horsepower. As speeds increased, the automobile chassis became not only more important to the function of the automobile in drivability and comfort but for safety as well.

Through the 1930's, 40's and 50's, these suspension designs went through radical changes as designers and engineers searched for better and safer systems. By looking at some of the designs of this period, we can easily see that there was indeed a lot of experimenting taking place. It wasn’t until the late 1950's and early 60's that the engineers really started to get a handle on how to really make the automobile chassis work well.

No sooner did they have it fairly well figured out but along came more improvements like integral power steering, disc brakes, and possibly the biggest single improvement of all -"radial tires". This new tire design completely changed the way independent suspensions (all suspensions for that matter) were designed. Although adding radial tires to earlier suspension designs definitely improved them, the full benefit of these tires could not be achieved until chassis designers redesigned the suspensions to fully utilize them. Items like the caster and camber curve built into these suspensions needed to be altered to properly take advantage of the new radial tires, as well as other facets of the suspension like anti-dive, roll centers, static alignment settings, and even the steering system itself.

It wasn't until about the mid 1970's that the engineers were able to even come close to accomplishing everything. However, not all chassis were redesigned at the same time. This was the case, for various reasons, for all the different automobile manufacturers (Ford, Chrysler, GM, etc.). Certain body styles, that were not ready to be changed, retained their outdated chassis designs well into the 70's even though the radial tire had been around for several years.

By 1975, however, most passenger car chassis had been improved for use with the new tire. It is very important to keep this in mind when comparing different year model front suspension designs for use in non-factory applications (such as a street rods). For that reason, we should focus the rest of our discussion only on those front suspensions designed and used after 1974.

Suspension Components

To appreciate the different suspension designs, we must first understand the differences between them and how that relates to the function of the automobile. We will limit our discussion to twin "A" arm (upper and lower control arm) suspensions, as this comprises nearly all independent suspensions used in street rod conversions today.

1) Lower Control Arms

The lower control arm is probably the single most important component of the independent front suspension. It is very important to understand that the lower control arm not only supports the entire weight of the front of the vehicle (through the lower ball joint) but, also, controls the front wheel movement throughout its travel. This, in turn, determines how well (or poorly) the automobile performs (rides and handles). For that reason we will start here with our discussion.

The term "control arm" begins with the word "control" and that is just what it should do - "control the chassis". The pavement that we drive upon cannot be controlled therefore the tires on our vehicle must be allowed to move with the contour of the road. The trick here is to allow the tire to move independently of the auto with the least amount of negative feedback to the chassis and steering while keeping the tires planted firmly and squarely on the pavement. This is accomplished mainly through the lower control arms. The overall dimensions of the control arms and how they are mounted in relation to the chassis has a very large effect on how well (or poorly) they allow the vehicle to perform.

In order to understand the lower control arms main function, we must look at the forces put upon it through the tires as we move down the road. Since we spend most of our driving time moving forward (as opposed to reverse), it makes sense to develop a suspension to take advantage of that fact. As a tire rolls down the highway, it encounters imperfections (rises and deflections) in/on the pavement that force our tires not only to move up and down but rearward as well.

Yes, I said rearward. Visualize, for the moment, the front forks on a motorcycle; notice how they are angled forward. One of the reasons they are angled this way is to allow the tire to move rearward as it moves up. This is done simply because, as the tire encounters a rise in the pavement, the force from this rise contacts the tire slightly ahead of the axle centerline trying to push it not only upwards but rearward as well. Now if the motorcycle were built with the forks straight up and down, it would not only ride poorly but handling would suffer as well. So, let's compare this feature to the automobile lower control arm design.

There are three basic ways to mount the lower control arms to a chassis:
A) Square
B) Skewed rearward
C) Skewed forward

A) Square mounted lower control arms exist when, while looking from overhead, the axis running through the inner control arms mounting points is parallel to the centerline of the chassis. This is a very common (and simple) method for the mounting of the lower control arms. It has been used by all of the various auto manufacturers at one time or another. It was used on the Mustang II suspensions (and its clones) as well as torsion bar suspensions, trucks and many other chassis. It can be found in front steer (steering ahead of the axle centerline) as well as rear steer (steering behind axle centerline) versions. It is a very simple design and very easy to build a chassis around, however, as you will see it does not allow for the best in overall ride and handling.

The reason for this loss of performance can be understood by visualizing the lower ball joint movement in bump and rebound from the side of the chassis. With this type of lower control arm mounting the ball joint moves straight up and down with no rearward movement at all. As we learned earlier, the front suspension needs to move slightly rearward as it moves upward in order to allow for the smoothest possible ride. Square-mounted lower control arm geometry does not allow for that. Many suspensions like this use large soft rubber strut rod bushings in front of or behind the control arm to cushion this rearward movement. This is a very inefficient way to cushion the rearward movement as this allows the wheel to move about erratically, which changes the alignment settings as it moves, and transfers negative feedback to the chassis and driver. This is a very uncontrolled situation.

Removing the strut rod and bushing and replacing it with a full lower control -arm design (on the same axis) does in fact eliminate the erratic front to rear movement of the wheel but will create a harsher ride as a result. Now, if we angled this control arm down at the rear and/or up at the front we could then allow the wheel to move rearward and properly absorb the road imperfections. Unfortunately, doing this would disable the front suspensions anti-dive and create excessive nose-diving and weight transfer during braking. The inner axis for the control arms should always be mounted parallel to the ground. Light weight vehicles (under 2500 lbs.) seem to be a more acceptable place for strut rod type suspensions as these cars put less force (due to less weight) against the strut rod bushing and use up less suspension travel than do the heavier (2600 lbs. and up) vehicles.

B) Skewed rearward lower control arms exist when the inner-mounting axis is installed at an angle to the centerline of the chassis so that the front inner mounting point is further away from the chassis centerline than the rear mounting point. This design is usually found on rear-steer (steering linkage behind the front axle centerline) suspension systems. This type of control arm mounting was usually required to supply the clearance necessary to pass the steering linkage under the engine and past the control arms to the spindles. This design was generally reserved for those vehicles that could not use front steering due to radiator and/or body clearance problems

The main flaw to this type of lower control arm mounting is that it forces the lower ball joint to move slightly forward as it moves up and this is just the opposite of what we want to obtain. Mounting the inner control arm axis 1 to 2 inches higher than the ball joint height usually counteracted this for. This makes the ball joint move almost straight up instead of forward for the first 1 to 2 inches of travel. This, however, still does not allow the ball joint to move rearward during upward travel and therefore will not contribute to the smoothest possible ride. The inner axis, however, is still designed to be mounted parallel to the ground.

A good example of this suspension design can be found on the 67-69 Camaro as well as the 68-74 Nova. This suspension design should only be chosen when the body design does not allow for a front steer design. GM discontinued this suspension design after the 1974 Nova in favor of its skewed forward front steer design.

C) The skewed forward lower control arm design also exists when the inner mounting axis is installed at an angle to the centerline of the chassis, but with the front inner mounting point closer to the centerline than the rear mounting point. This suspension was originally designed in the early 1960's and then redesigned in the 1970's for use with the radial tire. It is usually only found with the front steer design and is the basis for virtually all GM rear wheel drive mid-size, intermediate, and full size passenger cars built since the mid 1970's as well as S-10 pick-ups since 1982 and full size pick-ups since 1988.

This control arm design still mounts the inner control arm axis parallel to the ground like the other suspensions but from the overhead view angles the inner axis the opposite of the skewed rearward design. This control arm design allows the ball joint to move rearward as it moves up around a controlled axis (no strut bushings to compress here). This, in turn, allows the suspension to absorb rearward movement, as it should without the erratic movements associated with strut rod bushing compression and still doing so while maintaining the proper anti-dive. This type of control arm mounting also allows the caster alignment to be maintained closer to its initial static setting while in bump or rebound, something the other two designs cannot do.

In recent years Ford and Chrysler both have adopted this suspension design for not only some of their passenger cars but for their pick-ups as well. This lower control arm mounting design is by far the most modem and the best design available for today's rear-wheel drive vehicles when vehicle performance is the main chassis priority (and why shouldn't it be?). In the 1980's, some GM rear-wheel drive vehicles changed to the Mcpherson strut type front suspension, which took the place of the spindle and upper control arm, but still maintained this lower control arm geometry and steering system.

Lower control arm length is very important to the proper function of the independent front suspension. It can generally be said that longer is better when it comes to control arm length although there are practical limits (i.e. engine clearance). To determine the minimum length required for the lower control arm, we merely need to compare factory vehicles wheelbase lengths with their respective control arm length.

If you measured several factory vehicles wheelbases (manufactured after 1975), you could see that a direct relationship exists between wheelbase length and lower control arm length (as the wheelbase grows in length so does the lower control arm). In fact, you would find that (at least for those vehicles known to have had excellent chassis performance) their lower control arms were at least l/8th the length of their wheelbase!

This longer control arm length promotes smoother ride and better wheel control than would a shorter control arm. This longer length allows the wheel to move from bump to rebound with the least amount of sideways scrub, which improves all aspects of chassis performance as well as decreasing negative feedback to the chassis and driver.

It should also be noted that in order to measure the true (effective) length of a skewed forward (or rearward) control arm we must measure along an imaginary line between the two lower ball joints. By measuring from the center of one ball joint along that line to where that line crosses over the inner control arm axis of that control arm is the true (effective) length of the control arm.

2) Upper Control Arm
The length, as well as the mounting location, of the upper control arm is mostly dictated by the length and mounting location of the lower control arm, as well as by the roll center height and camber change requirements, and by the amount of anti-dive percentage needed for the automobile. The upper arm should be at least 1/2 the length of the lower control arm for the proper camber change curve (for maximum tire adhesion while cornering). Camber is the inward or outward leaning of the top of the tire in relationship to the pavement. Caster is the angle of the spindle as viewed from the side. For maximum cornering potential, the tires tread should remain as square to the pavement as possible at all times.

Since the body/chassis of all cars lean while cornering due to weight transfer, the suspension system should have the necessary amount of camber change gain built in to accommodate the lean of the car and the deflection of the tires sidewall. The mounting height of the inner pivot point of the upper control arm, as well as the outer pivot point (ball joint) and spindle height determine not only the amount of camber change built into the suspension but the roll center height as well.

Generally, as a roll center height increases so does the amount of camber change that is built into that front suspension. Since the length and mounting location of the upper control arm directly controls the camber change curve, roll center, anti-dive and caster change requirements of the car, it is very important that the donor car be of a comparable weight and balance (front to rear ratio, center of gravity height, etc.) as the street rod you are building.

The front-to-rear weight ratio also affects the anti-dive percentage since the anti-dive requirement depends upon how much weight is transferred to the front suspension during braking and not just upon how much static weight there is. A car with a heavy rear weight may require more anti-dive than the same car with less rear weight. Most factory production cars have an anti-dive percentage averaging between about 25% and 50%.

The roll center height is built into the front suspension primarily by the elevations of the mounting points (and relationship) of the upper and lower control arms. A good roll center height for most any street rod weighing about 2500 lbs. or more should fall somewhere between 2" and 4" above ground.

A higher roll center than this would increase the camber change to drastically and cause excessive tire wear to occur. Consequently, a lower roll center (at ground level and below) would decrease the camber change curve and decrease the handling potential of the automobile. Unfortunately, many of the aftermarket front suspension systems available today have a very low roll center height (at ground level or below) and will never allow the auto to reach its full handling potential.

Caster change is the increase or decrease of the caster angle as it moves in bump or rebound. When we align the front suspension of an automobile, we usually set static caster somewhere between 2' and 4' positive. As the suspension moves into bump or rebound ideally it should remain as close to the original static setting as possible to minimize unfavorable steering feedback to the driver.

However, most all factory independent front suspensions, with any amount of anti-dive built in, will gain some caster as it moves into bump and lose some caster as it moves into rebound. This is due mainly to the anti-dive angle built into the upper control arm mounting location. As the suspension moves into bump, the upper ball joint moves rearward and gains castor. Then as the suspension moves into rebound, the upper ball joint moves forward and loses caster.

But remember, we said earlier that the lower control arm (on skewed forward designs) also moves slightly rearward as it moves up and thus this helps eliminate some of the caster gain built in by the upper control arm mounting. Therefore, you can have the necessary anti-dive percentage built in without all of the unnecessary caster gain normally associated with it if you use the skewed forward mounted lower control arm design.

3) Spindles
The spindle height (ball joint center to ball joint center) is also very important to the suspension system and is designed as a complementary unit to work with the upper and lower control arms to maintain the proper geometry. The king pin axis (angle) built into a spindle varies according to such factors as the weight of the vehicle and wheel width and offset for which it was originally designed. Generally, heavier vehicles require more angle than lighter vehicles. Thus, using a spindle from a lighter vehicle under a heavier one can cause problems such as unfavorable steering feedback to the driver and/or chassis. Changing spindles from one suspension to another should not be done without full knowledge of suspension and steering design. However, if we chose the correct factory suspension system for our street rod in the first place, it should already have the correct spindle for our application.

4) Brakes
Brakes can many times be the first indicator that the suspension system choice under a particular street rod is just not adequate. How many times have your seen or heard of a fellow street redder who has installed a later model suspension system under his street rod only to find that the brake size is just to small to adequately stop the car? This should be the first indicator that too much weight, overall, is being transferred to the front end of the car during braking. And if the brakes are being overloaded, then so must be the entire front suspension.
Keep in mind; you cannot just look at the static weight on the front suspension but also how much weight is being transferred to it during braking. Very simply if we look at only those front suspensions from factory vehicles with a comparable weight and wheelbase to our street rod then the factory brake size should be more than adequate. As for disc vs. drum brakes, it’s obviously a no brainer so there's no need to go into that discussion.

5) Steering
Basically there are two types of steering designs, recirculating ball (steering box) and rack and pinion. Upon comparing different size/weight vehicles it doesn't take long to see that the smaller/lighter (about 2500 lbs. and under) vehicles many times use a rack and pinion whereas the larger/heavier (about 2500 lbs. and up) use the steering box design. The rack and pinion was designed primarily because these smaller more compact cars needed a smaller and more compact steering system.

Generally the shorter the vehicles wheelbase the quicker the steering ratio and the longer the wheelbase the slower the ratio. Using a steering system from a shorter (and usually lower center of gravity) vehicle in a longer vehicle usually creates a twitchy and hard to drive auto simply because you can never relax while behind the wheel. The steering ratio should be matched to the vehicles wheelbase, center of gravity height, and to the type of driving you intend to do. By the time we get to the steering mechanism anyway it usually has already been chosen for us. In other words, if we have narrowed down the correct suspension choice by way of the physical aspects of our car and by the control arm design then we probably have already chosen the correct steering system simply by default.

To often a street rod is built utilizing a suspension and steering system from a short wheelbase low center of gravity auto such as the Corvette under a much longer much higher center of gravity car only to find it doesn't ride and handle like expected (at least not like it did under the Corvette) simply because the physical aspects of the two vehicles are to far apart. In this case the longer wheelbase makes the Corvettes steering ratio to quick and the higher center of gravity amplifies it.

The steering system on independent front suspensions are mounted in one of two ways: Either in front (front steer) of the suspension or behind (rear steer) At high speeds, the Ackerman requirements of the steering changes such that the front-steer system will allow for better and more precise handling. The rear-steer system has a better Ackerman for slow (parking lot) speeds but does not work as well at high (freeway) speeds. Radial tires also tend to like front steer systems better partly due to the their elasticity over bias ply tires. Most rear steer systems were designed prior to the radial tire becoming standard equipment and at that time the rear steer system was more acceptable. Both will steer the vehicle but the front-steer system has the definite edge when it comes to handling.

The steering system must be designed to function properly with the suspension system it is mated to and since the factory has already done this for you leave it alone. It also should be noted that most of the time attempting to adapt a rack and pinion to a suspension that was not originally designed for a one is usually the easiest and quickest way to create a major bump steer problem, so don't try it!

6) Springs, Shocks, and Stabilizer bars

Choosing front springs for any street rod is not that hard if you have chosen the proper front suspension to start with. Usually, the springs from the donor car are within the range of the street rods requirement if the suspension was chosen correctly. Many times the donor car was available with different engine combinations requiring different spring rates already giving you a wide range of choices for your project. Also, many factory models cars were available with handling packages which means sometimes not only did they have slightly stiffer spring rates but possibly sat a little lower as well. These cars also usually had larger stabilizer bars.
If the suspension system you chose was available with any of these options then you have more freedom to tune your street rod to your preference and driving style. There are whole books written on spring rates and stabilizer bar combinations and more still being written today. We will save the rest of that discussion for another time but end by saying that if you have chosen a suspension from a comparable size weight vehicle to your own then there should be a factory spring set made for that application that will work correctly under your street rod.

Conclusions

Choosing the best suspension for any application is not that hard if you simply use your own common sense and realize its the vehicles overall weight and weight location that dictates what suspension will work best for your application and its the wheelbase (and a few other factors) that determine the proper steering ratio required, the rest just falls into place.

Be aware, however, that the best suspension for your street rod is very seldom the easiest to adapt and that the extra effort and expense of installation will quickly be forgotten when the finished product drives and handles the way an automobile should. Don't choose a suspension system based upon how cheap or easy it is to adapt (which has been a common mistake by many a street redder in the past). Choose it because it will allow your car to drive and handle the way it should like a comparable weight/ wheelbase late model vehicle does.

All manufacturers of suspensions made to fit your application will claim the "proper geometry", "the proper anti-dive", and the "best ride" but how can this be when the suspension they use is sold for a 2000 lb Model A as well as a 4500 lb mid 50's sedan. Usually these suspensions are made with very short control arms that do allow them to fit within the tightest of locations and under the smaller lighter cars. In fact they generally work just fine under the smaller cars but under the heavier longer cars they will never allow you to fully achieve the ride and handling potential that the longer control arm suspension will.

Remember all the springs, shocks and stabilizer bars in the world will not turn the wrong suspension into the right one!

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