# The Influence of Roll and Weight Transfer on Vehicle Handling

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# Motivation

- Design decisions related to vehicle roll directly influence the stability of the vehicle at the limits
- (If you get it wrong, you will probably end up sliding off of the road)

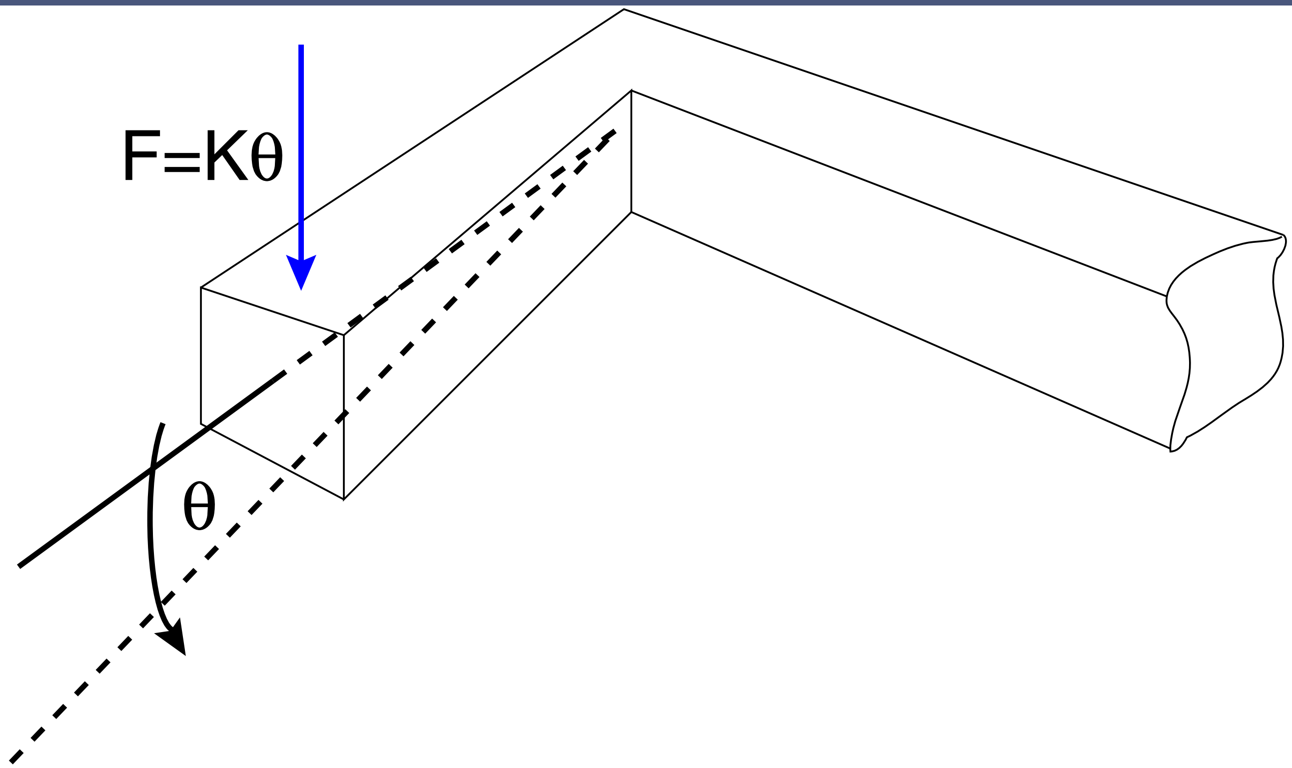
# Goal of this Talk

- Introduce useful models for understanding vehicle roll behavior.
  - All models are wrong, some are useful
  - Primarily static model insights today

# Overview

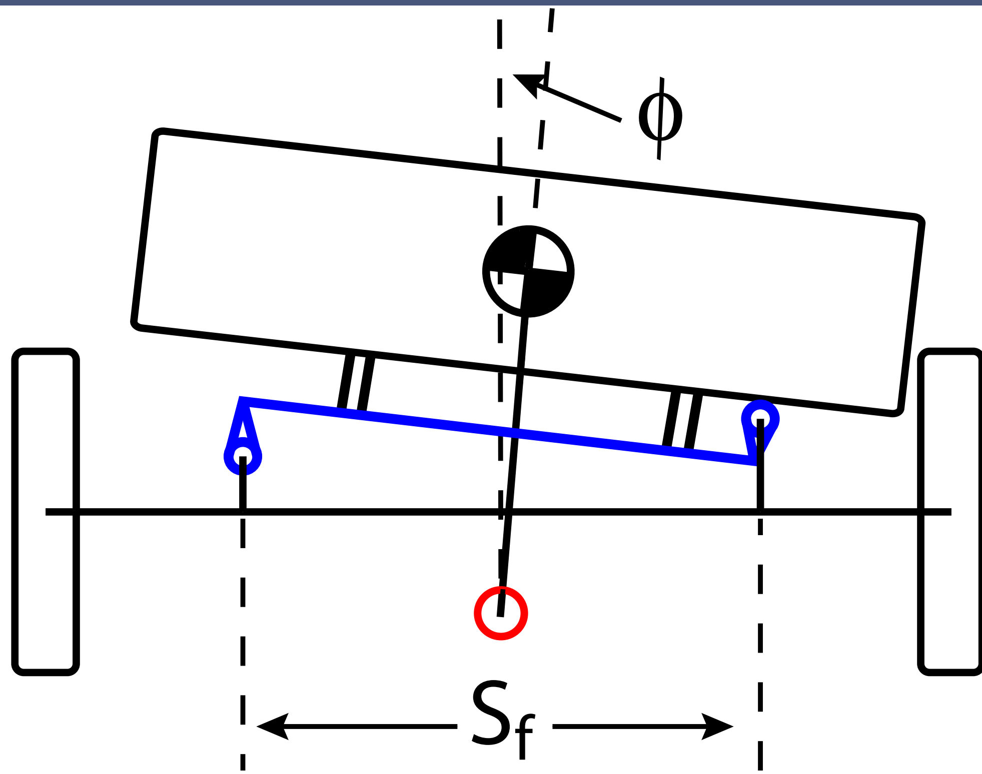
- What is a sway bar (stabilizer bar) ?
- Simple models of vehicle roll and assumptions
- Review approach
- Work through the dynamics and algebra of roll
- Interpret the mathematical results
- Summarize key points covered

# Stabilizer Bars



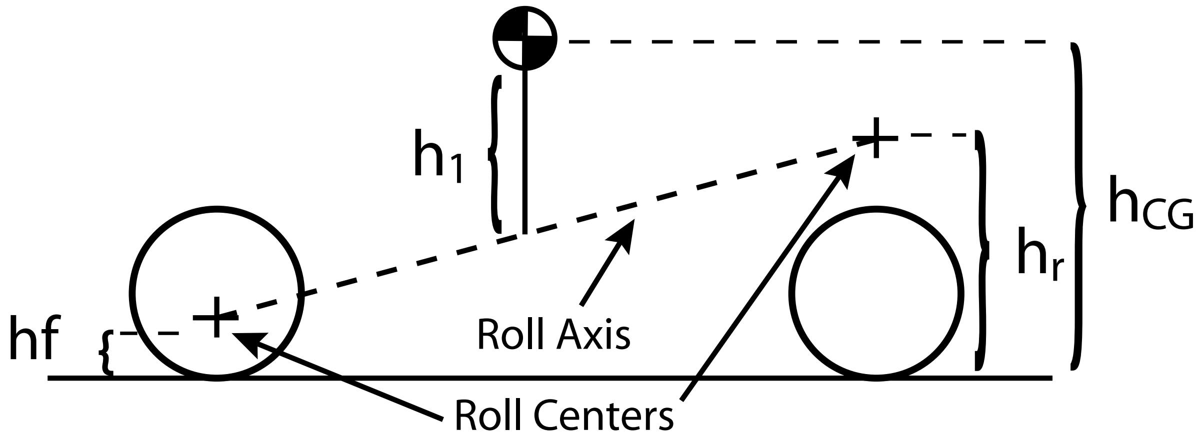

- Essentially roll bars are torsional springs

# Stabilizer Bars II



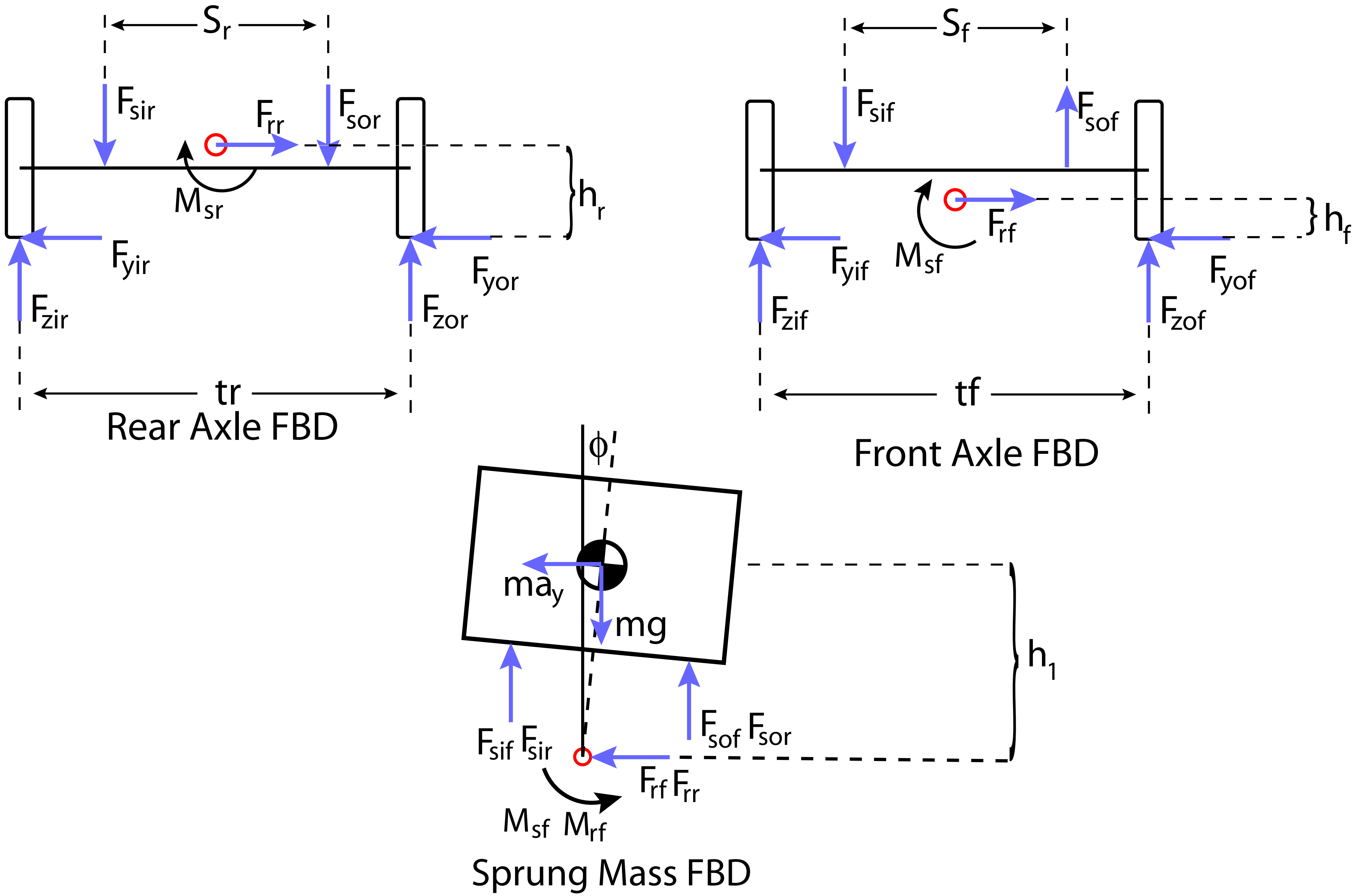

- Stabilizer bars attach to the suspension and chassis and provide forces through torsion

# Modeling Roll




- The roll axis connects the front and rear roll centers
- For small angles, this is not a bad assumption

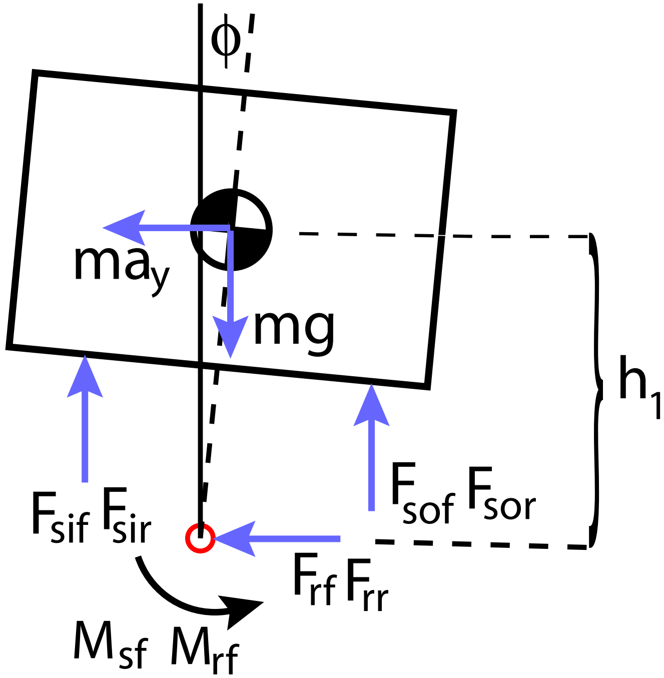
# Modeling Roll II



# Approach

- Solve for the roll angle in terms of lateral acceleration
- Solve for the weight transfer on each axle
- Interpret the effect of this weight transfer on handling
- Discuss how springs and roll bars are used to tune vehicle behavior

# Sum the moments about the roll center




Sprung Mass FBD

$$\begin{aligned}\Sigma M &= mgh_1 \sin(\phi) + (F_{sif} - F_{sof})\frac{S_f}{2}\cos(\phi) \\ &+ (F_{sir} - F_{sor})\frac{S_r}{2}\cos(\phi) - (M_{sf} + M_{sr}) \\ &= -ma_y h_1 \cos(\phi)\end{aligned}$$

# What are typical roll angles?

- Some very loose guidelines

| $RollRate$ | Application |
|---|---|
| $1-5$ | Race Cars |
| $3-4$ | Sports Cars |
| 5 | Sport Sedan |
| 7 | Pretty soft |
| 8 | Late 60's early 70's |

- Even in the extreme, the roll angles are small in the sense of linearization

# Assume Small Roll Angle

- Once again,

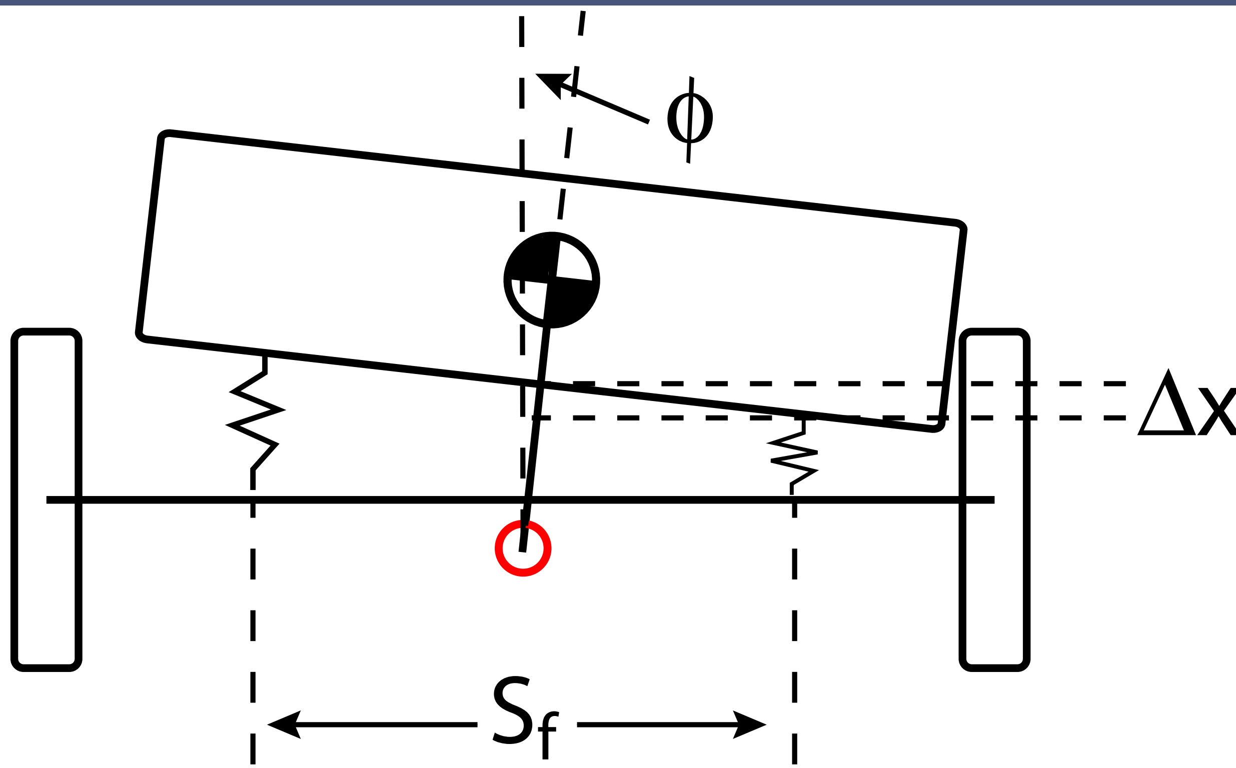
$$\begin{aligned}\Sigma M &= mgh1\sin(\phi) + (F_{sif} - F_{sof})\frac{S_f}{2}\cos(\phi) \\ &+ (F_{sir} - Fsor)\frac{S_r}{2}\cos(\phi) - (M_{sf} + M_{sr}) \\ &= -ma_y h_1\cos(\phi)\end{aligned}$$

- Assume small roll angle,

$$-ma_y h_1 = mgh_1\phi + (F_{sif} - F_{sof})\frac{S_f}{2} + (F_{sir} - F_{sor})\frac{S_r}{2} - (M_{sf} + M_{sr})$$

- The inside and outside forces may be written in terms of the roll angle

# Spring forces




$$F_{sof} = F_{sfs} + K_{sf}\Delta x$$

# Spring forces

- For the front and rear

$$
\begin{aligned}
F_{sof} &= F_{sfs} + K_{sf}\Delta x \\
&= F_{sfs} + \frac{1}{2}K_{sf}S_f\phi \\
F_{sif} &= F_{sfs} - \frac{1}{2}K_{sf}S_f\phi \\
&\Rightarrow \\
\frac{1}{2}\left(F_{sof} - F_{sif}\right)S_f &= \frac{1}{2}\left(2\frac{1}{2}K_{sf}S_f\phi\right)S_f \\
&= \frac{1}{2}K_{sf}S_f^2\phi \\
\frac{1}{2}\left(F_{sor} - F_{sir}\right)S_f &= \frac{1}{2}K_{sr}S_f^2\phi
\end{aligned}
$$

# Stabilizer Bar Forces

- Stabilizer bars may be modeled as torsional springs
  - Remember that the vehicle body is rigid. The roll angle, $\phi$, is the same front and rear

$$M_{sf} = K_{stabf}\phi$$
$$M_{sr} = K_{stabr}\phi$$

- You will visit this assumption again in a future lab (it is a good one)

# Roll Moment Equation

- From before,

$$-ma_y h_1 = mgh_1\phi + (F_{sif} - F_{sof})\frac{S_f}{2} + (F_{sir} - F_{sor})\frac{S_r}{2} - (M_{sf} + M_{sr})$$

- Now,

$$\begin{aligned} -ma_y h_1 &= mg\phi - \left(K_{stabf} + \frac{1}{2}K_{sf}S_f^2\right)\phi - \left(K_{stabr} + \frac{1}{2}K_{sr}S_r^2\right)\phi \\ &\Rightarrow \\ ma_y h_1 &= \left(K_{\phi f} + K_{\phi r} - mgh_1\right)\phi \\ &= \left(K_\phi - mgh_1\right)\phi \end{aligned}$$

# Solving for Roll Angle

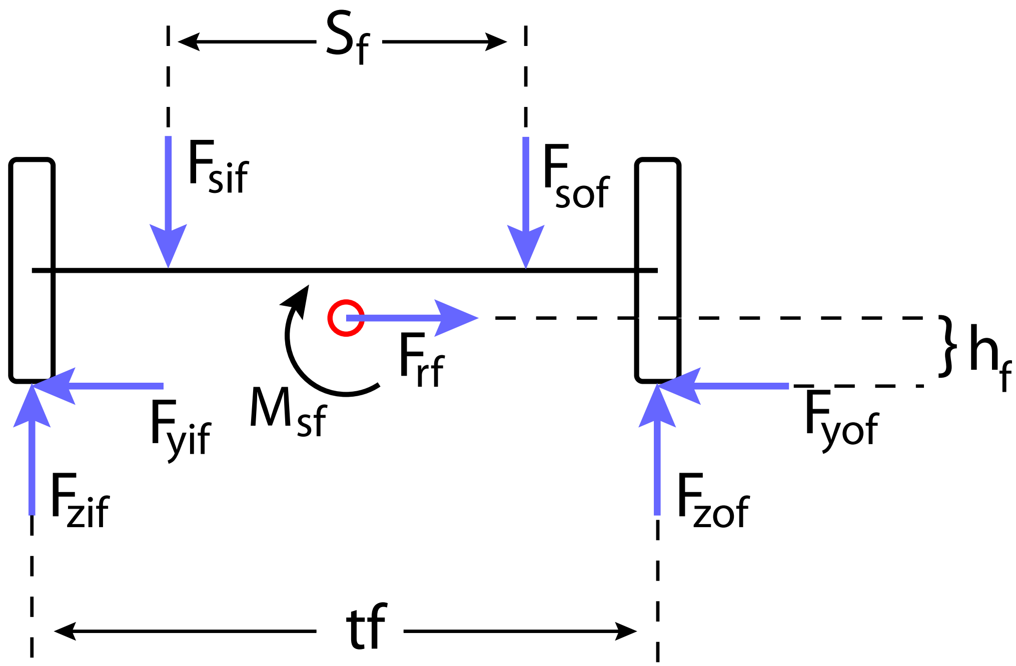
- The roll angle depends upon stiffnesses, mass and lateral acceleration

$$
\begin{aligned}
m a_y h_1 &= \left(K_\phi - m g h_1\right)\phi \\
&\Rightarrow \\
\phi &= \frac{m h_1}{K_\phi - m g h_1} a_y
\end{aligned}
$$

- In other notation

$$
\phi = \frac{w h_1}{K_\phi - w h_1}\left(\frac{V^2}{Rg}\right)
$$

# Weight Transfer




Front Axle FBD

- Now that we have the roll angle, we can figure out the weight transfer terms on the axle diagrams

# Weight Transfer II

- Sum the moments about the front roll center

$$\Sigma M = M_{sf} + \frac{S_f}{2}F_{sof} - \frac{S_f}{2}F_{sif} + \frac{tf}{2}F_{zif} - \frac{tf}{2}F_{xof} + h_f F_{yif} + h_f F_{yo}$$

$$\Rightarrow$$

$$K_{\phi f}\phi - t_f\left(\frac{1}{2}\left(F_{zof} - F_{zif}\right)\right) + h_f \frac{w_f}{g} a_y = 0$$

$$\Rightarrow$$

$$K_{\phi f}\phi - t_f\left(\Delta F_{zf}\right) + h_f \frac{w_f}{g} a_y = 0$$

$$\Rightarrow$$

$$\Delta F_{zf} = \frac{1}{t_f}\left(K_{\phi f}\phi + h_f \frac{w_f}{g} a_y\right), \text{ and similarly for the rear}$$

$$\Delta F_{zr} = \frac{1}{t_r}\left(K_{\phi r}\phi + h_r \frac{w_r}{g} a_y\right)$$

# Weight Transfer III

- Now plug in our expression for $\phi$ to savor the meaning of all of this math.

$$\begin{aligned}\Delta F_{zf} &= \frac{1}{t_f}\left(K_{\phi f}\phi + h_f \frac{w_f}{g} a_y\right) \\ &= \frac{1}{t_f}\left(K_{\phi f}\frac{h_1}{K_{\phi f} + K_{\phi r} - mgh_1} + h_f\right) m a_y\end{aligned}$$

- Remember the expression for roll angle is

$$\phi = \frac{mh_1}{K_{\phi f} + K_{\phi r} - mgh_1} a_y$$

# What happens when when $K_\phi$ increases?

- If $K_\phi$ increases, then for the same lateral acceleration the roll angle will be smaller.
- If the roll angle decreases, then $\Delta F_{zf}$ decreases, ie, the weight transfer is less.
- Race cars are often tuned to minimize load transfer (load transfer affects peak side force, more on that later.)

# What happens when when $K_{\phi f}$ increases?

- Is $\Delta F_{zf}$ with $K_{\phi f}$ scaled by $(a > 1) > \Delta F_{zf}$

$$\frac{1}{t_f}\left(aK_{\phi f}\frac{h_1}{aK_{\phi f} + K_{\phi r} - mgh_1} + h_f\right) ma_y \qquad (>?)$$

$$\frac{1}{t_f}\left(K_{\phi f}\frac{h_1}{K_{\phi f} + K_{\phi r} - mgh_1} + h_f\right) ma_y$$

$$\frac{a}{aK_{\phi f} + K_{\phi r} - mgh_1} (>?) \frac{1}{K_{\phi f} + K_{\phi r} - mgh1}$$

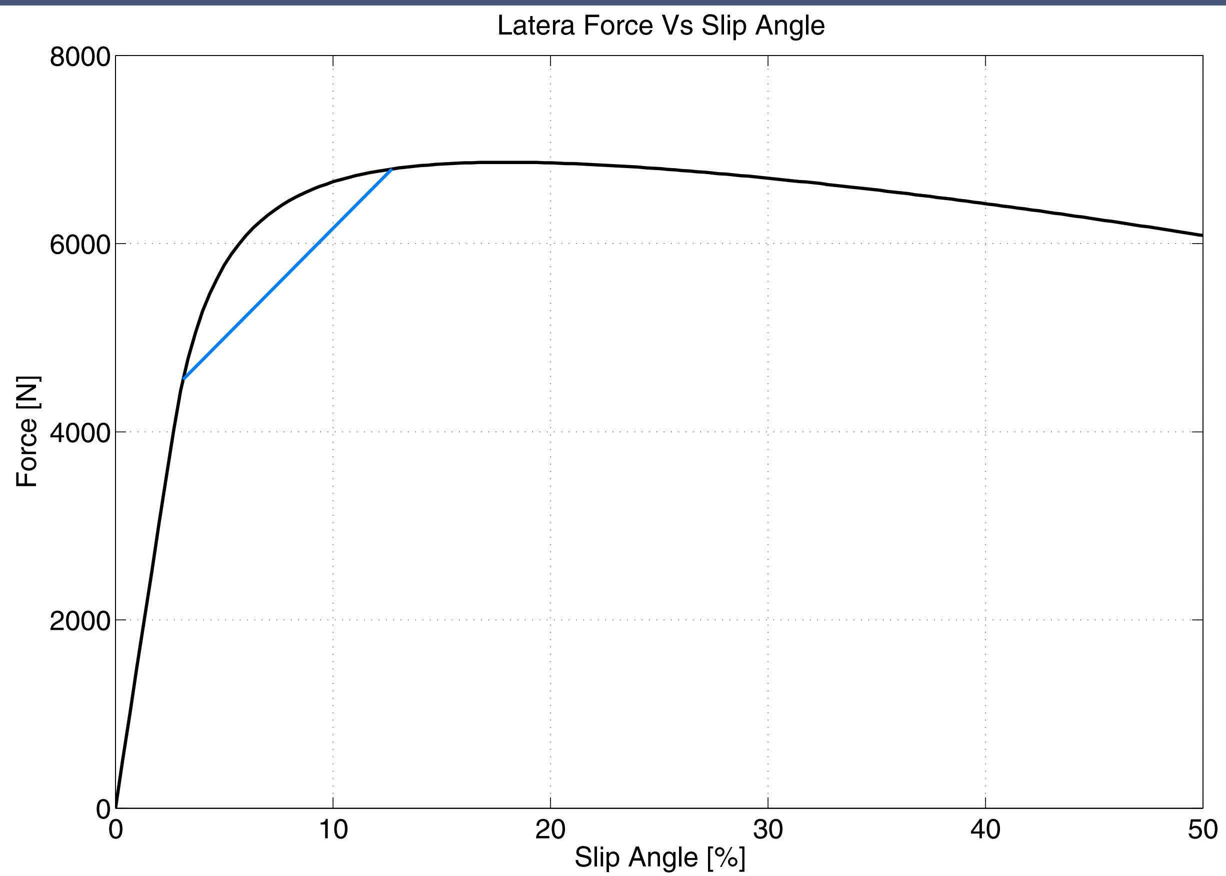
$$a(K_{\phi r} - mgh1)(>?)(K_{\phi r} - mgh_1)$$

- $\Delta F_{zf}$ increases, and $\Delta F_{zr}$ decreases

# The major points

- Increasing the roll stiffness on both the front and rear axles decreases weight transfer
- Increasing roll stiffness on only one axle increases the load transfer on that axle and decreases it on the other
- This load transfer stuff really is critical for designing cars which behave well at the limits

# Tires




- As you know, tires are nonlinear near the peak of the curve
- Since this curve is concave down, load transfer reduces your peak side forces

# General Design Rules

- Increasing the front roll stiffness will tend to make the vehicle more understeering
  - At the limits it is generally considered safer to understeer rather than oversteer
- Increasing the rear roll stiffness will tend to make the vehicle more oversteering
  - This is ok as long as overall the vehicle is still understeering

# This is just the beginning

- Depending on how the suspension is designed, vehicle roll will often steer the vehicle
- Roll also effects camber which also affects the force-slip curves
- The force-slip curves also depend upon normal load directly...

# Summary

- Simple models show how vehicle roll directly effects limit handling performance
  - Adding roll stiffness to the front tends to makes the vehicle more understeering
  - Adding roll stiffness to the rear tends to make the vehicle more oversteering
  - Increasing roll stiffness in general tends to increase peak attainable side forces

# El fin

Questions ?

# Minute Sheet

- Please take a minute to fill out my Minute Sheet