PART III

CORNERING & STABILITY

BY ROGER HUNTINGTON

LAST MONTH, some of the fundamental factors that combine to make up the suspension characteristics of a given automobile were discussed. It was pointed out how the sprung and unsprung masses oscillate and how both oscillations (at widely different frequencies) must be damped by the shock absorbers. Then the action of centrifugal force on the various car masses, transferring weight from the inside to outside wheels in a turn, was described. This lateral weight transfer is actually controlled by the same laws that give us our fore-and-aft weight transfer under braking or acceleration. But the vital factor in the weight transfer phenomenon is how the "roll couple" is distributed between front and rear wheels. This depends not only on the static front-rear weight distribution, but on the relative front and rear roll stiffnesses, roll-center heights, unsprung weight, etc. These factors combine to determine the actual cornering loads on the four wheels.

The area of study this month is how these wheel loads combine with the cornering characteristics of the wheels and tires (studied in Part I) to determine how the car actually feels and handles in a corner—or on the highway in a cross wind, whenever the sprung mass is acted upon by a substantial side force.

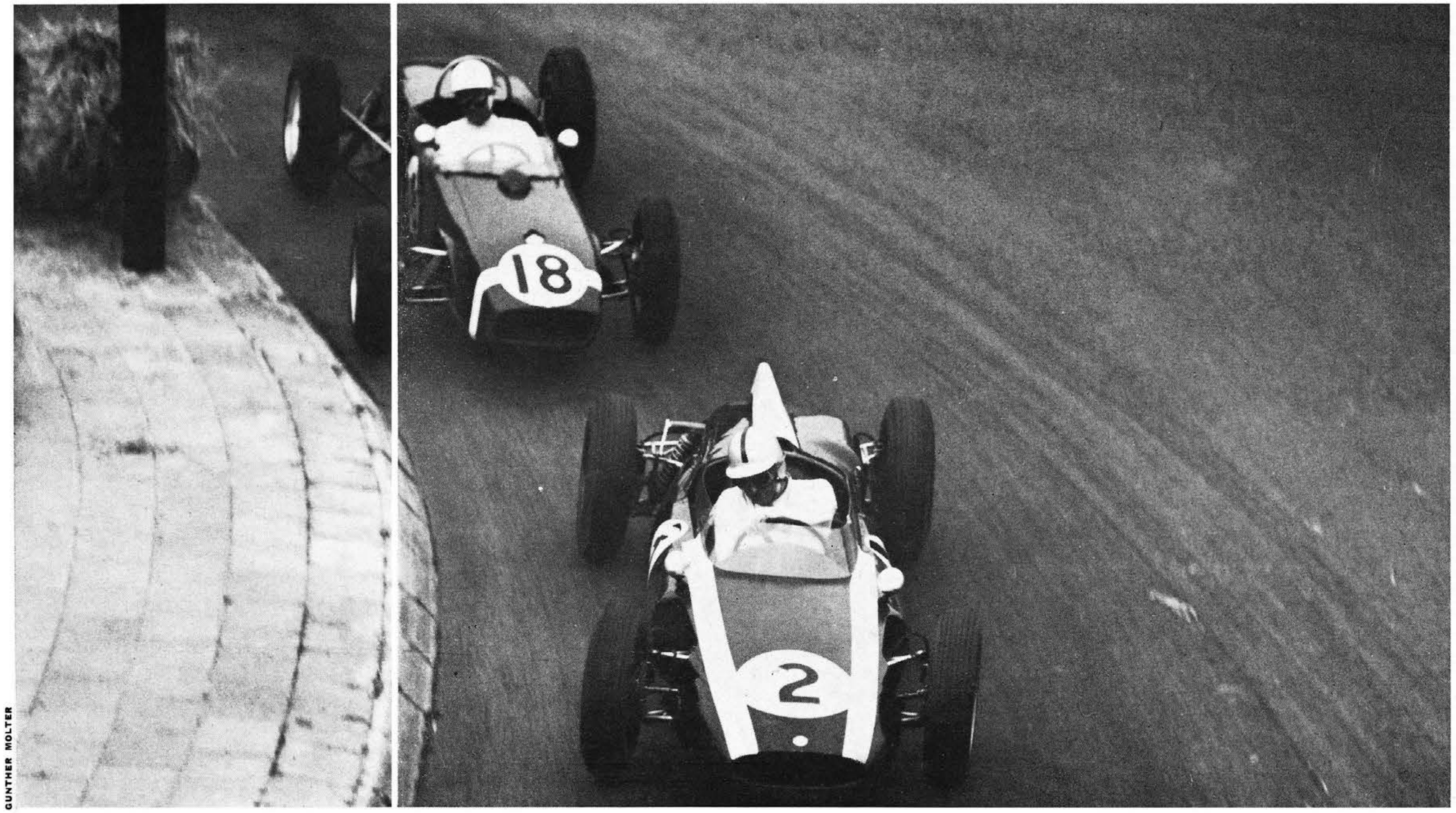
Oversteer and Understeer

Every enthusiast has heard the terms "oversteer" and "understeer" used in relation to the handling of a car. Many probably have a good idea of what they mean. Stated very simply, oversteer means a situation in which the rear end of the car tends to steer, or pull, outward on a turn (or under a cross-wind force) more than the front end. The rear literally oversteers the front. The car feels as if the rear end would lose traction and "washout" before the front end in a really tight turn—and it probably would. It should be noted that with an oversteering car it is actually necessary to steer the front wheels away from the center of the turning circle in a tight turn. Otherwise the rear end would come right on around and the car would spin out. In other words, the turn is set up by steering into it with the front wheels, but once the car is turning the rear end takes over—and the car just about steers itself. Little steering wheel force is needed.

An understeering car acts just the opposite. Here, the front end tends to run wide in a turn. The car feels as though it would plow off the road front end first in a really hard turn. The driver has to constantly pull the steering wheel in toward the center of the turning circle, and possibly apply more and more pressure, as the car speed increases. Steering is always much heavier than with an equivalent oversteering car.

These concepts are easily pictured, but actually the automobile engineer looks at oversteer and understeer in an even different way. This technical concept may actually be simpler than the above explanation: Oversteer is when the tire slip angles on the rear wheels are greater than the front slip angles. Understeer is when the front slip angles are larger than at the rear. That's all there is to it. If the rear slip angles are greater than the front it's easy to see that the rear end of the car would tend to steer outward more than the front, giving the familiar oversteer "feel." Larger front slip angles would tend to make the front end plow or steer away from the center of the turning circle.

Remembering this simple slip-angle relationship will put the reader ahead in understanding chassis handling characteristics.



GUNTHER MOLTER

RELATIVE ANGLES OF ATTACK in cornering are shown by two Grand Prix cars at Monte Carlo bend. First car, steering into bend, demonstrates understeer while second is in oversteering attitude.

Effect of Slip Angles on Handling

At this point, just about all the essential factors have been covered to permit an actual prediction as to how a given car design will handle while it's still on the drawing board. The concept is very basic: Part I disclosed what major factors affected the slip angle that a given tire would assume when producing a given cornering force (side thrust) under a vertical load. Also, last month the factors that determined the actual vertical loads on the four wheels in a turn were described. In fact, calculations for the loads were made for a typical cornering example with the stock Corvair. Side thrust figures can be readily calculated by figuring the total centrifugal force (using car speed and radius of turn) and distributing it front and rear according to the weight distribution. From here it's a straightforward job to read the actual front and rear slip angles off a graph of the tire performance.

This indicates whether the car oversteers—and how much. In the example of the Corvair described last month, the rear slip angles were substantially larger than the front angles. This would unmistakably indicate an oversteer condition, at least under the 0.6-g cornering force assumed in the calculations. The degree of oversteer wouldn't be as heavy as on, say, a Volkswagen (with less built-in rear-end steer, higher c.g., etc.), but it's there. And it could be (and was) predicted on paper before the car was built.

Space won't permit going much deeper into this technical aspect of the chassis design science. But a review of some of the major factors in the slip angle picture is in order to see how they can be used to adjust the handling of a given car design. For instance, if a car has excessive understeer many things are possible to increase the oversteer tendency, which, of course, would have the effect of reducing the understeer. It merely requires increasing the rear tire slip angles in relation to the front.

The most obvious change is to reduce the cornering power of the rear tires, making them run at a higher slip angle to develop the same side thrust. This could be done by reducing the inflation pressure, using a narrower wheel rim, a smaller tire, or one with fewer plies or a smaller cord angle. Another promising path is to increase the rear-end roll stiffness, so the rear tires absorb more of the total roll couple on the sprung mass. This could be done with stiffer springs on the rear, or you could put a torsion anti-roll bar on the rear end that would boost the roll stiffness with relatively little effect on the ride. (This was very effective in reducing understeer on the late pre-'63 Corvettes.) A more obscure trick would be merely to widen the rear track width, possibly using reversed wheel rims, although this is particularly not recommended. Other factors being equal, the roll stiffness of a suspension increases as the square of the track width or lateral spring base. (This is how the wide-track Pontiacs get such good stability with soft springs.)

On the other hand, understeer could be reduced by going the other way on the front suspension . . . that is, by increasing the cornering power of the front tires, while leaving the rear end alone. This would be changing the relative front-rear slip angles, which is all you're after. Thus you could increase front tire inflation, use wider rims, larger tires, more plies. Or remove the front anti-roll bar to throw ▶

more of the total roll couple on the rear end, and thereby take cornering load off the already overloaded front tires. A reduction in front end roll stiffness will reduce understeer—even chopping front track width will do it. Picture a 3-wheeled car with the single wheel in front (like the old Davis project of the late '40s). This has zero front roll stiffness; 100% of the roll couple is absorbed by the rear suspension and you have almost a completely oversteering car!

Up to now the effect of suspension geometry on slip angles hasn't been mentioned, primarily because this is generally a factor that is designed into a chassis on the drawing board. While it can't be readily adjusted, it can have a huge effect. Remember, the camber angle of the wheel has a big effect on slip angle. When the top of the wheel tilts away from the direction of the side thrust (center of the turning circle) the camber thrust acts opposite to the side thrust, and thus increases slip angle. This is one big reason why modern cars with "wishbone" front suspensions tend to understeer. The outside front wheel tilts at nearly the same angle that the body rolls in a turn; this reduces its cornering power, increases the slip angle, and thus increases the understeer tendency. Similarly, our modern rear-engine Grand Prix Formula I cars would tend to oversteer with all that weight and power in the rear. But by putting some negative camber on the rear wheels (where tops of the wheels tilt inward) they add the camber thrust of the outside tire to its side thrust, and thus reduce the slip angle. Use of the very wide wheel rims on these cars has also had an important effect on handling. Their steer characteristics are said to be quite neutral under most conditions —in other words they evidence no pronounced tendency toward oversteer or understeer.

Designing suspension geometry is a series of difficult compromises. A high front roll center reduces front camber tilt and roll couple, but the unusual angles of the suspension arms may present space problems. To reduce camber tilt with a relatively low roll center means that the wheel must swing through a large camber angle as it deflects up and down. This could introduce a high degree of lateral tire scrub, or could even cause some front wheel wobble from gyroscopic reactions. And at the rear end there's the big problem of how much roll steer to build into the suspension geometry. The possibilities are endless. By adjusting the "splay," pin locations, length and shackle angles of a rear leaf spring, almost any desired degree of steering in or out can be obtained as the body rolls under centrifugal force in a turn. With a linkage-type rear suspension (coil springs) this problem is even easier—easy enough to go too far. Excessive rear end steering causes the car to wallow noticeably in turns and wander about on the highway in a cross wind.

But, in spite of everything, the average American passenger car of today handles infinitely better than cars of even six or eight years ago. Prime reasons: somewhat higher front roll centers; reduced front roll stiffness; greater track widths; better front-rear weight distribution because of more aluminum in the front of the car; improved rear end roll steer geometry; and, of course, improved tires and shock absorbers. When Chrysler brought out its torsion bar front suspension in late 1956, the cars opened a new era in the cornering of American passenger cars. Everybody thought it was the magic of the torsion bars. Actually, the secret was nothing more than a new arrangement of the old fundamental factors listed above. The cars would have handled just as well with coil springs. The fact that Chrysler products are still the best-handling cars in the industry is a tribute to the progressive engineering that continually pours out of the Highland Park offices.

High-Speed Cornering

Perhaps this would be a good place to talk about the technical factors involved in getting a car around a corner in the minimum possible time.

First off, it goes without saying that a car is going to corner at the highest speed when the total side thrust load (which opposes centrifugal force) is as much as possible equally divided between the four tires. Only then can all the tires do the maximum amount of work. This means there must be no excessive oversteer or understeer for fastest cornering. Nor can there be any big excess of weight on one end of the car. The ideal is near-neutral steer characteristics and 50-50 weight distribution, although there has always been much controversy on this point.

To be technical, it could be said that the ideal setup is near 50-50 distribution, but with the steering tending toward understeer. This is because the slip angle is increased when torque is applied to a tire. A tire has a fixed amount of traction available. For example, when a car is developing full side thrust in a corner while coasting, and then power is suddenly applied, the amount of forward thrust must be subtracted from the side thrust—and the tire will break loose. Engineers usually picture the maximum lateral and longitudinal thrusts available from a tire in terms of a vector diagram contained in a circle that represents the maximum possible thrust in any direction. (See diagram.) The actual thrusts can be calculated with simple trigonometry. If the maximum possible traction is 1000 lb., and a forward thrust is 500 lb., for instance, then the maximum side thrust that can be developed would be 865 lb. (It is figured by calculating the angle of the vector, which would have a cosine of 500/1000, then taking the sine of that angle and multiplying by the length of the vector, or 1000 lb., to get the length of the lateral component.)

It should now be obvious why some understeer is desired for optimum cornering with a rear wheel drive car. With the rear slip angles somewhat less than the front, some power can be applied in a corner (which increases the rear slip angles) without getting into excessive oversteer. If the car had absolutely neutral steer characteristics with power off, and was cornering right on the limit of adhesion, it would theoretically spin out tail first when even the least amount of power was applied. Few cars ever operate on this ragged edge, however. And yet a considerable amount of forward thrust is needed to maintain speed in a corner. Not only is it necessary to buck wind resistance and chassis friction, but the rolling resistance of tires is much higher when running at a big slip angle than when rolling straight forward.

This brings us to the phenomenon of the "4-wheel drift." The technical factors here should be plain by now. This is merely a well-balanced car and suspension combination cornering on the limit of adhesion, with all four tires running at a steep slip angle. The reason the front tires don't have to be steered in the direction of motion (can, in fact, be pointed off the road toward the inside of the turning circle) is because their slip angles are as great as the rear slip angles. All four tires are working to the fullest. The fact that the 4-wheel-drift is a comparatively recent phenomenon in auto racing is only evidence of the refinement of the modern high-performance chassis. In the old cart-spring days the cars oversteered so badly, even with power off, that high-speed cornering bordered on the dirt-track "broadsliding" technique—where the front wheels are steered more or less in the direction of motion, and the rear end hangs outward at a steep angle. Needless to say, maximum cornering speeds aren't developed this way.

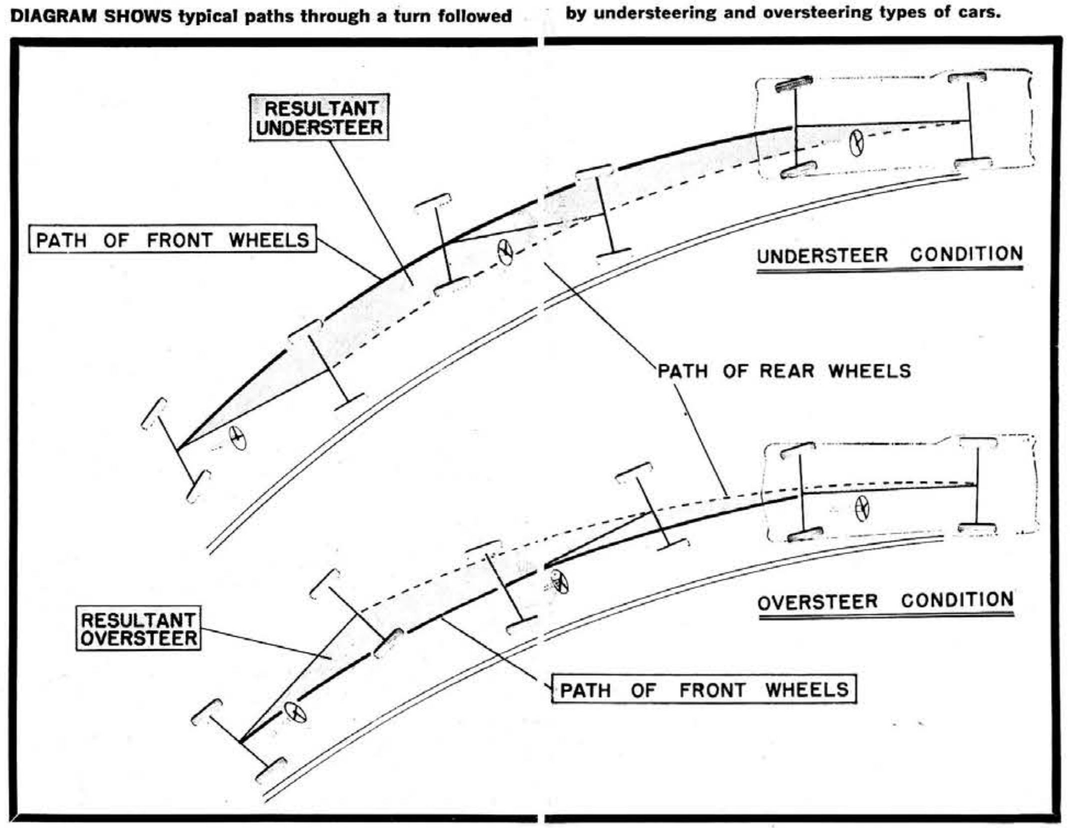
Stability

A basic understeering car is inherently stable on a straight highway; an oversteering car is not. Here's why: When an understeering car is acted upon by a side force (like a cross wind) the front wheels naturally assume a larger slip angle than the rears. Thus, the front of the car tends to steer away from the side force. This, ▶

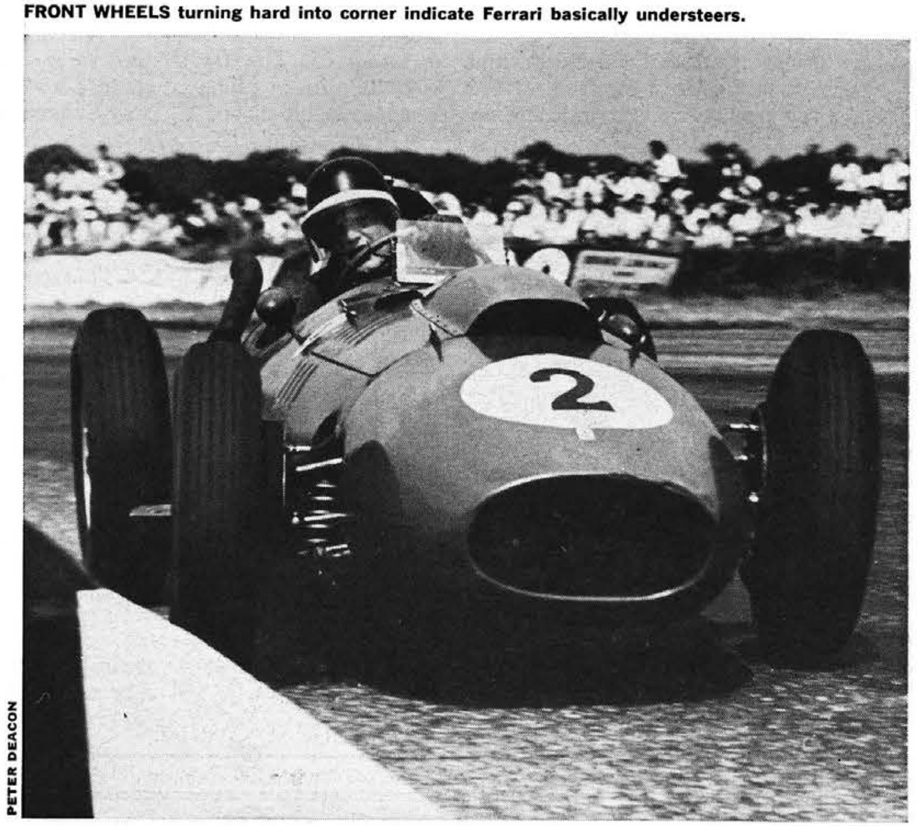
DIRT TRACK racer "broadsliding" around turn is classic oversteer study.

JOHN O'DONNELL

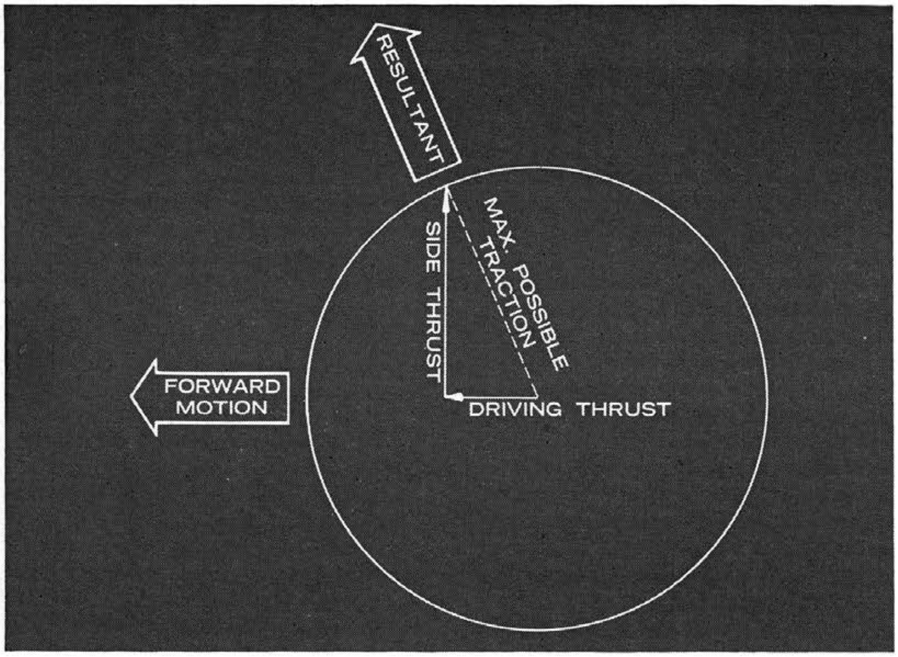
DIAGRAM SHOWS typical paths through a turn followed by understeering and oversteering types of cars.



FRONT WHEELS turning hard into corner indicate Ferrari basically understeers.



PETER DEACON



ENGINEERS CAN picture tire forces with vector diagram.

CORNERING & STABILITY

in turn, generates a centrifugal force that opposes the original side force. With the two forces acting automatically to cancel each other, the car stabilizes more or less by itself. On the other hand, with an oversteering car, the rear tires assume larger slip angles than the fronts. The rear of the car oversteers the front, and the car tends to steer toward the side force. Thus, the resulting centrifugal component acts in the same direction as the side thrust, and the effect is compounded. The driver must whip back on the steering wheel to turn the front of the car away from the force and develop centrifugal force the other way.

It's very easy to feel these effects on the road. An understeering car will go down the road in a cross wind with practically no corrective action of the steering wheel. With an oversteering car the driver has to correct for it all the way. This is one reason why American auto engineers always design a considerable amount of understeer in their family passenger cars. Some cornering ability is sacrificed, but the straight-line stability is much improved. The trend now is to use quite a lot of initial understeer, so the car is stable on the highway under the relatively light side wind forces, crown thrust of the road, etc. But more and more roll oversteer is built into the rear suspension. This effect comes into action only after the body has tilted a substantial amount, as under hard cornering forces, and keeps the car from plowing too much at the front end under these conditions. The steering actually tends toward neutral in an average hard corner. Then, as the limit of adhesion is approached, the car usually goes into oversteer, and the rear end washes out first. Applying power in a turn, of course, hastens this effect.

Avoiding this ragged edge (and most drivers do) allows the car to be a practical package that is very stable in all normal driving and yet feels quite neutral (with the attendant light steering forces) on the faster curves. It's a good compromise. The most serious problem is a tendency to wander some in a very high cross wind (especially the station wagons).

But there's also a cute new phenomenon becoming apparent in late high-performance family car options: The big-inch engines give such tremendous torque at medium speeds that they can actually heel the body over sideways several degrees when the throttle is floor-boarded. The rear suspension doesn't know whether it's torque or a side force that's tilting the body, so the roll oversteer immediately goes to work—and steers the car neatly to the left! Surging the throttle with hands off the steering wheel in one of these cars makes it snake back and forth down the road. Independent rear suspension solves this problem and will undoubtedly be the next big step forward.

That about covers cornering and stability; next month, the steering system. ■

ALTERED ROLL ANGLES with different front end suspension and anti-roll bar effect are graphically pictured here.