Suspension Design Theory and Anti-Squat Behavior

Purchasing a full suspension mountain bike introduces an added level of complexity with rear linkage designs and leverage ratios. Everyone talks about pedal platforms, and how well certain bikes climb or descend. But how do you actually quantify different suspension designs? In this article, I will discuss the kinematics of suspension design and compare different designs.

When discussing rear suspension design and geometry its important to distinguish between a few different determining factors. There is a difference between the leverage ratio that exists based on suspension geometry and the shock force curve. For example, coil shocks for the most part have a linear force curve. This can be explained using Hooke's the distance (x) it moves. Different springs have varying spring constants (k values) depending on setup. This is true of springs in motor vehicles, bicycles and many other applications. The k-value represents the amount of force required to move the spring a desired distance. Hooke's law equation simply states that a proportionally increasing force will be required to move the spring a distance x.

Hooke's law cannot be used to model an air shock though. As you move through the travel of an air shock, you are reducing the size of the air chamber in the shock. As you reduce the volume inside the shock, the air is forced into a smaller space. Gases do not compress linearly like a coil. Effectively, the k-value in the equation changes as air can volume changes instead of remaining constant like a coil. This results in ramp up at the end of travel as the chamber becomes increasingly smaller. This behavior makes air shocks a lot easier and less expensive to tune. Adding volume reducers changes the behavior of the shock and allows for fine-tuning.

There is a lot more going on inside of a rear shock, but for the purposes of this article it is important to understand how an air spring curve works and the non-linear nature of an air spring. The chart below shows the linear nature of a coil spring compared to shocks with difference air volumes and how they change the force required to move it the same distances.

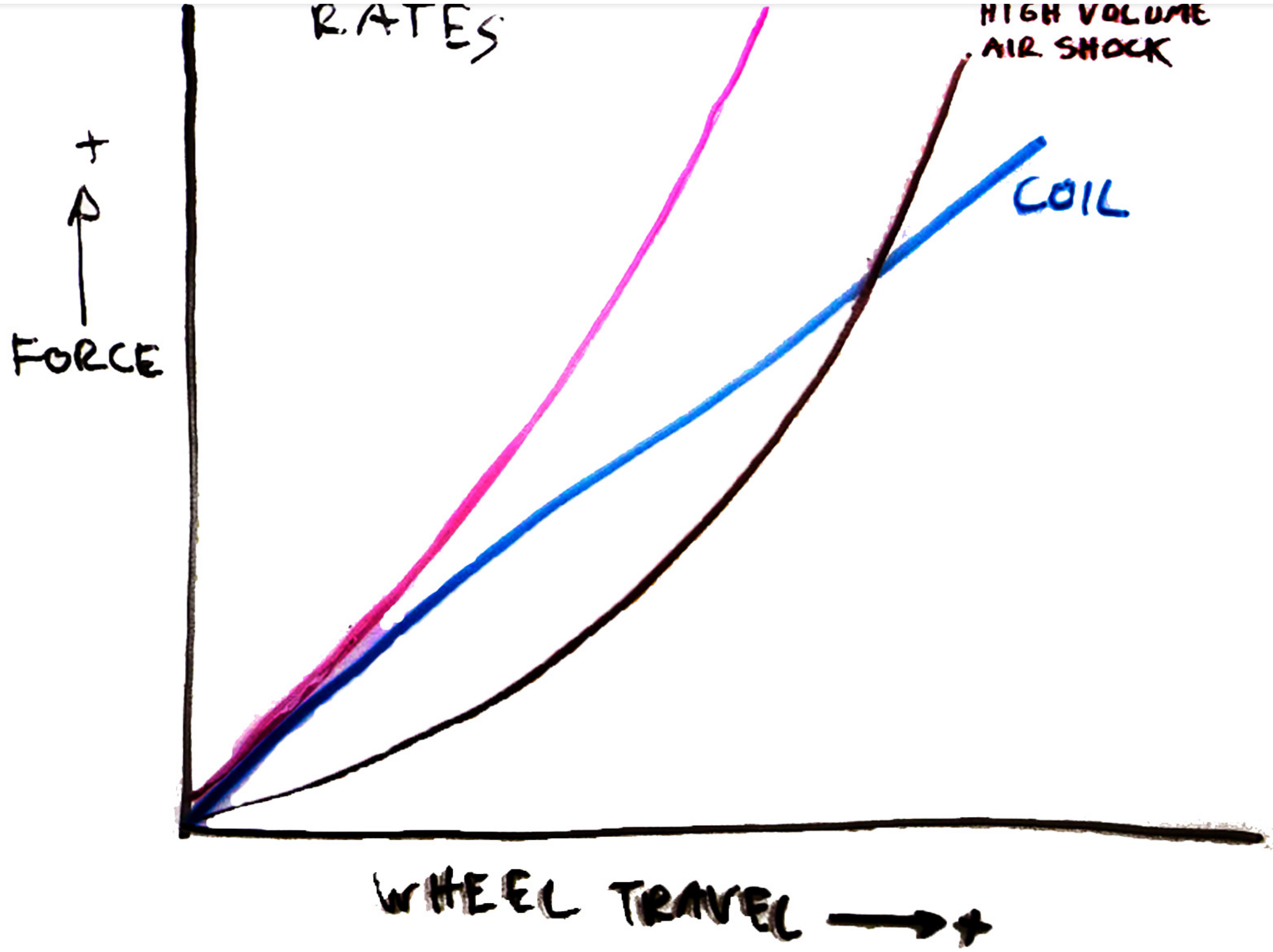
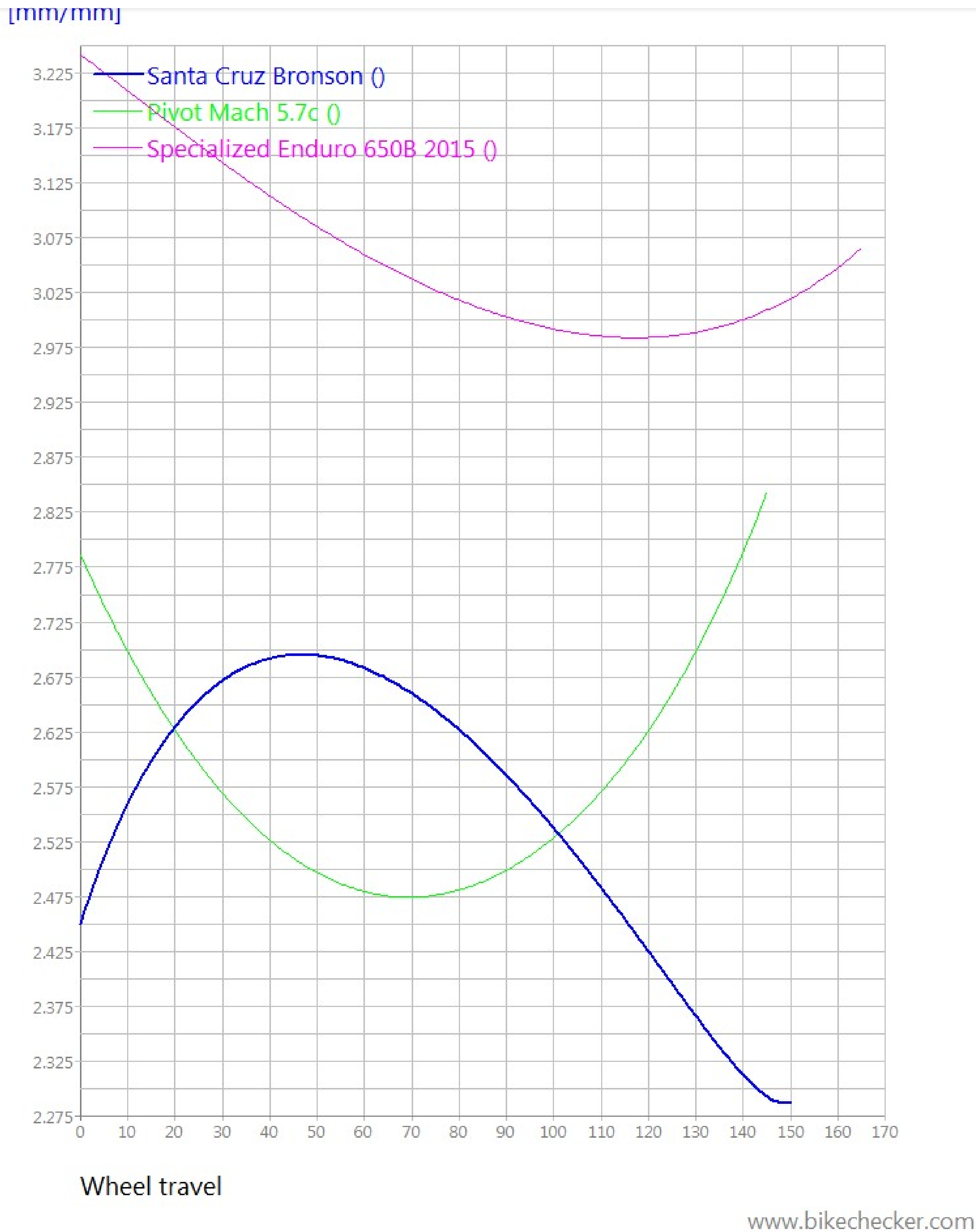


Image courtesy of Santa Cruz Bicycles

Now lets discuss the kinematics of bicycle frame design. Kinematics is defined as the motion of points and bodies without consideration of the causes of motion. In layman's terms this means the suspension behavior without taking into consideration the rider weight or any forces on the rear wheel or frame. Kinematics analyzes the simple mechanical movement of the rear wheel through its travel. For example, my mountain bike has six inches of rear axle travel, but my shock only has a two-inch stroke. This suggests that for every inch of wheel movement, my shock will compress 0.33 inches. Except that my bike does not have a completely linear suspension design. So perhaps the first inch of shock travel will result in four inches of rear wheel movement but the last inch of shock travel will only move the rear wheel two inches. This is all determined by the kinematics of suspension design including linkage lengths, the number of pivots and their placement on curve and that's when the debate between DW-Link, VPP, Specialized FSR, Single-Pivot, and a multitude of other linkage designs begins.

Now that we have a better understanding of shock rates and leverage ratios, lets talk about the infamous "pedal platform." For most mountain riders (downhill excluded) the climbing characteristics of the bike are very important. Obviously when you are grinding up that hill, you don't want your suspension bobbing up and down, absorbing all of the energy you are trying to translate to the rear tire. The goldilocks zone of pedal platforms allows enough travel to absorb bumps, keep the tires planted and stay stiff enough to not loose power. Creating an amazing pedal platform is usually accomplished by tuning frame leverage ratios, shock curves, and chainring size. Yes that's right, the size of your chainring will actually affect your suspension performance, more on that in a bit.

This issue here is that the ideal pedal platform changes based on riding conditions, rider weight, and shock performance. Also, when you increase the stiffness of the ride around the correct sag zone, you will also start to sacrifice small bump compliance. So it's really this epic compromise of a million different factors. Plus, it's ultimately going to be up to the rider as to what type of ride they want. Some people like a super hard feeling platform, sacrificing that small bump compliance, and others like a plush ride that bounces a bit more under pedaling but feels like a magic carpet floating over rocks.



The chart above compares the leverage ratios of three different mountain bikes from Pivot, Santa Cruz and Specialized. The y-axis of the graph is a ratio of millimeters of vertical travel wheel will move vertically 2.5 to 3.25 inches. Larger leverage ratios mean that more force is being translated from the wheel into the shock. So in a hypothetical situation, if you had two bikes, both with 150mm of travel, both with the same air shock, set to the same pressure, but one bike has a leverage ratio at the correct sag of 2.5 and the other is 2.7. This means that when the bike with the 2.7 hits the same bump, it's going to use up more shock travel than the bike with the 2.5 ratio. The scenario only considers the kinematics of the bicycle though (ignoring all forces), but obviously there are a lot of other factors at work here, so the leverage ratio is not the ultimate guide to showing you how your suspension will feel.

In this next section we will discuss how chainring size affects your ride characteristics. This was the part that just blew me away when I discovered what a difference it made. For the longest time I never had a clue that chainring size made any difference except when it came to your gear ratio. Let me explain why it matters. Isolating the rear axle of the bicycle, we can analyze the different forces being exerted on it and how they affect performance. In an over-simplified model, the main forces pushing or pulling on the axle include the weight of the rider, the shock, the normal force from the ground and the chain tension. All of these forces are applied to the axle in different directions and all of the forces have different magnitudes. When one force overcomes another, the axle moves in the direction of that force if the pivot linkage allows it.

The force of the ground pushing up will always be in the same direction, up from the bottom, parallel with the vertical axis of the bike. The direction of the force from the shock will depend on the bicycle design, but will remain constant for that specific bike and for the most part will be pushing down on the axle in the opposite direction of the normal force from the ground. This leaves the force pushing down from the mass of the rider multiplied by gravity and the force of the chain pulling forwards. These are the two forces that can change direction and affect suspension performance. As you start biking up a hill, the direction of your weight changes relative to the bike. The force of your weight will always

Now here comes the kicker, you actually change the direction of the chain force when you shift gears. Think about this, if you are running a 34-tooth ring up front and are shifted into your 34-tooth cassette cog, the chain will be parallel to the ground, because the two gears are the same size. But, if you shift into a 42-tooth cog in the rear, suddenly the chain has a slight angle since one gear is larger then the other. Suddenly by shifting from the 34T cog to the 42T we have changed the direction of the chain tension force from parallel to the ground to a slight angle towards the ground.

How do all of these forces affect suspension? This is where anti-squat graphs come into play. Anti-squat can be thought of as the tendency of the suspension to overcome and counteract forces and remain at the correct sag position. It is represented as a percentage. An anti-squat of 0% means that chain plays no role in preventing bob in the suspension. 100% anti-squat means the drive force completely counteracts suspension bob. If the anti-squat percentage is more than 100, it means that the drive force is greater and will actually extend the rear wheel outwards and unload the shock.

So the anti-squat percentage is directly related to how firm your "pedal platform" feels. Any anti-squat number of a 100% or more will make for a very firm suspension feeling while pedaling, completely counteracting forces due to acceleration. Anything less than 100% will result in a mushy feeling while pedaling and excess pedal bob.

And while there are many geometry factors set in stone that control anti-squat, the chain angle is one that can be changed and makes significant differences to the anti-squat percentage. As an example, we will compare different gearing combinations for a 2015 Specialized Enduro 650b. While the plots show the anti-squat across the entire range of travel, the sweet spot to look at is around the correct sag percentage—usually about 25%. Which for a 160mm travel Enduro would be 40mm of rear wheel travel.

to 36 teeth ranges from 108.5% to 91% respectively. Meaning that there will be more pedal bob when climbing with a 36 tooth than with any of the other combinations. At 40mm of rear wheel travel, the 32T chainring results in 100% anti-squat. Seeing this, it probably safe to say that Specialized designed this bike around the 32T ring. This makes a significant argument against changing your chainring sizes to tailor to your riding style.

One important thing to keep in mind about anti-squat is that only under constant pedaling will you see the anti-squat behavior that is affected by chainring size. If you are descending, standing the pedals, then something else called pedal feedback occurs. Pedal feedback is very similar to anti-squat. It is the same force acting along the chain, but it is acting in the opposite direction. When the rear suspension activates, the rear axle travels and while traveling it pulls the chain with it. So as you travel over a series of rocks, the chain repeatedly gets tugged back resulting in chatter in the pedals. The amount of chatter felt in the pedals is dependent on gearing combinations because it changes the chain length from engagement on the cog to the ring.

The above graphs analyze the same 2015 Specialized Enduro 650b we looked at earlier in the article. The first chart shows the bike with a 32T chainring, shifted into the 42T cog in the back. The plot compares wheel travel with degrees of counter-clockwise feedback in the crankarms. So for instance, if you bottom out the bike on a jump and use up all 160 millimeters of travel, there will be enough chain pull for 18 degrees of counter clockwise rotation. This results in a very rough ride with a lot of pedal chatter that feeds directly into your legs. But, if you were to downshift into the 14 tooth cog before beginning your descent you would see pedal feedback reduced to at most 4.5 degrees or only 2.5 degrees in the 10-tooth cog. From this, I would always recommend downshifting before beginning your descent. It will result in a smoother ride with less pedal feedback.

something to be said for having two or three chainrings to switch between to reduce pedal feedback while descending and increase anti-squat while climbing? If Specialized designed the 2015 Enduro around a 32T ring, surely they designed older bikes around doubles and triples. Looking at an older Stumpjumper, I found that climbing with a 22T front ring and a 32T rear cog results in around 100% of anti-squat at the correct sag. But if this same frame where equipped with a new 1x drivetrain with a 32T cog in the front, climbing in the 42T cog would only produce 78% anti-squat. This is amazing to me that ring size has such a large affect on these numbers. It's also a little disconcerting because I ride an older frame and have converted to a 1×10 setup. I probably experience a lot less anti-squat than I could if I was running a 2x setup. I will definitely have to build a model of my frame to find out how much of a difference it makes.

While I think its safe to say that most new mountain bikes are designed around a 1x setup, not all bikes are created equal. The chart below shows anti-squat for a Pivot compared to our 2015 Enduro. The Pivot has much higher anti-squat numbers across the spectrum. This isn't good or bad; it just is a different design methodology that will result in a very different ride depending on terrain.


as [%]
Specialized Enduro 650B 2015 a1 (32/42) (as)
Pivot Mach 5.7c a1 (32/42) (as)
138%
136%
134%
132%
130%
128%
126%
124%
122%
120%
118%
116%
114%
112%
110%
108%
106%
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Wheel travel
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even begin to account for the behavior of the shock. Shock air volume, high and low speed compression, and rider weight will play a factor in changing the modeled behavior. Hopefully your take-away from this article is a better understanding of the factors that can affect your ride performance. I can't begin to tell you if the difference between 10% of anti-squat on your bike due to a chainring size difference will be noticeable enough to bother you. The important part is that you love riding your bike and you get out there and do some serious shredding. Happy trails.

Science Behind the Magic *delves into the inner workings of your two-wheeled steed. Web Content Editor, Brett Murphy, uses his mechanical engineering background to explain the latest industry advances and breakdown component design.*

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