Racecar 101

James Wright

September 8, 2022

Outline

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 muddied.

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

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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**

[1] Assuming distance is constant

What famous equation involves acceleration?

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Newton's 2nd law!

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We care about acceleration, so rearange:

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

How do we maximize acceleration?

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

Balancing ↑Force vs ↓Mass

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Sometimes $\uparrow$ mass $+ \uparrow$ force $= \uparrow$ acceleration

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Increases the total vehicle mass, but increases power output
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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:

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- 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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   - 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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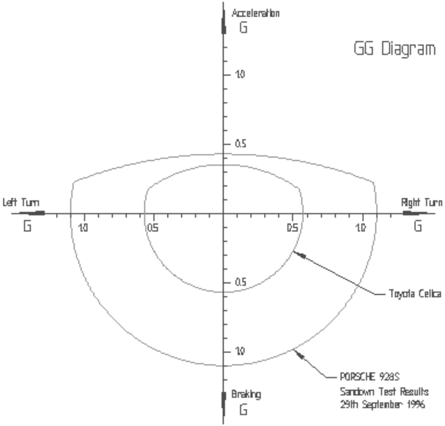

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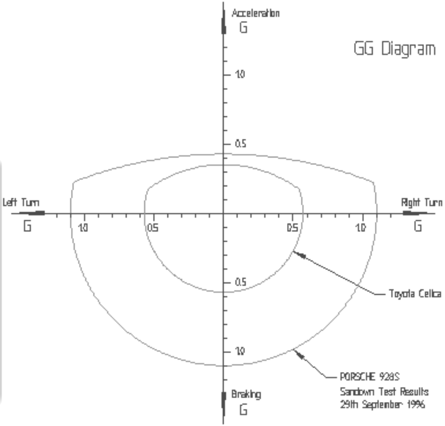
G-G Curve (or Traction Circle)

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



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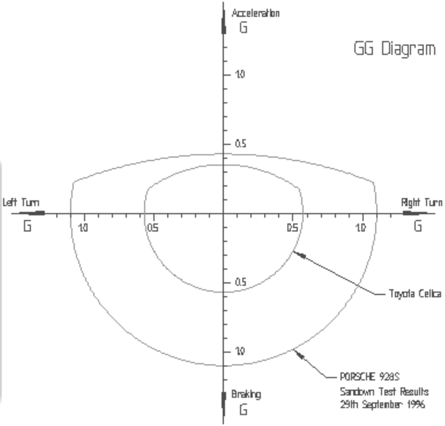

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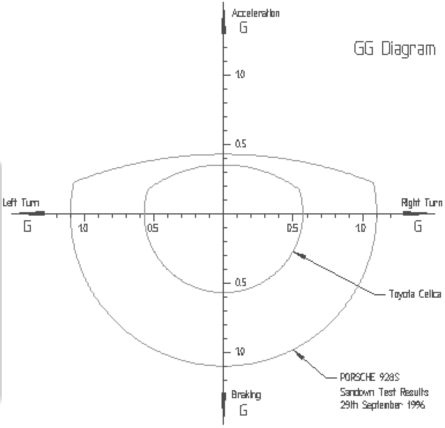

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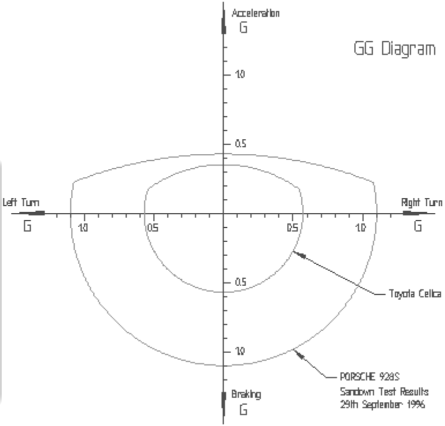

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G-G Curve: Misc Remarks

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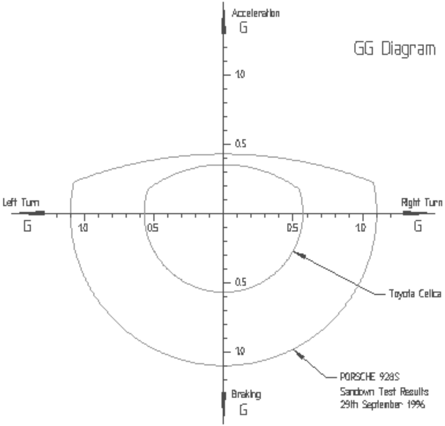

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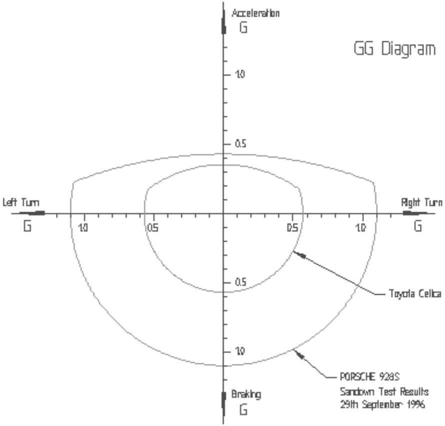

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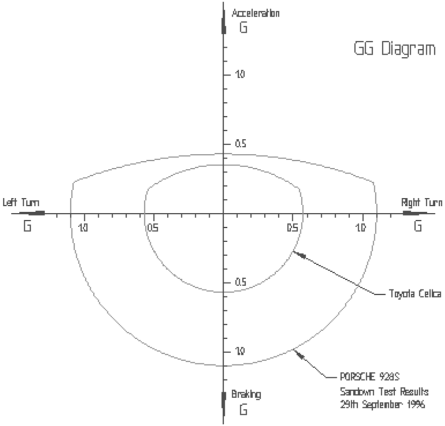

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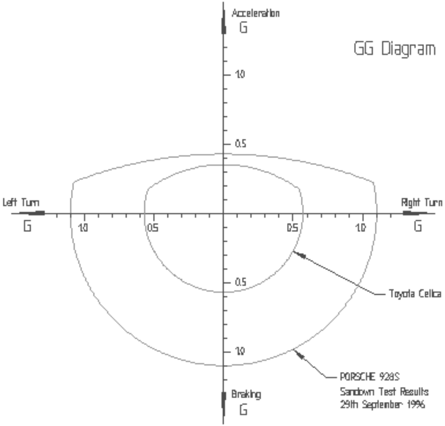

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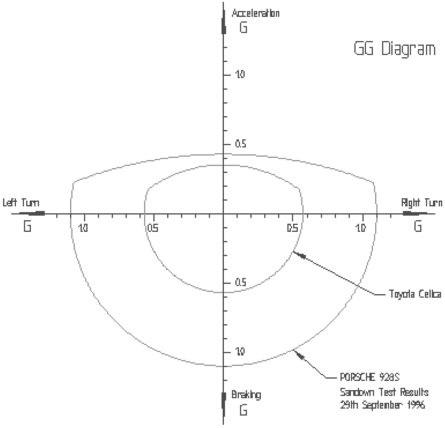

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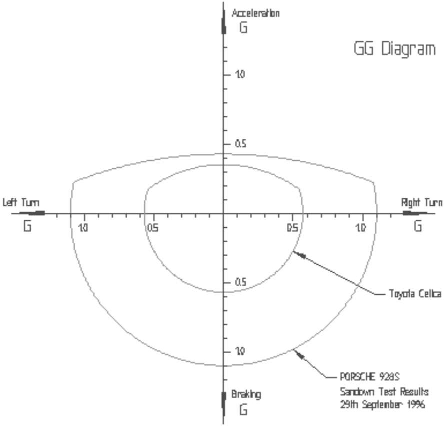
  - **Positive acceleration is nearly always limited by the power unit, not the tires**
  - For (nearly) all cars, the power unit is the most severe acceleration limitation.



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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

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- 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:

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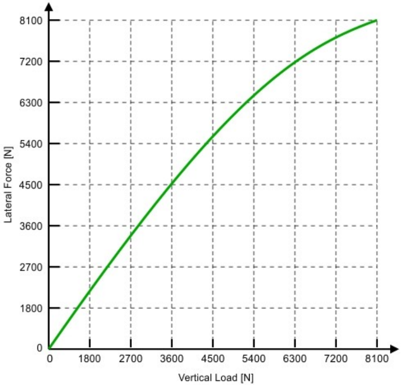

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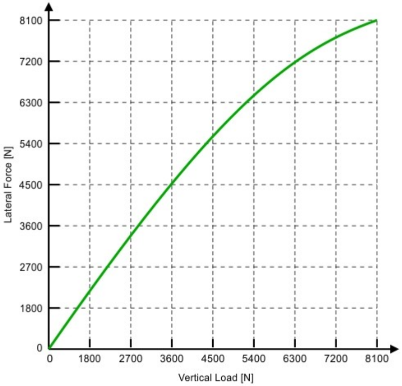

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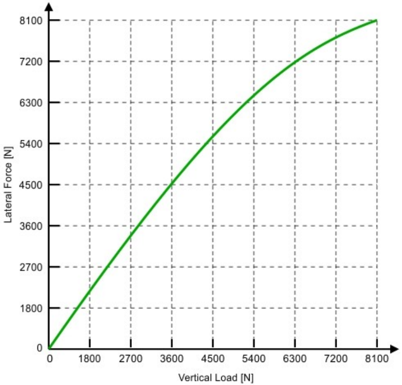

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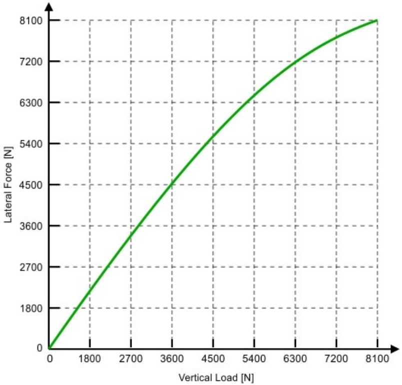

Load Sensitivity is the singular most impactful thing in racecar design

It alters practically every single decision

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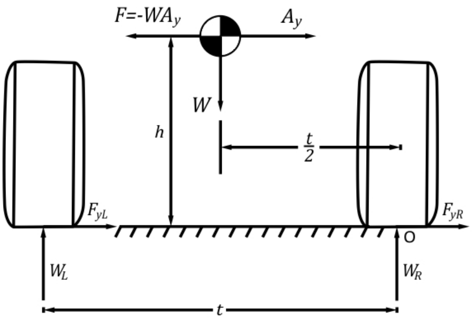

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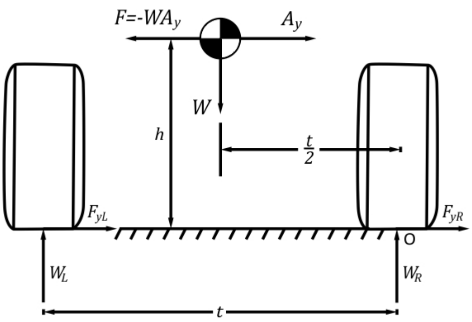
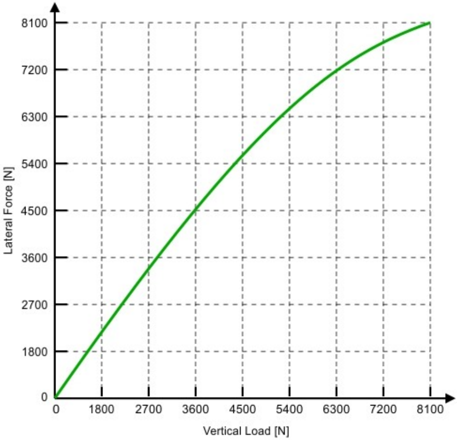
- **Reduces global vehicle grip due to load sensitivity**



Load Transfer Example

No load transfer vs 50% load transfer

Assume 4.5kN of static vertical load on each tire.



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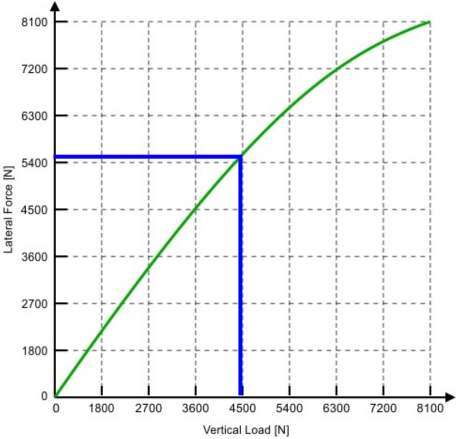

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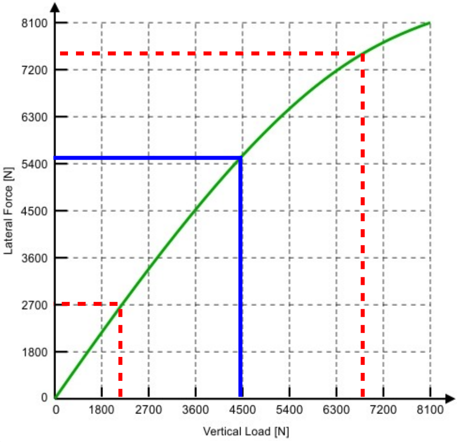

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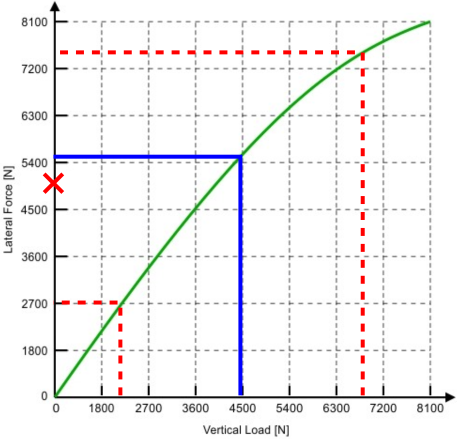

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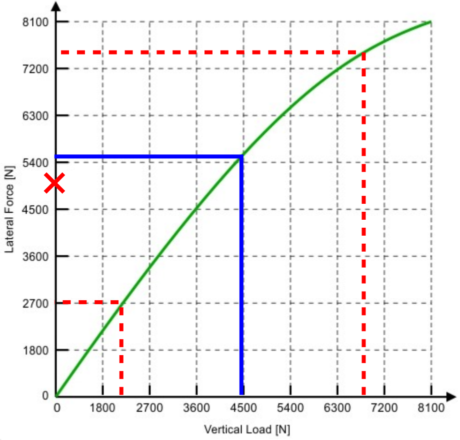
8% Drop in total traction!



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- Now we'll cover orientation/rotation

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Rate of Change	a	α
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State Variable	V	ω

- Moments can be calculated from a force F and distance r via $M = F \times r$

Angular Acceleration for Racecars

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This is where balance and control comes into play

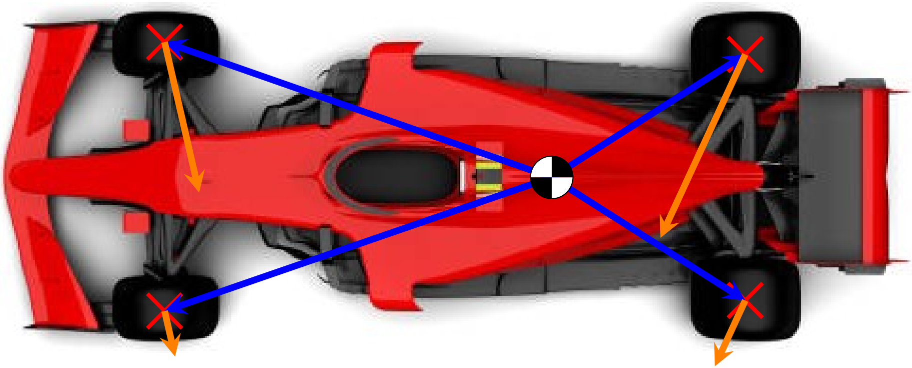
Ensure that the car is oriented such that we can achieve maximum linear acceleration

Vehicle Balance

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

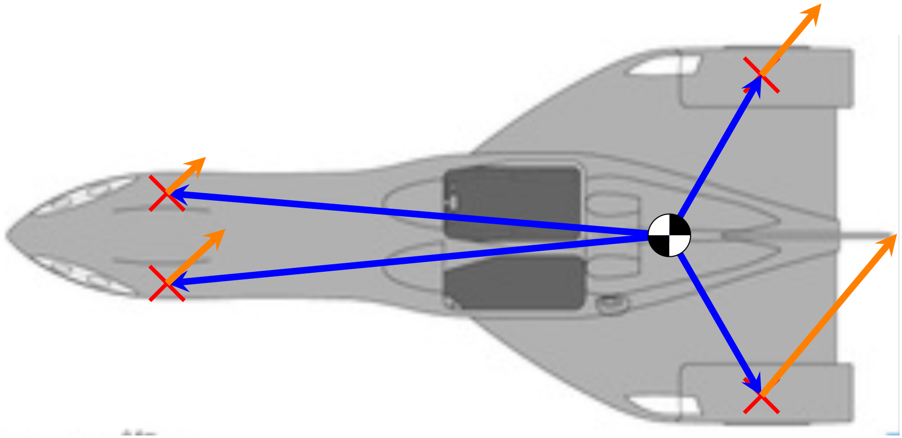
Vehicle Balance - Formula 1 Car

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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- 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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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