

THE PERFECT CORNER 2

A Driver's
STEP-BY-STEP GUIDE
to Optimizing
COMPLEX SECTIONS
Through the
PHYSICS OF RACING

THE SCIENCE OF SPEED
SERIES



PARADIGM SHIFT
DRIVER DEVELOPMENT

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2

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to Optimizing
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Through the
PHYSICS OF RACING

The Science of Speed Series

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DRIVER DEVELOPMENT

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CONTENTS

STANDARD LINE THEORY SUMMARIZED & TESTED	8
SETTING CORNER ENTRY/EXIT ANGLES & THE 90-DEGREE LIMIT	15

DOUBLE APEXES

COMPARING A DOUBLE APEX TO A CIRCULAR RACETRACK	23
LINKING DOUBLE APEX ENTRY & EXIT ANGLES	32
THE DOUBLE APEX RULE & SHORTCUT CUES	34
DOUBLE APEX TYPES (DECREASING/INCREASING RADIUS, HAIRPINS)	43

CHICANES

THE IDEAL CHICANE VS YAW INERTIA	55
THE CHICANE RULE & SHORTCUT CUES	61
OPTIMIZING CHICANES WITH IMAGINARY CONES	67

STRAIGHTS

THE SURPRISING SCIENCE OF OPTIMIZING STRAIGHTS	72
THE FULL-THROTTLE CORNER RULE* (APEX LIMITS & THE SHORTEST PATH)	75
THE PROBLEM WITH INDUCED DRAG	82
CHOOSING YOUR EXIT ANGLE TO THE NEXT CORNER	86

CASE STUDIES: COMPLEX SECTIONS

REDUCING DRAG IN A FULL-THROTTLE TO STANDARD CORNER	94
LINKING MULTIPLE CHICANES & DOUBLE APEXES	98
SHORT CHICANES TO OVER 90-DEGREE EXIT	102
EXPANDING DOUBLE APEX TO 90-DEGREE EXIT (SLOW VS FAST VEHICLE)	106
THE FINAL TEST (SHANGHAI INTERNATIONAL CIRCUIT TURNS 1-4)	110

"If you can't explain it simply, you don't understand it well enough."

- Albert Einstein

BEYOND THE STANDARD CORNER

While the basic principles of Line Theory that we learned in *The Perfect Corner* will take you far, there are some unique track situations that take special rules. While the eventual answer is not any harder to execute than a standard corner, how we get there can be a little complex. This will be worth the effort however, because while trial and error will often eventually lead you to at least close to the right answer with standard corners, understanding how Line Theory works in more complex track sections can give you a significant advantage. Even in the higher levels of motorsport, some drivers misunderstand how to optimize complex track sections and will debate various ways to handle them. Being able to quickly determine how to optimize a complex section can be a great benefit and we can do this with just a few new rules.

We'll start out with a summary of basic Line Theory and then we will push your understanding of its rules to the limit. Next, we will look at the new rules needed when combining corners, as well as the surprising science of optimizing straights. Finally, we will end by breaking down some of the most complex corner sequences in the world. If you can learn how to solve these puzzling track sections, you will be able to figure out how to drive anything.

You can also be assured that these rules provide a complete solution. They work with virtually every vehicle, on any track. You sometimes hear discussion about which corner on the track is most important or the concept of grading corners, but while certain corners will certainly have greater potential to change your lap times, this doesn't affect how you should drive them. There is time to be gained and lost in every corner and you can use the same principles to optimize them all.

STANDARD LINE THEORY SUMMARIZED

To get started, let's lay out a basic summary of everything we learned about Line Theory so far in *The Perfect Corner*.

- A driver should set their braking point based on how their entry spiral carries them to the apex. If their spiral does not reach the apex, they need an earlier braking point. If their spiral would carry them off the inside of the track, they need a later braking point.
- Once the driver starts turning into their entry spiral, they will try to reduce their radius as quickly as possible by maximizing their tire forces pushing them in the ideal direction. The pre-apex ideal direction is basically at the same angle as the track during corner entry.
- An entry spiral's starting speed determines its size and therefore where in the corner it needs to start. For a given corner, a larger, faster, and earlier starting spiral will create an earlier apex. A smaller, slower starting spiral will create a later apex, but will need to start later.
- With an earlier apex, the vehicle will be at a higher speed and will have turned less as it passes by. A later apex will have a lower apex speed and the vehicle will have turned more as it passes.
- The shape of the inside of the corner will determine the exact location of the apex. This will create a steady progression of a certain speed and angle attainable as the apex moves from earlier to later along the inside of the track.
- As they pass the apex, the driver will maximize the vehicle's acceleration in the ideal direction. The post-apex ideal direction will be in the same direction as the track exit.
- If maximum acceleration would carry the vehicle off track, the driver needs a later, slower apex. If there is space left at trackout, the driver will need an earlier, faster apex. This new apex will require a different spiral and thus a different braking point.

But are there no exceptions? What about off-road driving? What about racing on a wet track? What about elevation changes and banking? These situations don't actually change the rules, but they will test how well you understand them. As an example, while racing in the rain, it is often standard practice to avoid driving on the standard line if on a well-worn track where the racing line is very slippery when wet. If the grip on the standard line is only half what driving off the line produces then this will just effectively change where the edges of the track are. Those curbs are no longer the edge of the track. Now the edge is where the track grip level significantly changes and you must use Line Theory principles to optimize around these new track limits. If you used your car control abilities to find this area of high grip, you might discover that now your apex is out in the middle of the track or it could even turn a standard corner into a double apex. You still want to maximize your movement in the ideal direction before and after the apex, but the results are completely different now from when the track was dry.



Often the best line for an off-road motorcycle is wherever the rut has formed.

Changes in track geometry work the same way. Off-camber corners, high banking, crests, dips. They might change the grip you have at any moment, but the rules stay the same. For example, consider a corner that is off-camber near the apex and then transitions to have some banking near the corner exit. A car would gain extra force production capacity (grip) as it progressed through its acceleration arc. This would change its lateral vs longitudinal force generating capability

to be as if it was a less powerful car. So just like a less powerful car, this would create a more circular acceleration arc, but only for that specific corner. A driver goes through this same line finding process on every corner however. Different cars, setups, pavement grip levels, track geometry, weather. These will all create a unique solution each time. The process and the rules however, will always be the same.

Beyond just modifying a line, track geometry can also progressively change the efficiency of different lines and minimize or magnify mistakes. For example, a well designed curb will cause a car to progressively lose grip the farther off track it drives. The more curb used however, the more ideal the line so there can be a range of lines where using more and more curb won't change lap times very much. A well marbled track causes the opposite to happen where a car progressively loses grip the further off line and into the marbles it drives.

Bristol Motor Speedway has actually used track geometry on purpose to promote close racing. The track has a progressive banking where the higher line is more angled. This evens out the efficiency of multiple lines to make passing easier. Sometimes track geometry can even be so extreme however, that the best line might be completely different from what the ideal line would normally be. Often the best line through a corner for an off-road motorcycle is wherever the rut has formed. The force generating potential in the rut is so much higher that it could be far from a normal ideal line for a fresh track, but still be faster.

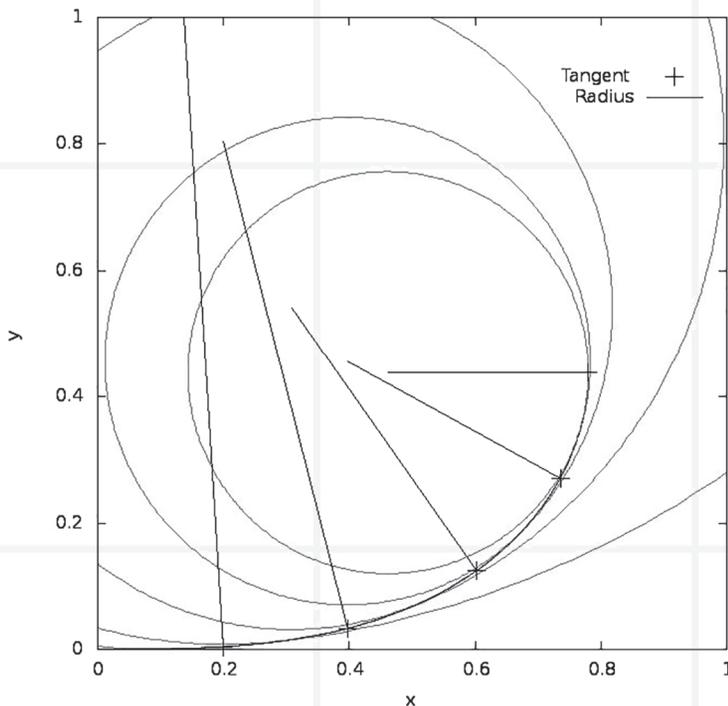


Bristol Motor Speedway's progressive banking promotes close racing by increasing the efficiency of alternate lines.

LINE THEORY TESTED

Whether it was the track designer's intention or not, a racetrack will sometimes fool you. The track edges can be a red herring. As we move beyond standard corners, you'll learn how the key to navigating complex sections is often to find the real limits of the track. To visualize your own perfect racetrack within the real track and optimize around the ideal points, which are not necessarily always the track edges.

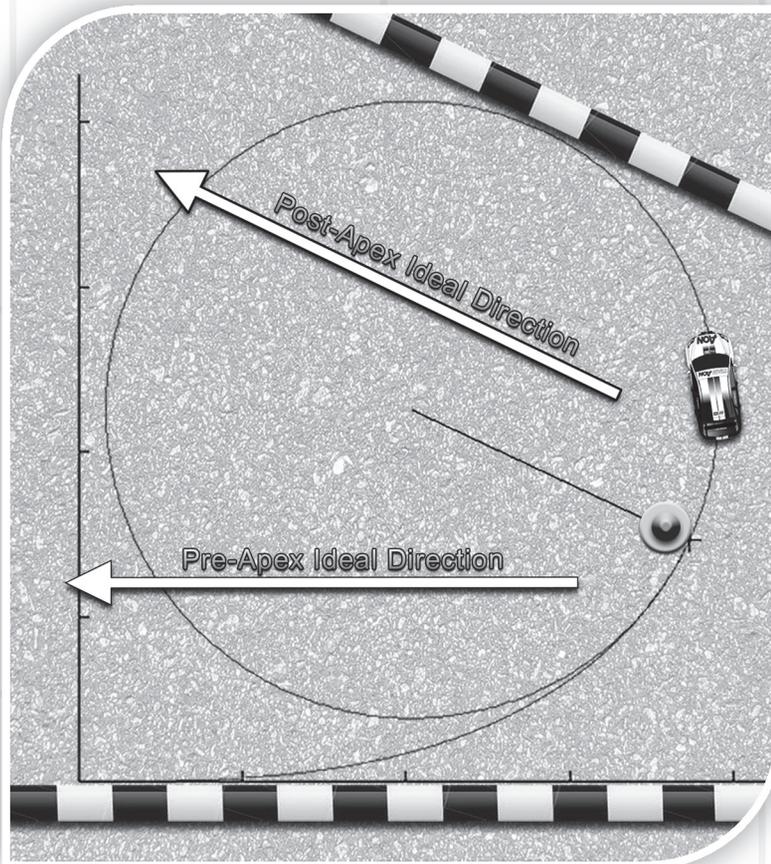
Before we get to complex sections however, we are going to first deepen our understanding of basic Line Theory. We are going to put it to the test. We're going to try to break it. Doing thought experiments like these can be a really good exercise to help you understand the physics of racing and how you can apply it in any situation.



You might recognize this graph from the end of *The Perfect Corner*. It shows how the Euler spiral is essentially made of a series of smaller and smaller circles as you travel along the path. We are going to use this illustration for this first section, as it will allow us to have an exact measure of how our apex speed and angle will change as we move along the spiral.

A STANDARD CORNER

Let's start with a basic corner made of two track edges and a cone for an apex. This would mimic a standard road course corner. We've laid out the spiral to show how you would optimize this configuration. You can easily identify the corner entry ideal direction in this section, as it will be parallel to the graph. The entry spiral starts at the exact same angle as the graph edge at the bottom. Because this corner is optimized, it is also at the same angle as the track edge.

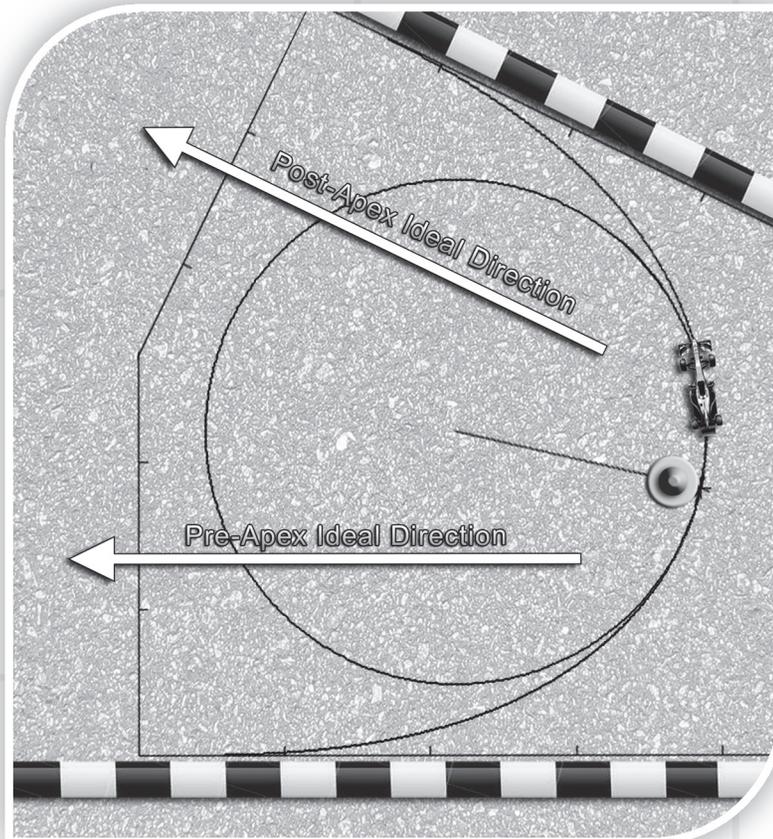


The size of the circle shows the maximum speed the car could attain at the apex. This example car will maintain this speed throughout the rest of the corner at full throttle. This is not completely realistic, but is quite close to reality for lower-powered cars and will help to visualize how the attainable apex speed will reduce as the circle shrinks while the car moves along the spiral with a later and slower apex.

The corner ends when the circle meets the track edge. Here that is 90 degrees from the apex and the car would continue straight at this point along the track edge. The corner exit ideal direction is therefore at the same angle as the track edge.

A STANDARD CORNER (HIGH-ACCELERATION)

Now let's look at how this same corner would look with a car having the same maximum grip potential, but more power to accelerate. We have flipped and copied the Euler spiral so the corner exit path will have an increasing radius that mirrors the corner entry. This would be the idealized path the astronaut would travel on and only a high-powered 4-wheel drive car would ideally drive this line. A high-acceleration rear-wheel drive car in a slow corner could come very close however.

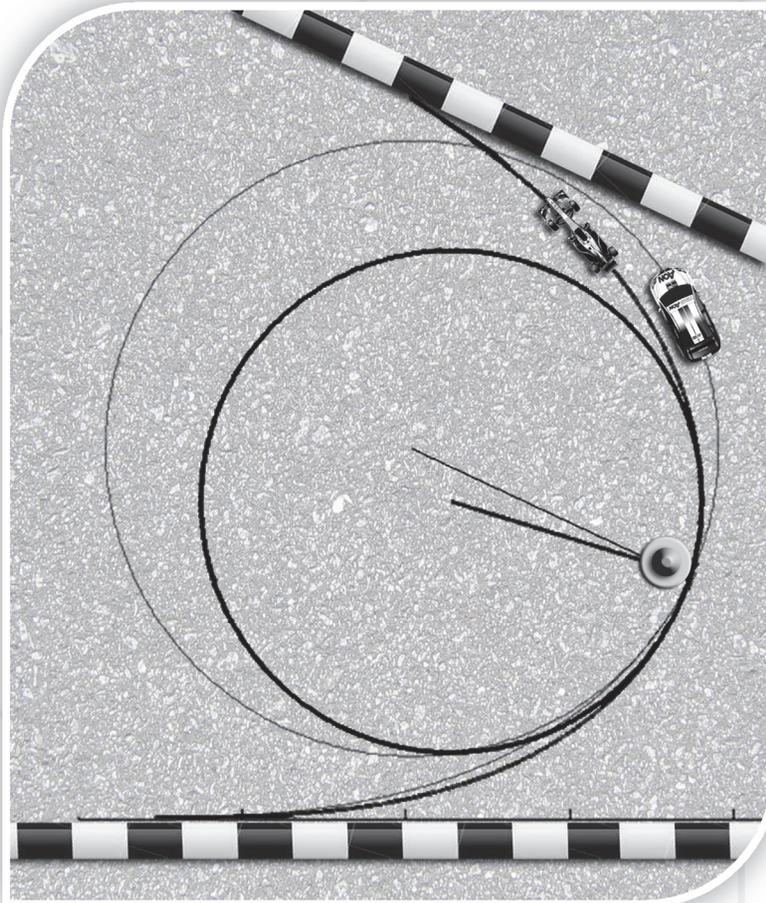


Notice how the ideal directions are still the same as previously and follow the track edges. The ideal direction would be parallel to the angle the car starts and ends the corner. This is determined by the track edge, not the acceleration potential of the car.

The high-power car is able to accelerate in the post-apex ideal direction more effectively than the slower car, but will require a later, slower apex to accomplish this. The high-power car will take slightly longer to get to its apex, but will complete the entire corner much faster.

LOW VS HIGH ACCELERATION

Here we have overlaid our previous two illustrations. The thicker dark line shows the high-acceleration car. Both apexes are basically at the same point at the cone, but the higher acceleration car has a later and slower apex. You can see that the apex speed is slower because the circle is smaller and the angle of the radius line shows that it has also turned more by the apex. The car with greater acceleration would need this slower, later apex to better use its power during corner exit.

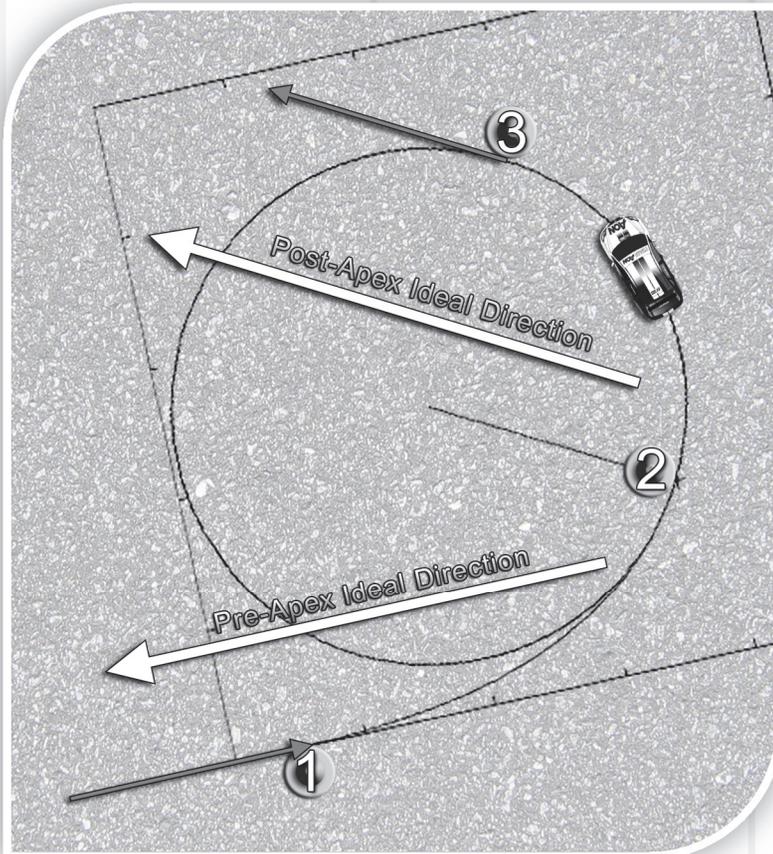


It's useful to note that the lines are quite close to each other, especially at corner entry. Practically every car from a super high-powered F1 car to a low-powered stock autocross car would travel somewhere between these two lines. The speeds could be very different, but the paths of travel are fairly close. The biggest difference is where the car hits the track edge at corner exit and as we start to mix things up, that difference is going to become important.

This should all just be a review so far, but we wanted to make sure you're up to speed if it has been awhile since reading *The Perfect Corner*.

SETTING YOUR OWN IDEAL DIRECTION

Let's now remove the curbs and replace them with cones. On a normal racetrack, your ideal direction is usually easy to visualize and follow because it will basically be the same direction as the edge of the track. When you are only limited by a single point as with a cone however, you can decide your own direction of travel as you pass it, and thus your own ideal direction. So let's see how we go about optimizing a corner when we have this freedom to choose how we approach and leave it.



Because we aren't limited by the track edge, we can pass the 1st cone at a greater angle than the curb was allowing. This angles out our pre-apex ideal direction and allows a slightly faster corner entry.

The corner exit however, looks identical to before as the placement of the 3rd cone makes this low-powered car still have a 90-degree corner exit. Having freedom to choose your own ideal directions won't always necessarily allow you to complete a corner faster. It depends on the cone placement, but also on the car capabilities. So let's see how the high-acceleration car would optimize this.

End of Sample

STILL MANY LAPS TO GO

Working up new tracks sections can help you to test and solidify your knowledge, but don't limit yourself to just road courses. You can look at the many different types of motorsport to see how the physics of racing can work anywhere. Watch how superspeedway racers will use the Double Apex Rule through the high-banked turns. Watch how dirt bike racers look for the grip generating ruts. See if you can figure out why rally racers use Scandinavian flicks and high slip angles. Try to find other examples of your own. There are plenty.

If this is your first read-through, you might be feeling pretty overwhelmed right now. We don't expect a driver to be able to absorb everything the first or even second and third time through. While the rules of Line Theory are pretty straight forward, figuring out how to apply them to new track sections can be quite the mental workout sometimes. There is no need to jump straight into complex sequences if you aren't ready. We recommend you start simply and work your way up. Take it one corner and one page at a time.

We wish we could just tell you to be smooth and don't miss the apex, but if it were that simple, where would the fun be? Although the road to true understanding is not always easy, if you love motorsport as much as we do, the destination is definitely worth the journey. It's quite a powerful feeling to know exactly what you should be doing at every instant on track - and not just what, but why. Not because someone told you so, but because you truly understand it yourself. For while none of us will ever quite reach it in reality, in our minds, every single one of us can drive...

**THE
PERFECT
CORNER.**

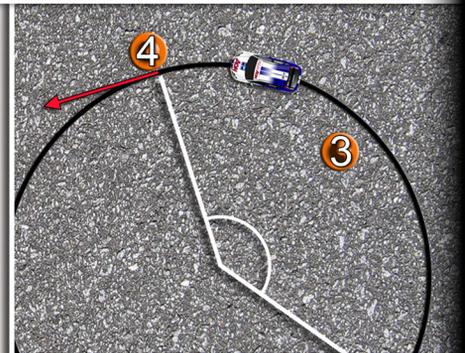
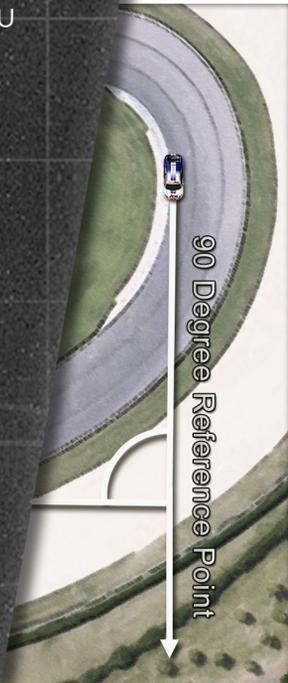
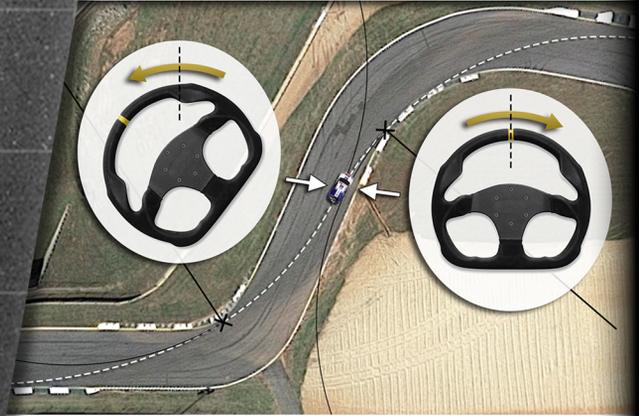
READY FOR THE NEXT LEVEL?

Learn how the physics of racing can be applied to advanced track sections. We show you the rules needed for double apexes and chicanes, as well as how to link them in complex sequences. Plus you'll learn the surprising science of optimizing straights:

Finally, the last section will really put you to the test as we break down some of the most complex corner sequences in the world. If you can solve these puzzles, you will understand how to drive anything.

Learn how there is no such thing as a throwaway corner and how every single section of a track can be driven to perfection.

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