The Theory of Slow Turns In Auto Racing

Forward

It's not a game of pushing down; it's a game of lifting up.

The ideas put forth here have evolved somewhat since I first struggled to put them into words at the ELF/Winfield Ecole du Pilotage at Paul Ricard in 1989, over breakfast with the other homeboys in the week of at the ELF/Winfield Ecole du Pilotage at Paul Ricard in 1989. "Driving a car is a game of Calculus", I claimed, trying to intimidate them. "...just like Pong is a game of linear interpolation, and playing music is a game of logarithms."

"Remember, Calculus is all about curves and how fast they are getting steeper, right? In other words, about rates of change, and rates of change of rates of change, and rates of change of rates of change of rates of change. Well, there is Calculus all over the car. For starters, note that the steering wheel does not set the direction of the car. There is no North South East West on the steering wheel. It sets the *rate of change* of the direction of the car. And you set the rate of change of the wheel by turning it fast or slow. And you could start turning it slow and then gradually faster, so you can set the rate of change of the rate of change of the rate of change of the direction."

"Now suppose you are traveling North along the Y axis", I continued. "And approaching a 90 degree right-hander. Just beyond which is a wall parallel to the X axis. As you turn, you are approaching the wall with the sine. So you want to brake with the cosine."

I knew at the time that wasn't quite correct, but it did succeed in unsettling them considerably, if only for a few moments. Furthermore, if we replace the 90 degree arc of a circle with one from an inward spiral, and the roadway is only one lane wide, it gets interestingly close.

Abstract
This paper describes a theory concerning the optimal behavior in the first half of a slow turn in automobile racing[1]. More precisely, negotiating them in a mid-engine car.

Disclaimer
Do not try this in your Porsche.

One has to either take it to the track or take the utmost care in selecting a place and time where traffic conditions make it possible to drive fast without endangering anyone but one's self.

Objective
Regarding the abstraction of weight transfer: It must be stated that one but not the only of my goals here is one-upmanship. Mr. De La Tour said to me "The car will turn quite sharply" and I wish to reply "Actually it will turn *arbitrarily* [sharply], you just don't know how".   Hence the leap from 2c to 2d, which seems to say that the car can be made to make a right angle.

Prerequisite
This theory accepts as correct the force diagrams in "The Technique of Motor Racing", Piero Taruffi, 1959 (1936?).
https://www.amazon.com/Technique-Motor-Racing-Driving/dp/0837602289
Taruffi was an engineer before he was a grand prix racer. In this book, he lays out the force diagrams showing braking and turning. The reader will kindly picture a right angle made by the braking force vector, which starts in the center of the car but points in the opposite direction and sticks out the back; and the turning force vector, which has the same starting point but is perpendicular to the former, pointing outwards and sticking out the drivers door. As it is a right angle the vector sum is also the hypotenuse. When the vector sum exceeds the available traction, the car will leave the road, and with the absolute value of the hypotenuse/vector sum, as the latter points backwards.

Background
In motor racing:
- A fast turn is a turn for which one does not lift.
- A medium turn is one for which one lifts and perhaps brakes lightly or moderately
- A slow turn is one for which one brakes hard and deep; up to ⅓ - ½ way into the turn

I predict that for the purpose of their study, these definitions will require modification from their traditional values to:
- Fast:	A turn for which one does not lift

[1] Or, at least, attempts to

- Medium-fast: A turn for which one lifts but does not brake
- Medium: A turn for which one lifts and brakes but not as hard as possible
- Slow: A turn for which one must brake with the full ability of the car

Part I - General Theory of Turning

Postulate 1. At the end of the straightaway you have to be braking with 99.9% of your available traction; in other words, as hard as you can without locking the wheels.
Proof of Postulate 1: If you did not, then you could have braked harder, and thus it would have taken less time to slow down, and you could have waited longer to begin, and thus driven more of the straight at top speed and have a lower lap time.

Postulate 2. At the apex of the turn you should be using 99.9% of your available traction due to turning; in other words, going as fast as the car will sustain the road.
Proof of Postulate 2: If you are not, then you could be going faster and getting a lower E.T. through the turn, and a lower lap time.

General Theory of Turning:

The optimal behavior by the driver between the beginning of the turn and the point where the driver stops turning the wheel in is to release the brakes in a way that complements the increasing demand for traction due to turning, and in doing so keeps the vector sum of the two forces adding up as closely as possible without equalling the amount of available traction.[2]

Discussion:

Braking results in downforce which gives more traction which in turn allows harder braking. The effects are more pronounced in street cars where the suspension has more travel and the tires have less pressure and do not deform as readily.
Suppose we are doing 120 on a straightaway rapidly approaching the onset of a 30MPH turn, Because momentum increases with the square of velocity, if the car slows by 30mph on the straight then enters the turn at 90, we expect that redirecting the car and its kinetic energy through the first 22.5 degrees - the first half of the first half of the turn - as it slows from 90 to 70 for an average of 80 will require 4X the traction than it will through the second 22.5 as it slows from 50 to 30, for an average of 40.

Fortunately there exists more available traction in the first 22.5 because the brakes are being applied harder. It will be gone when the car has slowed and is at the clipping point, and has to be, it being time to accelerate.

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[2] It isn't an easy sum to do, but that's what it is.

Postulate 1 said that you must be on the brakes as hard as you can w/o locking the wheels at the end of the straightaway. So you have all this downforce from being on the brakes at the onset of a turn. And you are going way too fast. What a happy coincidence!

Suppose we reject Postulate 1 and wish to conclude our braking before the turn. Our analysis begins to resemble "Poker with Game Theory" in which we have a table whose column headers read "Player 1:" "Never bluffs" "bluffs with 1:2 ratio" and "Always bluffs".
We can prepare three columns: "In turns:" "Never brakes" "Releases Brakes beginning at onset by the same formula that describes the turn" and "Brakes as hard as possible until desired cornering speed is reached:.

Part II Racer's abstraction of Weight Transfer

The Theory of Increasable Traction

The Theory of Increasable Traction is not completely true nor is it intended to be. It is a conceptual model.

2a. You can effectively turn the car into a slot car - pinned to the road at the front - by pushing down on the front end… -if- you push hard enough.
2b. You can push down on the front wheels as hard as you like by braking correspondingly hard.
2c. You can brake as hard as you like by going correspondingly fast beforehand.
2d. Therefore the front end of the car will turn arbitrarily sharply.

Part III Racing Car Design

Theory of Mid-Engine Requirement

3a. The theory of slow turns only works in mid-engine cars, as both axles of a mid-engine car will experience loading due to the CG of the motor during braking.
3b. A front engine will lend its mass to downforce almost solely on the front and will not support the theory.
3c. Rear-engine: the Racer's Abstraction of Weight Transfer is an approximation and works only until the rear eventually lets go. It will let go sooner in a rear-engine car. ,Traditional Porsche owners know from experience that their cars will spin under braking easier than will other designs, and that they must adjust their driving style accordingly. This calls into question whether the theory of slow turns also does not apply to them, since if one can spin the Porsche more readily, under braking, then one must brake less when driving it, and "brake as hard as is possible" is a different thing, and if it is different, then how is "the sum of the braking and turning forces" versus the available traction" affected?

Considering this makes it apparent that Taruffi's force diagrams are only valid for mid-engine cars; and in fact, for neutral-handling cars. Imagine if the engine and CG were moved far behind the rear axle, artificially far: at some point they will raise the front wheels in the air when parked. Now bring them forward until the front comes down to the road. At this point if you put your foot on the rear bumper and relax the front wheel will go back up in the air. This car has almost no traction in front, but even before that condition, when the engine was not so far back, for the same reason it already will spin easily, tending to rotate the car around the rear wheels .

Conclusion

In rowing, there is a saying: ***Approach your footstretchers as you would approach God.***
Adapted to auto racing this becomes: ***Release the brakes as you would approach God.***