Transverse Leaf Springs: A Corvette Controversy

By Matt Miller

Introduction

A lot of people give Corvettes flack because they employ leaf springs. The mere mention of leaf springs conjures up images of suspensions on horse-drawn buggies, old cars and trucks, and Harbor Freight utility trailers.

Even magazine reviews of the latest Corvettes talk about how "antiquated" their leaf spring designs are, and many a Corvette enthusiast has converted his car to aftermarket coilovers in the belief that they are inherently better than the composite transverse leaf springs found on the front and rear suspensions of all Corvettes since 1984.

But is that true? Does the Corvette's use of transverse leaf springs mean it has an inferior, outdated suspension design? The short answer is "No!" To find out why, we'll cover some basics on springs and suspensions and see how the facts add up.

What is a Spring, Anyway?

We all intuitively know what springs are. But technically speaking, a spring is an elastic mechanical device that stores potential energy. When mechanical energy is put into a spring, it deforms and can release that energy back in the opposite direction. We measure a spring's energy storage by its "spring rate," which defines its energy storage. The spring rate defines the increase in force required to move the spring a certain amount. For example, if a spring has a rate of 100 lb/in (pounds per inch), it means that 100 lbs of force will move one end of it 1", an additional 100 lbs will move it another inch, and so on. If that spring is compressed 5", then it is pushing back with 500 lbs of force. That is all a spring does by definition. It's a very simple device and a very simple concept. People tend to get led astray when they believe a spring's function is more complicated than it really is.

A spring, by its self, has very little damping, which is only caused by the internal friction in the material of the spring. This results in a tendency for the spring to oscillate: repeatedly alternating between compression and extension over and over again. This oscillation can be mitigated by adding a stronger damping mechanism, such as a shock absorber.

Types of Springs

Springs come in many shapes, sizes, and materials. Flat springs may be the simplest form there is. The flat spring is usually a long strip of metal or wood that is fixed at one end and deflected at the other. A diving board is a flat spring. So are the limbs of a bow used in archery.

Another form of spring is the torsion spring, which is deflected by twisting a (usually) round section of bar or tubing (think about a sway bar). Torsion springs have been used on many types of vehicles, including many current race cars. There are disc or Belleville springs, which are wavy or conical discs that deflect toward flatness. They are really just a variation on the flat spring. And there are gas springs, which deflect by compressing captured gas such as air. A tire is a rudimentary gas spring, believe it or not, and so is an air shock on a mountain bike or luxury car.

Coil springs are probably what we think of first when we picture a vehicle spring. Coil springs are usually a round-section bar wrapped in a spiral, and they are deflected along the axis of the spiral. But coil springs can also be made of square-section bar or flat strips (e.g. a Slinky). **Functionally, a coil spring is just a combination of a flat spring and a torsion spring** - it just packages differently. If you unwind a coil spring, you'll see that it's just a long piece of material that's fixed at one end. When a coil spring compresses, that material is deflected like a flat spring and twisted like a torsion spring. In doing so, it stores energy and releases it just like a flat spring or a torsion spring. There is no functional difference. **Remember that!**

Examples of coil springs with different spring cross-sectional shapes.

Most automotive springs are made of metal. However, any material that can deflect and return all the way back to its original shape can be used as a spring. Wood is a naturally resilient material that works well. Some composite materials make good springs, and fiberglass is probably the most common of those.

<u>But What Is a Leaf Spring?</u>

A "leaf spring" is the name we give to a flat spring used in a vehicle's suspension. Leaf springs actually predate automobiles and were used on horse or oxen-drawn wagons. Leaf springs were typically made of multiple flat springs stacked and bound together to obtain the desired spring rate and support. Several examples of the use of multi-leaf springs can be seen on Page 1. These multi-leaf springs usually had a limited lifetime due to fatigue and corrosion. In the past few decades, advances in composite material manufacturing enabled the construction of a fiberglass single-leaf "monoleaf" spring. While it looks like a flat spring, such a spring is actually made by stacking layers of filament material and then bonding them together with a resin. So internally it resembles a traditional multi-leaf spring.

An example of a composite monoleaf spring

<u>Vehicle Suspension Basics</u>

In order to discuss why the transverse leaf springs in Corvettes are **not** a bad thing, we need to understand the very basics of a car's suspension, and how springs are used in them.

A vehicle with a rigid frame and rigidly attached axles is not a good thing. It would physically punish its occupants over every bump, and it would do a poor job of keeping its tires in good contact with the road. A suspension is intended to allow the tires some compliance over uneven road surfaces while maintaining control of the tire's motion and alignment throughout that compliance (i.e. "locating" the hub and wheel or axle). Even go-karts have suspension functions built into their flexible frames, and tires can be a major part of some vehicles' suspensions (remember, we said they are a type of spring). But more sophisticated vehicles usually use a set of links to attach each wheel and hub to the frame of the car while carefully controlling its motion and alignment. For example, all generations of Corvettes have front suspensions that use upper and lower "A-arms" to constrain fore-aft wheel movement while controlling vertical wheel movement and camber, and a steering linkage to control "toe" of the wheels.

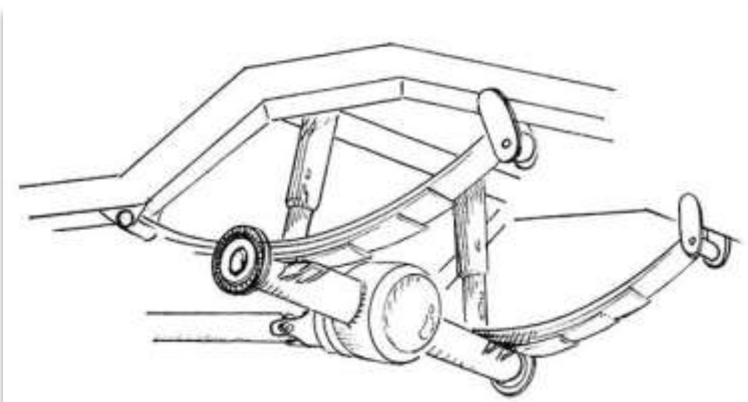
Suspensions have to be resilient in addition to being compliant. They have to keep the car centered somewhere in the middle of suspension travel when at rest ("static ride height"), and they have to return back to that ride height after a bump or acceleration force displaces it. That is accomplished by having the suspension store energy and release it in the form of force exerted over a distance. This energy management is measured in "wheel rate": the amount of force required to compress the suspension a certain amount at the tire's contact patch. A spring is what provides that wheel rate.

Without damping, a vehicle's sprung mass oscillates on its suspension. After a vehicle hits a bump in the road, the suspension is compressed and extended and the vehicle tends to continue bouncing down the road. The addition of shock absorbers damps the spring oscillation, and their damping rates can be carefully tailored for the spring rate, mass, and intended use of the vehicle.

In a sophisticated suspension, the only thing a spring does is provide wheel rate (i.e., suspension resilience). We don't want it to locate the hub. We also don't want it to damp the natural oscillations of the sprung suspensions. We have other, separate parts of the suspension for those jobs. But springs are sometimes asked to locate the hubs/wheels of a vehicle. In some applications, a coil spring can be used to locate the item it is suspending:

Coil spring locating a playground riding toy

In vehicles, leaf springs lend themselves to this double-duty because they are only compliant in one axis and relatively stiff in the other two. A Hotchkiss suspension uses two leaf springs running fore/aft to locate a solid axle longitudinally and laterally, while allowing vertical compliance:



Typical Hotchkiss rear suspension layout, locating the solid rear axle

The Hotchkiss design can be found in a *lot* of older cars, such as first- and second-generation Camaros and Firebirds; and the majority of pickup trucks. It is cheap, simple, and rugged; and for such a crude design it is surprisingly effective. But it has serious drawbacks for a high-performance car. It is difficult to calculate its suspension geometry. Due to the compliance of the end shackles and bushings, it allows the axle to comply side to side. It can suffer from "axle wrap-up" if the power and traction are high. It's difficult to change its geometry or ride height. It's difficult to find an assortment of spring rates to adjust the car's handling. And it entails a solid-axle suspension, which is generally inferior to an independent suspension.

History of Leaf Springs in Corvettes

C1: Front double-A-arm with coil springs; rear Hotchkiss with metal leaf springs.

C2/3: Front double-A-arm with coil springs; rear 3-link independent suspension with two lateral links and a trailing arm, with a **transverse multi-leaf steel spring.**

C4: Front double-A-arm with a **transverse fiberglass leaf spring**; rear 5-link independent suspension with two lateral links, two trailing arms, and toe, link with **transverse fiberglass leaf spring**.

C5-7: Front double-A-arm with **transverse fiberglass leaf spring**; rear double-A-arm independent suspension with **transverse fiberglass leaf spring**.

<u>So Is the Corvette a Relic?</u>

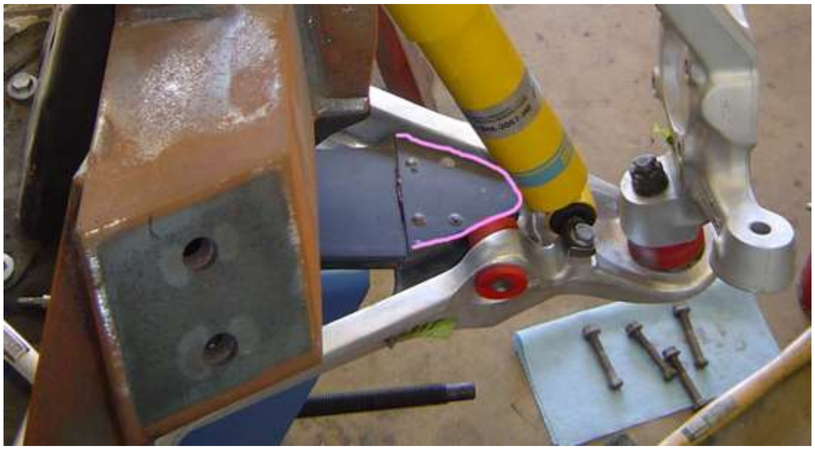
The short answer is "No!" It is true that the C1 used the Hotchkiss design that we have already said is not ideal for a performance car. It used two leaf springs to not only provide spring rate, but also to locate its solid rear axle. But 66 years ago, it wasn't too far off the state of the art, and it was far better than a lot of other performance cars. The C1 is a relic now, but it wasn't in its day.

Beginning in 1963, Chevy began using transverse leaf springs in the rear of Corvettes. The steel multi-leaf spring was heavy and it had some friction between the leaves as it deflected. But unlike the C1's Hotchkiss design, **in the C2 the rear leaf spring doesn't locate anything in the suspension**: it is clamped to the frame-mounted differential in its center, and each end is connected by a bolt to the knuckle (the upright that houses the hub). When the suspension moves up and down, the end(s) of the spring deflect and provide spring rate. The C2's leaf spring isn't part of the suspension geometry at all. Remember how we said we don't want a spring to locate the hubs, and we don't want it to damp the suspension motion? Well, in the C2 we are there, with the exception of a minor amount of damping from the inter-leaf friction.

Steel multi-leaf transverse spring in rear of a C2 Corvette.

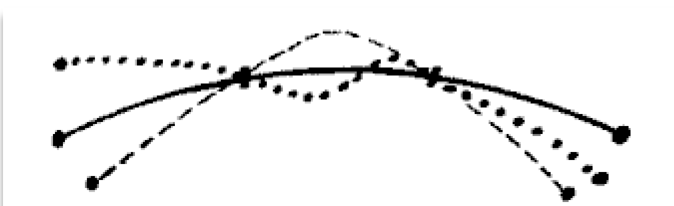
The C4 came out for the 1984 model year, and among its many suspension improvements were two spring innovations: the front eschewed the coil springs of its predecessors in favor of a transverse leaf with widely-spaced center clamps, and both leaf springs were now a single leaf made of fiberglass. In making both springs fiberglass "monoleaf" designs, Chevy got rid of the inter-leaf friction of the old-school steel multi-leaf spring. The fiberglass layup is 85% lighter than a steel multi-leaf, it does not suffer from corrosion, and it has a much higher fatigue cycle (i.e., many more cycles of deflection before failure).

The front leaf works like the rear, in that it is clamped to the frame on its center, and each end is independently deflected by the suspension. Again, its only function is to provide elastic resilience in the suspension (i.e. wheel rate) – it does not locate anything in the suspension.



C4 front suspension from a restomod project, minus the swaybar and with one end of spring sitting on the A-arm pad highlighted with pink for clarity.

However, unlike the rear spring, the C4's two frame clamps are spaced quite far apart: about 16". This allows the center of the spring to develop a "standing wave" between the two clamps. The result is that when only one side of the suspension moves (like hitting a bump on just one side), or when each side moves in opposite directions (when the car rolls and one side compresses while the other extends), the spring creates an "S" shape in its center. That S-shaped wave creates an anti-roll effect, exactly like a swaybar does. This is a benefit, because it means that Corvette engineers could use a smaller-diameter, lighter front swaybar than they could have if the car used coil springs (which have no anti-roll rate).



Standing wave in a C4 front leaf spring

The C4's unique fiberglass transverse leaf springs were so successful that Chevrolet has continued their use for all subsequent generations. Beginning with the C5, the rear spring was clamped with similar spacing to the front, allowing the same ant-roll wave effect that the front enjoys. Also, the ride height at each corner was made adjustable with jack screws at each spring end. The C6 and C7 continue to employ this setup. Taking Corvette's lead, other cars have since used fiberglass transverse monoleaf springs, including some Volvos, Mercedes, and other GM models.

<u>Pros and Cons of the Transverse Leaf</u>

Additional advantages of the fiberglass monoleaf springs compared to coil springs include total weight, especially when the smaller swaybar is factored in: it has been calculated that the front C4 spring/swaybar combo is at least 15 lbs lighter than a comparable coil spring setup would be. The fiberglass leaf also has packaging advantages, especially in front where low overall height and wide wheels are desirable. Finally, both springs' deflection geometry closely matches the control arms' geometry, which means that the motion ratio remains constant throughout the suspension travel. Compare this to a coil spring that compresses vertically whereas the control arm swings in an arc: the angle of the arm's travel relative to the coil spring's axis changes, and therefore the spring's leverage on the suspension changes with suspension travel.

I have seen people complain that because the spring is one unit from left end to right end, and/or because it has this anti-roll rate built into its clamp arrangement, that the Corvette does not truly have an independent suspension. This is untrue. Unlike a beam axle design, each side of the Corvette's front and rear suspensions can move independently, albeit with some amount of additional anti-roll rate associated with it. But guess what: any car that has coil springs and a swaybar has the exact same anti-roll rate associated with its independent movement. It's no different!

People often bring up the notion that leaf springs are "antiquated." It's true that steel flat springs are probably as old as steel itself. However, coil springs were invented over 250 years ago, and early steel coil springs were used in mattresses. Does that mean that all cars with coils should be likened to colonial mattresses? In fact, the composite monoleaf spring was only invented for the C4 Corvette 35 years ago, so they are much more modern than steel coil springs! Many modern sports prototype and open-wheel race cars use a variation of a flat spring called a Belleville washer in their suspension linkages for anti-roll. Does that mean they are antiquated buggies?

There are some potential disadvantages to the transverse leaf, but most will not affect most owners. This is just a guess on my part, but it may be more expensive for a car manufacturer to buy/build one fiberglass monoleaf than two coil springs. A definite disadvantage is that there are not as many aftermarket options with which to modify the stock spring rates. One of the main suppliers of aftermarket options was Vette Brakes and Products (VB&P), but they have recently gone out of business. So especially for those who want much higher rates for competition, aftermarket coilovers may be the only solution right now. Another possible disadvantage is that on the front of the C4 (and only the C4), the lack of height adjustment on the stock spring makes changing front ride height more difficult than with aftermarket coilovers. This is not a problem endemic to the transverse leaf concept – it's no different than most cars' OE coil springs that don't adjust for ride height. Finally, the front leaf springs can be more difficult to remove and replace than aftermarket coilover springs, especially in a C4. This is really only a disadvantage for those who want to bring an assortment of spring rates to a competition and "dial in" the handling by trying several different spring sets. To be clear, if you keep your Corvette stock, then none of these disadvantages will ever affect you, and the last disadvantage won't even affect most people who modify their Corvettes for competition.

<u>What About the C8?</u>

If scuttlebutt and leaked CAD drawings are correct, it does look like the transverse leaf's run in Corvette suspensions is coming to an end. The C8 is probably designed with coilovers at both ends of its suspension. There could be several reasons for this. Coilovers may package better with the all-new mid-engine chassis. They may just be cheaper for GM to procure. And if GM sees a semi- or fully-active suspension in the C8's future, it would be easier to replace coilovers with a hydraulic ram or air springs than it would be to replace leaf springs.

The best explanation for the C8's use of coilovers, sadly, may just be marketing. Much of the public and even the automotive press persists in associating the transverse fiberglass monoleaf spring with horse and buggy suspensions. And with the C8 going upmarket in price (at least a bit) and targeting more exotic cars, Chevy may have given in to consumers' misguided public perception that sophisticated cars must have coil springs.

Conclusion

All forms of mechanical deflection springs have existed for centuries, including the coil spring. The C4 Corvette pioneered a thoroughly modern implementation of the flat spring by using fiberglass transverse leaf springs front and rear to provide spring rate, but not to serve as suspension links. As such, these "monoleaf" springs offered advantages in terms of weight, packaging, lifespan, and rate linearity. They work exactly the same as a coil spring: by deflection of an elastic material. The popular idea that replacing a monoleaf spring with coil springs improves or modernizes suspension's function is a misguided one.

References and Additional Reading

Acxess Spring. "History of Springs." https://www.acxesspring.com/english/blog/history-of-springs.html/

Milliken, William F., and Douglas L. Milliken. *Race Car Vehicle Dynamics*. Society of Automotive Engineers, 1995.

Van Valkenburgh, Paul. "Engineering the New Corvette." *Road and Track's Guide to the All New Corvette*. CBS Publications, 1983.

McLellan, Dave. *Corvette from the Inside*. Bentley Publishers, 2002.

Lamm, Michael. *The Newest Corvette*. HP Books Inc., 1983.

Falconer, Tom. *Collector's Originality Guide, Corvette 1968-1982*. Motorbooks, 2001.

Timothy Z. "Coil, Leaf, and Torsion Bar – Describing the 3 Different Kinds of Springs." https://www.carid.com/articles/coil-leaf-and-torsion-bar-describing-the-3-different-kinds-of-springs.html.