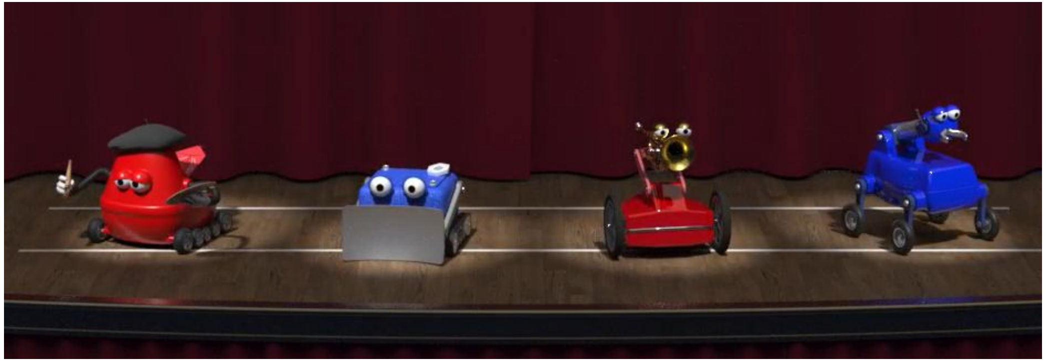
Math for FTC Robots



Wait, math and physics is useful?

Why is math important?

- So your robot doesn’t break!
- Less likely to burn out motors.
- Practice engineering skills.
- Impress the judges.

Disclaimer

We are going to be looking simplified situations.

This means that a real world situation may act differently

Wheels: What does wheel size change?

Wheels: What does wheel size change?

Speed or Velocity

Circumference of the wheel (circle)
Wheel diameter 3in or 4in

$$C = \pi \times d \qquad C_1 = 3.14 \times 3in = 9.42in$$
$$C_2 = 3.14 \times 4in = 12.46in$$

Velocity
REV HD Hex Motor Free speed N=150rpm

$$V = C \times N$$
$$V_1 = 9.42in \times 150\frac{rev}{min} = 1413\frac{in}{min} \times \frac{1\,min}{60sec} = 23.55\frac{in}{sec} = 1.96\frac{ft}{sec}$$
$$V_2 = 12.46in \times 150\frac{rev}{min} = 1869\frac{in}{min} \times \frac{1\,min}{60sec} = 31.15\frac{in}{sec} = 2.59\frac{ft}{sec}$$

Wheels: Percent Increase

$$percent\ increase = \frac{New\ Value - Old\ Value}{Old\ Value} \times 100\%$$

$$percent\ increase = \frac{2.59 - 1.96}{1.96} \times 100\% = 32\%\ increase\ in\ speed$$

Other ways to change speed?

- Check the software and change speed in the programming.
- Gearing down is when a large gear drives a small gear. It will increase the speed but lower the torque.
  - Gearing down will have a gear ratio less than 1
- Gearing up is when a small gear drives a large gear. It will lower the speed but increase the torque.
  - Gearing up will have a gear ratio greater than 1

Gearing

$$Gear\ Ratio = \frac{Driven\ Gear\ Teeth}{Driving\ Gear\ Teeth}$$

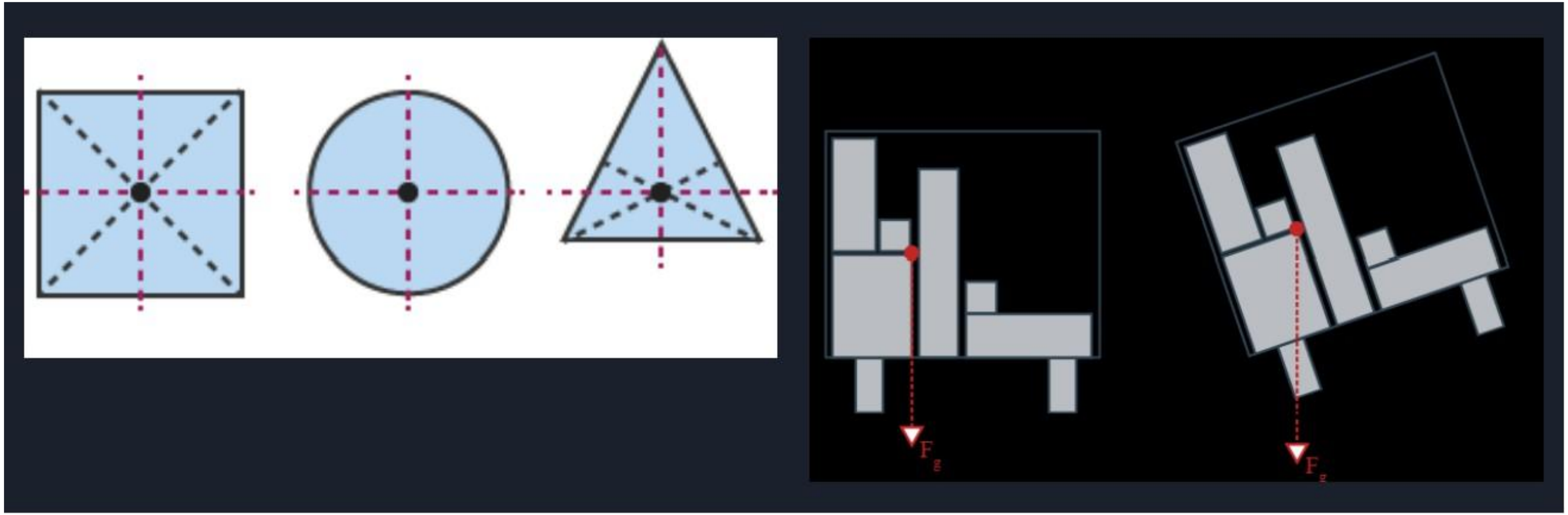
$$Gear\ Ratio = \frac{45t}{72t} = 0.625$$

$$Output\ Speed = \frac{Input\ Speed}{Gear\ Ratio}$$

$$Output\ Speed = \frac{2.59\frac{ft}{sec}}{0.625} = 4.14\frac{ft}{sec}$$

$$percent\ increase = \frac{4.14 - 2.59}{2.59} \times 100\% = 60\%\ increase\ in\ speed$$

Center of Mass



A simple way to find the center of mass is to use a flat piece wood and some ~1in PVC pipe and balance the robot, like a playground seesaw.

Motor: Selecting a Motor

Motor: Selecting a Motor

What information is needed to select a motor?

- Speed
- Torque
- Power
- Electrical requirements

All this information is provide on datasheet or website

REV HD Hex Motor http://www.revrobotics.com/rev-41-1301/

Example: How to select a motor for an Arm?

Assume a robot (on earth) has a mass of 42 lb and is being lifted 4in.
What is the ***work*** needed to complete this task?
What is the ***power*** if the lift happens in 5 seconds?

Conversions

- Mass 42 lb = 19.05kg ≈ 20kg
- Distance = 4in = 10.16cm = 0.1016m

Example: How to select a motor for an Arm?

Find the power is needed to complete the task. Think big picture.
What information do we have?

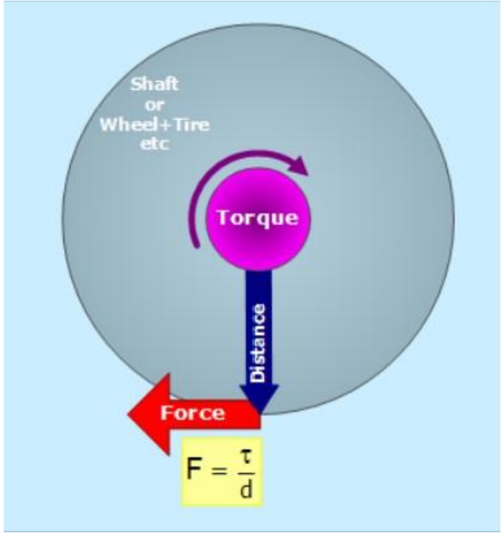
- Mass - mass of the object being moved or lifted — 20kg
- Acceleration On Earth — assume 9.81 [m/s^2]
- Distance - How far is the object moving? — 0.1016m
- Time - How fast does this move happen? — 5 seconds

Example: Definitions

Mass (m) is used to measure the amount of matter in an object. Often expressed in units of [kg] or [lb].

Acceleration (a) is used to describe how fast an object's speed is changing. Expressed in units of [m/s^2] or [in/s^2].

Force (F) is the potential for an object to do work. Often expressed in units of [N].



Torque (T) roughly quantifies the turning force on an object like a gear or a wheel. Torque is commonly expressed in units of [Nm], [oz · in], or [in · lbs].

Example: Definitions

Work (W) is used to describe changes in energy. Work is independent of the path taken and is defined as force times displacement. For example if a 1 [kg] weight is lifted vertically 1 [m] against gravity at a constant velocity the work done is 1[kg]*9.8[m/s^2]*1[m] = 9.8 [kg*m^2/s^2] or 9.8 joules[J]. But joules are also [Nm].

Power (P) is the rate of work over time. One way to think about power and work, is that it takes the same amount of work to carry a brick up a mountain whether you walk or run, but running takes more power because the work is done in a shorter amount of time. The SI unit for power is the Watt (W) which is equivalent to one joule per second (J/s).

Example: Work

$$Force = Mass \times Acceleration$$

$$F = m \times a = m \times g$$

$$F = 20kg \times 9.81 \frac{m}{s^2} = 196.2N$$

$$Work = Torque = Force \times Distance$$

$$W = T = F \times d$$

$$W = 196.2N \times 0.1016m = 19.93J$$

$$or\ T = 19.93Nm$$

Note: The equations are for one dimension.

Example: Power

$$Power = \frac{Work}{Time}$$

$$P = \frac{W}{t}$$

$$P = \frac{19.93J}{5s} = 3.98W \approx 4W$$

With a safety factor of 2

$$P \times 2$$

$$P \times 2 = 4 \times 2 = 8\,W$$

Example: Does the motor work?

Look back at the datasheet. REV HD Hex Motor
Check both the Stall Torque[Nm] and the Power [W]

- If the motor does not have enough power, pick a different motor.
  - Found on a different REV page Max Power = 15 [W]
- If the motor does not have the correct Stall Torque, use gearing.
  - The REV HD Hex Motor Stall Torque = 4.2 [Nm]

Example: Does the motor work?

$$Gear\ Ratio = \frac{Driven\ Gear\ Teeth}{Driving\ Gear\ Teeth}$$

$$Gear\ Ratio = \frac{86t}{28t} \times \frac{86t}{42t} = 6.29$$

$$Output\ Torque = Input\ Torque\ \times Gear\ Ratio$$

$$Output\ Torque = 4.2\ Nm \times 6.29 = 26.41\ Nm$$

$$Input\ Torque = \frac{Output\ Torque}{Gear\ Ratio}$$

Consider using a Safety Factor of 1.5-2

Note: Gear teeth numbers are metal gears from REV.

Links for more information

- Power and Torque with Lego models : driving 4 answers
- Gear Ratios with Lego models : driving 4 answers

- Forces - Newton's Laws: Crash Course Physics #5
- Work, Energy, and Power: Crash Course Physics #9
- Motor Power - Electric Current: Crash Course Physics #28

- REV How to Guide - Choosing an Actuator

Good Luck this Season!