Robotics 311 : How to build robots and make them move

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ROB 311 – Lecture 9

- Today:
  - Review laser cutters
  - Discuss modifying .DXF files for use in the FRB laser cutter
  - Discuss design and living hinges and best practices
  - Water jet cutting

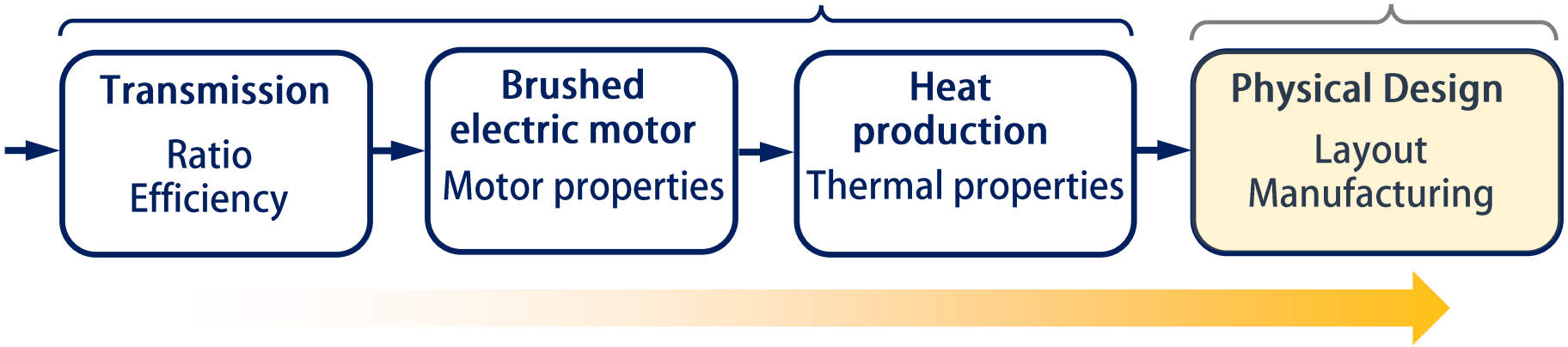
- Announcements
  - HW 2 posted
  - Due 10/4 at class start
  - Where are the instructions for all the FRB prototyping machines?
    - Canvas\Resources\Instructions for Prototyping Machines

Manufacturing Types

"spec'ing"
This happens first

Now you know:
- Torques
- Speeds
- Ratio
- Rough sizing

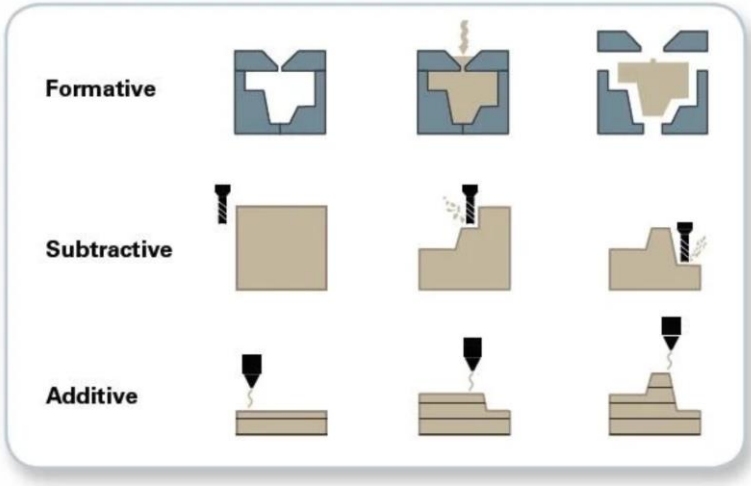
Upcoming focus of the class



- So far, we have spec'd the components – we've chosen the architecture and now we need to make it a reality
- This includes choosing the physical layout, solid modeling, creating design files, and manufacturing
- We will go over *manufacturing* first for the sake of lab
- There are three types of manufacturing
  - Formative
  - Subtractive
  - **Additive**

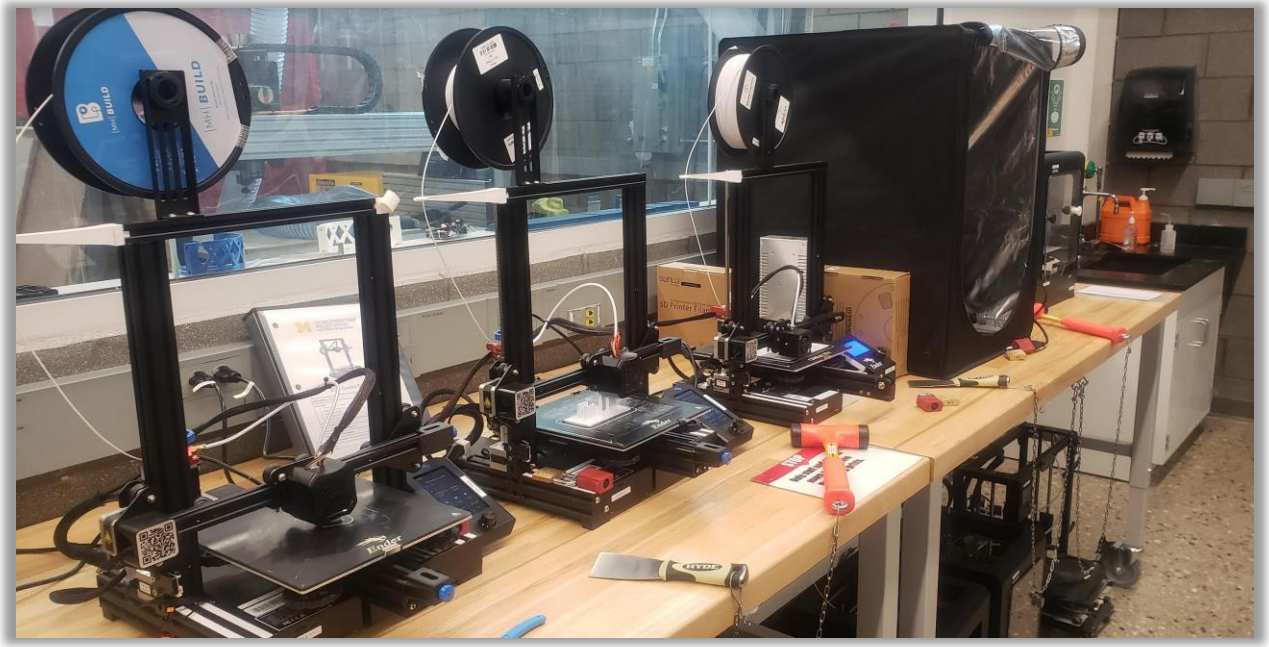
Some

What we will focus on in this course



Where to 3D Print

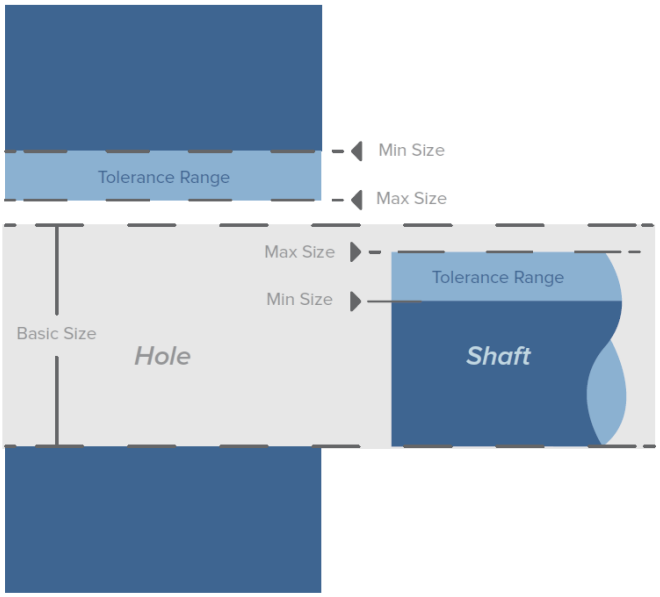
- Printers are located in FRB Makerspace
- 3x Creality Ender 3 (FDM)
- You will have to use slicing software (Cura)
- Save .gcode to SD card -> insert into 3D printer
- Manuals uploaded to Canvas\Prototyping Machine Instructions
- PLA filament – provided for free
- Layer thickness: .1 - .4 mm
- Print size: 220 x 220 x 250 mm

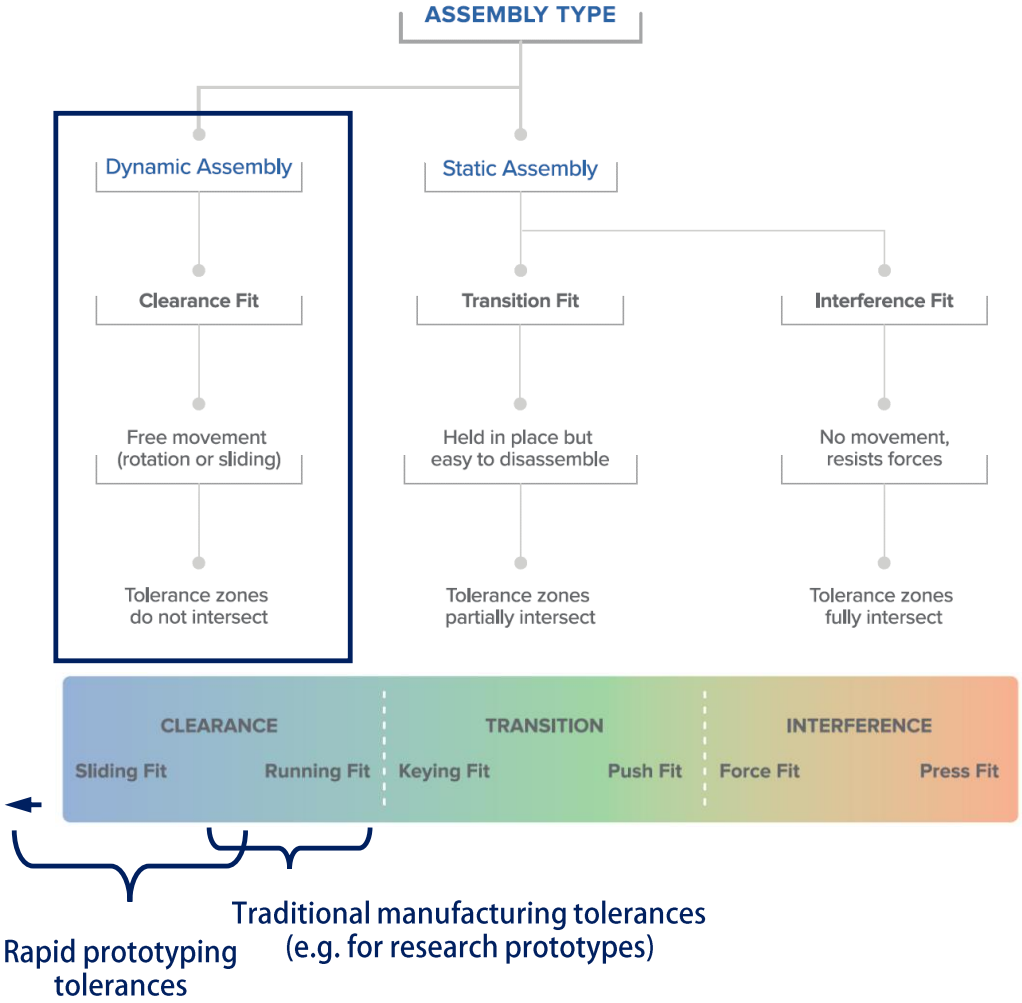


FRB Makerspace
1141 FRB

Load .gcode onto SD card and insert into printer

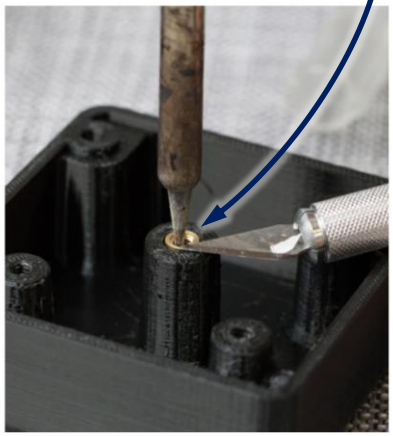
Best Practices – Tolerancing





- You may need to add 0.2 - 0.3 mm to diameter of parts that rotate (OD)
- You may need to add 0.1 mm for clearance holes
- Layers compress to make holes smaller in FDM printing

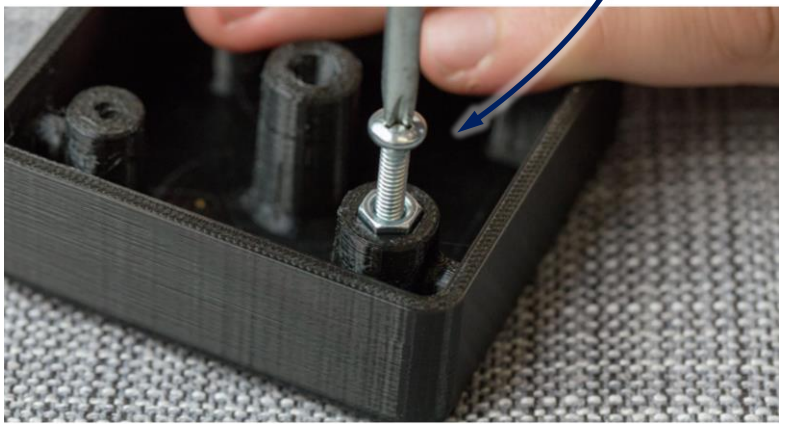
Best Practices – Fasteners



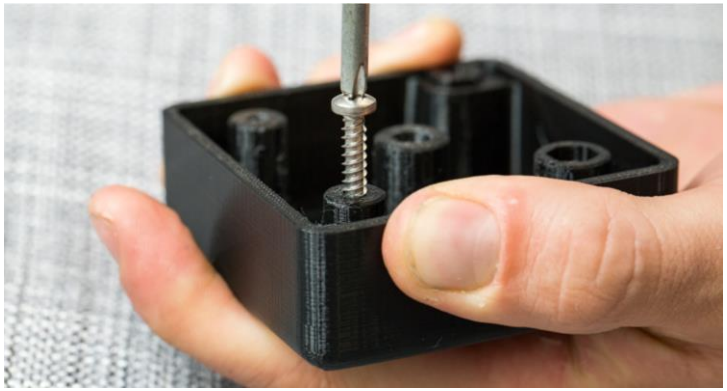
These are awesome (demo!) and should be used whenever possible

Threaded inserts can be heated and installed in a part. They come in both metric and English sizes. A soldering iron can be used to heat the insert for installation. Simple and robust.

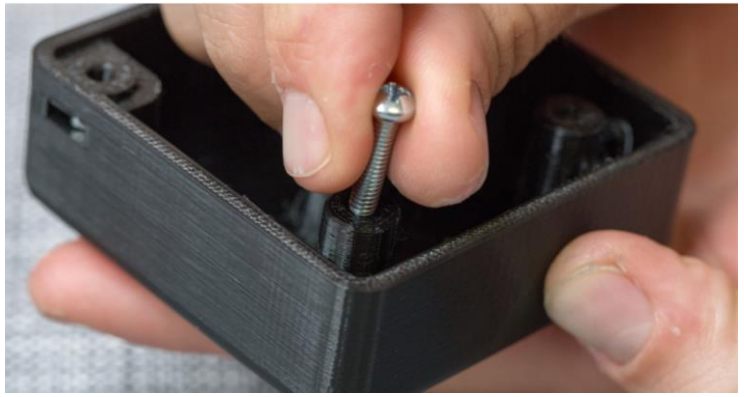
We used mostly these in our ball-bot



Hex nuts can be designed to be captured in the part, so additional tools are not needed.



Self-tapping screws can be used to provide a secure fit. Inserts and hex nuts will be more robust and easier to assemble / disassemble.

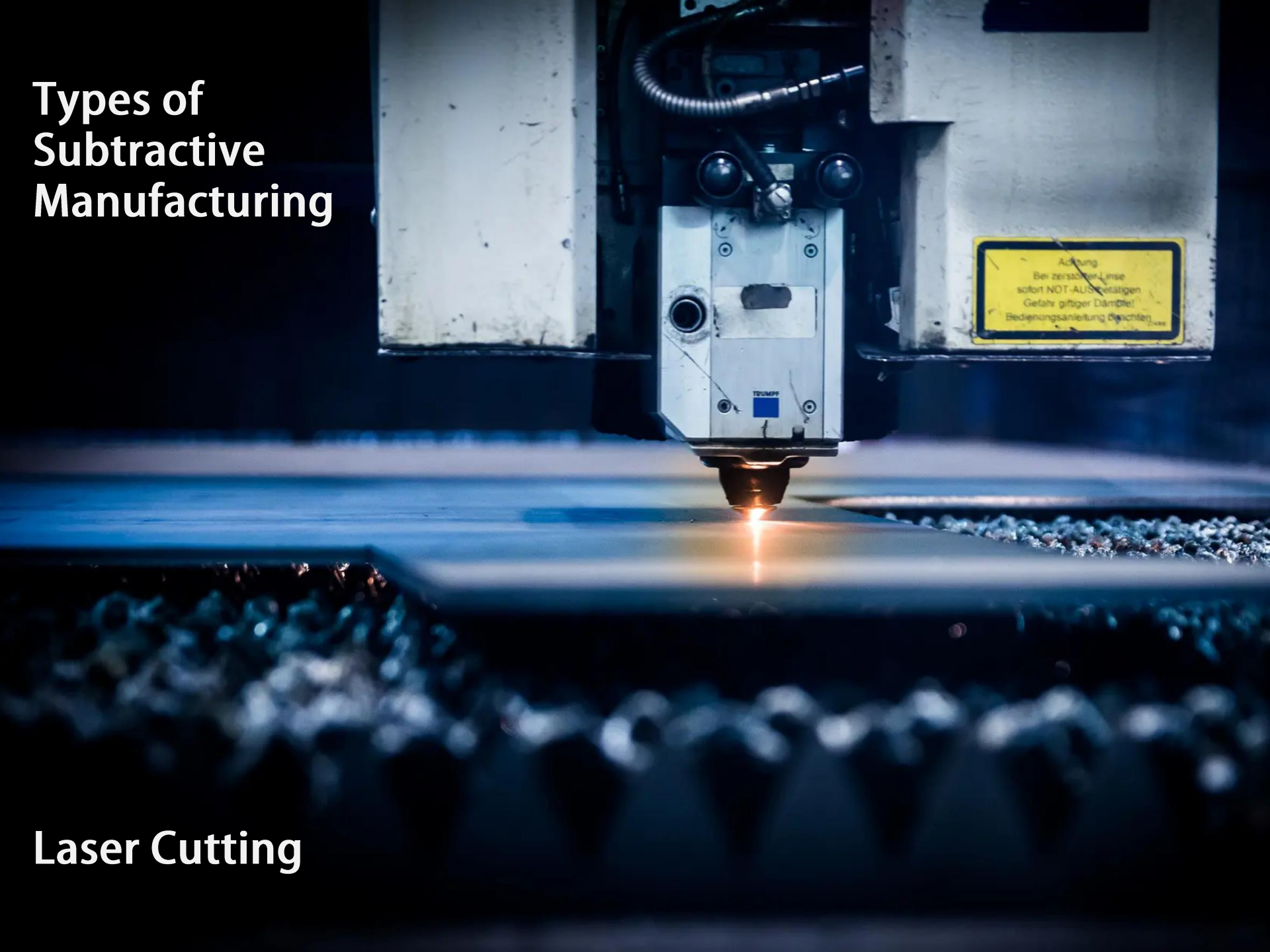


Machine screws will provide the lightest hold and should be avoided. Much shallower thread depth compared to the self-tapping screw. SLA can be tapped in solid modeling but use other methods, if possible.

Best Practices – Where to Get Solid Models

- Many times you may want to make something that requires the solid model of something common
  - iPhone, body parts, characters, etc.
- Repositories exist where you can download / view solid models
  - www.grabcad.com – online repository with 1.3M+ solid models
  - www.thingiverse.com – online repository with millions of STL files
- With the 3D printing instructions, you can just download and print!

Types of Subtractive Manufacturing

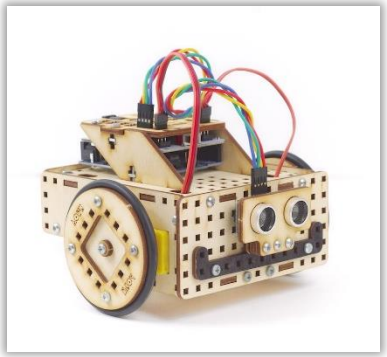


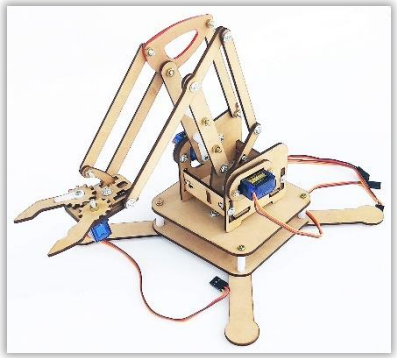
Laser Cutting

Subtractive Manufacturing

- 3D printing is a key aspect of rapid prototyping, and some methods from subtractive manufacturing are also quick and easy
- Subtractive manufacturing:
  - CNC machining (milling, turning, boring, etc.)
  - Laser cutting
  - Water jet cutting

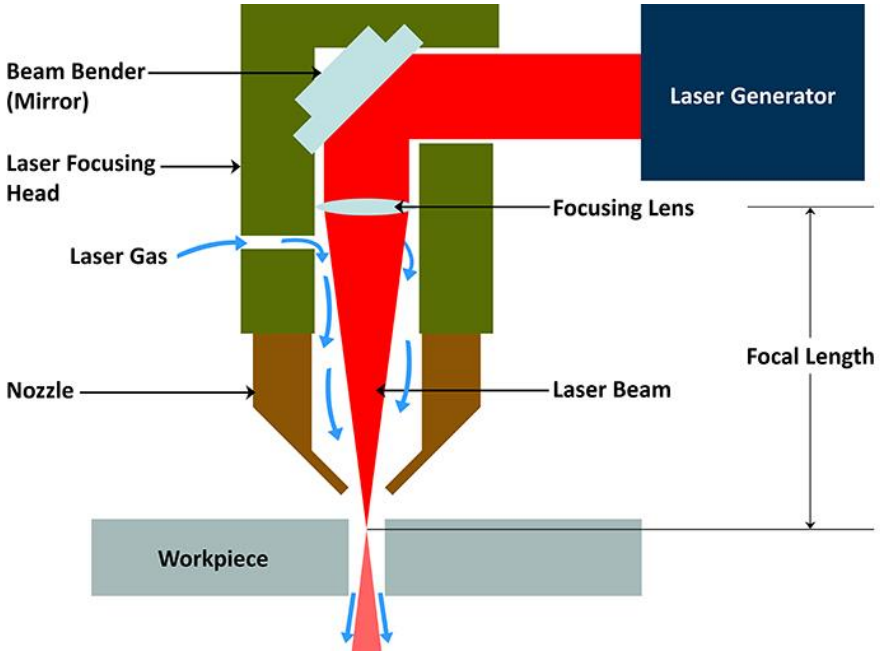
  } We will discuss these
- These are powerful tools for prototypes generation
- A little clever design goes a long way





Laser Cutters

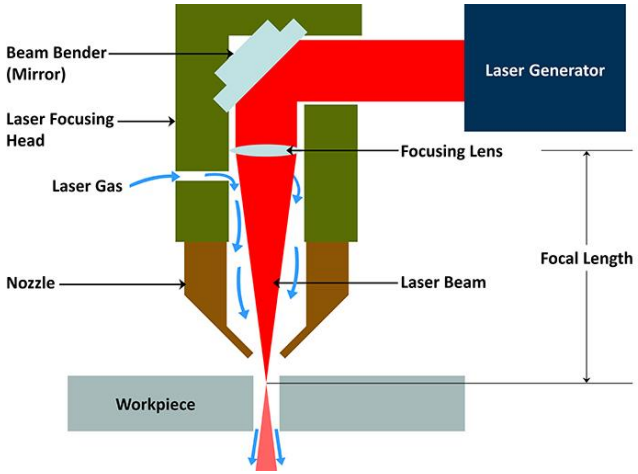
- A laser cutter focuses a laser onto the surface of a part
- Can cut detailed parts as well as raster images (2D)
- Protective gas layer
- The cut has some slight width due to the laser
- Known as "kerf"
- Three types of laser cutters

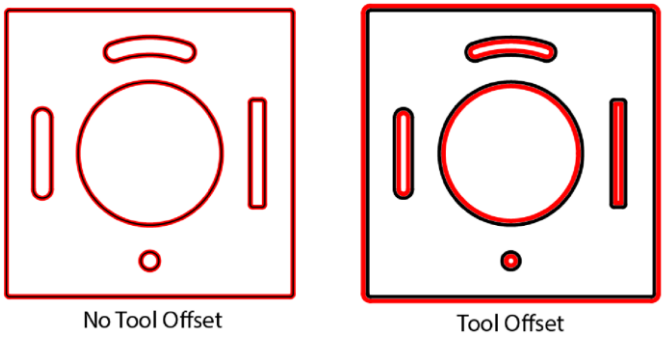


  - **CO_2 lasers** – tubes containing specialized gas produce a laser that is focused on the part. Power ranges from 25 – 100 W. Cuts most organics, some plastics, and some thin metals
  - **Fiber lasers** – Solid state laser enabling a small focal diameter. Up to 100x more powerful than CO_2 lasers, and versatile, being able to cut metal.
  - **Nd:YAG / Nd:YVO lasers (Neodymium lasers)** – powerful lasers with a narrow focal length used to cut many materials, even some ceramics

Kerf and Tool Paths

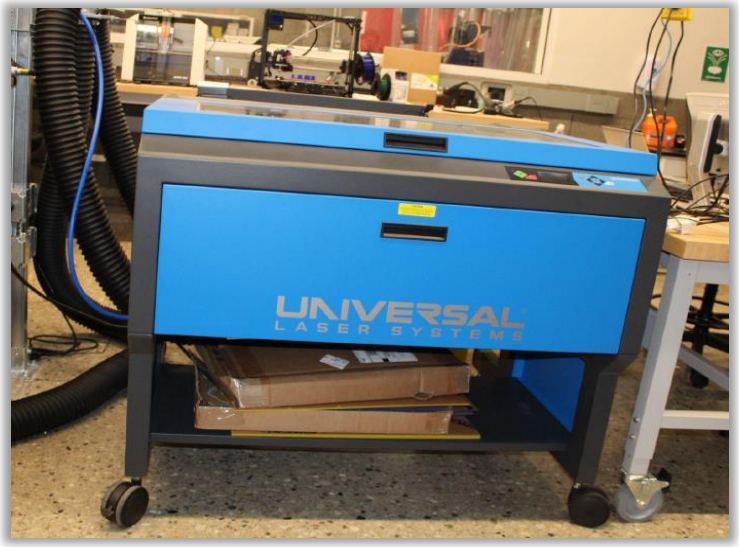
- Kerf
  - Typically 0.08 – 0.45 mm
  - Depends on:
    - Laser optics and focusing
    - Material type / thickness
- Consequences
  - Parts will be undersized
  - Holes will be oversized
- Tool paths can be offset to account for kerf
- Universal CO_2 laser does not offset kerf
- You will need to modify the parts / .DXF file to account for any tolerances needed





FRB Makerspace – Laser Cutter

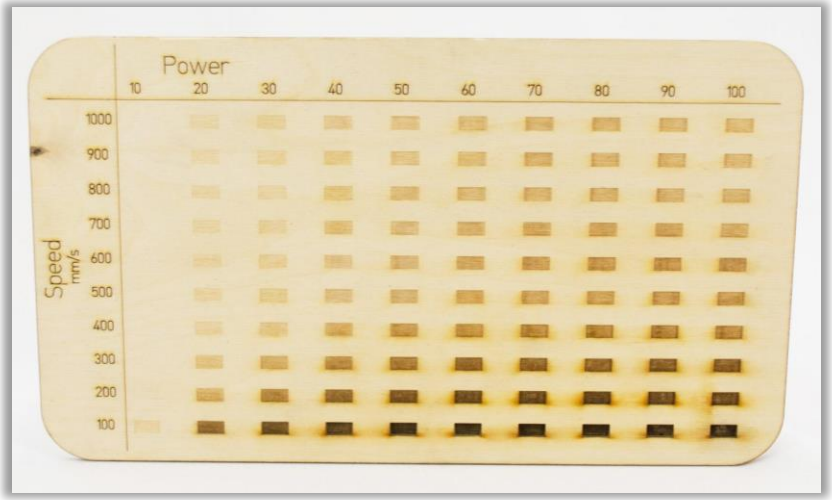
- Laser cutter in FRB Makerspace
- CO_2 Laser
- Universal PLS 75 W
- See instructional information / SOPs uploaded to Canvas
- Laser cutters can be dangerous!
- Follow all safety procedures
- You will need to learn the SOP
- Settings
  - **Power** – intensity of the laser
  - **Speed** – cutting speed
  - **PPI** – laser pulses for rastering
  - **Z-axis** – always set to off



Program to operate CO2 laser

Vector and Raster Settings

- Vector graphics – graphics that can be scaled. Functions represent the relationships between the pixels, rather than pixel-level data
- Raster graphics – individual pixels (e.g. bitmaps) that encode images. Raster graphics are not scalable
- Line colors
  - Vector cutting – red line
  - Vector etching – black line
  - Raster etching – black filled area
- Other colors are user definable
- Setting the colors can be used to create intricate parts with high detail
- Sometimes test parts are used to verify laser settings



Vector and Raster Settings

- Materials and settings for Universal CO_2 laser
- These are a guide and should be verified with Alyssa / test parts

ACRYLIC	POWER	SPEED	PPI	PASSES	DEPTH
LIGHT RASTER ENGRAVE	22	100	500	1	.002"
DEEP RASTER ENGRAVE	100	90	500	1	.010"
VECTOR ENGRAVE	2	4	1000	1	.005"
VECTOR CUT	100	2	1000	1	.25"

ANODIZED ALUMINUM	POWER	SPEED	PPI	PASSES	DEPTH
RASTER ENGRAVING	30	100	500	1	.001"
VECTOR ENGRAVING	4	4	1000	1	.001"

CORK	POWER	SPEED	PPI	PASSES	DEPTH
RASTER ENGRAVING	80	90	500	1	.01"
VECTOR ENGRAVING	4	4	500	1	.01"
VECTOR CUT	25	1.6	500	1	.060"

GLASS	POWER	SPEED	PPI	PASSES	DEPTH
RASTER ENGRAVING	100	30	300	1	.001"
VECTOR ENGRAVING	10	7.9	300	1	.001"

LEATHER	POWER	SPEED	PPI	PASSES	DEPTH
RASTER ENGRAVING	19	100	500	1	.001"
VECTOR ENGRAVING	3	4	500	1	.001"
VECTOR CUT	50	4.1	200	1	.1"

LEATHER	POWER	SPEED	PPI	PASSES	DEPTH
RASTER ENGRAVING	19	100	500	1	.001"
VECTOR ENGRAVING	3	4	500	1	.001"
VECTOR CUT	50	4.1	200	1	.1"

MARBLE	POWER	SPEED	PPI	PASSES	DEPTH
RASTER ENGRAVING	100	82	500	1	.003"
VECTOR ENGRAVING	10	4	500	1	.003"

MATTE BOARD	POWER	SPEED	PPI	PASSES	DEPTH
RASTER ENGRAVING	30	80	250	1	.005"
VECTOR ENGRAVING	10	4	250	1	.005"
VECTOR CUT	25	3.2	200	1	.050"

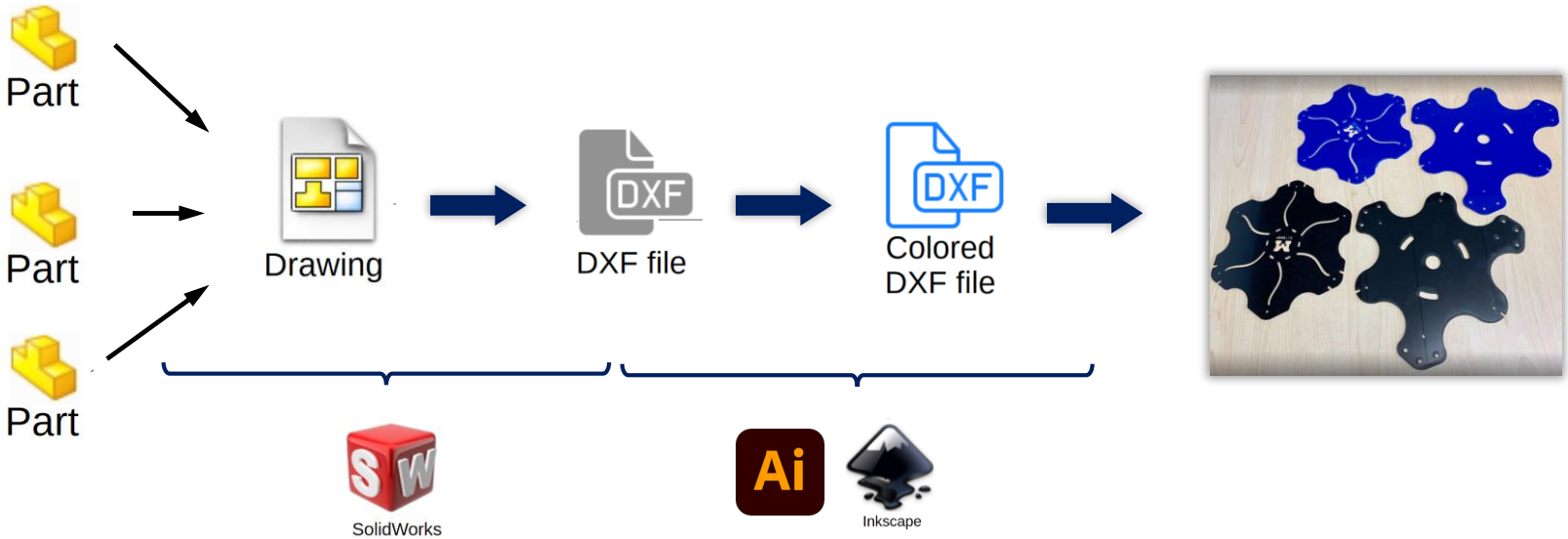
OTHER PLASTICS	POWER	SPEED	PPI	PASSES	DEPTH
RASTER ENGRAVING	15	100	500	1	.001"
VECTOR CUT	25	1.2	500	1	.060"

RUBBER STAMPS	POWER	SPEED	PPI	PASSES	DEPTH
RASTER ENGRAVING	100	23	500	1	.030"
PERFORATED VECTOR CUT	60	3.1	90	1	.040"

WOOD	POWER	SPEED	PPI	PASSES	DEPTH
RASTER ENGRAVING	100	596	500	1	.020"
VECTOR ENGRAVING	80	10.1	500	1	.030"
VECTOR CUT	50	3.1	500	1	.125"

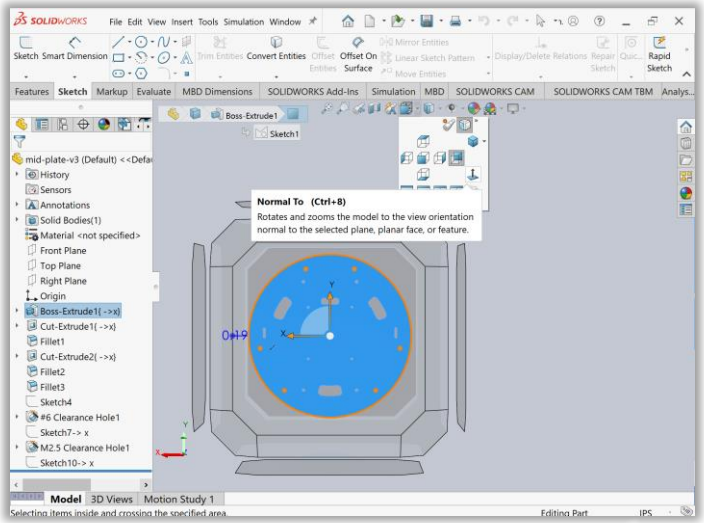
How to Create .DXF Files

- Laser cutters operate in 2D – we need to create 2D files to provide to the laser cutter
- First is to create a drawing in Solidworks
- Then the drawing can be saved as a .DXF file
- Once created, the .DXF file must be altered to provide the correct colors
- The colors of the .DXF provide instructions on the cut type (cut vs. raster)



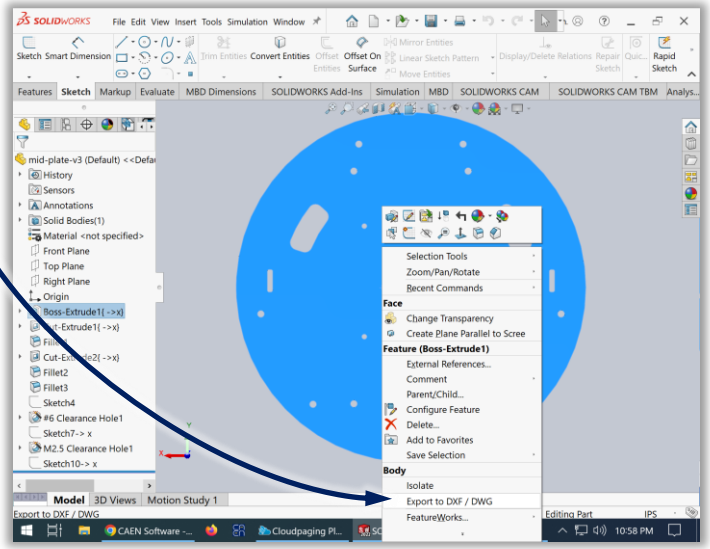
How to Create .DXF Files

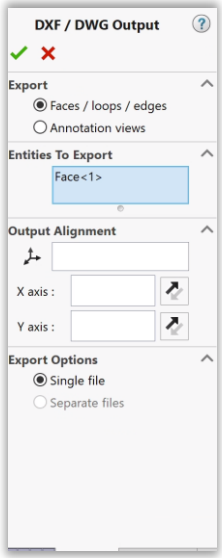
- One easy way is to export directly from Solidworks
- This is especially easy for 2D parts
- To create a .DXF from a 2D part
  - Set part units to “IPS”
  - Select the face to cut
  - Right click and select ‘Export to DXF / DWG’



Set to “IPS”

This exports opens the menu to export a face as a .DXF

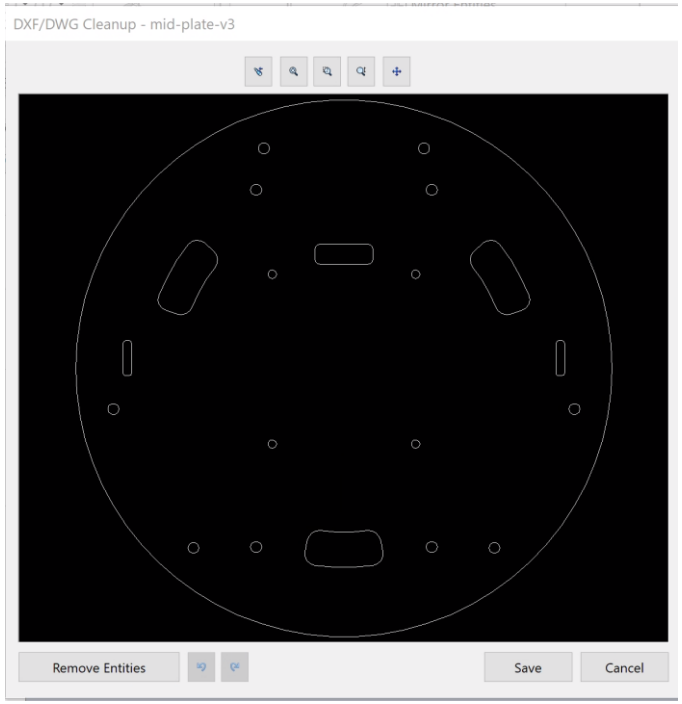


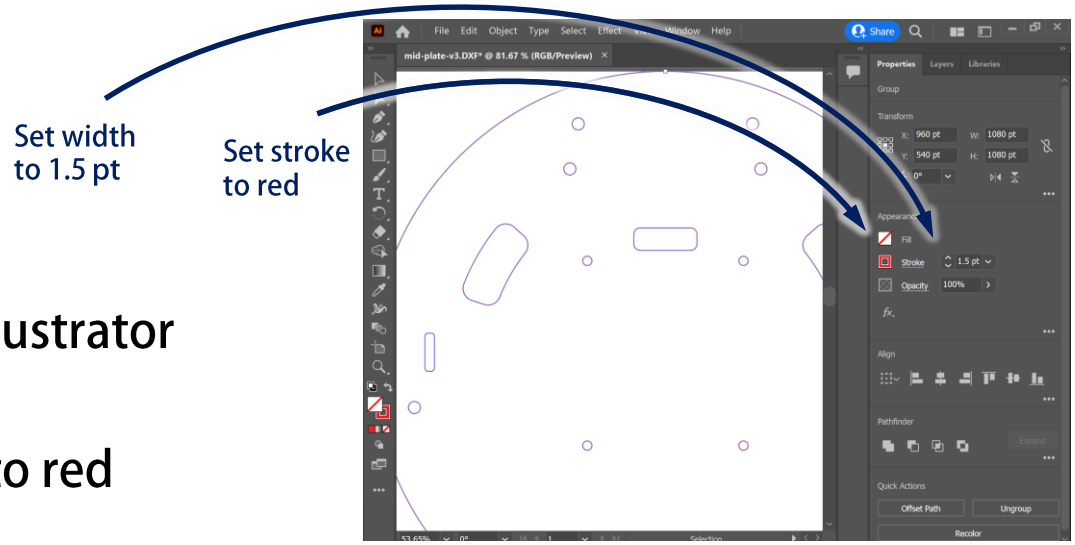


Settings that allow adjustment of export and axis alignment

Changing Colors in Illustrator

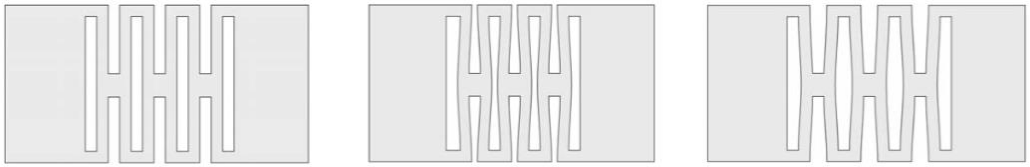
- Solidworks allows you to view the .DXF before it is exported
- Adjustments can be made (removal of lines)
- Once the .DXF is created, we need to change the colors
- To tell the laser cutter how to proceed, we need to color the lines in the .DXF file
- Two options:
  - Red: Cut
  - Black: Raster
- Change the colors in Adobe Illustrator or Inkscape
  - Select all then set stroke to red
  - Increase width to 1.5 pt





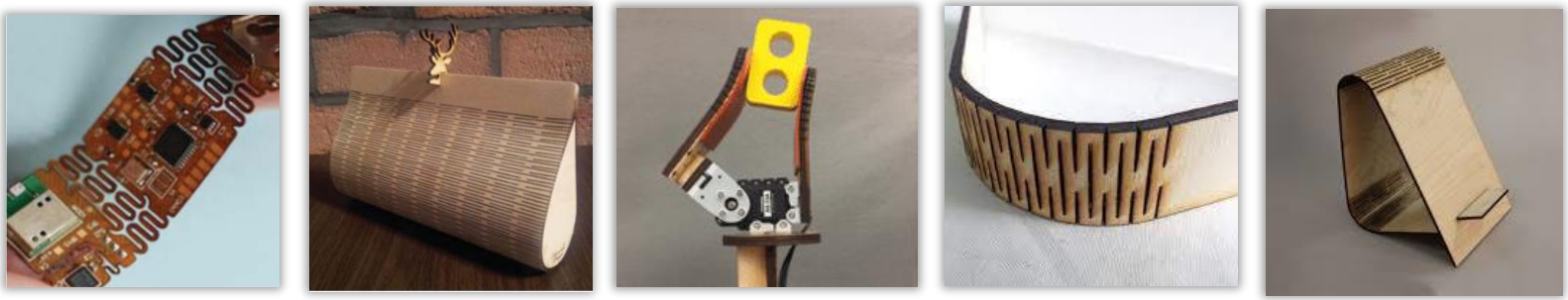
Best Practices – Flexure Design

- One helpful aspect of laser cutting is the ability to make compliant designs / flexures
- One type of flexure available is a straight 'Lattice Hinge' (a.k.a. living hinge)
- A lattice hinge is an alternating set of cuts that enables flexion, compression, and extension
- Often the kerf thickness is used as the material removed
- Often used in laser cut wood



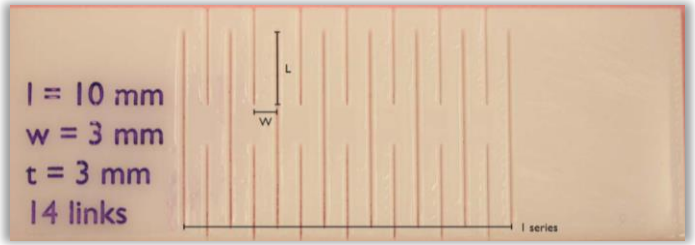
Straight Lattice Hinge | Compression | Extension

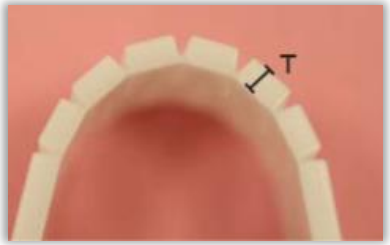
- Variations and applications



Best Practices – Flexure Design

- A straight lattice hinge is parametrized by four parameters (w, T, l, N)
  - w – width of lattice flexure
  - T – thickness of material
  - l – length (or height of cut)
  - N – number of individual flexing elements
- Dimensions defined to be independent of overall flexure width





- Increasing l decreases stiffness and increases maximum deflection
- Increasing w increases stiffness and decreases maximum deflection
- Increasing N has no effect on stiffness but increases maximum deflection

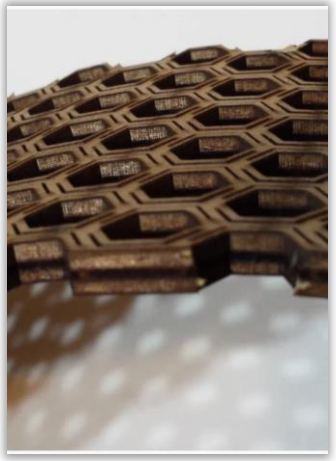
Best Practices – Flexure Design

- This is one example of a living hinge, but there are many – Demo!

Wave Lattice

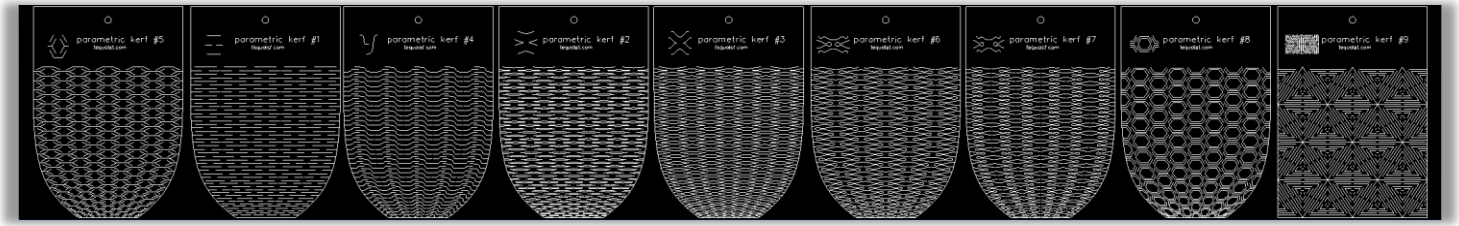
Cross Lattice

Fillet Lattice



Beehive Lattice

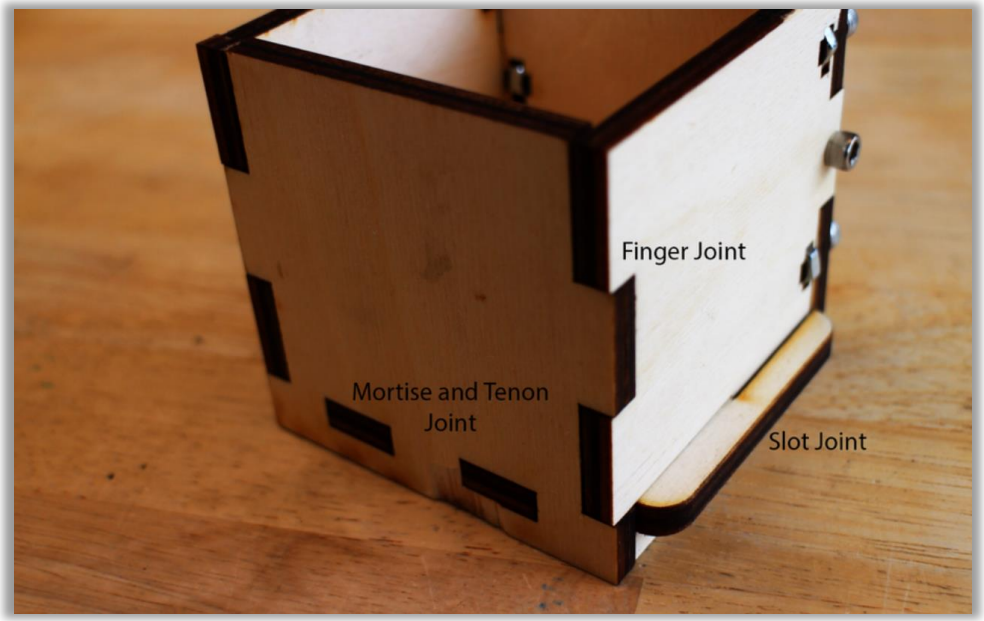
- Straight lattice hinge is the most common and reliable
- .DXF with living hinge patterns is uploaded to Canvas w/ today's lecture
- Solidworks can be used to add these lattice examples to modify / pattern



Instructables\Aaron Porterfield

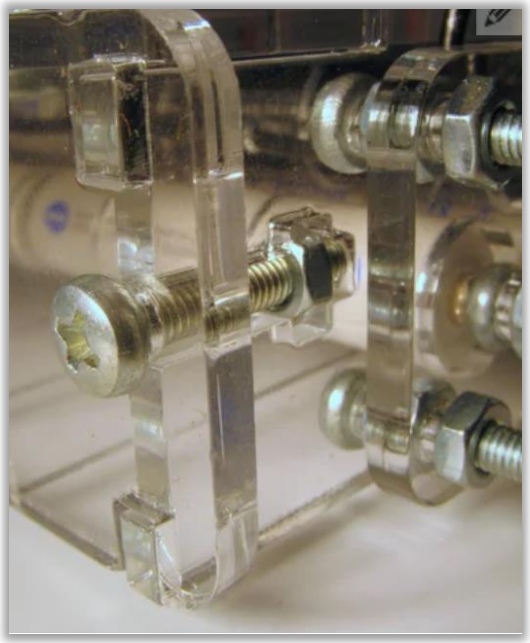
Best Practices – Joints

- With a little clever design, parts can be quickly and easily joined
- Many different types of joints, including
  - Finger joints
  - Mortise and tenon joints
  - Slot joints
- Add 0.25 mm tolerance to height and width of slot

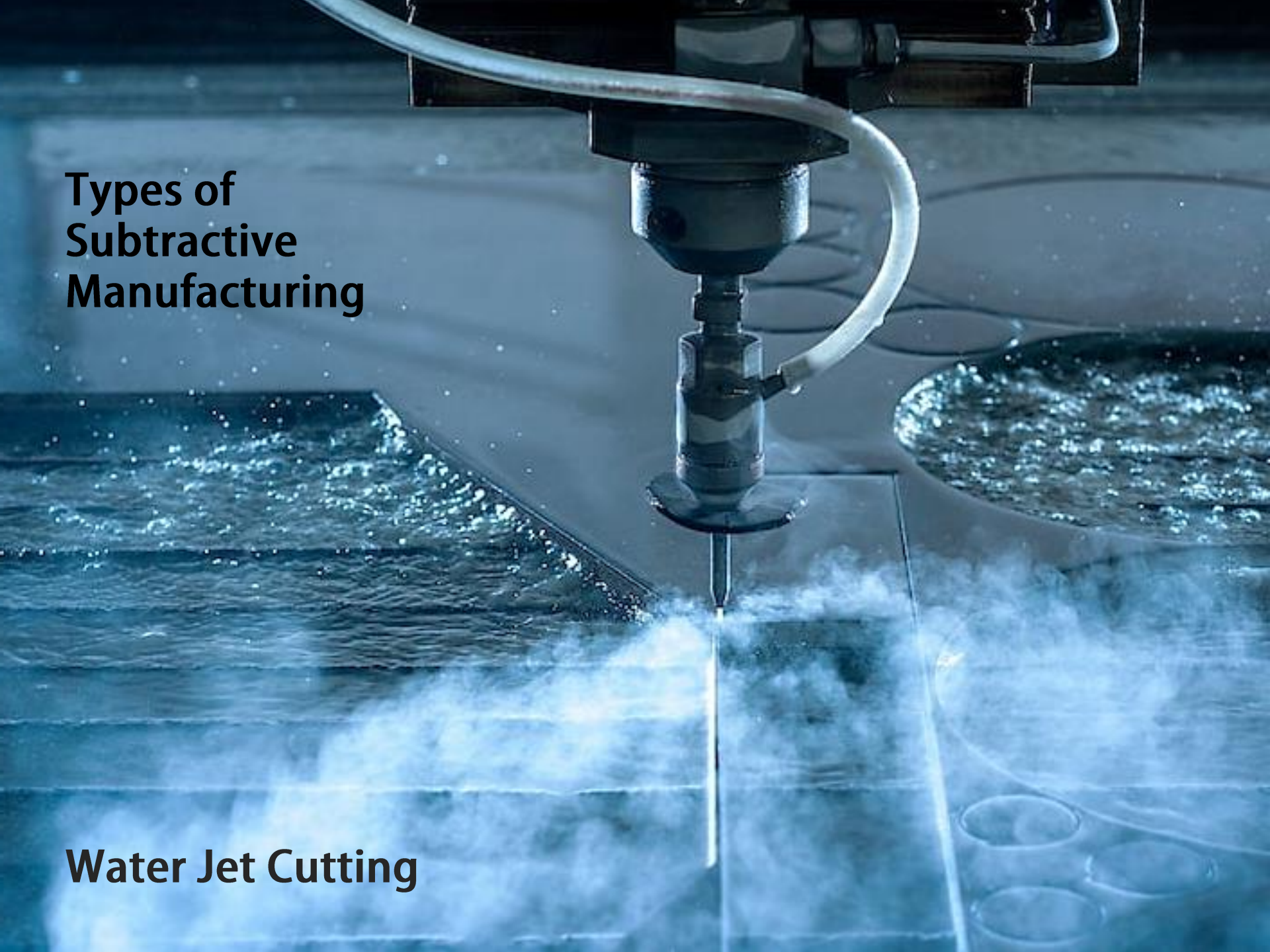


Best Practices – Fasteners and Stacking

- Nuts can be easily captured by oversizing slots for a hex / square head
- Sizes / solid models for fasters can be downloaded from McMaster-Carr
  - Parts usually received in 1 day
- Add 0.25 mm tolerance for spacing

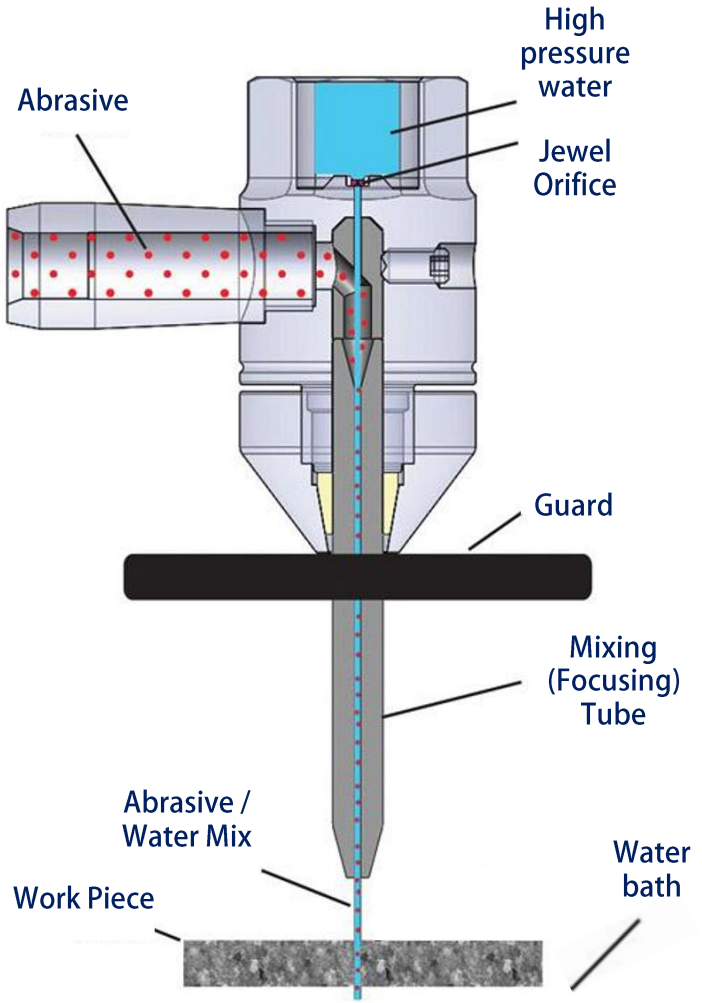


- Parts can be sliced into layers and glued together
- Could be used for neat chassis designs
- Free programs can slice 3D models
  - Fusion 360
  - Autodesk's 123D Make
    - No longer produced but still downloadable


Types of
Subtractive
Manufacturing
Water Jet Cutting

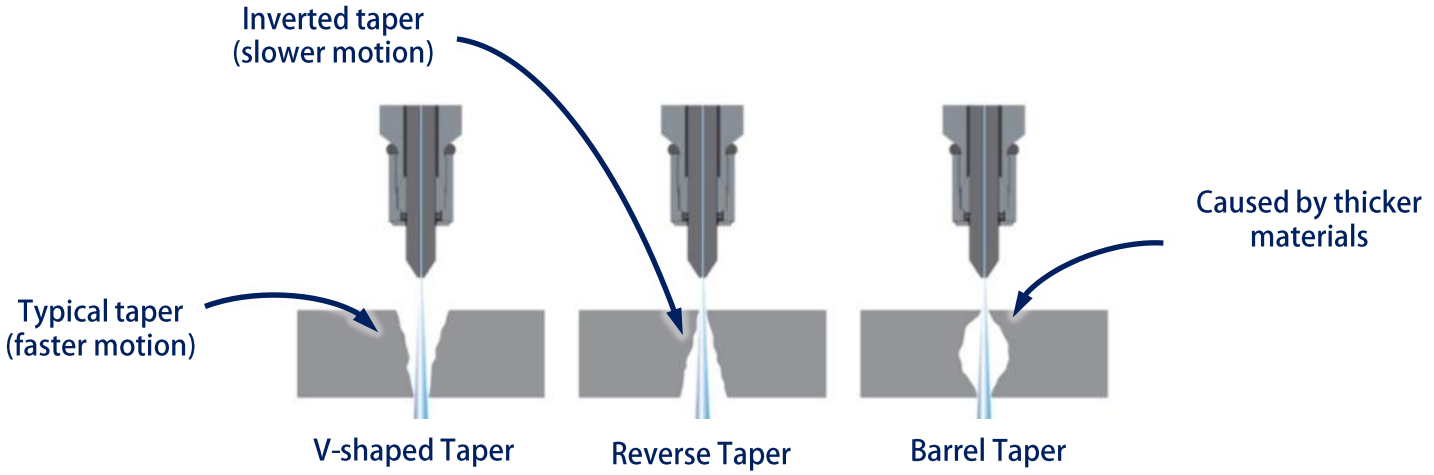
Water Jet Cutter

- Water jet cutting can be used to create metal parts with similar design advantages as laser cutting
  - Simple 2D designs
  - Quick, convenient prototyping
- Anatomy of a water jet cutter
- Key benefit: works on thick metals
- Metal is cut by high pressure stream of water and abrasive garnet
- Water jet cutters can cut many materials, including all metals, plastic, rubber, glass, CF, etc.
- Materials can be thick (< 25 mm)
- No heat affected zones (doesn't alter properties)
- Reasonably consistent edge quality



Water Jet Cutter

- Kerf is ~0.01 mm – 1 mm, depending on
  - Water jet type
  - Nozzle quality
  - Part thickness
  - Cutting speed
  - Fineness of abrasive media
- FRB water jet cutter (ProtoMax) has a kerf between 0.01 mm – 0.15 mm
- The cutter is typically offset by 0.5x kerf width



Water Jet Cutter

- ProtoMax water jet
  - 30,000 psi cutting
  - 12” x 12” bed
- Larger water jet available in GG Brown
- Nozzle / mixing tube diameter: 0.76 mm
- Some modifications to design should be made to facilitate manufacturing
  - Internal corners have a minimum radius
  - Minimum internal fillet radius: 0.5 mm
- The material needs to left around the edge to secure
  - Leave 20+ mm around edge
- Minimum part separation of 3.5 mm when nesting parts to cut
- Design with lines and arcs

Water Jet Cutter

- Just like laser cutting, you export a .DXF
- Quality and cutting options are setup in software
- This is done using ProtoMax LAYOUT
- It will prompt you for the units
- Once imported, you have options to select the quality
  - Higher number means higher quality cut (slower with more blasting media)
  - Colors of lines denote quality for specific cuts
- Then you 'clean your' drawing to address any issues
  - Checks for overlapping elements
  - Gaps, duplicate cuts, etc.