EECS 192: Mechatronics Design Lab

Discussion 12: AGC & Mechanical Tuning

GSI: Justin Yim

15 & 16 Apr 2015 (Week 12)

- Vehicle Dynamics
- Suspension Tuning

Vehicle Dynamics

Goals

What's the ultimate goal here?

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- Reduce race time

How do we do that?

what you want

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- Fast cornering - fast through turns
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- Maximize tire grip!

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Simple Friction Model

Let's make some back-of-the-envelope estimates of tire grip and its effects on performance.

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- How can we estimate the coefficient of friction?

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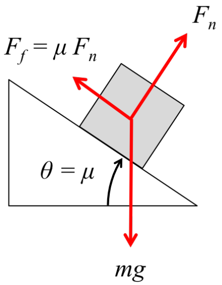
- Simple friction model $F_f = \mu F_n$
- How can we estimate the coefficient of friction?
- Put your car on a ramp, tip until it slides. Do this! Measure the angle!



Linear acceleration

Back-of-the-envelope linear acceleration

- Car model: point mass m on a straight track of length d in gravity g
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- If the car starts and ends at rest, what is the shortest time to drive d? Discuss with your team mates or a partner.

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  - Depends on tire grip!

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- 1) What is its maximum acceleration?
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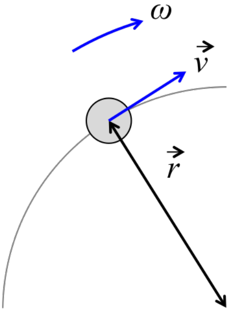
- 2) How can we express the time in terms of a and d?
  - $\frac{d}{2} = \frac{1}{2}a(\frac{t}{2})^2$
    $t = 2\sqrt{\frac{d}{\mu g}}$

Cornering

Now let's look at a simple model for cornering

- Car model: point mass m in constant-speed circular motion
- What are the acceleration and force vectors?



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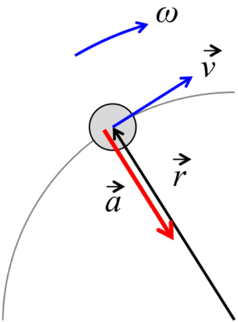

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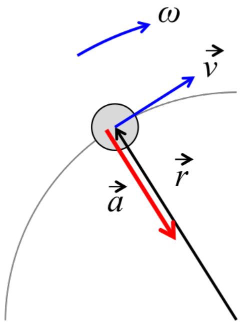

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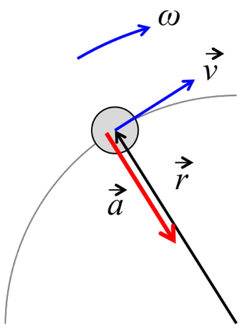

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- $\mu m g = m\frac{v^2}{r}$
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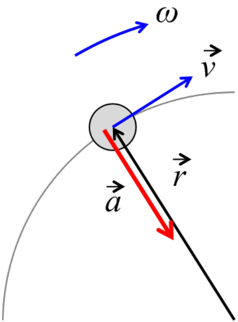
- Simple models aren't perfect, but they're a good start to figure out what's possible.



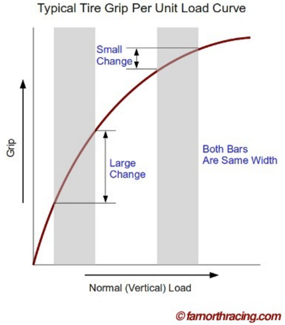
Tire Grip Curves

Now let's look at more detailed models:

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 from (link)

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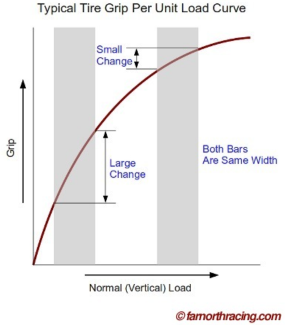
- Don't trade a loss of larger amount of grip for a gain of smaller amount of grip



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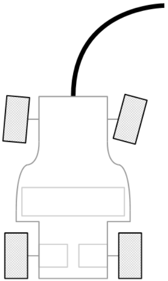
Lateral Weight Transfer

And a more detailed car model with four wheels:

What happens to my effective weight distribution when turning?

assume stiff suspension for simplicity

analysis with springs much more involved



direction of travel

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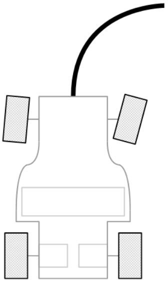
So total grip reduced - how to fix?



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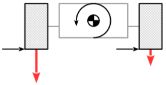

weight transfer

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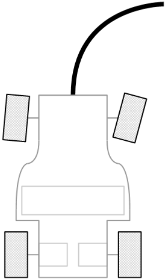
So total grip reduced - how to fix?

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



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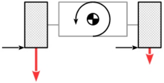


weight transfer

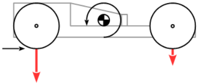
Longitudal Weight Transfer

What happens to my effective weight distribution when accelerating?

Longitudal Weight Transfer

What happens to my effective weight distribution when accelerating?

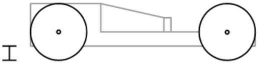
- Acceleration force produced at rear wheel
- Applies torque pitching up
- Increases traction on rear wheels
- Decreases grip on steering wheels



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

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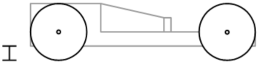


ride height

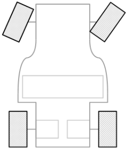
We know lower center-of-gravity minimizes weight transfer. What are the limits?

- Need to clear uneven surfaces
- Don't drag your chassis

Ackermann Steering

Let's look more closely at your car's steering.

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



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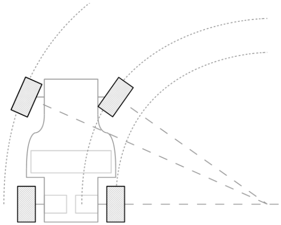
You may have noticed that your wheels aren't parallel when turning. Why?

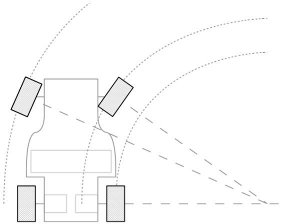
- Different turn radius for inner/outer wheels: it's equivalent to two bicycle steering models glued side-by-side.
- Ackermann steering: angular difference between inner and outer wheels for different turn radius
- A result of the different lengths / angles of steering linkages



Slipping

Given the Ackermann steering geometry...

What happens if the front wheels slip?



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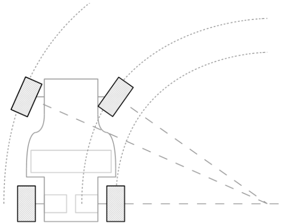
What happens if the front wheels slip?

- Understeer: turns less than intended
- Turning radius increased

What happens if the back wheels slip?



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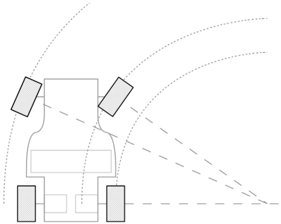

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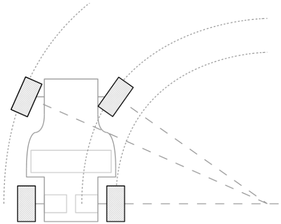

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What sensors might you use to tell the car is slipping? Sideways? Accelerating/braking?

Suspension Tuning

Make sure your electronic hardware is working first.
This suspension tuning is icing on the cake in comparison.

Disclaimer

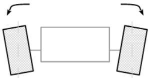
- Justin's research is with legs, not wheels
  - I've tuned exactly zero cars
- These slides were made in a previous year with information from various Internet sources, which hopefully is correct
  - (it passes the "smell test")
- If it sounds wrong, it might really be...

not actually *that* bad

Camber

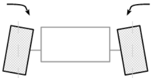
Camber: angle between wheel and vertical (from front)

- Positive if tilting outwards
- Negative if tilting inwards



positive camber

What's optimal to maximize contact area?



negative camber

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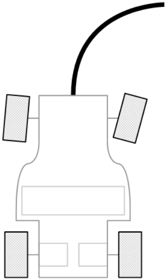
What's optimal to maximize contact area?

- 0 degree, ideally

But need to account for turning chassis roll



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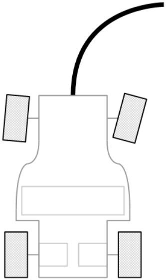
- So slightly negative camber (-1°to -4°) to increase traction when cornering



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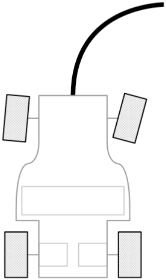
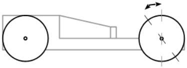


camber effects from turning

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

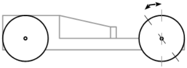
Caster: angle between steering axis and vertical

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

What are the stability effects of positive caster?

think shopping cart "caster" wheels

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



caster

self-centering effect

Toe

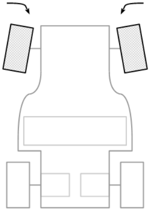
Toe: angle between wheels, viewed from top

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

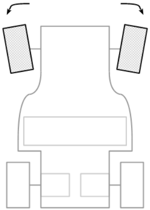
Effects of toe:

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

Why might toe be bad?



toe-in



toe-out

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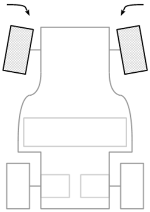
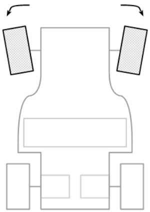
Why might toe be bad?

- Wheels rub against road - reduces tire life



toe-in



toe-out

Benchmarking

Obviously, what matters in the end is measurable performance

So, what are some ways to measure success?

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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

- 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?