EECS 192: Mechatronics Design Lab

Discussion 12: Mechanical Tuning

written by: Richard "Ducky" Lin Spring 2015

15 & 16 Apr 2015 (Week 12)

- Introduction
- Mechanical Tuning
- Vehicle Dynamics

Introduction

Disclaimer

- I'm not a mechanical engineer
  - I've tuned exactly zero cars
- Information here from various Internet sources, which hopefully is correct
  - (it passes the "smell test")
- If it sounds wrong, it might really be...

not actually *that* bad

from knowyourmeme.com

Goals

What's the ultimate goal here?

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- Reduce race time

How do we do that?

what you want

from Big Rigs: Over the Road Racing

a game that you should never touch

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How do we do that?

- High acceleration - speed on straights
- Fast cornering - fast through turns
- High deceleration - slowing for turns

Essentially maximizing acceleration. How?

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- High acceleration - speed on straights
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Essentially maximizing acceleration. How?

- Maximize tire grip!

what you want

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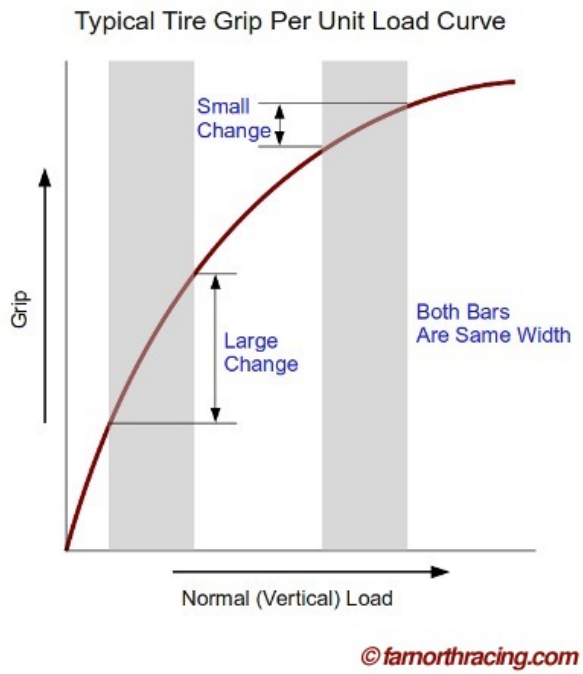
Tire Grip Curves

Tire Grip vs. Load Curve

- Tire grip is nonlinear with load
- Diminishing returns with more pressure

So I have 4 tires - what's the optimal distribution?



tire grip curve

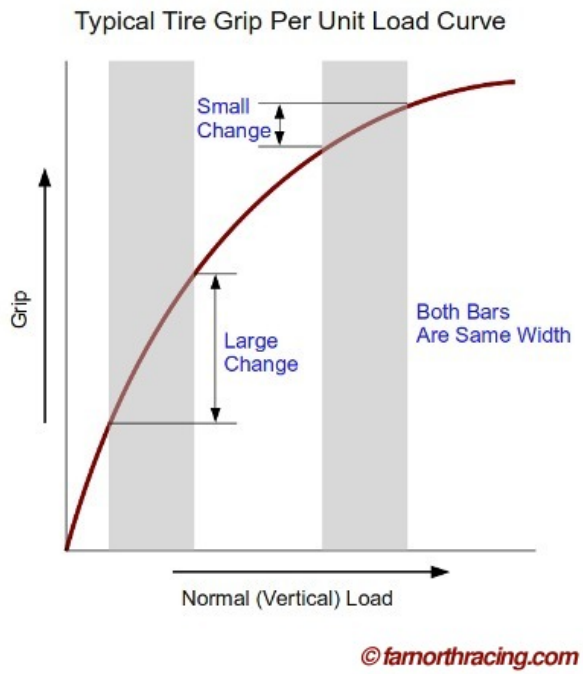
Tire Grip Curves

Tire Grip vs. Load Curve

- Tire grip is nonlinear with load
- Diminishing returns with more pressure

So I have 4 tires - what's the optimal distribution?

- Completely even
- Don't trade a loss of larger amount of grip for a gain of smaller amount of grip



tire grip curve

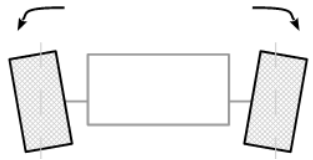
Mechanical Tuning

Camber

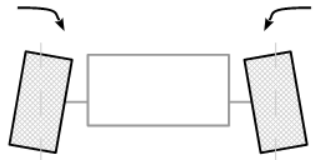
Camber: angle between wheel and vertical (from front)

- Positive if tilting outwards
- Negative if tilting inwards

What's optimal to maximize contact area?



positive camber



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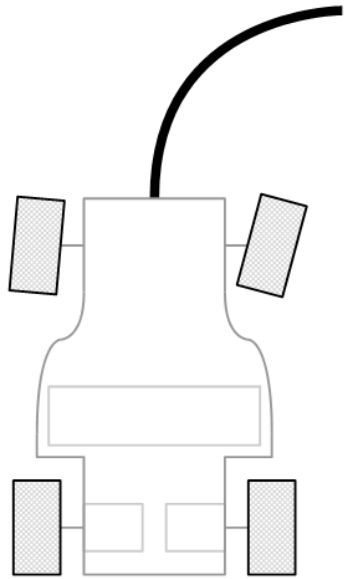
- 0 degree, ideally

But need to account for turning chassis roll



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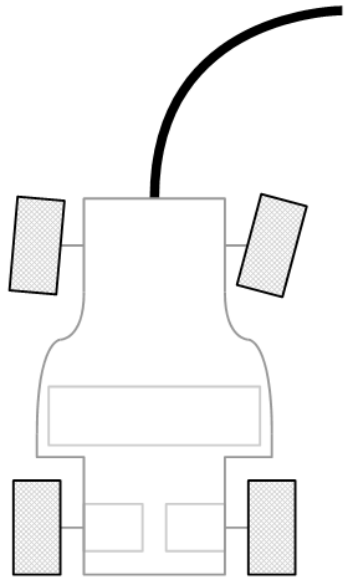
- So slightly negative camber (1°-4°) to increase traction when cornering



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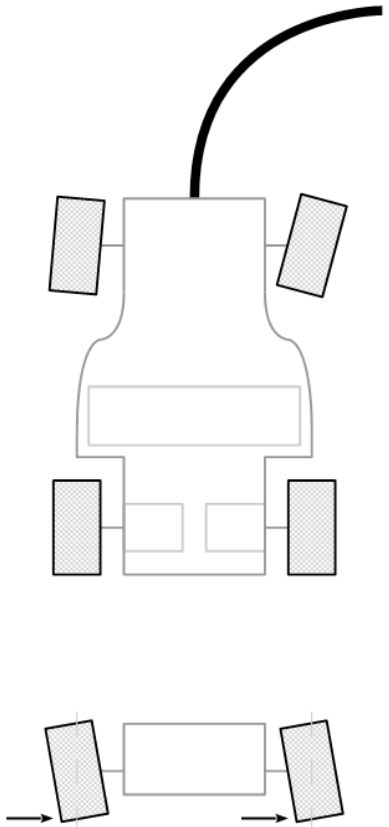
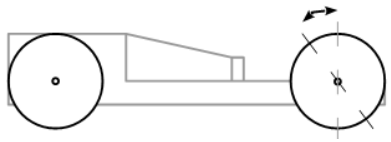


camber effects from turning

Caster

Caster: angle between steering axis and vertical

- Positive when steering axis line intersects road ahead of contact patch



caster

What are the stability effects of positive caster?

think shopping cart "caster" wheels

Caster

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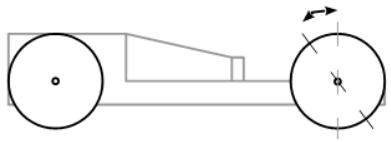


caster

What are the stability effects of positive caster?

think shopping cart "caster" wheels

- Self-centering effect
  - Contact patch "trails" steering axis
- Typically 3°-5°recommended
  - Less may increase steering at stability cost
- Overall effect is fairly small

self-centering effect

Toe

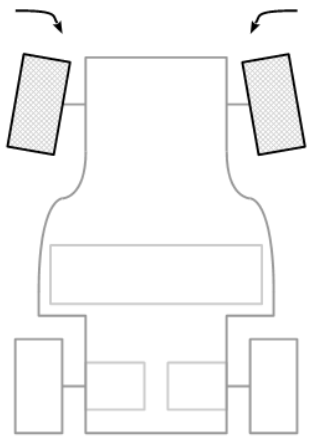
Toe: angle between wheels, viewed from top

- Toe-in (positive): inwards towards front
- Toe-out (negative): outwards towards front

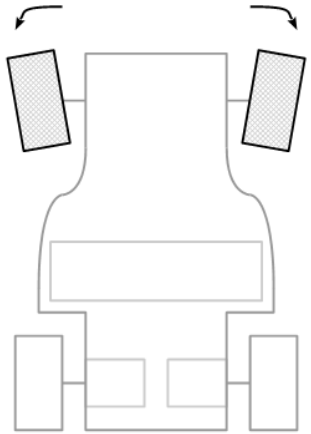
Effects of toe:

- Toe-in provides straight-line stability
- Toe-out provides better turn-in but amplifies disturbances
- Small changes produces noticable effect
- Recommended range (front): -3°-1°

Why might toe be bad?



toe-in



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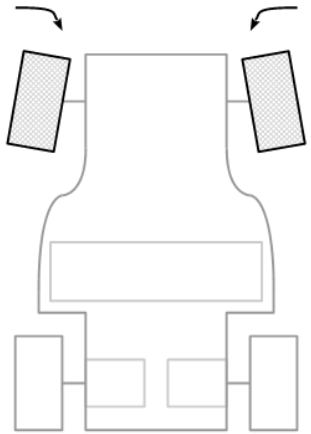
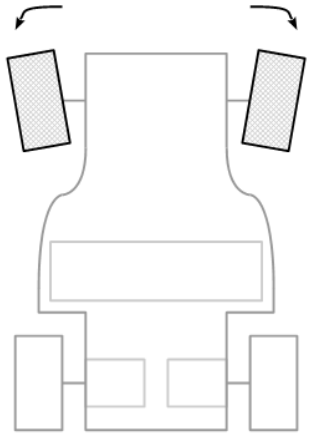
Why might toe be bad?

- Wheels rub against road - reduces tire life



toe-in

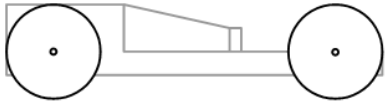


toe-out

Weight Distribution

Freescale Car setup:

- Front wheels: steering
- Rear wheels: power



What does front/back weight distribution do?

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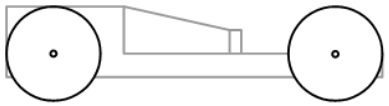


What does front/back weight distribution do?

- Towards front: more steering grip
- Towards back: more acceleration traction

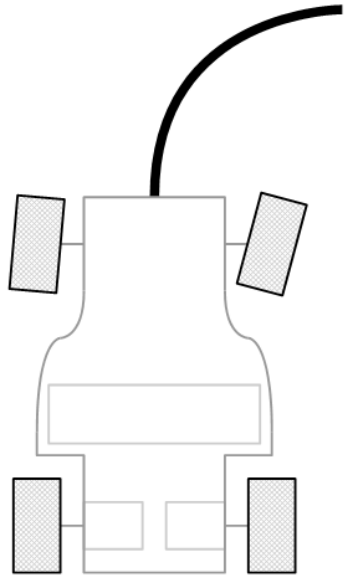
Vehicle Dynamics

Lateral Weight Transfer

What happens to my effective weight distribution when turning?

assume stiff suspension for simplicity

analysis with springs much more involved



direction of travel

Lateral Weight Transfer

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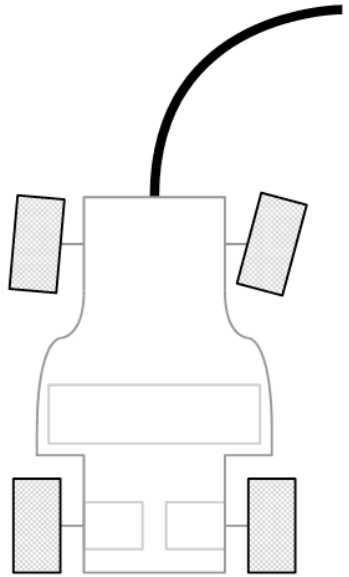
- Inward turning force from wheels
- Applies torque, rolling to outer side of turn
- Increases pressure on outer wheel
- Decreases pressure on inner wheel

So total grip reduced - how to fix?



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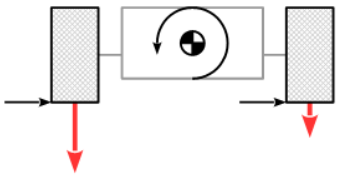

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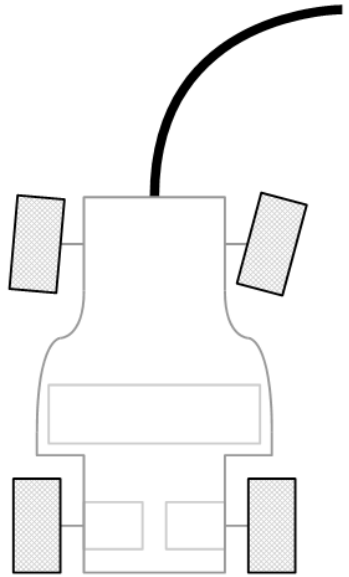
So total grip reduced - how to fix?

- Note lever effect of turning force
- Shorten lever to reduce torque



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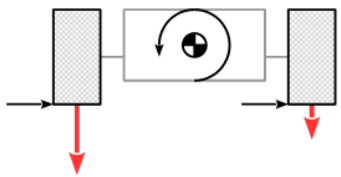


weight transfer

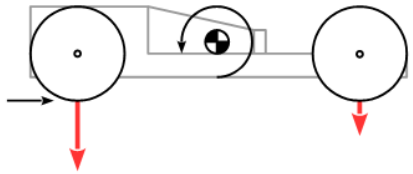
Longitudal Weight Transfer

What happens to my effective weight distribution when accelerating?

Longitudal Weight Transfer

What happens to my effective weight distribution when accelerating?

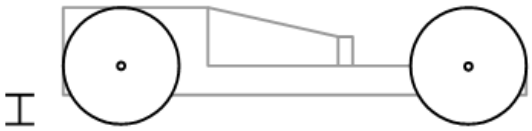
- Acceleration force produced at rear wheel
- Applies torque pitching up
- Increases traction on motor wheels
- Decreases grip on steering wheels



Tuning Ride Height

Ride height: distance between track surface to underside of chassis

We know lower center-of-gravity minimizes weight transfer. What are the limits?



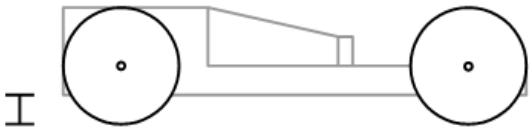
ride height

Tuning Ride Height

Ride height: distance between track surface to underside of chassis

We know lower center-of-gravity minimizes weight transfer. What are the limits?

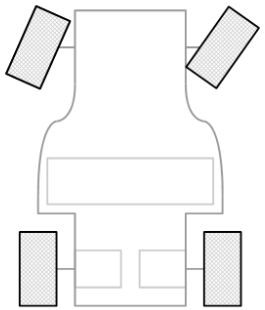
- Need to clear uneven surfaces
  - Like the courtyard tile gaps
  - Or the Freescale Cup hump
- Don't drag your chassis
  - *you know who you are...*



ride height

Ackermann Steering

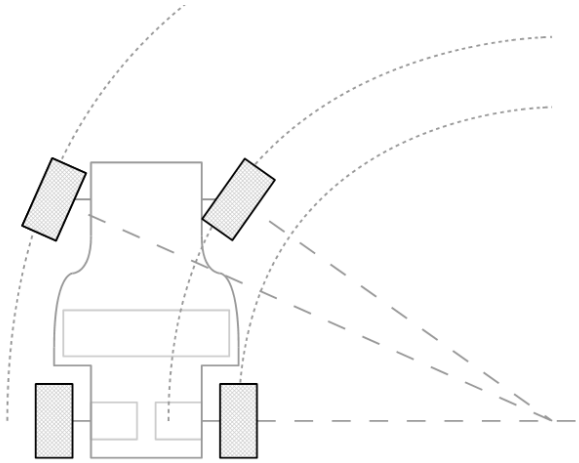
You may have noticed that your wheels aren't parallel when turning. Why?



Ackermann Steering

You may have noticed that your wheels aren't parallel when turning. Why?

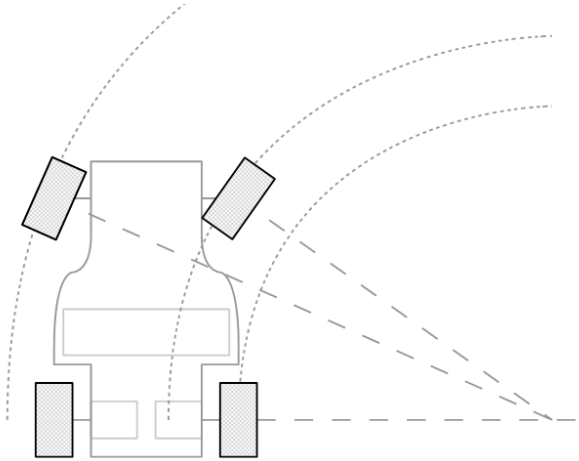
- Different turn radius for inner/outer wheels
- Ackermann steering: angular difference between inner and outer wheels for different turn radius
- A result of the different lengths / angles of steering linkages



Slipping

Given the Ackermann steering geometry...

What happens if the front wheels slip?



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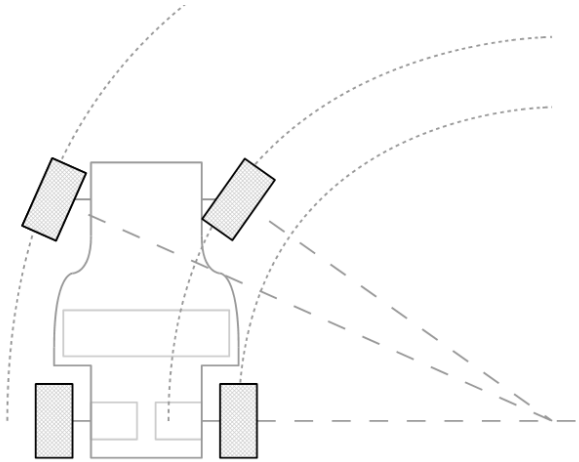

What happens if the front wheels slip?

- Understeer: turns less than intended
- Turning radius increased

What happens if the back wheels slip?

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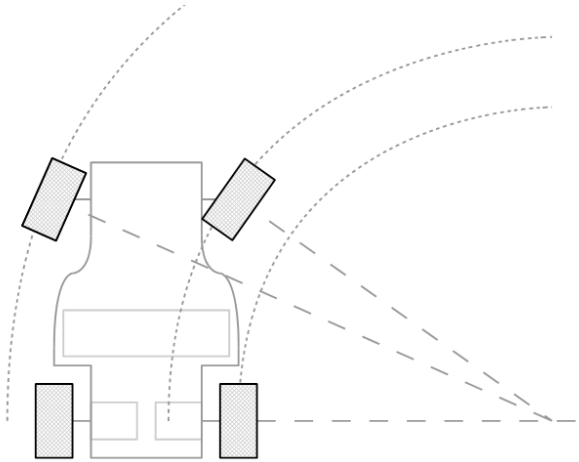

What happens if the front wheels slip?

- Understeer: turns less than intended
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What happens if the back wheels slip?

- Oversteer: turns more than intended
- Turning radius decreased

Benchmarking

Obviously, what matters in the end is measurable performance

So, what are some ways to measure success?

Benchmarking

Obviously, what matters in the end is measurable performance

So, what are some ways to measure success?

- Straight-line acceleration
- Maximum cornering velocity
- Minimum cornering radius

We've typically had less experience with mechanical tuning

- Try to benchmark and measure results
- Have a known-good configuration
  - "The better is the enemy of the good"
- Sensor and control algorithms important

Summary

Summary

- **Demo:** adjusting suspension parameters
- Maximize grip to maximize acceleration to reduce track times
- Tune camber (slightly negative), caster (slightly positive), toe
- Lower center of gravity: minimize weight transfer
- Measure, measure, measure

- Many topics not covered: tires, springs, shocks, sprung roll

(Possibly) one more discussion section left

- Any topics people want to see?