Building Mechanisms

Design Process, Mechanisms, & 3D Printing

A Little About Me

Mechanical Engineering,
Biomedical Specialty

Vehicle Safety, Automated (“Driverless") Cars

- Co-founding mentor (2017-2025)
- Three kids through FTC
- Winners of the Inspire, Connect, Think, & Motivate Awards
- Winning Alliance

- Mentor
- Three kids through FRC
- Former World & State Champions
- Impact, Sustainability, & many more awards

Overview

We’ll review the following:

- Design Steps
- Mechanisms: Types, Merits & Demerits
- 3D Printing Tips & Tricks

Design Process

1. Determine Game Strategy for Auto & Tele-op periods
    a. First principles
    b. “What” first, then the “how”
2. Brainstorm Robot Concepts
3. Sleep on it
4. Prototype and testing phase
    a. The shorter the feedback loop the better
    b. **Key Metrics**: auton points, cycle time(s)
5. Design Freeze
6. Build the robot for competition
7. Test final robot
8. Compete
9. Evaluate and improve the robot
    a. Make faster, lighter, less parts, more robust

[Source]

Mechanisms

Types, Merits & Demerits

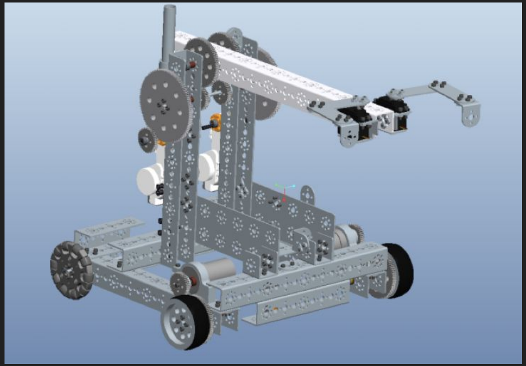
We Stand on the Shoulders of Giants

Thank you Team Rush Robotics 27 for some of the following tips!!!!

Design Tips

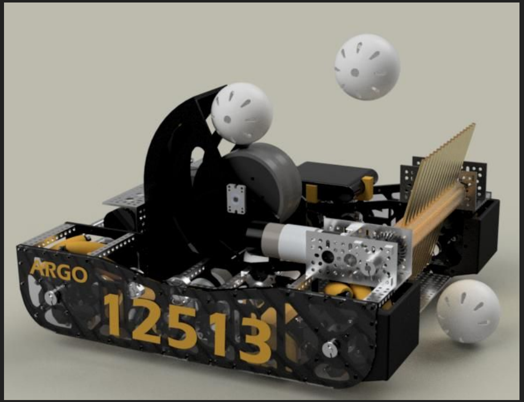
- Focus on doing a few objectives well…you can always add something later ;-)
- The lighter, the better
- Less is more
- Understand your team's abilities
- Establish milestones

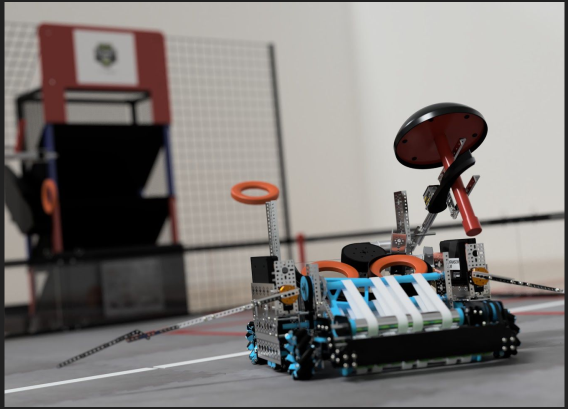
Arms with Grippers



Merits	Demerits
Efficient use of material	Unstable extended while moving
Good reach	Fragile
Limited number of motors	Can only move light loads
Easy to build	High center of gravity

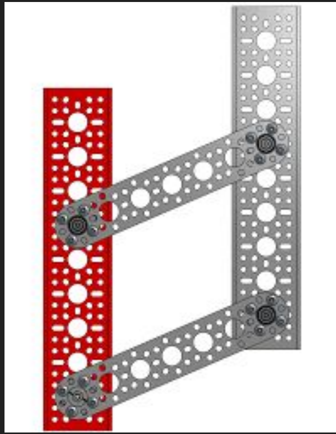
Shooters





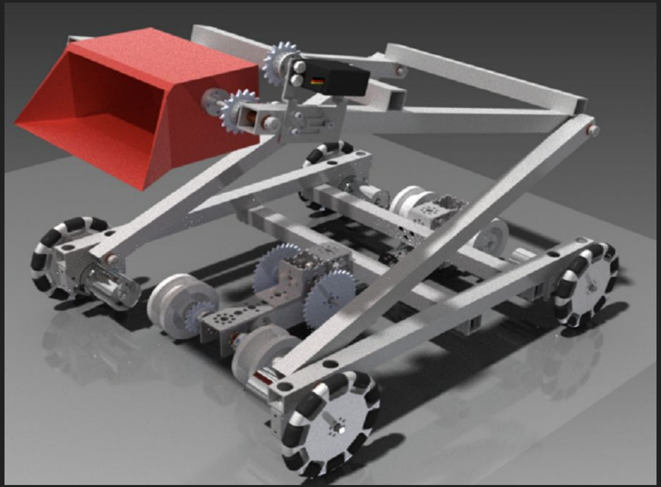
Merits	Demerits
Fun	Inaccuracy
Can move fast	Temperamental when moving
Limited number of motors	Could be driver-dependant

Four-bar Linkage



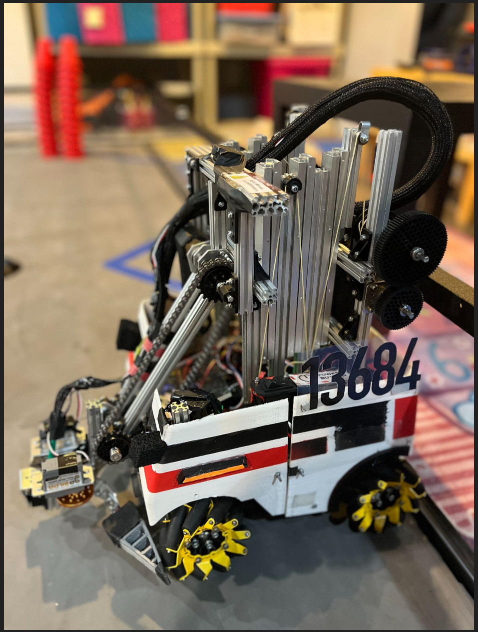
Merits	Demerits
Robust and durable	Can be complex
Moves fast	Sway at extension
Robotics' "Top Gun"	Not much adjustment

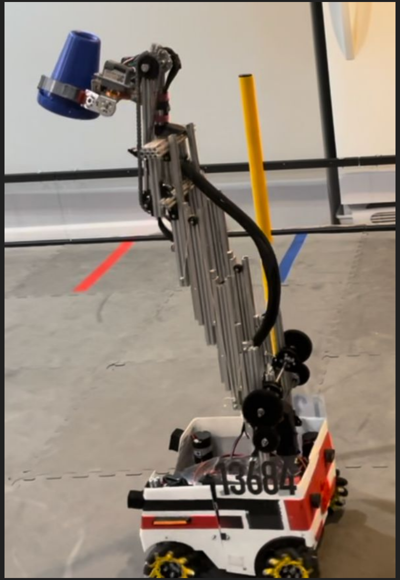
Scoop Arms



Merits	Demerits
Simple	Hard to accurately dump
Moves fast	May collect too many parts
Collects many pieces at once	Not much adjustment

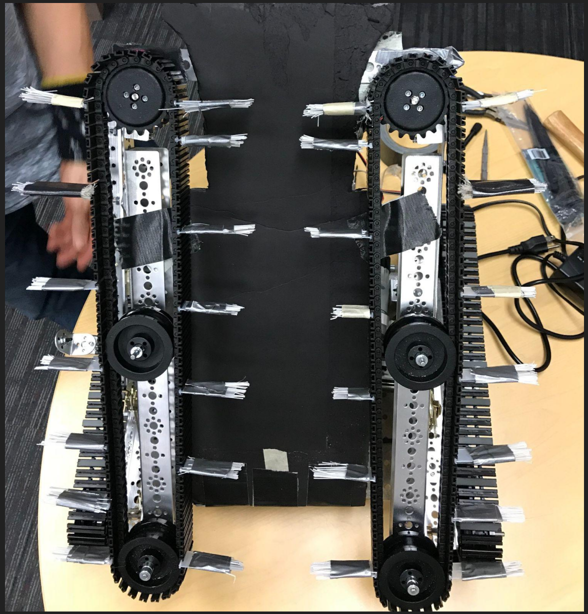
Sliders

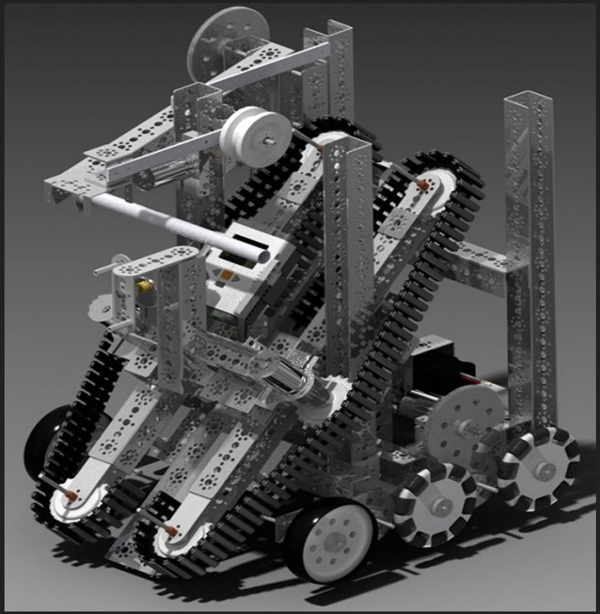




Merits	Demerits
Can be made with commercial, off the shelf parts	Keeping the string on can be tough; belts sacrifice room
Can reach high heights.	High CG when extended & moving. May tip & sway
Simple	Must drive up & down

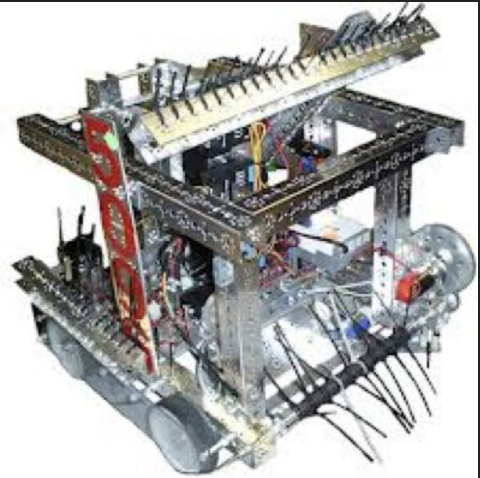
Belts

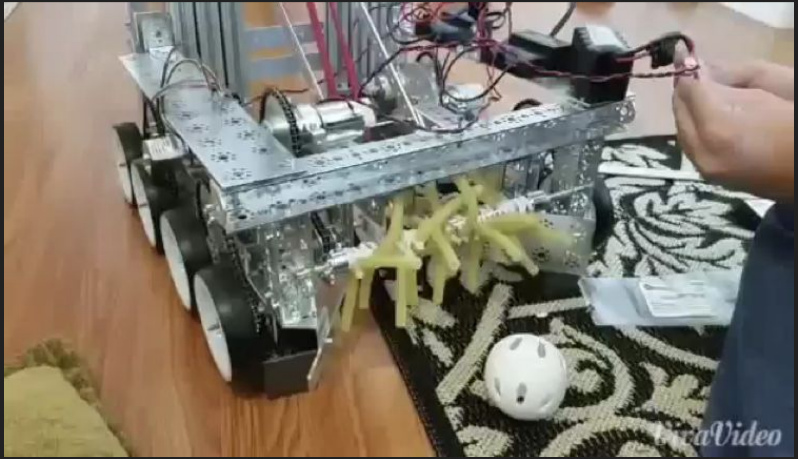




Merits	Demerits
Fast part loading	Treads tend to break or decouple
Can suck parts in from many directions	Belt tensioning can be a career

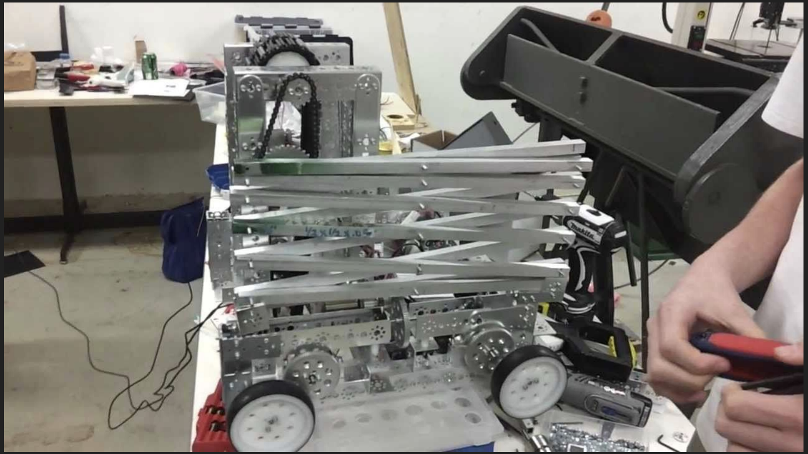
Sweeper





Merits	Demerits
Fast part loading	Can break when running into wall
Can suck parts in from many directions	Not great for outputting balls
Easy to build	Can be a tangle hazard

Scissor Lift



Merits	Demerits
Compact	Unstable at heights
High height	High CG may lead to tipping
Easy to build	Wobbles when moving

Tape Measure

Merits	Demerits
Compact	Unstable at heights
High height	Susceptible to damage
Easy to build	Wobbles when moving

Build Team

3D Printing Tips & Tricks

Overview

We'll review the following:

- 3D Printers Access
- Computer-Aided Design (CAD) to Slicer
- Materials
- Using available STL files for shorter iteration time
- Common design considerations

3D Printing Access

Where can I get parts 3D printed?

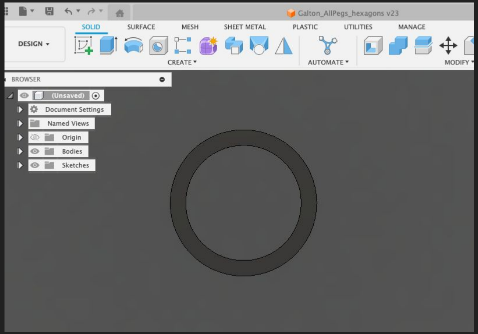
High school supports Plymouth-Canton Community Schools (P-CCS) FIRST Tech Challenge (FTC) Teams

Online Services

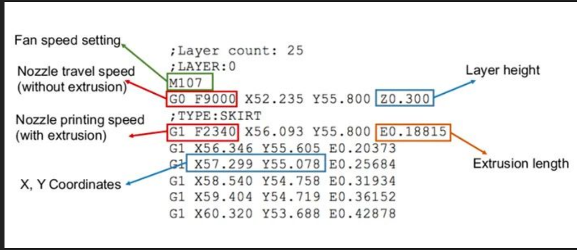
Purchase

Computer-aided Design (CAD) to a Slicer

What is a slicer?



CAD file



G-code

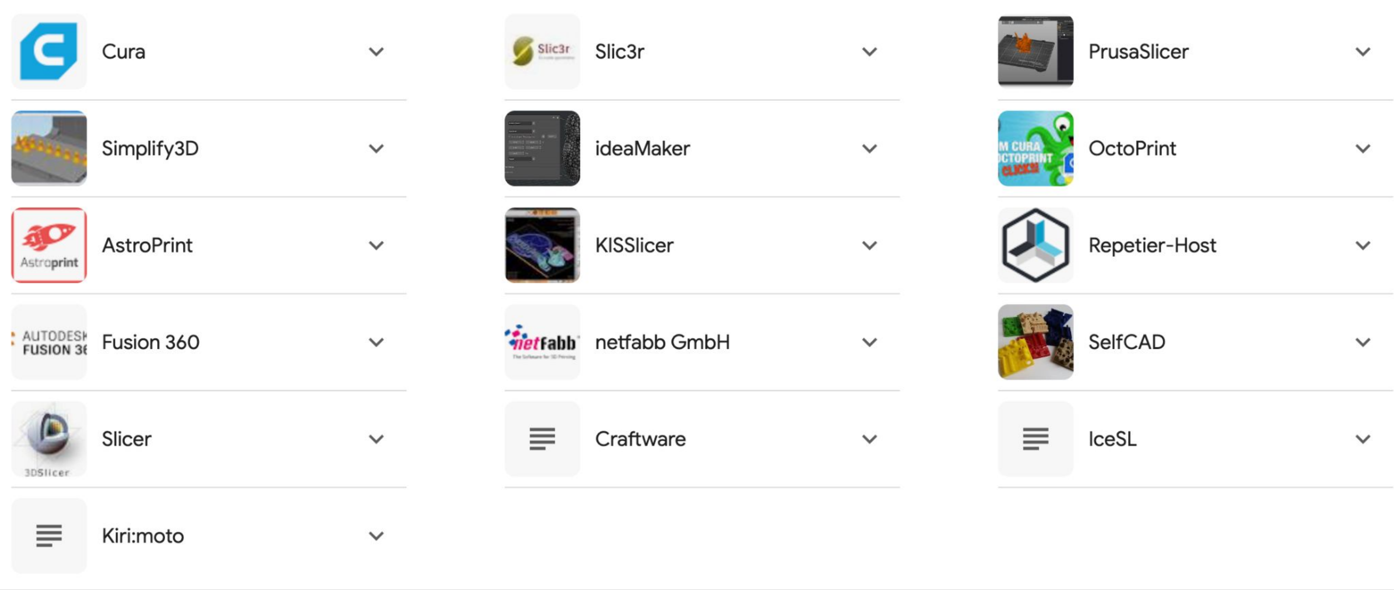
3D Printer

CNC

A slicer translates CAD so the 3D printer can lay down the filament

Computer-aided Design (CAD) to a Slicer

Slicers available to download

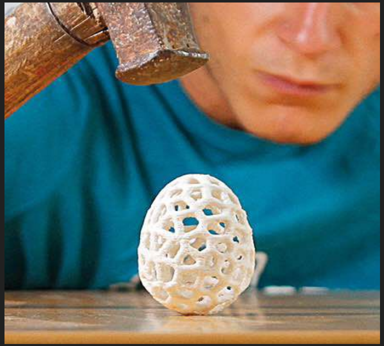


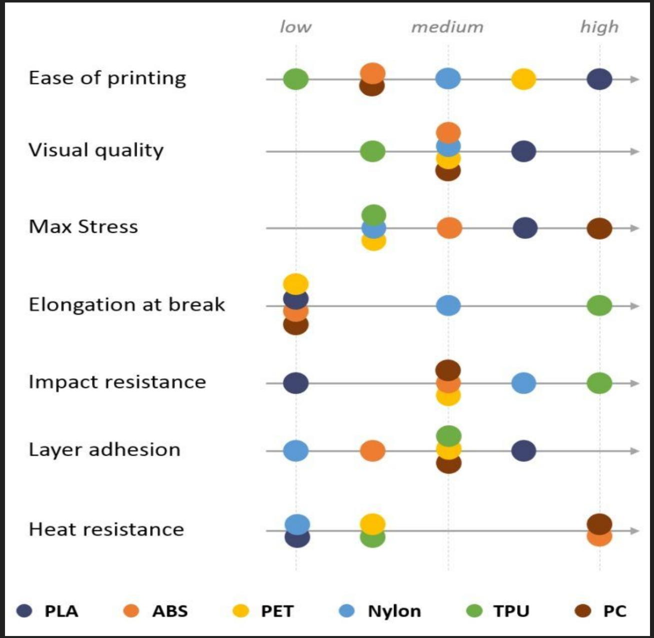
Computer-aided Design (CAD) to a Slicer

Slicer Settings for Fast, Accurate, and Strong Prints

	Value
Nozzle Opening	0.6 mm
Infill Fill Pattern	Adaptive Cubic
Elephant Foot Compensation	0.4 mm
Perimeters	3
Support Material (Style)	Organic
Bridge Flow Ratio	0.95 (95%)

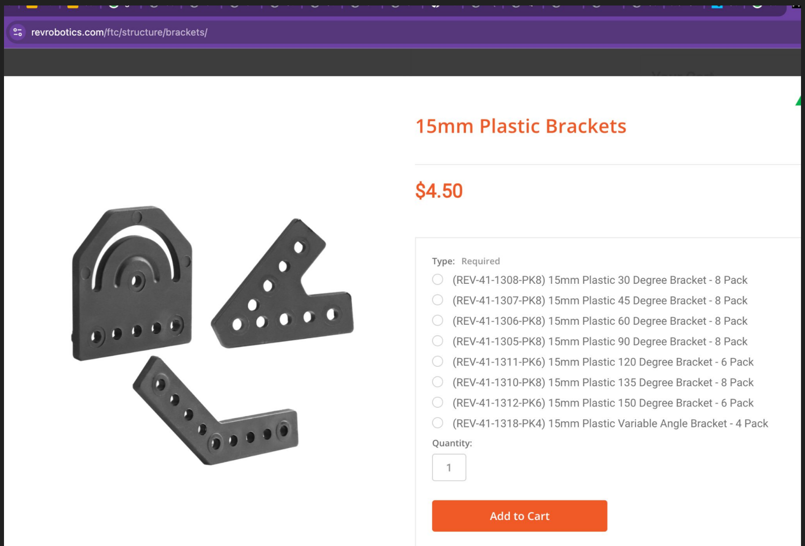
3D Filaments Materials and Properties

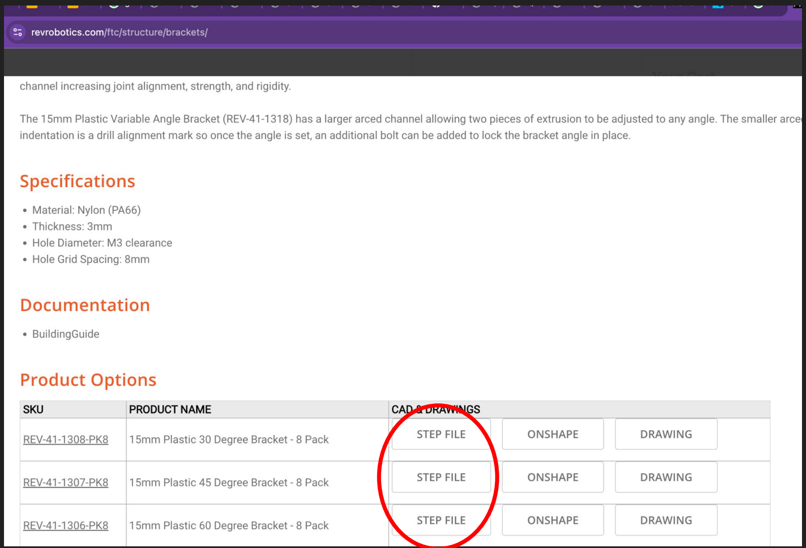




Takeaway: Determine the use then decide what material works best

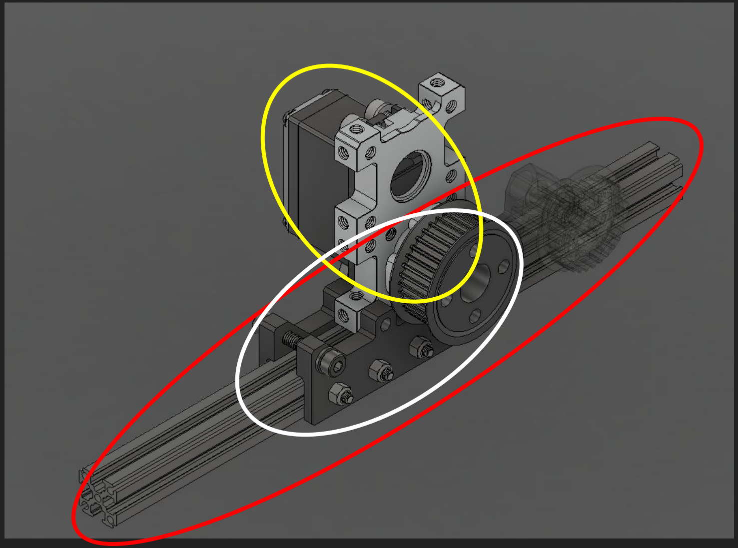
Existing CAD / Step Files





Takeaway: Can directly print parts, via a slicer, for quicker assessments

Existing CAD / Step Files

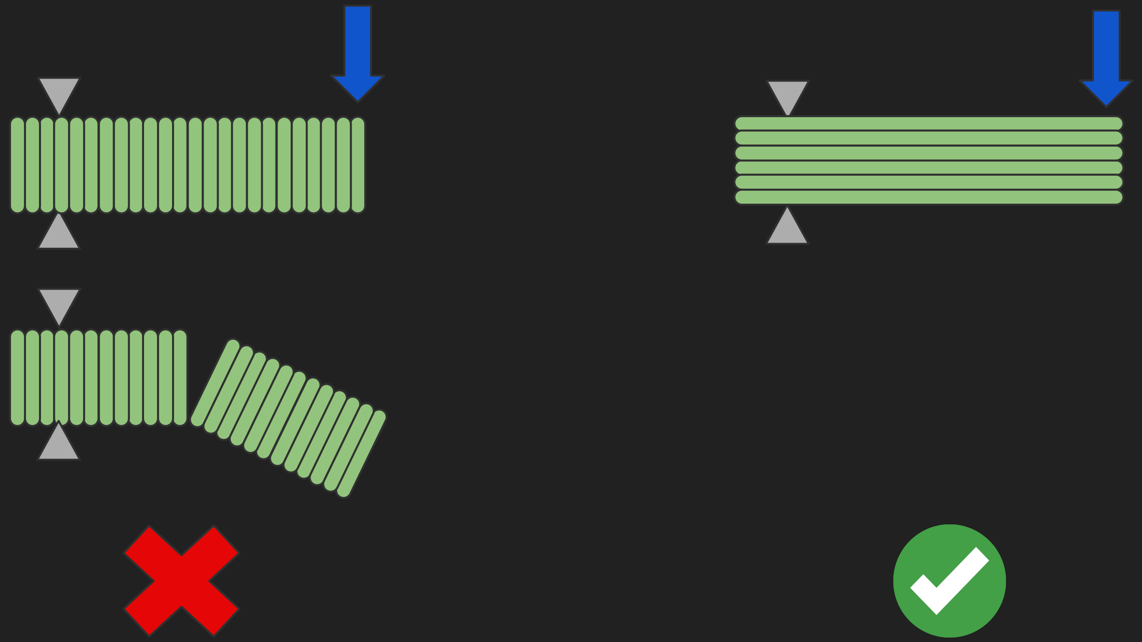


GoBilda
REV
Adapter

Takeaway: Can print nearly any adapter using components from two different companies

Considerations When Designing

What is the direction of the force & how can I print it?



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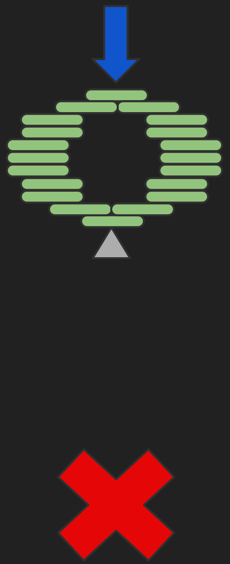

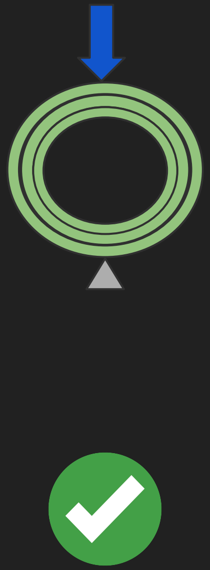

Considerations When Designing

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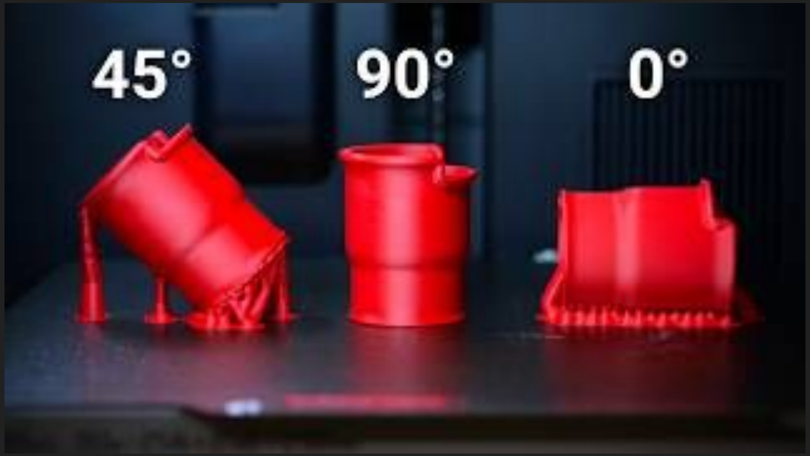
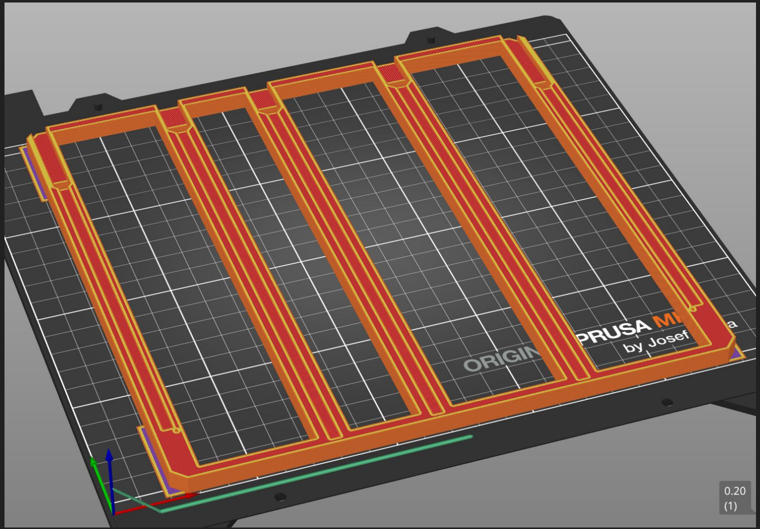
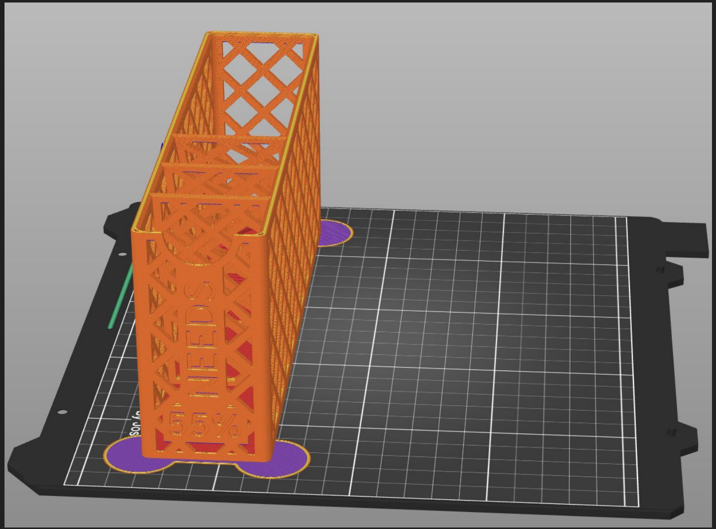


[*Stop Printing Flat: The 45° Secret for Stronger Parts*]

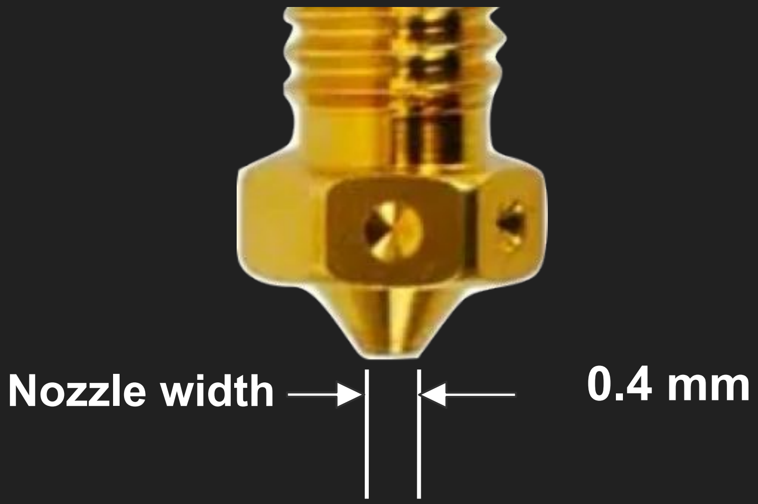
Common Considerations: Print Time

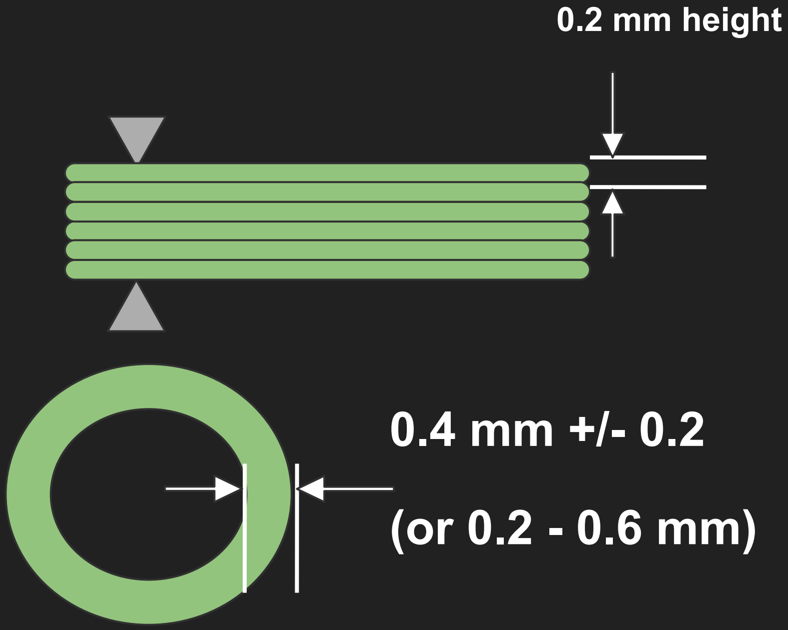




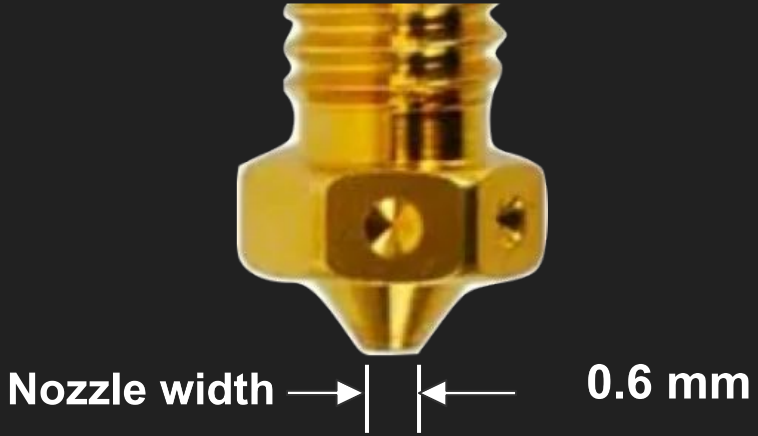
Takeaway: Prints requiring higher z-axis positions take longer to print

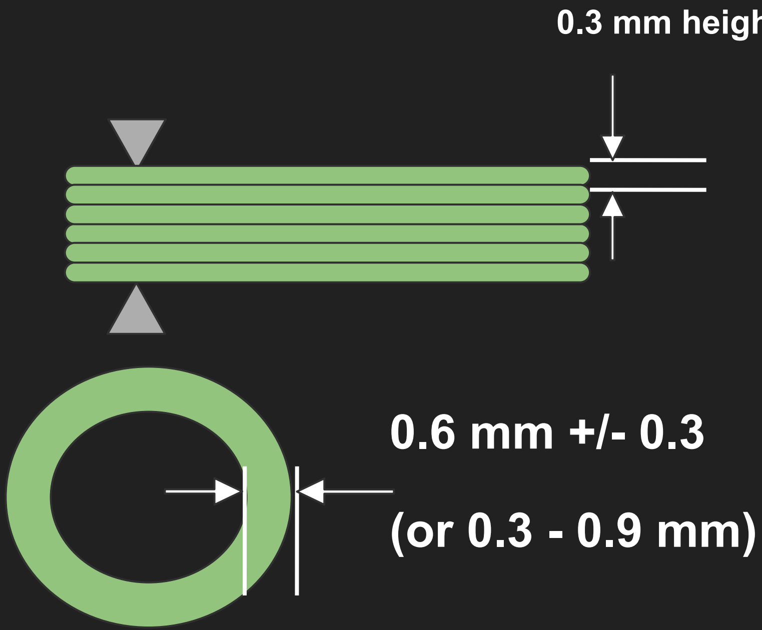
Common Considerations: Tolerances & Nozzle Width





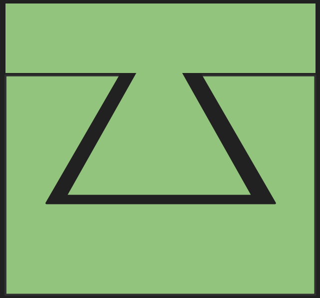
Common Considerations: Tolerances & Nozzle Width





Common Considerations: Tolerances & Nozzle Width

Examples Gaps for Joints with a 0.6 mm nozzle



Dovetail: 0.5 mm gap

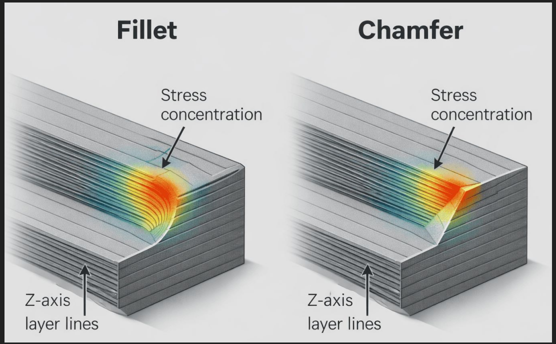
Hole: 0.4 mm gap

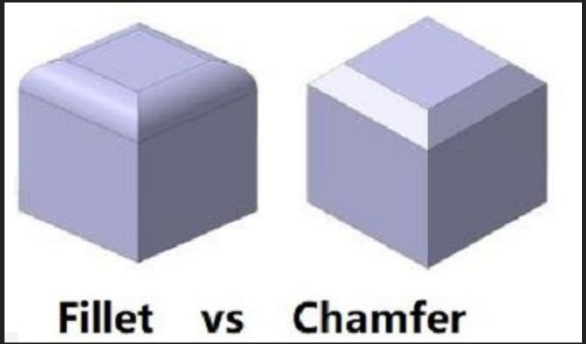
Takeaways:

- Tolerance is roughly one half (½) of the nozzle width
- If possible, we recommend a 0.6 mm nozzle as a good balance of print time, strength, & appearance

Common Considerations: Chamfer vs. Fillet

When to fillet and chamfer in 3D printing?





Fillets:

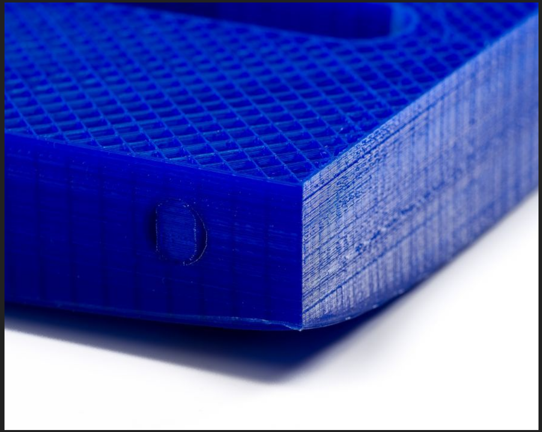
- Pros
  - Soften corners on the sides of
  - Reduces stressors w/ soft corners
  - Reduces print mess-ups
- Con
  - Prints look layered/unpretty on top edges

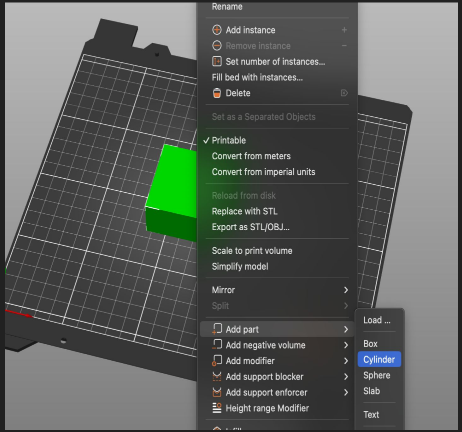
Chamfers:

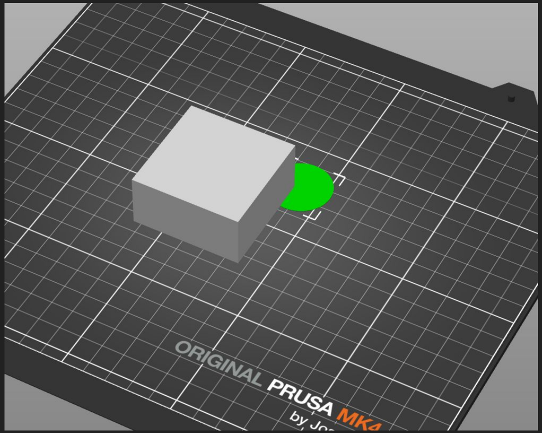
- Pros
  - Ease for assembly
  - Cleaner prints
- Con
  - Little filament stress reduction

Common Considerations: Lifting corners

Ways to address corners lifting off the build plate



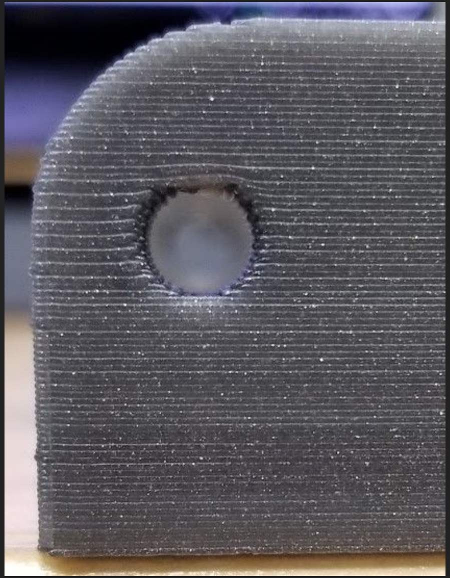


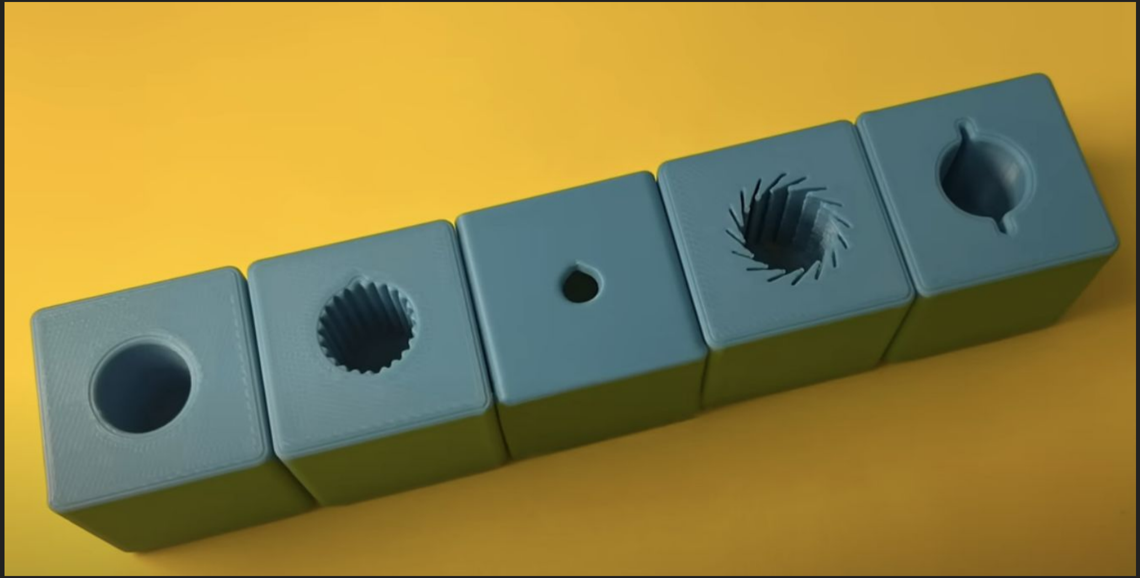


Takeaway: “Mickey” mouse ears is a targeted way to reduce corners lifting

Common Considerations: Printing holes on side of object

Ways to make holes that can accept cylindrical objects

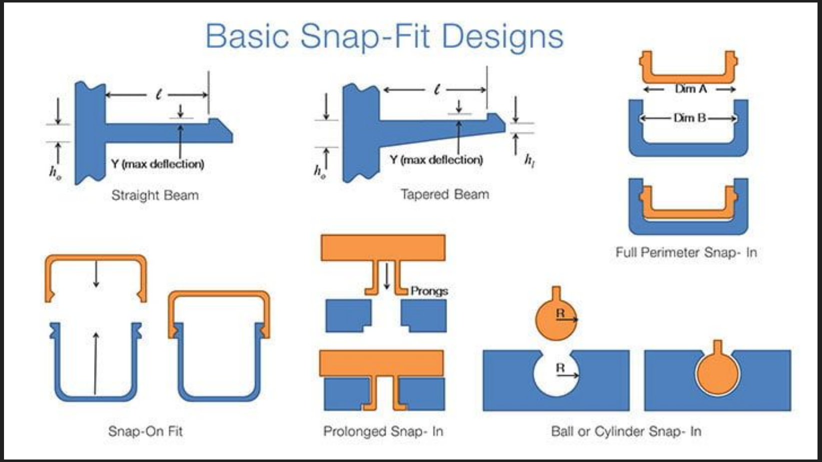




Takeaway: Apply modifications for side holes to keep the hole circular

Common Considerations: Attaching two parts together

Ways to 3D print attach two components together mechanically



[Snap fit]()

Dovetail

Summary

- Design Process
  - Plan, Do, Check, Act
- Mechanisms: Types, Merits & Demerits
  - Learned the merits and demerits for various mechanisms
- 3D Printing Tips & Tricks
  - How to go from CAD to slicer to 3D print
  - Uses and materials
  - Leveraging available STL files from vendors for quicker prototyping
  - Common design considerations
- Questions?

Good luck this season!!!

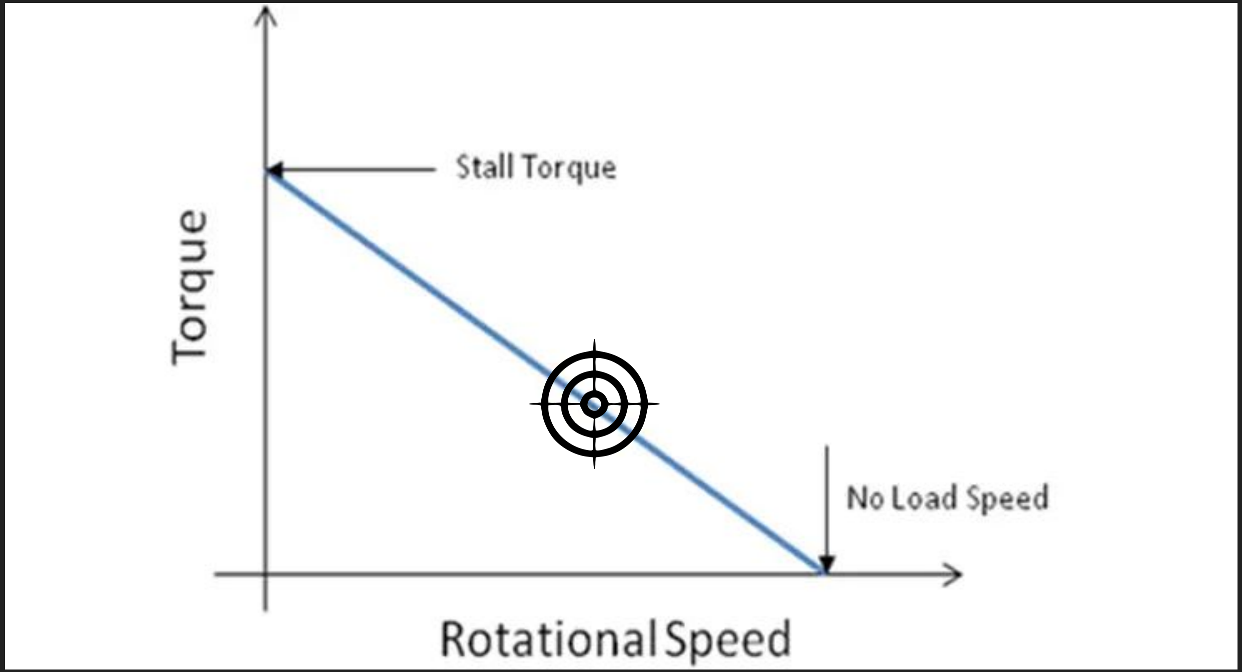
Reference

Why are we learning about force, torque, work & power?

Goal: We want to be fast AND we want to be strong enough to perform the task

Why are we learning about force, torque, work & power?

Torque and speed are generally inversely proportional



Core Concepts

- **Spe**

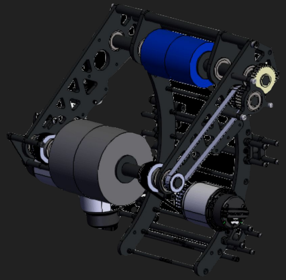
Core Concepts

- **Speed is distance traveled over time. What is the formula & units?**

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}} \rightarrow \frac{\text{miles}}{\text{hour}} \rightarrow \frac{\text{centimeters}}{\text{second}}$$

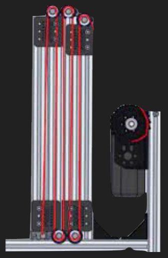
Core Concepts

- **Rotational speed is rotations over a period of time.**
- **What are the <u>units</u> for rotational speed?**



$$\textbf{Rotational Speed} = \frac{\text{Rotations}}{\text{Time}} \rightarrow \frac{\text{Revolutions}}{\text{Minute}} \rightarrow \text{RPM}$$

- **How to convert RPM to linear speed the elevator will travel up in cm/s?**



Circumference = C = 2*Pi*radius (cm)

$$\textbf{Elevator Speed Up}\ \text{(cm/s)} = \frac{\cancel{\text{Rev}}}{\cancel{\text{Min}}} \times \frac{\text{C (cm)}}{\cancel{\text{Rev}}} \times \frac{\cancel{\text{Min}}}{60\ \text{(s)}}$$

Core Concepts

- **Torque is.the force to twist or turn something**

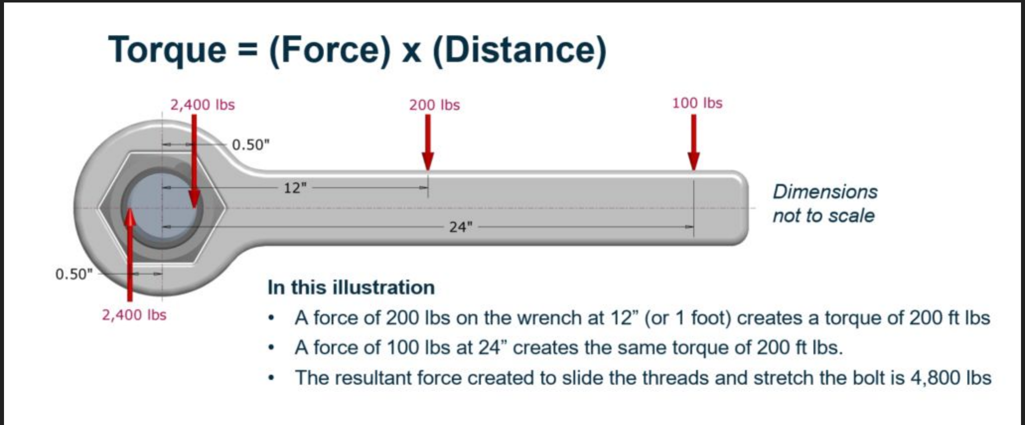
Which wrench would you choose that requires the least amount of force from you?

Core Concepts

- **Torque is the force to twist or turn something**

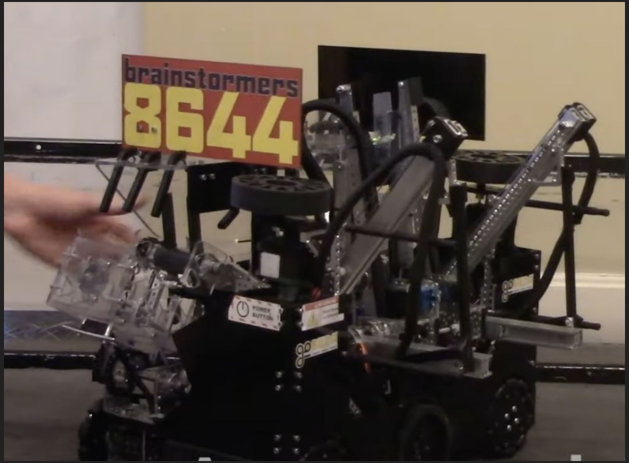
Torque = Force x Distance

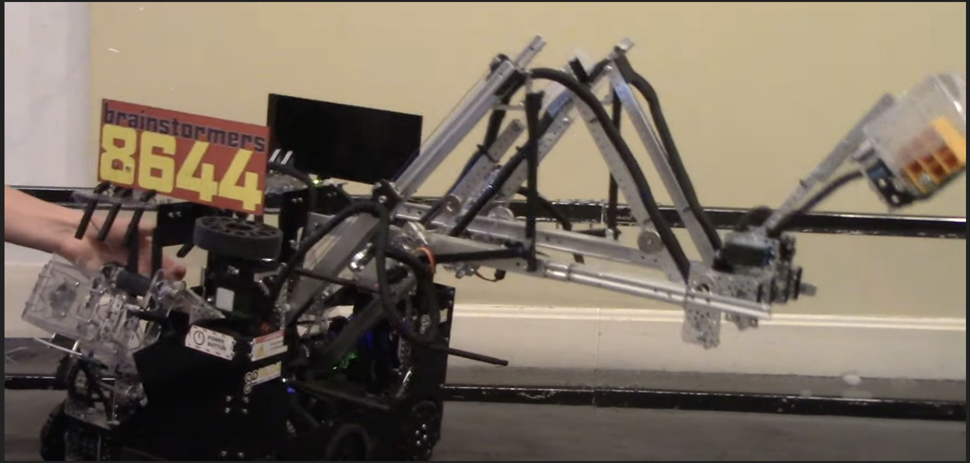
T = Fd (Nm)



Core Concepts

- **Work is a change in energy.**
  - **For FTC, this means moving something from one place to another**





Work = Force **x d**istance = **Fd (Joules)**

Core Concepts

- **Power is.the rate of change in energy.**

more time => less power

less time => more power

Power = Work / Time (Watts)

How to choose an actuator

1. Calculate work (W = Fd = mad)
2. Calculate power (P = Work / time)
3. Compare power calculation result with maximum motor power output

Example Problem

- Assumptions
  - Instant acceleration
  - No friction
- Game piece weight: 0.5 kg
- Lifter weight: 1.5 kg
- Lifter maximum height: 1.5 meters
- Time to full extension: 5 seconds

Work = (0.5 kg + 1.5 kg)(9.8 m/s^2)(1.5m) J

Power = 29.4J / 5s = 5.88 W

Power (w/ Safety Factor) = P*2 = 11.76 W

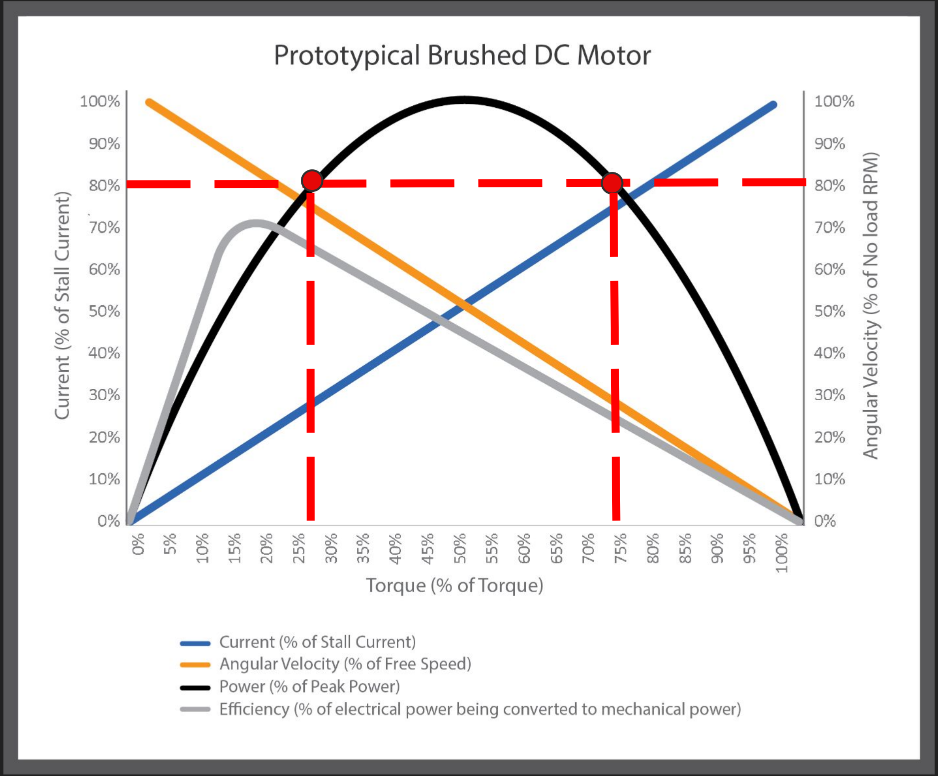
How to choose an actuator

Power (w/ Safety Factor) = P*2 = 11.76 W

	Stall Torque	Free Speed	Operating Voltage	Stall Current	Maximum Output Power
HD Hex, No Gearbox REV-41-1301	0.105 N·m 14.8 oz·in	628.3 rad/s 6000 RPM	12 V	8.5 Amps	15 Watts
HD Hex, 40:1 Spur REV-41-1301	4.2 N·m 594.7 oz·in	15.7 rad/s 150 RPM	12 V	8.5 Amps	15 Watts
HD Hex, 20:1 Spur REV-41-1301	2.1 N·m 297.4 oz·in	31.4 rad/s 300 RPM	12 V	8.5 Amps	15 Watts
HD Hex, 20:1 Planetary REV-41-1301	2.1 N·m 297.4 oz·in	31.4 rad/s 300 RPM	12 V	8.5 Amps	15 Watts
~~Core Hex, 72:1 REV-41-1300~~	~~3.2 N·m 453 oz·in~~	~~13 rad/s 125 RPM~~	~~12V~~	~~4.4 Amps~~	~~[illegible] Watts~~

How to choose an actuator

1. Use the power from our example and find on the y-axis (e.g 12 W/15 W = 80%)
2. Draw a horizontal line starting at the % of power
3. Draw two dots where the dotted line crosses the power curve
4. Where the vertical lines intersect the x-axis is the torque range of the motor
5. Tips:
   a. Prioritize maximizing power & efficiency
   b. Use the lower torque first; If it doesn't work out then can increase power



How to choose an actuator: REV Robotics Motor Example

- **Requirement:** Lift 10 lbs game piece w/ 2” diameter pulley
- **Stall torque =** 2.1 Nm x 27% = 0.567 Nm (~5 lbs. w/ 2 inch diameter pulley)

	Stall Torque	Free Speed	Operating Voltage	Stall Current	Maximum Output Power
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~~Core Hex, 72:1 REV-41-1300~~	~~3.2 N·m 453 oz·in~~	~~13 rad/s 125 RPM~~	~~12V~~	~~4.4 Amps~~	~~[illegible] Watts~~