

Racecar 101

James Wright

September 8, 2022

Outline

- 1 What makes a car fast?
- 2 Vehicle Basics
- 3 Vehicle Balance and Control
- 4 Three Tenants of Racecar Design

Note

This first part is a very simplified breakdown

- It's not the most accurate
- It's not to insult anyone's intelligence

It's simply to not distract from the things that can be easily forgotten or muddled.

Also, I like audience participation. Ask questions. I'll be asking y'all questions.

Me



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What makes a car go fast?

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To make a car **faster**, you must make the car **accelerate more**

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What famous equation involves acceleration?

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Newton's 2nd law!

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We care about acceleration, so rearrange:

$$a = \frac{F}{m}$$

How do we maximize acceleration?

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Decrease Mass

- Make things lighter

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The latter two hold **only if the tires can transfer the torque**

Balancing \uparrow Force vs \downarrow Mass

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Bigger Engine

Increases the total vehicle mass, but increases power output
Depending on the ratio, can lead to better acceleration.

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Smaller/Narrower Tires

Decreases total vehicle mass, but decreases total acceleration potential
Also reduces unsprung mass (improves vehicle handling and response)

Longitudinal Acceleration

Simplest acceleration to model:

$$a = \frac{F}{m}$$

Tire traction capacity sets upper limit of the acceleration.

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- This is as much for safety as it is performance
- Ensure that car is capable of absolute maximum braking acceleration

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② Power (positive)

- Almost always limited by the power unit (ICE, electric motor, rubber band windup, etc.)

Lateral Acceleration

Turning causes *Lateral Acceleration*, which is not a change in speed, but of direction:

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Therefore given:

- a force, F (tire traction)
- a mass, m (the car)
- and a radius, r (the track/racing line)

there is a **limit to the maximum velocity**

Lateral Acceleration cont.

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 - How?

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 - Increase the maximum force the tires can exert
 - How?
 - Aero downforce
 - Different tires
 - Suspension design, etc....

Quick Review

Higher Acceleration = Faster Car

	Limited by	How to make better?
Longitudinal Acceleration	Force (Braking and Power)	Bigger Engine/Brakes
	Mass	Reduce it
Lateral Acceleration	Force (Tire Traction)	Increase Grip
	Mass	Reduce it

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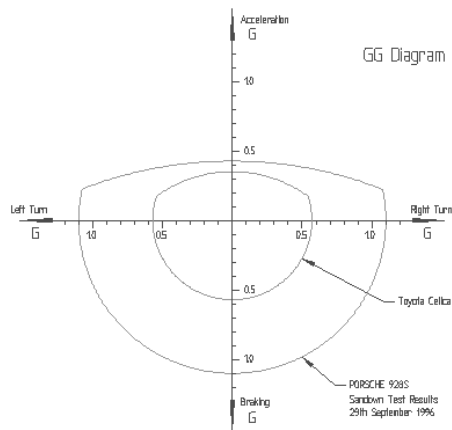


Figure 2

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G-G Curve (or Traction Circle)

- Plots **maximum steady-state acceleration** that a vehicle can have in **any direction**

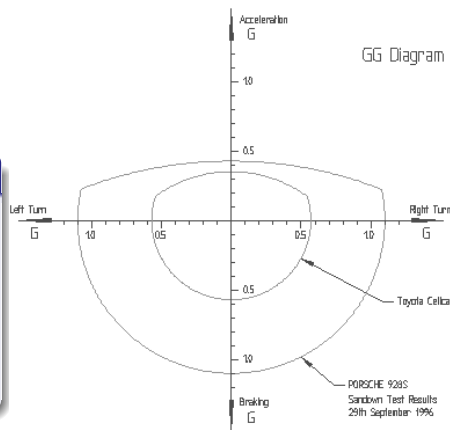


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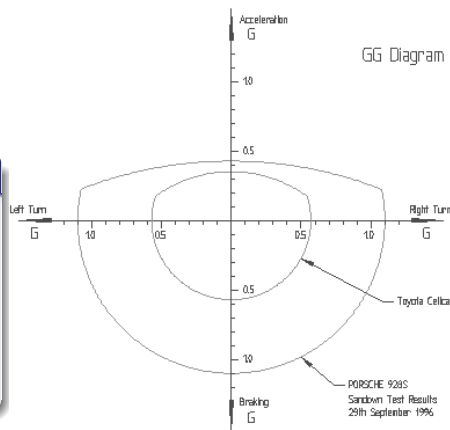


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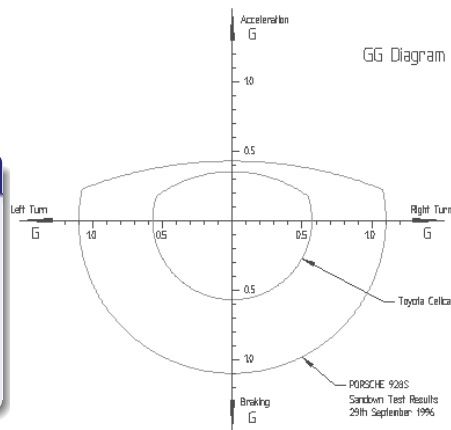


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- On the circle = driving at the edge

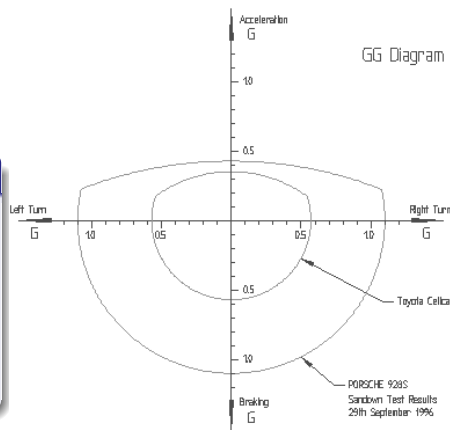


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G-G Curve: Misc Remarks

- Circles

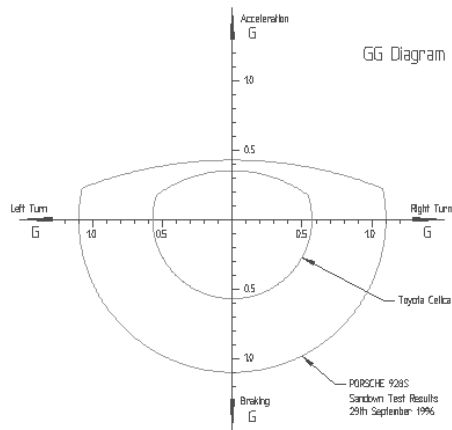


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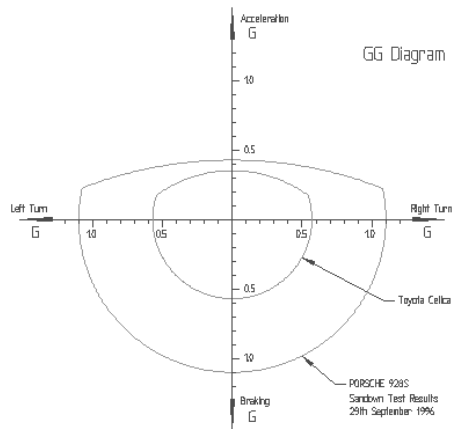


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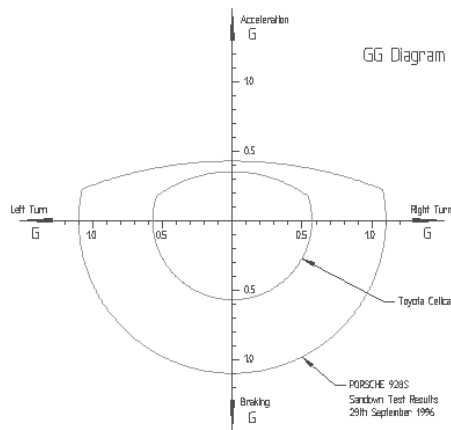


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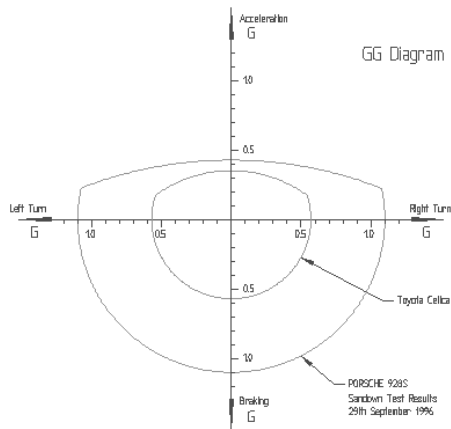


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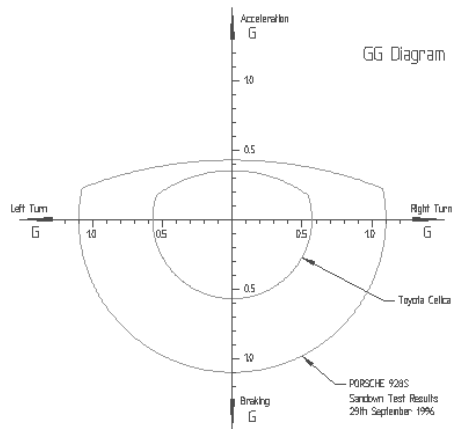


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 - Top part of curve isn't *quite* circular
 - **Positive acceleration is nearly always limited by the power unit, not the tires**
 - For (nearly) all cars, the power unit is the most severe acceleration limitation.

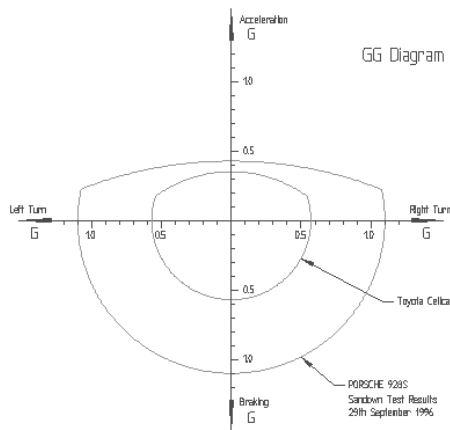


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How do tires generate force?

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Via friction with the ground

Tires and Friction

Newton's Law of Friction

$$F = N\mu$$

where F is the max static friction force, N is the normal force, and μ is the static friction coefficient

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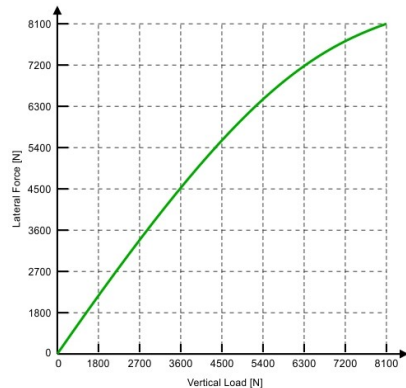
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- Tires create force via **static friction**
 - A tire is in *kinetic* friction if it's locked up or doing a burnout
- μ is generally assumed to be constant
 - So F is linearly dependent on N

Tires and Load Sensitivity

- Tires **do not** have a constant μ :

$$F = N\mu(N)$$

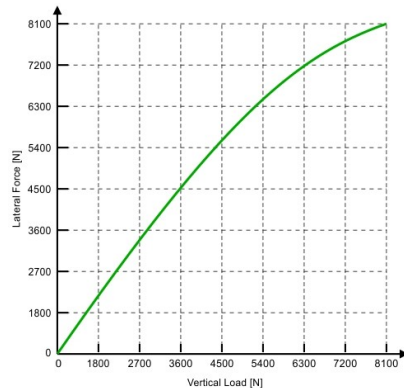


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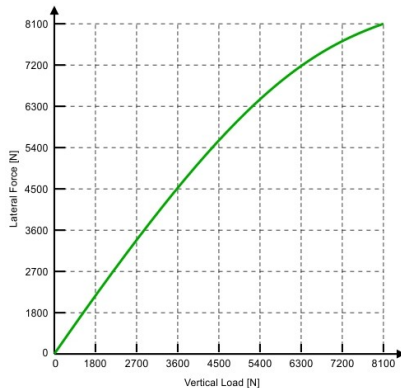


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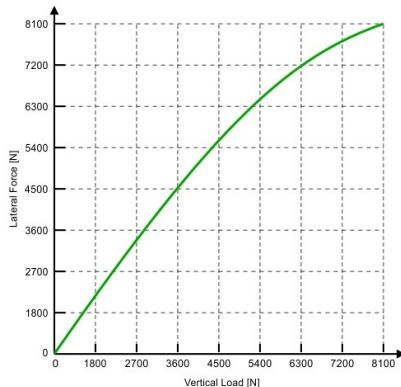


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Load Sensitivity is the singular most impactful thing in racecar design

It alters practically every single decision

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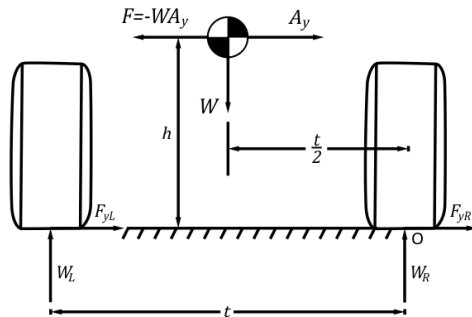
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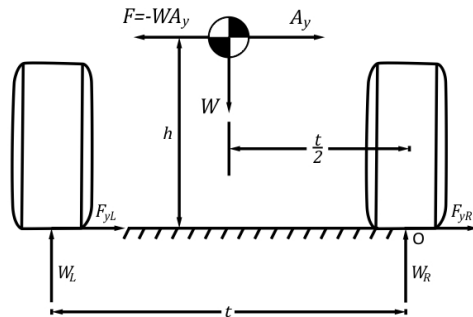
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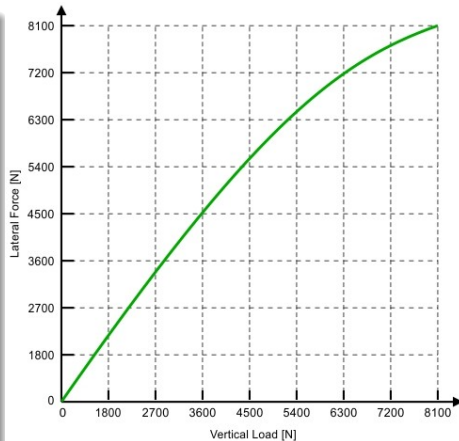
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- **Reduces global vehicle grip due to load sensitivity**



Load Transfer Example

No load transfer vs 50% load transfer

Assume 4.5kN of static vertical load on each tire.

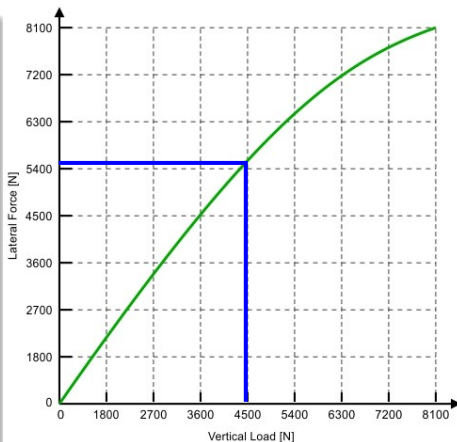


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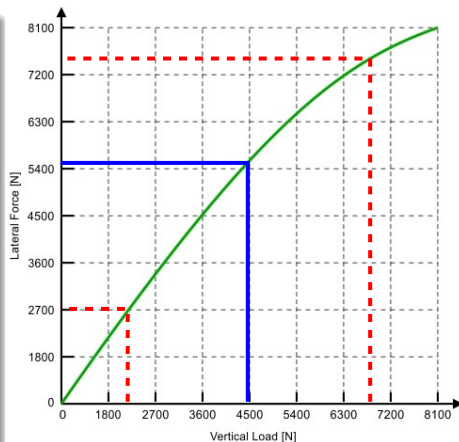
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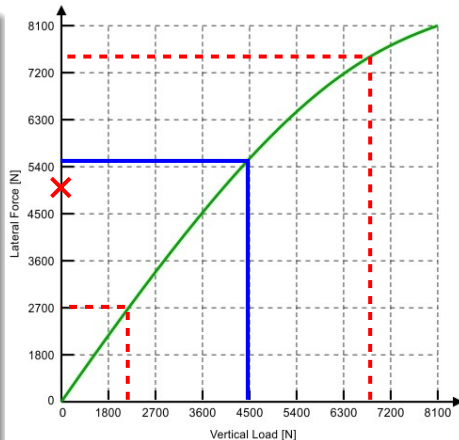
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8% Drop in total traction!

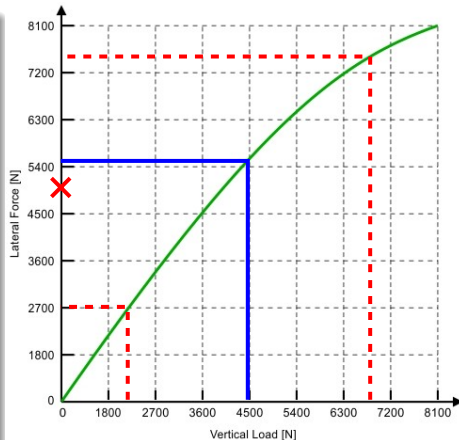


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- Now we'll cover orientation/rotation

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Object's resistance to change	m	I
Rate of Change	a	α
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- Moments can be calculated from a force F and distance r via $M = F \times r$

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This is where balance and control comes into play

Ensure that the car is oriented such that we can achieve maximum linear acceleration

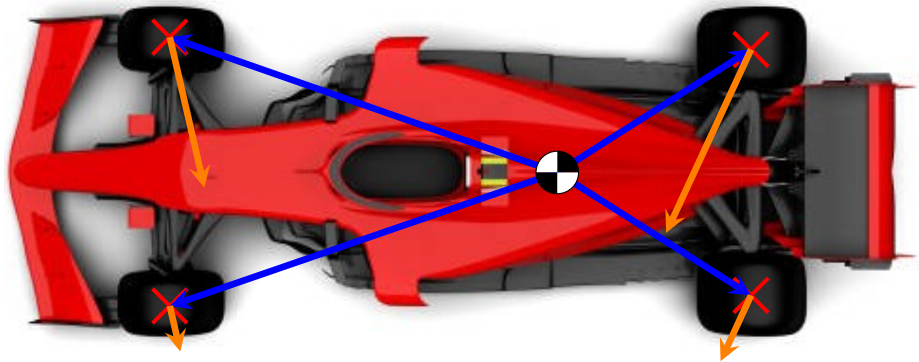
Vehicle Balance

Why do Formula 1 and Indy cars have larger tires at the rear than the front?

Vehicle Balance - Formula 1 Car

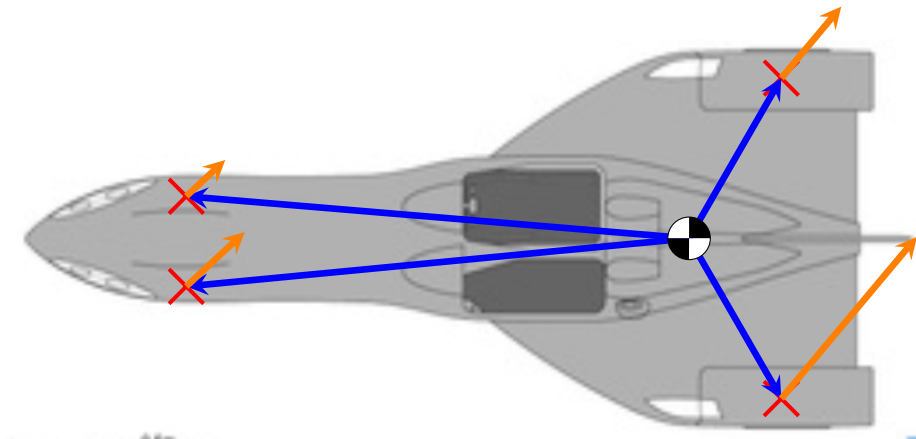
Balance the moments of the car

$$M = F \times r$$



Vehicle Balance - Delta Wing

Balance the moments of the car $M = F \times r$



Oversteer vs Understeer

Neutral Steer

Moments in perfect *imbalance*

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Under Steer

Unbalanced moments cause under-rotation

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- A car can dynamically change between all three states

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Unbalanced moments cause over-rotation

- The latter two prevent achieving maximum linear acceleration
- A car can dynamically change between all three states
- Changes occur due to differences in load transfer, suspension magic, and through dynamic movement

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Three Tenants of Racecar Design

In order of importance:

- ① Make it Lighter
 - Improves acceleration, load transfer, responsiveness, etc.

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The car that is lighter, has a lower CG, or has a lower inertia will be faster

Recommended Resources

- *Tune to Win* by Carroll Smith
 - Vehicle dynamics for normal people
 - Covers the gamut of racecar design topics (aero, cooling, VD, powertrain, etc.)
- *Racecar Vehicle Dynamics* by Milliken & Milliken
 - "The Bible"
 - It's a textbook, but incredibly useful
 - More specialized to vehicle dynamics (shocking given the name)

Questions