12 Things to Know about ‘Lifted’ Suspension Engineering:

1. **Roll-Center Geometry**.

Roll-center is the imaginary point around which the body leans in a turn and also around which it moves when the suspension flexes on a trail. There is one roll-center each for the front and rear suspensions. The location of each roll-center for most solid-axle suspensions is defined by the geometry of the track-bars (aka panhard bars). On late-model solid-axle Jeeps, the front track-bar runs in front of the axle from the frame on the driver’s side to the axle on the passenger’s side. The rear bar is behind the axle and the attachments are reversed. The actual roll-center is found by drawing an imaginary vertical line down the middle of the vehicle and another straight line between the bolts at the ends of the track bar (ignore the bends in the bar). The intersection of these two lines is the roll-center.

Roll-center is important to suspension engineers because its correct placement relative to the center of gravity is central to managing both body lean and weight transfer in turns. The farther apart the roll-center from the center of gravity, the more lean you have and the more handling degrades. If the roll center location is not ideal for the vehicle, it forces the engineer to try to ‘correct’ the problem with spring and/or shock tuning – which always results in a loss of performance somewhere else. This is one of the critical geometry parameters that must be right before you tune, or lift, the vehicle. When properly located relative to the center of gravity the roll-centers (defined by track bar placement) will allow the engineer to further optimize overall suspension performance via springs and shocks, etc. – without the burden of having to attempt to compensate for poor geometry. If one looks at the track-arm locations on AEV JK suspension systems, one will see that both the front and rear track-arms have been significantly repositioned to place the roll-centers in the optimal locations for either 3.5 or 4.5-inch lift heights.

2. **Control-Arm Geometry**.

Control-arms are the links in the suspension that connect the axles to the frame and locate them fore and aft. On most solid-axle suspensions there are two arms – one above the other – at each corner of the vehicle. In stock, un-lifted form, they are usually running roughly parallel to the ground. The reason for having an upper and lower control arm is to keep the axles from ‘flipping over’ due to braking or acceleration forces. But their length and angle of operation relative to the axles also define some important imaginary geometry points called ‘instant centers’. Like roll-centers, instant-centers and their relation to the center of gravity determine most of the ‘automatic’ handling behaviors that happen during bumps, turns, acceleration, braking, and combinations of these. Some of these behaviors have names that may be familiar such as anti-squat, which is geometric resistance to the rear end dipping during acceleration. But there are more behavioral parameters such as anti-dive (similar to squat but for the front end during braking), and roll-steer that are just as important to overall vehicle setup. Roll-steer occurs when the lean of the vehicle in a turn causes the control arm geometry to actually skew the axles like a skateboard – actually producing its own vehicle direction change without the driver's input.

Depending on how the geometry is set up, this effect can be a good, stabilizing one such as under-steer or a bad, destabilizing one such as over-steer. Sometimes packaging and ground clearance considerations can make it difficult or impossible to achieve good geometry on a lifted 4x4. But if geometry is ignored, bad qualities like over-steer can render the vehicle twitchy and hard to handle on mountain roads. In simplified terms, 'bad' roll-steer is caused by any lift kit that increases the control-arm angles too much, adding dangerous amounts of roll over-steer. This effect is most dramatic in rear suspensions because they have no driver controlling or compensating for direction of travel via steering. Roll-steer is caused by the fact that non-horizontal arms also move the axle fore and aft as they move up and down due to body lean – and the steeper the arms, the larger the fore-aft movement.

To some extent, longer-than-stock arms (i.e. 'long-arms') can improve all parameters by reducing control-arm steepness and re-locating the instant centers. But this is only true if the left and right long-arms are properly angled toward one another at the chassis end to a degree that's appropriate for their side-view angle to the ground. If both angles are not correct, the 'long' benefit is wasted. Thus for both 'simple' (short-arm) and more complex long-arm systems, a suspension engineer must know how to locate control arms for the best possible combination of all the effects, which requires them to consider everything from handling priorities, driver preference, and other suspension factors including ride frequencies and shock valving. Done properly, correct geometry is the basis for a safe, enjoyable and highly versatile suspension. An example of how AEV optimizes the angle of the control-arms in its JK suspension systems can be seen in its front Geometry Correction Brackets. These brackets not only improve the approach angle of the front control-arms, they change the location of the instant-center and create a significant anti-dive quality under hard braking.

3. Frequency-Based, Progressive Rate Springs.

Frequencies are the speed at which a spring-mass system moves when disturbed. In the case of a Jeep, the body and chassis are the mass, while bumps (and also handling maneuvers) are the disturbances. Since there are front and rear springs, the forward and rearward halves of the Jeep actually represent two spring-mass systems that must interact with each other. To understand the concept of frequency-based spring rates, think of a shock-less vehicle driving over a single speed-bump. When the front end hits the bump it starts to oscillate up and down at a certain speed. This is the front's ride frequency. The rear encounters the same bump at a time delay determined by wheelbase and vehicle speed. The key is that the rear needs to react faster than the front so that the oscillations of the rear can catch up to the front in about one cycle (from ride height to some amount of 'up', then 'down', and back up to ride height). This is important because if the vehicle doesn't naturally tend to level out quickly after a bump, the shocks will be overtaxed with trying to control body position/motion instead of their real purpose of simply getting rid of the oscillations.

So to ensure the best possible combination of ride and handling, the front and rear spring rates must be derived to create the proper front and rear frequencies relative to one another.

Proper suspension engineering will consider the sprung weights of the vehicle, wheelbase, load-carrying requirements and the relevant speeds the vehicle will encounter. To further enhance the spring's ability to maintain proper frequencies under varying load conditions, a suspension engineer will design a progressive-rate spring (especially for the rear), which will keep the frequencies closer to constant over the expected load range.

Worth noting is that determining a spring's ideal rate is not as simple as weighing the vehicle and adding on some extra capacity for passengers and cargo. Unfortunately this is a common approach in the suspension aftermarket where the frequency-based method used by the vehicle makers is not known let alone applied. All of AEV's coil springs have been frequency tuned just like OE springs.

4. Ideally Tuned/Matched Shocks.

Shock absorbers are designed to serve two functions: damp out body motions and serve as the downward/rebound (or droop) limit of the suspension travel. Shock tuning should be undertaken after geometry, spring design, and stabilizer bar sizing is complete. When approached in this order, the shock tuning is free to focus mainly on refining ride quality rather than masking handling issues caused by bad geometry or incorrect spring rates. Actual shock tuning itself is the special way in which the shock's internal parts (valves) are optimized so that the damping forces they generate are ideally matched to the spring frequencies, geometry effects and weight of the vehicle.

Interestingly, despite all the advances in computer modeling, auto companies still employ dozens of test drivers to tune shocks on vehicles because it takes many iterations and significant seat-of-the-pants feedback before the ideal tuning recipe can be determined. Further, shock tuning can't be done efficiently (often not even effectively) on normal roads. It requires specially designed "ride roads" at a proving ground with select bumps and other features that can be driven over and over again – in exactly the same way – until the ideal valving can be determined. Typically this process can take many months, thousands of miles and literally hundreds of shock rebuilds. To develop shocks for AEV's JK suspension systems, AEV teamed with Bilstein at Chrysler's proving grounds in Michigan. The end result was a shock that helped bring out the best in AEV's geometry and spring rates. This allows AEV JKs to remain on course over washboard surfaces and even to carve corners with racecar-like confidence – all without compromise to ride comfort.

5. Steering Geometry.

Since any street-legal vehicle must have a mechanical steering connection from driver to tires, this system is critically affected by any suspension height change. Most enthusiasts are by now aware that for solid axle vehicles, the track-bar and steering drag-link must be parallel to avoid 'bump-steer,' but that's just the beginning of the considerations. Roll-steer is caused when the steering linkage doesn't pass through the roll-center of the suspension geometry – meaning that every time the vehicle leans or articulates, there is a steering input that the driver didn't intend. This happens because there is a small lateral shift of the axle relative to the pitman arm on the steering box. This shift effectively steers the vehicle without driver input. To visualize this, think of holding the steering wheel (and consequently all of the linkage) steady and moving the axle side-to-side. Since the steering didn't move but the axle did, the steering knuckles must rotate to make up the difference – which creates unwanted steering. On twisty, bumpy roads, roll-steer, along with the larger problem of *rear* suspension roll-steer (see #2), can keep the driver very busy trying to maintain the intended direction. This is because the vehicle is always doing 'extra' things the driver didn't intend. This quickly leads to driver fatigue and frustration with the behavior of the vehicle. To eliminate this in AEV's JK suspension systems, AEV engineers developed the JK High-Steer Kit. This kit repositions both the track-arm and steering drag-link. The new positions flatten the operating angles and ensure that the drag-link passes through the roll-center of the suspension geometry. The overall result is reduced driver fatigue, improved safety and very precise steering response.

6. Control Arm Joints & Bushings.

For factory vehicles, the bushings in the control arms seem boringly simple with little to do but 'load up' when the suspension is severely articulated. In the late '90's the elimination of these 'loaded bushings' was fingered as the key to more flex for vehicles such as the then-new Jeep TJ. Indeed several off-road suspension companies staked their name on kits that revolved in large part around replacing boring rubber with fancy 'swiveling' joints of many designs. The problem is that those rubber bushings are just as much a key tuning element of the overall suspension as are the springs, shocks, and stabilizer bars. The purpose of the stock bushings is to provide a delicate balance between providing enough 'give' for low ride harshness, while remaining durable enough to last for an acceptable range of miles. Engineers accomplish this by choosing the ideal durometer (material stiffness) combined with sizing. The reality is that bushings literally are a science of their own. For example, track bar bushings that are too soft result in vague steering and a tendency to shimmy (aka 'death wobble'), but bushings that are too stiff can cause the bar or brackets to fail. Meanwhile control arm joints that are all-metal or have thin hard-plastic races in them, provide no isolation and invariably result in a harsh ride and bracket failures. Yet the reason they exist in lift kits is because once the off-road aftermarket discovered that stock suspensions have some inherent 'bind' at large degrees of flex, they replaced the bushings with joints that seek to eliminate the bind altogether. But they ignored (or were unaware) of the fact that the bushings we actually coping with bind quite well and they were also absorbing part of the impact forces from bumps, etc…which is actually their primary function!

The reason why this impact shock absorption is so important is not just for ride comfort, it's also there to keep the chassis brackets and even the arms themselves, alive. With fewer or no soft bushings in the chassis, it begins to self-destruct even from seemingly mild on-road impacts. The brackets, or the welds that hold them, slowly start to crack and eventually fall apart. Often this sort of failure of the stock brackets, etc. is blamed on the original vehicle maker, which is simply unfair and incorrect because the elimination of isolation from the bushings is the primary culprit! Thus the challenge with control arm bushing design for on/off-road suspensions, is to add a tolerance for 'misalignment' (bind) that comes from increased articulation while preserving the isolation that keeps the chassis together and passengers comfortable.

In some cases such as Jeep TJ, the factory control arm bushings are actually very good at isolation (via a lot of relatively soft material) and they also tolerate a considerable amount of articulation bind. Unfortunately, the arms they're part of are short and weak and thus not up to the rigors of hard off-roading. But all too often the aftermarket replacement arms come with non-isolating 'flex joints' that sacrifice ride quality and durability for the sake of flex. In reality that flex could have been had by keeping the bushings and just upgrading the arms. In other cases such as Jeep JK, the arms are longer and strong enough for even hard off-road use and contain similar factory-tuned and durability-validated bushings as the TJ. So no replacement for the sake of off-road performance is necessary. This is the reason that AEV has chosen to retain the factory control arms in its JK suspension systems.

7. Electronic Correction/Calibration (ProCal).

This is the newcomer to the world of suspension modification. Now that Electronic Stability Program (ESP) is standard on every new Jeep, a suspension system must be designed to work with these stability programs. This is because their benefits are too large to accept simply disabling them as a 'solution'. Stability programs exist to assist the vehicle in 'saving itself' from going out of control. For example, the vehicle might individually brake one wheel to correct a spin. No human driver has the controls (or speed) to execute such a save, but the computer has. However these programs are painstakingly calibrated to the stock vehicle and depend on the computer's knowledge of vehicle speed, tire size, and other parameters to perform their feats. Additionally, on newer vehicles things like automatic transmission shift points are dependent on the computer's knowledge of vehicle speed, so incorrect values mean poor performance and even possible failures. Along with all of these electronics-dependent functions comes the unfortunate reality that usually the only way to correct them is also electronic. Consequently, a 'programmer' device is needed to insert new calibration points so that the systems can function properly with the lift, tires, etc. in place. This is why AEV developed its ProCal module which is included in certain versions of its JK suspension systems.

8. Motion Ratios and 'Internal Clearances'.

Motion ratios are simply the relationship between one moving part and another. In suspensions, one of the most important is shock vs. wheel, where 1-to-1 would mean that for a 1-inch bump, the shock strokes 1 inch. In some cases this ratio might me ideal, but alternate ratios can also be used as long as the tuning of the affected part (shock, spring, etc.) is adjusted accordingly. For example, the further away from the wheel (or angled from vertical) a shock is placed, the firmer its valving must be to compensate for the greater leverage applied by the wheel. An example of this would be the front shocks on AEV's JK suspension systems. AEV has reposition the front shocks in the interest of chassis clearance at maximum articulation, however AEV custom-tuned these shocks to compensate for the resulting change in movement ratios.

Internal clearances are simply the myriad of places where the moving parts of the suspension would crash into other parts of the chassis if allowed to move too far beyond the normal range. Typically this movement is supposed to be limited by the bump-stops (up-travel), shock lengths (down-travel) and steering stops (max. turn angles). Aside from the obvious need to avoid self-destruction, providing adequate clearances for all possible motion allows confident and more enjoyable use of the vehicle. AEV has carefully clearanced all components to ensure bind and noise-free movement in all of its JK suspension systems.

9. Durability.

As simple as the concept of durability may seem, 'overbuilt' isn't really the best answer. Overbuilt simply means that due to a lack of technical resources such as FEA modeling or maybe a lack of time, patience or even money to do proper field testing, the designer/manufacturer has resorted to throwing more material at an accessory design. The result is a heavy accessory that can cause a cascade of new problems, including additional durability issues. The problem is usually not in that accessory, but in those around it that must now be upsized to cope with its extra weight. This is a classic 'pulling the thread on the sweater' until it's completely unraveled. This is also how 6000 lb. Jeeps happen, and yet consistently experience more trail failures than lighter rigs on the same trail. Instead, durability is actually a science of its own: For example, making a bracket that doesn't fail means not only optimizing the design of the bracket itself, but also fully understanding and managing the forces that apply to it from the overall system. Knowing what the worst-case loads will be, how different loads will combine together, and what the trade-offs of different system-level solutions would be (part of FMEA analysis). A further example would be an extended track bar bracket that doesn't induce a guaranteed failure of the stock bracket it's bolted to because of the excessive additional leverage it causes. If you evaluate the bracketry and other components in AEV's JK suspension systems, you will notice that they are robust and yet factory-like in appearance. This is because they have all been truly engineered for the task they manage – in relationship to the factory components with which they integrate.

10. Traditional Expectations.

Like so many markets, off-road aftermarket suspensions suffer from a fair amount of 'creative inertia'. That is, once something is accepted as 'the way to do it' on one platform, many falsely assume that the entire 'recipe' applies equally well to another platform. Or perhaps a company may prefer to convince its customer of this because it has become their niche or specialty. The "long-arm legacy" from Jeep TJ to JK Wranglers is a perfect case-in-point: Long-arm-based suspensions are indeed central to the ideal geometry solution for TJ. This is because the stock short-arm geometry degrades rapidly with lift height. In contrast, though the 5-link/solid-axle JK suspension is similar to the TJ in basic concept, it has numerous improvements over TJ such as 40% longer boxed-section arms, longer track bars, etc.. This means that long-arms are not central to, or even necessary for, correct geometry in JKs lifted up to 4.5-inches. This is among the key reasons why long-arms are not included in AEV's JK suspension systems.

11. Value.

Though not directly a technical issue, value is the measure of what you get for the money you spend on a suspension system. In the often mail-order world of suspension kits, quantity of parts is all too often confused with value – often resulting in additional purchases and/or even replacement purchases that far negate the original hoped-for savings. Engineering comes into the picture in two ways: First, the included parts – regardless of how many – should actually be well designed according to sound and proven engineering practice. Second, the parts that are included should be all of the ones – and the only ones – that are really needed to deliver the performance promised. Because there is so much misconception in the market regarding what is 'the right way' to do a given lift height and type for a given application, a bargain-hunter will often dismiss a highly-contented kit as being full of 'fluff.' This helps them justify buying something cheaper, but they often wind up paying much more in the end after they discover the design, durability, or performance shortcomings of the cheaper option. Likewise a system with less content can sometimes be dismissed for being 'incomplete' if traditional expectations are skewed by marketing campaigns or creative inertia. And finally in both cases there is always the risk that the design is simply executed incorrectly – resulting in either the wrong parts or the wrong tuning of the parts. The painful result is that many customers are forced to try and sort out their suspensions on their own, which invariably generates frustration and unnecessarily thin wallets. With AEV's JK suspension systems, AEV has painstakingly evaluated every aspect of the JK's performance in relationship to the added lift height our suspension creates. Because of this, AEV's customers get exactly the right content in the kit.

12. Dual-Mode equals DualSport.

If the typical 4x4 owners are honest with themselves, they will have to admit that the majority of their driving is still on-road – even if they go 'off-road' every single weekend. At that point a truly dual-mode suspension is what's needed. But due to decades of living without good dual-mode suspension options, most consumers, shops, and even the off-road media seem to think they can't be made. That is simply not the case if basic vehicle dynamics and OE-style engineering are applied to suspension design! Whether due to a lack of engineering know-how or a lack of interest in offering dual-mode systems, most manufacturers simply don't design their suspension systems with an expanded spectrum of performance (i.e. add more off-road ability without losing on-road). Instead they simply shift the spectrum toward off-road performance and let the customer suffer the on-road consequences. Aside from the usually obvious and sometimes frightfully dangerous safety issues such systems cause, the large percentage of miserable on-road driving experience eventually turns to dissatisfaction at some level – resulting in re-modifying, more parts and labor, and even selling the vehicle in disgust.

This need not be the case for Jeep JK owners. AEV offers a fully engineered, truly dual-mode suspension system appropriately named 'DualSport.' AEV's DualSport Suspension Systems are the culmination of all the critical OE engineering principles discussed in this document. Because of this these suspension systems not only improve off-road capability, they increase on-road performance too. These truly dual-mode suspensions elevate the enjoyment of driving a lifted Jeep everyday and eliminate the compromise or any need to 'suffer for the sake of the sport.'