Lecture 9b

Prototyping

Agenda

- Mechanical Prototyping
- Electrical Prototyping
- Mechatronics Prototyping
- Rapid Prototyping
- Prototyping Case Study

01
Mechanical Prototyping

Ways to put things together

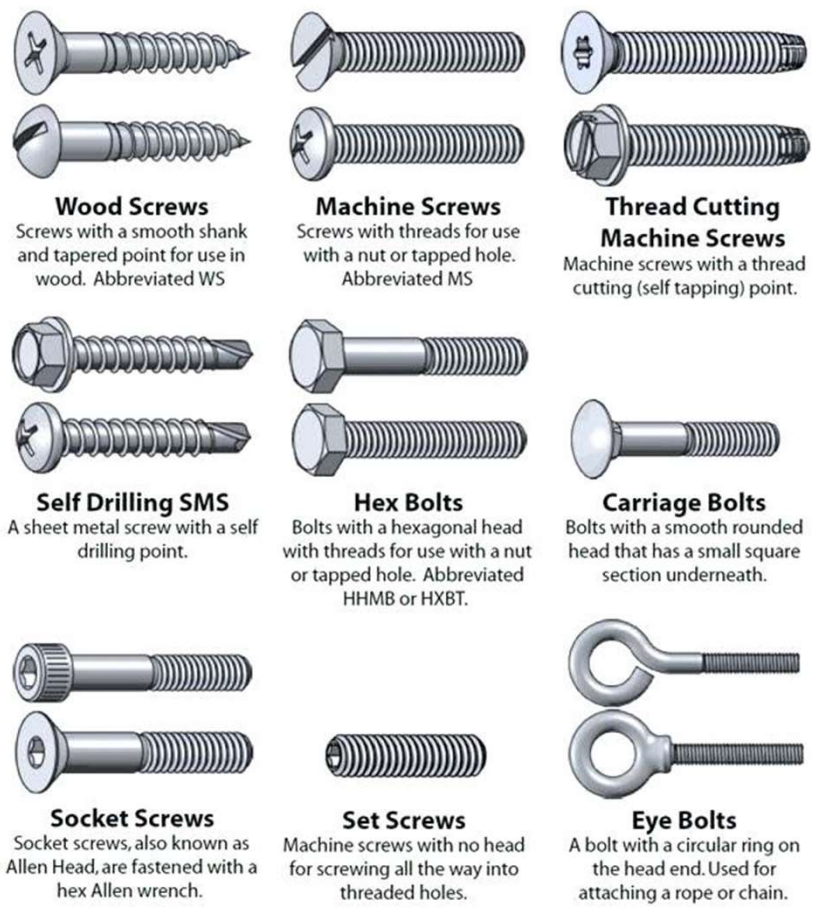
- Fasteners
- Press fit (interference fit)
- Adhesives
- Other useful connections

Fasteners

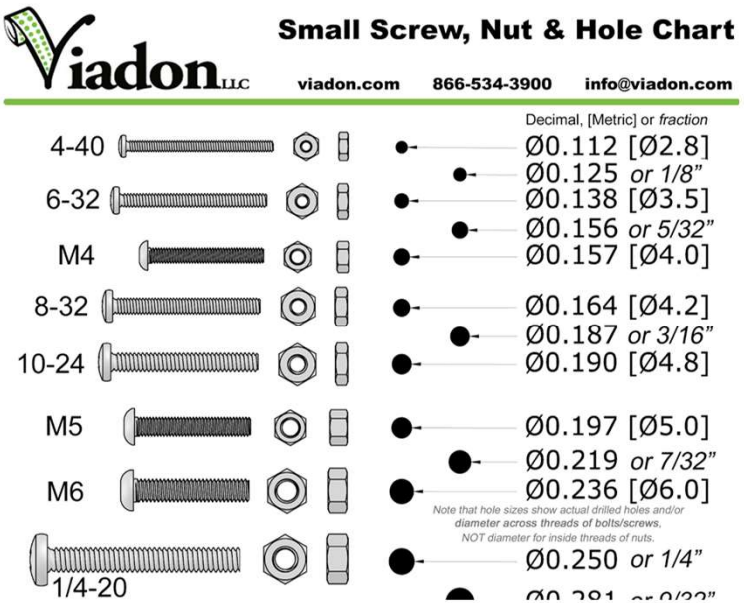
- Decision points:
  - Do I need a point?
  - Am I drilling/tapping?
  - Types of screw head:
    - hex (bolts)
    - flathead/phillipshead
    - hex socket
    - Specialty (set/eye)

cheapest

most torque



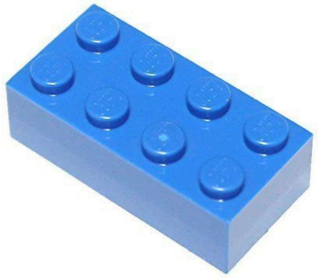
Fastener Sizes

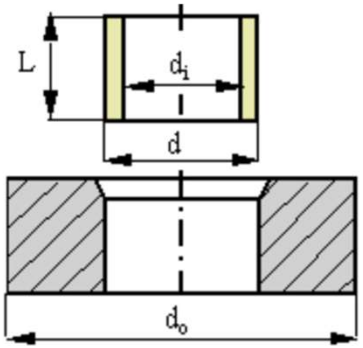


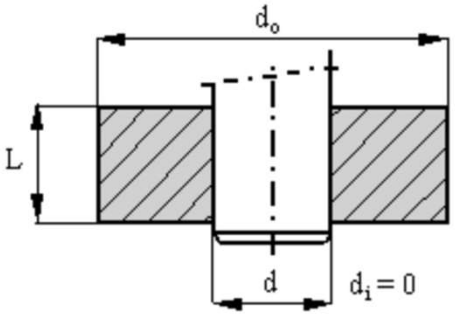
Size (nominal diameter)	Coarse (NC, UNC) Threads per Inch	Coarse (NC, UNC) Tap Drill[a]	Fine (NF, UNF) Threads per Inch	Fine (NF, UNF) Tap Drill[a]
0 (0.060)			80	$\frac{3}{64}$
1 (0.073)	64	No. 53	72	No. 53
2 (0.086)	56	No. 50	64	No. 50
3 (0.099)	48	No. 47	56	No. 45
4 (0.112)	40	No. 43	48	No. 42
5 (0.125)	40	No. 38	44	No. 37
6 (0.138)	32	No. 36	40	No. 33
8 (0.164)	32	No. 29	36	No. 29
10 (0.190)	24	No. 25	32	No. 21
12 (0.216)	24	No. 16	28	No. 14
$\frac{1}{4}$	20	No. 7	28	No. 3
$\frac{5}{16}$	18	Let. F	24	Let. I
$\frac{3}{8}$	16	$\frac{5}{16}$	24	Let. Q
$\frac{7}{16}$	14	Let. U	20	$\frac{25}{64}$
$\frac{1}{2}$	13	$\frac{27}{64}$	20	$\frac{29}{64}$
$\frac{9}{16}$	12	$\frac{31}{64}$	18	$\frac{33}{64}$
$\frac{5}{8}$	11	$\frac{17}{32}$	18	$\frac{37}{64}$
$\frac{3}{4}$	10	$\frac{21}{32}$	16	$\frac{11}{16}$
$\frac{7}{8}$	9	$\frac{49}{64}$	14	$\frac{13}{16}$
1	8	$\frac{7}{8}$	12	$\frac{59}{64}$

Press-fit

- Securing 2 pieces with friction
- Interference fit, hole is smaller than shaft by small amount
- Roughly, force to remove = force to insert
- Large force (e.g. arbor press) used to elastically deform hole/shaft
- **Challenging with rapid prototyping methods**







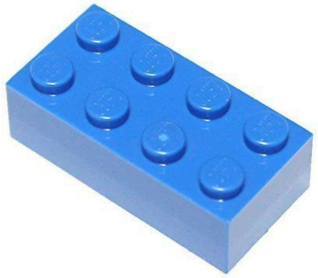
d_i	20	mm	L	20	mm	E_i	100	GPa	ν_i	0.3
d	23	mm	$\delta^{1)}$	0.023	mm	E_o	210	GPa	ν_o	0.3
d_o	80	mm	$\mu^{2)}$	0.12						

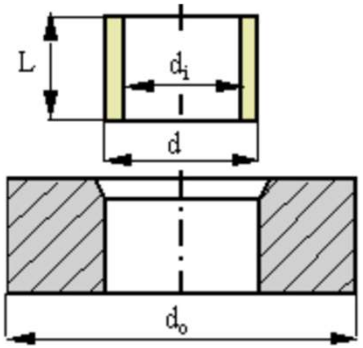
http://www.tribology-abc.com/calculators/e3_8.htm

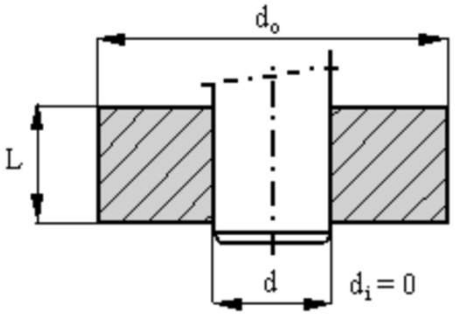
Press-fit

References:

- http://www.tribology-abc.com/sub1.htm
- Calculator: http://www.tribology-abc.com/sub23.htm
- Machinery's handbook: http://www.knovel.com/knovel2/Toc.jsp?SpaceID=10110&BookID=309
- ANSI Standard B4.1-1967, R87, ANSI B4.2-1978 R94 (metric)







d_i	20	mm	L	20	mm	E_i	100	GPa	ν_i	0.3
d	23	mm	δ [1]	0.023	mm	E_o	210	GPa	ν_o	0.3
d_o	80	mm	μ [2]	0.12						

http://www.tribology-abc.com/calculators/e3_8.htm

Adhesives

- Reactive (stronger):
  - CA glue (superglue)
  - epoxy
  - JB-weld
- Non-Reactive:
  - hot glue great for prototyping
  - wood glue

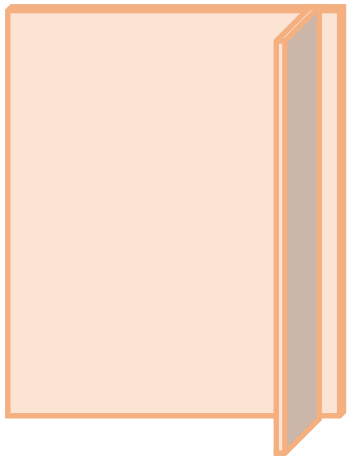
	Wood/ Plywood	Metal	Rubber	PVC*	Glass	Plastic*	Fabric, Paper, Leather	Canvas	Fiberglass (FRP)	Poly-carbonate	Plaster	Ceramic/ Brick	Concrete*
REACTIVE	Epoxy	Epoxy	Epoxy	~~Epoxy~~	Epoxy	Epoxy	~~Epoxy~~	~~Epoxy~~	Epoxy	~~Epoxy~~	~~Epoxy~~	Epoxy	Epoxy
	~~Acrylic~~	Acrylic	Acrylic	~~Acrylic~~	Acrylic	Acrylic	~~Acrylic~~	~~Acrylic~~	Acrylic	Acrylic	~~Acrylic~~	Acrylic	~~Acrylic~~
	Urethane	Urethane	Urethane	Urethane	Urethane	Urethane	~~Urethane~~	~~Urethane~~	Urethane	Urethane	~~Urethane~~	~~Urethane~~	~~Urethane~~
	Polyurethane	Polyurethane	Polyurethane	~~Polyurethane~~	~~Polyurethane~~	~~Polyurethane~~	Polyurethane	Polyurethane	~~Polyurethane~~	~~Polyurethane~~	~~Polyurethane~~	~~Polyurethane~~	~~Polyurethane~~
	Cyanoacrylate	Cyanoacrylate	~~Cyanoacrylate~~	~~Cyanoacrylate~~	~~Cyanoacrylate~~	Cyanoacrylate	Cyanoacrylate	Cyanoacrylate	~~Cyanoacrylate~~	~~Cyanoacrylate~~	~~Cyanoacrylate~~	Cyanoacrylate	~~Cyanoacrylate~~
	Silicone	Silicone	Silicone	~~Silicone~~	Silicone	~~Silicone~~	~~Silicone~~	Silicone	Silicone	~~Silicone~~	~~Silicone~~	Silicone	Silicone

NON-REACTIVE	PVA	PVA	PVA	~~PVA~~	~~PVA~~	PVA	PVA	~~PVA~~	~~PVA~~	~~PVA~~	~~PVA~~	PVA	~~PVA~~
	Contact Adhesive	~~Contact Adhesive~~	Contact Adhesive	~~Contact Adhesive~~	~~Contact Adhesive~~	~~Contact Adhesive~~	Contact Adhesive	Contact Adhesive	~~Contact Adhesive~~	~~Contact Adhesive~~	~~Contact Adhesive~~	~~Contact Adhesive~~	~~Contact Adhesive~~
	Hot glue	Hot glue	~~Hot glue~~	~~Hot glue~~	Hot glue	~~Hot glue~~	Hot glue	~~Hot glue~~	Hot glue	~~Hot glue~~	Hot glue	~~Hot glue~~	~~Hot glue~~
	Construction adhesive	Construction adhesive	~~Construction adhesive~~	~~Construction adhesive~~	~~Construction adhesive~~	~~Construction adhesive~~	Construction adhesive	Construction adhesive	~~Construction adhesive~~	~~Construction adhesive~~	~~Construction adhesive~~	Construction adhesive	Construction adhesive

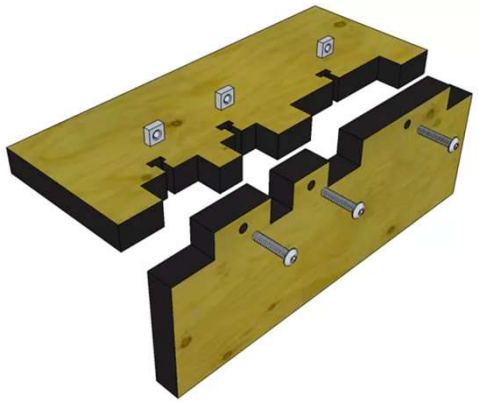
https://d-lab.mit.edu/resources/publications/d-lab-learn-it-adhesives

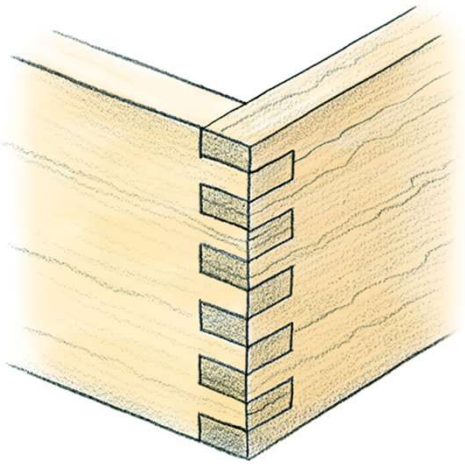
Check-in point – make a corner

https://www.addicted2decorating.com/mdf-vs-plywood-differences-pros-and-cons-and-when-to-use-what.html



Useful Connections - corner joints





box joint

https://makezine.com/2012/04/13/cnc-panel-joinery-notebook/

Useful Connections - mounting to shafts

Shaft with a flat on it
"D-Shaft"

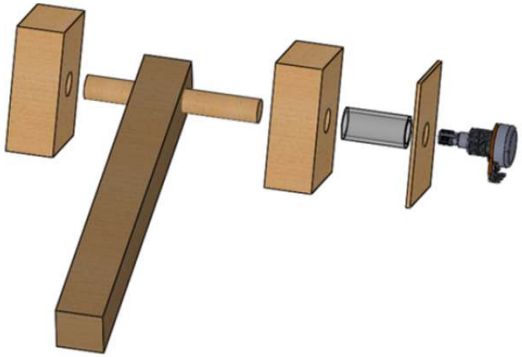
Shaft couplers
(from mcmaster)

"Universal"
mounting hub
(from pololu)

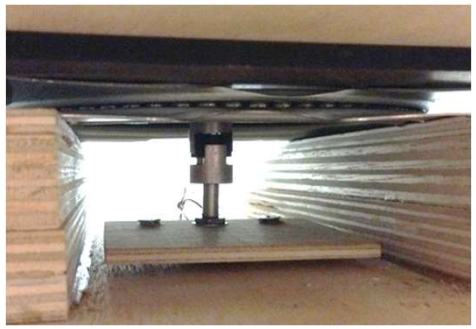
Hex wheel
adapter
(from pololu)

Easiest: lasercut a D-shaped hole

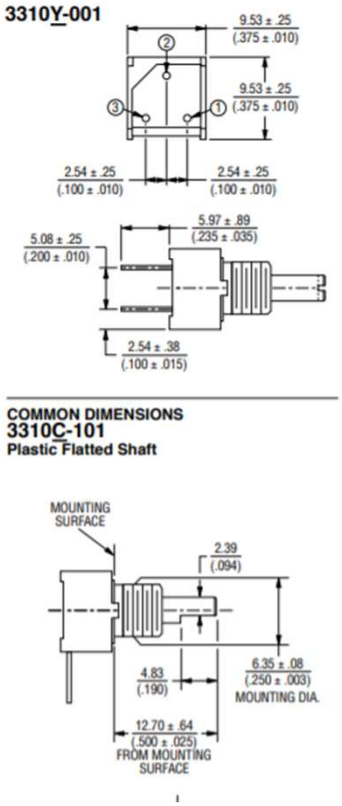
Designing for Potentiometer



https://drededcurseofme218.weebly.com/mechanical-system.html

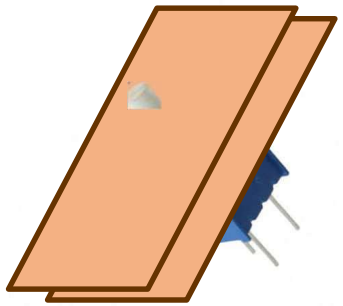


https://newyorknewyorkme218a.weebly.com/mechanical.html



https://www.bourns.com/docs/Product-Datasheets/3310.pdf

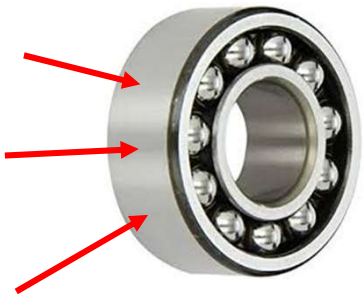
¼-32 Nut



Digikey

Useful Connections - joints that move

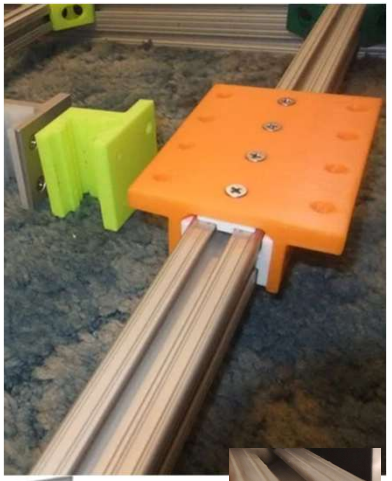
Rotational: Ball bearings



Thrust bearings - ball or roller bearings for axial loading

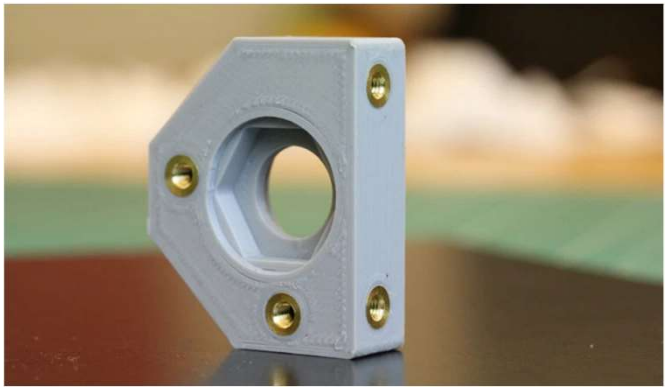
Translational:

linear bearings or bushings, t-slots, v-slots



Useful Connections - heat-set inserts

- Add reliable metal threads to laser-cut or 3D printed parts
- Great when thru-holes for nuts+bolts are not possible
- Some amount of interference is required for a good fit - check McMaster for recommended dimensions
- Don't touch plastic with a soldering iron

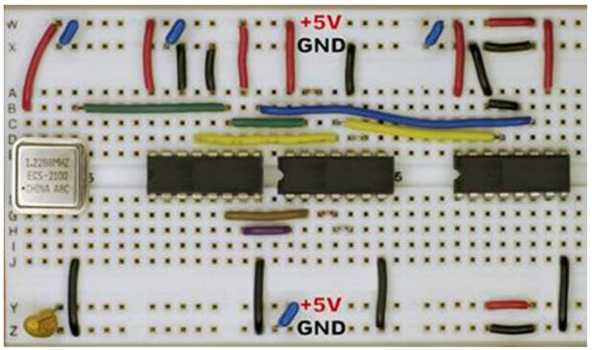


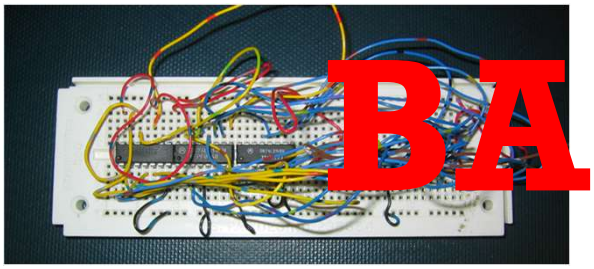
02

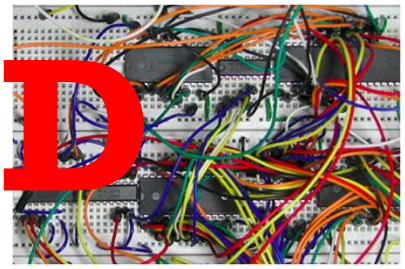
Electrical Prototyping

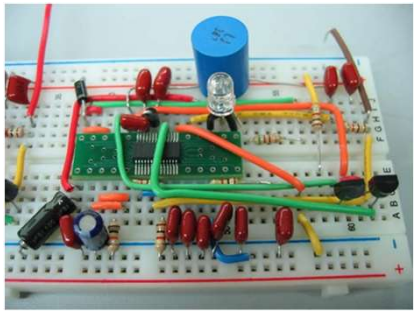
Breadboard until you have everything right

- don't spaghetti-wire!!
- keep wires as short as possible
- draw circuit diagrams, and wire your breadboard to mimic them
- keep wires as 2D as possible
- color code as much as possible









Solder connectors for components, batteries

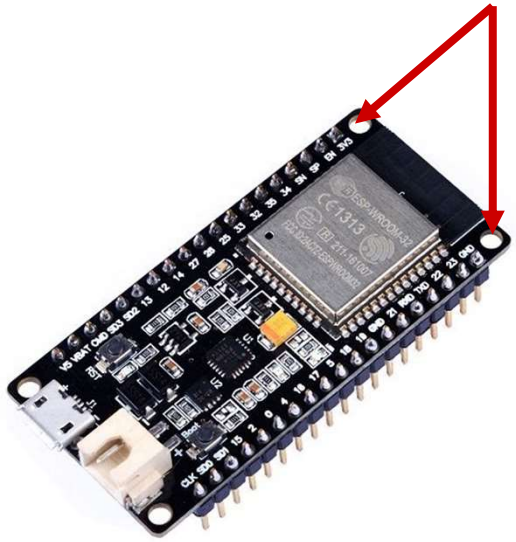
- use Molex connectors to make wiring more reliable, electronics more modular
- more reliable = faster debugging
- use larger (higher amperage) connectors for power, makes switching batteries safer/faster

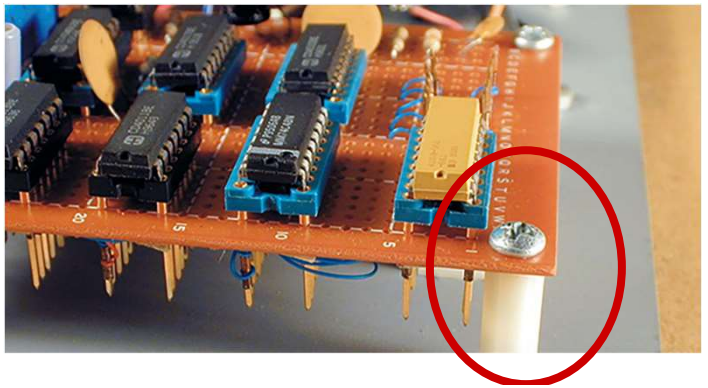
Solder connectors for components, batteries

strip wire → crimp → solder → insert into housings → connect

Mount microcontrollers/electronics

- mount to something rigid with standoffs
- that's what these are for





Random Pointers

- Mount electronics so they are accessible - don't spend precious time disassembling your robot to get at buggy circuits
- Mount a big power switch in line with the battery for your robot
  - you can save the robot from itself if something is going drastically wrong

03

Mechatronics Prototyping

More than just a sum of its parts

- Mechanical
- Electrical
- Software
- Interfacing

Slower to Iterate

Faster to Iterate

Mechanical **Electrical** **Software**

Easier to debug

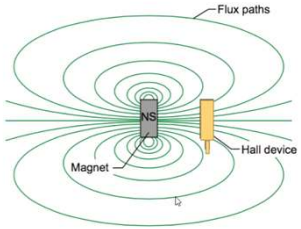
Harder to debug

Interfacing

How to make your own life easier

- Start SIMPLE, and build up
  - Build in parallel, if possible
- Pseudocode/Diagrams
- Subroutines/Subsystems
- Clean Code & Wiring

ı.com



https://www.freepik.com/premium-vector/pyramid-magnetic-balls_7585187.htm

Jenga Tower of 50 Blocks by Johanne

dwrl.utexas.edu/2015/10/19/examining-code-debugging-rhetoric/

Debugging

- A lot of times, the new thing is the problem
- Sometimes, the new thing broke the old thing
- Print statements for code, O-scope for wires
  - Don't forget to remove/comment excess prints after!

04a

Rapid Manufacturing (@Penn… Remotely)

When to use rapid manufacturing?

- 3D printing and laser cutting highly capable manufacturing processes

Titanium
embodi3d.com

Quadruped (Sarah Bergbreiter)
nanoscribe.com

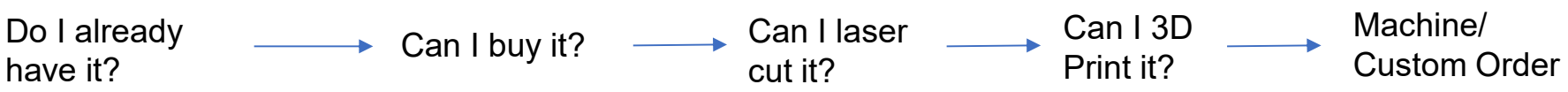
When rapid manufacturing may NOT work

- High forces or pressures
- Many cycles (fatigue)
- Very large

- Can it be purchased?

When to use rapid manufacturing at Penn?

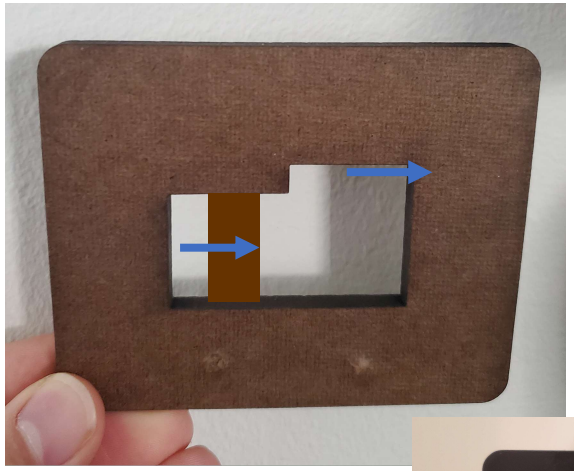
- Laser cutting is great for regularly-shaped parts, larger parts, robot chassis…
- 3D printing can be unreliable and is slower
  - the Makerbots can be finicky
- 3D printing works for whatever you can't make, laser cut, or buy

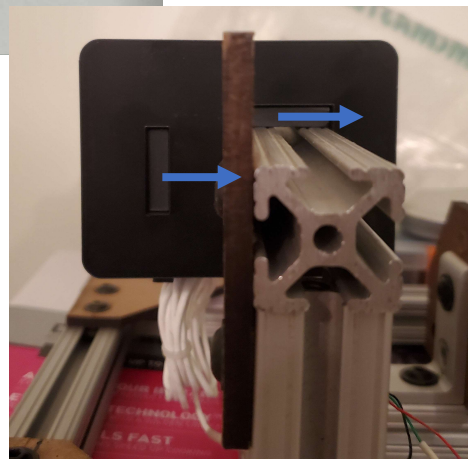


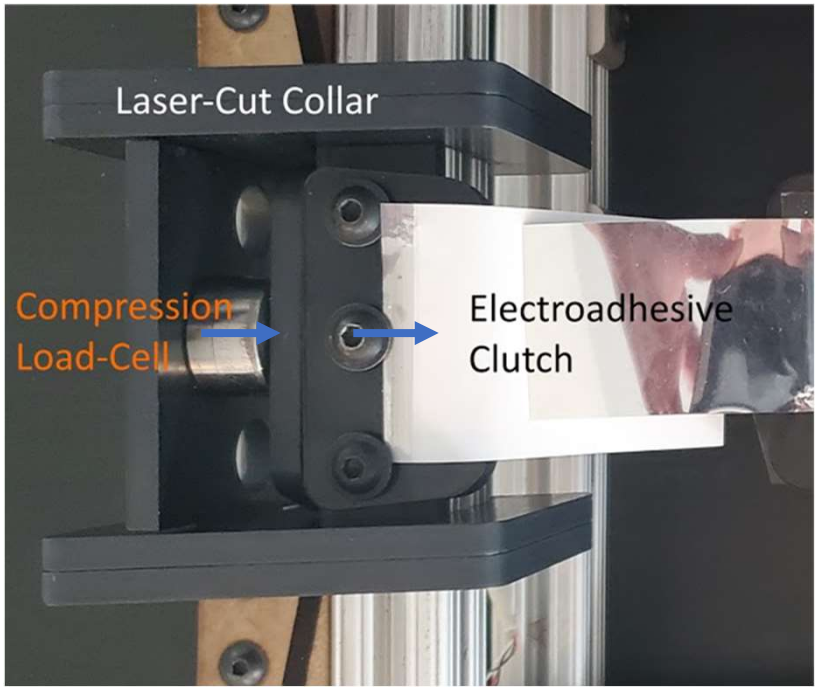
Design/Prototyping challenge

- I want to do a tensile test on AL foil.
- My only sensor is a compressive load cell
  - 3 screw holes in the back
  - ~1/4” diameter pressure area
- **How should I attach them?**

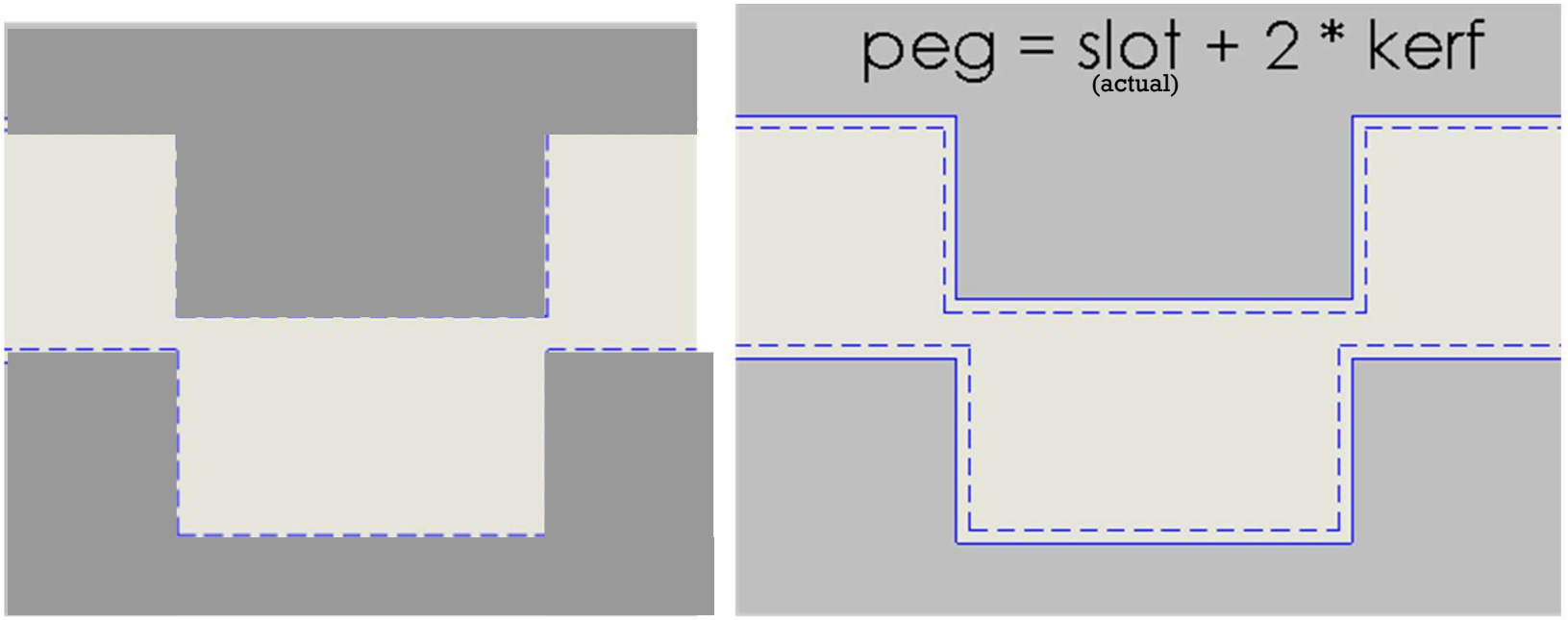
My (labmate's) solution:







Kerf



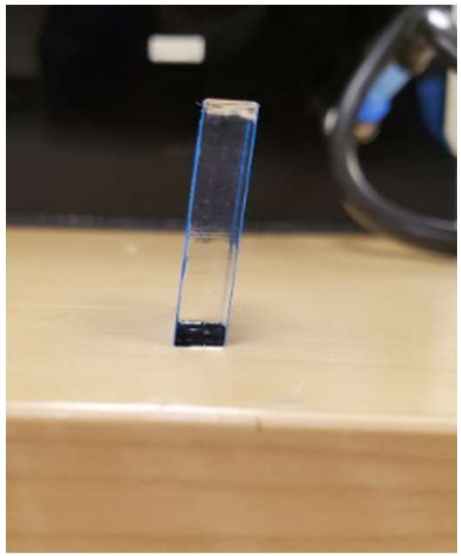
Kerf = 0.007”

- Useful links:

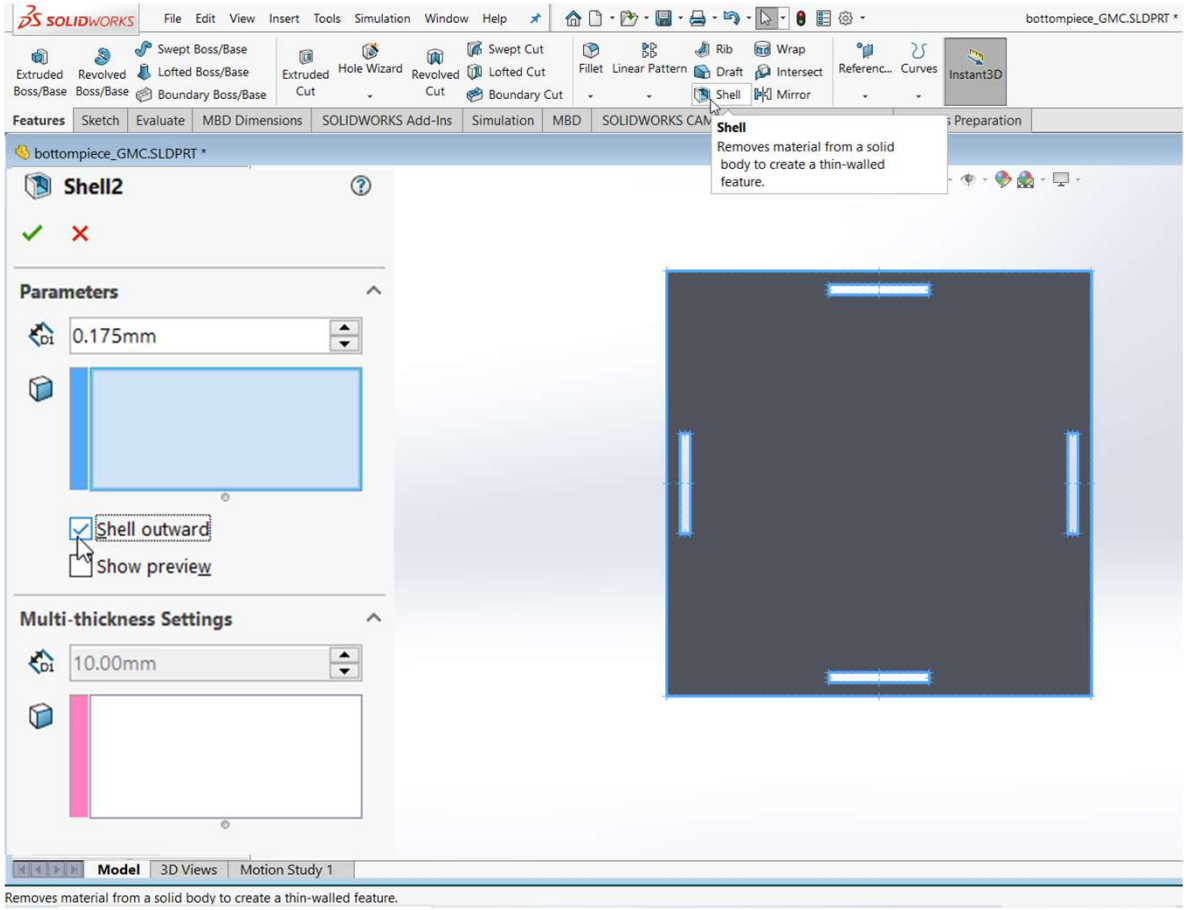
https://meamlabs.seas.upenn.edu/rapid-prototyping-lab/lasers/usage-guide/
https://meamlabs.seas.upenn.edu/rapid-prototyping-lab/tips-and-tricks/

Another aspect of Kerf

- This is a “straight” cut
- Don’t over-rely on your model
- Leave some wiggle and use adhesive (recommended)

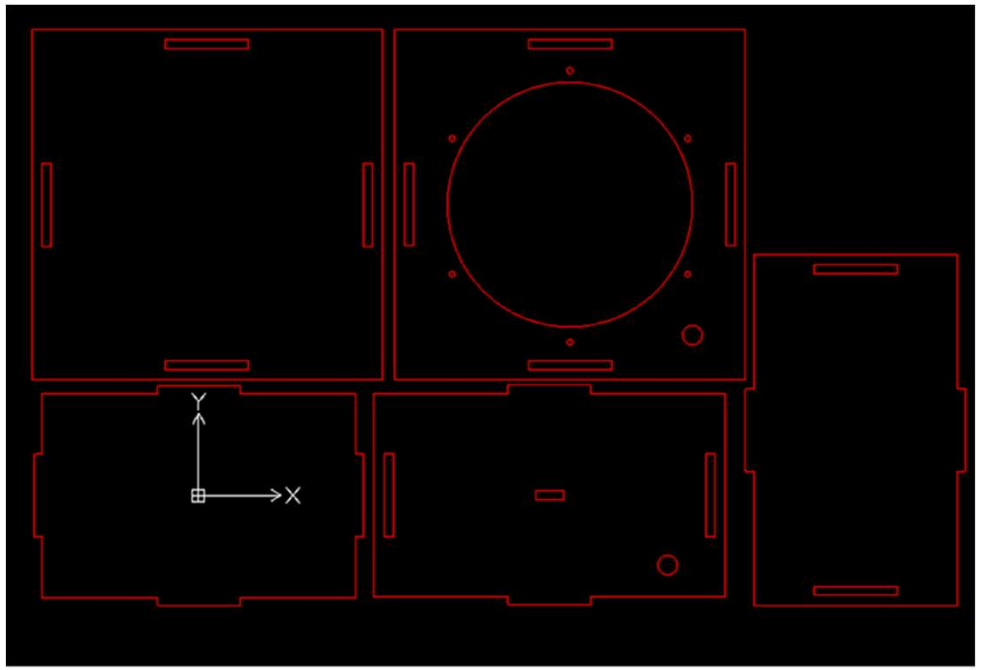


Kerf in Solidworks – the shell function



Shelling is an alternative that allows for design with the intended dimensionality

Example



04b

Creating .dwg files

RPL Materials - Acrylic and MDF

Acrylic

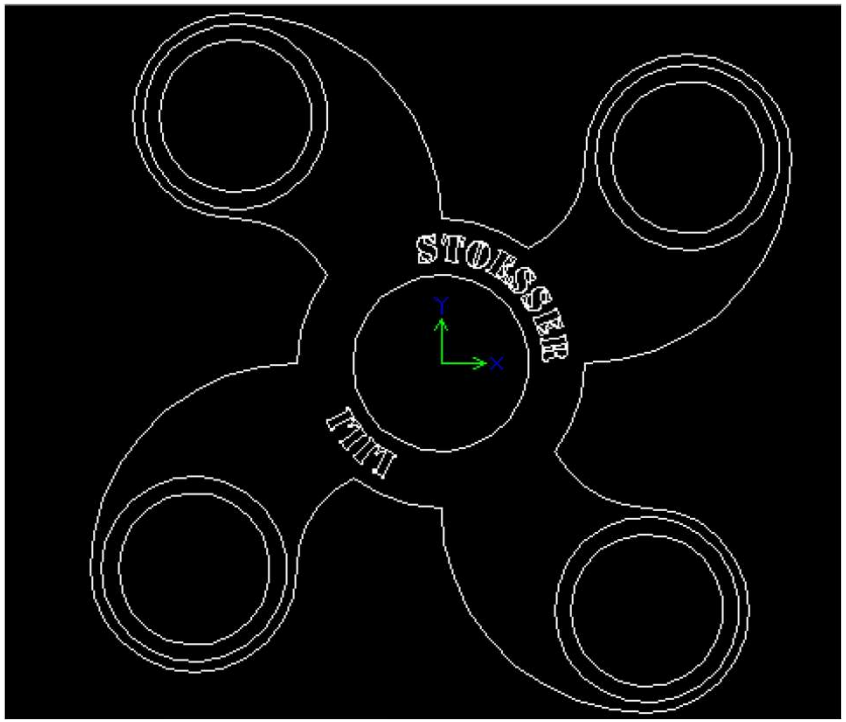
- ¼ inch (black, white, clear, and smoke)
- ⅛ inch (black, white, clear, smoke, red, yellow, green, and blue

MDF

- ¼ inch
- ⅛ inch

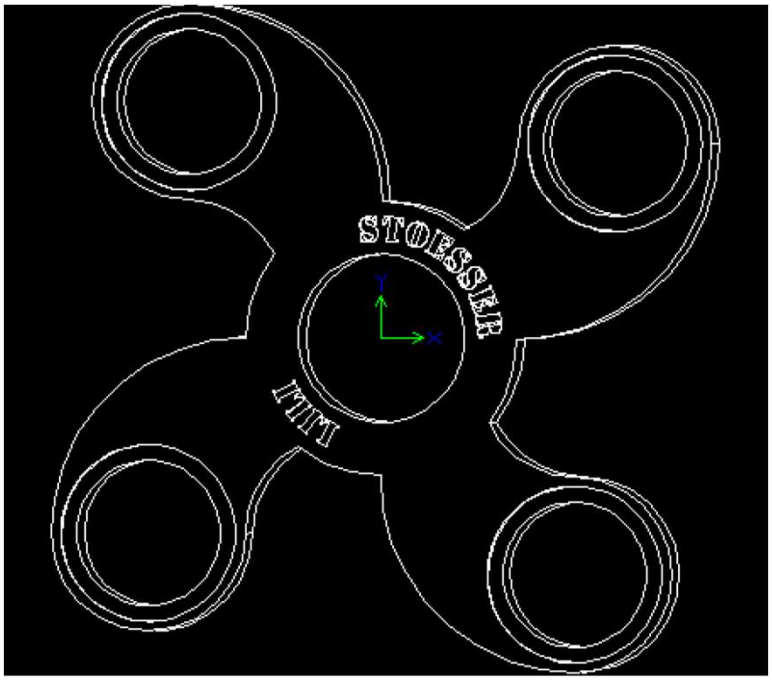
Saving as a .dwg

File -> save as -> change file type to .dwg



Bad!

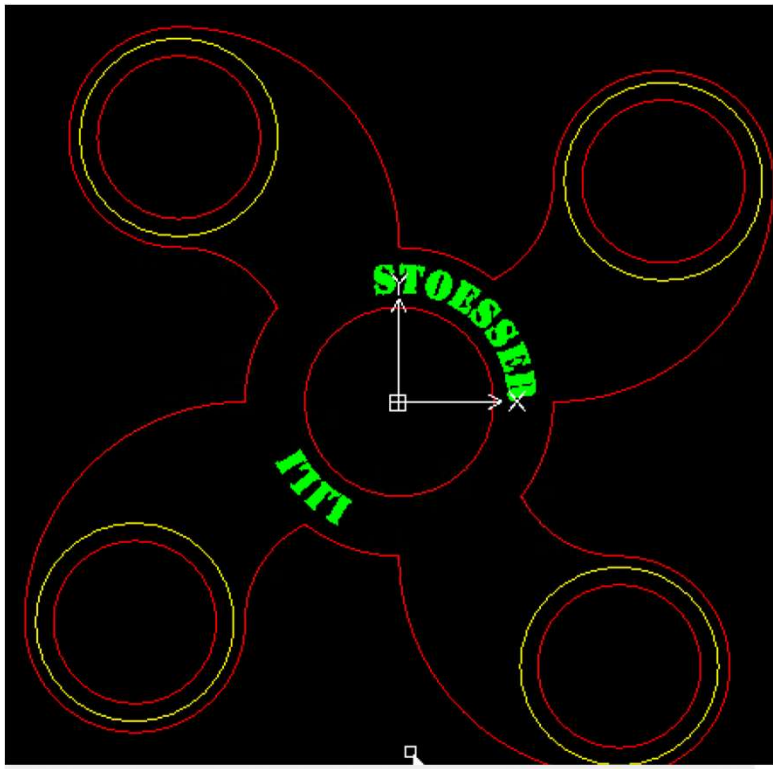
click control + 8 to snap to a front view



Open .dwg in DraftSight

DraftSight and Solidworks are available on the virtual PC lab

- Delete "Solidworks Educational Product…"
- Highlight ALL lines and set line width to 0.05in
- Change line colors
  - To cut all of the way through make lines **red**
  - Make vector etched lines **yellow**
  - To raster etch use the "hatch tool" and set the pattern to solid. Then make your filled in features **green**



3D printing

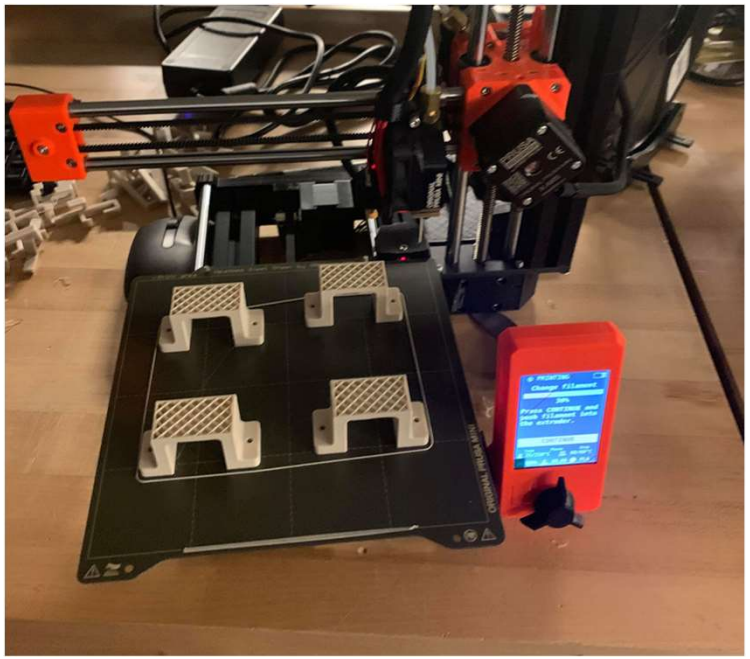
RPL Printers (Lulzbot mini 2)

- PLA

Preparing files

- Save as .STL
- Open your STL in CuraLULZBOT
- Make sure your part is flat on the bed
- Save as .gcode

Just send us your .sldprt

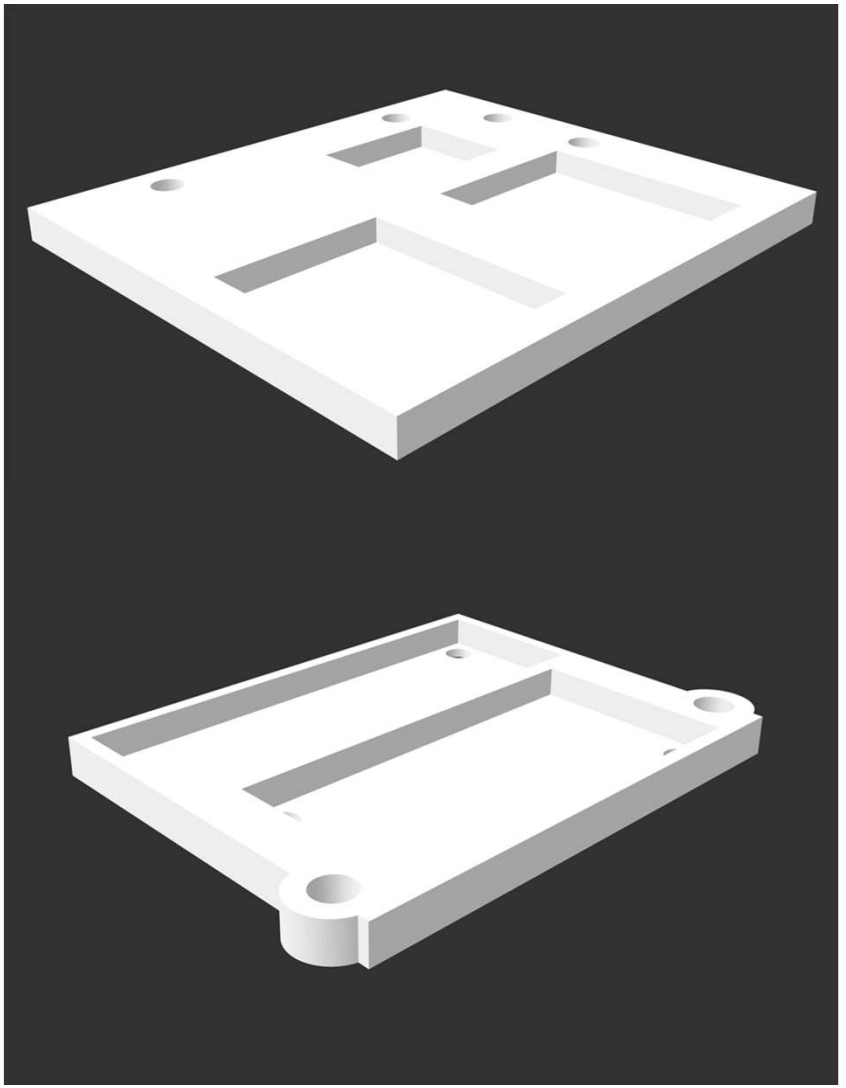


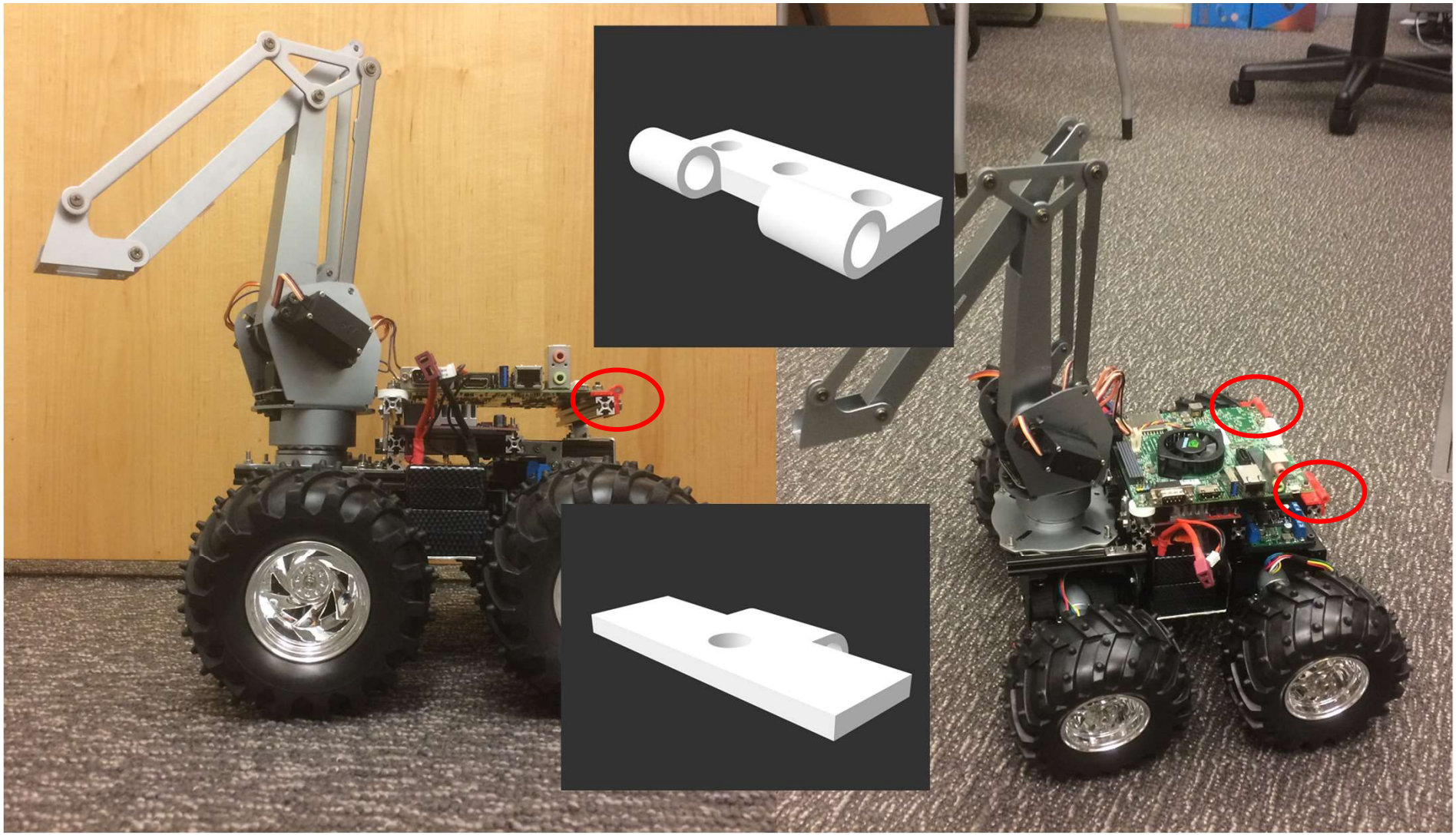
Tips!

- Make a Solidworks assembly BEFORE you cut/print anything
- MDF is easier to press fit (acrylic is more likely to snap)
- Be creative!

05

Prototyping Case Study





Summary

- Prototype things so that their function is easy to visualize
  - applies to coding, electronics, mechanics
- Work on mechanical aspects EARLY
  - This prototyping will take the most time