Robotics 311 : How to build robots and make them move

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Photo credit: Brenda Ahearn / U-M CoE

ROB 311 – Lecture 10

- Today:
  - Review .DXF creation
  - Finish water jet cutting
  - Review best practices
  - Do in-class manufacturing example

- Announcements
  - HW 2 due 10/4 at class start
  - Send me your .STLs if you want Nylon SLS parts by Friday at noon

Manufacturing Types

'Rapid prototyping'

Spec'ing analysis completed

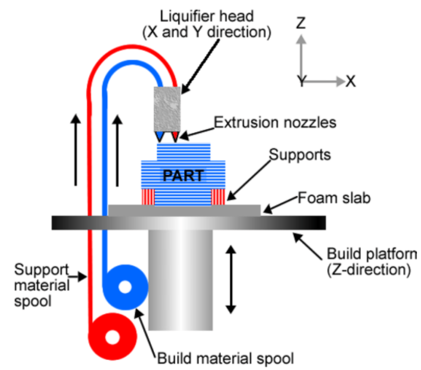
Additive Mfg.
3D
Plastics
Convenient

Laser Cutter
2D
Acrylic, wood,
Convenient

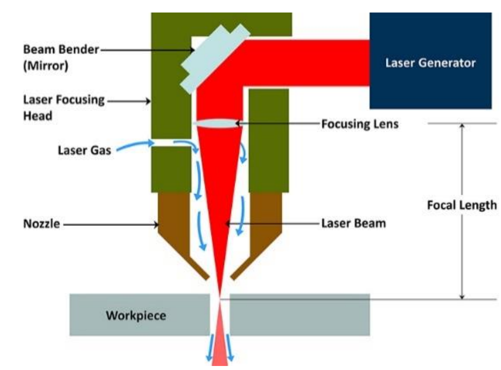
Water Jet Cutter
2D
Anything
Less convenient

Layout next...

- We've learned how to spec our robot to complete some desired function
- We're learning rapid prototyping methods and design
- For the sake of lab, we began with manufacturing
- We have already covered
  - 3D printing
  - Laser cutting
  - Most of water jetting



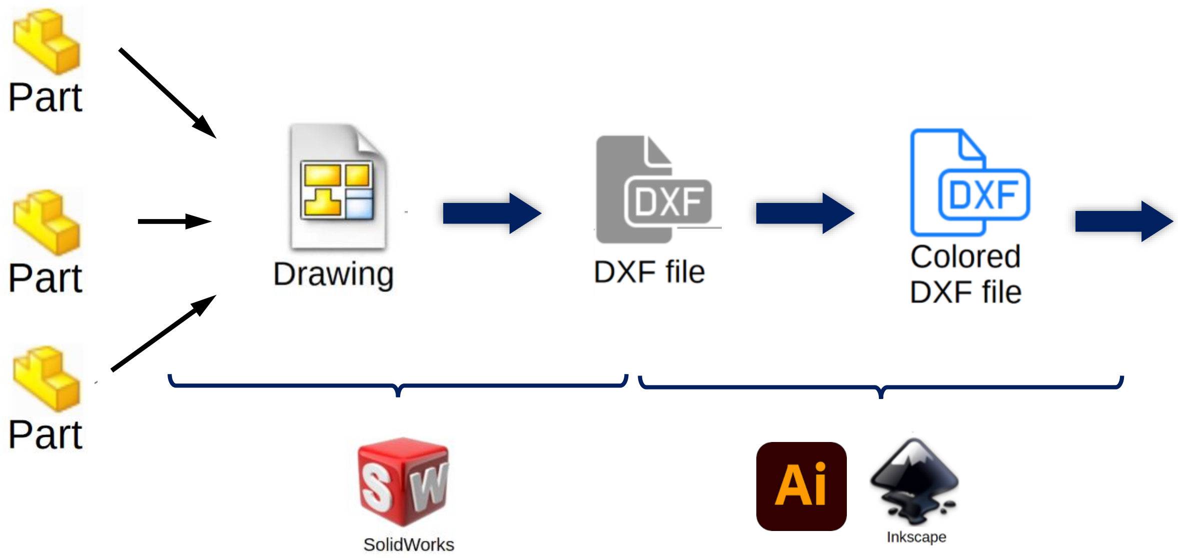
3D printer anatomy



Laser cutter anatomy

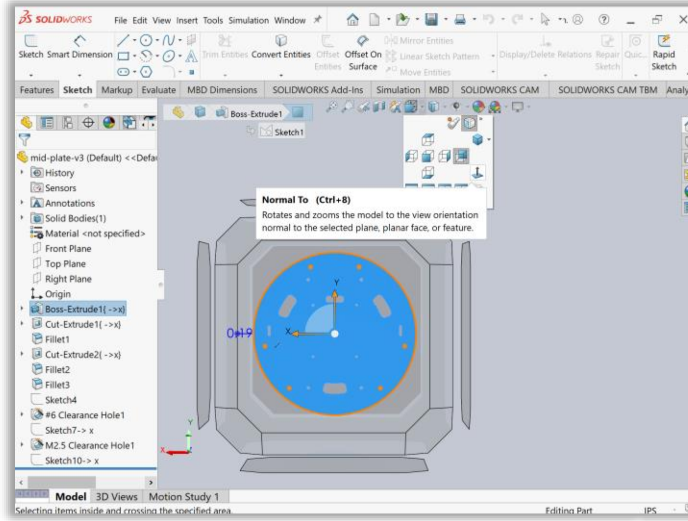
How to Create .DXF Files

- 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)



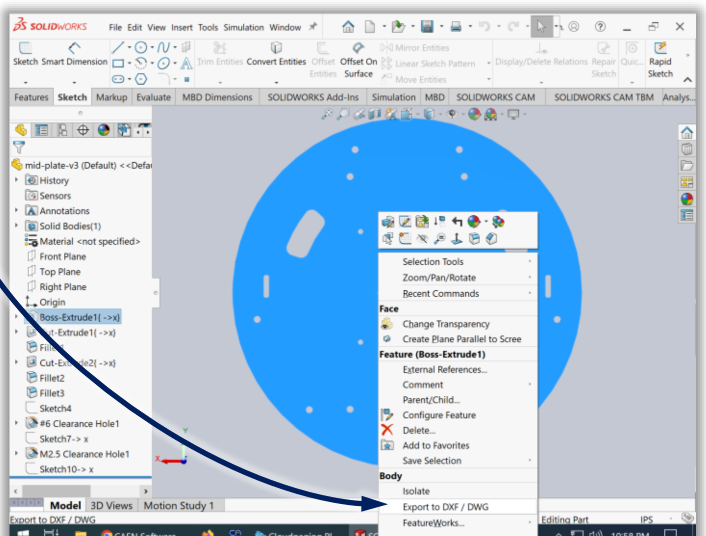
How to Create .DXF Files

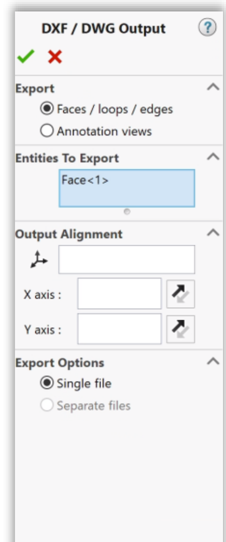
- One easy way is to export directly from Solidworks
- This is especially easy for 2D parts
- To create a .DXF from a 2D part
  - Set part units to “IPS”
  - Select the face to cut
  - Right click and select ‘Export to DXF / DWG’



Set to “IPS”

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

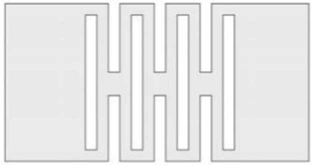




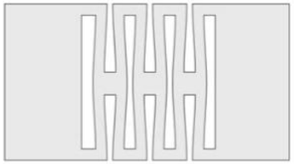
Settings that allow adjustment of export and axis alignment

Best Practices – Flexure Design

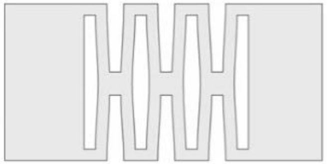
- One helpful aspect of laser cutting is the ability to make compliant designs / flexures
- One type of flexure available is a straight 'Lattice Hinge' (a.k.a. living hinge)
- A lattice hinge is an alternating set of cuts that enables flexion, compression, and extension
- Often the kerf thickness is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



Straight Lattice Hinge

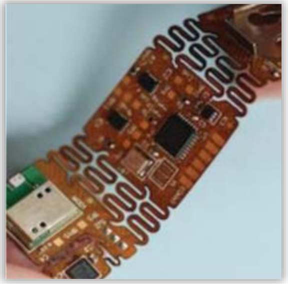


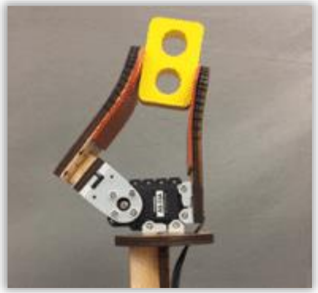
Compression



Extension

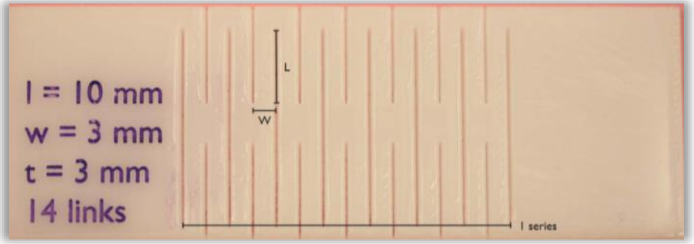
- Variations and applications

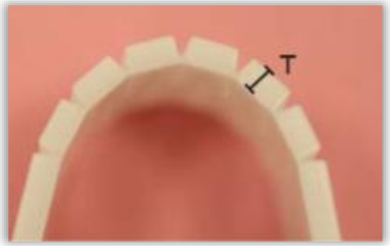




Best Practices – Flexure Design

- 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

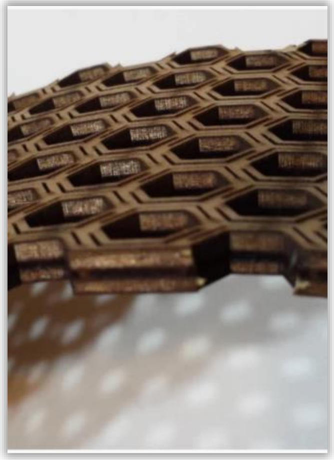
Best Practices – Flexure Design

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

Wave Lattice

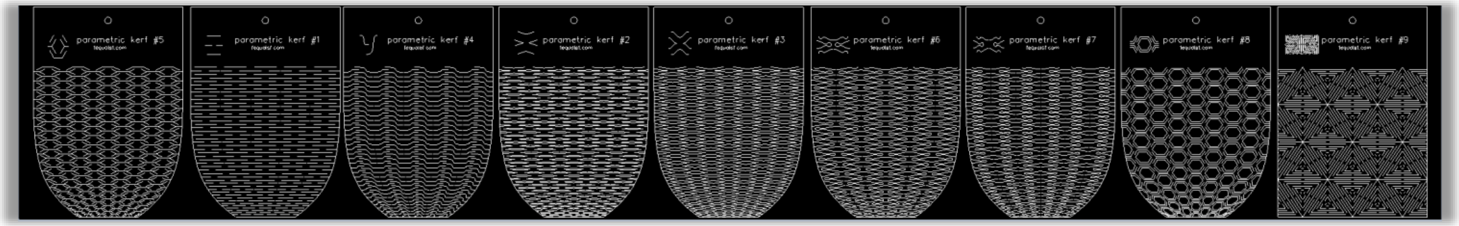
Cross Lattice

Fillet Lattice



Beehive Lattice

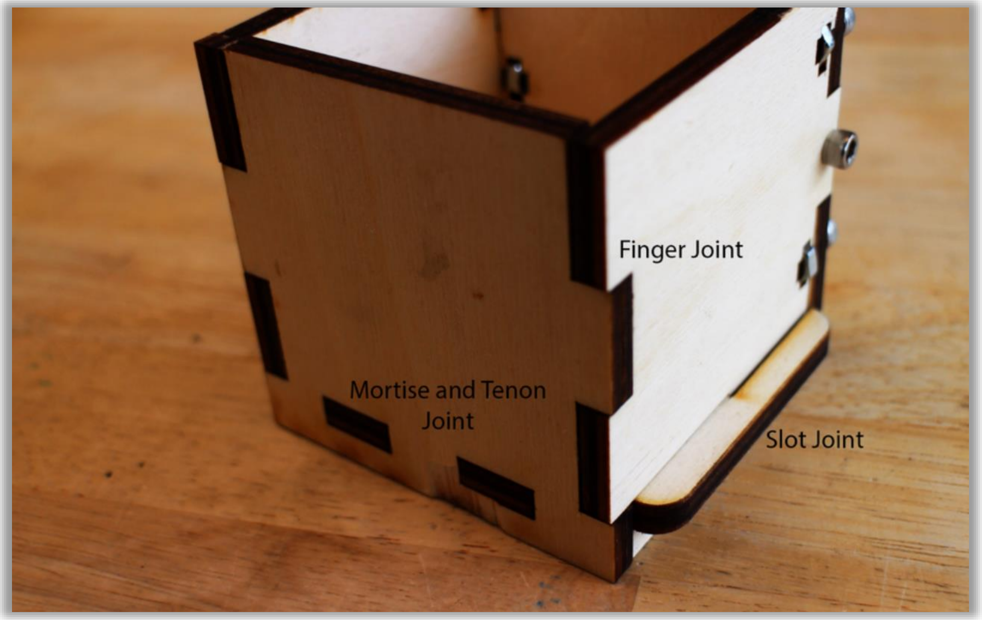
- Straight lattice hinge is the most common and reliable
- .DXF with living hinge patterns is uploaded to Canvas w/ today's lecture
- Solidworks can be used to add these lattice examples to modify / pattern



Instructables\Aaron Porterfield

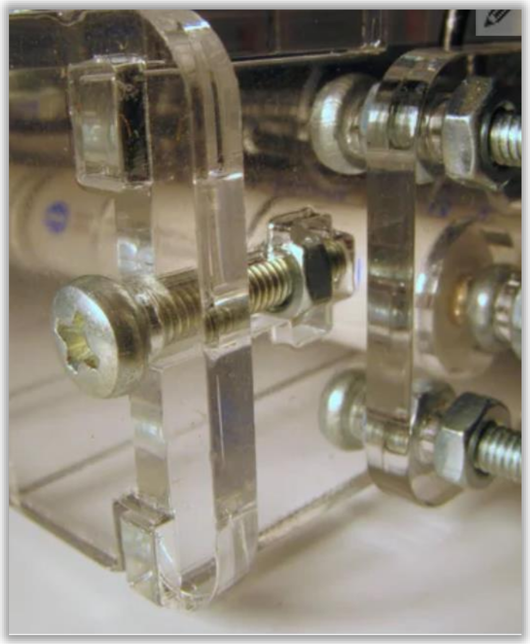
Best Practices – Joints

- 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

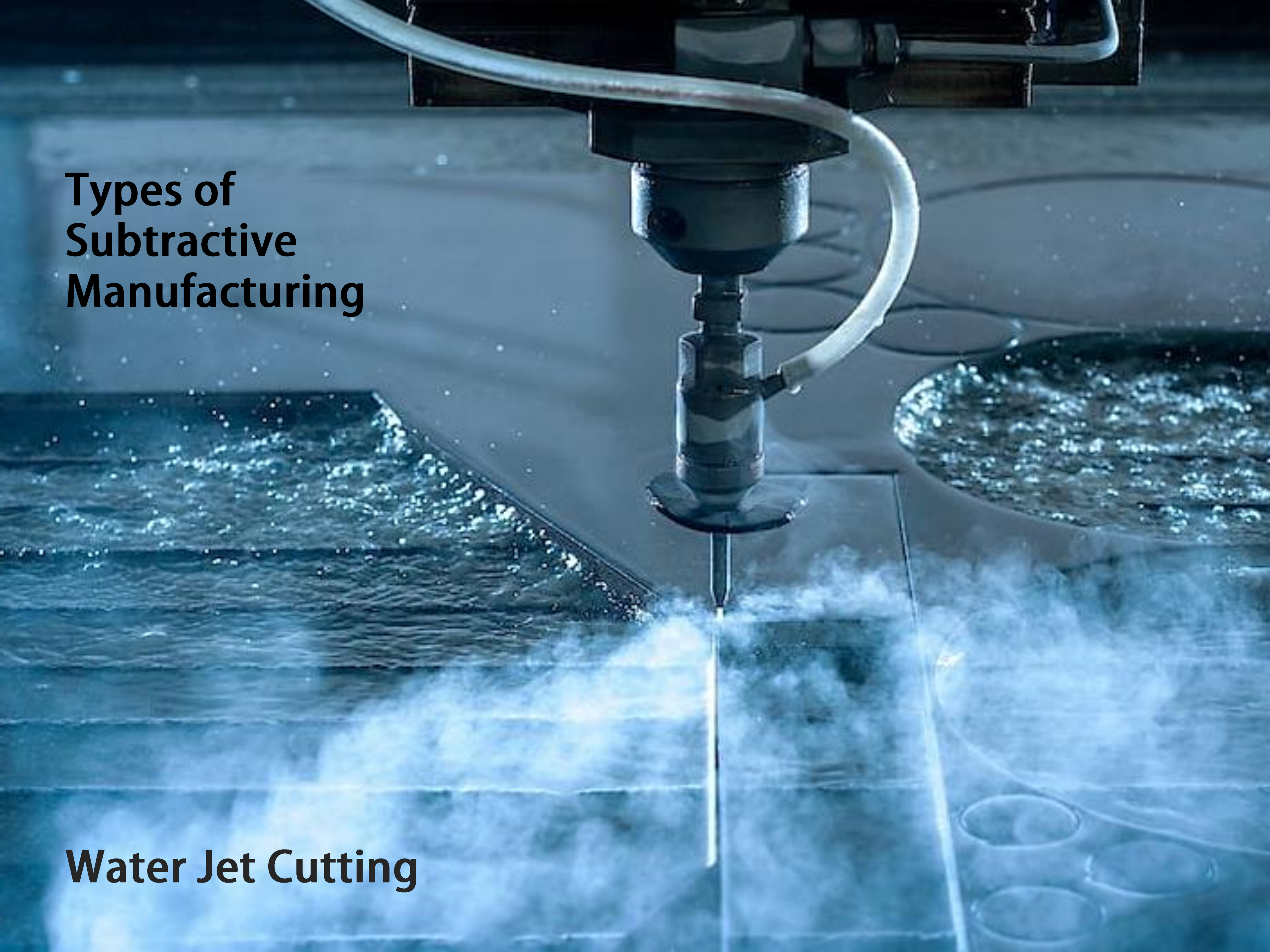


Best Practices – Fasteners and Stacking

- 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

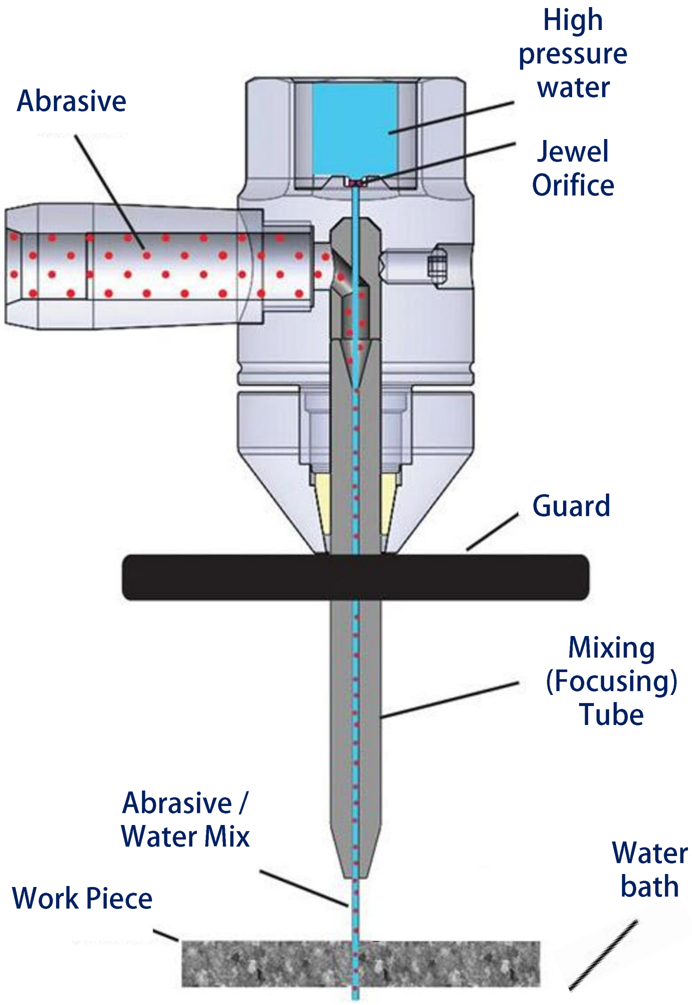


- Parts can be sliced into layers and glued together
- Could be used for neat chassis designs
- Free programs can slice 3D models
  - Fusion 360
  - Autodesk's 123D Make
    - No longer produced but still downloadable


Types of
Subtractive
Manufacturing
Water Jet Cutting

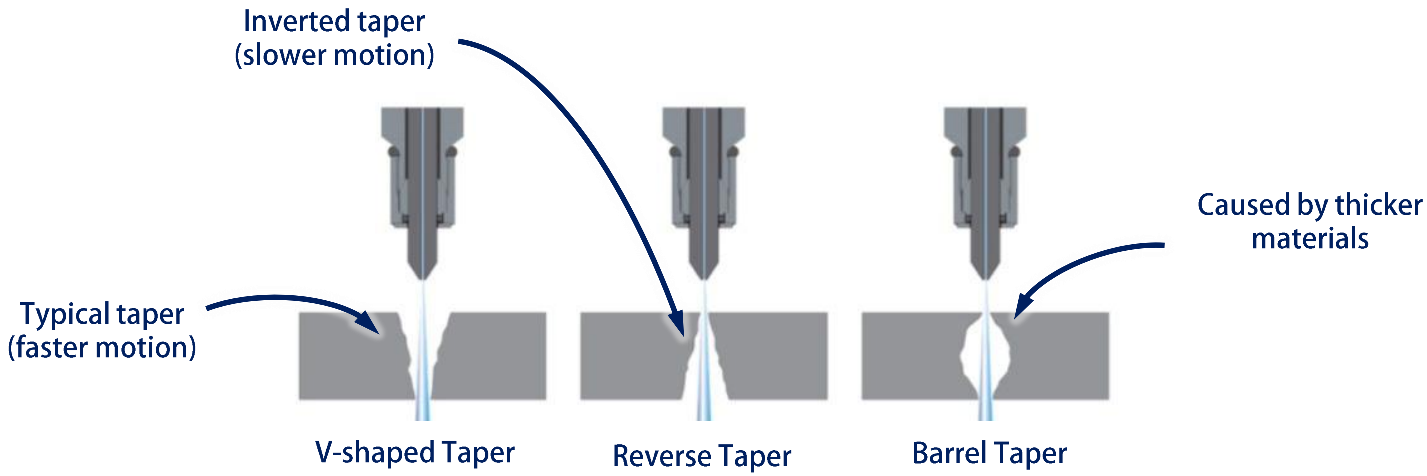
Water Jet Cutter

- 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

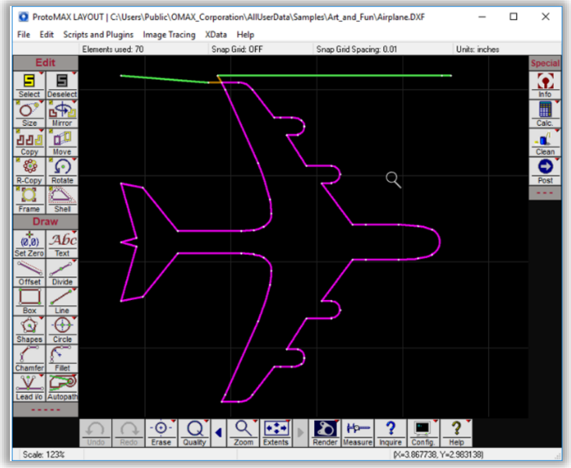


Water Jet Cutter

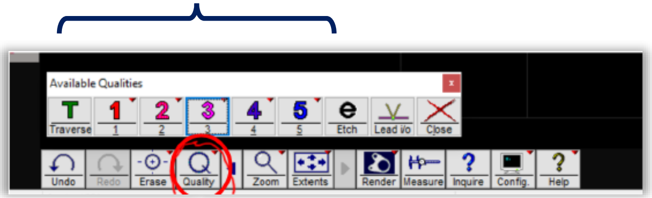
- ProtoMax water jet
  - 30,000 psi cutting
  - 12" x 12" bed
- Larger water jet available in GG Brown
- Nozzle / mixing tube diameter: 0.76 mm
- Some modifications to design should be made to facilitate manufacturing
  - Internal corners have a minimum radius
  - Minimum internal fillet radius: 0.5 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 when possible

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.



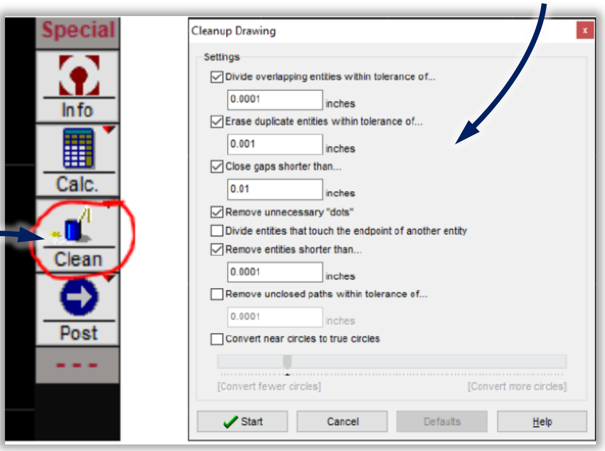
Quality selection



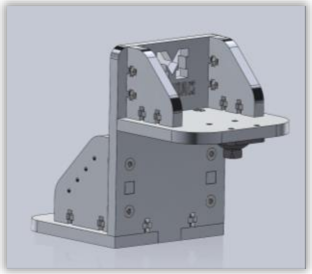
To set quality, select this button

Options

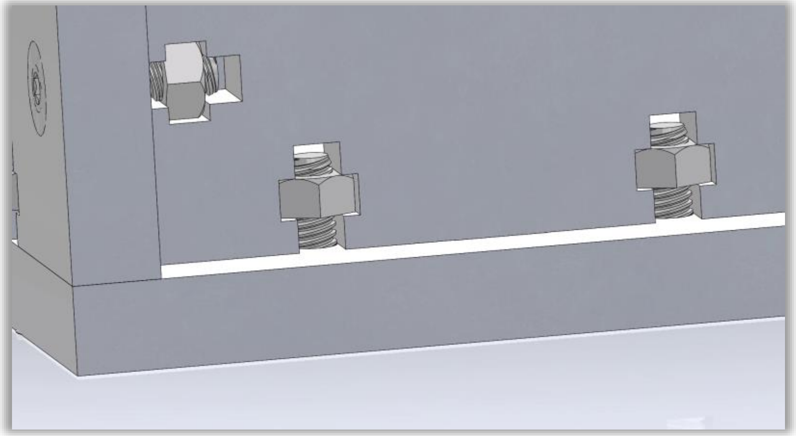
This will automatically clean your drawing



Best Practices – Fasteners and Tabbing Text

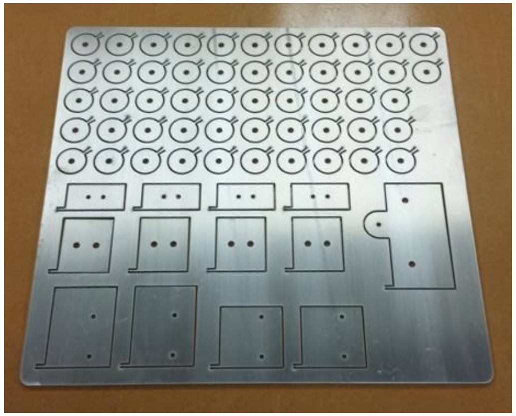


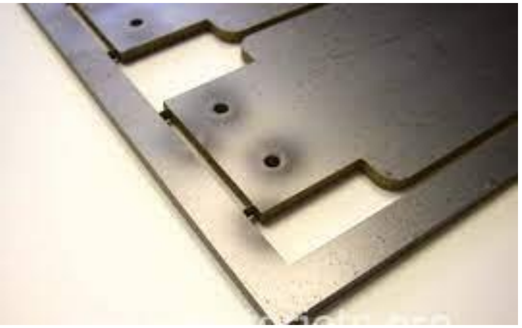
- Similar to a laser cutter, nuts can be easily captured using a hex or square nut
- Nut dimensions can be found from McMaster-Carr
- Extra space is needed to ensure fit
  - Oversize slot for nuts by 0.75+ mm to ensure fit
  - Easy way to make assembly / disassembly convenient
- You also may wish to add small, filled features
- For example, the inside of an 'o ' or an 'A'
- This can be done by adding ~1 mm tabs
- Tab width depends on the quality of the water jet
- Demo!



Best Practices – Tabbing

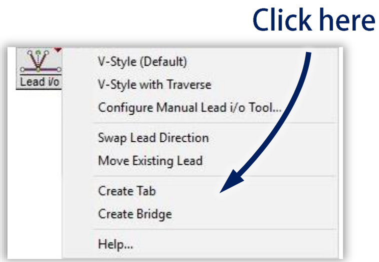
- Once a part is cut from the material, it falls into the water bath
- Sometimes this is inconvenient
- Tabbing is a solution that enables the parts to stay connected to the work piece
- A tab is a small piece of material that connects your part to the work piece
    - A bridge from the main work piece to your part
- Tabbing can be added manually in ProtoMax LAYOUT or in Solidworks / your .DXF file
- This is good practice if you are cutting many small parts

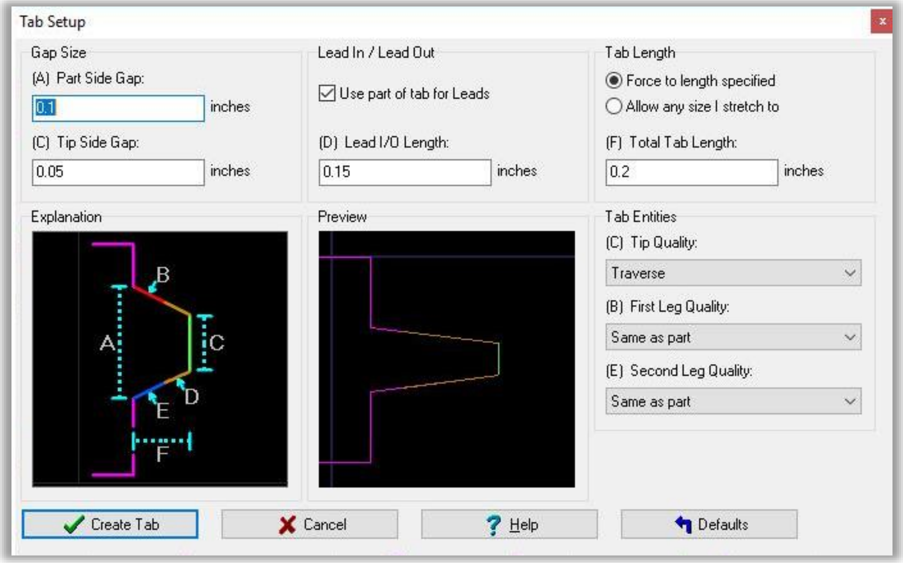




Best Practices – Tabbing

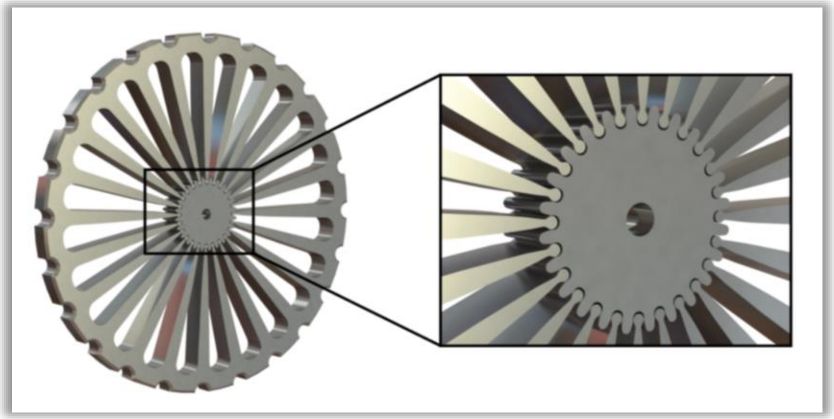
- To create a tab, open your part in ProtoMax LAYOUT
- First, right click on the Lead I/O button and select Create Tab
- Then click where you want the tab
- Once Create Tab is selected, options will appear to setup the tab
- Setup parameters include:
    - Part side gap (A)
    - Tip side gap (C)
    - Lead I/O (D)
    - Total tab length (F)
- This process can be repeated to add multiple tabs
- ~1 – 3 mm size tabs





Best Practices – Flexures

- Water jet cutters can be used to design flexible elements, like laser cutters
- Flexures from metal are more like springs
- Spring design is outside the scope of this course—but interesting!
- Research example
  - Developed the equations to predict the mechanics
  - Fit inside output pulley
  - Cut with Wire-EDM → water jet?



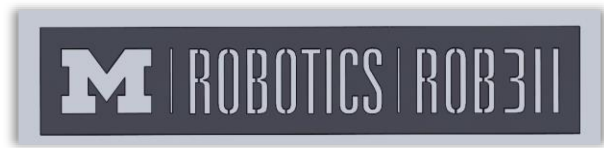
Example torsion springs that could be cut with a water jet

$$\theta_{des} = \sqrt[3]{\frac{8tnL^3\sigma_d^3}{27E^2kr}}$$

t – spring thickness (m)
n – number of flexures
L – radial length of flexure (m)
σ_d – design stress (Pa)
E – elastic modulus (Pa)
k – spring stiffness (Nm/rad)
r – contact radius

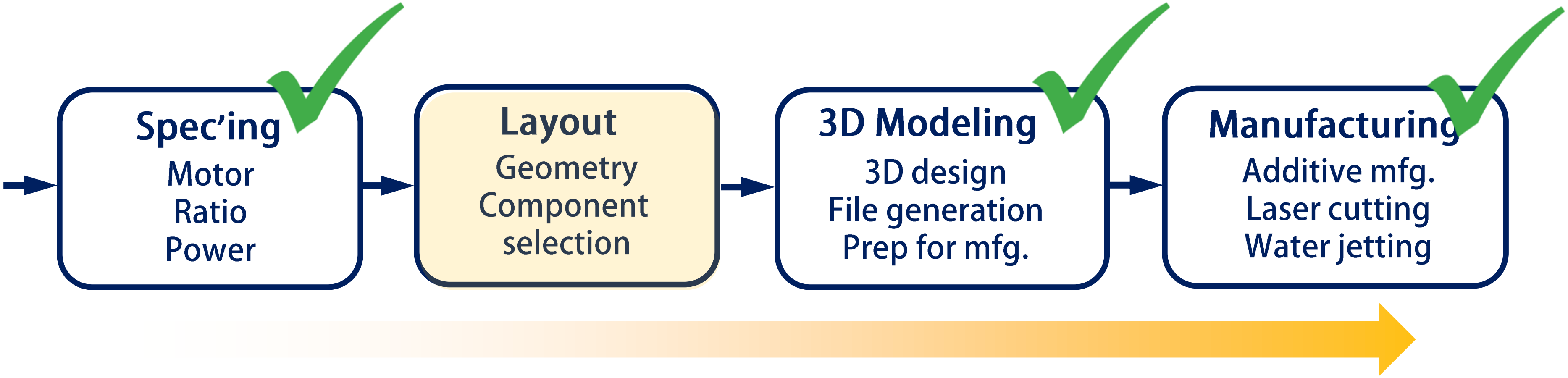
Manufacturing – in-class example

- We're basically finished with manufacturing!
- I'd like to walk through an example together that combines many tools we learned
- This will serve as the quiz for this week
- Goal: Create extruded boss of M | Robotics and ROB 311
- In addition, you can use these in your ball-bot design



- Steps:
  - Export M | Robotics logo as .DXF from AI
  - Create a 3/16″ plate in Solidworks as an extruded boss
  - Import the .DXF in Solidworks
  - Modify the sketch to include ROB 311 (by using an pasted/edited B and I)
  - Add tabs to hold inside letters in place
  - Scale the sketch and extrude cut the profile through the plate

Manufacturing Types



- We've learned how to spec and make robots, now lets talk about design layouts
- This is often moving motion from one place to another (kinematics)
- In robots, motion moving from the actuator to the end effector
- It begins with understanding the geometry of your robot and transmissions
- Very application specific!
- Coming up:
  - Introduce transmissions and linkages
  - In-depth example of ball-bot geometry and kinematics
  - Move to mechatronics, ball-bot dynamics, and control