Porsche 911 Suspension Geometry

We look at the factors that affect a 911's ride height, its center of gravity, and more.

STORY BY CHRIS ANDROPOULOS
PHOTOS BY CHRIS ANDROPOULOS AND PORSCHE

A COMMON ADAGE among auto enthusiasts is that suspension design and tuning is a "black art." While the practice of suspension tuning may seem to be more art than science and the results can be quite subjective, there are some concrete fundamentals to suspension design. It is practically impossible to cover all aspects of suspension geometry in one article, as entire books have been written about suspension theory and design. But Porsche's approach to the suspension design and geometry of its 911 road car (and its higher performance and racing derivatives) can be distilled into one feature.

Suspension Geometry Basics

The main goal of a performance car suspension is to maintain an optimal interface between all tire contact patches (which are relatively small at any given instant) and the road during all phases of driving. There are myriad factors which determine the tire contact patch during transient maneuvers, such as the roll stiffness of the suspension, damping characteristics, vehicle weight distribution, tire sidewall and tread stiffness, suspension bushing compliance, aerodynamics, and so on. However, the basic geometry of the suspension plays a major role in controlling the motions of the individual wheels and affecting weight transfer during transient maneuvers.

When a vehicle is negotiating a turn, the centripetal force exerted by the friction between the tire contact patches and the road causes weight transfer from the wheels on the inside of the turn to the tires on the outside of the turn. The total amount of weight transfer is determined by the combination of cornering force exerted upon the vehicle, along with the height of the center of gravity (CG) of the vehicle's mass. In other words, the lower the CG is, the less weight transfer will occur, which is desirable as it allows the vehicle's mass to remain more evenly distributed between the inside and outside tires, which enhances cornering grip.

Another factor influencing cornering grip is body roll, which is induced by the compliance of the suspension springs. Severe body roll causes the CG to move laterally, which increases the amount of weight transfer to the outside tires during a turn. Therefore, it is desirable to minimize the body roll of a performance car. An important concept to remember is that even if a vehicle has a completely solid suspension and zero body roll, side-to-side weight transfer will still occur. Again, lowering the CG is the only way to decrease the amount of weight transfer.

An easy method of quelling body roll would be to install very stiff suspension springs and anti-roll bars, but this usually results in a harsh ride and poor tire-to-road contact on anything but the smoothest road surfaces. Besides lowering the CG as much as possible, the best way to control body roll and wheel movement while cornering is by careful design of the suspension geometry.

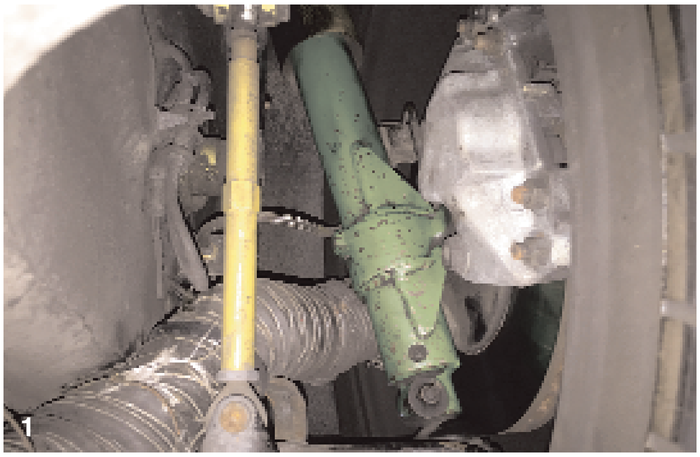
One of the crucial determinants of a vehicle's cornering behavior is the height of the roll centers of the front and rear suspension. The roll center is an imaginary point in space (see diagram) about which the sprung mass (essentially the body and anything else "suspended" by the suspension) of the car rolls. Both the front and rear suspension each have their own roll center, which is determined by the configuration, length, and angle of the control arms as viewed from the front (or rear) of the car.

The static roll center height can vary greatly between different suspension designs, and can even be below the ground in certain cases, but is usually located somewhere between the ground and the underside of the chassis of most performance vehicles. Ideally, the height of the vehicle's CG and of that of the roll center are as close as possible, which minimizes body roll. If the CG is too high and/or the roll center is too low, the sprung mass will exert greater leverage upon the suspension arms during cornering, which increases body roll.

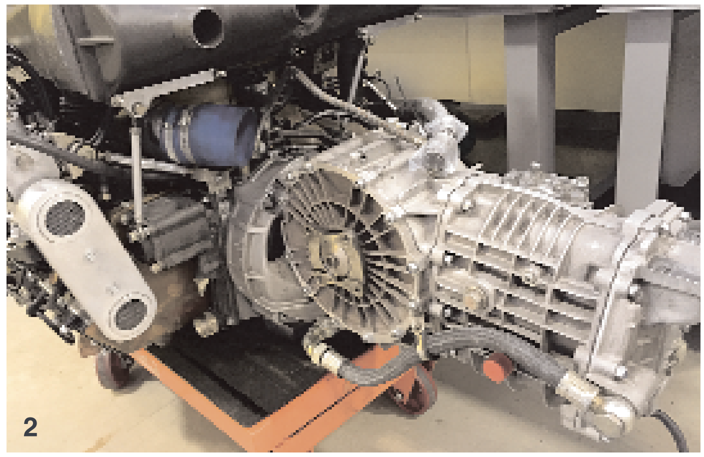
Furthermore, the location of the roll center is movable and changes in conjunction with the movement of the suspension arms (the diagram shows the static roll center of a typical MacPherson strut front suspension), so this must be taken into account by engineers. It is crucial to minimize the movement of the roll center during cornering to ensure predictable handling characteristics.

In the days of the early 911, suspension engineers hand-plotted the movable roll center of the suspension with each degree of body roll using paper and pencils, and then tested the result with prototype chassis. In modern times, the same process is simulated by using powerful computer models and is simulated down to the most infinitesimal of details. Even so, the concept is only fully proven when the rubber meets the road!

Suspension geometry is a three-dimensional subject, and there are many

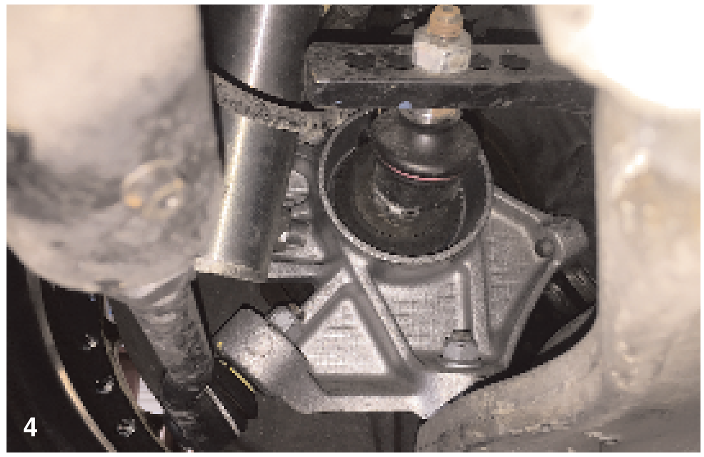


1



2

3



4

more considerations that are beyond the scope of this article. When the vehicle is viewed from the side, an imaginary line scribed between the front and rear roll centers is known as the roll axis, the angle of which is a major determinant of chassis balance (understeer vs. oversteer). The configuration, length, and angle of the suspension control arms in relation to the vehicle's CG as viewed from the side also determine the anti-dive behavior of the suspension during braking as well as anti-squat characteristics of the rear suspension during hard acceleration.

911 Suspension Geometry

As outlined in the "911 Suspension Evolution" article that appeared in the February 2016 (#234) issue, the original Porsche 911's MacPherson front suspension configuration was born out of practicality rather than ultimate performance. While the lack of upper control arms saves room for a luggage compartment, it does sacrifice some favorable wheel control characteristics.

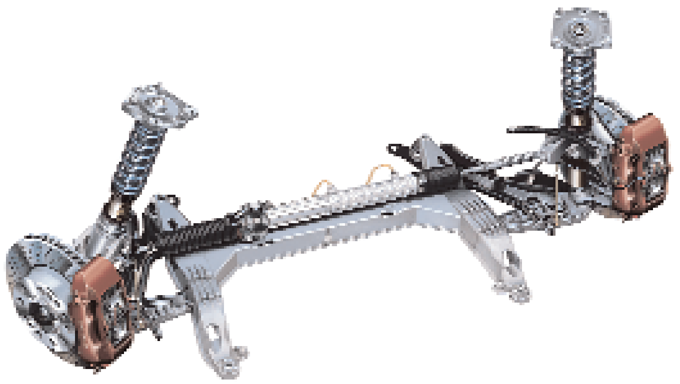
Most pure racing cars use the classic double A-arm or double wishbone design; with this configuration, the length and angle of both the upper and lower A-arms can be altered to achieve the desired roll center. More importantly, the movement of the upper control arm can be used to enable camber gain of the outside wheel as the suspension compresses during cornering, which helps to prevent the tire sidewall from "rolling over." The upper mounting point of the MacPherson strut design is fixed, which limits the ability of the outside wheel to maintain a proper camber angle during hard cornering. However, the CG advantages afforded by the low placement of the 911's flat-six engine helped to mitigate these effects.

Porsche's first major change to the 911's suspension geometry occurred with the production-based 911 RSR racer of 1973. The front ride height had been reduced significantly to lower the RSR's center of gravity, which limited suspension travel to the point where the suspension would bottom out during certain turns. Porsche remedied this by raising the height of the spindles by 0.7 inch to allow the lowered ride height while maintaining full suspension travel.

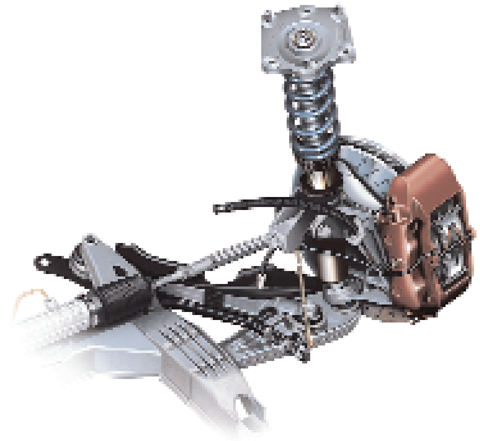
Another benefit of the revised RSR spindle location is that it restored the correct front A-arm angle in relation to the body (at the original spindle height, the A-arms angled upwards from the body mounting point to the lower ball joint, which served to lower the roll center height). Because the roll center height decrease was greater than that of the CG, the potential body roll actually increased!

Porsche also made suspension geometry changes to the rear of the 911 RSR. As mentioned in the previous 911 suspension article, the original 911 street car's semi-trailing arm rear suspension geometry was designed to keep the outside rear wheel as upright as possible throughout the suspension travel.

However, the ever-increasing envelope of chassis and tire performance throughout the 1960s meant that to maintain optimal contact patches for the fat 260 mm-wide rear tires during cornering, the RSR needed more negative camber of the outside rear tire as the suspension compressed. To this end, the forward mounting points at the rear torsion bar tube (or "pickup" points) of each rear trailing arm

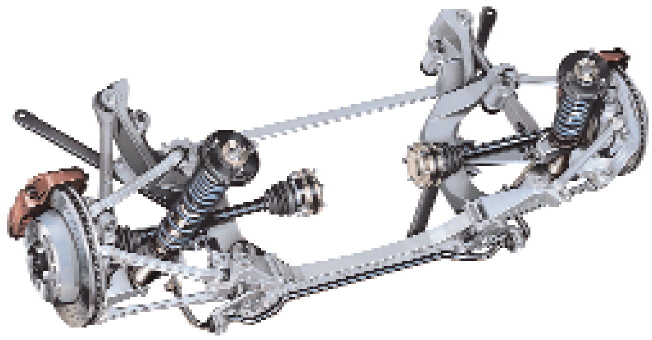


5



6

1) This 911 track car has RSR-style raised front spindles to restore proper suspension travel and geometry. 2) A 935 engine with the "upside-down" transaxle that was necessary to restore proper axle angles at the 935's low ride height. 3) Detail of an original 993 Carrera 4 front upright and drive axle. 4) A lowered 993 Carrera with factory 993 RS front uprights and tie rods to restore correct front suspension and steering geometry. 5 & 6) Porsche has maintained the basic MacPherson strut front suspension design for its sports cars as shown in this example of a 996 GT3 front suspension. 7) Porsche's multi-link rear suspension design (996 shown) ensures precise wheel control in all planes.



7

were moved both inward and rearward. This meant that the geometry of the RSR trailing arms somewhat mimicked a 356 swing axle in that the negative camber of each rear wheel increased with suspension travel (though in a much more precise and controlled manner).

The 911 Turbo (930) street car shared the RSR's inward and rearward relocation of the rear trailing arm pickup points, with the additional change of raising each by 0.4 inch to reduce rear end squat during acceleration. The 930 maintained the basic street 911's front spindle height, but the rearmost mounting point of each A-arm was raised, giving the A-arms a slight downward rake (as viewed from the side of the car), which served to reduce front end squat during hard braking.

RSR Turbo & 935

As Porsche's 911-based race cars evolved ever further away from their street car origins, so did the suspension design and geometry. Porsche's first turbocharged racing 911, the Carrera RSR Turbo of 1974, dispensed with the 911's torsion bars altogether, which saved 66 pounds versus the previous, normally-aspirated RSR (which had coil helper springs). The sheet-metal front A-arms of the street car were replaced by lightweight, tubular versions with spherical bearings and turnbuckles to allow for easy adjustment of camber, caster, and even the wheelbase!

The radical 935 built upon the lightweight suspension design of the Turbo RSR and its aerodynamic enhancements demanded an even lower ride height. The forward pickup points for the rear spring plates (which pivoted on a large spherical bearing rather than about the torsion bar carrier of the street 911) were raised to correct the roll center of the drastically lowered rear suspension. The extremely lowered rear ride height of the 935 resulted in severe angles for the rear axle constant-velocity (CV) joints, so the 930-based transaxle was actually flipped upside-down to normalize the axle angles!

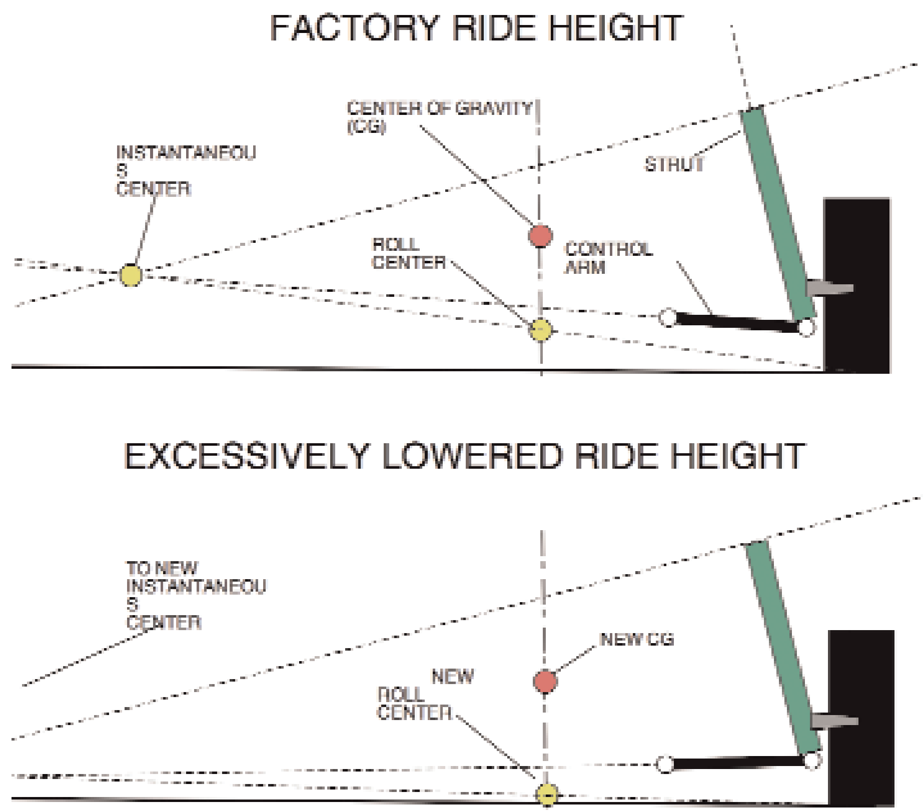
964 & 993 RS

The 1989-1994 964 represented Porsche's first thorough revamp of the 911 chassis, though the basic MacPherson strut front and semi-trailing arm rear suspension design remained. The original 911's strut housing with a welded-on spindle and steering arm was replaced by a modular design with a separate strut housing that bolted to a lightweight aluminum wheel/hub carrier (or "upright" in racing parlance).

The 964 front upright was designed to accommodate the front axles of the all-wheel-drive Carrera 4 variant, so the Carrera 2 and Turbo versions used the same front upright, but with a with a simple stub axle instead of a drive axle. A dual-row ball bearing assembly was press-fit into the wheel carrier, and the stub or drive axle was press fit into the inner race of the wheel bearing.

All street 964 models including the lightweight RS version (which was not offered in the U.S.) used the same front suspension geometry. However, the 993 RS of 1995 (along with the racing 993 GT2) featured a redesigned front upright design with a raised hub carrier and revised and reinforced mounting points for the lower ball joint and steering tie rod end. This served the same purpose as the raised spindle of the earlier 911 RSR spindle and corrected the lower A-arm angle in relation to the body and restored suspension travel at the lowered ride height of the 993 RS and GT2.

The intricate multi-link rear suspension of the 993 enabled precise wheel control in all planes, but it also presented a challenge when the chassis was lowered to a race-ready ride height. To correct the rear roll center of the racing 993 GT2 and preserve its anti-dive and anti-squat characteristics, Porsche engineers revised the mounting points of the rear suspension subframe, which served to "tilt" the entire subframe upwards towards the rear of the car and correct the angles of the various suspension arms.



Changing the lower control arm's angle slightly can have a big effect on roll center height. The center of gravity is lower with decreased ride height, but it's further from the roll center, resulting in more body roll.

996 & 997

The 1999-2005 996 series saw Porsche's continued use of a cast aluminum upright/hub carrier at all four corners of the car. The roadgoing 996 Carrera and GT3 (and the initial 996 GT3 Cup race cars) all shared the same basic suspension geometry and mounting points for control arm ball joints and tie rod ends, though the castings for the uprights varied with differing brake caliper bolt spacing and wheel bearing sizes.

As Porsche's 996-based factory race cars evolved from GT3R to RS and RSR and into the 2005-2012 997 generation, they sprouted more prominent aerodynamic accouterments, along with wider wheels and track width. The ride height also became progressively lower, with each new variant, so the uprights were altered accordingly to properly locate the outer control arm ball joints. For the more extreme RSR variants, the front and rear subframes were also modified with raised inner pickup points for the rear control arms to ensure correct geometry.

Ride Height Tips

A common modification for street 911s (and other Porsches) of all ages is to lower the chassis ride height for both handling and styling purposes. This is especially prevalent in U.S.-spec cars, as for many years their ride heights were actually raised to meet U.S. Department of Transportation (DOT) headlamp and bumper height regulations. While it might be tempting for some to "slam" the suspension down to a racing ride height and eliminate any semblance of a tire-to-fender gap, care must be taken not to go too far when doing this. The Porsche factory's geometry-correcting measures outlined above were not arbitrary and should be taken seriously.

When determining the ideal lowered ride height of your Porsche, a good rule of thumb is that it should not be any lower than "rest of the world" (RoW) "sports" or M030 specifications, as these are often the lower limits of the existing suspension geometry. Anything lower will require geometry-correcting measures—not only for optimal handling—but also to ensure proper suspension travel and range of motion for the ball joints.

It is common practice to quickly determine ride height by measuring the distance between the top of the fender/wheel arch to the ground. This is not a reliable measurement as the fender heights may vary due to production tolerances (even with a precision automaker like Porsche) and the possibility of past accident damage or body repairs. Also, varying wheel and tire diameters can affect this measurement.

For the early 911, the factory service manual stipulates an exacting ride height specification that references the difference between two measurements: one between a hard point of the chassis and the ground, and the other between the wheel centerline and the ground. The importance of this method is that it determines the relationship between the inner and outer control arm mounting points and thus the control arm geometry, irrespective of the wheel and tire diameter.

Another consideration when radically lowering a chassis is the possibility of bump steer, or toe change of the front wheels during suspension travel, which is caused by an improper relationship between the steering tie rods and the lower control arms. For the early 911 chassis, steering rack spacers and bump-steer correcting tie rod ends are available. For the 964 and 993, bump steer is corrected by installing the aforementioned 993 RS front uprights and tie rods.

For the well-heeled enthusiast, there are myriad uprights and subframes available from Porsche Motorsports which can bolt into any 996 or 997 chassis. However, careful research is necessary to determine which combination of uprights, axles, hubs/wheel bearings, brake components and suspension arms/subframes will work at a particular ride height and with your chosen wheel/tire package. ■