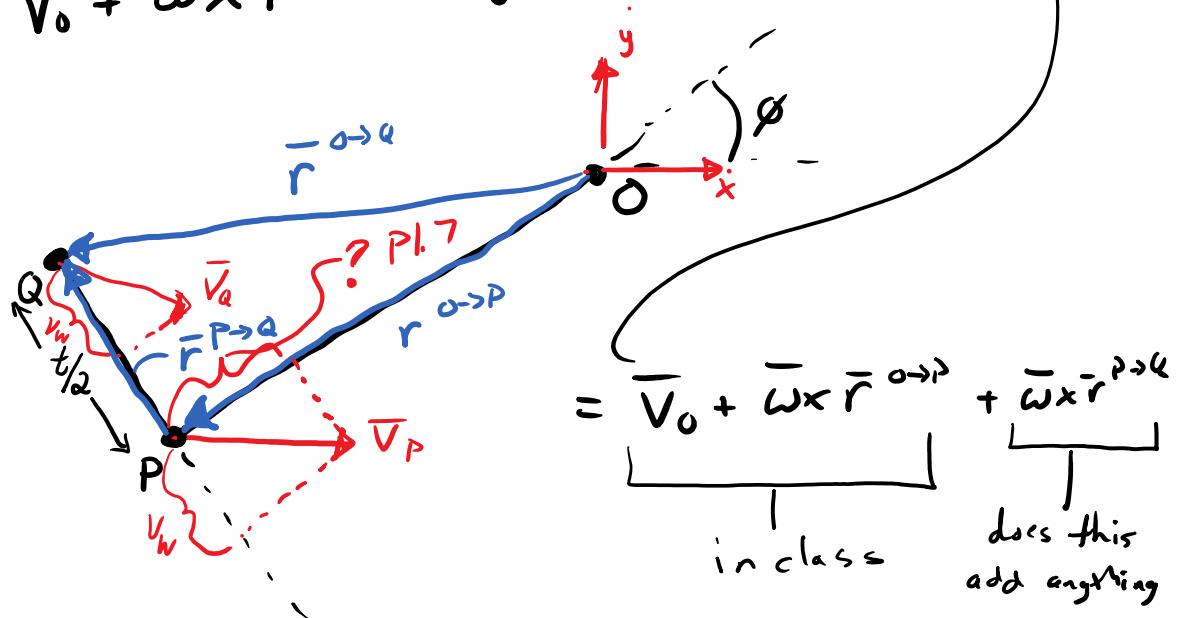


$$\bar{V}_Q = \bar{V}_0 + \bar{\omega} \times \bar{r}^{O \rightarrow Q} = \bar{V}_0 + \bar{\omega} \times (\bar{r}^{O \rightarrow P} + \bar{r}^{P \rightarrow Q})$$



$$= \boxed{\bar{V}_0 + \bar{\omega} \times \bar{r}^{O \rightarrow P}} + \boxed{\bar{\omega} \times \bar{r}^{P \rightarrow Q}}$$

in class does this
 add anything

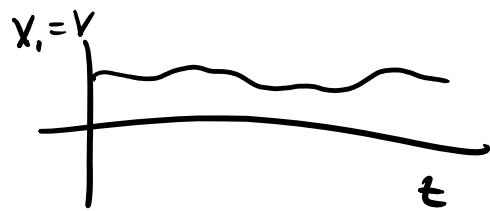
project $\bar{\omega} \times \bar{r}^{P \rightarrow Q}$ onto axle to V_w

$$O \xrightarrow{\bar{r}} P \quad \bar{r}^{O \rightarrow P} \quad \bar{r}^{P \rightarrow Q}$$

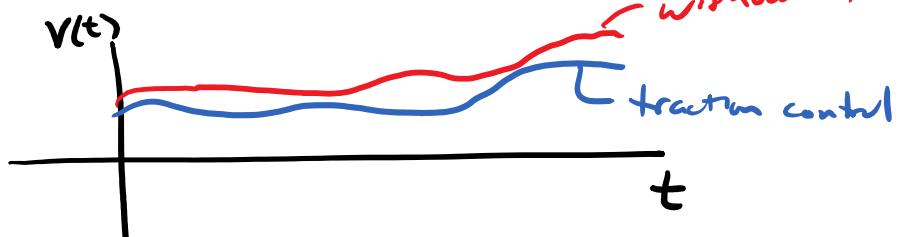
Lab 2 Plots

Time varying variables ?

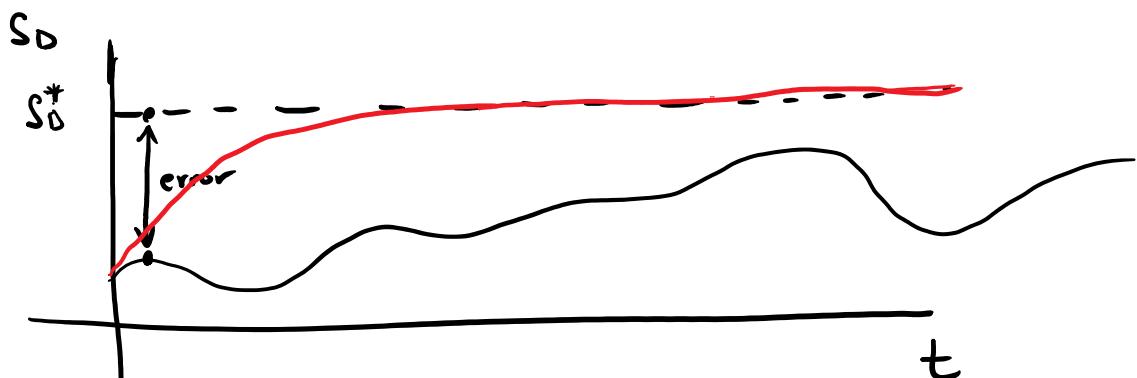
state variables	$x(t)$
input variables	$r(t)$
output variables	$y(t)$



$$y(t) = \bar{f}(x(t), r(t), t, c)$$



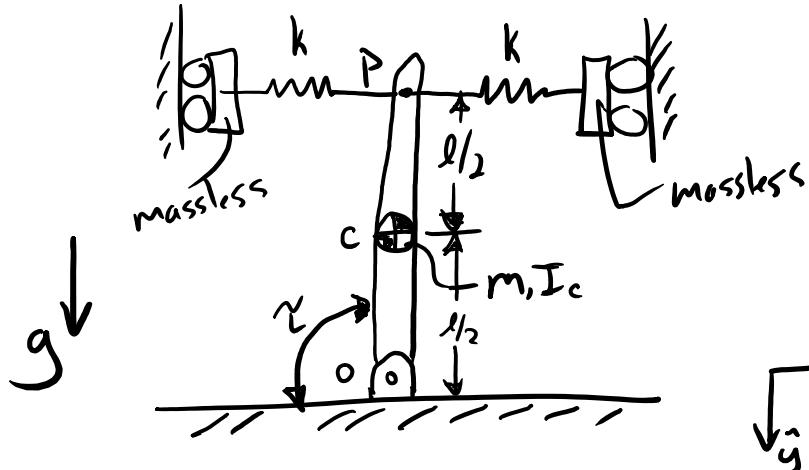
s_D^* : desired slip ratio



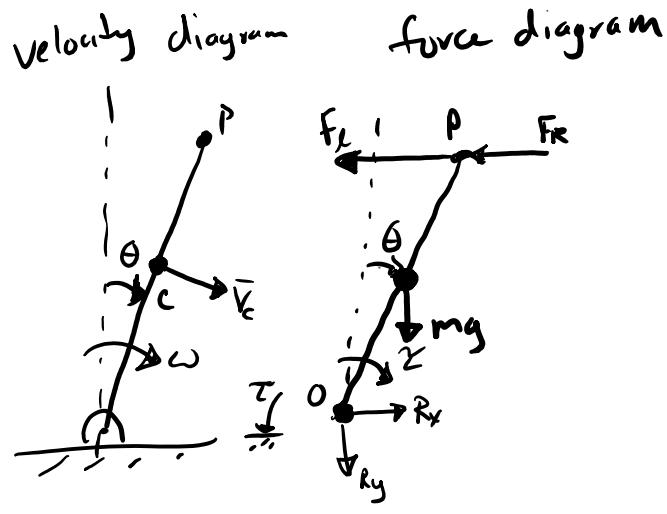
$$s_D^{error} = s_D^* - s_D$$

$$\zeta_D = f(s_D^{error})$$

$$\tau_D = k s_D \overset{\text{error}}{=} k(s_D^* - s_D)$$



velocity diagram



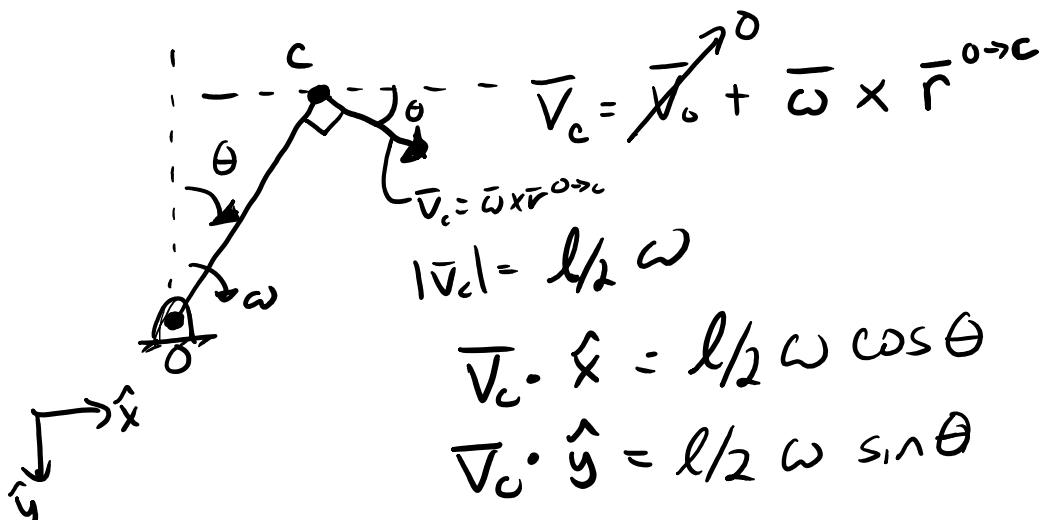
Newton's 2nd Law: velocity of the mass center of every body
+ velocity of every particle

Euler's 2nd Law: angular velocity of every body

Make FBD: ID forces

$$\sum F_x = m \frac{d \bar{V}_c \cdot \hat{x}}{dt} \quad \sum F_y = m \frac{d \bar{V}_c \cdot \hat{y}}{dt}$$

$$\sum \gamma = I_c \frac{d \bar{\omega}}{dt}$$



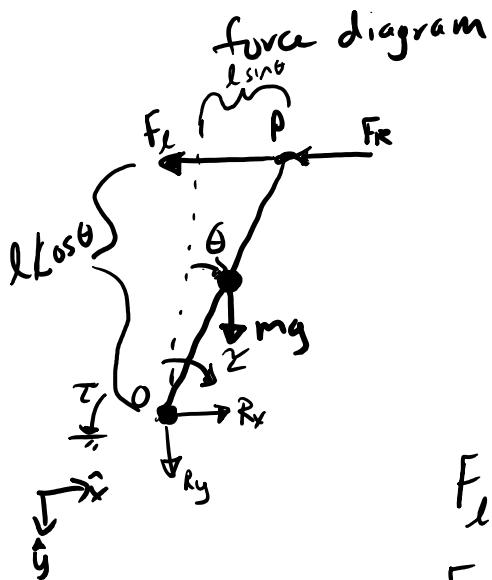
$$\sum F_x = m \frac{d(l/2 \omega \cos \theta)}{dt} = m l/2 \dot{\omega} \cos \theta - m l/2 \omega^2 \sin \theta$$

$$\sum F_x = m \frac{d(l/2 \omega \cos \theta)}{dt} = m l/2 \omega \cos \theta - m l/2 \omega \dot{\theta}$$

$$\sum F_y = m \frac{d(l/2 \omega \sin \theta)}{dt} = m l/2 \dot{\omega} \sin \theta + m l/2 \omega^2 \cos \theta$$

$$\sum \gamma = I_0 \frac{d\bar{\omega}}{dt} = I_0 \ddot{\omega}$$

$$\frac{d \sin(\theta(t))}{dt} = \cos \theta \cdot \dot{\theta} = (\cos \theta) \omega$$



$$\sum F_x = -F_f - F_R + R_x$$

$$\sum F_y = mg + R_y$$

$$\sum \gamma = -(F_f + F_R)l \cos \theta + mg l/2 \sin \theta + \tau$$

$$F_f = k l \sin \theta$$

$$F_R = k l \sin \theta$$

$$\sum F_x = -2k l \sin \theta + R_x = m \frac{l}{2} \dot{\omega} \cos \theta - m \frac{l}{2} \omega^2 \sin \theta$$

$$\sum F_y = mg + R_y = m l/2 \dot{\omega} \sin \theta + m l/2 \omega^2 \cos \theta$$

$$\sum \gamma = -2k l \sin \theta l \omega \dot{\theta} + mg l/2 \sin \theta + \tau = I \ddot{\omega}$$

$$I \ddot{\omega} = \tau - 2k l^2 \sin \theta \cos \theta + mg l/2 \sin \theta$$

$$\dot{\theta} = \omega$$

two
first
order
ODEs

$$I\ddot{\omega} = \gamma - 2kl^2 \sin\theta \cos\theta + mgl/2 \sin\theta$$

$$\dot{\theta} = \omega$$

two
first
order
ODEs

small angles to make linear model

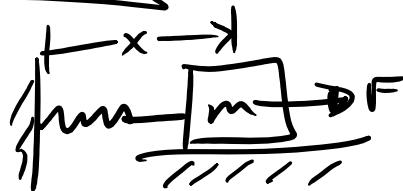
$$I\ddot{\omega} = \gamma - 2kl^2\theta + mgl/2\theta = \gamma + (mgl/2 - 2kl^2)\theta$$

$$\dot{\theta} = \omega$$

linear ODE version

$$I\ddot{\theta} + (2kl^2 - mgl/2)\theta = \gamma$$

$$m\ddot{x} + kx = F$$



if $2kl^2 - mgl/2 < 0 \Rightarrow$ system's unstable

$$2kl^2 < mgl/2$$

$$k < \frac{mg}{4l}$$

unstable system !!