Anatomy of a Corner

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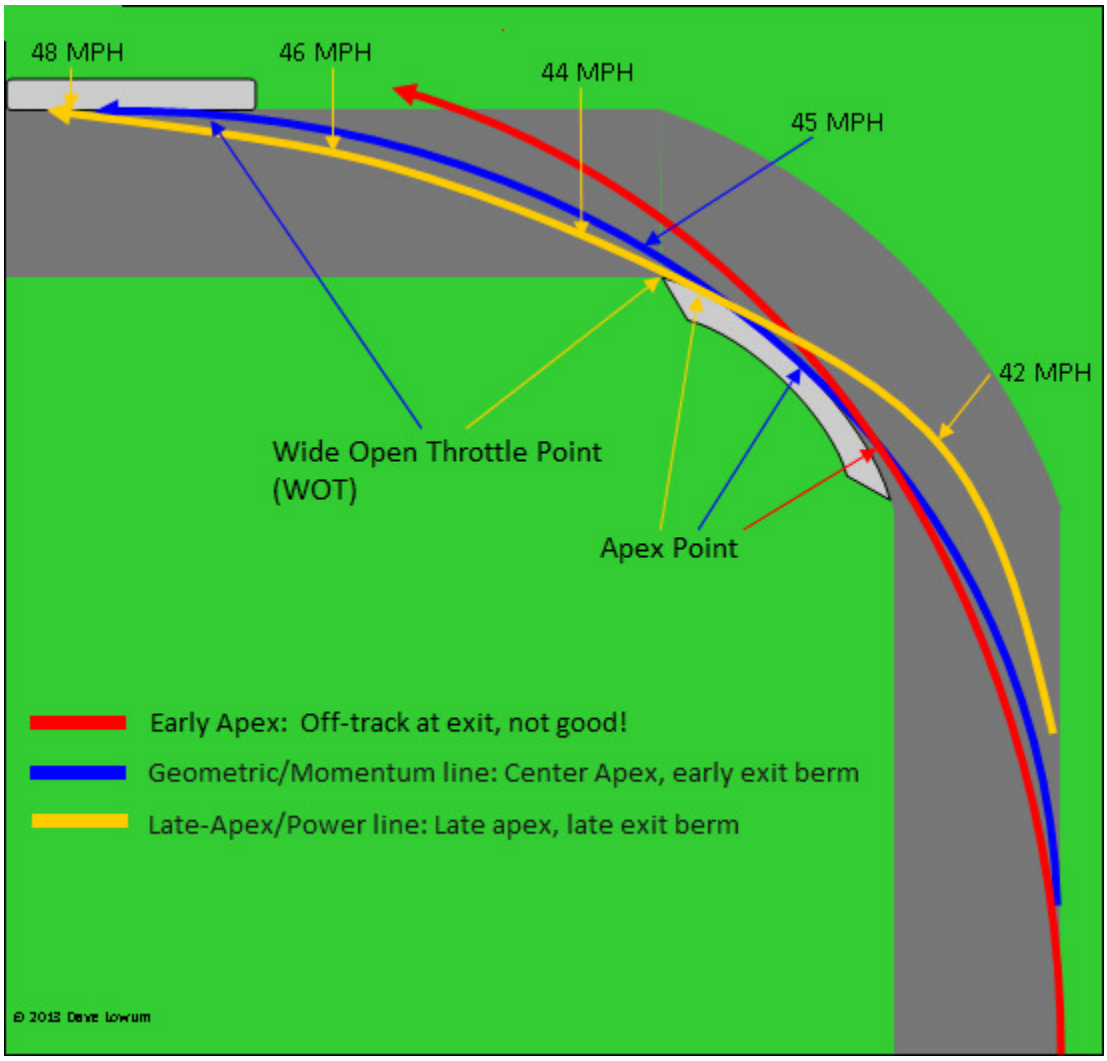
Abstract:

This may wind up getting a little bit technical, but there is a LOT of material to cover, and I teach from a Socratic perspective: I want you to understand why things are done the way they are, or work the way they do, and not just take things on blind faith. So, we'll start out with the basic background and physics behind driving aggressively on a road course.

I typically like to break down any given corner on a track into four major points:

BRAKING:	Where you stop accelerating, and begin to decelerate for the corner.
TURN-IN:	Where you initiate the arc that will carry you through the corner.
APEX:	The closest point of approach to the inside edge of the corner.
TRACK-OUT:	The point where you have unwound the wheel and are now traveling straight.

Any given corner will have a variety of possible "lines" through it. Each has its own benefits and drawbacks. But, there is just one called "the racing line". It's usually just called "the line" and it's the single fastest possible way through a corner. While each track will have its idiosyncrasies, generally speaking, "the line" will start at the outside edge of the track (driver's left for a right-hand corner) for braking and turn-in, migrates to the inside edge at apex, and then migrates back outside again for track-out. This line is actually an arc superimposed through the corner, an arc that belongs to a considerably wider radius than the natural corner, and thus allows higher speed than running either the outside edge or the inside edge.



The apex point is what determines which variation of the line you are driving. An apex point at the geometric center of the corner allows you to maintain the highest possible speed through it; however, that comes with the price of having to delay throttle application. This line particularly suits lower-horsepower cars, as you sacrifice as little speed as possible. With higher horsepower cars, which usually tend to be heavier as well, I **strongly** advocate the late-apex line. The late apex line lets you drive a little deeper into the corner, braking slightly later, and therefore making a slightly sharper turn at a slightly reduced speed. Entry speeds will be sacrificed, but you can be at wide-open throttle much sooner with the late-apex line rather than having to delay full throttle until track-out. Lower horsepower cars like the ubiquitous Miata will take more of a geometric line, but the Mustang/Corvette types have sufficient power to take advantage of the late-apex line's earlier throttle-on point.

CONSISTENCY

Consistency cannot be stressed enough. It is the key to learning to drive well and should be the first overall goal that you need to set for yourself as a high-performance driver. Consistency comes from hitting your marks on every corner, every lap the exact same way.

When starting out, you want to focus on consistency first. Don't worry so much about speed because it will come later of its own accord. Hit your braking points with the same pressure every time and hit your turn-in and your apex points. Track-out will be a derivative of the last two and can be used to judge whether you need to adjust your earlier points or not.

- Start by finding a speed where you can comfortably hit your apex point and start moving your braking point closer and closer to the corner in 10 foot intervals.
  Note the point you used when the car just pushed past the apex, not really getting all the way inside to the edge of the track.
- If you wind up running out of track before you get completely straight (onto the rumble-strips, or dropping a couple of tires in the dirt), then you turned in too soon.
- If you don't get all the way to the edge of the track, you turned in too late. If you wind up with your tires within a foot of the edge of the tarmac, it means you nailed it.
- You can also use the apex as a gauge for your braking point, but this will require that you hit your turn-in marks.
- Move your braking point away from the corner by five feet. This will lower your entry speed by a fractional amount, but lets you hit the apex point.

You can double-check yourself by carefully monitoring your tachometer at track-out. As you move your braking point closer and closer to corner entry, you will necessarily be increasing your corner entry speed. At some point, you will find that your vehicle's velocity is high enough that you have to delay throttle at exit, and results in a net slower speed at track-out. If you find this, back off on entry a bit to increase exit speed.

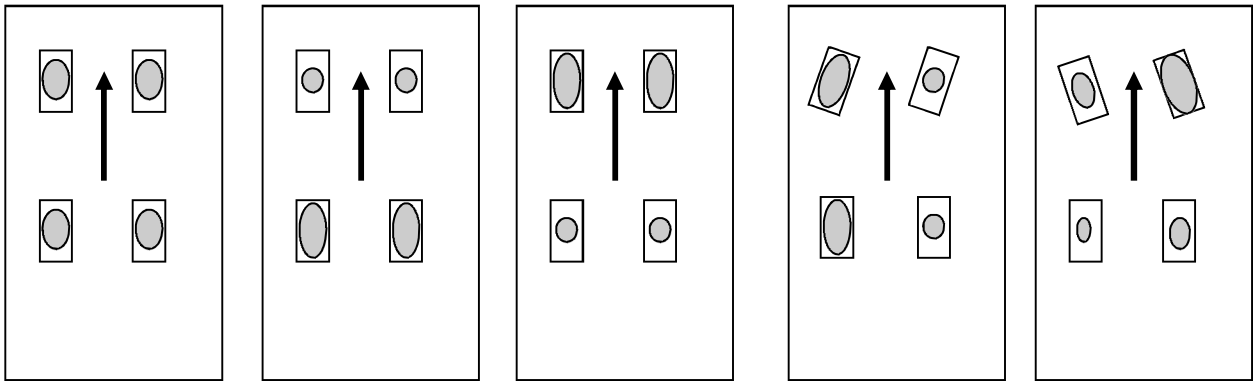
If you have executed both of these analyses, then you have maximized the corner. You can't brake later or carry more speed into the corner because they will cost exit speed. With the available grip budget,

you simply can't go through the corner any faster. For you to make those adjustments, however, you MUST hit your marks consistently.

If you blew your turn-in point for example, there's no valid exit speed comparison, so there is no usable information to be gathered. If you hit your marks and make your adjustments, you will start picking up speed. As the speed increases at exit, you will carry that advantage all the way down the straightaway to the next braking zone. Keep in mind that you *may* need to adjust the next braking point to compensate for the added speed! If you hit your marks, you will go faster. Guaranteed. Don't lose sight of this while you're still establishing your line and your marks. On any given track, prioritize the corners based on the length of the following straightaway. In terms of lap times, the most important corner is the one preceding the longest straight.

CONTACT PATCH AND VEHICLE DYNAMICS

The first thing to understand is that ANYTHING you want the car to do; whether it's to accelerate, decelerate, or turn is translated through the tire's contact patch. This is defined as the area of tire in contact with the pavement and will change based on the vehicle dynamics being applied. When you are in steady-state cruise, the load applied to each tire is roughly equal and the four tires at that point in time have the maximum amount of traction available. That being said, steady-state cruise has absolutely no place on a race track. Ever. When you apply a control input (gas, brake, steering), you will start to transfer the load around between the tires. This increases the contact patch on some, while decreasing it on others. Whenever you alter the loading balance on the tires, the net tractive capability is reduced.



Contact patch: steady-state cruise | Contact patch: Accelerating | Contact patch: Braking | Contact patch: Turning (right) | Contact patch: Trail-Braking (left)

When you accelerate, load (frequently called weight) is transferred from the front tires to the rear tires. This is just like when you see dragsters lift their front end. When you brake, the load is transferred from the rear tires to the front. When you turn, the load is transferred from the inside pair of tires to the outside pair. And yes, when you do more than one thing, the load is transferred in yet another direction. For example, when accelerating out of a corner, you are simultaneously transferring load to the outside pair of tires and to the rear pair. This results in an asymmetric loading, where the outside

rear tire has the bulk of the load, and thus more traction, while the inside front has nearly none. Load transfer can be overdone. The result of that is either:

Induced Understeer: where the car turns at a rate lower than that of the steering input (the front end pushes through the corner)

Oversteer: where the car turns at a rate greater than that of the steering input. (the rear end steps out and tries to be in charge of the change of direction)

The actual mechanism of the load transfer is pure inertia. Newton's First Law of Motion in action: *The more mass involved, the higher the level of inertia, and the more energy required to change its vector.* This is why a heavy car is harder to accelerate, decelerate, or turn than a lighter one, and the reason why a Miata will ALWAYS be faster than a Mustang through the corner.

In the end, the contact patch is what determines the net available grip at any given instant, something I call "grip budget." If you stay within your grip budget, you will go where you intend to. If you exceed your grip budget by "cashing out" more than the tires can provide, you will experience understeer, oversteer, agricultural racing, a spin, or frequently a combination of *all of the above*. Also, please note that the tires themselves have maximum grip at a small amount of slip, or slide, much like a drag tire offers the best traction with a small percentage of wheel spin. This is why you will see many race cars pointing a little bit towards the inside of the corner at track-out, but still traveling parallel to the edge of the track ("Tail out"). *Slip angle* is defined as the angle difference between the direction of the tire carcass and the wheel itself. Race tires generally have higher desired slip angles than street tires.

TIP: Try to start thinking in terms of load transfer, so that you get a gut-level understanding of what you're asking the car to do at any given time. Understand that if you elect to trail-brake into a corner, you are heavily loading the outside front tire while dramatically unloading the inside rear tire at the same time. By adjusting the loading of the various corners of the car through brake pedal pressure, you can either create or compensate for various handling ills. Depending on how you transfer the load (as well as the tractive capability of the contact patch) you can *induce* understeer by overloading the outside front tire causing it to slide or you can create *oversteer* by unloading the rear tires and allowing the car to rotate. This balancing act is a good reason why *trail-braking* is generally considered to be an advanced technique.

BRAKING TECHNIQUE

Often referred to as "threshold braking," your goal is to be on the very edge (hence threshold) of ABS activation or wheel lockup during your braking event. As we know from the discussion about contact patches, the tires are what actually slow the car down. The brakes are simply the mechanism initiating deceleration. If you are braking at the tires' limit of adhesion, you are decelerating at the maximum possible rate. This equates to the minimum amount of time on the brakes, as well as the shortest possible distance. Think of it this way: every extra second you spend with your foot on the brakes is a second that you could still be accelerating.

One of the most overlooked parts of braking technique is the art of getting into AND out of the brakes. I advocate the "touch-press" method. The touch-press method intentionally separates the braking action into two phases. First, your foot moves over from the gas pedal to touch the brake pedal itself, then and only then, will you press down quickly (but smoothly) to the threshold limit. This helps avoid the potentially negative vehicle dynamics associated with simply stomping on the brakes. The transition from "touch" to threshold should be approximately .25 seconds and should be smooth and linear. From a vehicle dynamics standpoint, this helps to manage the load transfer forward and prevents overloading the springs and dampers. The more violent the load transfer, the more likely you'll overshoot your suspension travel, causing a minor oscillation and subsequent reduction in traction. The touch-press method transfers the load quickly but gently, thus maintaining a higher grip level and braking capability.

Equally important to remember is to use the same philosophy when coming OFF the brakes as well since you will have an opposing load transfer as you finish slowing down and begin accelerating again. Getting into the habit of trailing off the brakes rather than just jumping off will also serve you well if and when you start to trail-brake.

Other benefits from the "touch press" method are:

- Reduced pad consumption
- Reduced fluid temperature (less chance of boiling the brake fluid)
- Reduction in peak temperatures experienced by the braking system. Shorter but harder braking actually induces less heat into the rotor than a longer/ softer braking event.

One final thought about threshold braking and vehicle dynamics… IF you are braking at the limit of your tires grip, you will NOT have any available "grip budget" left over.

STEERING TECHNIQUE

There is no magic involved here because in reality, it's actually very simple. Keep your hands locked at the 9:00 and 3:00 positions on the wheel at all times unless actively making a gear shift. As with braking, you want to make a SINGLE rapid, but smooth motion on the wheel. Again, we are focusing on that quarter-second-ish pace. The main key here is to use the wheel to initiate load transfer smoothly and focusing on getting the maximum necessary wheel input done at about the same time the suspension takes a set, indicating that the dampers are controlling the springs and the car is stable.

The **First Sin** to avoid is multiple wheel motions in a given corner. Every time you change the wheel angle, you are loading or unloading the suspension. Sawing the wheel will simply delay the point where the chassis is stable, which then delays the point where you can start accelerating again. With higher-level drivers, you may well see them making multiple *minute* adjustments through any given corner. This is done intentionally, with load transfer firmly in mind, and only when the car is simply not responding as desired. If you find yourself in an *understeering* situation, you MAY elect to open the wheel back up a bit to reduce the load transfer slightly in hopes of getting more bite out of the tire and finish the corner pulling in more wheel angle to stay on line. This can become helpful in FWD cars. Some corners are simply like that, but they're the exception to the rule. This is done more instinctually than it is consciously. If you find yourself in an *oversteering* situation, you may have to make a similar

adjustment to the one just described of playing with load transfer in the hunt for more traction. Counter-steering as the car oversteers is a gross exaggeration of what I'm talking about, but the principle still applies.

The **Second Sin** to avoid is "snapping" the wheel over too quickly. This is a tendency often demonstrated by drivers with autocross experience. This is a habit that must be broken when transitioning to driving on a road course. Generally speaking, the cornering speeds on a road course are considerably higher than on an autocross track and the corner radii are also generally much larger. So there is really no reason to have to dial in the steering angle nearly as rapidly. When too much steering angle is fed in too quickly, the car will tend to understeer on entry as the front wheels start sliding prior to the load transfer being completed while the suspension is still in motion. In a worst case scenario, the driver would continue to add steering angle to compensate up to the point where the suspension finally sets, the tires bite, and you are then faced with a sudden onset of oversteer. This describes a situation of transitioning from over your grip budget to under grip budget. The **ONLY** situation where "snapping" the wheel is **required** is where you find yourself understeering off course and into the grass. In this case, you would quickly straighten out the wheel so the suspension can "reset" weight distribution in hopes of getting the much desired change in direction. *(More on that later)*

THROTTLE TECHNIQUE

Even more so than with the brake or steering techniques, you want to be smooth on the throttle. NEVER simply mash the gas. Feed it in keeping firmly in mind what this does to your contact patches and "grip budget". Your goal is to be either at wide-open-throttle or about to be wide-open-throttle. If you have to delay throttle application because the car isn't set (exceeding "grip budget"), then you are losing time. Having to get out of the throttle and then back in due to wheel spin also causes a loss in time.

Many instructors recommend that students think of having a raw egg between their foot and the pedal, and treat it accordingly. I don't necessarily agree with that. I suggest adding as much throttle as you can without exceeding the "grip budget", and then try to induce understeer or oversteer. Once you FEEL what it's like "balancing the car on the throttle," you'll know exactly what I mean. It almost feels like you use the wheel just to initiate turn-in, but you actually maintain your line through a corner with the throttle. (*Also called "steer with the rear"*)

An experiment to try (<u>not at race speed!</u>): Find a nice highway on-ramp with a constant radius (most are). Put the car dead-center at entry with your wheel and then just hold the wheel there. As you add throttle, you'll find yourself drifting towards the outside edge. Easing off the throttle a touch will bring you drifting towards the inside edge. You should shoot for the same effect when cornering on a race course. Use the wheel to establish your arc through the corner and then maintain or adjust your line with the throttle. This allows the suspension to stay set, gets all the load transfers sorted out, and results in a stable car. THEN you start feeding in more and more throttle until you're at the edge of understeer, and at that point you are using 99% of your "grip budget".

STRING THEORY, AKA SEPARATION OF CONTROLS

Putting this all together, we come back to "grip budget" and the desire to use as much of it at all times. *String theory* as applied to open-tracking is the concept that there is an "imaginary string" connecting the steering wheel and your right foot. You can use full throttle or brake pedal while the car is straight, but that should reduce the amount of pedal input you should use shortly after steering angle is added, until you reach the point where the "grip budget" is completely used up turning the car leaving you with nothing left available for acceleration or braking.

Always do your threshold braking in a straight line so that you are using 100% of your grip to slow the car down. If you have executed this properly, you should be done with your braking and at proper entry speed right as you hit your turn-in point. At this point, you should be completely off the brakes, and have just enough throttle-in to maintain your speed through the turn-in (called maintenance throttle).

Once the car has initiated the turn and you feel the suspension set, begin feeding in more and more throttle staying consistent with the line. As you hit the apex, start unwinding the wheel while simultaneously adding more throttle. The concept to try to understand while driving on a track is that you're ALWAYS on the gas or the brake at any given time, whether it be just a little or the whole lot. NEVER simply coast!

A note on trail-braking… As you may have figured out, there is a "grey area" between the end of the braking zone and the point where the grip budget is spent cornering the car. Trail-braking maximizes your use of that short period of time by extending the end of the braking event into the turn-in phase. Simply put, you're past turn-in before you are completely off the brakes. This can allow you to move your braking point slightly closer to the corner; however, it also completely ***eliminates*** *any safety margin at the most critical part of the corner. Simply put, it can save a few thousandths of a second when executed properly. But, it can cost you tenths of a second, full seconds, a spin, or your car if there's a wall handy when executed poorly. This should be the* ***last thing*** *you work on, and only after you can run a string of laps within two tenths of a second per mile of track. TIP: You can use trail-braking technique in very tight corners to artificially help rotate the car by inducing oversteer. However, you have to be able to catch it properly!*

PROBLEM RECOVERY

It is inevitable that you will eventually over-cook a corner and find yourself with the realization that you're simply not going to make the corner. You should NEVER attempt to turn the car if you know that you're just going too fast. You should realize this no later than 2/3 of the way through the braking zone. There are few actions to take that all but guarantee a happy outcome, but the proper technique may vary with chassis type!

First, stay HARD on the brakes and keep the wheel straight. Ninety percent of the time, you will find that simply extending the braking zone far past turn the turn in point will give you sufficient room to slow the car down enough while keeping it on the tarmac. It'll be an ugly corner, but you'll keep the car clean. The other ten percent of the time when you are simply unable to finish slowing down on the race course, you should stay on the brakes while keeping the wheel straight and simply drive the car off the

end of the corner. Whether you encounter grass, gravel, or sand, you NEVER want to exit the racing surface with the wheel turned. The edge of the tire and rim can dig in the ground and cause a roll over. If you drive off straight, you will have control of the car.

Understeer recovery: You need to transfer load forward. This means you have to either ease off the gas or add a touch more brake as appropriate. This will allow the front tires to bite. For high-speed *understeer* mid-corner, you slightly unwind the wheel *slightly* until you feel the car start to respond again. Then wind the wheel back in. (This is the "wheel snap" alluded to earlier.)

Oversteer recovery: Do NOT get off the gas! That will transfer load forward, reduce rear grip, and turn the oversteer situation into a spin. The solution is to gently add MORE throttle. If that doesn't work, use the wheel to correct for the skid. This is usually caused by excessive entry speed or excessive use of throttle after apex.

IF YOU SPIN: immediately go "both feet in" hard on the brakes and clutch in. Once you spin, there's no saving it. The mission now is to stop as soon as possible. It's also possible that your attempts at "saving it" will put you off-track at corner exit. If this is the case, slowly and gently get off the throttle AND DO NOT try to pull the car back on track at high speeds. The ground will often be eroded at the very edge of the track that creates a rut for you to cross. That rut can catch a tire and produce unpredictable results. Get the car slowed down and then carefully pull it back on as gently as possible after making sure you are clear. If you are unsure, stay put, and look for a corner marshal to wave you back on. It's also track etiquette to give your corner marshal a "thumbs up" to let them know you are okay. After ANY off-track excursion, take the next few corners gingerly (and OFF LINE!) to clean off the dirt, mud, grass, debris, etc., from the tires or dripping from your undercarriage. This will have a significant impact on your "grip budget", and not in a good way.

CONCLUSION

In the end, the art of going faster is really all about focus and consistency. Focus on executing the fundamental techniques properly, and then apply them consistently. Make effort to ingrain these techniques on a subconscious level. This will allow you to focus on one of the most important things on track: VISION. Always keep your "eyes up" and out of the car. Look far down the track while giving a regular scan of the mirrors. Look and THINK ahead of the car! As you approach your braking point, scan through the corner to see if there's anything that might impact your line. As you reach your braking point, look through the turn-in point to your apex point. As soon as you initiate turn-in and you know the car is on line, look past the apex to your track-out point. As you reach apex, look as far down the track past track-out as you can and begin thinking about how you're going to approach the next corner. By keeping your "eyes up," you will have as much advance warning as possible for any situation you may encounter; flags, slower traffic, debris on the line, a spinning or stalled car, or even wildlife. This gives you more time to see, process, think rationally, and execute calmly. It's also much easier to properly execute a pass if you saw the other car, studied their tendencies, planned where and how you would make the pass, and then adjusted paceto make it all happen, rather than simply running up on them and THEN trying to figure out how to get around them.

Focus. Consistency. Vision. These are the hallmarks of a high-performance driver.