INTRODUCTION TO MECHANICAL DESIGN

Richard Li
Team 1325 Inverse Paradox

ABOUT ME

RICHARD LI

- Honours Mechatronics Engineering 2020, University of Waterloo
- Co-Founder/Mechanical Lead, University of Waterloo Autonomous Sailboat Team
- Design/Controls Mentor, 1325
- Design Consultant/Chief Designer, 1325
- Interests: memes, napping, dressing well, lifting weights, and listening to obscure music
- Fun fact: won the first hackathon I went to

PURPOSE

- Introduce you to physics concepts used by electromechanical engineers
- Develop a basic understanding of DC motor theory and pneumatics
- Show you how you can use physics to solve engineering problems

OVERVIEW

- Static & Dynamic Analysis
- DC Motors
- Pneumatics

DEFINITIONS

- Scalar: a directionless quantity
- Vector: a quantity that has a direction associated with it
- Force: a push or pull (N) (Vector)
- Torque: twisting force (Nm) (Vector)
- Pressure: force per unit area (psi, PA) (Scalar)
- Energy: ability to do work/move things (J) (Scalar)
- Power: energy used per unit of time (W) (Scalar)
- g: $9.8m/s^2$ acceleration due to gravity (vector)

MORE DEFINITIONS

- Displacement: vector change in position
- Velocity: change in displacement over time
- Acceleration: change in velocity over time
- Free-body diagram: a simplified diagram of an object that shows all the external forces acting on it
- Center of Gravity (COG): the point at which the force of gravity can be modelled to apply at

STATIC & DYNAMIC ANALYSIS

NEWTON'S LAWS

1. An object's velocity will not change unless acted upon by an external force

2. An object's acceleration is proportional to the force applied divided by its mass (F=ma)

3. Every action has an equal and opposite reaction

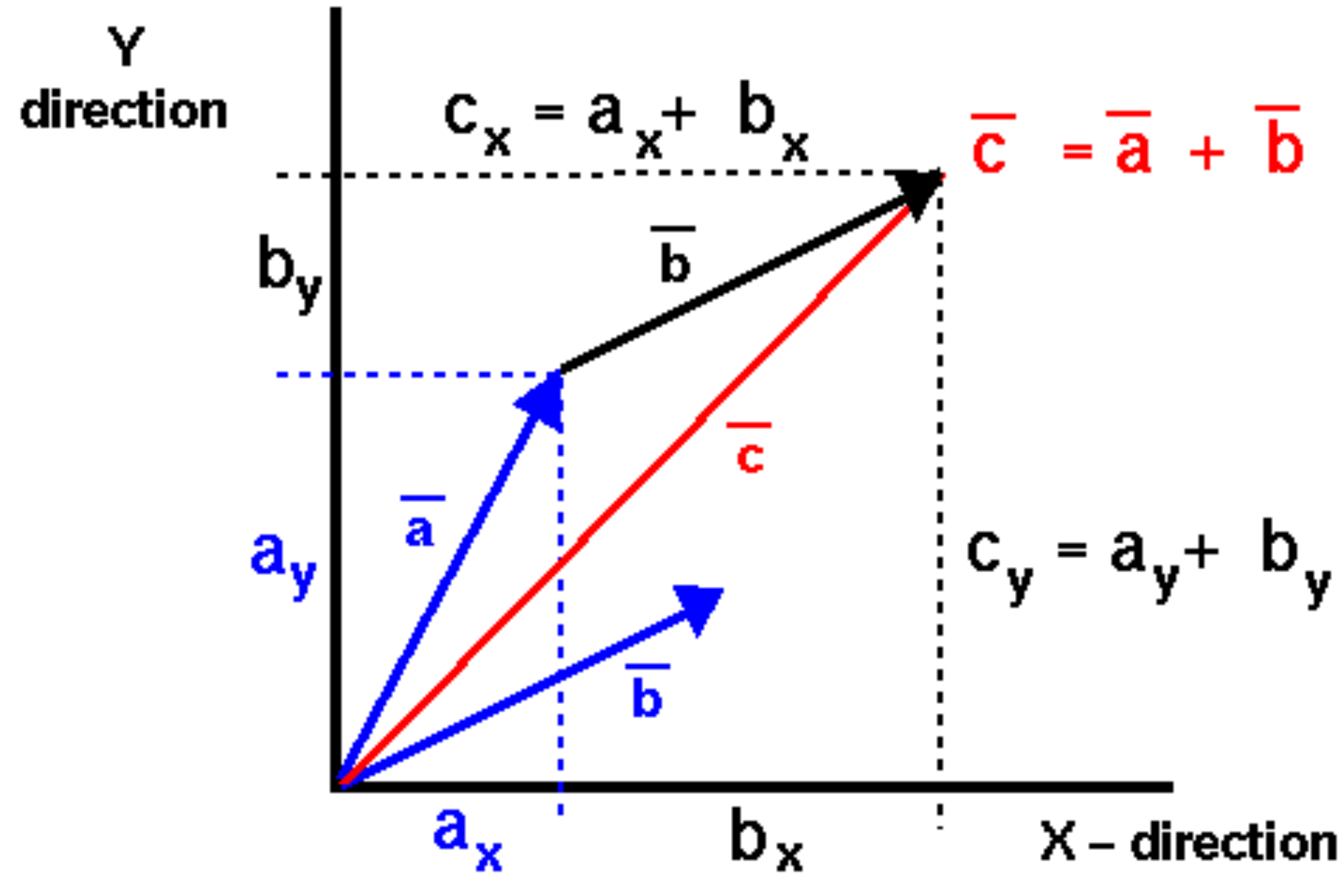
VECTOR ADDITION

- A vector can be expressed as a quantity with a direction (e.g., 10N[SW])
- A vector can also be expressed as a set of components (hooray trigonometry!)
- Vector addition only works if the units work (don't add velocity and force)

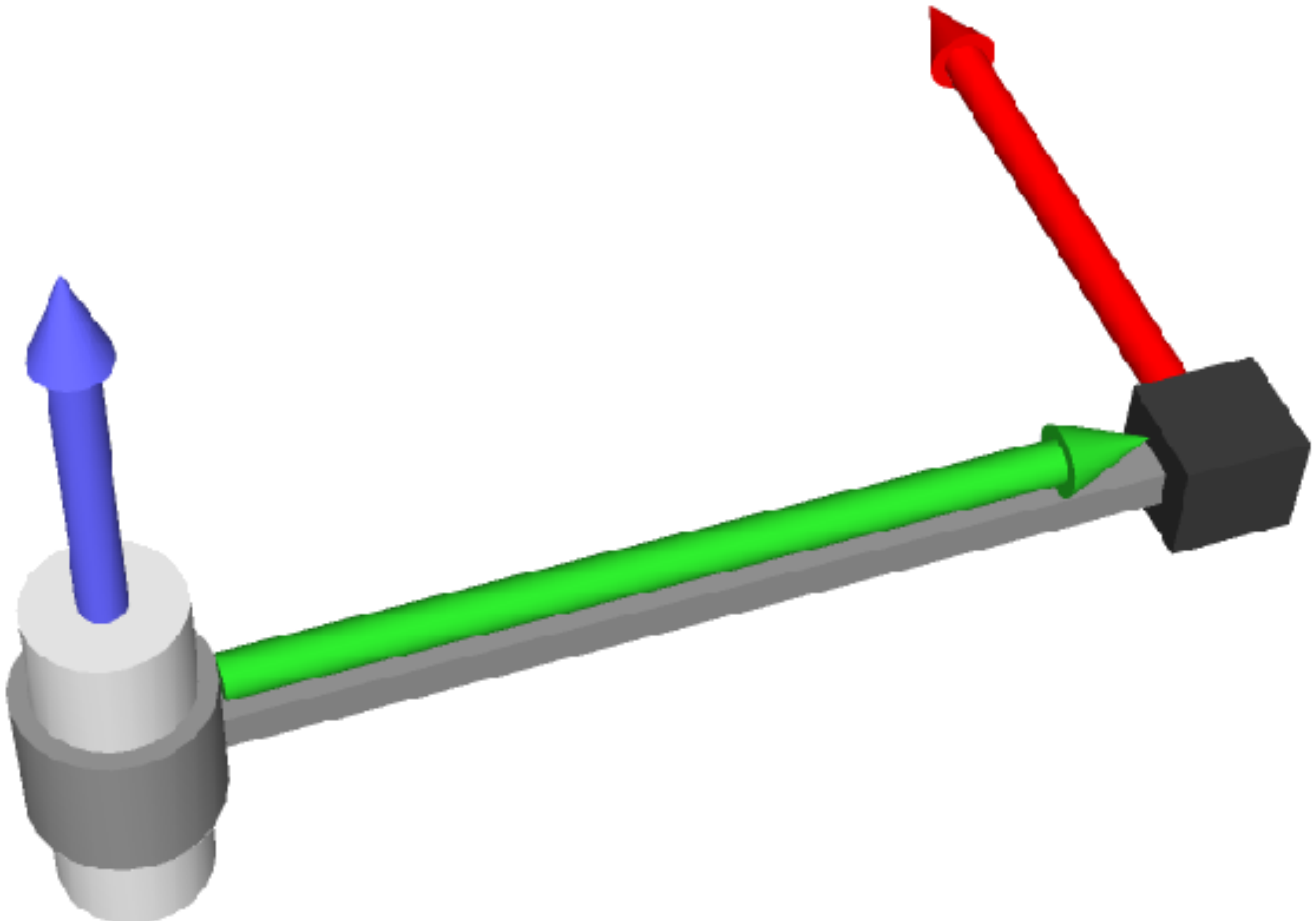
COMPONENTS

A vector quantity has both magnitude and direction.

Add the vector components.



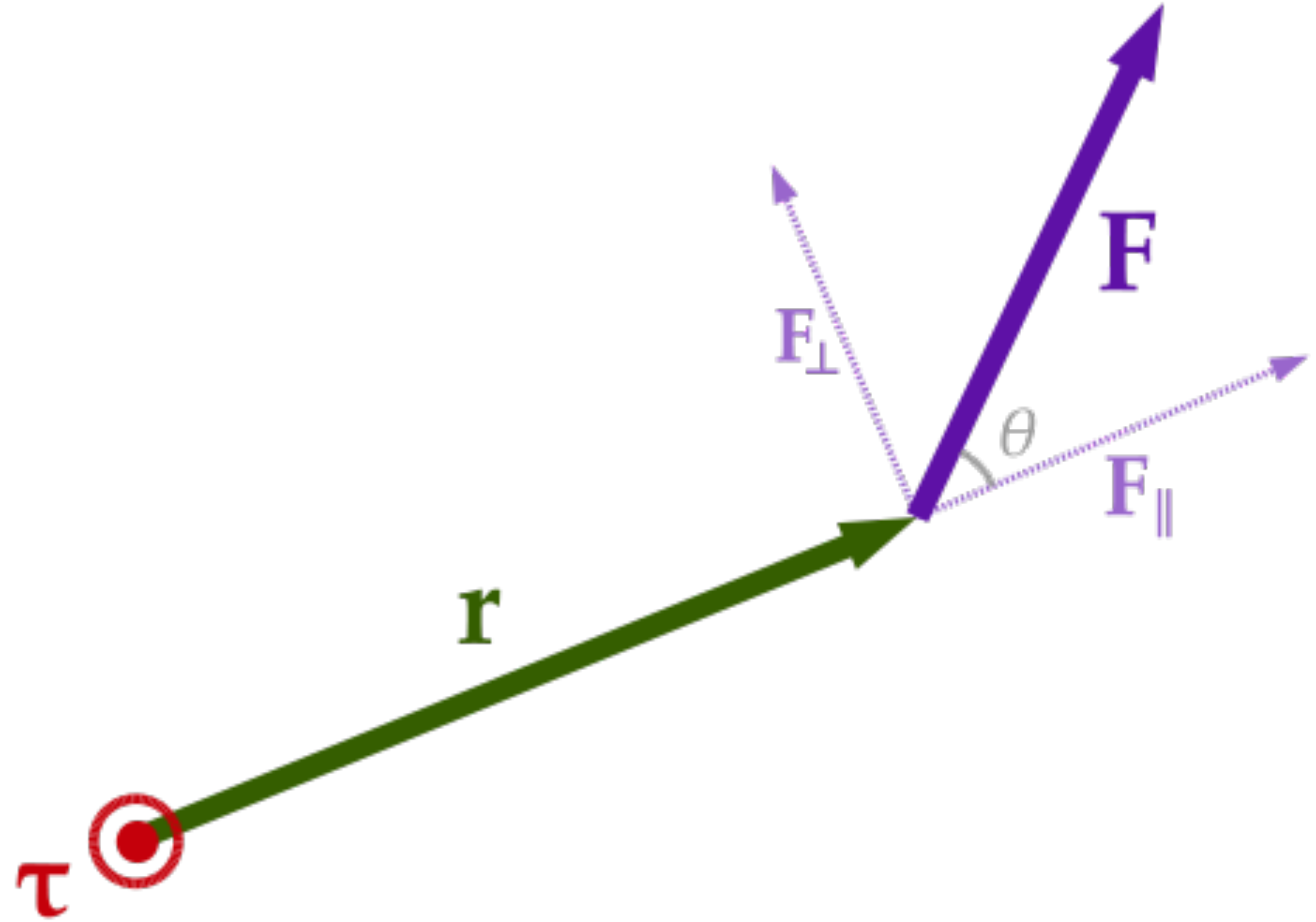
TORQUE/MOMENT



$$\tau = \mathbf{r} \times \mathbf{F}$$

TORQUE/MOMENT

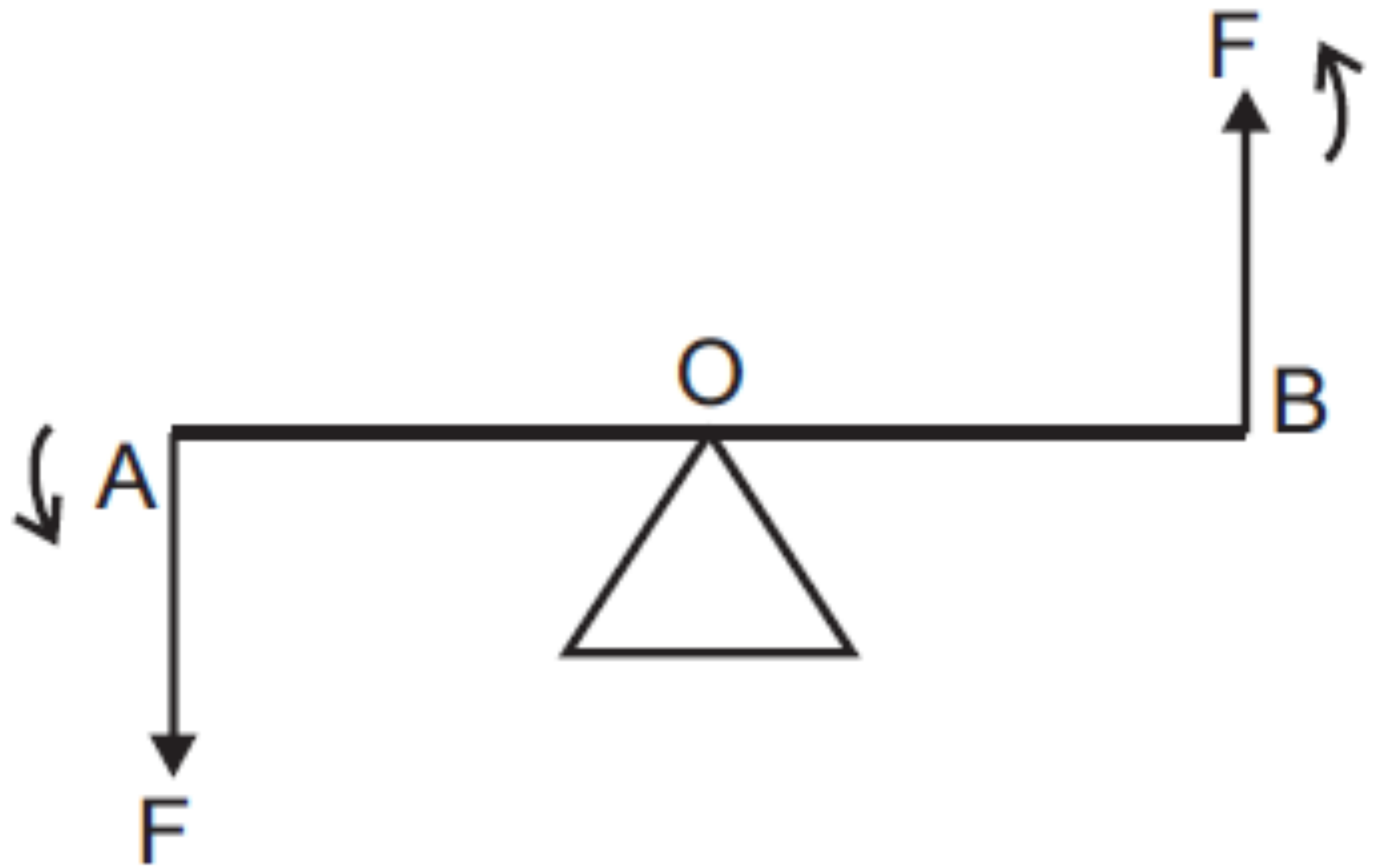
T = F * r * sinθ



STATIC ANALYSIS

- $F_{net} = 0$
- $M_{net} = 0$
- If net force or net moment isn't zero, something will move or spin

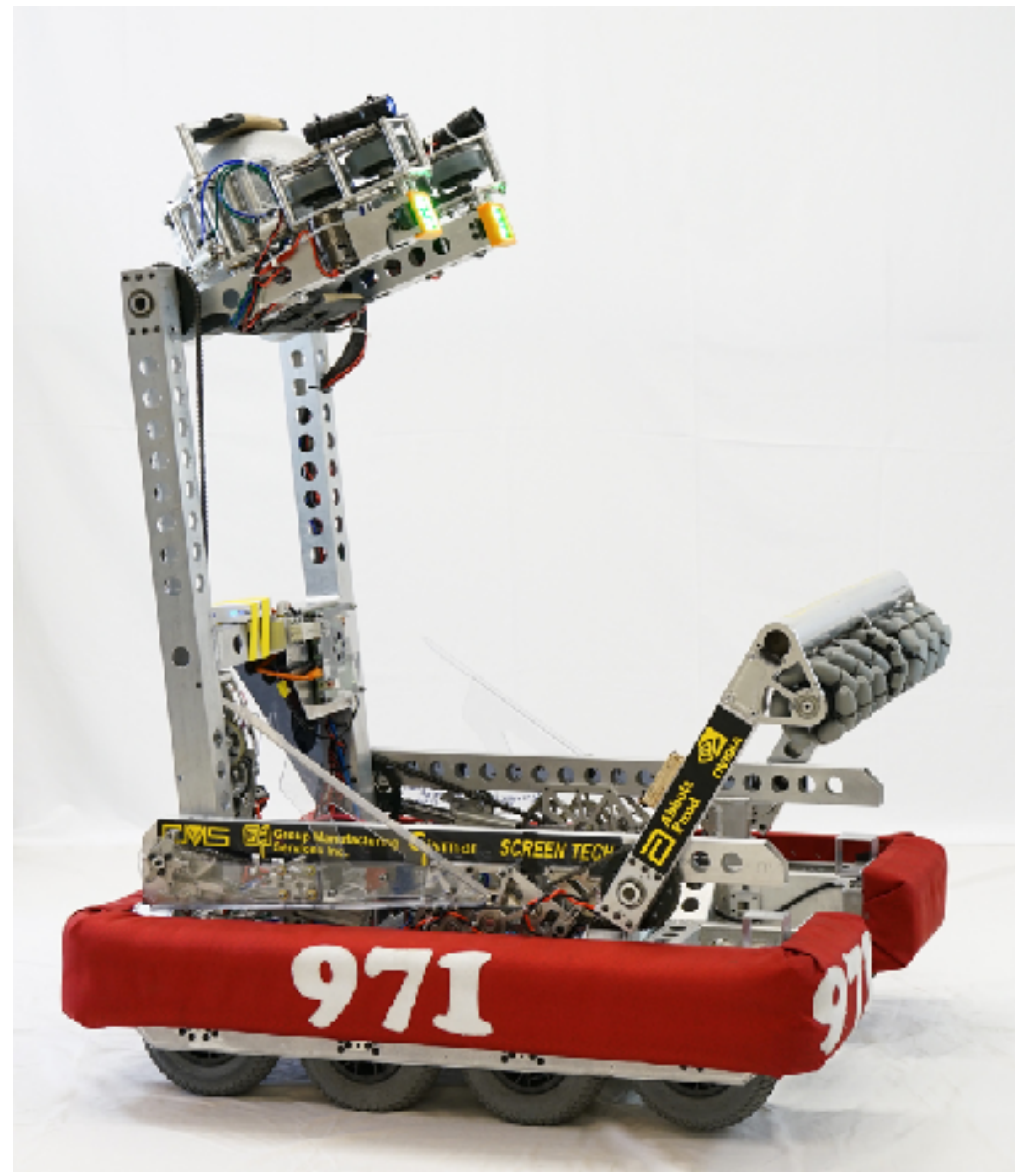
COUPLE MOMENT



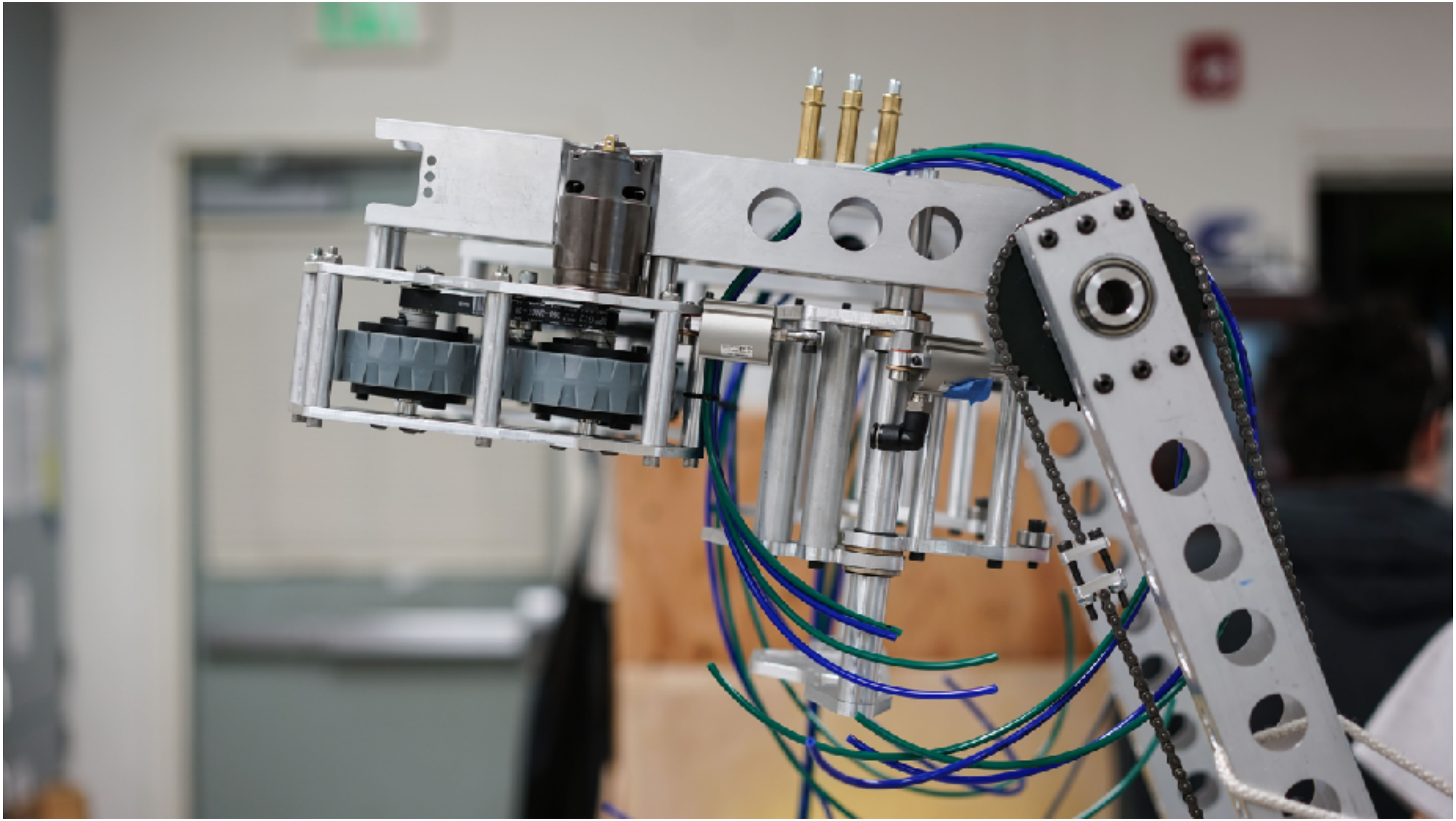
EXAMPLE

ASSUMPTIONS

- Shooter Weighs 15lb (6.8kg)
- Center of gravity is halfway along length
- Shooter is 16 in long (0.4m)
- Assume chain has no tension
- Calculate torque required to hold shooter at 10 degrees from ground
- Calculate force on support axle

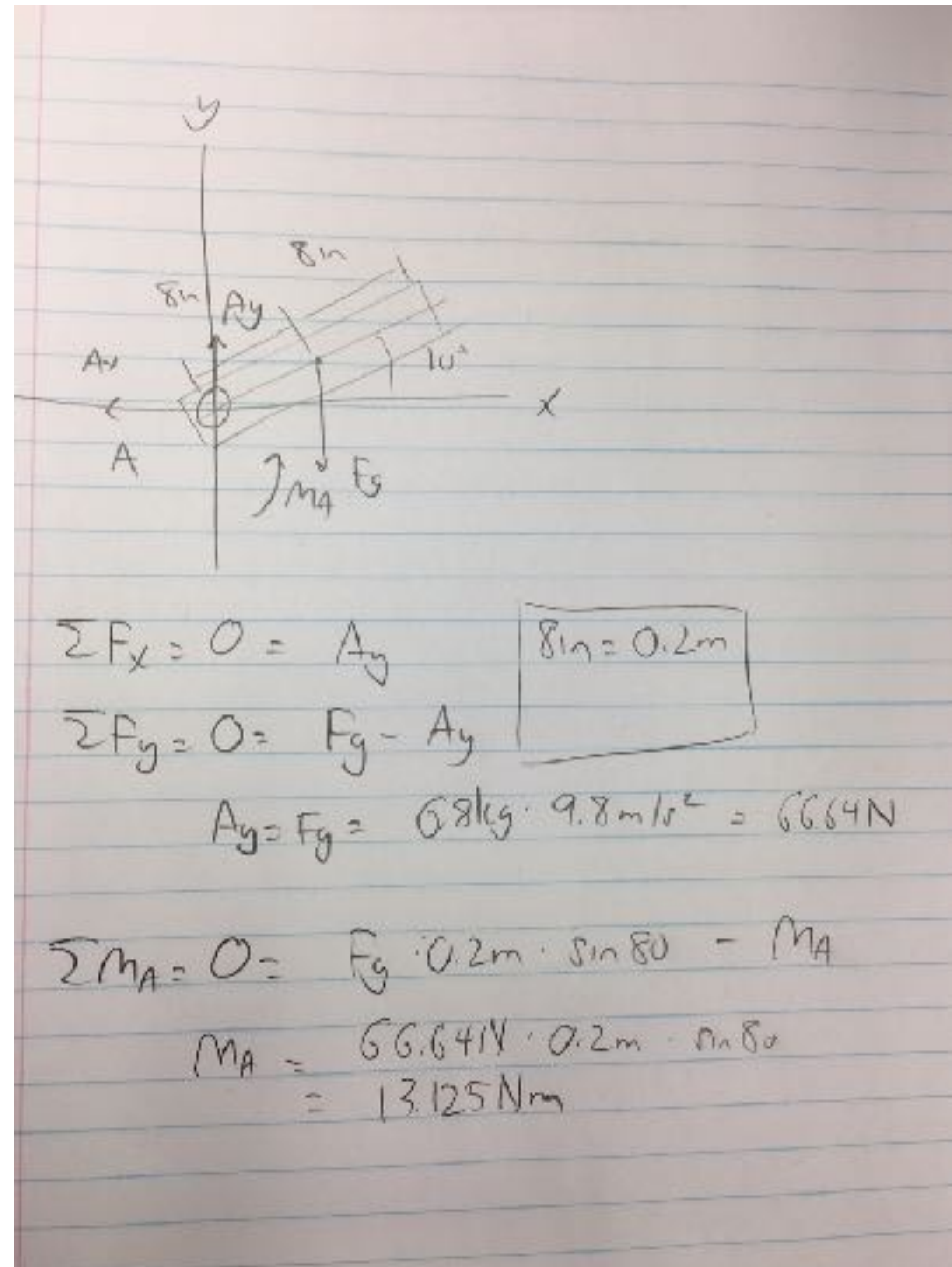


EXAMPLE



STATIC ANALYSIS

1. Draw a free body diagram
2. Write equilibrium equations
3. Solve!



DC MOTORS

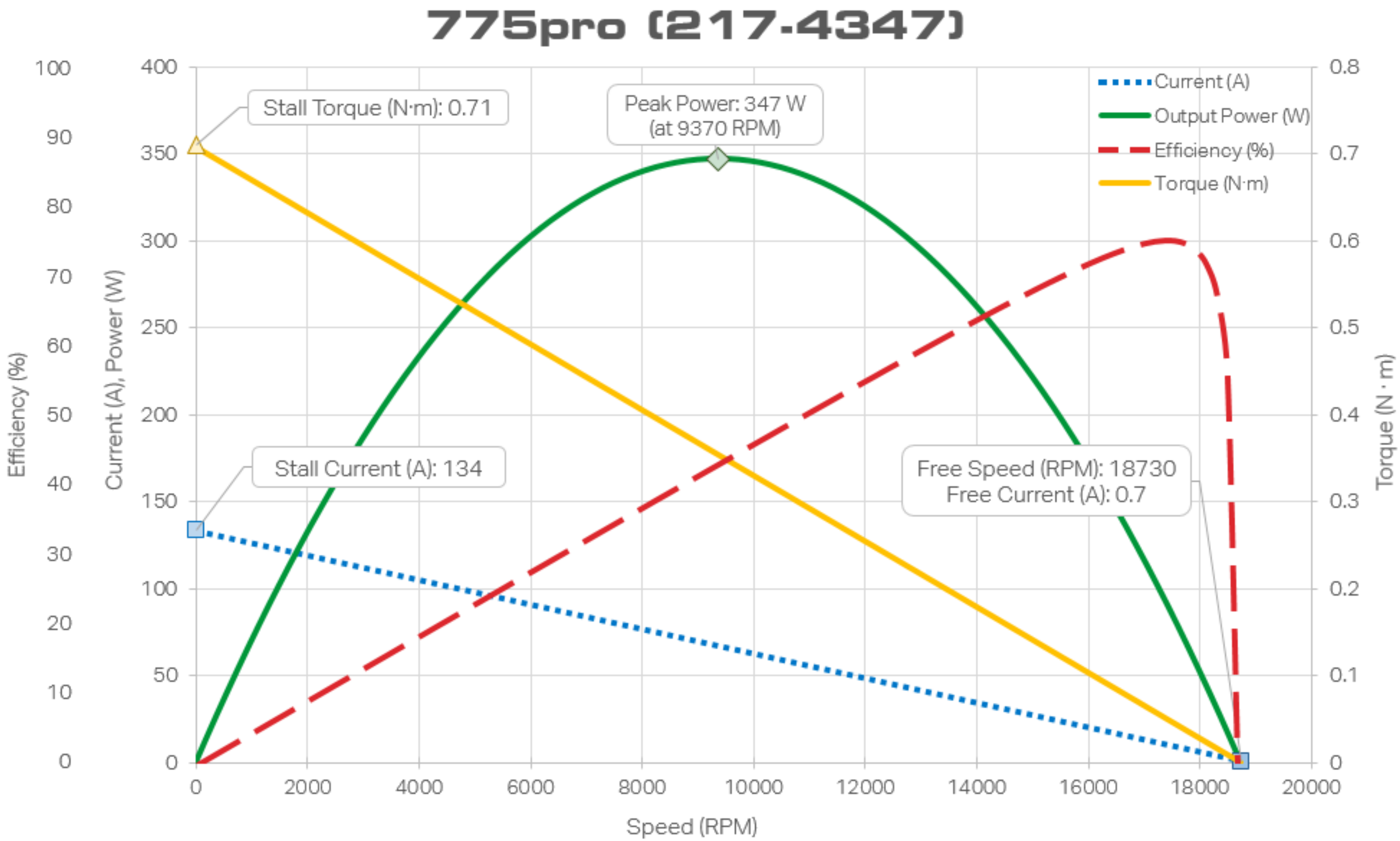
DC MOTOR BASICS

- Stall Torque (T_s): the torque a motor outputs at 0rpm
- Free speed (ω_f): max rpm of the motor with no load
- Stall current: The current the motor draws at 0rpm (the max current it draws)
- Power Rating: max power output of the motor

DC MOTOR MODEL

- Behaviour of a DC model can be modelled as follows:
- $T = K_i \times i$ (Nm/A, A)
- $\omega = K_v \times V$ (rad/sV, V)
- $P = T \times \omega$ (W, Nm, rad/s)
- K_i & K_v are constants for each motor
- Very rudimentary model: can further enhance w/ friction and moment of inertia

READING MOTOR CURVES



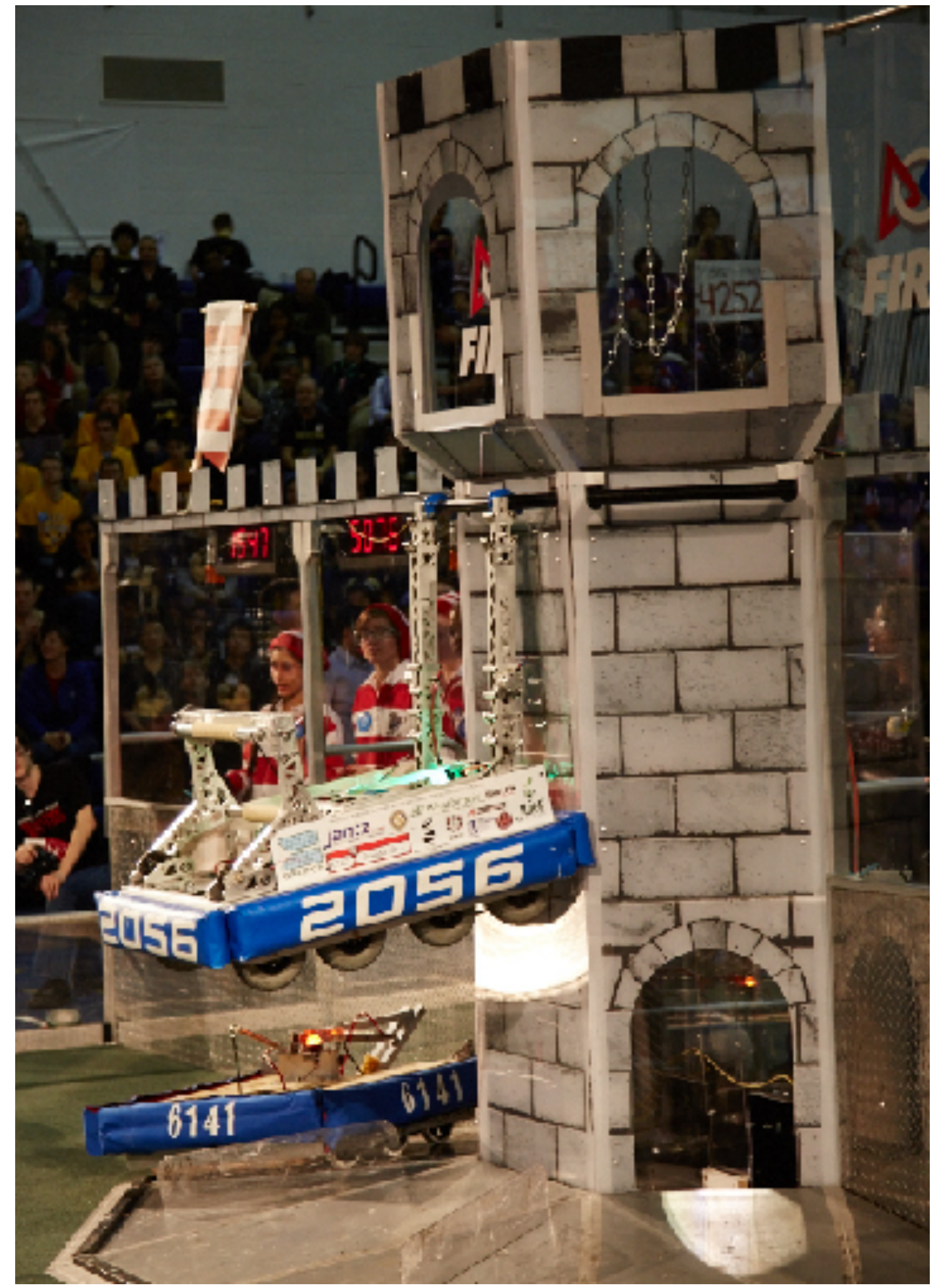
DYNAMIC ANALYSIS

- Fnet != 0
- Mnet != 0
- Stuff moves (which you should want it to)

EXAMPLE

ASSUMPTIONS

- Robot weighs 155lb (70kg)
- No friction
- Moved by 1 775 pro motor through a 100:1 reduction with a 1.5in diameter spool
- Calculate theoretical travel time for 30in



Unit Conversions

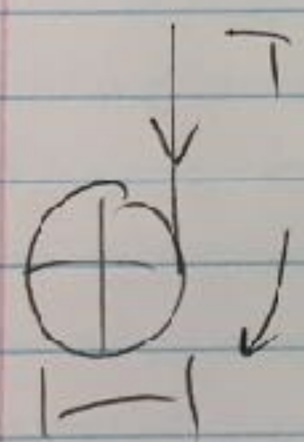
30in = 0.762m

1.5in = 0.0381m

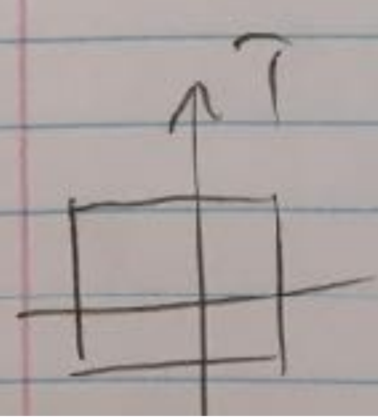
Motor Specs

0.71Nm · 100 = 71Nm

Calculating Linear Force



$$T_1 = \frac{71Nm}{0.5 \cdot 0.0381m} = \boxed{3727\,N}$$

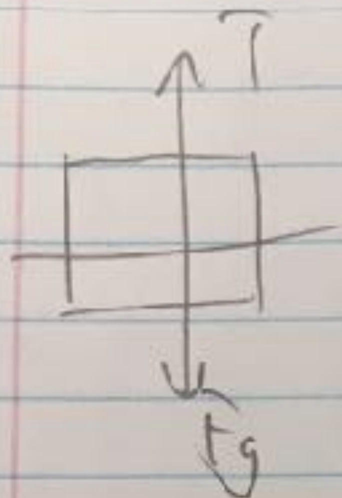


$$F_{net} = 0 = T_2 - F_g$$

$$T_2 = 70kg \cdot 9.8m/s^2$$

$$= 686N$$

$$F_{net} = 0 = T_2 - F_g$$



$$T_2 = 70kg \cdot 9.8m/s^2$$
$$= 686N$$

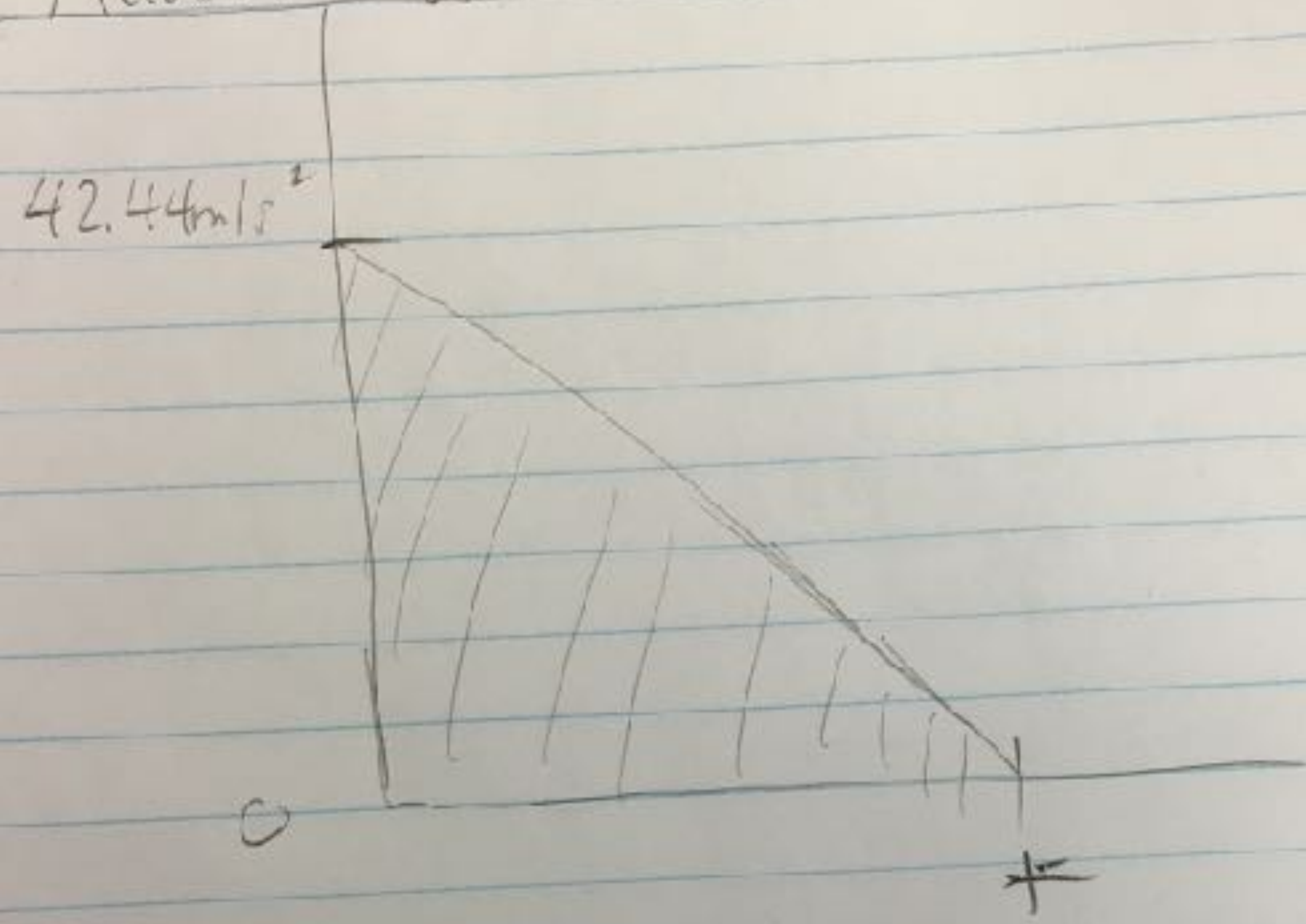
$$\frac{686N \cdot 0.0381m}{2} = 1306Nm \sim 180rpm$$

$$\text{Max Linear Speed} = \frac{180rpm \cdot 0.0381m \cdot \pi}{60}$$

$$= 0.356m/s$$

$$\text{Initial Accelration} = \frac{3727N - 686N}{70kg} = 4344m/s^2$$

Acceleration vs. Time

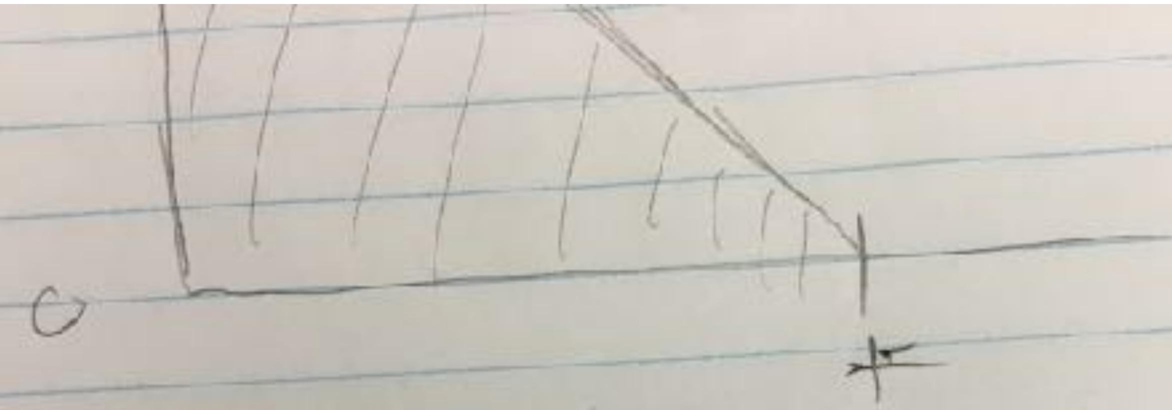


$v_f = \frac{1}{2} a t$

$t = \frac{2 v_f}{a}$

$= \frac{2 \cdot 0.356 m/s}{42.44 m/s^2}$

$= 0.0162 s \approx 0$



$$V_f = \frac{1}{2}at$$

$$t = \frac{2v_f}{a}$$

$$= \frac{2 \cdot 0.356\,m/s}{42.44\,m/s^2}$$

$$= 0.0167s \simeq 0$$

$$\text{Time to scale} = \frac{0.762\,m}{0.356\,m/s} = 2.14s$$

PNEUMATICS

Pneumatics in FRC

- The use of compressed air to do work
- Pneumatic devices in FRC can use a maximum of 60psi
- Pneumatic cylinders are the most commonly used linear actuators in FRC
- Cylinders have two positions (typically): extended and retracted
- Cylinders are defined by bore size & stroke length
- Cylinders can be single acting or double acting (usually)

HOW A PNEUMATIC CYLINDER WORKS

PNEUMATIC CYLINDER MODEL

- $F = P \times A$ (constant force)
- 60psi = 413.685kPa
- $A = \pi r^2$ ($r = 0.5 \times$ bore)
- optional: subtract area of cylinder rod for more accurate number

QUESTIONS?

RICHARD.LI1325@GMAIL.COM