Push, Pull, or Both

by: John Werner

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I remember watching an IMSA GTO/GTU race a few years ago. The first place GTU car, a rear wheel drive Mazda, was following one of the GTO class Audio Quattros through a fast right hand sweeper. The Mazda looked like it was glued to the back of the Audi until about half way through the corner when the back end of the Mazda slid out and the car went pirouetting through the grass. After the race they asked the driver of the Mazda what had happened. "I was following [the Audi] when all of the sudden the car just lost it."

There was a time, when most cars sold in North America were Rear Wheel Drive (RWD). The back wheels had the responsibility to push the car along while the front wheels did most of the steering.

In the past decade, the market has changed from RWD to Front Wheel Drive (FWD). In a front wheel drive car, the front wheels do both the dual jobs of pulling the car and steering it.

More recently, the popular trend has been towards more Four and All Wheel Drive[1] (4WD & AWD) vehicles, in which both the front and rear wheels are used to propel the car.

As the drive systems for cars have changed, the way cars behave in different conditions has also changed. In this article we will look at how these.

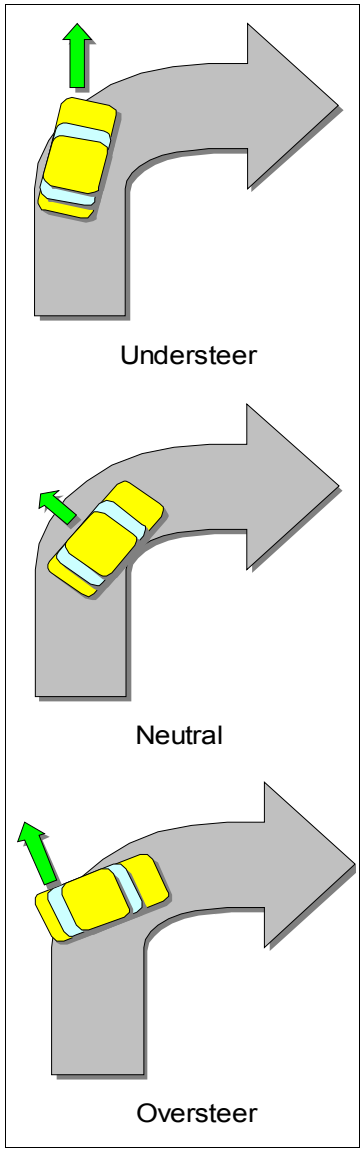

Figure 1, Handling Characteristics

Now, before we go too much farther, I need to lay some groundwork in basic car dynamics. First, some simplified definitions:

Oversteer The condition in which the rear wheels of the car have more lateral slip (sideways slide) than the front wheels. When you oversteer, the back end of the car is the first thing to hit the tree.

Understeer The condition in which the front wheels of the car have more lateral slip (sideways slide) than the rear wheels. When you understeer, the front end of the car is the first thing to hit the tree.

Neutral The condition in which the front and rear wheels have the same lateral slip.

"Figure 1, Handling Characteristics" shows how these might look on a car trying to negotiate a very tight corner.

You may have noticed that I said "has more lateral slip than." Whenever you are turning, all of your tires have a little bit of lateral slippage, but for the sake of our discussions, we will only consider which, if either, end is slipping more.

There is a technical term you will sometimes here thrown around called "slip angle." Slip angle is really just a fancy way of saying the difference between the direction the tire is rotating and the direction it is really moving. Using this technical term: *oversteer* is defined as the case when the rear wheels have a greater slip angle then the front; *understeer* is the case when the front wheels have a greater slip angle then the rear wheels, and neutral is when both the front and rear wheels are running at the same slip angle.

The other concept I want to briefly introduce is the "Traction Circle."

1 AWD and 4WD are often used interchangably, but they are not the same. In a typical 4WD vehicle, the front and rear wheels are coupled through an open differential that may have the ability to be manually locked. When the center differential is not locked, the worst case traction leaves power going only to either the front or back pair of wheels. In an AWD vehicle, the front and rear wheels are coupled through a special differential that guarantees that some of the power will always go to both the front and rear wheels. Neither end will receive all of it. The way the power (or torque) split is controlled varies by vehicle. This article discusses AWD vehicles, but is generally applicable to 4WD as well.

The traction circle is used to describe the way traction works between a tire and the road. Each tire has a fixed amount of traction that is available no matter which way you try to slide – not roll – it.

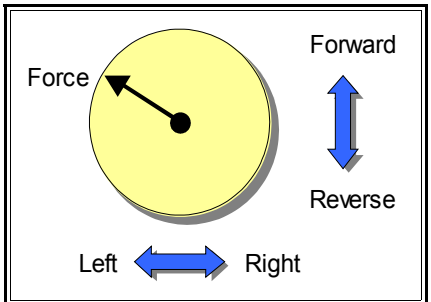

Figure 2, The Traction Circle

The circle shown in "Figure 2, The Traction Circle" shows the traction available for a particular tire. There is also an arrow called "Force." This is the work, or force, that is being applied to the tire. If the force goes outside the circle, the tire slides. From observation, you will see that if you want the most forward-reverse force (braking or acceleration), you can not apply any left-right force (turning), and vice versa.

In real life, this means that if you are trying to brake as hard as possible, you can't expect the tires to try to turn at the same time. If you are turning as hard as possible, you can't expect the tires to try to accelerate or brake the car at the same time.

It helps to know the language used to describe the differences in handling and why certain actions are better or worse in different situations.

Rear Wheel Drive

Lets start with rear wheel drive cars. Rear wheel drive cars will have a tendency toward oversteering when you apply too much power while turning. If you go into a corner in an overpowered RWD car and stand on the gas, the back end of the car will come out. At the wrong time, or in the wrong place, this can be disastrous. To counteract this, most car companies like to design their cars so that they like to understeer. They do this through the design of the front-end geometry and alignment of the car.

So, how do you corner in a rear wheel drive car? In a rear wheel drive car, the rear wheels are pushing the car through the corner. Since they are always pointing straight, they aren't helping you turn and trying to make you go straight. This means you don't want them pushing to hard while you are cornering or you will soon find yourself either facing the way you came or driving straight out of the corner.

As you come up to the corner, you want to brake reasonably hard, let off a tiny bit, and turn the wheel as you back off the brake. Braking like this transfers weight to the front tires and makes them turn in better. This is caused by weight transfer[2]. While going through the corner, keep the throttle constant until it is time to straighten out the steering wheel. As you start to straighten out the steering wheel, you want to start feeding in a little more throttle until you are pointing straight and have full throttle.

Front Wheel Drive

How about cornering in a front wheel drive car? In a front wheel drive car, the car is really pulled through the corner by the front wheels. To get the most out of the car, you want to take advantage of this fact.

In a front wheel drive car, you brake and turn in like you do for a rear wheel drive car, but once you start into the steady part of the corner, you want to feed in a lot of throttle. This will help pull the car around the corner. The tricky part here is that it is possible to give the car too much throttle and cause the front wheels to break loose.

If the front wheels do break loose, don't just try turning the wheel more, it will make matters worse. If you remember the traction circle, you will see that trying to make the tires turn even more just takes us farther out of the traction circle. You also don't want to lift off the throttle because that will make the rear end of the car lighten up and cause you to oversteer. Weight transfer strikes again! The proper course of action is to get the forces back into the traction circle, so first, do the unnatural thing and straighten out the steering a little then ease a little off the throttle. You may actually find the car will suddenly start turning tighter even though you are steering less. This is because the front wheels are back within the traction circle and are turning the car again.

Do you get the idea it is like treading a tight rope? Good. It is.

There is another technique used in when driving front wheel drive cars called left foot braking. Basically, as you go through the corner, you lightly apply the brakes while applying the throttle. Since the front wheels are being driven, they will not see to much of a change in the forces acting on them, but the rear wheels, which are not driven, will see a big change. The net result of all of this is that the rear wheels start to slide, or run at a higher slip angle. This happens because they are being asked to do both

2 Weight Transfer is a fairly straight forward idea to describe, as long as you avoid the physics of it. Simply put: when you accelerate, the back end of the car gets heavier, and the front end gets lighter. When you brake, the front end of the car gets heavier, and the back end gets lighter. Since your traction is dependent on weight, this translates into the front and rear traction changing. We actually can effect the traction circle, to a small degree, by how we accelerate and brake. This, of course, effects slip angles, and thus under and oversteer. So, when you really look at it, both the actions of your hands and your feet determine how you go through a corner.

braking and turning (remember the traction circle). Left foot braking can make an understeering car handle neutrally or even oversteer.

All Wheel Drive

What about All Wheel Drive cars? All AWD cars handle differently. There are many different ways of implementing what car companies now call All Wheel Drive. The system Volvo chose to use in their first AWD car, the 850 AWD, makes 90% of the power normally go to the front wheels with only 10% normally to the rear. Mitsubishi, in their Eclipse GSX, split the power 40% front, 60% rear for normal driving. Most of the all wheel drive World Rally Championship cars actually allow the drive to control the power split via a knob on the dash. Many systems have a viscous coupling that allows the torque to be automatically re-split as the driving conditions dictate.

In a car that has most of the torque going to the front wheels, we want to consider it to handle mostly like a front wheel drive car and drive it as such. The difference comes as we try to apply power in the turn. With the front wheel drive car, you have to carefully tread the tight rope between power and understeer. In an all wheel drive car, you don't. The all wheel drive system will take care of that for you.

In cars with the AWD system biased so that more of the power goes to the back, you want to think of it as a RWD car. This time, as you go through the corner, you can start applying power as soon as you are done turning into the corner. The back end of the car will start to oversteer, causing the all wheel drive system to send the power to the front wheels. This will pull you through the corner.

So, cornering really comes down to braking and turning in, then standing on the gas as you go through the corner. Well, almost.

You can actually put the car sideways in a corner and then drive it out so that as you leave the corner the car will be going straight down the road, but pointing at almost sideways to the road. If you have seen some of the World Rally Championship pictures, you know exactly what this looks like.

Left foot braking can also be used with all wheel drive cars, but the success of it really depends on the all wheel drive system.

The advantage of all wheel drive is that it keeps you out of more trouble. The disadvantage is that it lets you get in much deeper before you are in trouble. In an overpowered all wheel drive car, you can actually reach the point where all of the wheels are spinning. At that point, you discover what it is like to slide off the road sideways. The trick, once again, is to walk the thin line between applying power and making the tires slide.

So what happened to the Mazda in my opening story? It fell victim to the handling differences between AWD and FWD, and the different driving style required by both. As the Audi went through the corner, both the front and rear wheels worked together to move the car through the corner. If the front or rear of the car started to slip, power simply went to the other set of wheels. This allowed the Audi to actually accelerate through the corner. In the rear wheel drive Mazda, just the rear wheels were doing the work of pushing the car. As he tried to keep up with the Audi, he finally go to the point where the power going to the rear wheels made them break loose. Since there was no place to transfer the power to, the Mazda spun.

The best place to learn about and practice handling your car is in a controlled situation where you know no one else will get in your way and such that if things go wrong, you aren't going to hit something. This generally means closed circuit races, autocrosses, and driver's schools. Your local chapter of the SCCA can probably help you find one of these.

The next best place is an empty, snow covered parking lot free of lamp poles, cars, people, and anything else you don't want to hit if you make a mistake.

The worst place is a busy road in rush hour traffic. Remember, drive with your head.

About the Author: John Werner resides with his wife and two children outside of Rochester, NY. He owns and actively competes in a modified 1965 Volvo 122S and a 1991 Mitsubishi Galant VR-4.

In his free time, John edits the Internet's oldest FAQ (Frequently Asked Question) website on Snow Tires, The Snow Tire FAQ, http://www.snowtire.info, and writes for the Volvo Club of America's bi-monthly magazine, *Rolling* (http://www.vcoa.org).

By day, John works full time writing embedded software for fire and security alarm systems, and has US Patents ranging from Automotive Ignition Systems to Ink Jet Printers.

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