ISDN2400 Physical Prototyping

Subtractive Manufacturing

By Rob Scharff

February 2025

Today's lecture

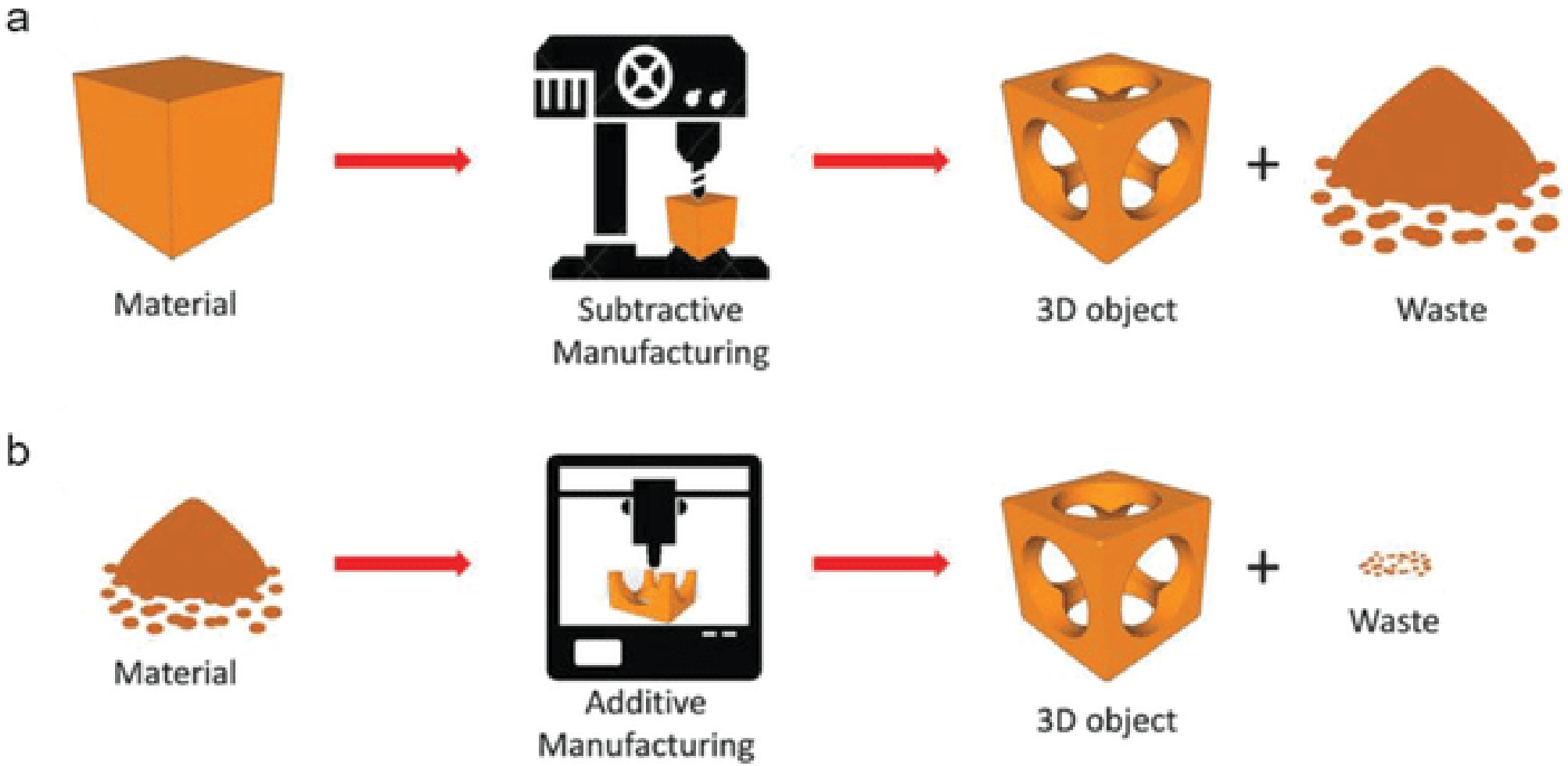
- Introduction to subtractive manufacturing
- CNC processes
- Time for group work

Subtractive Manufacturing

"Subtractive manufacturing is a process where an object is produced by removing unnecessary materials from a stock to create the desired geometry"

www.digitalengineering247.com/glossary/subtractive-manufacturing

Additive vs. Subtractive Manufacturing



Chen et al., "Additive Manufacturing of Piezoelectric Materials", 2020

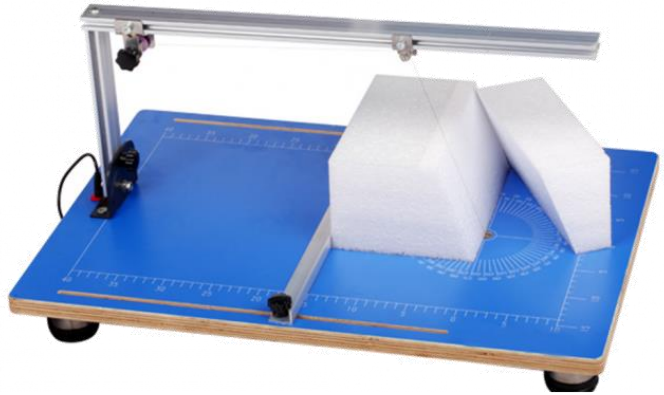
Additive vs. Subtractive Manufacturing

- Key differences:
  - Material waste
  - Strength and heat-conducting properties
  - Dimensional accuracy
  - Range of materials
  - Lead time
  - Post processing
  - Design considerations

www.guitarmakingschool.ca/post/cnc-for-guitar-making

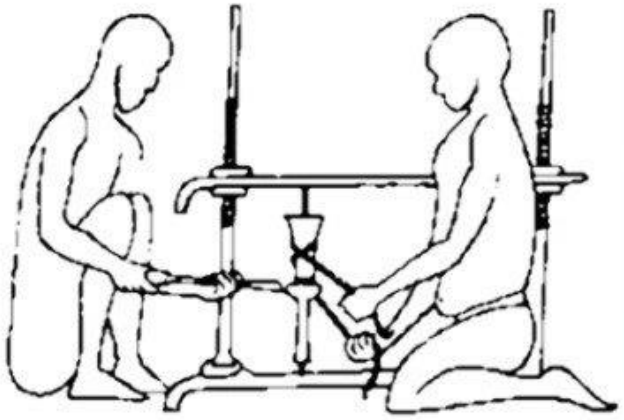
Manual subtractive manufacturing

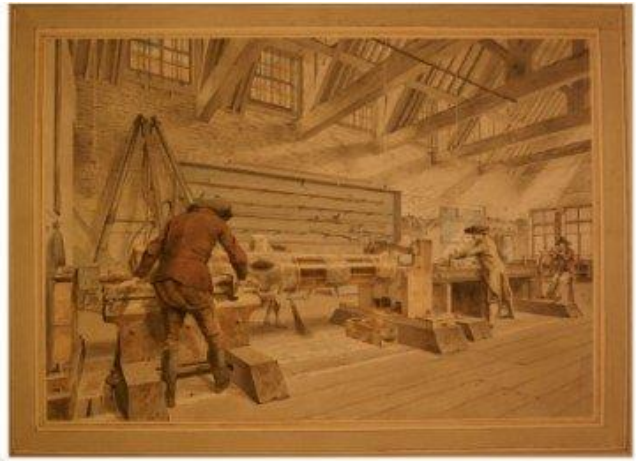
- Chisels, saws, hot wire cutters, knives

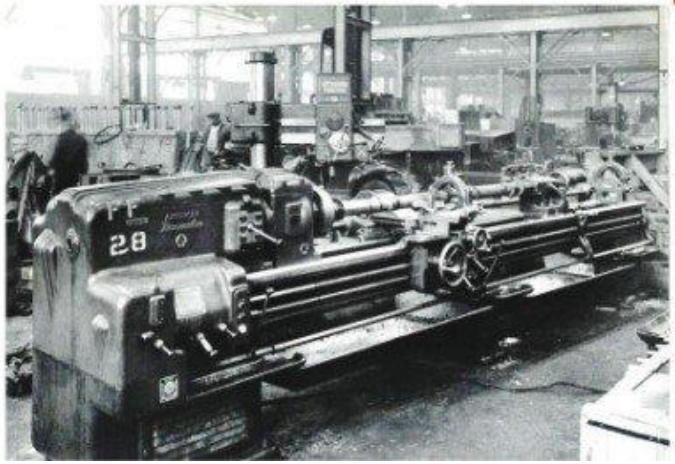


Automating subtractive manufacturing

- First lathes date back to ancient Egypt (1300 BC)
- Lathe: A machine tool that rotates a workpiece around an axis such that it can be shaped using a variety of tools







www.designreview.byu.edu/collections/designing-for-subtractive-machining

Birth of numerical control

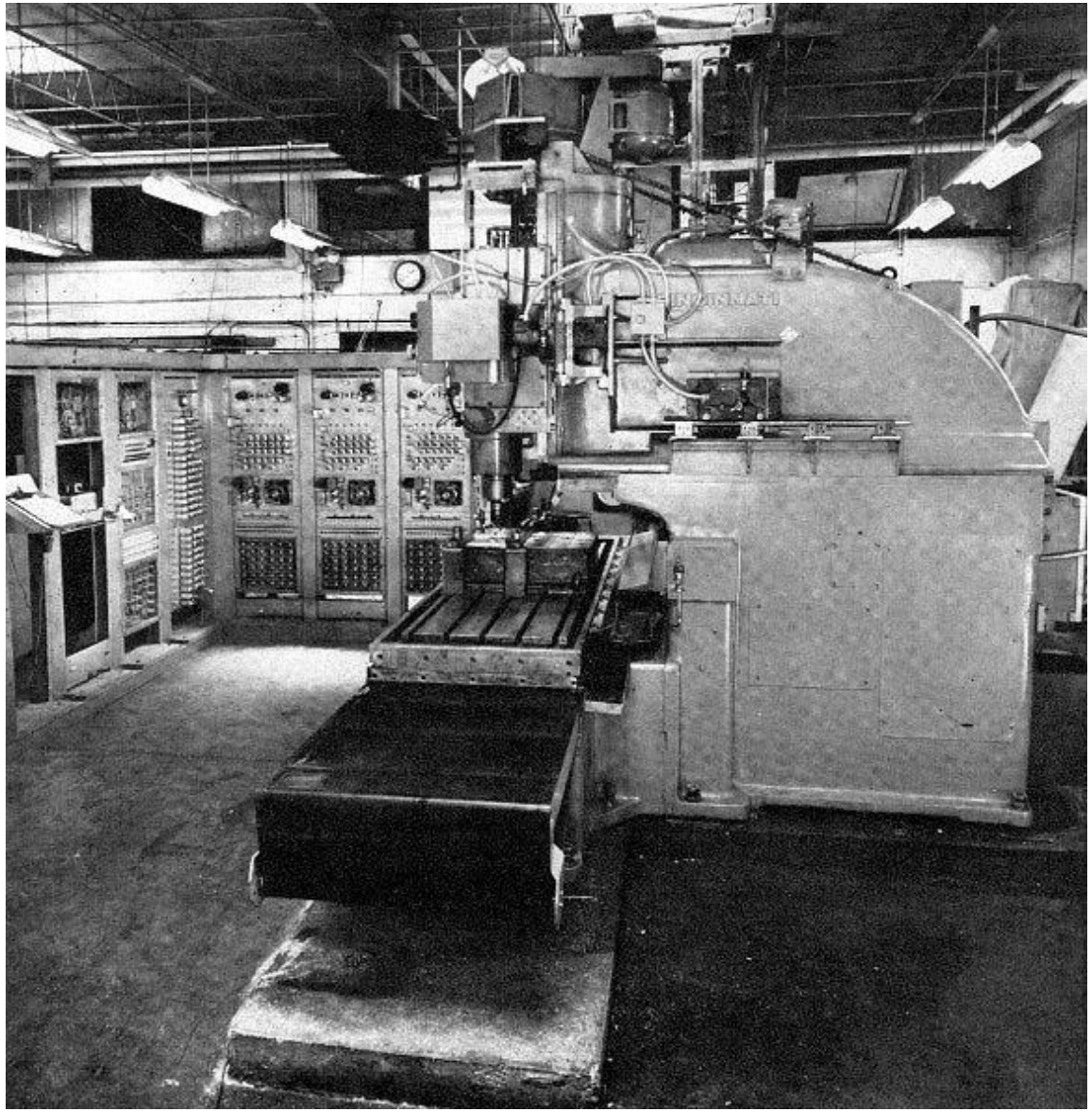
- How to easily vary the sequence of movements of an automatic machine tool?
  - Tracer control
  - Numerical control

Tracer control

- Required a physical model or drawing of the object to be manufactured
- Cincinnati Line-Tracer Hydro-Tel

Numerical control

- Required only a mathematical model and machine instructions (punch cards)
- Invented by Frank Stulen and Richard Parsons in 1952 to manufacture helicopter rotor blades
- Patented in 1958 as a "Motor Controlled Apparatus for Positioning Machine Tool"
- Retrofit Cincinnati Hydro-Tel vertical milling machine



www.medium.com/cnc-life/history-of-cnc-machining-part-1-2a4b290d994d

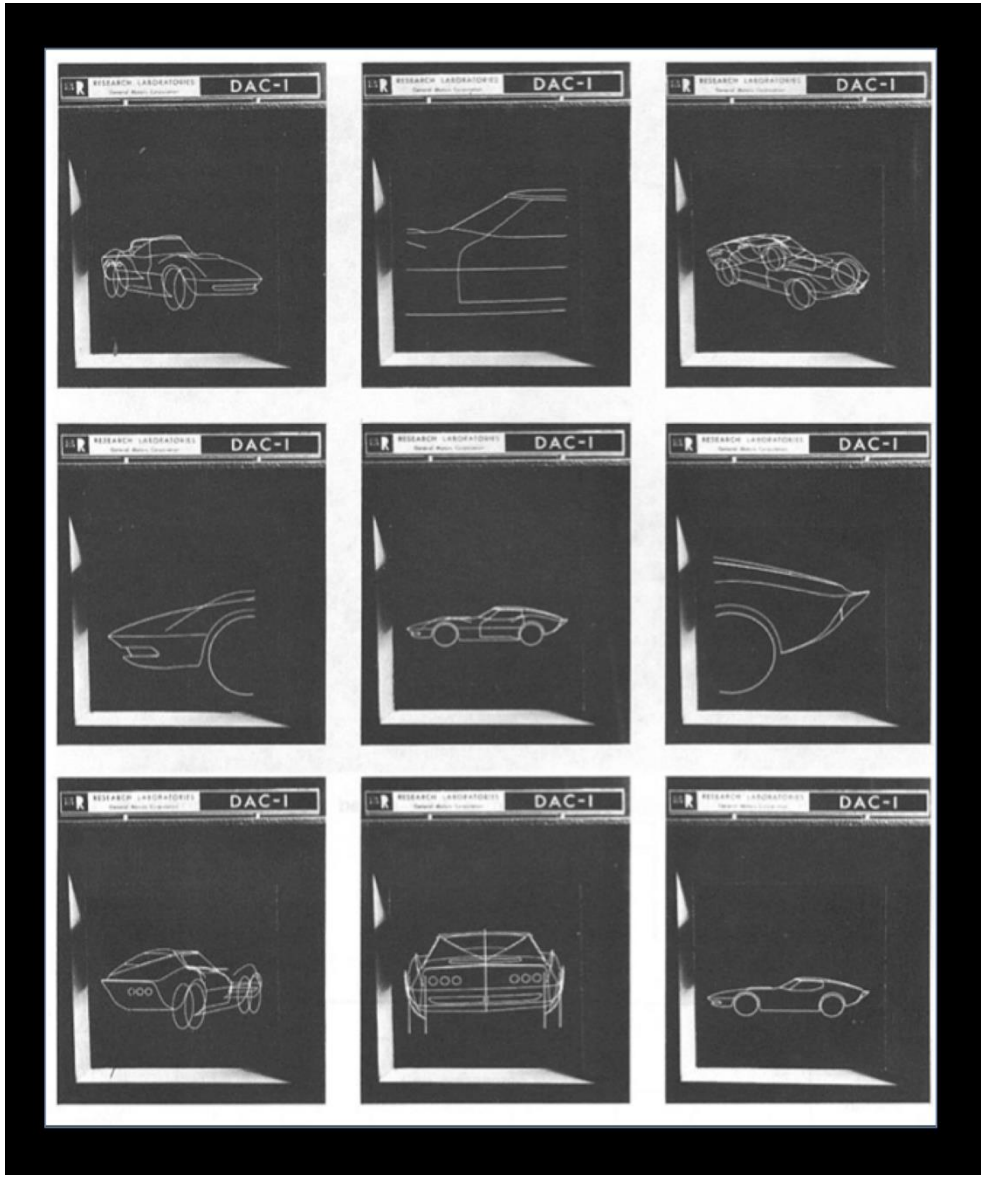
Computer Numerical control

- Punch cards replaced by computer control
- G-code used to tell computerized machines how to make something
- 1959: MIT showcases their CNC machine

www.medium.com/cnc-life/history-of-cnc-machining-part-1-2a4b290d994d

Graphical CAD

- The development of CNC played a pivotal role in the development of CAD programs
- 1959 - General Motors starts working on *Design Augmented by Computer (DAC-1)*



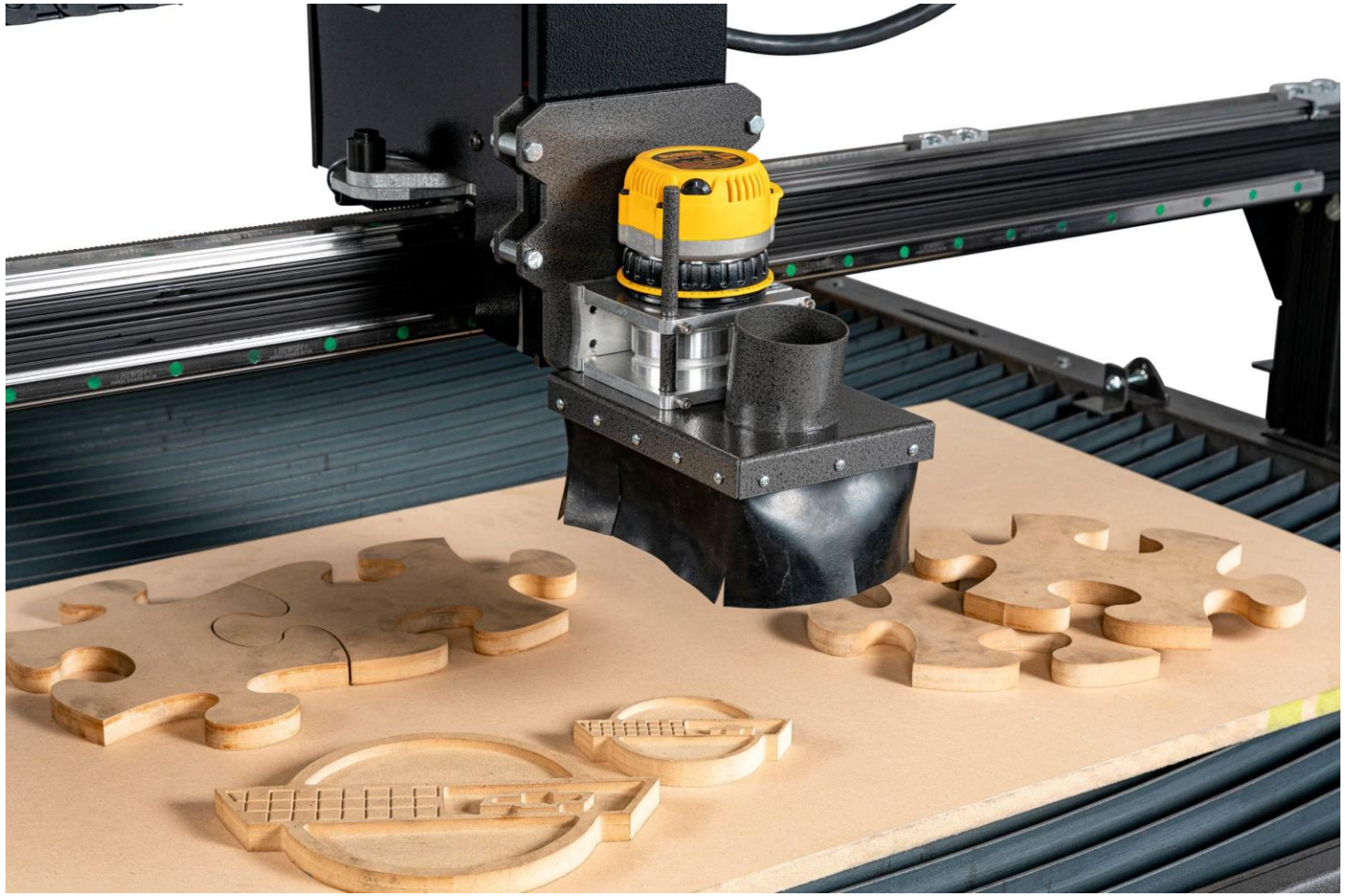
www.medium.com/cnc-life/history-of-cnc-machining-part-1-2a4b290d994d

Computer Numerical Control

- CNC mill
- CNC router
- CNC lathe
- CNC electrical discharge
- CNC laser
- CNC plasma cutter
- CNC waterjet

CNC Router

- Spindle moves along three axis
- CNC router
- Uses rotational speed to make cuts (1,000-30,000 RPM)
- For softer materials such as wood, plastic, and foam



CNC Electrical Discharge

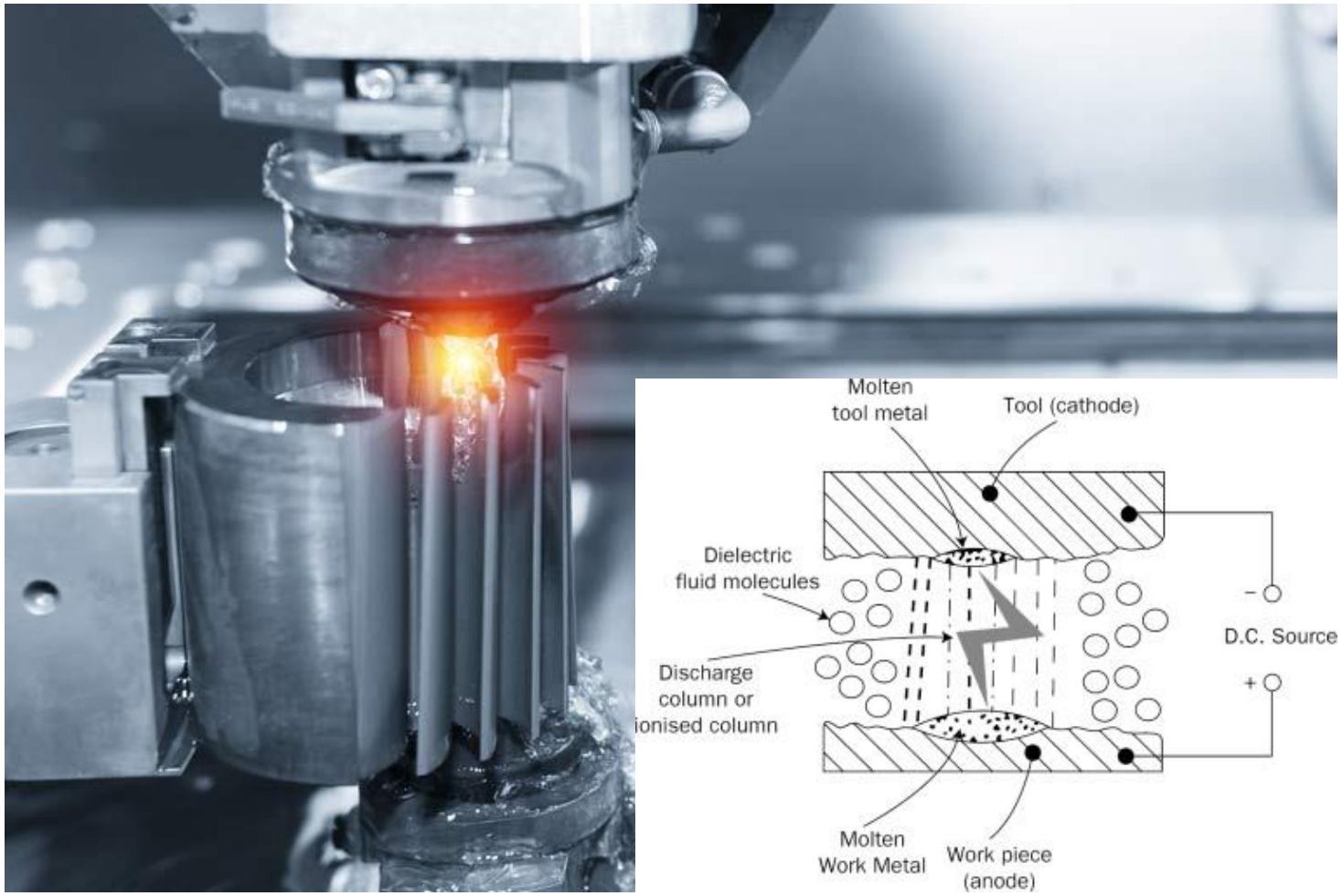
- CNC mill
- CNC router
- CNC lathe
- CNC electrical discharge
- CNC laser
- CNC plasma cutter
- CNC waterjet

Electrical spark between two electrodes (tool electrode and workpiece)

Vaporises material

Capable of machining thick plates of titanium and stainless steel

Wire-EDM and Sinker-EDM



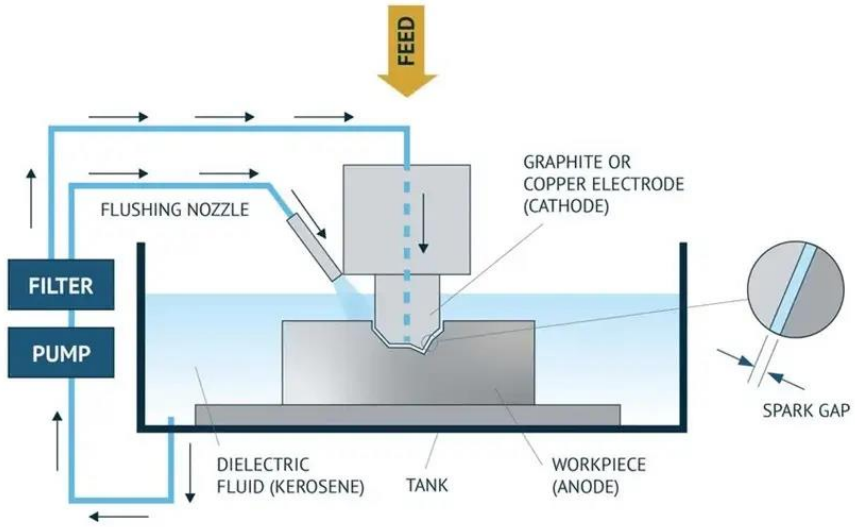
Palanikumar et al., 2013

Wire-EDM

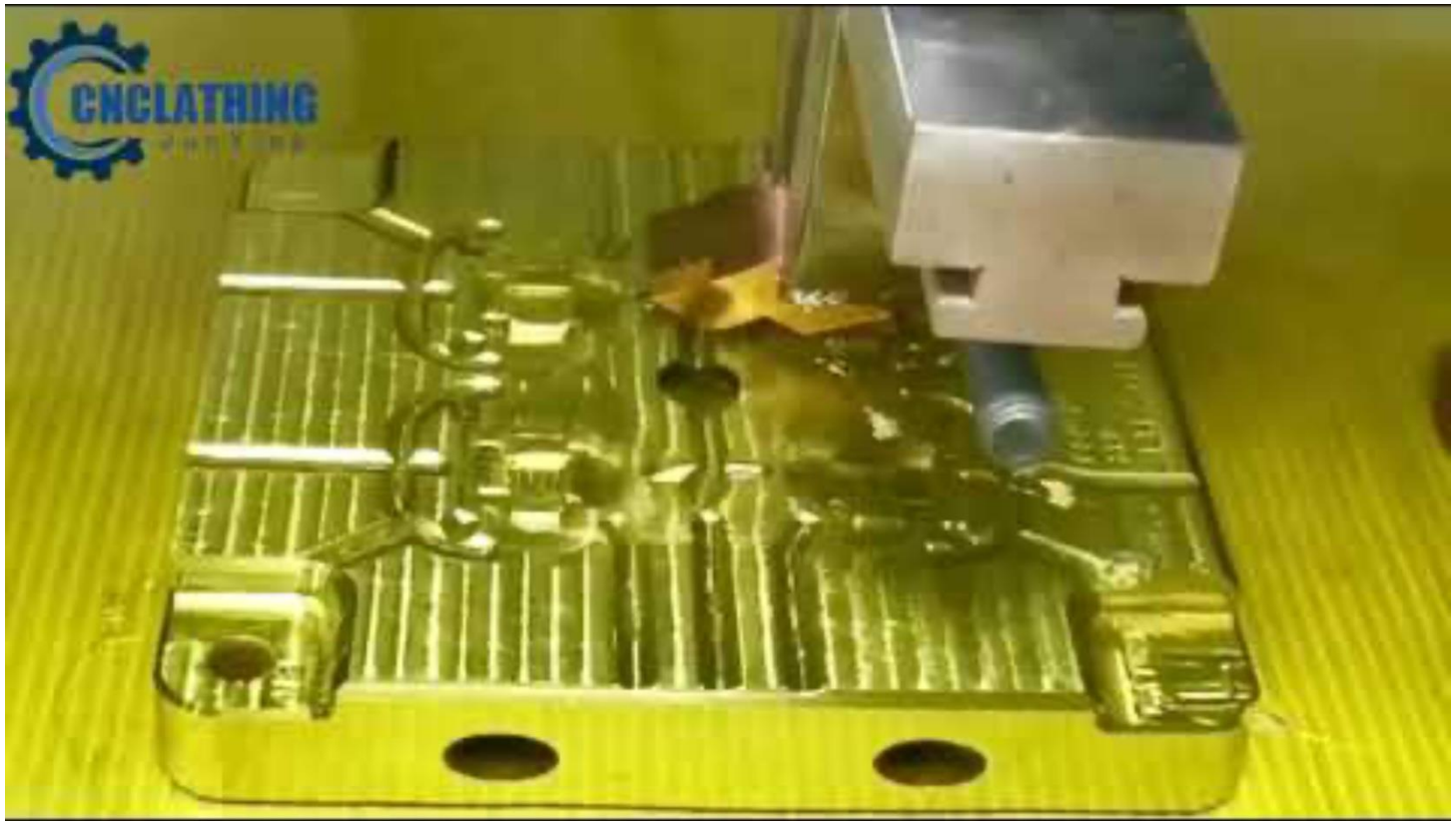
- Wire as electrode

Sinker-EDM

- Electrode in the shape of the desired feature



www.at-machining.com/electrical-discharge-machining



CNC Lathe

- CNC mill
- CNC router
- CNC lathe
- Cutting tool
- CNC electrical discharge
- CNC laser cutter
- CNC plasma cutter
- CNC waterjet

- A CNC mill spins around a central spindle
- CNC lathe
- Cutting tool
- CNC electrical discharge gradually reduces the workpiece's dimensions
- CNC laser cutter
- CNC plasma cutter
- CNC waterjet cuts cylindrical parts

CNC Waterjet Cutter

- CNC milling
- CNC router
- CNC lathe
- CNC electrical discharge machining
- CNC laser cutter
- CNC plasma cutter
- CNC waterjet

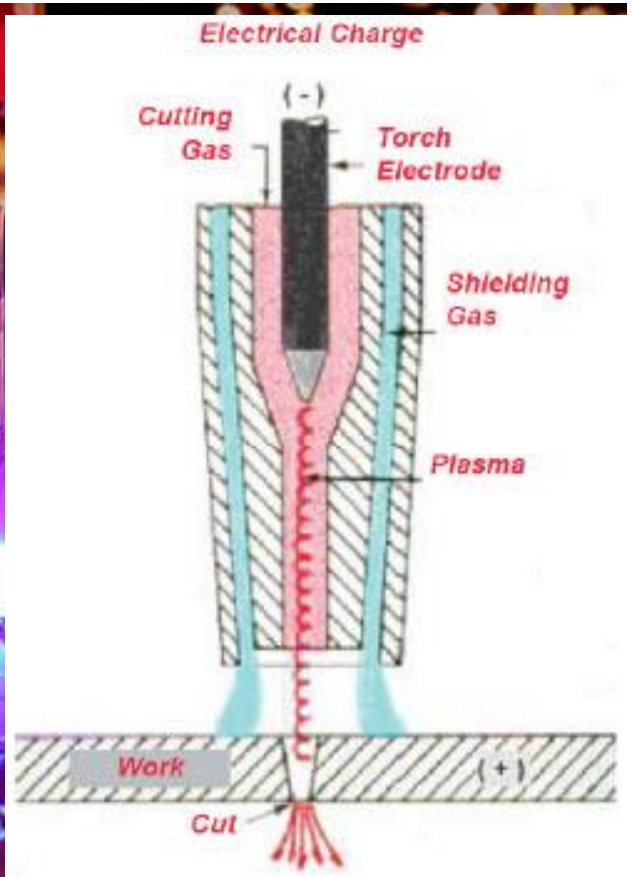
- High pressure water jet to cut through materials
- Addition of abrasive substance (e.g. aluminum oxide) to cut through hard materials

CNC Plasma Cutter

- CNC mill
- CNC router
- CNC lathe
- CNC electrical discharge
- CNC laser
- CNC plasma cutter
- CNC waterjet

- Cut through electrically conductive materials with plasma
- Electrical conductivity of the plasma causes the arc to transfer to the work

www.fractory.com/plasma-cutting/



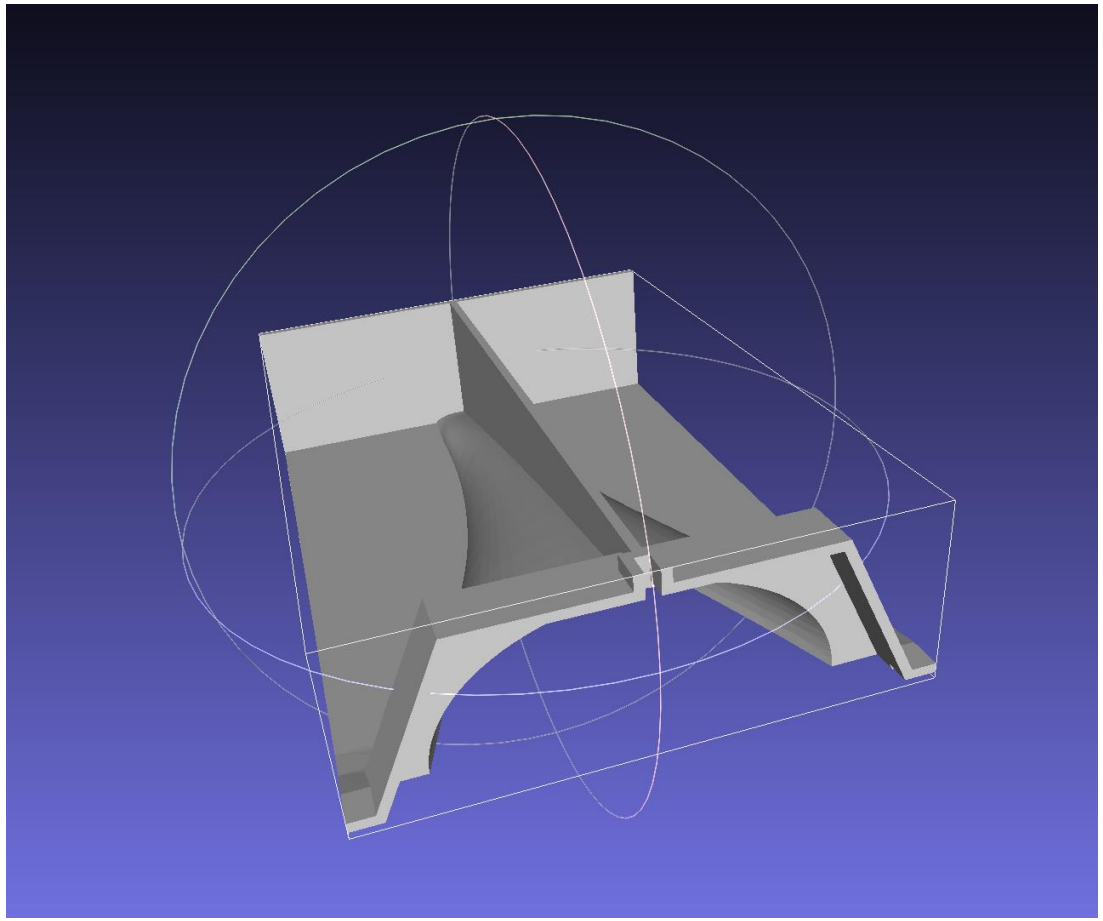
www.torchmate.com

CNC Mill

- Table moves in X-Y configuration
- Makes cuts using torque rather than rotational speed (1,000-15,000 RPM)
- For tougher materials such as metals
- Smaller cutting area

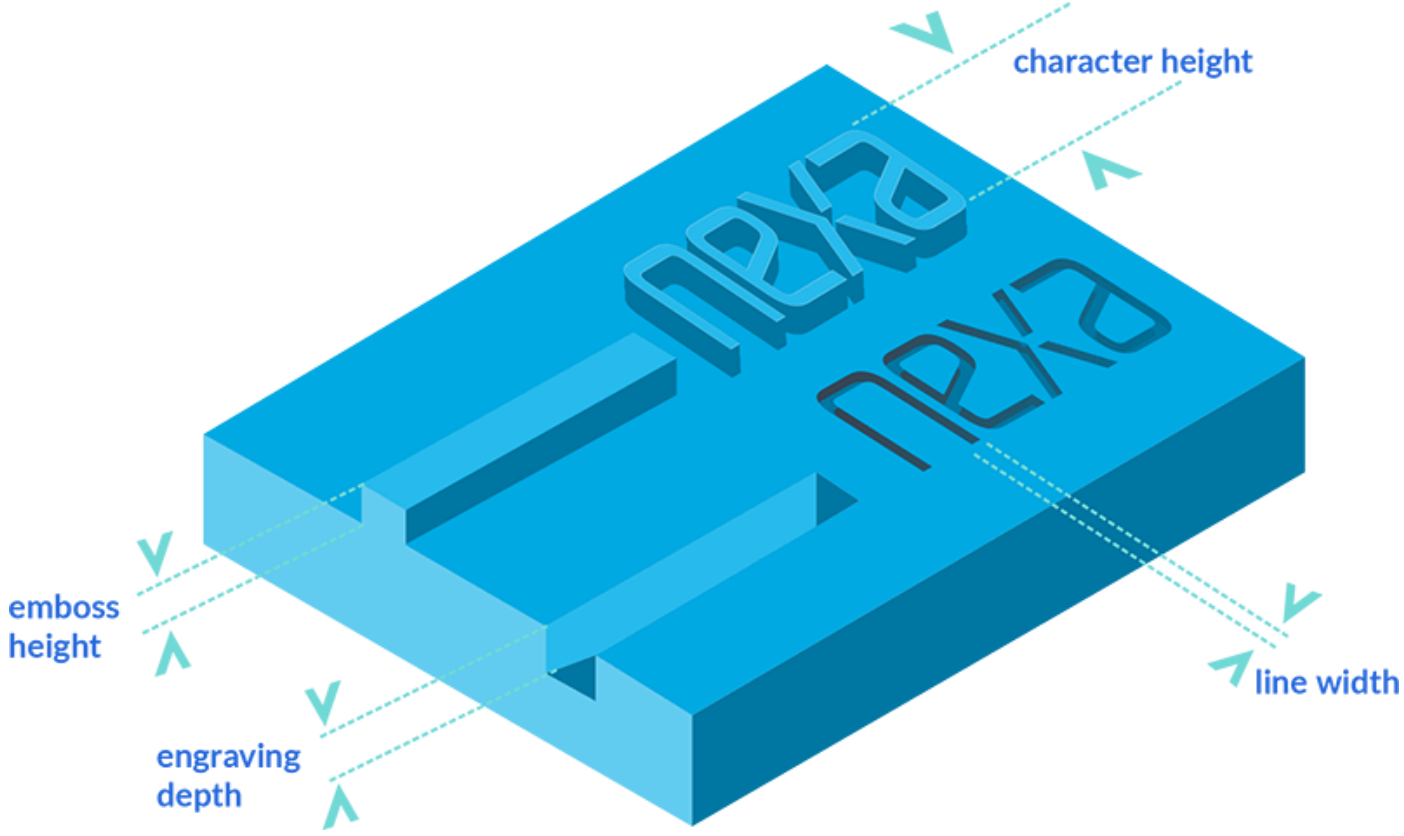
Design for Subtractive Manufacturing

- How to design this part for CNC milling?
  - Don’t remove more material than necessary



Engraving vs. Embossing

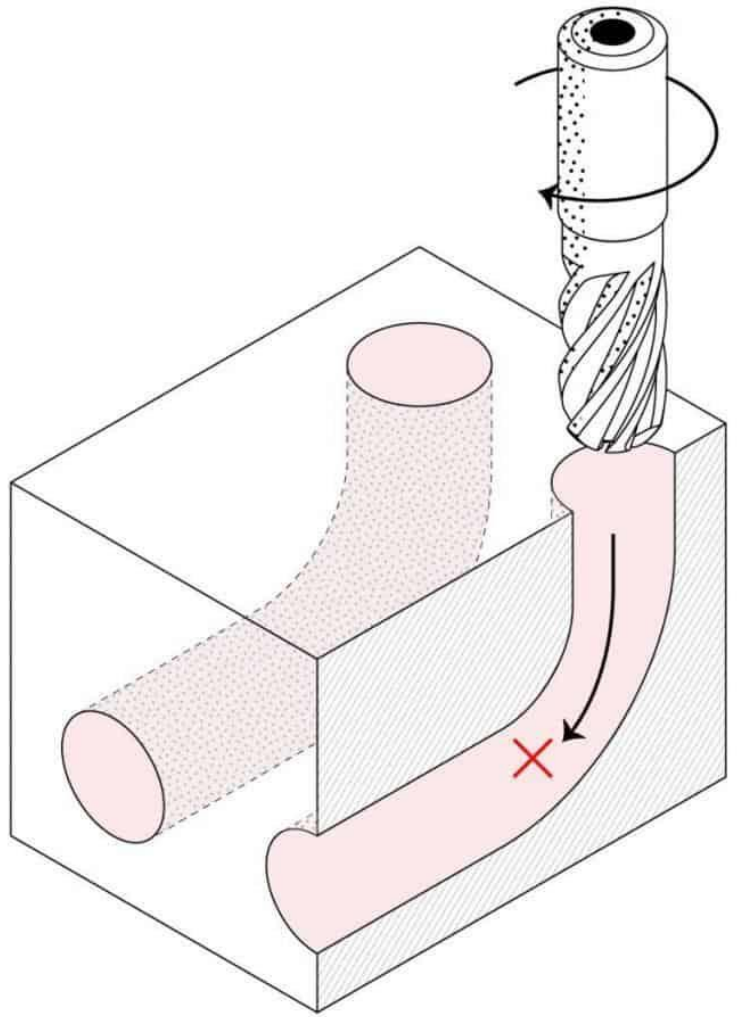
- Which option would you pick for subtractive manufacturing?
- Engraving:
  - less material waste
  - Less machining time



www.nexa3d.com/guides/design-guide/

Tool reach

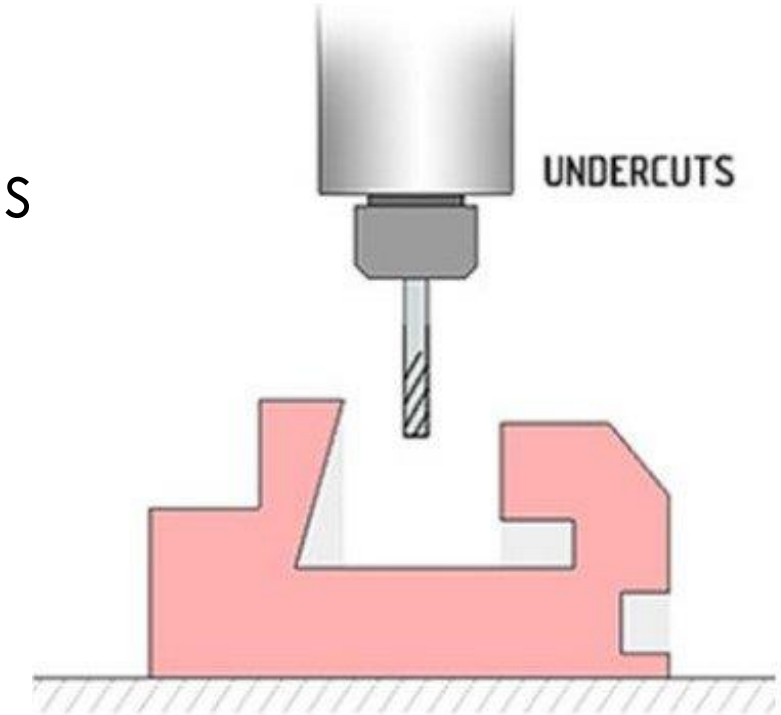
- The cutting tool has to be able to reach the position

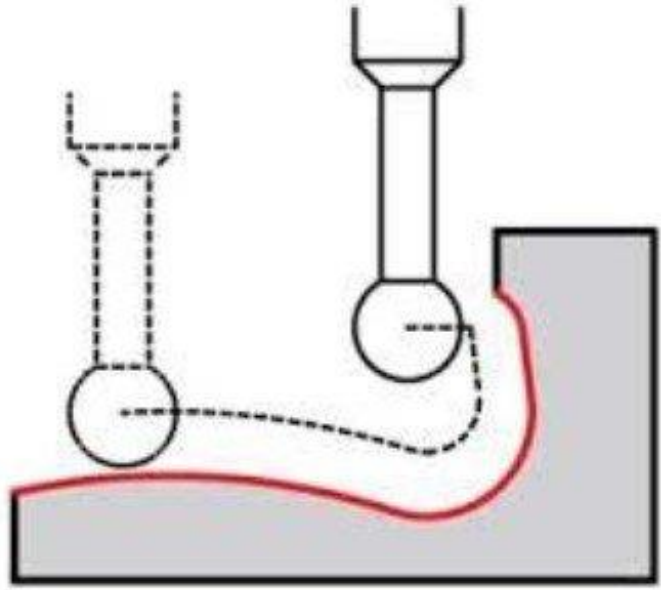


www.ddprototype.com/design-for-cnc-machining/

Undercuts

- Design features should align with the principal directions of the machine
- Multi-axis (>3) machines or specialized tools required to fabricate more complex parts

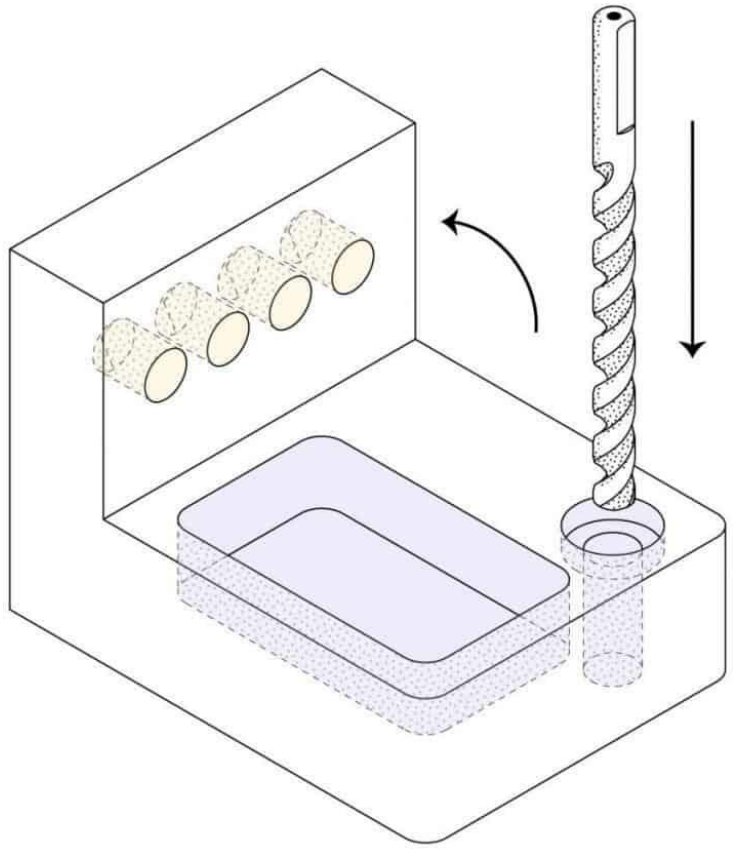




www.designreview.byu.edu/collections/designing-for-subtractive-machining

Workspace

- Minimize repositioning of the workpiece



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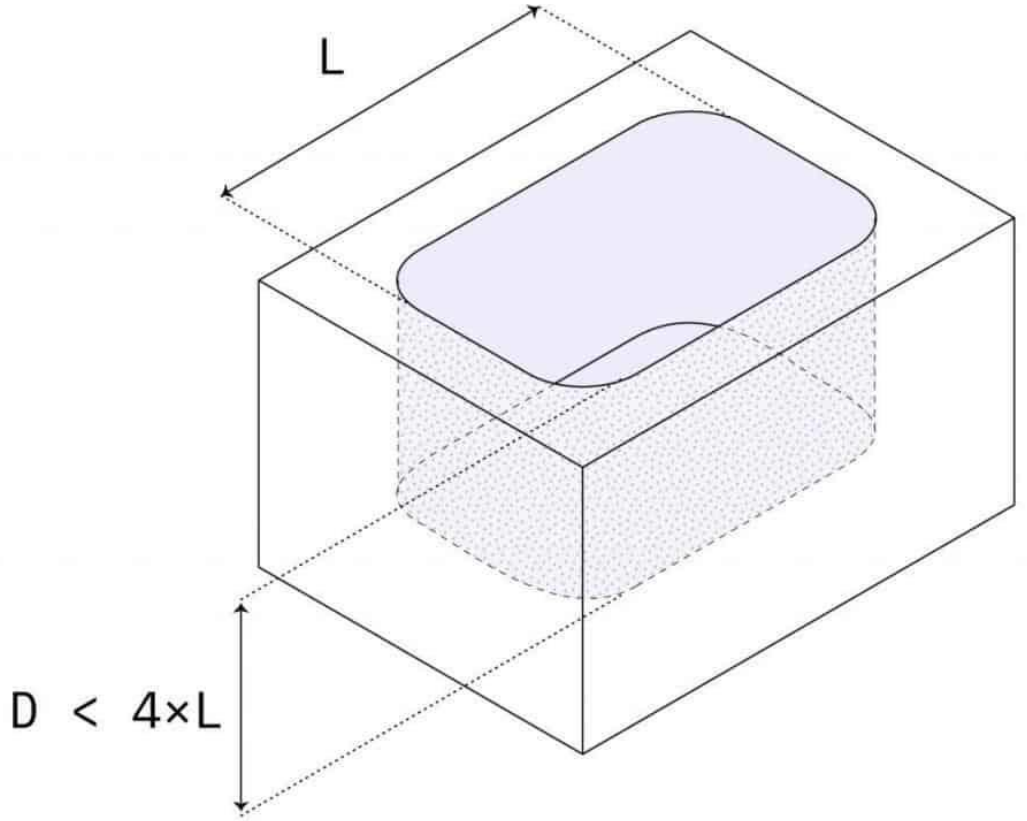
Cavities

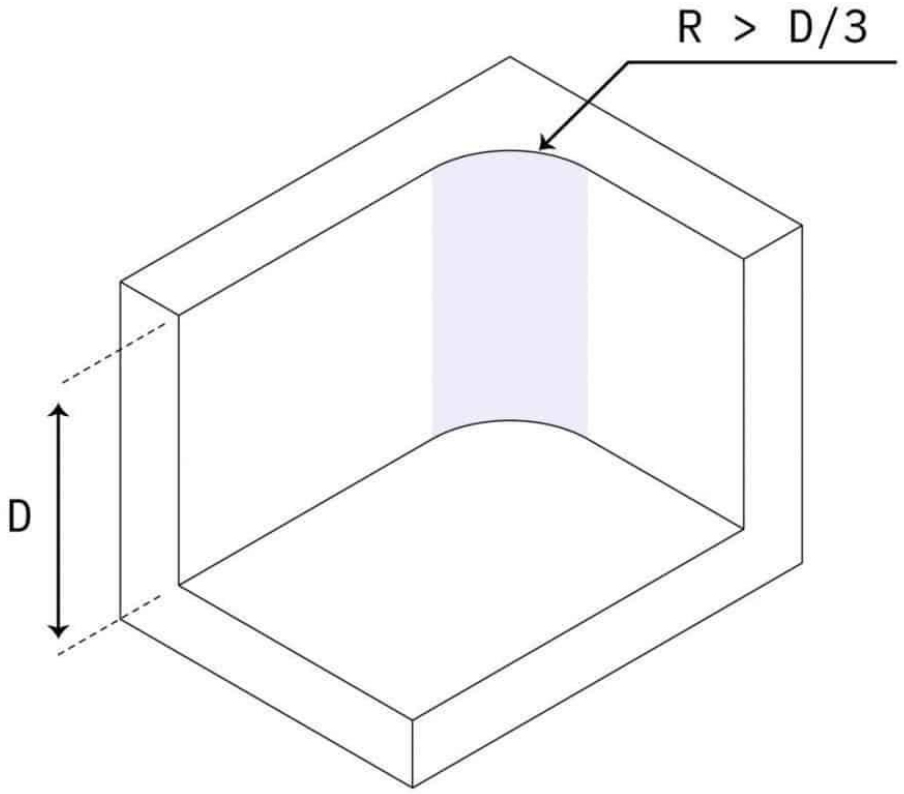
- No more than four times deeper than their width
- The longer the tool, the more chatter (vibrations) causing variations



www.ddprototype.com/design-for-cnc-machining/

Maximize vertical corner radius

- Radius: 1/3 of the cavity depth or greater
- Why?
  - Vibrations
  - Time
- Radius is inevitable (no straight corners)



www.ddprototype.com/design-for-cnc-machining/

Hybrid Manufacturing

Sefene et al., "Metal hybrid additive manufacturing: state-of-the-art", 2022

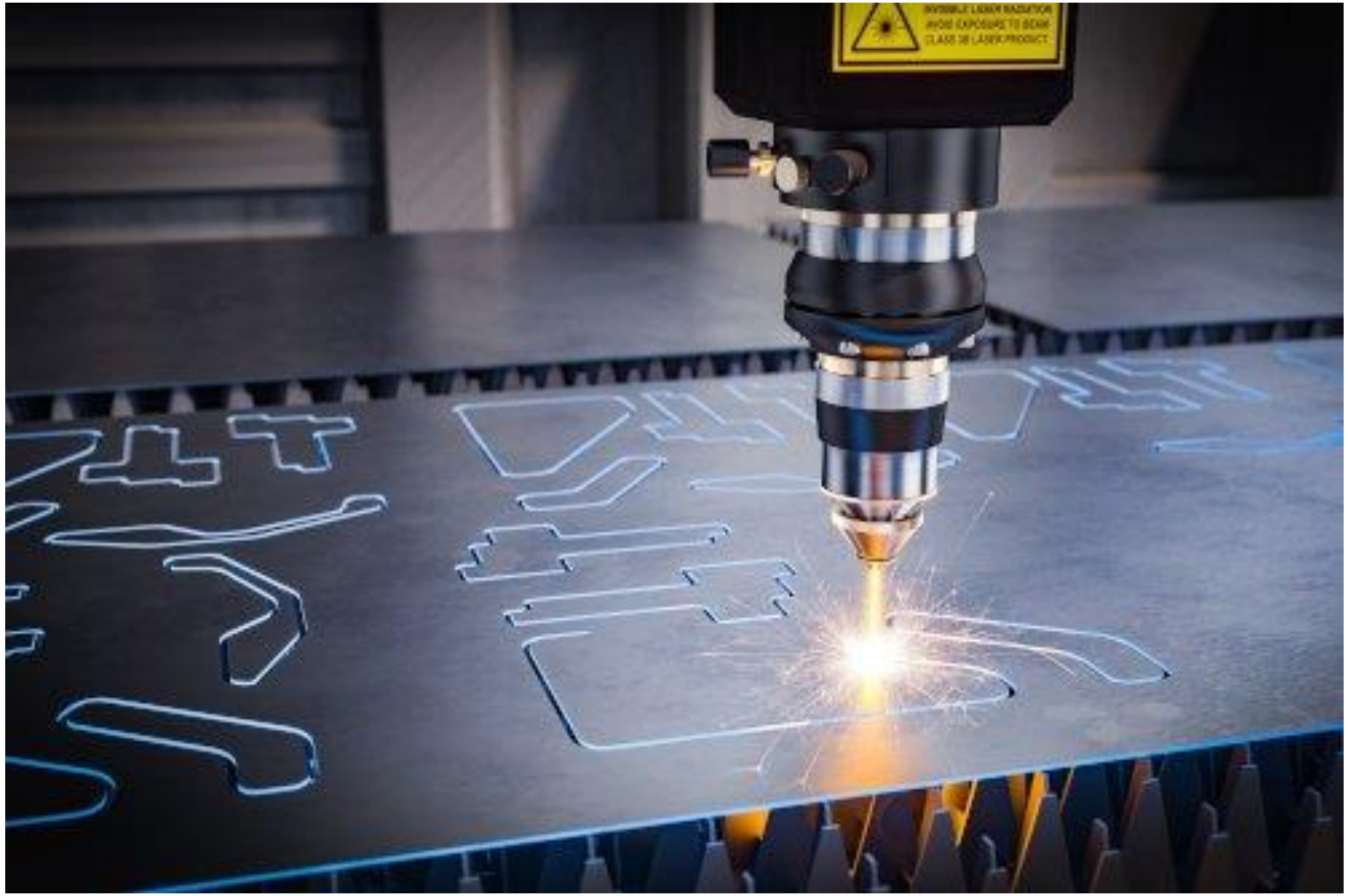
Hybrid Manufacturing

- Laser Deposition Welding + 5 axis CNC milling

CNC Laser Cutter

- CNC mill
- CNC router
- CNC lathe
- CNC electrical discharge
- CNC laser
- CNC plasma cutter
- CNC waterjet

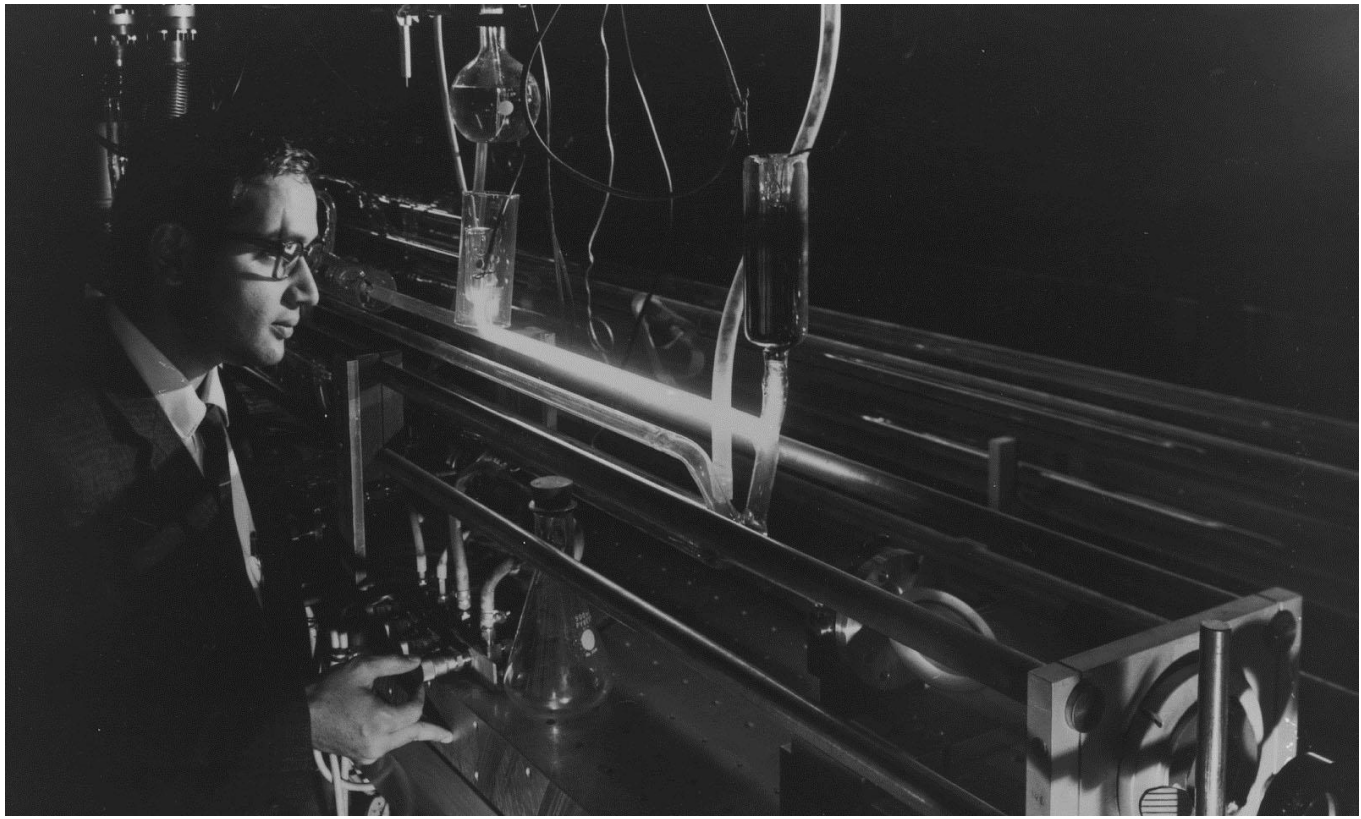
Laser cut through materials



Laser cutting

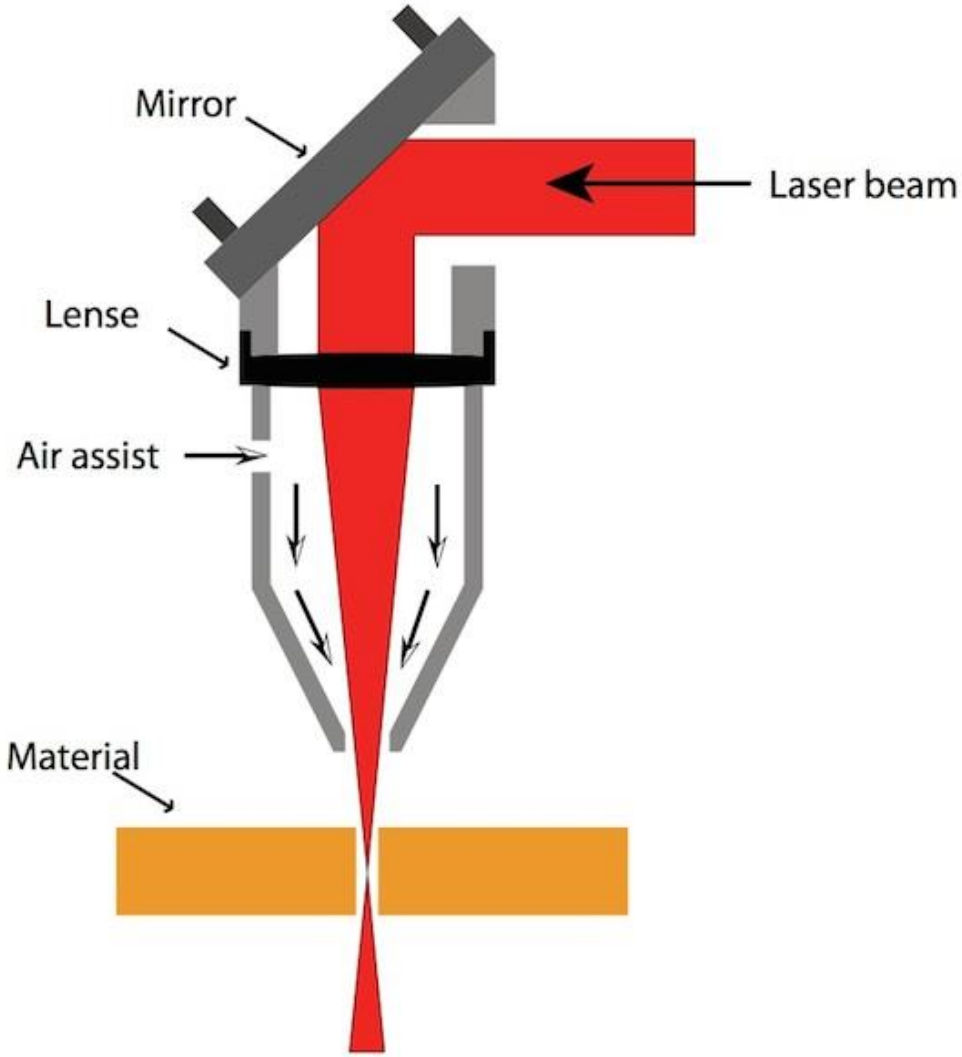
- LASER: Light Amplification by Stimulated Emission of Radiation

- CO_2 laser invented by Kumar Patel from Bell Labs in 1963



Laser cutting

- Engraving and cutting



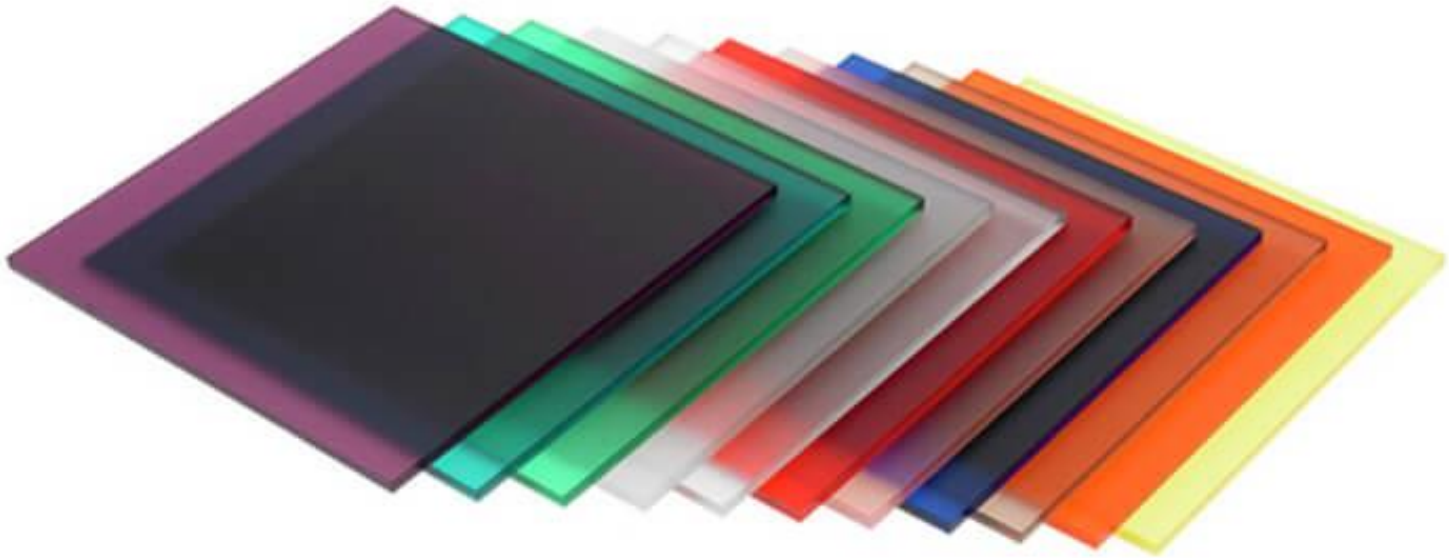
www.artisanmodelmakers.co.uk/blog/how-does-co2-laser-cutting-work/

Laser cutting

- Machine settings
  - Speed
  - Power
  - Air assist
  - Focal length

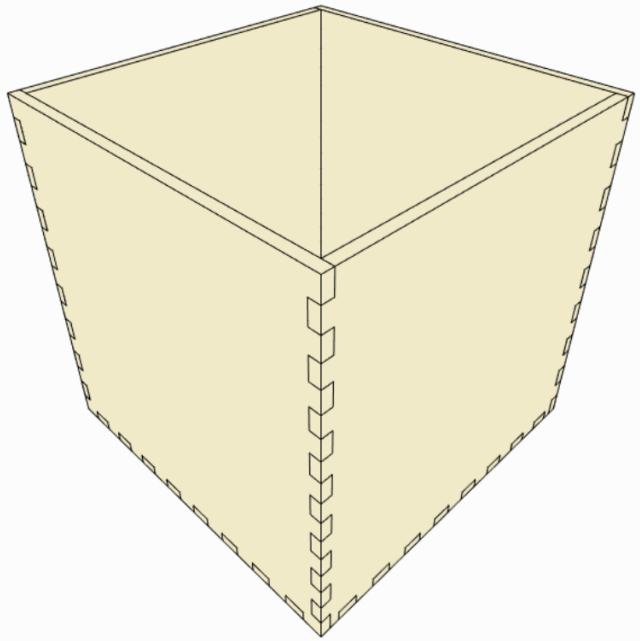
Laser cutting

- Materials
  - Wood
  - Veneer
  - Paper
  - Cork
  - Some types of plastic
    - PMMA (Perspex)
    - PET-G
    - POM
    - PLA
    - No PVC! (releases chlorine gas)



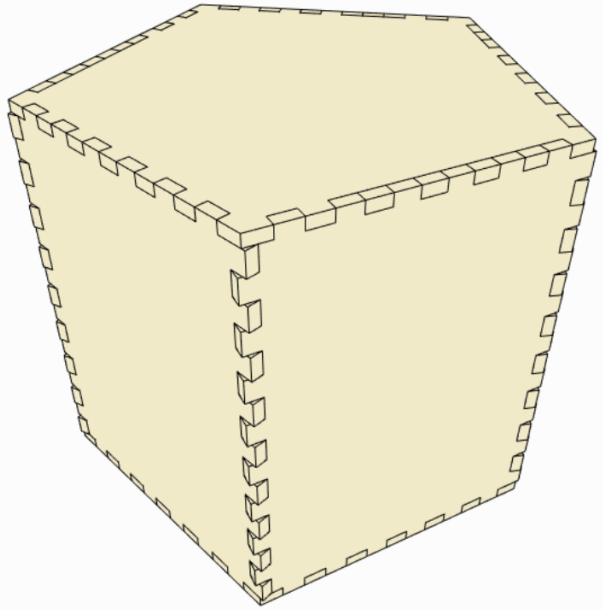
Flexible plywood

Tools for lasercutter



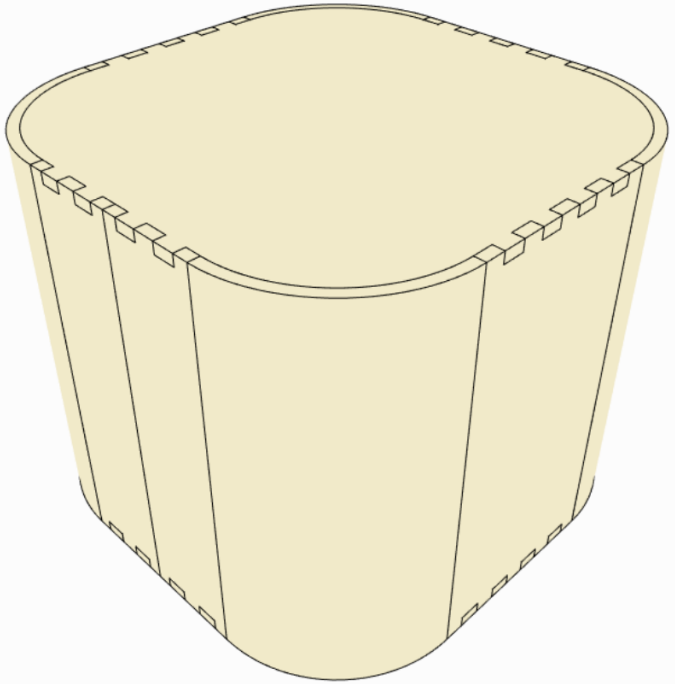
Basic Box

Simple boxes



Polygon Box

Polygon boxes with 3 or more sides



Kerf Bent Box

Boxes with round corners

www.makercase.com

SLICER
FOR FUSION 360

Sign In

3dbenchy.stl

Manufacturing Settings

Letter 8.5" x 11" x 0.1772"

Object Size

Units cm

Height 10.500

Width 16.256

Length 20.320

Original Size | Uniform Scale

Construction Technique

Interlocked Slices

Slice Distribution

Method By Count

1st Axis 9

2nd Axis 11

Notch Factor 0.100

Notch Angle 45.000

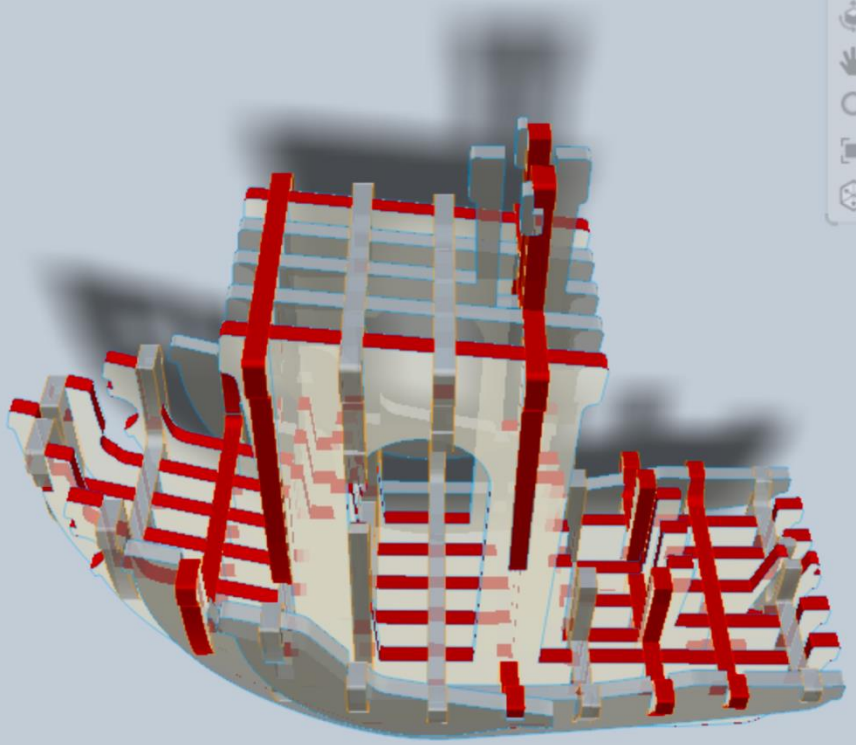
Relief Type Square

Slice Direction

Modify Form

Assembly Steps

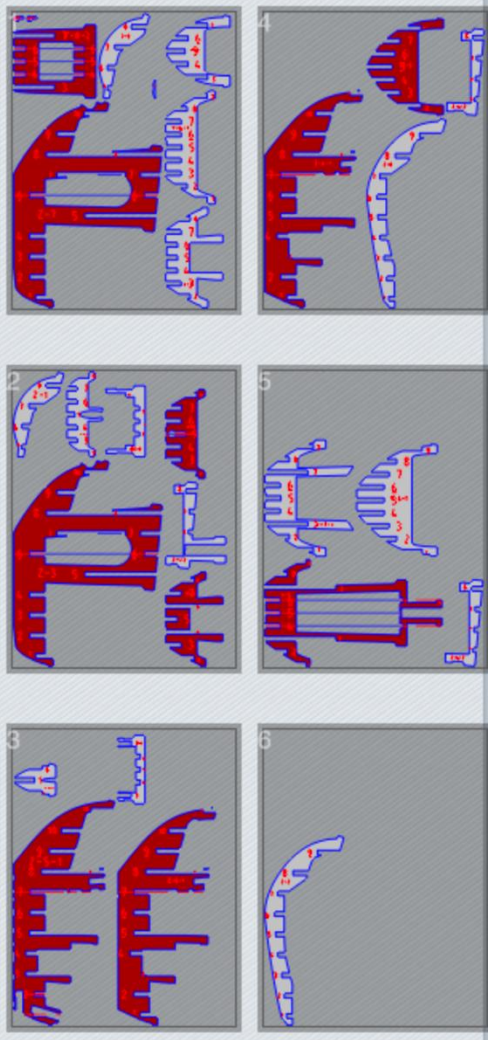
Get Plans



Cut Layout | Model Issues

Sheets 6

Parts 29



SLICER
FOR FUSION 360

Sign In

Model

3dbenchy.stl

Manufacturing Settings

Letter 8.5" x 11" x 0.1772"

Object Size

Units cm

Height 10.500

Width 16.256

Length 20.320

Original Size Uniform Scale

Construction Technique

Stacked Slices

Dowels Automatic

Diameter 0.635

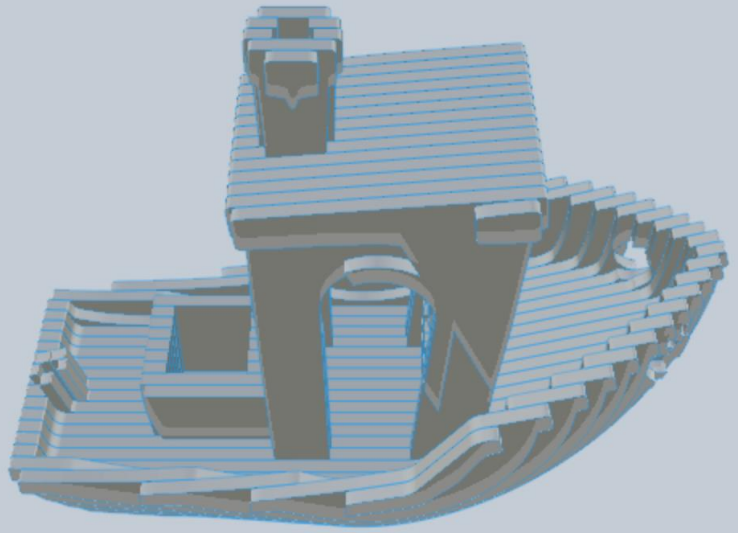
Shape Round

Slice Direction

Modify Form

Assembly Steps

Get Plans



Cut Layout

Model Issues

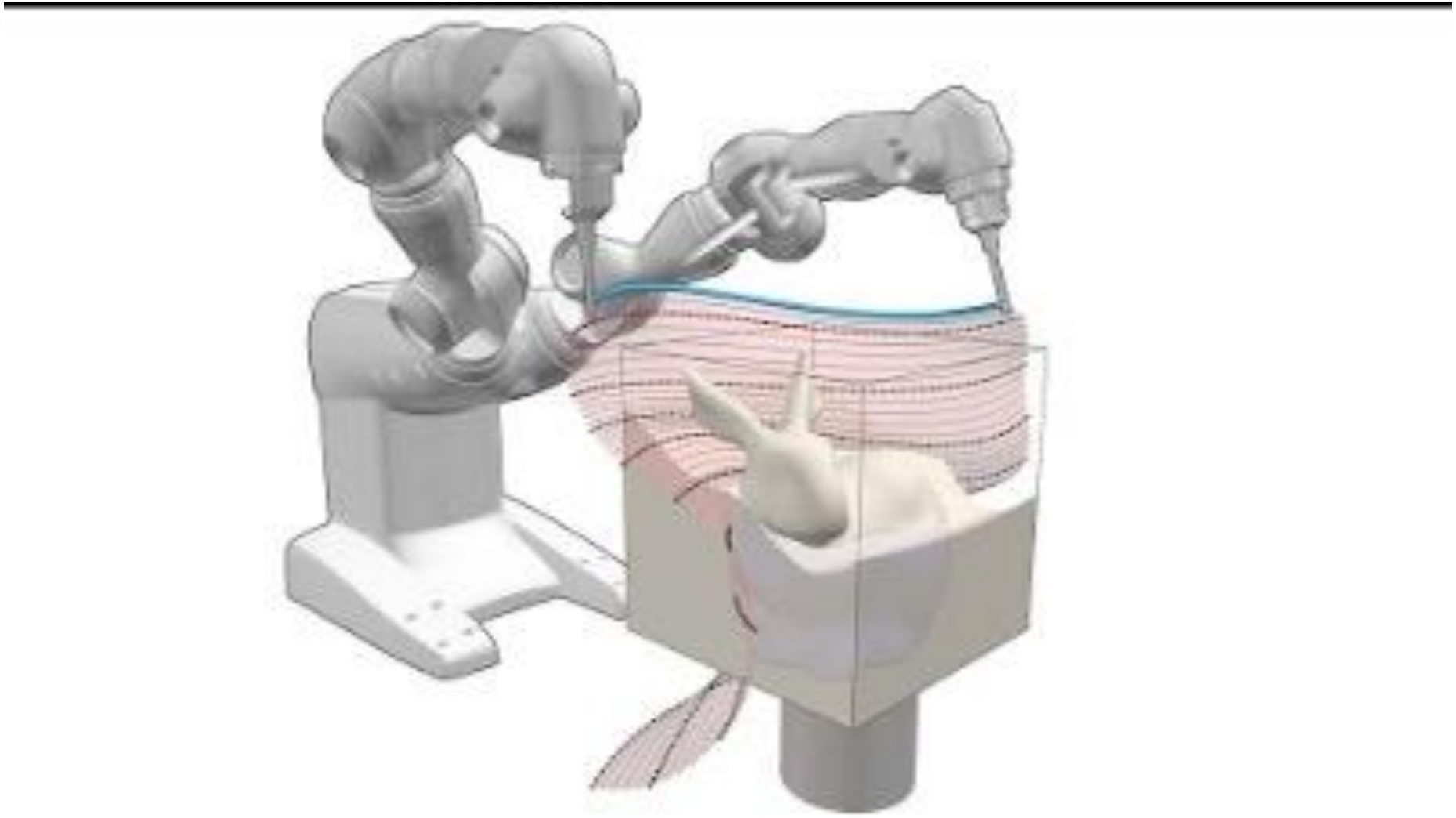
Sheets
0

Parts
36

Computer Numerical Control

- CNC mill
- CNC router
- CNC lathe
- CNC electrical discharge
- CNC laser
- CNC plasma cutter
- CNC waterjet
- CNC ?

Robot-controlled hot wire cutting



Next week's lab

- Lasercutting mold insert - Part #13

Questions?