# Racecar 101

James Wright

September 8, 2022

# Outline

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**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.

# 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 rearange:

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

# How do we maximize acceleration?

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- Make things lighter

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

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Depending on the ratio, can lead to better acceleration.

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

**Smaller/Narrower Tires**

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

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- Ensure that car is capable of absolute maximum braking acceleration

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- This is as much for safety as it is performance
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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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where $V$ is velocity, and $r$ is the turning radius.

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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**

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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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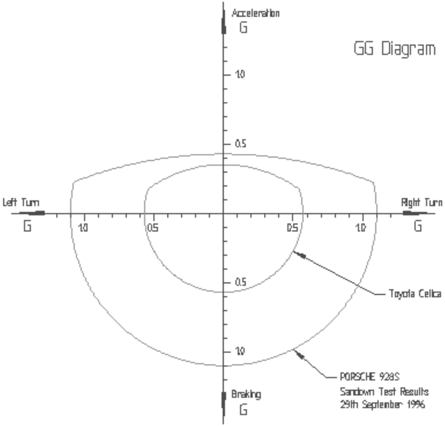


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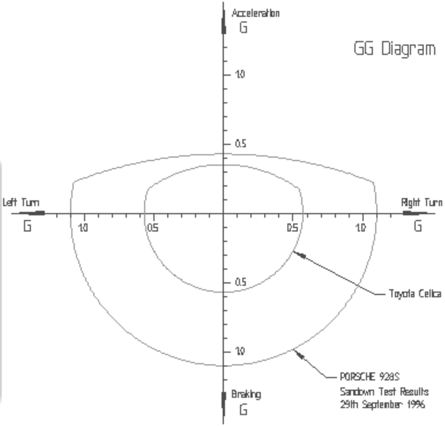
## G-G Curve (or Traction Circle)

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

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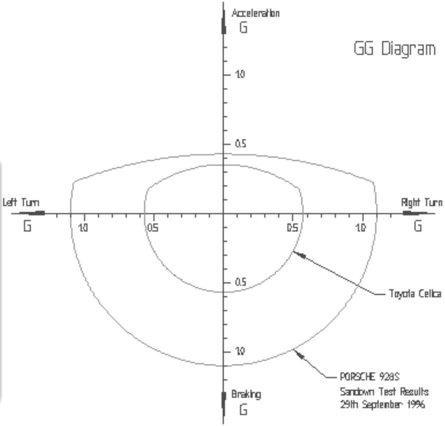


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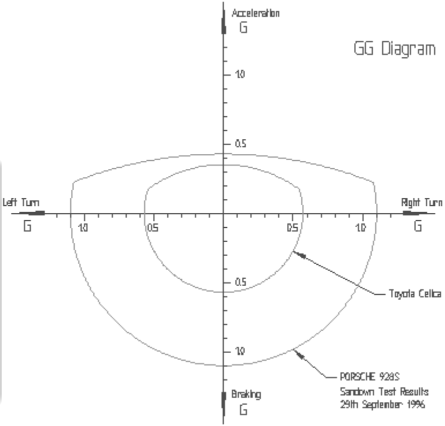


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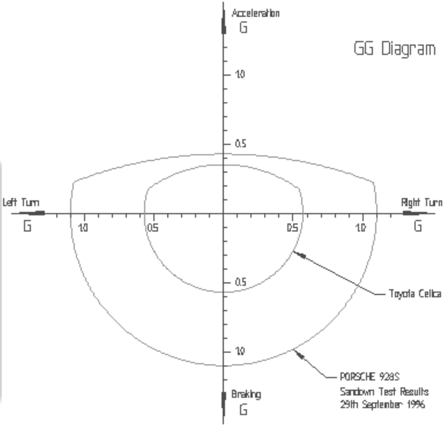


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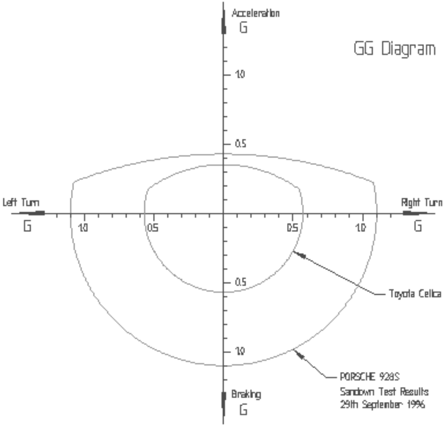
# G-G Curve: Misc Remarks

- Circles

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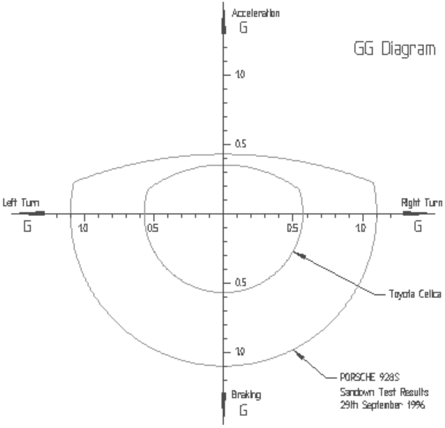


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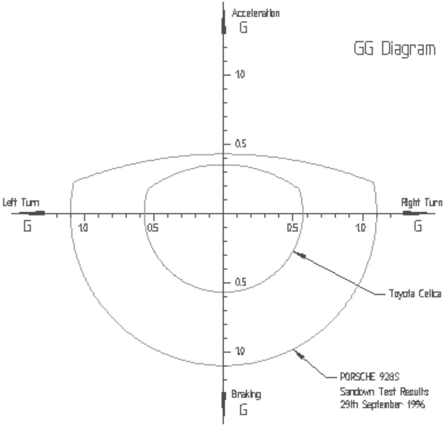


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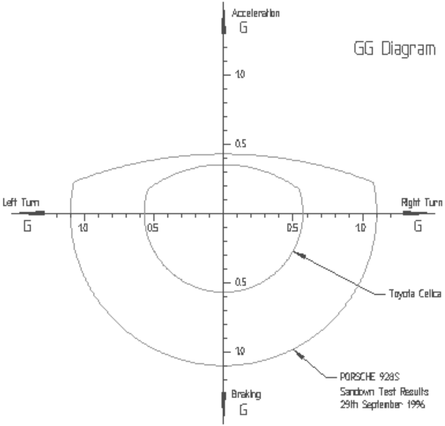


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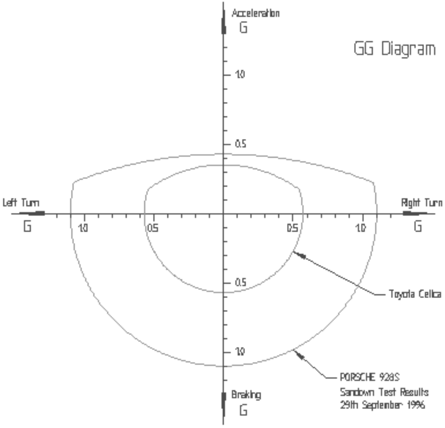


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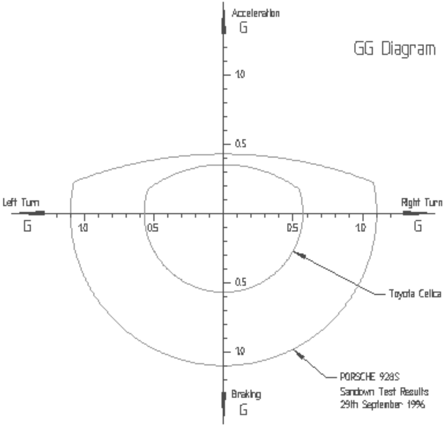
  - **Positive acceleration is nearly always limited by the power unit, not the tires**
  - For (nearly) all cars, the power unit is the most severe acceleration limitation.

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Via friction with the ground

# Tires and Friction

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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
- $\mu$ is generally assumed to be constant
  - So $F$ is linearly dependent on $N$

# Tires and Load Sensitivity

- Tires **do not** have a constant $\mu$:

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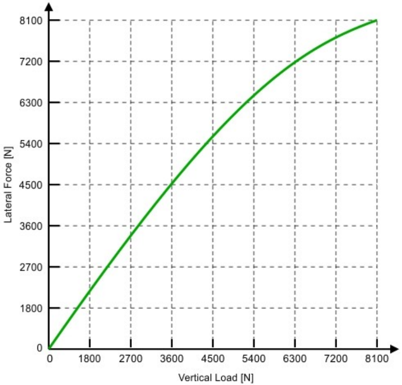

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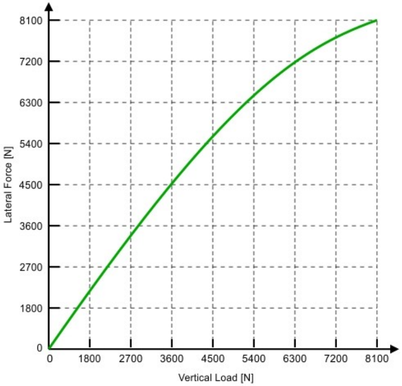

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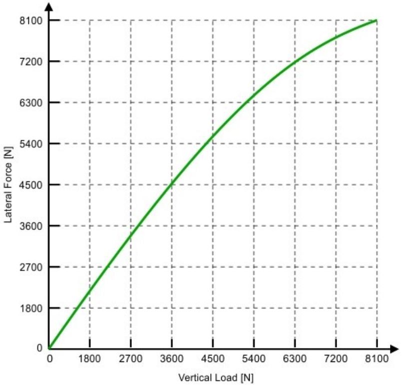

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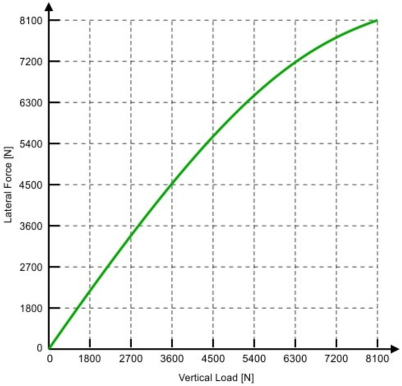


**Load Sensitivity is the singular most impactful thing in racecar design**

It alters practically every single decision

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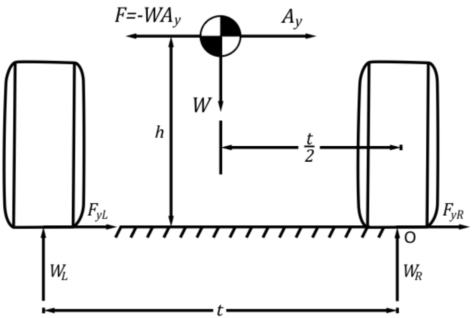

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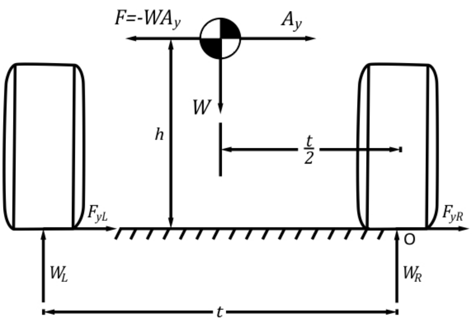
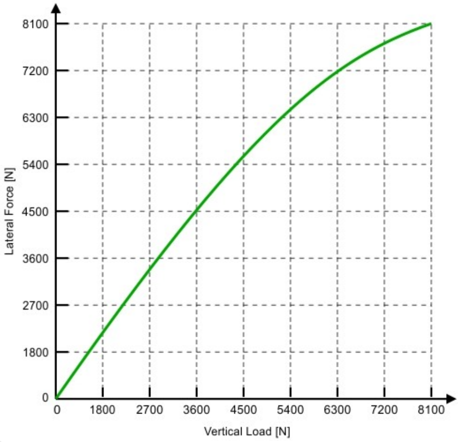
- **Reduces global vehicle grip due to load sensitivity**



# Load Transfer Example

## No load transfer vs 50% load transfer

Assume 4.5kN of static vertical load on each tire.



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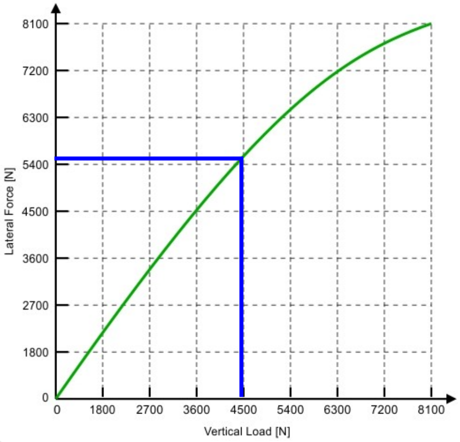

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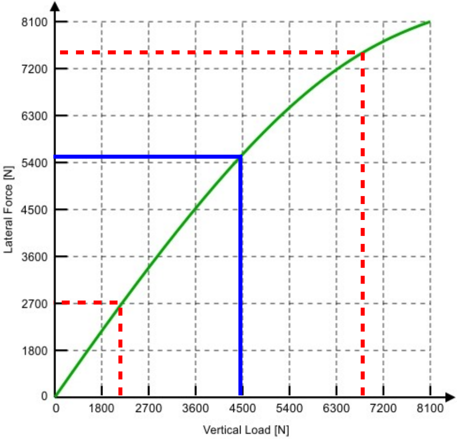

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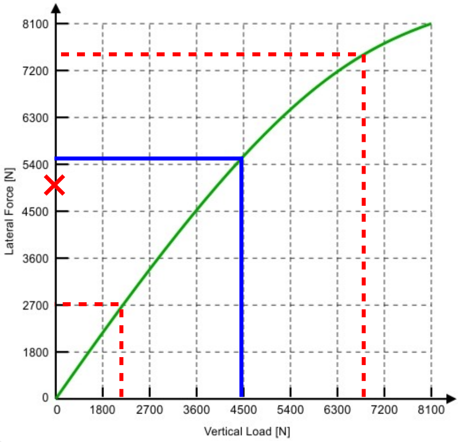

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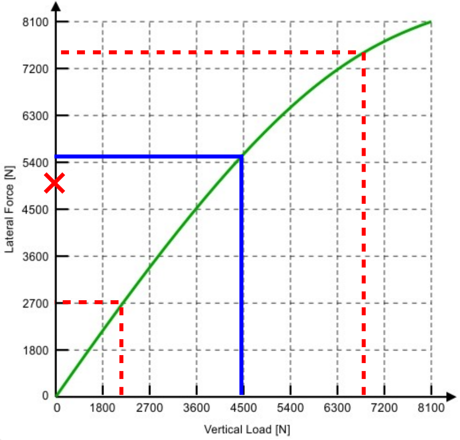
**8% Drop in total traction!**



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- Now we'll cover orientation/rotation

# Angular Momentum

## Conservation of Angular Momentum

$$M = I\alpha$$

where $M$ is the moments (torque) acted on the car, $I$ is the moment of inertia, and $\alpha$ is the angular acceleration

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where $M$ is the moments (torque) acted on the car, $I$ is the moment of inertia, and $\alpha$ is the angular acceleration

- Analogous to conservation of linear momentum:

| | Linear | Angular |
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| External Action | $F$ | $M$ |
| Object's resistance to change | $m$ | $I$ |
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- Moments can be calculated from a force $F$ and distance $r$ via $M = F \times r$

# Angular Acceleration for Racecars

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- Therefore, we *do not* want to maximize angular acceleration.
- We only want to **control it such that we can maximize linear acceleration**.

**This is where balance and control comes into play**

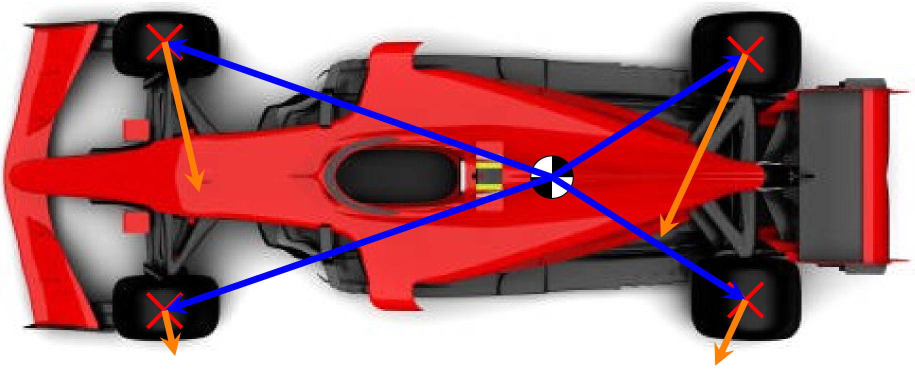
Ensure that the car is oriented such that we can achieve maximum linear acceleration

# Vehicle Balance

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

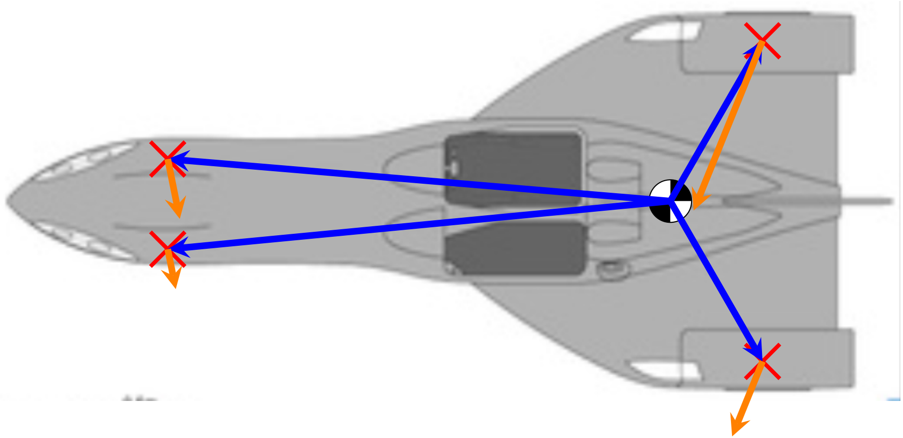
# Vehicle Balance - Formula 1 Car

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



# Vehicle Balance - Delta Wing

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



# Oversteer vs Understeer

## Neutral Steer

Moments in perfect *imbalance*

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Unbalanced moments cause under-rotation

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Unbalanced moments cause over-rotation

- A car can dynamically change between all three states
- Changes occur due to differences in load transfer, suspension magic, and through dynamic movement

# Table of Contents

# Three Tenants of Racecar Design

*In order of importance:*

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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