Advanced Driving & Sensitivity Concepts

By Warren Chamberlain

Dedicated to my Dad, who took me to my first race in October 1966
(CanAm at Laguna Seca), and worked his last SCCA club race in 2018.

William Warren Chamberlain II - January 1933 -- October 2018

Introduction

For drivers, the true language of speed is feel. Sure, words can be used to describe a feeling, but the really valuable information required to drive a car at the limit (energy, forces, movement, balance, etc.) that stuff is understood holistically by your ‘feeling’ intuition and instincts, not by your ‘verbal’ intellect.

This disconnect between intellect and the actual ‘stuff’ of speed is why it’s essentially impossible to explain how to drive, or how it feels to drive, at the limit in anything but a very rudimentary way. A great example of this is to watch car or motorcycle racers trying to communicate with their engineers. If you watch them ‘explaining’ a handling problem they may start with words (understeer, oversteer, etc.) but often the message is lost in the translation, so when words fail, the non-verbal part of them that actually does the driving (intuition and instinct), interrupts to show what the problem ‘feels like’. Hands start mimicking what’s being felt, or steering wheel/handlebar inputs are simulated, or shoulders and hips move to demonstrate the relationship between what the ‘front end’ and the ‘back end’ of the car/bike are actually doing on track.

That said, while intellect may not be great at performing the actual driving process, it is exceedingly good at planning, evaluating, predicting, quantifying, etc. various elements of your driving, or a complete driving performance; all of which can be very helpful for a racer. The difficult bit is getting intuition and intellect to communicate so the whole driving process can be optimized.

When I started racing, I was fast immediately (set the lap record my 3rd weekend), but I learned and drove like everyone else; instinctively/intuitively. I could not have told anyone how/why I was fast, I just did what came naturally without understanding it. In my 3rd season I had some unusual experiences when racing that gave me some insight into the mental processes going on when I drive, and the parts/levels of my brain that were being used when driving at the limit.

Anyway, those insights helped me discover the concepts presented in this booklet. For me, the concepts acted like translators for my intellect; allowing it to understand the meaning of the feelings my instincts and intuition were using to drive. Of course, it’s not a ‘direct’ translation; it’s more like the concepts provide a way of thinking about the source of the feelings, and the cause effect relationships between the feelings. Basically it just gave me another level of understanding, resolution, precision, and confidence in my driving. I hope you find these concepts useful, or at least interesting.

This booklet contains advanced concepts, so I’ve made the assumption that you know basic racing stuff like ‘the line’, traction circle, slip/drift angles, etc. Also I’m assuming you can get around the track at a reasonable pace without being completely overwhelmed. There are some mentions of different information processing methods mentioned in this booklet; detailed information about that can be found on my website (www.intuitivespeed.com), which provides a lot of other driving information such as:

- Learning Strategies for Racers
- Reducing the Sensation of Speed (information processing strategies)
- Concentration for Racers
- Confidence for Racers
- Training Techniques

This booklet provides my observations and opinions about advanced driving and sensitivity concepts. If you choose to act on any of the ideas, you do so of your own free will, and assume the risks inherent in racing. Therefore, I hereby disclaim any liability incurred in connection with the use of this information.

Advanced Driving & Sensitivity Concepts

Concept #1 - Tire, Traction & Cornering Terminology

Perhaps terminology is not really a concept, but complete and precise terminology does provide the building blocks for constructing and understanding concepts, so I've included mine.

Concept #2 - Speed as a Liquid™

This concept provides an analogy for thinking about how the kinetic energy stored within a car moving at speed flows through the chassis and into the tires to produce the loads that ultimately create traction, drift (slip) angles, and the forces that act on the car to get it around the track. This energy movement happens constantly, but since it can be very subtle, having a way of thinking about it can make it easier to tap into.

Concept #3 - The Energy Cycle™

This is the foundational concept for the way I view both the driving process and sensitivity because it illustrates the cause/effect relationships and timing of how energy moves during the cornering process, while also providing a way of thinking about how the different types (or modes) of sensitivity relate to driving. It also provides a framework for integrating the other concepts.

Concept #4 - The 3D Traction Circle™

This concept provides a visual framework for experiencing and thinking about tire capabilities, loads, traction, and drift angles in a more holistic way. Since these enigmatic sensations are mainly processed unconsciously by your intuition and instincts, they are very difficult, or impossible, to clearly describe with words. Hopefully this concept can work like a translator to help the intellectual portion of your brain to understand and interpret the meaning of these sensations at a much higher resolution than normal.

Concept #5 - Controlling Rotation & Plan Corners Backwards

Managing rotation is the key to most turns because, in general, it determines the point at which the entry phase of the turn is complete, and the exit phase begins. Therefore it defines when, and how hard, you can get back on the gas. Rotational forces are created (or hindered) by the relationship between the car's front and rear drift angles. However, it's important to recognize that the drift angles can be created in two ways (by heavily loading a tire, or by removing the load a tire needs to produce maximum traction).

Concept #6 - Driving a Trajectory, Not Just a Line

People often talk about 'the line' as though it was a point (the car's center of mass) traveling a specific path around the track. However, you are not driving a point, you are driving 4 contact patches that describe a rectangle. Therefore, I've always found it more helpful to think of driving a trajectory instead of just a 'line'. By trajectory, I mean the combination of the line your car's center of mass is traveling, overlaid with the drift-angle influenced orientation of your rectangular contact patches relative to the 'line'.

Concept #7 - Sensitivity and the Energy Cycle

The energy cycle provides a way of thinking about how the different types (or modes) of sensitivity can be influenced by paying attention to different elements of the energy cycle. Focusing on elements later in the cycle means your sensitivity is being used more for reacting to what's happening. Focusing on elements earlier in the energy cycle means your sensitivity is being used more for directing what will happen.

Concept #1 - Tire, Traction & Cornering Terminology

The Inuit (Eskimos) have approximately 50 names to describe something that we use one name to describe; snow. Why? Because there are many different types of snow (hard-packed, deep powder, wet, dry, corn, etc.). The differences are not important to us, so we just call it all snow, but when you live in the arctic, identifying and understanding the type of snow you are dealing with can be a matter of life and death.

For racers, feeling and understanding traction and the tire/track interface can be a life and death matter (or for Sim racers, a win/lose matter). However, for some reason, racers use very few words to describe tires, traction, and cornering. And the words we do use are often misleading and/or contradictory. For example ‘Slip Angle’:

The definition of slip is: “slide unintentionally for a short distance” or “slide suddenly and without intending to”.

However, this is not what racers mean when they use the term ‘slip angle’ because what they are really describing is an expected, gradual, and predictable (for a skilled driver) deviation from an intended path. So they really are describing drift not slip.

Anyway, I believe that a somewhat larger and much more precise tire/traction vocabulary could be very helpful in identifying and interpreting how you are controlling your tires, and where you are on the Drift vs Cornering Force curve (for cornering) and Percent Slip vs Cornering Force curve (for braking and acceleration) at any point on the track.

Below is my tire/traction/handling vocabulary. I’m not claiming its ‘right’, but it works for me.

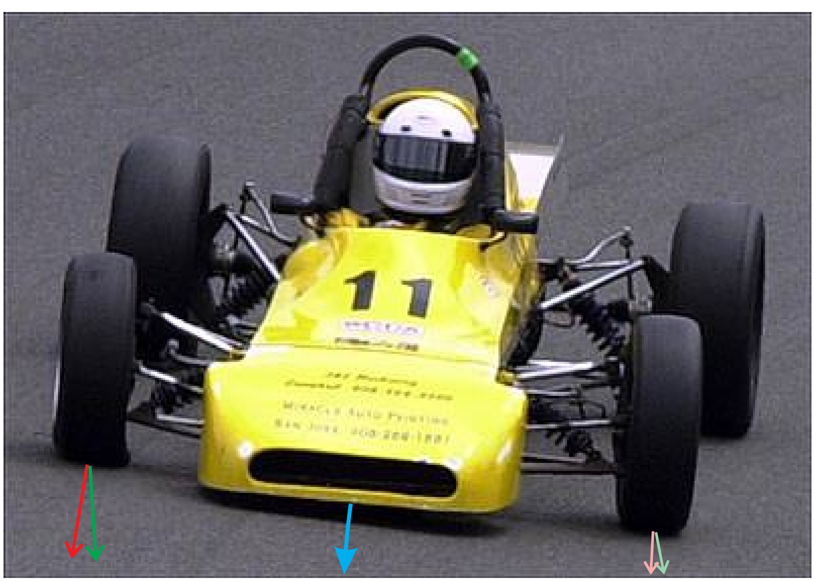
General Trajectory/Handling Terms

Drift = Any deviation from the path your wheels are describing, whether intended or not. Drift can be caused by a great deal of traction, which causes distortion of the tire's contact patch and sidewall, or by a lack of traction, which causes the tire to slide across the road.

Drift Angle (AKA Slip Angle) = The amount of drift (in degrees) that the tire/car is traveling away from the direction the front or rear wheels are pointing; so, the amount of deviation from the intended path.

Drift angles can be produced by both heavily loaded and lightly loaded tires. Both can produce the same amount of drift, but the drift is caused by different types/levels of traction.

Below is an example of two front tires with the same drift angle; the outside (driver’s right) front tire is drifting due to heavy loading and traction distorting the sidewall and contact patch. The inside front tire (left) is drifting due to less than optimum loading causing reduced traction. (so, both a ‘loaded drift’ and a ‘light drift’ on the same end of the car.)



Bright green shows the intended path of the loaded (outside) tire’s wheel, and Bright red show the actual (drift) path.

Light green and light red show the same for the *relatively* unloaded (inside) tire.

Blue shows the actual direction of the car, which is the same as the drift path.

Concept #1 - Tire, Traction & Cornering Terminology

General Trajectory/Handling Terms Continued

Drift Angle Cont. (AKA Slip Angle) = In addition to having the same drift angle for different reasons on one end of the car, you can also have drift angles happening for different reasons on the front and rear of the same side of the car.

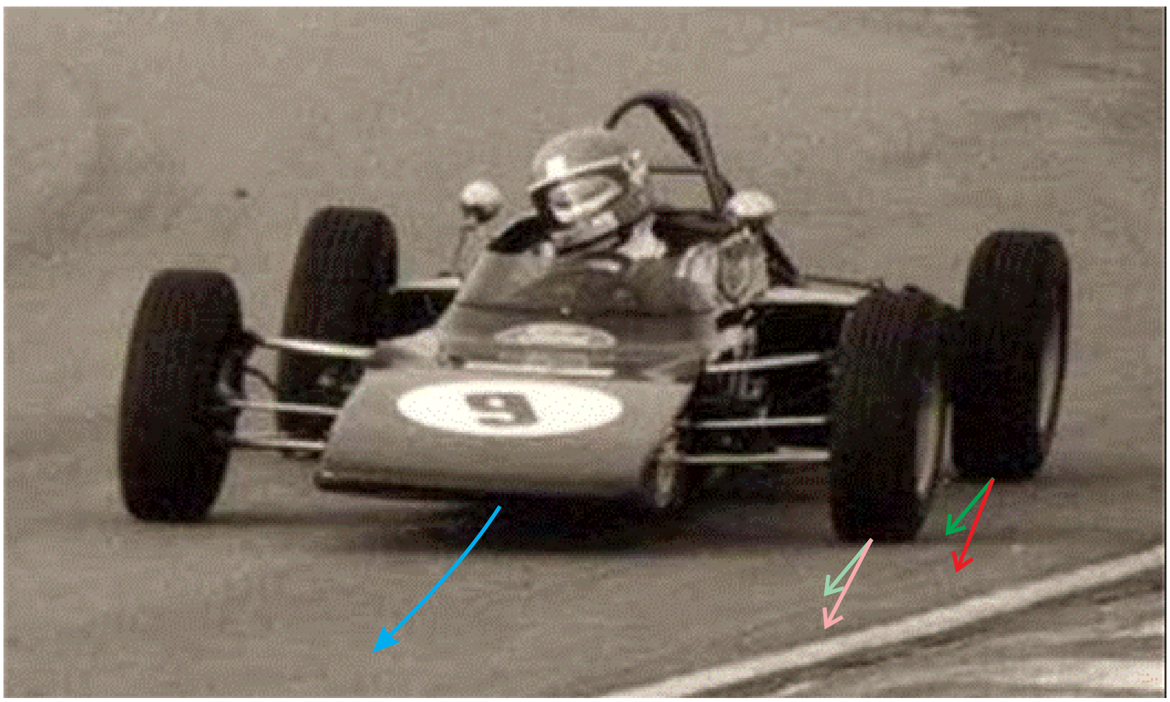
For example, you could use the throttle to transfer load from the front tires to the rear at just the right moment when the car is rotating in yaw at the apex of a turn to simultaneously create a loaded drift in the back of the car, and an unloaded drift at the front. When timed/executed properly, you can control excessive rotation by using the unloaded drift angle from the front to counteract the loaded drift angle from the rear of the car.

Below is Ronnie Peterson demonstrating simultaneous loaded rear tire drift and relatively unloaded front tire drift. This is as close as you can get to a true 4-wheel drift.

Bright green shows the intended path of the loaded (rear) tire's wheel, and Bright red show the actual (drift) path.

Light green and light red show the same for the *relatively* unloaded (front) tire.

Blue shows the actual direction of the car, which is basically the same as the larger drift path. The rear drift is slightly greater than the front, which is a requirement to complete the corner without 'understeering' off the track.



Understeer (push) = The handling condition that occurs when the front tires drift more than the rear tires. This can be caused by either insufficient or excessive loading of the front tires.

Oversteer (loose) = The handling condition that occurs when the rear tires drift more than the front tires. This can be caused by either insufficient or excessive loading of the rear tires.

Balance = The handling condition that occurs when the front and rear tires are drifting the same amount. This happens naturally & briefly at a turn's rotation point, but never for long, otherwise you'd eventually just drift diagonally off the track. This can also be made to happen by a skilled drive who understands loads & drift angles.

Percent Slip (longitudinal) = The difference between a tire's free-rolling speed and it's actual rotational speed, which can be greater (under acceleration), or less (under braking).

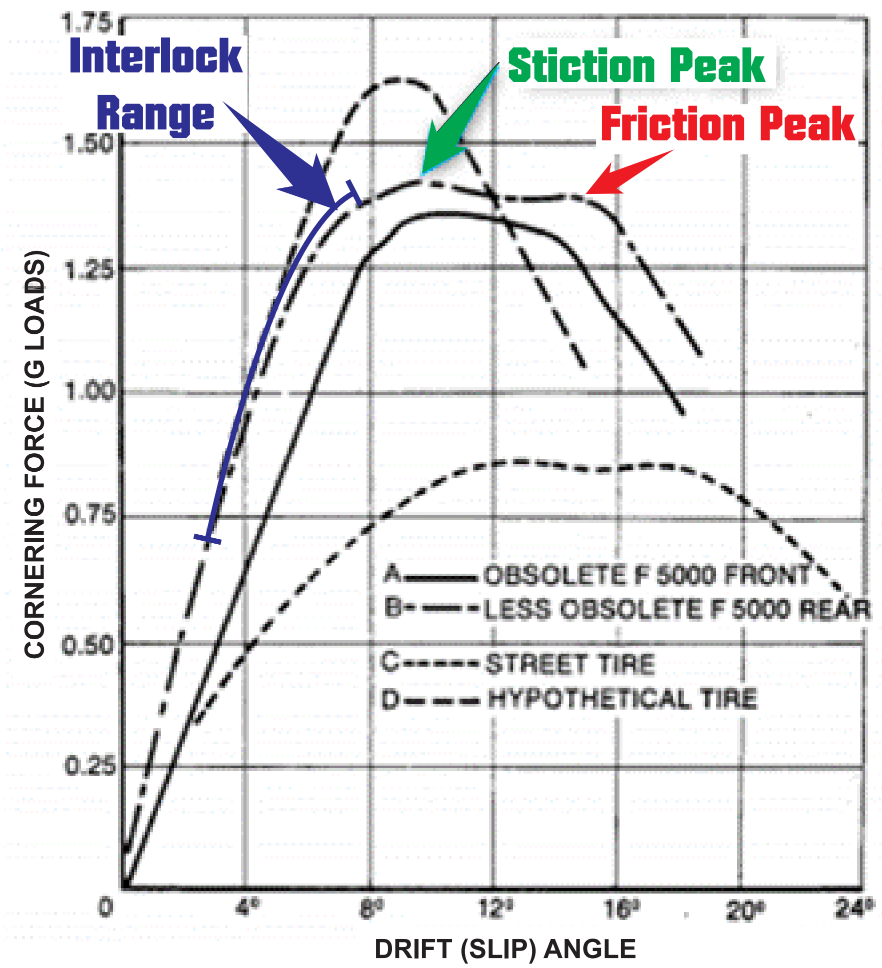
Concept #1 - Tire, Traction & Cornering Terminology

Traction Type Terms

Interlock = This type of traction is generated primarily by the interlocking of the tire's pliable rubber with the pores in the road surface. It is most prevalent at relatively low speeds/loads/drift angles (blue range in the image below). It is often where drivers who are struggling for speed get stranded because it feels relatively safe. However to produce maximum traction, an element of friction must be added to the mix by introducing more energy (speed) and therefore more load & drift angle.

Stiction = This type of traction is generated from an optimum combination of interlock and friction, which occurs as a result of applying an optimum amount of energy (speed) and load to a tire for a given turn. When done correctly the tire produces optimum drift angles at the stiction peak, which results in maximum traction, and minimum tire abuse such as overheating and scrub, (as illustrated by the green peak in the image below). Optimum drift angle is a function of a tire's design (9 degrees in the example below and maybe 5-6 degrees for more modern tires).

Cornering Force vs Drift Angle – curve 'B' below - (From Carol Smith's book *Tune to Win*).



Concept #1 - Tire, Traction & Cornering Terminology

Traction Type Terms Continued

Friction = This type of traction is generated by the surface of a heavily loaded tire scrubbing across the track surface. Maximum useful friction occurs at the third (red) peak on the previous page's Cornering Force vs Drift Angle illustration. The peak occurs at about 16 degrees of drift, and provides a traction level very close to that obtained at the Stiction peak (it's within about 3% to 5%). However, consistently driving at this peak usually scrubs speed and puts a lot of heat in the tires.

Note: Stiction and Friction are not mutually exclusive; they are simply two points on the traction continuum, and in between, they blend in various proportions.

Below is an example of friction cornering. Perhaps this is the fast way through (or out of) this corner (no technique is fundamentally good or bad… they are just optimum for your objectives in the current context or not), but you can literally see the rubber being torn from the tire and deposited on the track.

Specific Tire/Traction Terms

Slip = An unexpected loss of traction. Typically caused by a reduction in the track's coefficient of friction (e.g. oil, water, dirt, etc on the track).

Slide = A relatively low level of traction caused by the tire not carrying sufficient load to produce the amount of stiction or friction needed to create maximum traction.

Skid = Intermittent losses of traction caused by the inability to keep the tire in contact with (or 'hooked up to') the track surface (e.g. bumps, driver induced energy waves, excessive throttle, etc.).

Specific Tire/Traction Terms Continued

Scrub = A high level of traction produced by a tire that is overloaded (with acceleration/deceleration and/or cornering forces) to the point that it is producing larger than optimum drift angles, and therefore most of the traction is being produced by friction.

Light Drift = A relatively lightly loaded tire that produces a lot of drift angle, while still producing a good amount of traction. For example, the front tires on a car that is understeering slightly out of a high-speed sweeper.
(See the Ronnie Peterson example under the Drift Angle section.)

Loaded Drift = A tire heavily loaded with a combination of acceleration/deceleration and cornering forces that is producing optimum (or greater than optimum) drift angles.
(See the Yellow #11 car image under the Drift Angle section.)

4 Wheel Drift (the myth) = I don’t believe that a true ‘4 wheel drift’ can occur for more than a brief moment, and certainly not all the way out of a turn.

That is, if you’re driving fast, either the front end is drifting more (on the way into the turn) or the back end is drifting more (on the way out of the turn). In the classic, car cranked sideways, tail out, power on out of a turn, example of a ‘4 wheel drift’ (see below) there are only two tires drifting (the rears). The front tires are managing: the drift, the rear tire loading, and the trajectory of the car, by being pointed into (in the direction of) the drift at approximately the same (or a few degrees less) angle as the drift. That means the front tires would have essentially zero drift angle. So, the classic 4 wheel drift is actually a 2 wheel drift, but it’s still cool as hell!

Concept #1 - Tire, Traction & Cornering Terminology

Cornering/Driving Terms

Line	=	The two-dimensional path you intend to drive around a turn/track.
Yaw Rotation Point	=	The point in a turn at which your car rotates around its center of mass (stops entering and starts exiting the turn). Another way to think of this is the point when the front to rear centerline of the car rotates from being greater than tangent to the 'line' being driven, to being less than tangent (so, when the car stops pointing to the outside of the line being driven and starts pointing toward the inside of the line. The yaw rotation occurs naturally in every turn (usually near the apex), but you can (and should) control when it happens by controlling your car's Yaw Attitude.
Yaw Attitude	=	The angle at which you place your car on the line you intend to drive. The contact patches of your four tires describe a rectangular area. You can control the angle, or orientation, of your car's rectangle, with respect to the tangent of the Line you're driving, by using various driving technique and/or setup changes. If you're understeering, the front of your rectangle is pointing away from the turn; if oversteering, it is pointed toward the inside of the turn.
Trajectory	=	The direction the car is traveling, which is determined by how drift angles influence the car's yaw attitude in relation to the 'line' being driven.
Cornering Plan	=	The plan for getting around a corner at maximum speed, which involves managing energy flow (with the energy cycle), to apply loads to the tires, to create the traction & drift angles that will influence the car's yaw attitude, which will ultimately interact with the line being driven to control the car's trajectory (and therefore speed potential) through the turn.

Concept #2 - Speed as a Liquid

For me, almost immediately after I started racing, I could feel what was happening in my car and predict what was going to happen, but it seamed like black magic... like I didn’t really have conscious understanding and/or control of it. I wanted more; I wanted to understand where the sensitivity was coming from, and how I was able to translate what I was feeling into a meaningful interpretation that would allow me to confidently and consistently take my car to ‘the limit.’

As I gained more experience, knowledge, and sensitivity, I realized that a car at speed (or more specifically, the kinetic energy stored in the car) behaves like a liquid. Hit the brakes, and it flows forward, hit the throttle and it flows back, turn the wheel and it flows diagonally into the outside front tire. When turning, the energy also flows in yaw around the car’s center of mass. And, like any liquid, all of these flowing movements start gradually and build with time as long as more energy continues to be applied. Also, the liquid’s viscosity is different from car to car, for example; super low for karts (like water), low for small formula cars (like milk or buttermilk), and the viscosity continues rising as the cars get heavier.

So, I began to see my car’s chassis as a pan full of this liquid, the faster I went, the fuller it got. When I needed to make a tire work for me (to enter a turn for example), I thought of making driving inputs that would create a controlled flow of energy... pouring it through the suspension/spring/shock and into the tire.

Since tires require load to create traction, and they keep making more traction as load increases until the tire’s performance limit is reached, I began to think of my tires as water balloons. However, I thought of them as very delicate balloons because the liquid energy had to be poured into them gradually or they wouldn’t have time to expand... too much energy too fast and they would effectively rupture, spilling the energy and likely causing at least a loss of performance if not control.

This relationship between a tire’s ultimate traction capacity and the load it’s carrying is why anyone, regardless of how ‘fast’ you are, can spin at less than maximum speed/performance. Load a tire insufficiently, and you can spin even if it’s only performing at 1/2 of its ultimate capability. Likewise, pour half the load into a tire carefully, and then dump the rest in and you can spin because you did not give the tire’s capacity time to expand to it’s design limit.

The liquid analogy also address how energy can move in controlled currents, or in uncontrollable waves if not properly managed. The idea of uncontrolled waves is especially true in very high speed turns. For example, if the back end steps out, you must recognize that very early or you’ll likely never catch up (you’ll spin the direction the back end is going). If you do get correction in to ‘build a dam’ against the energy flow, but you don't plan for the wave rebounding off the dam (you’ll end up ‘over correcting’ and spin the opposite direction).

So, what does speed as a liquid mean in practice? An example might be:

1) When it comes time to turn, I try to carefully pour just the right amount of energy, at just the right rate, into the outside front tire to start the turn. The objective is to allow the tire to create maximum performance while avoiding the creation of unwanted energy waves/oscillation because energy waves/oscillations can unbalance the car by changing the loads on the tires in undesirable ways.

2) When the turn is initiated, I turn my attention to how the tire loading is progressing towards its peak performance, while also monitoring how the traction and direction change is starting a rotational flow of energy around the car’s center of mass.

3) As the front tire load/traction peaks, and the car approaches the apex of the turn, the rotational flow is gaining strength, so my attention turns to quickly and carefully moving the energy from the outside front tire to the outside rear tire to ‘check’ the rotational flow and orient car for optimum acceleration out of the turn.

Concept #3 - The Energy Cycle, an Introduction

While traction and ‘the limit’ can be sensed, interpreted, and predicted (all successful racers do so naturally; intuitively), they are very abstract concepts to try and describe and/or understand intellectually. That is, they can be experienced, but it’s hard to unravel the many factors (driver input, car type, car setup, tires, environment, etc.) that interact to, ultimately produce the maximum driver/car performance potential.

Once I realized that speed feels like a liquid to me, I needed a way to think about how I could use that realization to understand the whole process of cornering so that I could not only do it predictably and consistently at the limit, but so I could also observe and optimize the process.

After thinking about it, I realized that energy doesn’t just flow linearly into the tires, instead it flows and grows cyclically over time. It starts with one or more driver inputs, and then it grows as it travels through the following four interrelated elements or phases:

1 - Energy flows through the chassis.

2 - That energy pours into one or more tires and produces load.

3 - That load produces traction & drift angles.

4 - That traction produces forces that act on the car’s center of mass.

So, the cycle starts with a driver input placing a small amount of energy in motion, and then the energy level grows moment-by-moment as the forces acting on the car cause more energy to enter the cycle.

This cycle of increasing energy continues until:

- Equilibrium between the energy cycle and tire is reached. That is, the tire contains the maximum amount of energy it can handle (and therefore is producing the maximum traction it can). When equilibrium is reached the energy cycle reverses and the energy dissipates from the tire back into the chassis.

- There is no longer sufficient energy (speed) available to increase the cycle’s energy level, regardless of the tire’s capability. For example, not enough speed was carried into the turn.

- The driver executes an input that interrupts the energy cycle, and/or moves the energy from the current cycle to another location (tire).

Once initiated, the energy cycle can be managed with minimal mental resources if it is evaluated by recognition (how well it is matching what is expected) instead of the much higher cognitive load method of analysis, which requires a great deal of attention as the sensations from the cycle are continually evaluated to interpret their meaning.

(Information processing methods are explained in <u>much</u> more detail here).

Concept #3 - Energy Cycle Elements - Top View

Below is the framework I started with as the foundation for the energy cycle. It shows the four elements of the energy cycle, numbered to reflect their order in the cycle, and the intersection of the crosshair represents the energy cycle's origin (aka a driver input).

4 - Forces

Traction creates forces that act on the car's center of mass. Including the critical force of yaw rotation

3 - Traction

Tire loads generate both traction and drift (slip) angles.

1 - Energy Flow

Driver input causes energy to start moving (flowing) through the chassis and suspension, and into one or more tires.

2 - Tire Loads

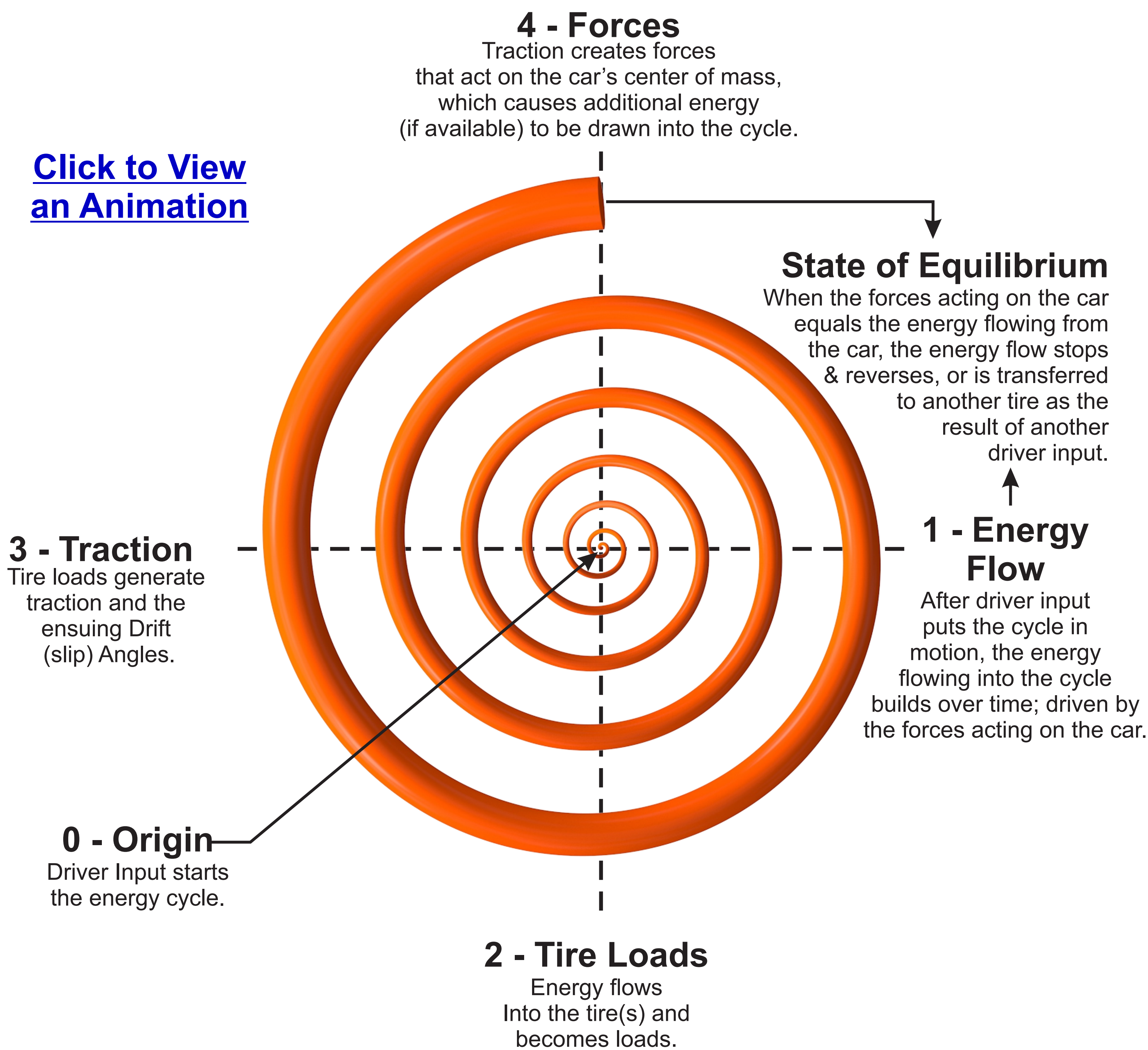
Energy flowing Into the tire(s) becomes loads.

Concept #3 - Energy Cycle Elements Interactions

The spiral represents how the energy cycle builds cyclically, as the forces acting on the car draws more and more energy (stored in the car as speed) into the cycle.

It's easiest to visualize how the energy cycle grows as an animation, so a link is provided below.

Click to View an Animation



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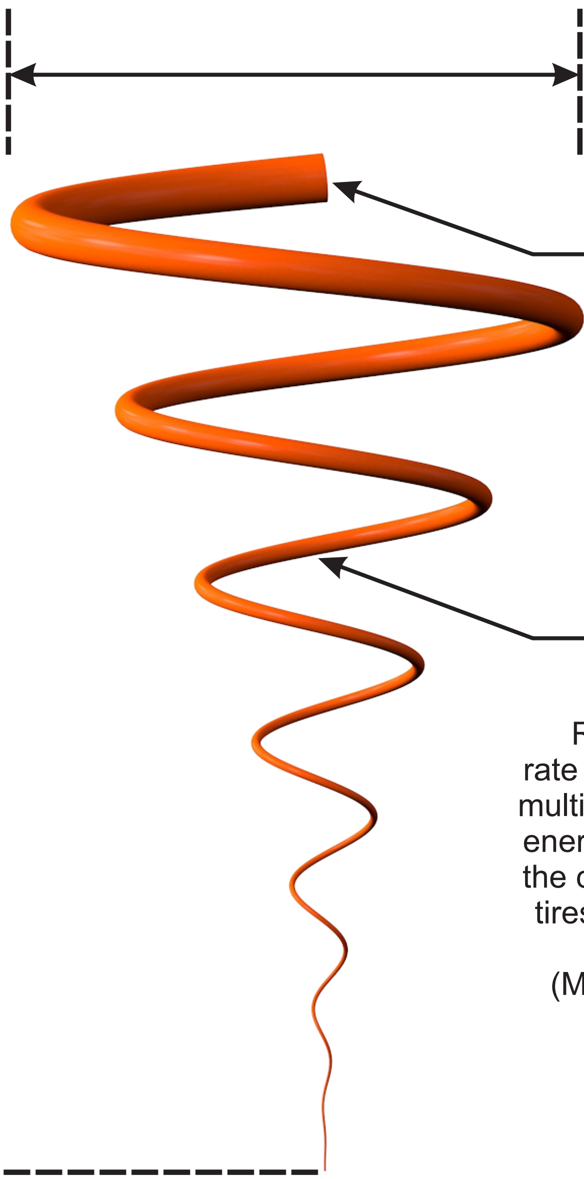
Concept 3 - Energy Cycle - Side View

A side view of the energy spiral makes it easier to see how the energy level grows over time, and how the revolutions take time to build the energy level. Even though the energy cycle takes time ti build, it can actually happen very quickly depending on the car, driver input, and turn.

This is easiest to visualize as an animation, so you a side and perspective view are provided (link below).

Cycle Diameter
Represents the amount of traction (G load & drift angle) the energy/load/tire combination is producing.

Click to View Animations



State of Equilibrium
When the forces acting on the car equals the energy flowing from the car, the energy flow stops & reverses, or is transferred to another tire as the result of another driver input.

Cycle Height
Total amount of energy in the cycle (Including the energy stored in springs and tire deformations).

Cycle Rotation Frequency
Represents the energy level's rate of change, which is impacted by multiple things including the available energy (the car's speed and weight), the coefficient of friction between the tires and track, how aggressive the driver input is, etc.
(More rotations = a slower cycle)

Origin
Driver Input starts the energy cycle.

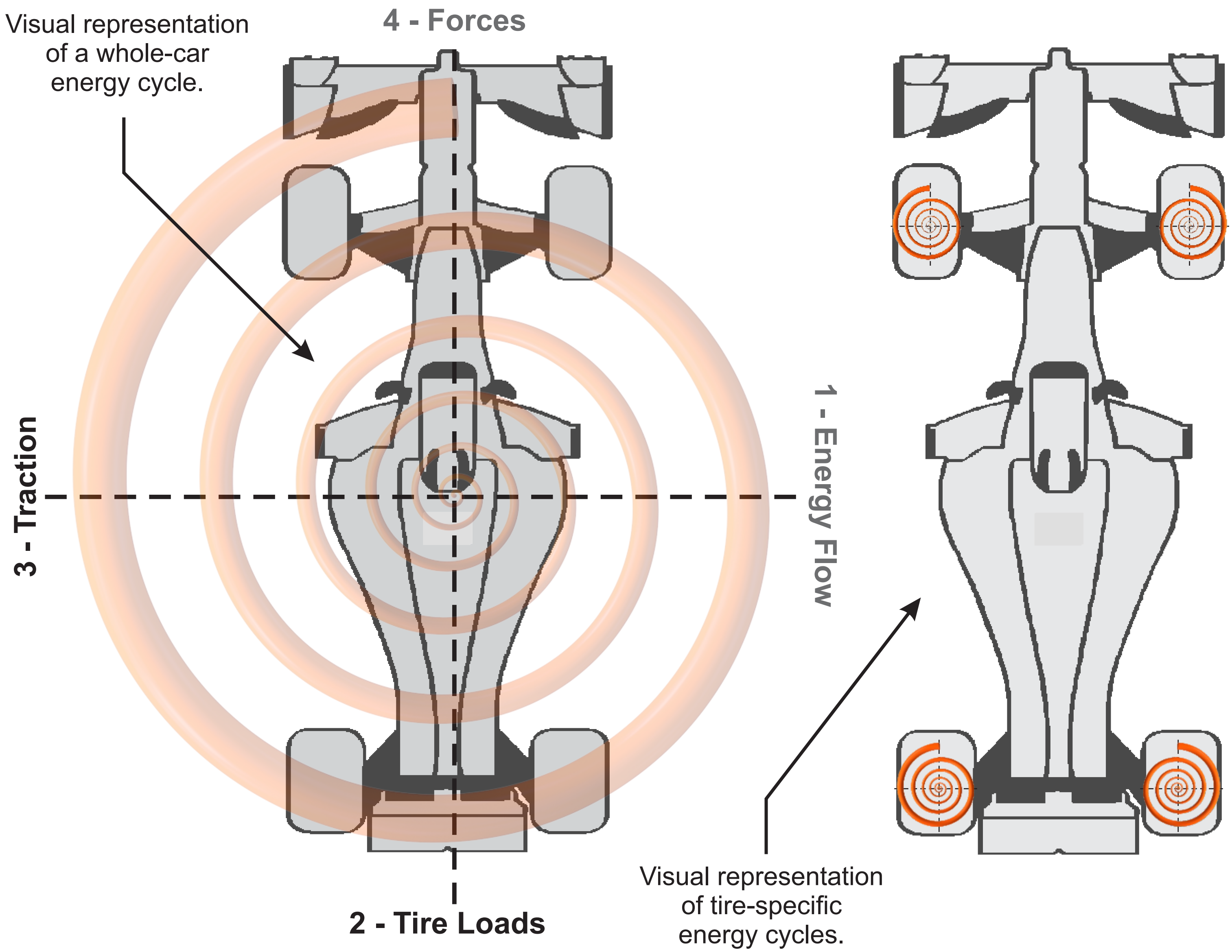
Concept #3 - Fast Energy Cycle - Top & Side View

By a ‘fast’ energy cycle, I mean like the difference between how energy flows through a kart vs how it would flow through a heavier car like a GT car or a stock car. The weight of the car essentially determines the viscosity of the energy, and therefore the maximum speed of the energy cycle, but driving inputs also have an impact on the energy cycle speed.

So, for example, braking hard, and turning a kart into a sharp turn, would cause the energy to flow very quickly; producing a very fast energy cycle with fewer rotations before reaching energy equilibrium.

Concept #3 - Using the Energy Cycle

While all of the energy cycle elements interact, I think of the elements #1 & #4 (*energy movement* and the *forces acting on the car*) as more 'whole-car' things, and the elements #2 & #3 (*tire loading* and *traction/drift angle*) as more 'tire-specific' things. When thinking in tire-specific terms, I think of each tire as having it's own energy cycle. That said, all tires should be carrying some load, and therefore will contain some energy, so you could also think of it in terms of one tire being the primarily active tire in a whole energy cycle... whatever works best for you.



When it comes to monitoring and managing the energy cycle, I prefer to deal with one tire at a time, because from a driver perspective, when cornering, there is only one critical contact patch at any given time (the outside front tire from turn entry to rotation/apex, and the outside rear tire for the remainder of the turn). When braking in a straight line, I focus on the tire that is most load sensitive (most likely to lock). Taking this one-tire approach profoundly simplifies my mental load when driving, which creates 'free' mental resources for other tasks such improving sensitivity, race craft, performance evaluation, etc.

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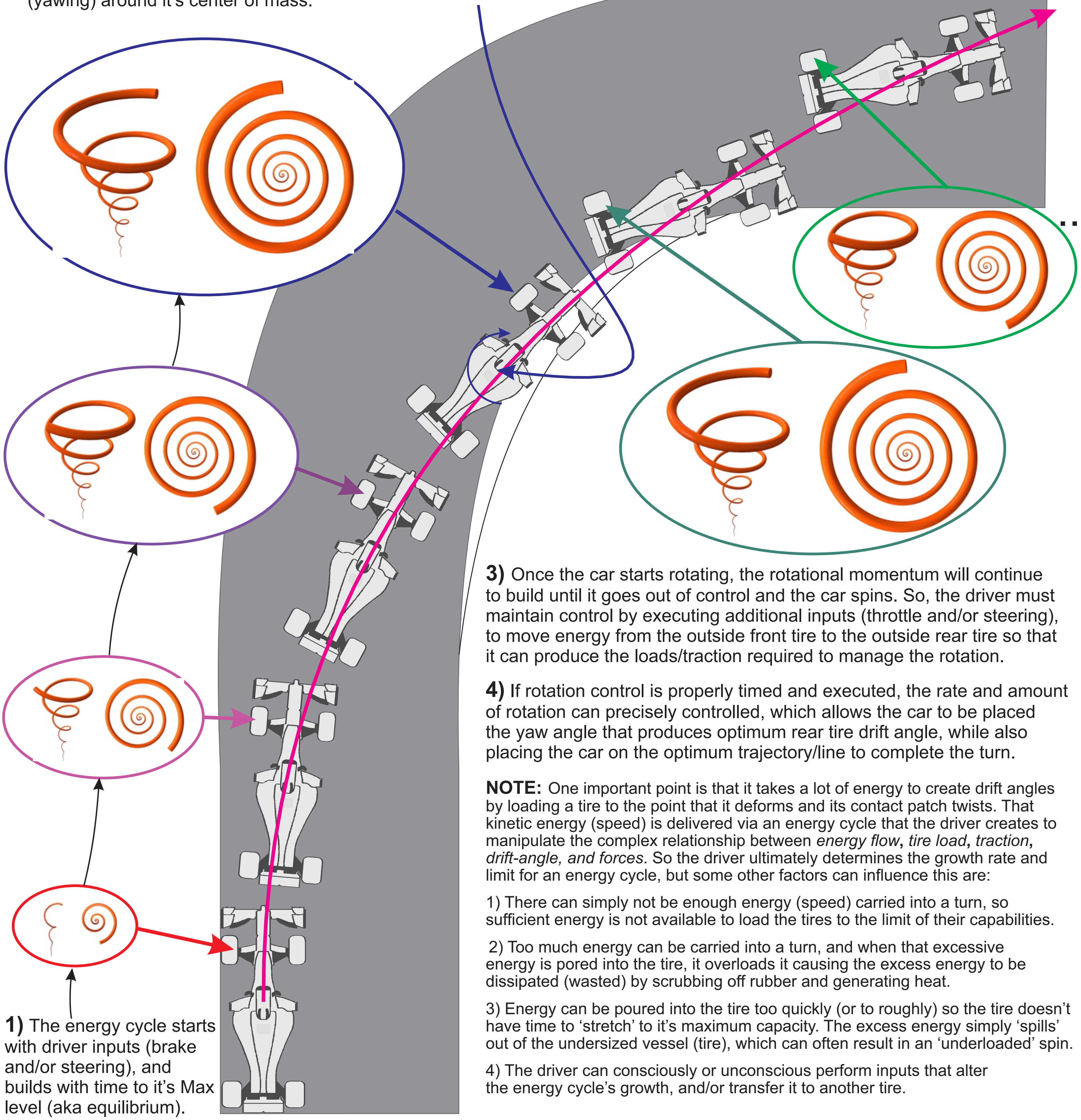
Concept #3 - Using the Energy Cycle - Tire Focus

2) When the energy cycle reaches equilibrium (typically at the rotation point/apex) the energy in the cycle begins to return from the front tire to the chassis, so there is no longer enough energy in the front tire to maintain optimal drift angle. With the front end unable to keep drifting predictably in an understeer attitude, the rotational momentum from turning into the corner starts to takes over and build momentum, which causes the car to begin rotating (yawing) around it's center of mass.



3) Once the car starts rotating, the rotational momentum will continue to build until it goes out of control and the car spins. So, the driver must maintain control by executing additional inputs (throttle and/or steering), to move energy from the outside front tire to the outside rear tire so that it can produce the loads/traction required to manage the rotation.

4) If rotation control is properly timed and executed, the rate and amount of rotation can precisely controlled, which allows the car to be placed the yaw angle that produces optimum rear tire drift angle, while also placing the car on the optimum trajectory/line to complete the turn.

NOTE: One important point is that it takes a lot of energy to create drift angles by loading a tire to the point that it deforms and its contact patch twists. That kinetic energy (speed) is delivered via an energy cycle that the driver creates to manipulate the complex relationship between *energy flow*, *tire load*, *traction*, *drift-angle, and forces*. So the driver ultimately determines the growth rate and limit for an energy cycle, but some other factors can influence this are:

1) There can simply not be enough energy (speed) carried into a turn, so sufficient energy is not available to load the tires to the limit of their capabilities.

2) Too much energy can be carried into a turn, and when that excessive energy is pored into the tire, it overloads it causing the excess energy to be dissipated (wasted) by scrubbing off rubber and generating heat.

3) Energy can be poured into the tire too quickly (or to roughly) so the tire doesn't have time to 'stretch' to it's maximum capacity. The excess energy simply 'spills' out of the undersized vessel (tire), which can often result in an 'underloaded' spin.

4) The driver can consciously or unconscious perform inputs that alter the energy cycle's growth, and/or transfer it to another tire.

1) The energy cycle starts with driver inputs (brake and/or steering), and builds with time to it's Max level (aka equilibrium).

Concept #4 - 2D & 3D Traction Circles

In the same way that the energy cycle provides a way to think about how driving inputs influence energy flow, and ultimately the car's behavior, the traction circle give us a way of thinking in a more detailed way about how our tires are working, and how the energy/load we control as drivers impacts their performance and longevity.

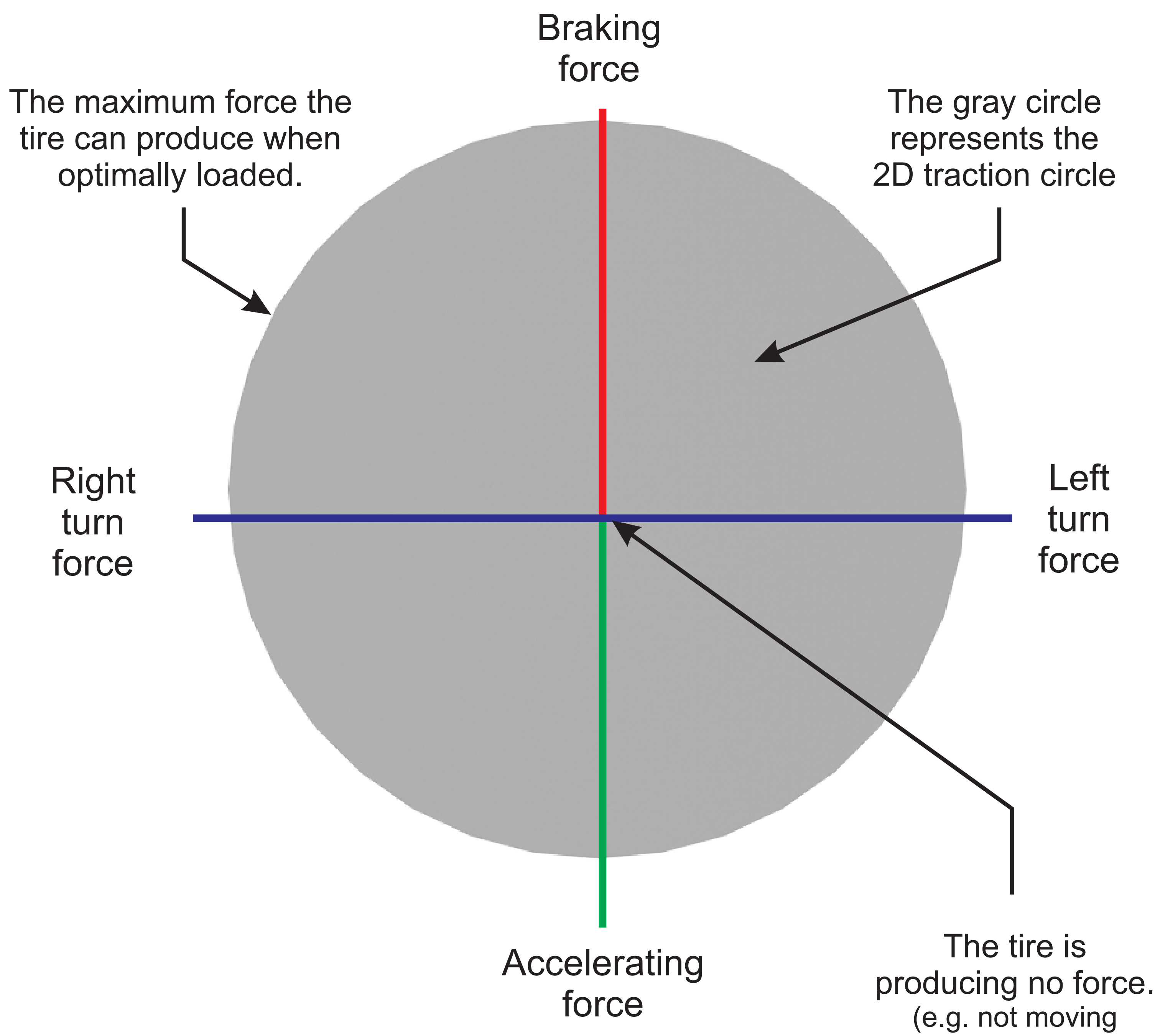
The idea of the traction circle (what I call the two-dimensional traction circle) has been around, basically unchanged, for at least 50 years. It's a very effective tool for visualizing a tire's maximum longitudinal and lateral performance potential. it's also effective at illustrating the idea that it's possible (really critical) to combine lateral and longitudinal forces to achieve maximum performance throughout a turn.

However, the 2D traction circle does have some limitations or weaknesses (explained in the following pages), so I came up with a visualization tool; the three-dimensional traction circle. The 3D traction circle provides the information from the 2D traction circle, plus additional information about full tire performance potential and traction types, while also dovetailing nicely with the concepts of *speed as a liquid* and *the energy cycle*.

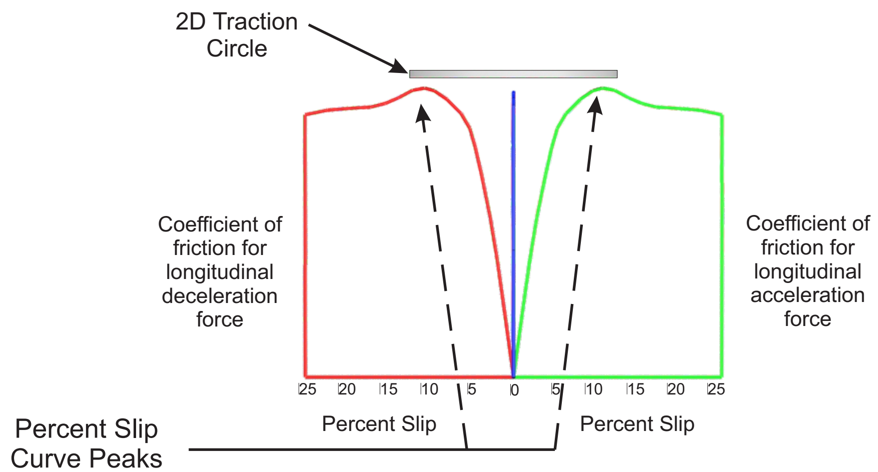
Basically the 3D traction circle is based on the tire's performance potential curves. For longitudinal performance, the (*percent slip vs coefficient of friction*) curve, and for lateral performance the (*drift angle vs G load*). Together, these curves represent the tire's full performance potential (all the way from unloaded to massively overloaded).

When viewed in 3D, the tire's potential appears as a vessel into which the driver can pour energy to create loads, traction, and drift angles. The diameter and height of the vessel changed dynamically based on it's current load, which reflect the fact that you must bring a tire to full potential by gradually pouring energy into it to create load/traction. That is, you must give the tire time to expand to its performance potential; pour too much energy too quickly, and the excess energy will 'spill' before the tire can 'expand' to hold it, which will likely result in a loss of control.

Concept #4 - The Two-Dimensional Traction Circle

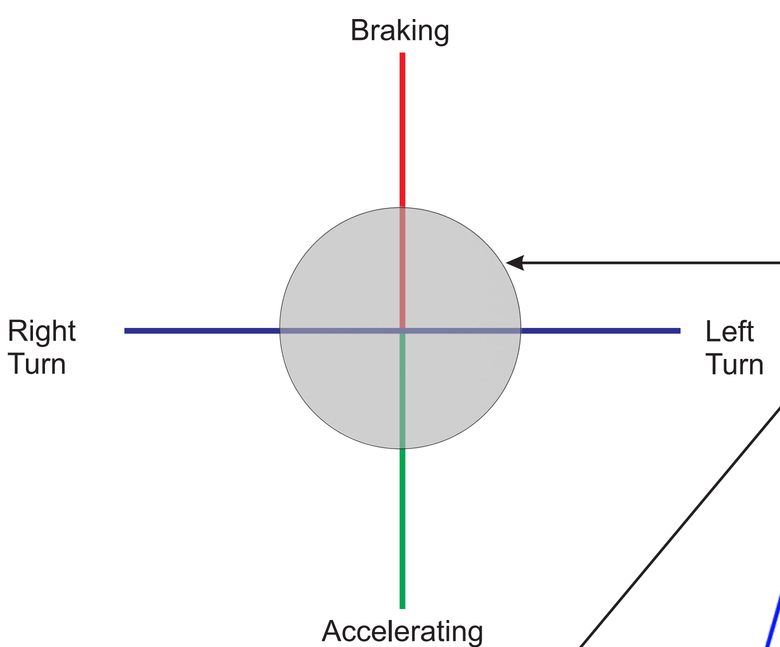


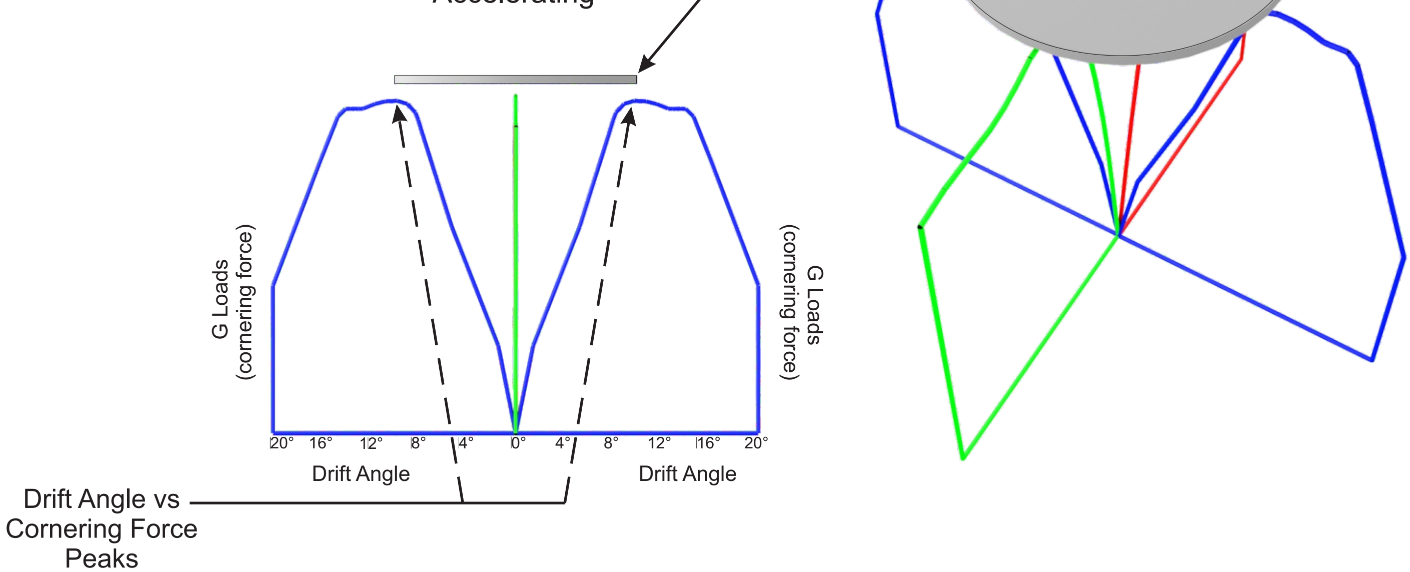
Concept #4 - 2D Traction Circle & Tire Curves Relationship



The 2D traction circle shows the tire's performance potential from zero potential to maximum potential because it is a reflection of the area from the origin to the peaks of the tire's performance curves...

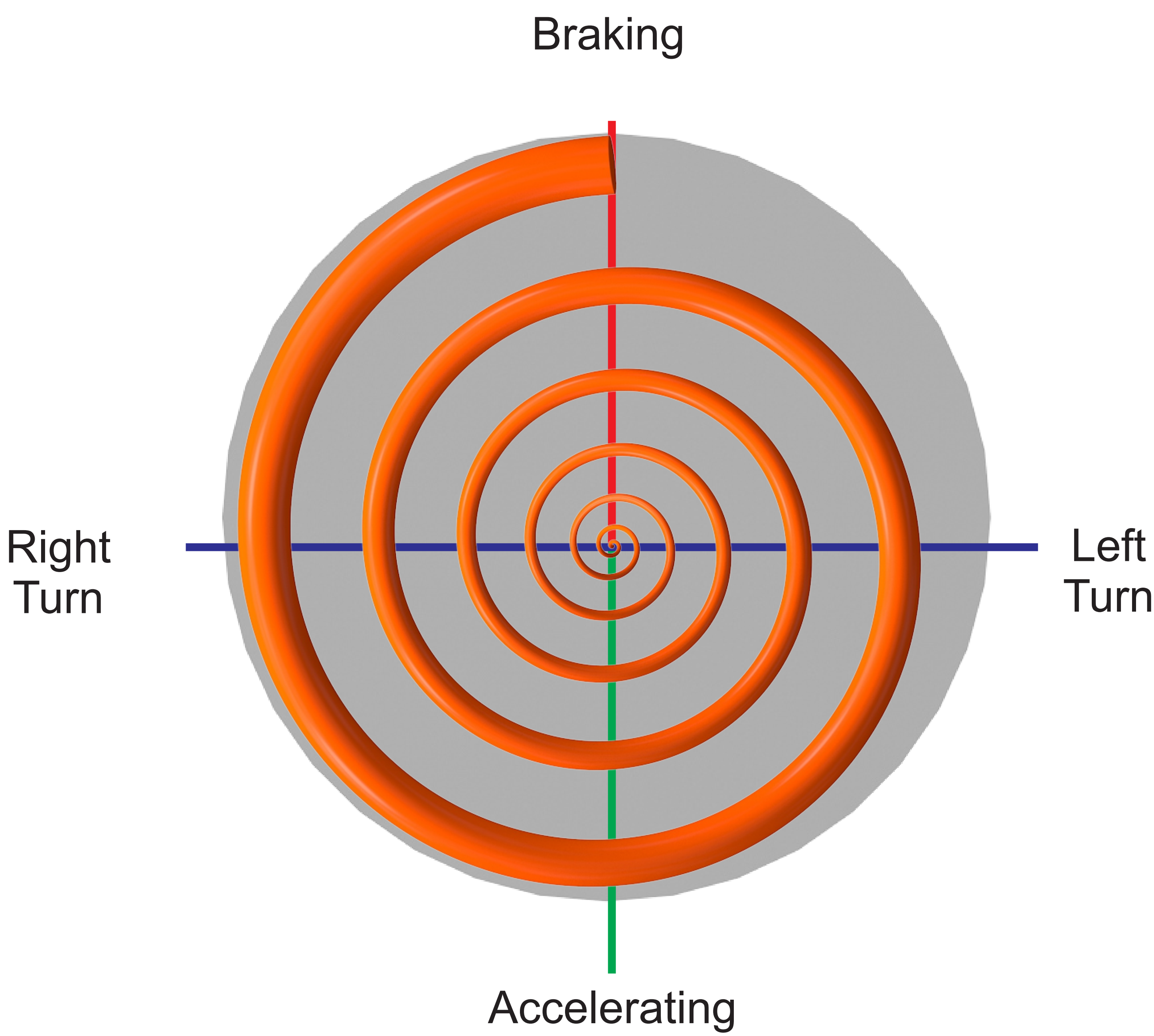
The *Drift Angle vs G Load* curve (for lateral force) and the *Percent Slip vs Coefficient of Friction* curve (for longitudinal force).





Concept #4 - Traction Circle & Energy Cycle Relationship

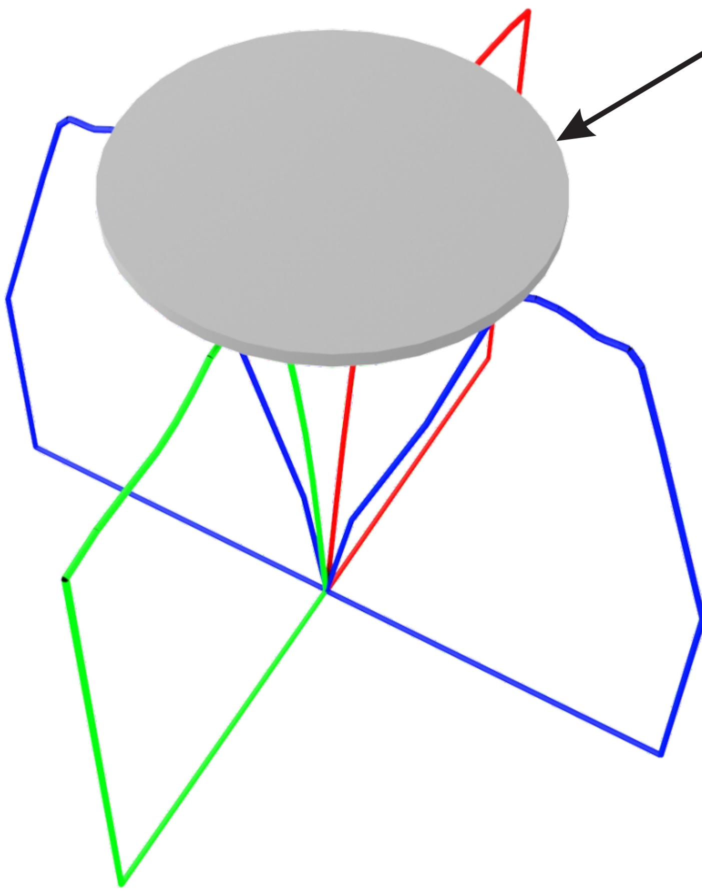
While the 2D traction circle shows the traction forces provided by the tires relative to the tire’s maximum capability, overlaying the energy cycle onto it provides a way of thinking about how those traction forces build and dissipate, and about the time it takes for that to happen.



Concept #4 - 2D Traction Circle Limitations

So, the 2D traction circle is a very useful tool for understanding traction. But, even though it has stood the test of time, it does have some limitations.

Limitation #1: The 2DTC only shows the information range from no performance to peak performance (but the *Slip/G* & *% Slip* curves show the tire's full performance range). So the 2D traction circle's performance limit (the edge) gives the false impression that going over the edge will result in something like this.



Limitation #2: The 2DTC provides no information about how the tire performance levels relate to the type of traction being generated. For example:

- Interlock
- Sticktion
- Friction
  (or Scrub in the extreme)

Limitation #3: The 2DTC does not provide a way of visually representing how energy/load impacts the tire's ability to carry additional load, how load can be increased up to the tire's maximum performance potential, and what happens if excess load is applied.

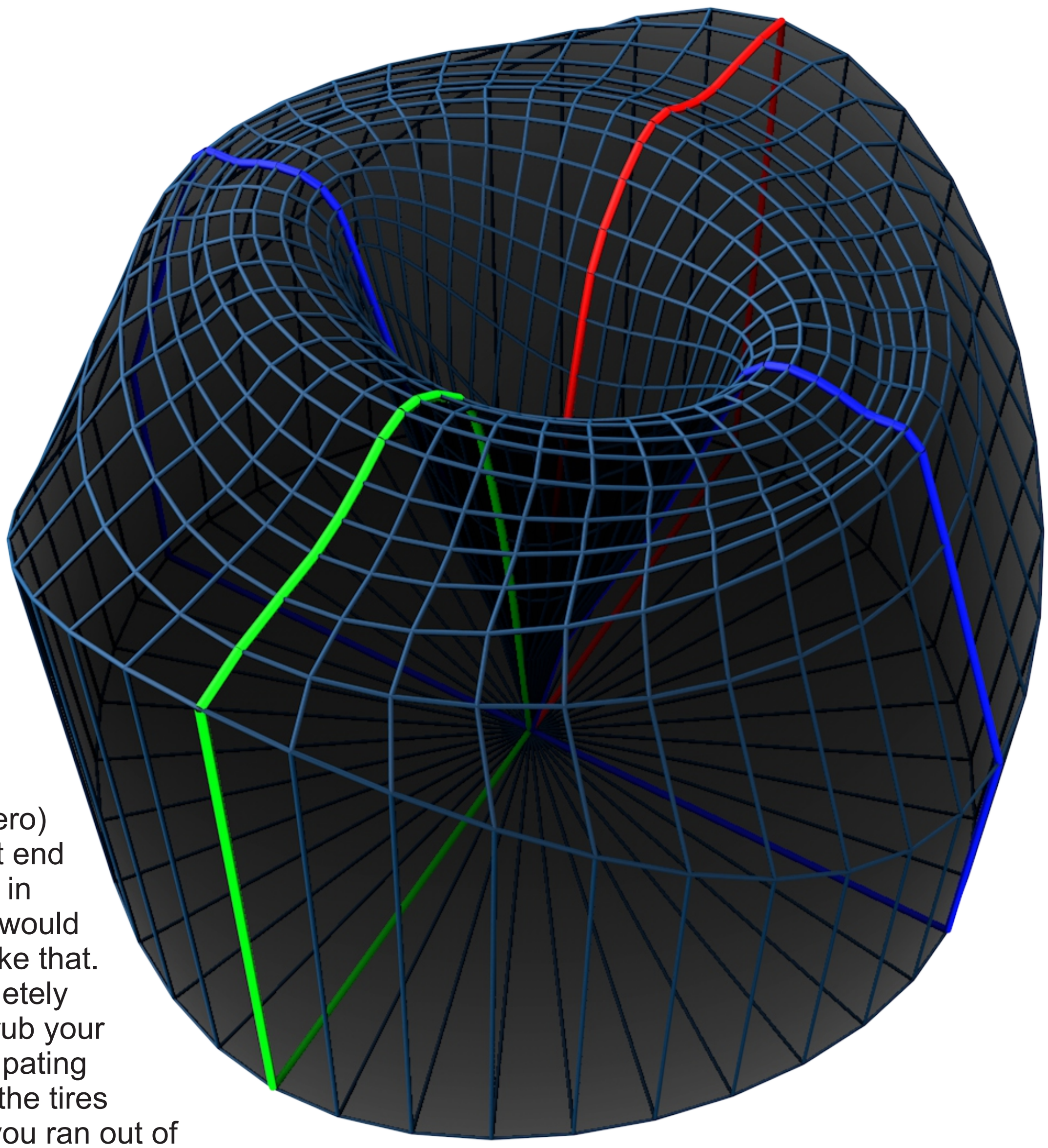
Concept #4 - The 3D Traction Circle

I created the 3D traction circle to address with limitations of the 2D traction circle, and to show a more complete picture of a tire's full capabilities, along with how the energy cycle relates to tires.

To make it, I 'swept' a tire's longitudinal percent slip curves (red & green curves below) and the lateral G curves (blue curves below) into a 3D shape. The opening in the shape represents the 'vessel' into which energy can be poured to create load, which creates traction, which creates drift angles.

A tire's capabilities change with load, so the 3D traction circle should also be thought of as varying in size (height, diameter, and vessel capacity) depending on the energy/load placed into the tire. So, from nothing (no 3D traction circle if there is no load) to full size (as shown below, which represents the extent of the tire's capabilities when being massively overloaded).

The 3D traction circle is not a perfect model, but for me it's still very useful.

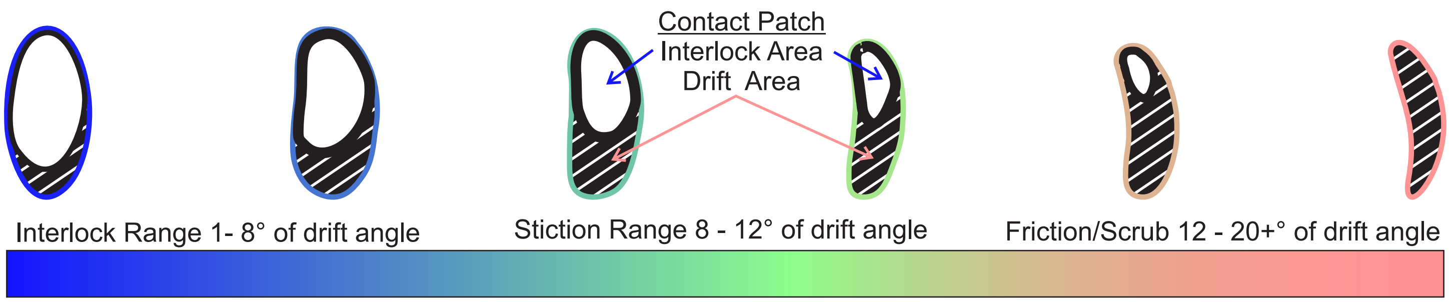


Note: The curves (outer edges of the 3D traction circle) end (drop off to zero) because the image must end at some point. However, in reality, the traction level would never just drop to zero like that. Instead, if you got completely sideways, you would scrub your way down the track dissipating energy (speed) through the tires and into the track, until you ran out of energy and stopped... or hit something.

Concept #4 - The 3DTC & Tire Performance Levels

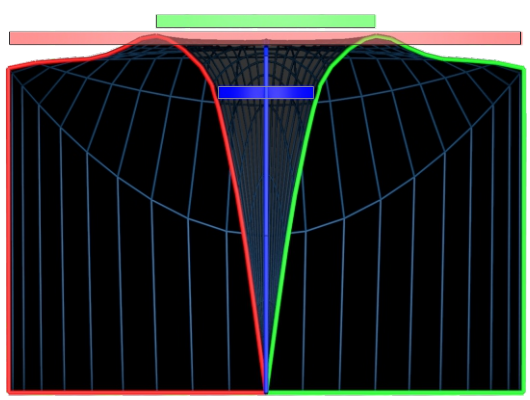
Earlier, I mentioned the difficulty of thinking about or identifying the tire performance levels when using the 2D traction circle model. What I mean by performance level is how the tire is generating traction, for example:

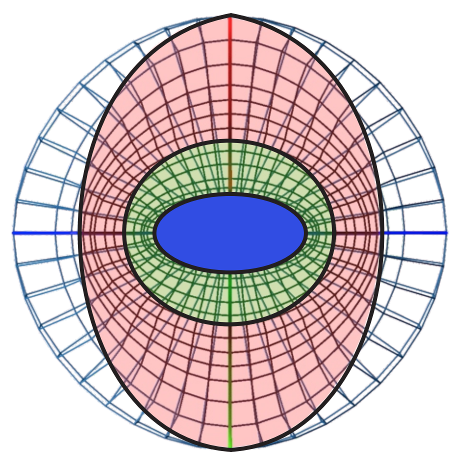
- Primarily by **interlocking** with (or adhering to) the imperfections in the track surface, which typically happens if tires are under loaded, meaning that they aren't given enough energy/load to allow them to generate optimum drift angles.
- Primarily by the **friction** from drifting (or scrubbing) the tire across the track, which typically happens when a tire is very heavily loaded. In moderation it looks cool and can be fast, but is hard on tires.
- Or with **sticktion;** a well managed balance of both of interlock and friction that produces maximum traction, as efficiently as possible by managing the load on/in the tire to generate the optimal amount of drift for efficiently produce maximum traction.



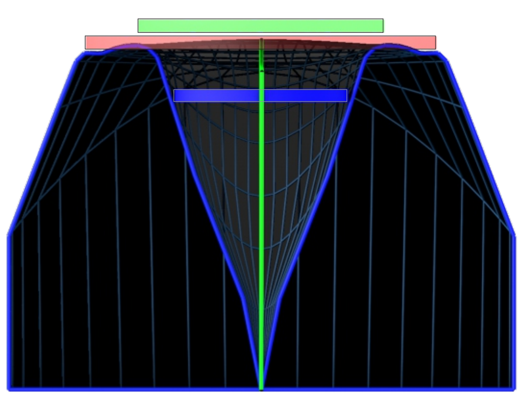
If you imagine the continuum of traction types ranges from interlock (blue), through sticktion (green) and finishes at friction/scrub (red), then hopefully you can see below the areas of the 3D traction circle in which those tire performance levels reside.

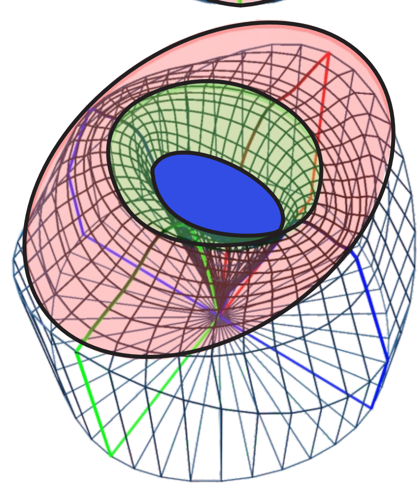
Longitudinal Tire Performance





Lateral Tire Performance



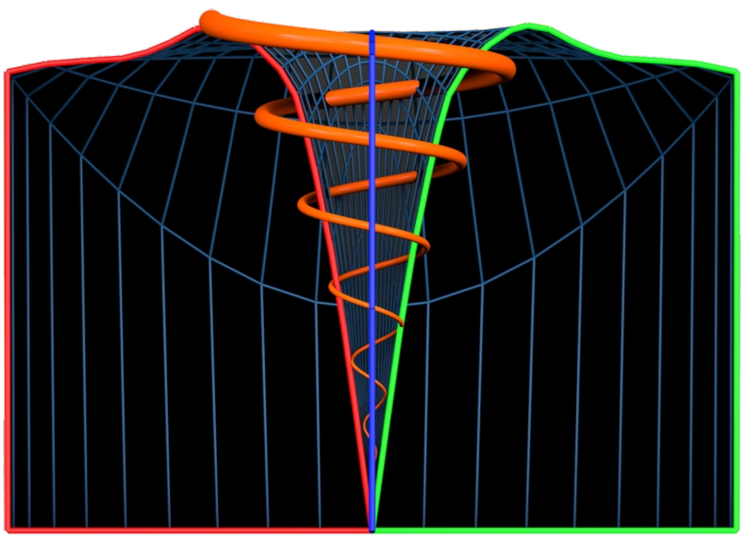


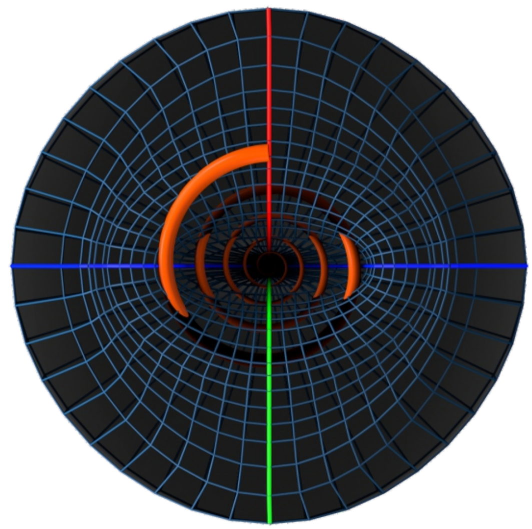
Concept #4 - The 3DTC & the Energy Cycle

This is just a visual representation of how the 3D traction circle & energy cycle relate to each other and to the generation of traction. Hopefully it shows that as the energy in the cycle rises, the load on the tire (and therefore the tire's capability to generated traction) rises, which means the drift angles rise.

However, if you keep pouring energy into a 'full' tire, it will spill over the 'optimum performance lip' (peak) into the inefficient 'friction' tire performance range (very high drift angle). If too little energy is poured into a tire, or energy is poured too quickly (faster than the tire's capabilities can expand), then the tire's performance potential will not be reached because a false (under loaded) limit will be created. In this case, drift angles are still produced, but at a lower overall traction level.

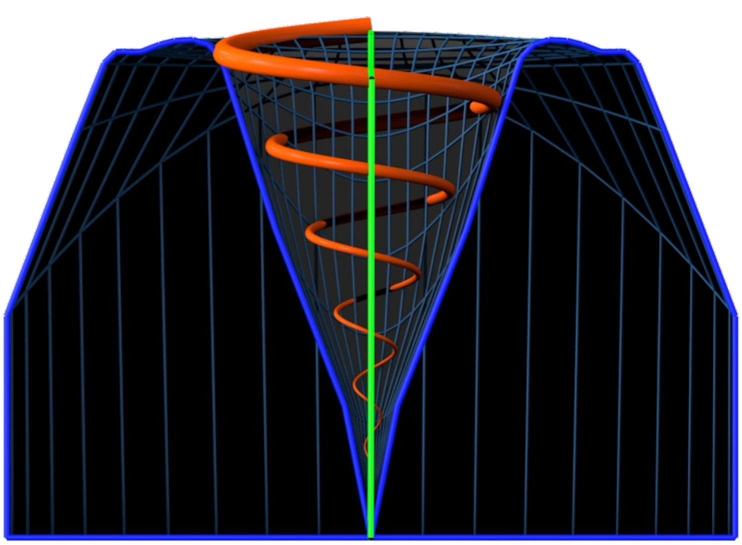
NOTE: I'm not very good with my 3D software yet, so I'm just trying to get the idea across with these very rough images and animations (link below). Please try to imagine that the energy cycle (orange spiral) does not venture outside of the empty (hollow) portion of the 3D traction circle, which represents the variable size vessel into which energy can be poured. Also imagine the orange spiral just leads the 3DTS growth rate (doesn't run so far ahead).

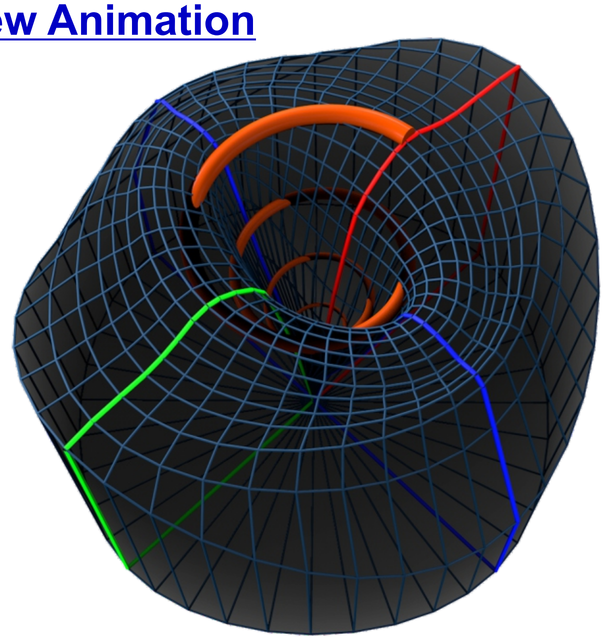




Click to See Side & Perspective View Animations

Click to See a Top View Animation





Concept #5 - Controlling of Rotation

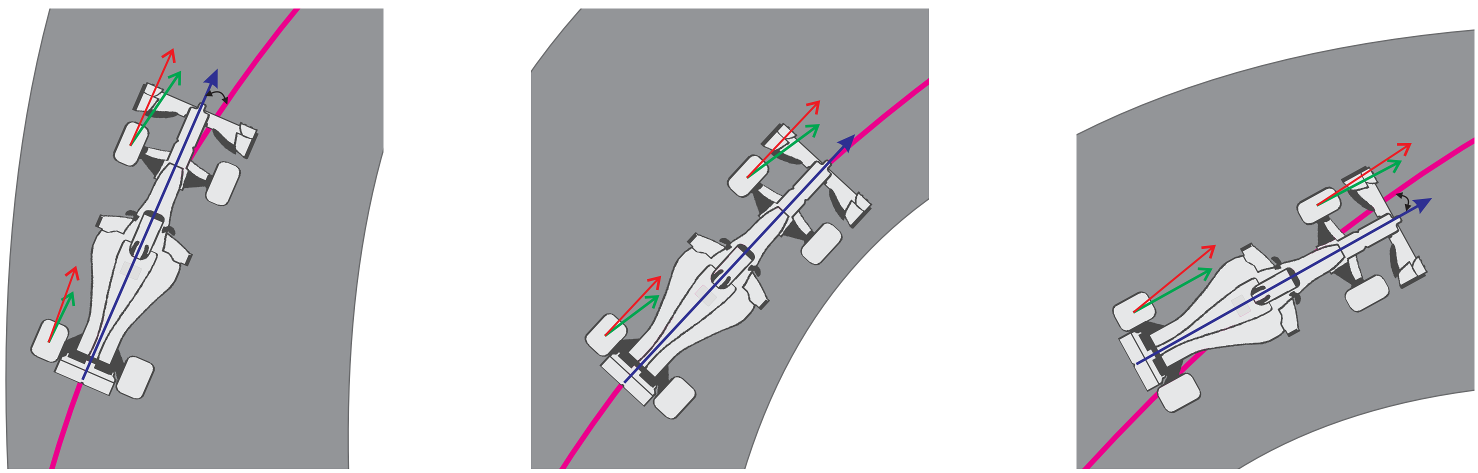
Concepts 2 - 4 are important because they provide ways to think about energy movement, traction/drift angles, and forces, but applying that knowledge to control rotation can pay huge dividends on track.

I believe the key to optimum performance in any turn is managing yaw rotation (rotation around the car's center of mass relative to the line being driven).

Corner Entry Phase
(Car is oriented greater than tangent to the line - hopefully by an amount equal to the optimum front tire drift angle.)

Rotation Point
(Car orientation rotates so it is tangent to the line and for a moment the front and rear drift angles are relatively equal.)

Corner Exit Phase
(Car typically keeps rotating until it's less than tangent to the line; the driver's job is to keep the orientation angle equal to the optimum rear tire drift angle.)



Pink shows the 'line' the driver is attempting to travel. Blue shows the car's orientation on the line, and it's approximate actual direction of travel.

The green & red arrow combinations show how the front and rear drift angles change relative to the car's orientation as the car travels through a turn.

By managing rotation, I mean strategically influencing one or more of the three elements of rotation: location, rate, and amount.

The location where rotation occurs is critical because it determines the end of the turn's entry phase, and the beginning of the exit phase, which mean it also signifies when you can get back on the gas.

The rate and amount of rotation profoundly influences how aggressively you can (or must) get on the gas, and how hard and efficiently you use your tires as a result of doing so. However, going back to the speed as a liquid concept, one other related factor that must also be taken into consideration when managing the rotation speed is how much momentum the rotational energy has and/or is building. The rotation momentum is influenced by the overall energy level (speed) of the car, and the time that un-managed rotation has been occurring.

If any reasonable amount of drift angle is carried into a turn, the car will always rotate naturally as it goes around the turn (typically at or near the apex). If the car did not rotate naturally, it could not finish the turn. However, fast drivers almost always instinctively, or knowingly, manipulate at least one of the rotation factors in each turn. But to be clear, the 'change' in rotation can be very subtle, like a few feet earlier or later than the natural location, or a few degrees more or less rotation amount, etc.

Concept #5 - Controlling of Rotation Cont.

Manipulating the rotation location and speed begins with using various driving techniques to influence the energy cycle of the outside front tire so that it peaks at the desired energy/load level, and at the desired location. Doing so, means optimum drift angle (and equilibrium of the energy cycle) is achieved, and rotation is triggered, where YOU want it to happen.

In general, the faster the turn, the more rotational energy and momentum there will be. However, rotation speed and momentum can be influenced with the energy cycle by manipulating the level of energy/load/traction for the outside front tire relative to the turn-in point. That is, turning in and letting the tire loads grow gradually will produce less rotational momentum, and a slower rotation. Whereas, ‘pinning’ the front end (with a lot of trail braking) to aggressively pitch the car into a slow turn, will produce a lot or rotational speed, but not as much momentum as a high-speed turn.

The point where the car goes tangent to the line being driven (where the front and rear drift angles will be relatively equal) is one of the most critical parts of any turn because while the front/rear drift angles might be the same, there is not enough energy available to give either tire optimum load/performance. This is the case because the energy from the energy cycle used to optimize tire loads, etc. for the entry phase of the turn, is now being split between the front and rear tires as it either directly (via driver inputs), or indirectly (via a combination of natural energy cycle collapse + rotational momentum) moves towards the outside rear tire. However, you cannot allow the energy/load to get to the outside rear tire when it feels like it; you must take control of the situation and get optimum load on that outside rear tire quickly enough that you can control the rotational momentum and rotation angle, but without inadvertently adding to the rotational momentum. Anyway, this tire loading ‘no man’s land” at mid rotation is why ‘they’ always say “avoid coasting at the apex.”

Anyway, when rotation begins, the rate is pretty much already established by the way you drove the turn’s entry phase. At that point it’s up to the driver to manage the amount of rotation. Again, this is done using driver inputs to influence the energy cycle so that optimal load is placed on the outside rear tire. To accomplish this, the driver has three tools: acceleration, counter steering, and timing.

Accelerating will do two things: 1) Transfer energy from the outside front tire’s energy cycle to the outside rear tire’s energy cycle. 2),Increase the car’s overall energy/speed.

Counter steering will pour energy out of the outside rear tire into the chassis and/or front tire.

Timing is what makes accelerating and/or counter steering work in the context of the current rotation rate, rotation momentum, and objective of the corner exit phase. For example, with a low-momentum, high-speed rotation (e.g. pitching the car into a low speed turn), the rotation amount can typically be controlled by waiting for the car to rotate the desired amount, and then getting hard on the gas to ‘hook’ the outside rear tire up, stop the rotation, and aggressively accelerate out of the turn (fine tuning with counter steering as needed); hard acceleration out being the ‘exit phase objective’.

However, when the car is rotating with more momentum, you must get out in front of the rotation ‘wave’, and take the momentum into consideration when timing the ‘checking’ of the rotation. Also, you must use the accelerator with much more finesse because the tire will already contain a lot of energy, so if you add too much more energy, too quickly, you will end up ‘spilling’ it, which will result in an increase of rotational momentum instead of ‘checking’ it.

That’s the basics of rotation, so now we’ll take it a step farther and move on to the related topic or using rotation to drive a trajectory on a line.

Concept #6 - Drive a Trajectory on a Line

In Concept #5, we talked about the importance of controlling rotation, but rotation and the racing line are intertwined. That is, change your line, and you will impact the energy cycle, tire loads, traction/drift angles, and rotation. Change any elements of rotation, and you will impact the line itself, and/or your ability to keep the car on the desired line at the desired speed.

Therefore, for advanced driving, the traditional concept of "a line” is too limited because it only represents a portion of the picture (the path you want the car's center of mass to travel around the track). Expanding the concept of "the line" to include the rectangle defined by the car’s four contact patches gives a much more complete picture of cornering because the constantly changing tire drift angles influence both the orientation of the car (rectangle) relative to the line it’s following, and the car’s actual direction of travel relative to the line.

Another important point is that the car’s trajectory determine’s how the energy from acceleration, deceleration, and cornering forces move through the car's center of mass, which determines to what extent the energy helps or hinders the cornering process. For example:

- Trying to accelerate hard out of a slow-speed turn with a trajectory that has the tail end hung way out does not allow the acceleration force to push relatively directly and efficiently though the car’s center of mass; instead the force tends to ‘spill’ in the direction of the drift, limiting how hard you can accelerate without losing control of the energy and spinning the car.
- However, in a mid-speed sweeper, where cornering forces are high and acceleration forces are lower, then if you tend to run out of track at the exit of the turn, it might be advantages to drive a trajectory that hangs the tail out slightly, so the acceleration forces (which aren’t high enough to push rear around) are put to work helping to push/drive the car away from the edge of the track.
- If your car is unstable (rotates into oversteer too easily) in a high-speed turn, then if the instability comes entering the turn it might be advantages to take a more shallow trajectory into the turn (to keep rotational momentum from building too quickly). If the instability is from the rotation point out, then it might be advantages to manage the rotation amount by driving a trajectory that checks the car’s rotation when it is at or near tangent to the line (by strategically removing front tire loads).

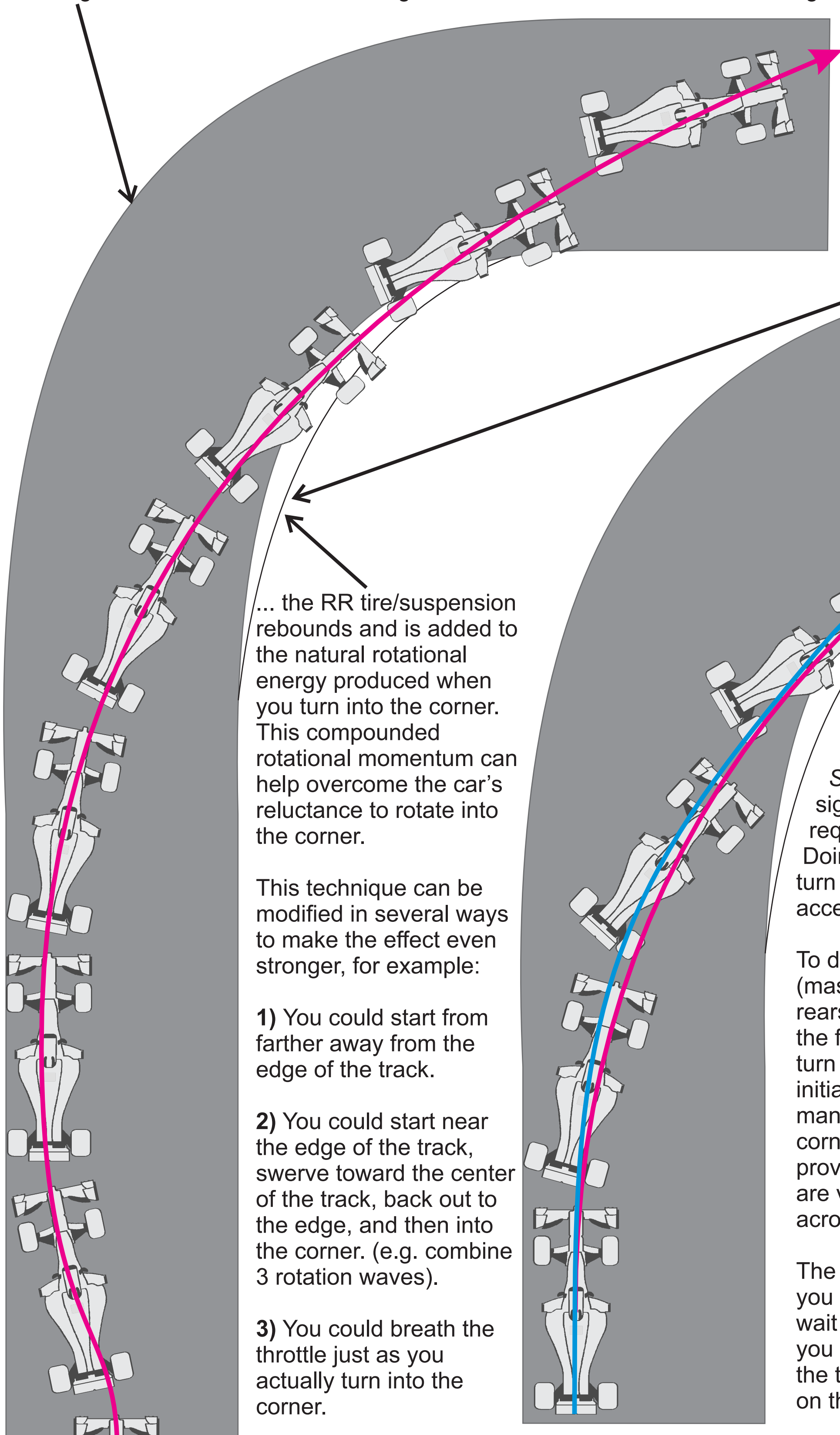
I believe that to extract the last bit of performance from a car/tack combination, a driver must combine their (intuitive and/or intellectual) knowledge of concepts 2-5 to formulate a cornering plan that allows for the driving of a trajectory for each corner (and each phase of the corner) that will optimize performance to best meet the objectives for each turn. When creating a cornering plan:

- I determine the priority of the turn relative to lap times (e.g. does it lead onto a long straight), and my specific objectives for each phase of the turn.
- I identify any special considerations for the corner, car, or conditions. For example, if camber, elevation, or surface changes need to be considered. Or if the tires go off quickly, so using less than optimum drift angles may be called for during the turn’s entry and/or exit phase.
- Then I identify where I want rotation to occur, and the rate and momentum of rotation needed to produce an optimum trajectory out of the turn to meet the objectives and considerations above.
- Finally I determine the entry phase trajectory for the turn by determining the energy cycle I will need to create to produce the outside front tire loading/traction that will make the car rotate where and how I want it to.

The next two pages show some examples of how to manipulate rotation and trajectory:

Concept #6 - Drive a Trajectory - Examples 1

An understanding of the *Speed as a Liquid* concept can allow you to enhance your car's level of 'natural' rotation. This might be helpful if your car generally handles well (so you don't want to change the setup), but you're having trouble getting the car to rotate into a sweeper that does not require braking. Since energy (and especially rotational energy) tends to move in waves, you can use this to your advantage by approaching the turn's turn-in point slightly away from the edge of the track, and then making two turns; one small turn out to the edge of the track, so you get to the edge of the...



... track just as you reach the turn-in point, followed by your turn into the corner in one smooth motion. In the example (at left) the initial left turn will send a small amount of energy into the right rear tire/suspension, and will start a small amount of left-hand rotational momentum. When you smoothly connect the first turn with the actual right-hand turn into the corner, the energy from...

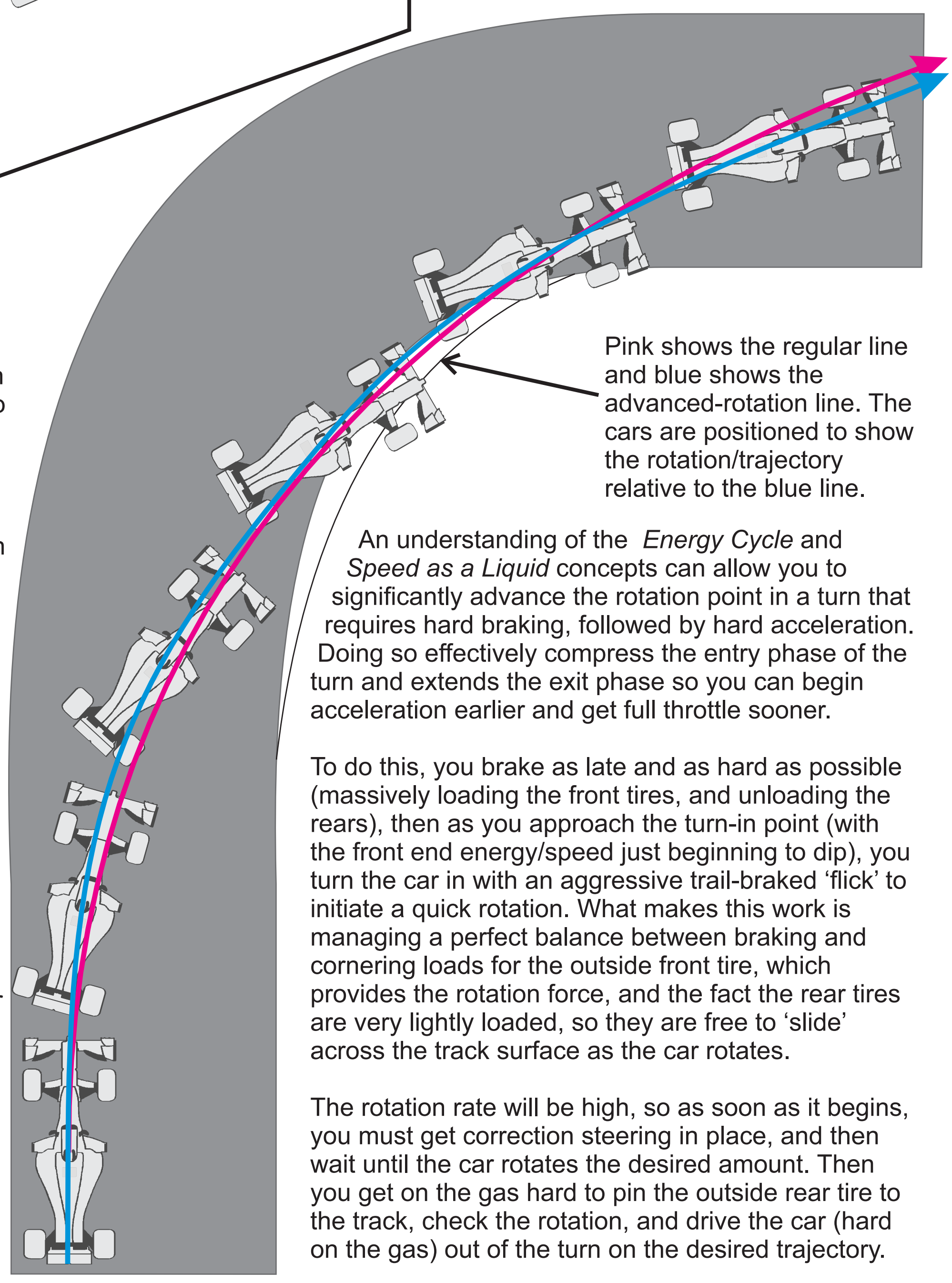
... the RR tire/suspension rebounds and is added to the natural rotational energy produced when you turn into the corner. This compounded rotational momentum can help overcome the car's reluctance to rotate into the corner.

This technique can be modified in several ways to make the effect even stronger, for example:

1) You could start from farther away from the edge of the track.

2) You could start near the edge of the track, swerve toward the center of the track, back out to the edge, and then into the corner. (e.g. combine 3 rotation waves).

3) You could breath the throttle just as you actually turn into the corner.



Pink shows the regular line and blue shows the advanced-rotation line. The cars are positioned to show the rotation/trajectory relative to the blue line.

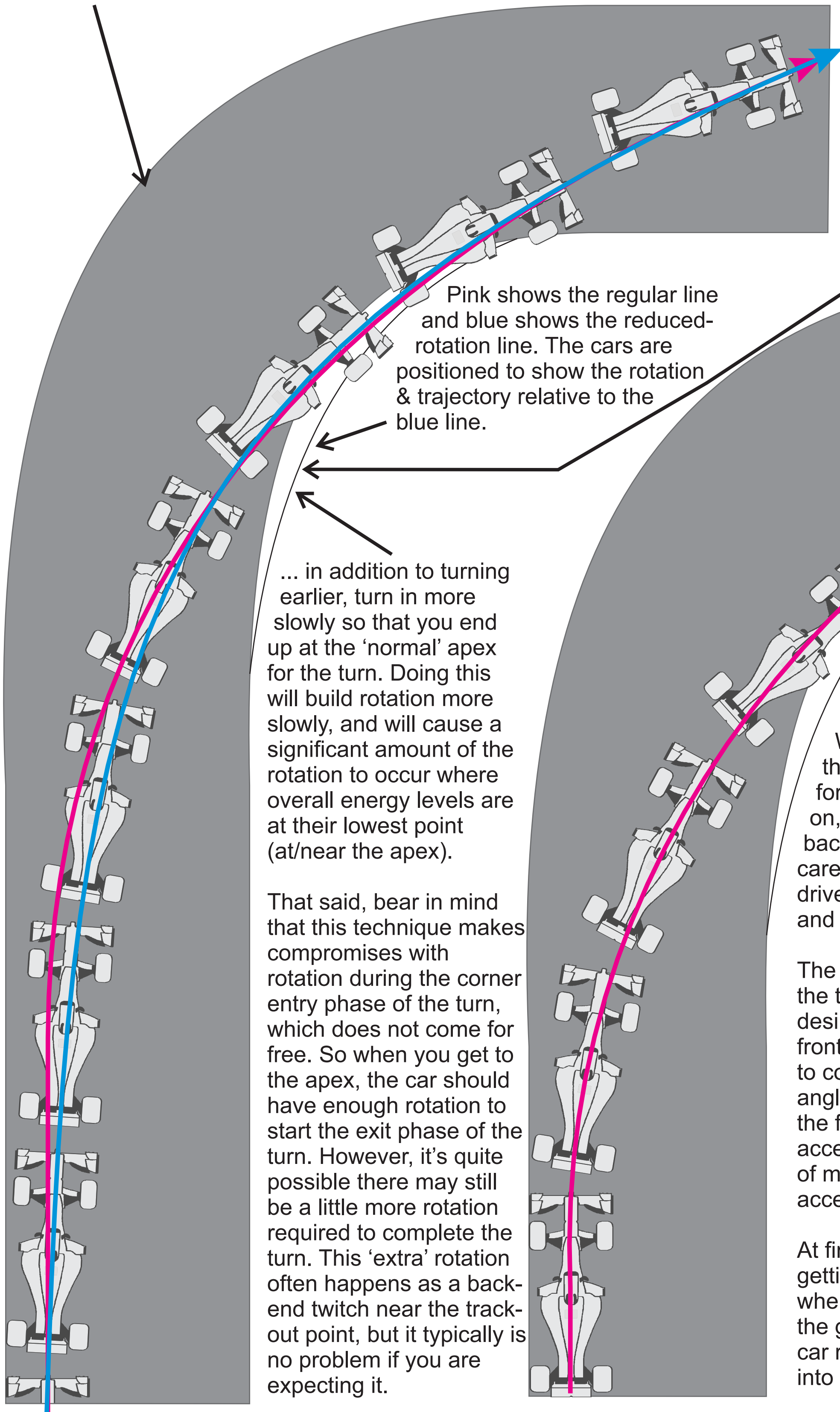
An understanding of the *Energy Cycle* and *Speed as a Liquid* concepts can allow you to significantly advance the rotation point in a turn that requires hard braking, followed by hard acceleration. Doing so effectively compress the entry phase of the turn and extends the exit phase so you can begin acceleration earlier and get full throttle sooner.

To do this, you brake as late and as hard as possible (massively loading the front tires, and unloading the rears), then as you approach the turn-in point (with the front end energy/speed just beginning to dip), you turn the car in with an aggressive trail-braked 'flick' to initiate a quick rotation. What makes this work is managing a perfect balance between braking and cornering loads for the outside front tire, which provides the rotation force, and the fact the rear tires are very lightly loaded, so they are free to 'slide' across the track surface as the car rotates.

The rotation rate will be high, so as soon as it begins, you must get correction steering in place, and then wait until the car rotates the desired amount. Then you get on the gas hard to pin the outside rear tire to the track, check the rotation, and drive the car (hard on the gas) out of the turn on the desired trajectory.

Concept #6 - Drive a Trajectory - Examples 2

An understanding of the *Speed as a Liquid* concept can allow you to reduce your car's level of 'natural' rotation momentum, while also moving the rotation point later in the turn. This might be helpful if your car generally handles well (so you don't want to change the setup), but is over-rotating into a high-speed turn, causing you to delay getting back to the gas while you manage the oversteer into, or even beyond, the apex. Because there is a relationship between the energy cycle's growth rate and rotational momentum, modifying the turn entry phase energy cycle can help manage the...

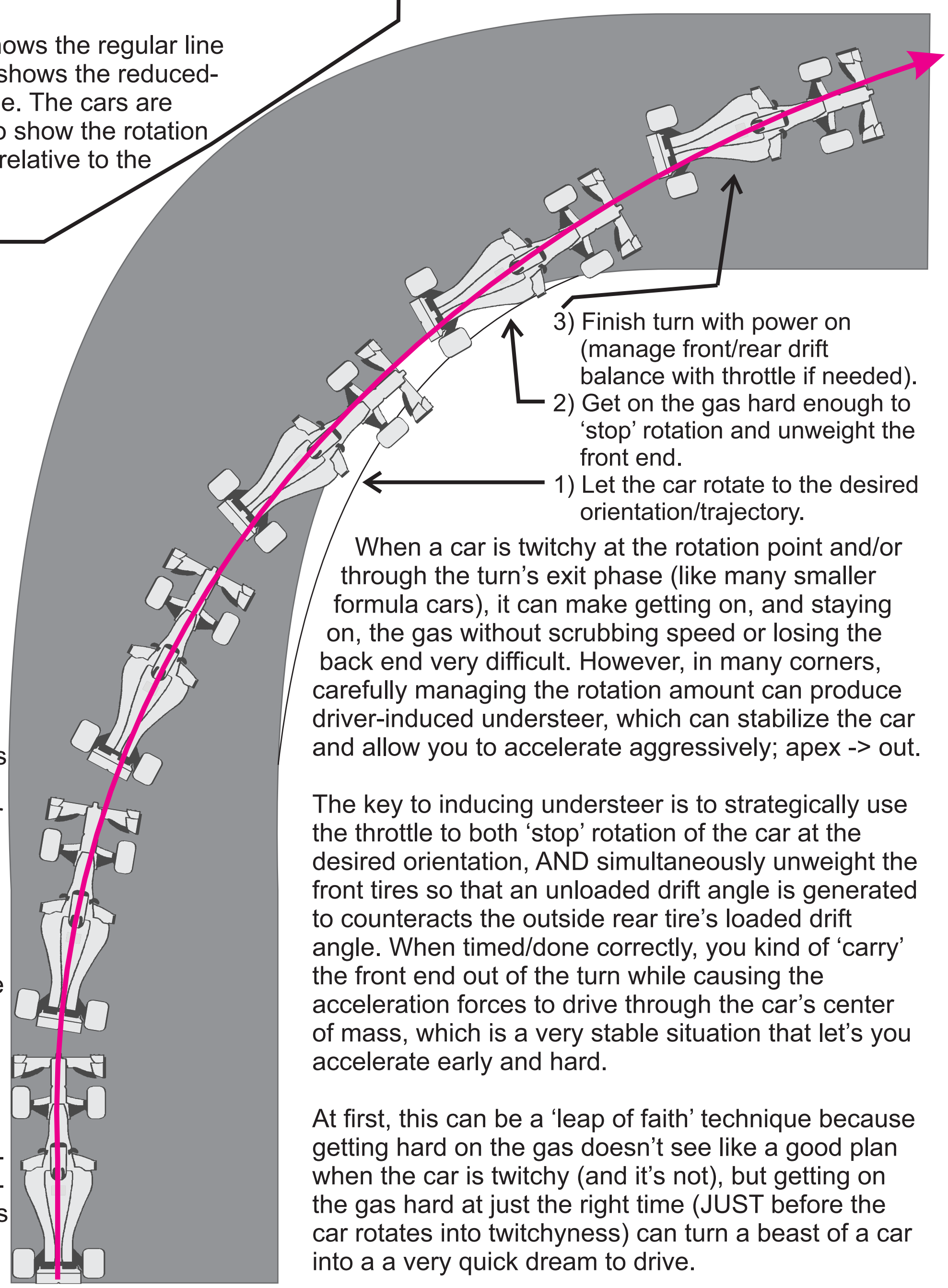


... rotation-driven instability by building the energy more slowly, and by directing the cornering forces more directly to the car's center of mass. Doing so produces less rotational momentum and a more 'understeering' trajectory through the turn both of which tend to stabilize the car on corner entry. To do this, turn in a little earlier (like a few feet - nothing crazy). However, ...

Pink shows the regular line and blue shows the reduced-rotation line. The cars are positioned to show the rotation & trajectory relative to the blue line.

... in addition to turning earlier, turn in more slowly so that you end up at the 'normal' apex for the turn. Doing this will build rotation more slowly, and will cause a significant amount of the rotation to occur where overall energy levels are at their lowest point (at/near the apex).

That said, bear in mind that this technique makes compromises with rotation during the corner entry phase of the turn, which does not come for free. So when you get to the apex, the car should have enough rotation to start the exit phase of the turn. However, it's quite possible there may still be a little more rotation required to complete the turn. This 'extra' rotation often happens as a back-end twitch near the track-out point, but it typically is no problem if you are expecting it.



3) Finish turn with power on (manage front/rear drift balance with throttle if needed).
2) Get on the gas hard enough to 'stop' rotation and unweight the front end.
1) Let the car rotate to the desired orientation/trajectory.

When a car is twitchy at the rotation point and/or through the turn's exit phase (like many smaller formula cars), it can make getting on, and staying on, the gas without scrubbing speed or losing the back end very difficult. However, in many corners, carefully managing the rotation amount can produce driver-induced understeer, which can stabilize the car and allow you to accelerate aggressively; apex -> out.

The key to inducing understeer is to strategically use the throttle to both 'stop' rotation of the car at the desired orientation, AND simultaneously unweight the front tires so that an unloaded drift angle is generated to counteracts the outside rear tire's loaded drift angle. When timed/done correctly, you kind of 'carry' the front end out of the turn while causing the acceleration forces to drive through the car's center of mass, which is a very stable situation that let's you accelerate early and hard.

At first, this can be a 'leap of faith' technique because getting hard on the gas doesn't see like a good plan when the car is twitchy (and it's not), but getting on the gas hard at just the right time (JUST before the car rotates into twitchyness) can turn a beast of a car into a a very quick dream to drive.

Concept #7 - Sensitivity and the Energy Cycle

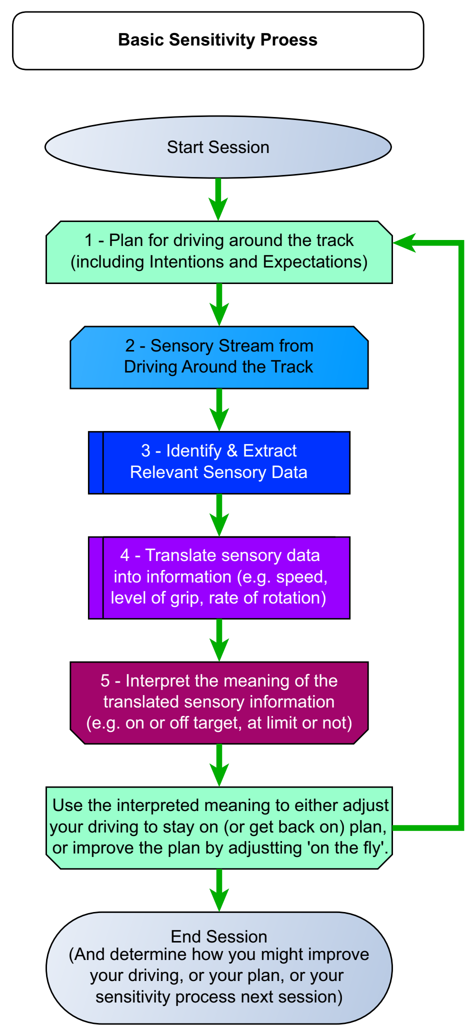
All the advanced driving concepts presented so far provide ways of thinking about what is happening when your drive, and how your intentions and inputs influence your car's performance. However your ability to use that knowledge to improve your driving is dependent on the breadth, depth, and resolution of your sensitivity:

- **Breadth** = The number of senses you are aware of and can tap into.
- **Depth** = The amount of USEFUL information you can extract from your senses.
- **Resolution** = The level of ability you have for interpreting what your sensations mean regarding the relationships between the car, track, tires, environment, and your plan for getting around the track as quickly as possible.

Anyway, before we dive into sensitivity, we should first look at what sensitivity is not:

- It's not one thing.
- It's not just the cliché "being one with the car."
- It's not just focusing all of your attention on one of more of your senses (assuming anyone actually has the mental bandwidth to do that when driving at full speed).
- It's not just feeling traction (you must also be able to feel what's producing and influencing traction, and understand where, when, and how to exert control over those things).
- It's not a mysterious gift that you either have or don't have; it's a skill (well actually a set of skills), so once the skills are identified and understood, they can be improved.

I view 'Sensitivity' as a catch-all term for the multiple intertwined processes and skills required to filter and prioritize the sensations you experience when driving, translate those sensations into information you can use, interpret the 'meaning' from that information, use that meaning to determine how close your car is to the 'limit',… and then, respond with appropriate driver inputs to stay at the limit, elevate your performance level if you've not found the limit yet, or recover control if you've overstepped.---->



At its core, sensitivity is an information processing skill. However, each of us has only so much information processing capability available at any given moment. The amount of your processing capability that can be devoted to sensitivity is dependent on how much of your cognitive resources are being consumed by other higher-priority, processing-critical activities.

For example, if you are driving your first few laps on a track that's new to you, then the most critical activity is staying on track while also trying to figuring out where you are, and where you're going next. In that situation, almost all of your information processing capabilities will be devoted to those visual tasks. That means during those laps, your sensitivity level will likely be very low.

Now consider a novice driver or an overwhelmed/low-confidence driver. Drivers in this situation typically will be constantly 'busy' with the tasks of driving, so they will likely not have much if any processing bandwidth available for more advanced tasks like driving with elevated sensitivity to traction, forces, etc.

Concept #7 - Sensitivity and the Energy Cycle

Since we have limited mental bandwidth with which to be sensitive, the first key to elevating sensitivity, is to free mental resources by making your mental processes for gathering, filtering, translating, interpreting, and responding to sensory information more efficient. The easiest ways to do this are:

- Only invest attention on the most important stuff at any moment; that's why I 'drive' only one tire at a time.
- 'Do' less so you can observe and feel more.
  In music, the structure and 'feel' of a song is created not just by the notes (the musician's actions), but by the relationship between the notes and the rests (the musician's inaction). If you remove the rests, the music disappears; it loses its structure and just becomes noise.

  In my mind, it is the same with driving. If you drive by focusing your attention from action point to action point (braking/steering/accelerating/etc.) you lock yourself into a constant level of business (and likely tension), which can limit the depth of your sensitivity, and therefore the quality of your driving. I believe that's the case because the 'rests' in driving (even though they are brief) represent your opportunity to relax into the moment, so that your intuition and instincts are set free, and your mind is given the bandwidth needed to feel and observe what is happening, which can elevate your driving performances from being a robotic step-by-step process for getting around the track, into art or even magic.

  "*He who sees inaction in action and action in inaction is wise among men*" – Bhagavad Gita

- Don't do or analyze that which you can automate or recognize.

  Another way to free critical resources (and carve out even more sensitivity time per lap), is to only 'DO' the most important actions in each turn and only analyze sensations that are not already part of your mental model of the track. Back to the music analogy, when a guitarist rips through a blazing fast riff, he is not investing attention on the playing of every note. He focuses on the whole riff and the 'key' notes that help him get through the passage with the correct timing and feel. The rest of (most of) the notes are played on autopilot, via mental and muscle memory. Doing something similar in racing can free a huge amount of mental bandwidth.

  For example if your plan for getting around a turn includes reference points for braking, turn-in, apexing, throttle-on, and track-out, that's a lot of stuff to 'do', and each 'task' you do shorten's the 'rests' needed for sensitivity. The braking and turn-in points are likely important to attend to because they create the energy cycle that sets up the rest of the turn. However, if you are reasonably familiar with the track/turn, for the rest of the turn, you can just trust in your mental model of the track to know where you should be on the track, the speed you should be going, the loads your tires should be carrying, and the trajectory you should be traveling.

  So, if you get the braking and turn-in right, the rest of the turn should just happen automatically. When you are in the 'automatic' portion of the turn, the only cognitive load is subconsciously comparing what's happening to what you expect (your plan for the turn). If things start going off plan, then 'you' jump back in and start 'doing' stuff to get back on plan for the turn. Any time that you can be in 'automatic' mode on track is time that you can relax, and focus on feeling and observe what's happening... and that is where the speed hides.

Click here for detailed information about the mental skills of analysis, recognition, mental models etc.

Concept #7 - Sensitivity and the Energy Cycle

Now that we've looked at ways to free mental resources for sensitivity, let's talk about where and how to use those resources. But first, consider this; awareness and focused attention are on the consciousness continuum, however 'attention' takes way more mental resources than 'awareness.' You only have to be sensitive enough to any particular thing/feeling/etc. to accomplish whatever job it is that you want to get done, so invest your hard-earned mental resources carefully.

Sensitivity is also very complex because it can be many things, depending how, when, and with what objectives you are looking at it. That is, I believe that when you look at sensitivity from different perspectives you will see that it can have different characteristics, for example:

A Mode: Reactive, Predictive, Managed or Directed
A Type: Interpretive or Proactive
A Direction: Incoming or Outgoing
A Management Method: Active or Passive

To make sense of all this, I relate the characteristics of sensitivity to the *Energy Cycle*. The next two pages have graphics that show/explain this... I recommend having a look now before reading on.

When appropriate, I also use the concept of *Speed as a Liquid* to understand and predict how energy will likely move within my car so that I can focus attention when need to sense/manage that. Likewise, I use the *3D Traction Circle* to understand and predict the state of, and trends for, the load, traction, and drift angle for the most important tire in the current turn phase.

I know all of that is kind of abstract, so here are example processes for how I might use different types of sensitivity (Interpretive and Proactive in this case).

Turn Task	**Interpretive Sensitivity & Sensitivity Focus - (turn with braking)**	**Management Method**
Braking	Focus on the braking point, then monitor traction and braking force to bring the tire to it's deceleration force limit without locking up.	Actively monitor/analyze traction and braking forces.
Entry Phase	Focus on the turn-in point, then focus on the outside front tire to monitor the growth of the energy cycle's traction and cornering forces elements to ensure they are building in a way that will cause the car to rotate where and how it needs to.	Actively monitor/analyze turn-in and corner entry forces, and calculate rotational momentum.
Rotation Phase	When rotation begins, actively manage the car through the rotation process (while switching focus from the outside front to outside rear tire) to ensure it rotates at the correct speed, and to the correct orientation, to produce the desired trajectory for the turn's exit phase.	Actively monitor the outside front tire energy cycle peaking, and perform driving inputs to manage the rotation process.
Exit Phase	After stopping rotation and beginning the turn's exit phase, focus on the outside rear tire and its traction level, drift angle, and the car's rotation forces to assess the tire's available traction level, so maximum acceleration can be applied without overloading the tire and/or adversely impacting the car's optimum trajectory out of the turn.	Actively monitor the load, traction, and forces from the outside rear tire as rotation ends, then monitor traction and drift angle to optimize the turn exit.

Turn Task	**Proactive Sensitivity & Sensitivity Focus - (no braking turn)**	**Management Method**
Entry Phase	Focus on the turn-in point, then, based on the mental model of the track and plan for the turn, focus on precisely executing the driving inputs required to create an energy cycle for the outside front tire that will produce the entry trajectory and rotation required to match the entry phase of the turn plan .	Actively monitor the turn-in timing, then just observe the results of the driving inputs and manually adjust if needed to stay on plan for the turn.
Rotation Phase	The corner plan includes the pre-defined driver inputs (throttle & steering), and related timing, needed to manage the rotation to produce the optimum corner exit trajectory, so sensitivity focus in on executing these precisely.	Observe the rotation control inputs, then just observe their results and manually adjust if needed to stay on plan.
Exit Phase	The corner plan includes the optimum outside rear tire load and drift angle throughout the turn's exit phase, along with the steering and throttle inputs needed to produce them, so again, focus is on executing the planned inputs precisely.	Observe how reality is matching the plan, with an extra focus on outside rear tire load/drift for the first part of the exit phase.

NOTE: The examples show the sensitivity types, as being separate things/processes, but in reality the different sensitivity types are blended to optimize performance.

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Concept #2B - Sensitivity - the Modes/Ranges

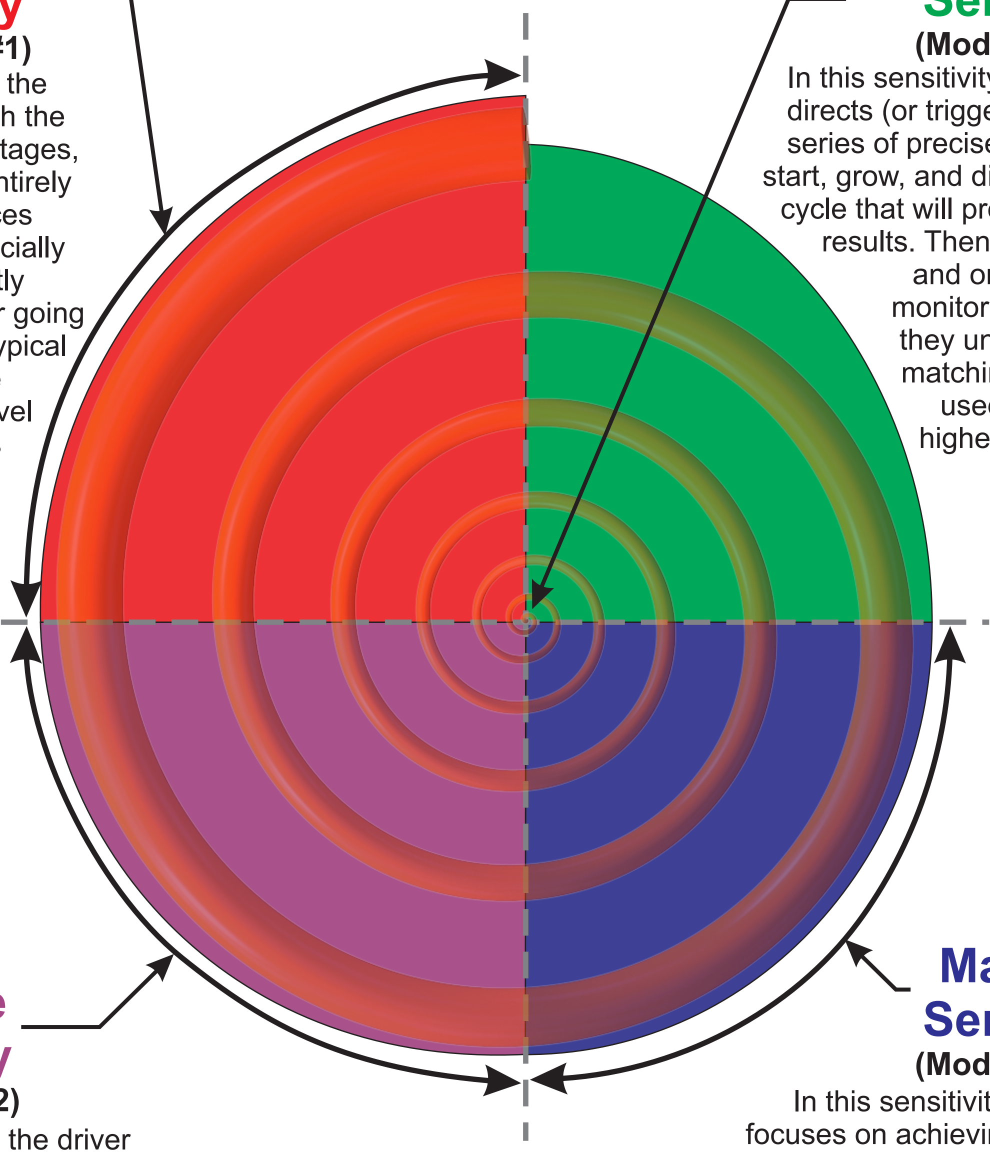
Sensitivity is much more than simply reading and reacting to what's happening on track. When you dig deeper, and especially when you try to understand sensitivity in the context of the energy cycle, you'll see that there are several distinct, but interrelated modes or ranges of sensitivity, which form a sensitivity continuum.

Reactive Sensitivity
(Mode/Range #1)

In this sensitivity range the driver can't connect with the energy cycle's earlier stages, so they focus almost entirely on traction and the forces acting on the car (especially rotation) while constantly working to keep the car going in the right direction. (typical for early-learning stage drivers, or for higher level drivers when traction is not predictable like on a wet or drying track.)

Directed Sensitivity
(Mode/Range #4)

In this sensitivity mode, the driver directs (or triggers) an automated series of precisely timed inputs to start, grow, and disperse an energy cycle that will produce the desired results. Then, the energy cycle and on-track results are monitored and verified as they unfold using pattern matching. (Typically only used by drivers at the highest learning stages and in predictable conditions.)



Predictive Sensitivity
(Mode/Range #2)

In this sensitivity range the driver focuses almost entirely on:

- For the lower learning stages, ‘feeling’ traction by analyzing their sensations.
- For middle and high range learning stages, using the current holistic context (and their mental track map) to recognize traction levels and predict traction trends.

Managed Sensitivity
(Mode/Range #3)

In this sensitivity range the driver focuses on achieving specific driving goals by managing the energy flow portion of the energy cycle to produce the tire loads (the cause), that will produce the desired traction & forces (the effect). Pattern matching (against the metal track model) is used to determine if the energy cycle is growing as expected, and if everything is on target to meet the driving goals, or if adjustments are needed to stay on target.

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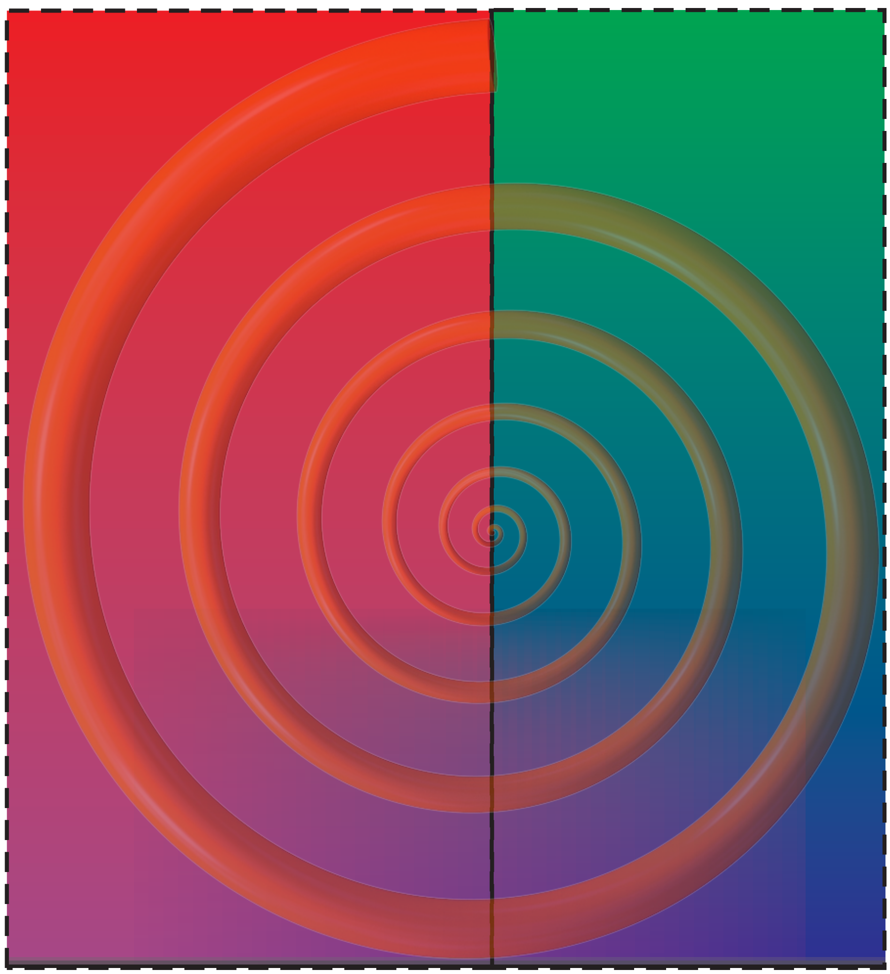
Concept #2B - Sensitivity - Types, Direction & Management

While sensitivity can be thought of as a continuum, with reactive sensitivity at one end and directed sensitivity at the other, the sensitivity modes can also be grouped/classified based on their type (interpretive or proactive), their direction of flow (incoming or outgoing), and how they are managed (active or passive).

If we represent the sensitivity continuum with color, (using red = Reactive, purple = Predictive, Blue = Managed, and green = Directed), and then overlay that with the energy cycle, it becomes clearer how the various sensitivity modes/ranges relate to the various sensitivity characteristics such as sensitivity types, directions, and management methods, as described below.



Sensitivity Type
when looking at things from a sensitivity type view, you can think of the left side of the continuum (red/purple) as the **interpretive sensitivity** type. For example when the driver focuses on the results of the energy cycle (traction and forces) to actively interpret what they are feeling, (or predict what will happen) so they can respond to those sensations to produce the desired results.

Sensitivity Type Cont.
The right side of the continuum (blue/green) can be thought of more as the **proactive sensitivity** type. For example, the driver focuses on performing a set of predefined actions, to create a specific energy cycle. Or they focus on the results they want from the energy cycle (to accomplish their cornering plan), and just do what is require on-the-fly to create that energy cycle. Typically, if a driver is at a high enough level to use proactive sensitivity, they will manage the process with passive management.

Sensitivity Direction
Another way to think about the sensitivity continuum and sensitivity types is to consider the sensitivity's direction. For example ***incoming sensitivity*** (red/purple) would come from focusing on what the car/tires are doing. ***Outgoing sensitivity*** *blue/green)* would come from focusing on executing actions precisely to produce/manage an energy cycle that will allow you to accomplish your goals.

Sensitivity Management

Active Management
Another way to think about sensitivity is to consider how you are mentally managing the energy cycle. For example, if you are driving with a more reactive approach to sensitivity, then you must manage the process by using a lot of mental resources to continually analyze what your sensations mean, and then interpret how you should respond.

Passive Management
If you are using a more proactive approach to sensitivity (creating the energy cycle per a cornering plan and/or predicting what the energy cycle will do),then you already know what, you want (you want to replicate your mental model for driving the track each lap), so instead of analyzing everything that you're feeling/sensing, you can use the more efficient pattern matching method of comparing reality to your metal track model to determine if the energy cycle is growing as expected and if everything is on target to meet your driving goals for the turn, or if adjustments are needed to stay on target.

Conclusion

In closing, I just want to say a few things:

One of the biggest challenges that arose when writing this booklet was trying to explain holistic concepts with language, which is by nature structured and sequential. The concepts had to be unraveled and dissected to write about them (at least that's the only way I could write it), but in reality all of the concepts are interconnected; each one influences, and is influenced by, the others, just like all driving inputs influence multiple things, while also being influenced by other factors such as speed, the track, conditions, etc., so keep that in mind... "The map is not the terrain."

When written out, I know that some of the concepts in this booklet might seem complex or confusing. However, if you focus on the overall meaning/message of each concept (instead of getting bogged down in the minutia when you first read it), and you try to think about your past driving experiences while looking for examples of what the concepts are describing, then you may find that the concepts do provide another perspective (or way of thinking about) what you felt when driving. If the overall concepts make sense to you in the context of your experience, you can just go with that, and then come back to this booklet later to dive into the details if you're interested.

Another point I want to make is that, in my experience, once I became aware of the concepts in this booklet, it took very little (if any) mental effort to 'use' them when driving. I'm not saying that, having read them, the heavens will open, and a beam of light will envelop your car as it circles the track at lap record pace. However, a light may go on in your head; you may find yourself 'understanding' what you're feeling on a deeper level, and you may begin to recognize the interconnectedness of the whole driving process in a way that allows you to predict and control it on another level.

I realize that the idea of these abstract concepts actually improving your on-track performance might sound like a fantasy or delusion. However, the first person I ever shared this information with was a Sports Car Club of America 'Spec Racer Ford' driver who had already been racing for two seasons, had done many hundreds of laps of testing, and had private instruction from 'big name' coaches, but he was still stuck at 6+ seconds off the pace. We emailed for about two months, discussing the more foundational information that's available on my website, and at his next race (held at his worst track) he took 3 seconds off his best time, and felt comfortable and consistent doing those times. Over the season, we talked about, and he applied, the concepts in this booklet, and at the end of the season, he was lapping 0.5 seconds under the lap record at his favorite track. Of course, that's no guarantee, and everyone is different, so while these concepts may work for some, they may not for others.

At any rate, I wish you artful driving, and successful and rewarding racing wherever you compete!

"*The mind, once stretched by a new idea, never returns to its original dimensions.*"
- Ralph Waldo Emerson