

Spring 2016

# Concepts of CNC at Pier 9

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# Concepts of CNC at Pier 9: Agenda I

- What is CNC?
- History of CNC
- Advantages/Disadvantages and File Preparation
- Toolpaths and Toolpath Terminology
- Pier 9 CNC Shop and workflows for machines
- CNC Milling Tools
- CNC Cutting Fundamentals

# Concepts of CNC at Pier 9: Agenda II

- Coordinate Systems
- Fixturing/Workholding
- CNC Operation
- Starter/Intermediate/Advanced Projects
- Considerations during CAD
- CNC Learning Path and Preparation
- Resources

CNC Overview

# What is CNC?

# What is CNC Milling?

- Subtractive Process
- Motion Control
- More complex than 3D Printing
  - Cannot send designs to CNC machines without a program
- 90%-10% split

CNC History

# From NC to CNC...







**FIGURE 1-15** The first successful N/C machine, developed by MIT.  
(Courtesy of Cincinnati Milacron)



**KTNC**

a machine that harnesses the **full** potential of numerical control:

**Kearney & Trecker Tape-Controlled**

# MILWAUKEE-MATIC

a flexible automated machining center that unifies milling, drilling, reaming, tapping and boring operations in a single machine

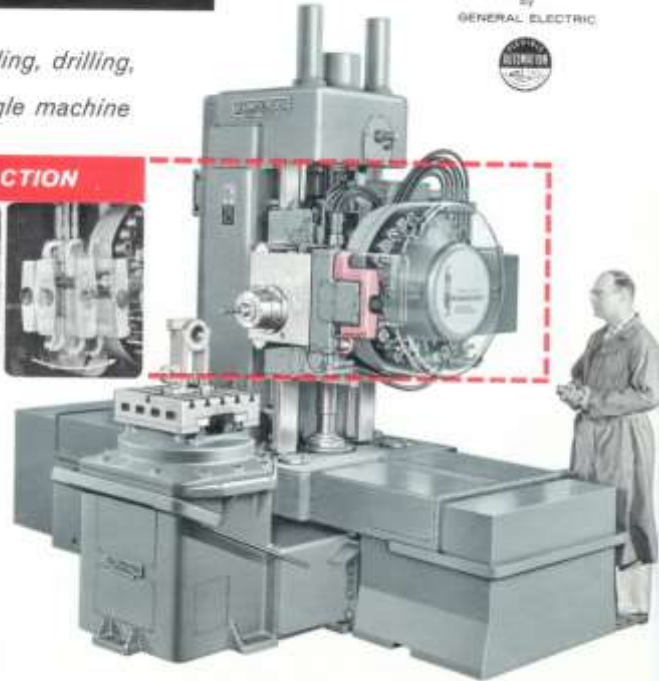
Program Controls  
by  
GENERAL ELECTRIC



**Here it is! KTNC AUTOMATIC TOOL CHANGER IN ACTION**



In a matter of seconds this exclusive **MILWAUKEE-MATIC** feature changes your production schedules from **MONTHS TO MINUTES!**



Here's what **MILWAUKEE-MATIC** means to your operations.

The MILWAUKEE-MATIC is the most significant achievement of the machine tool industry in the last 50 years. Briefly, it is a single machine that performs the many operations that are normally accomplished on several other machines to complete a part. MILWAUKEE-MATIC will improve almost every aspect of administrative planning—from plant management and finance to engineering and production.

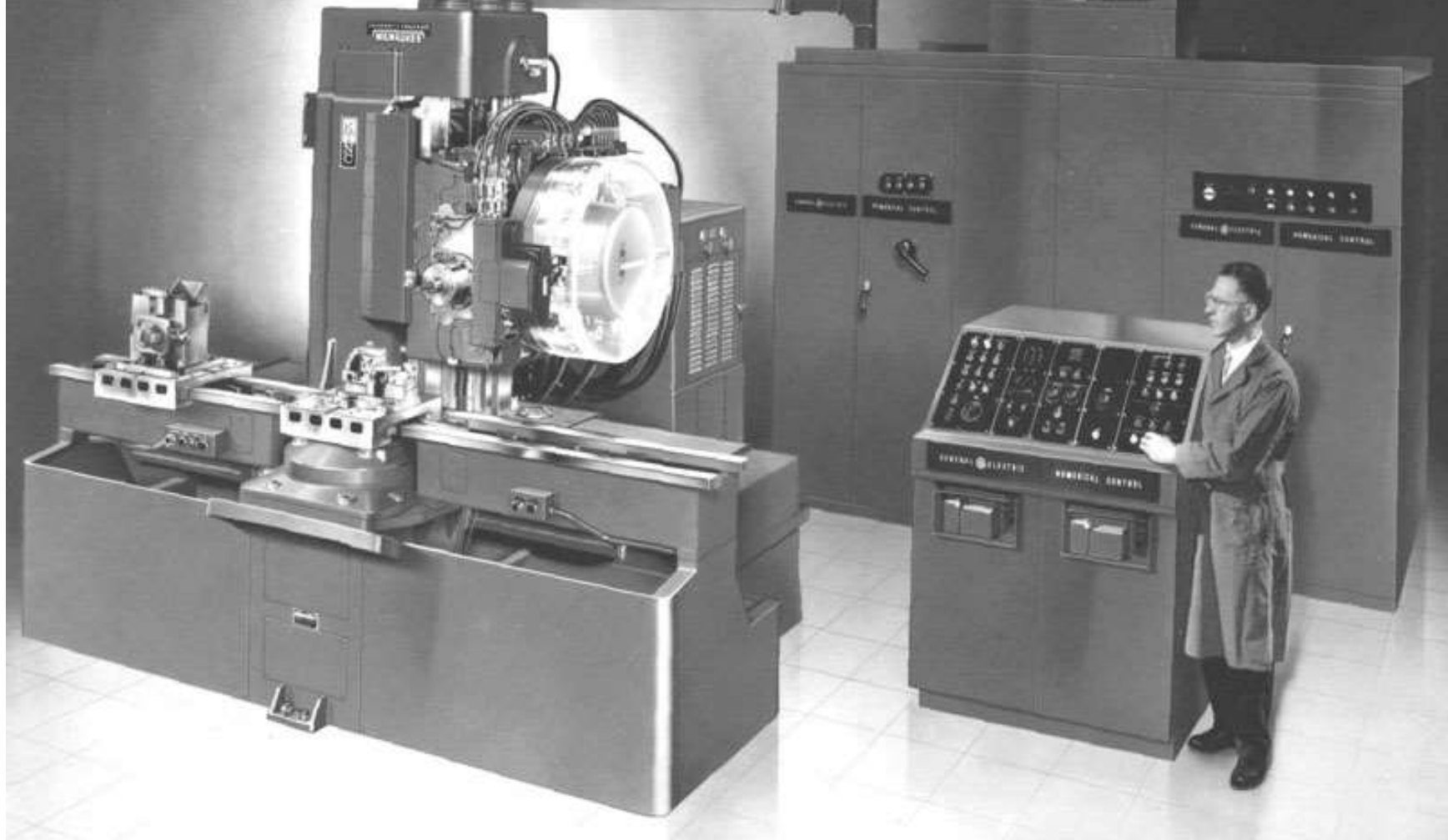
- Offers flexible automation for job-lot producers through numerically controlled positioning, straight-line milling, area and slope, tool selection, indexing and speeds and feeds.
- Cuts working capital requirements... business inventory.
- Boosts machine cutting time by as much as 75% by applying off-machine workpiece set-up.
- Slashes tooling cost... savings can pay for MILWAUKEE-MATIC in one to three years.
- Reduces lead time from months to days... permits rapid new product introductions and product changes.



KEARNEY & TRECKER CORPORATION, Dept. KTNC  
8800 W. National Ave., Milwaukee 18, Wisconsin

Designers and Builders of Precision and Production Machine Tools Since 1888

See Back Page...  
**FOR FANTASTIC SAVINGS!**





# Advantages of using CNC Machines

- Improved Automation
- Consistent/Accurate
- Mass Production
- Flexibility



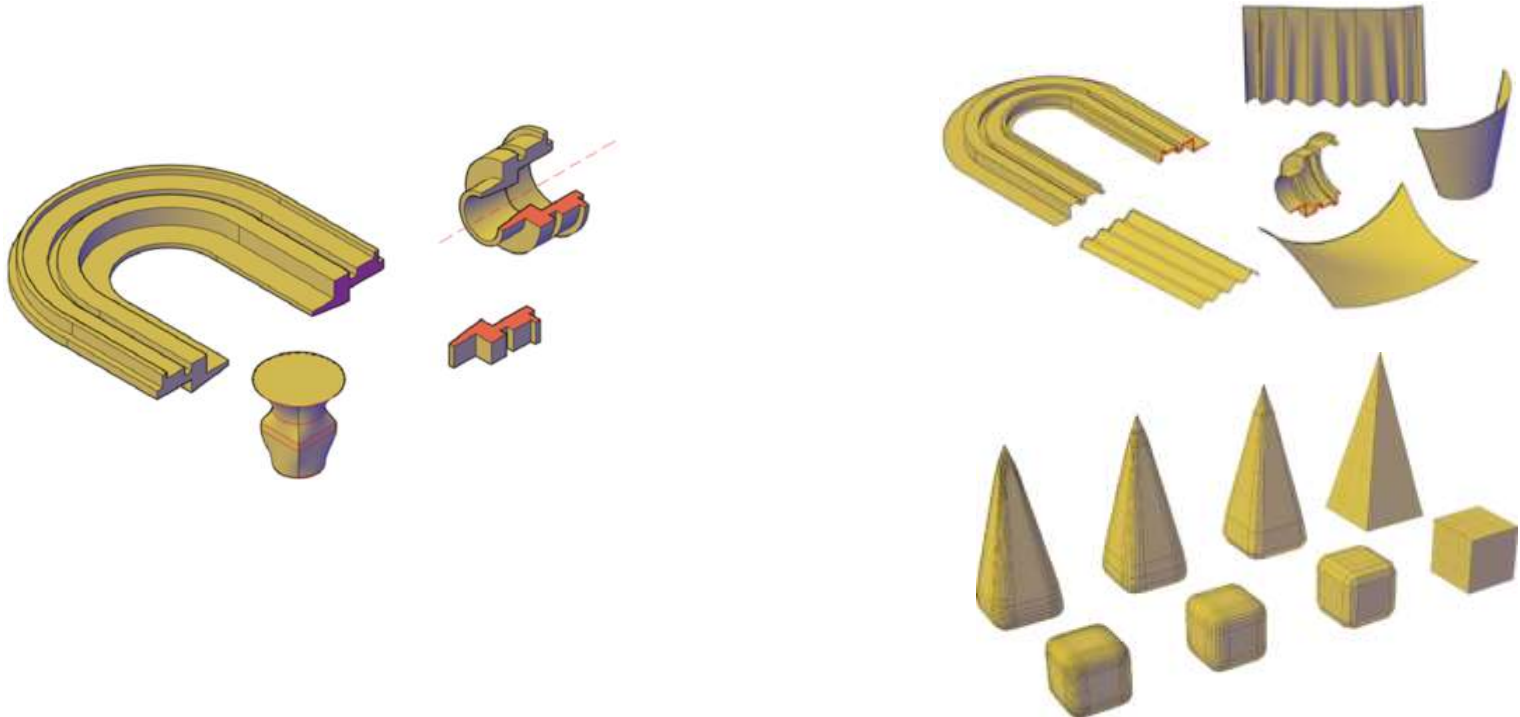
# Disadvantages of using CNC Machines

- Price
- Programming Skillset
  - They only do what they're told to do
- Space/Electricity/Maintenance
- Slower to make a single part

# How do you prepare a file for CNC machines?

- CAD
- CAM Software
  - Setup
  - Toolpath
  - Simulate
- Post Process
- Transmit to Machine
  - Dry run; Cut part

**CAD Design:**  
**USE SOLID MODELS (Fusion 360, Inventor HSM)**  
**Avoid surface models or meshes\***



# Key Terms Review

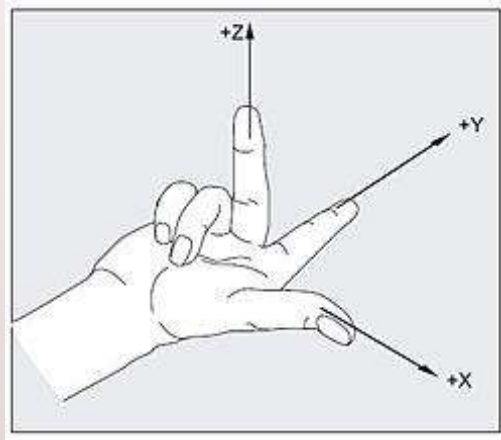
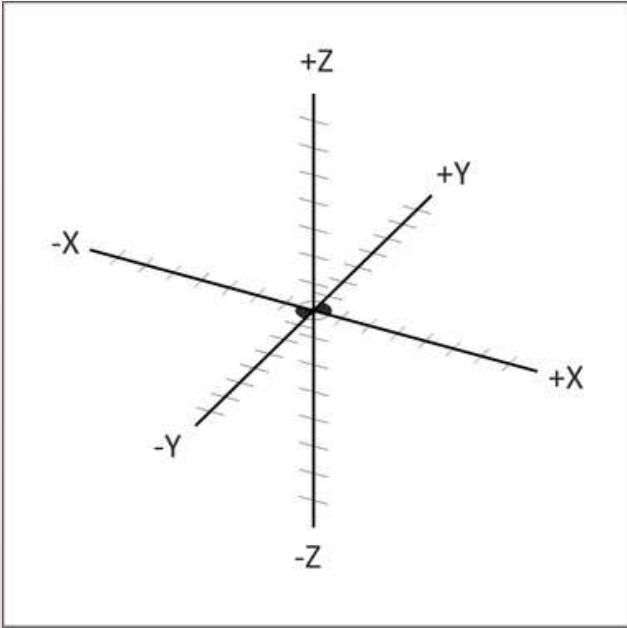
- CNC
- Subtractive/Additive Processes
- NC
- CAD to CAM
- Three steps in CAM
- Post Processor
- Solid Model



CNC Overview

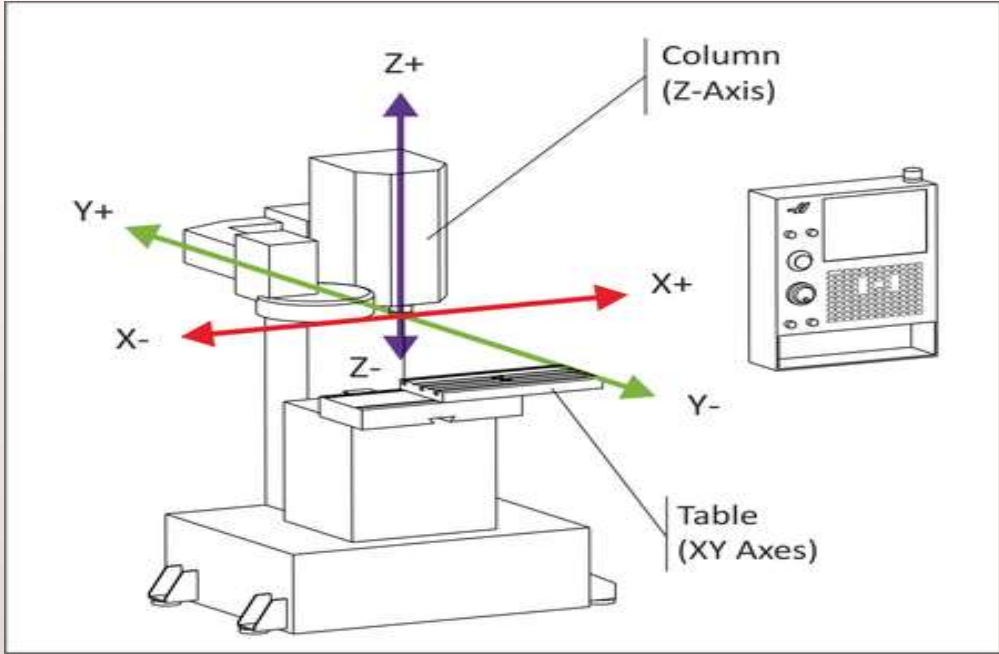
# Types of Toolpaths

**2D, 2.5D, 3D, 4-axis, 3+2 axis, 5-axis**



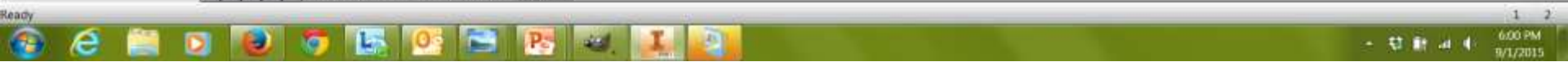
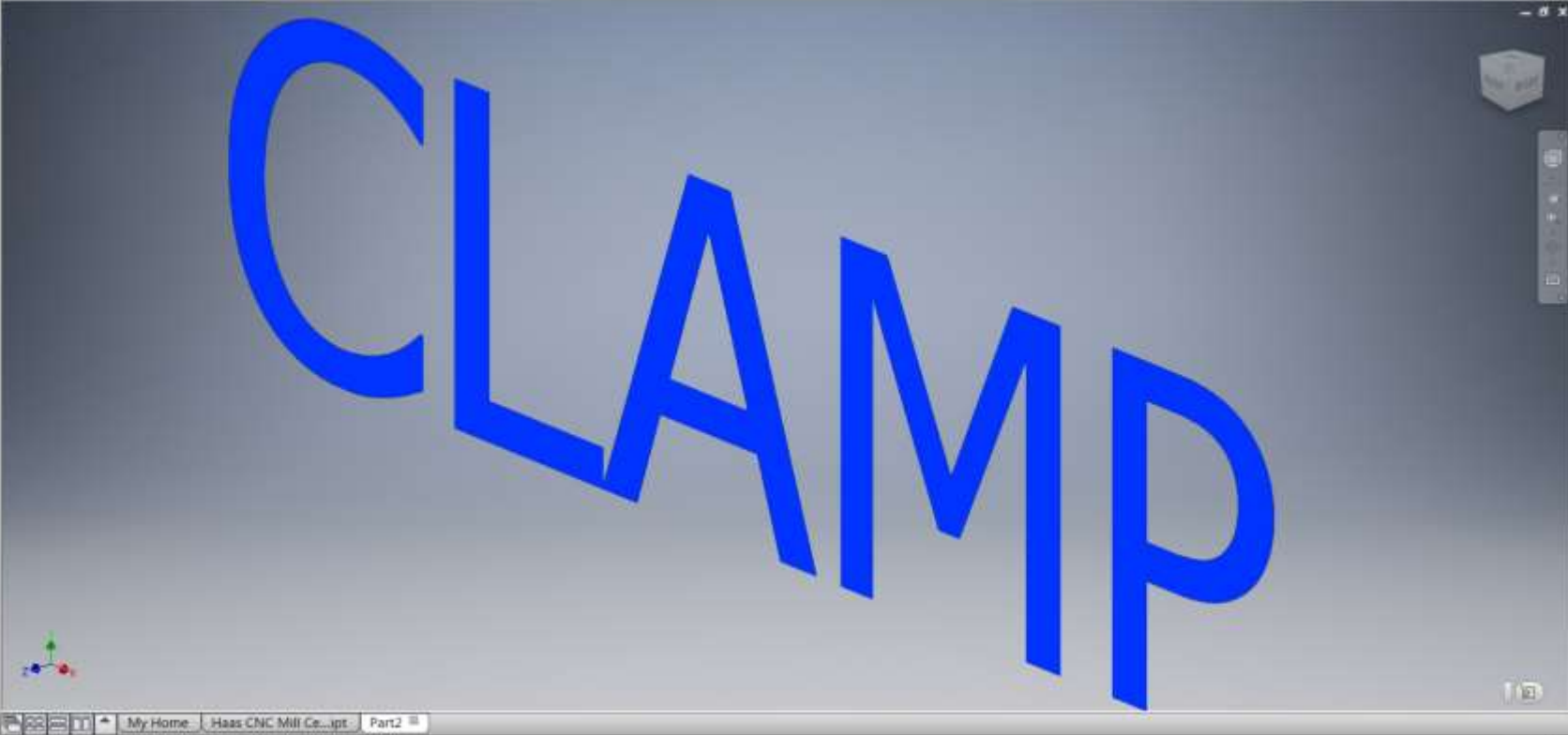
## Coordinate System

# Cartesian Coordinates and the Right Hand Rule



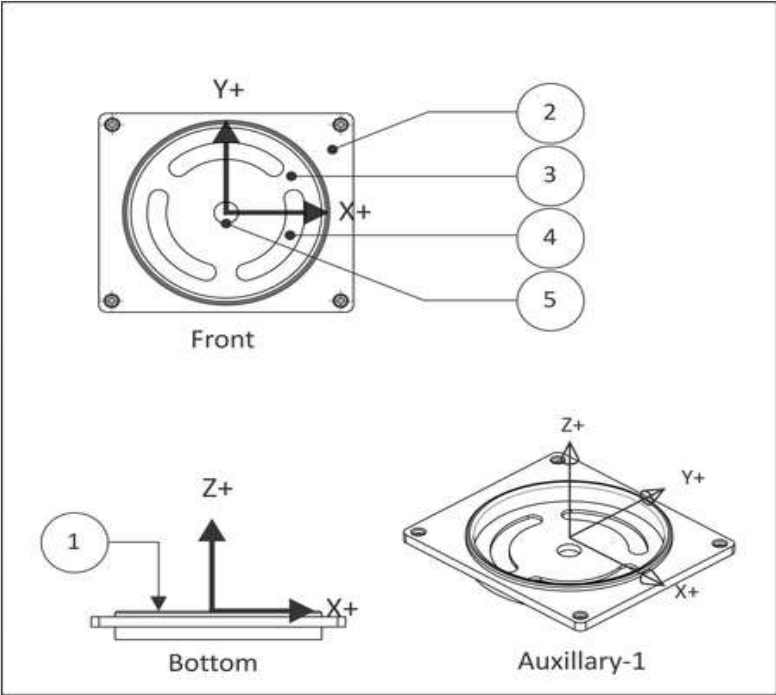
## Coordinate System

# Machine Coordinate System



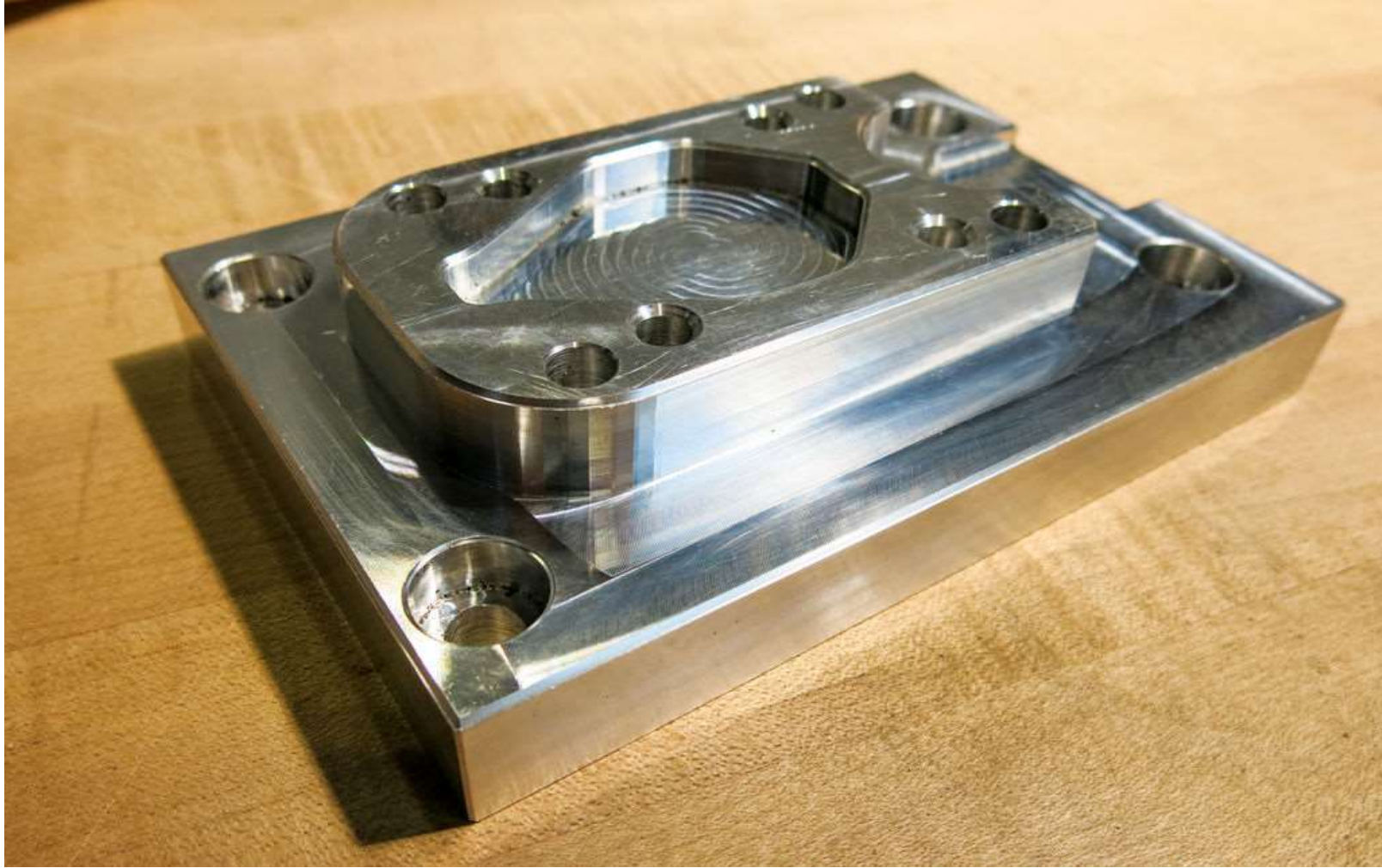




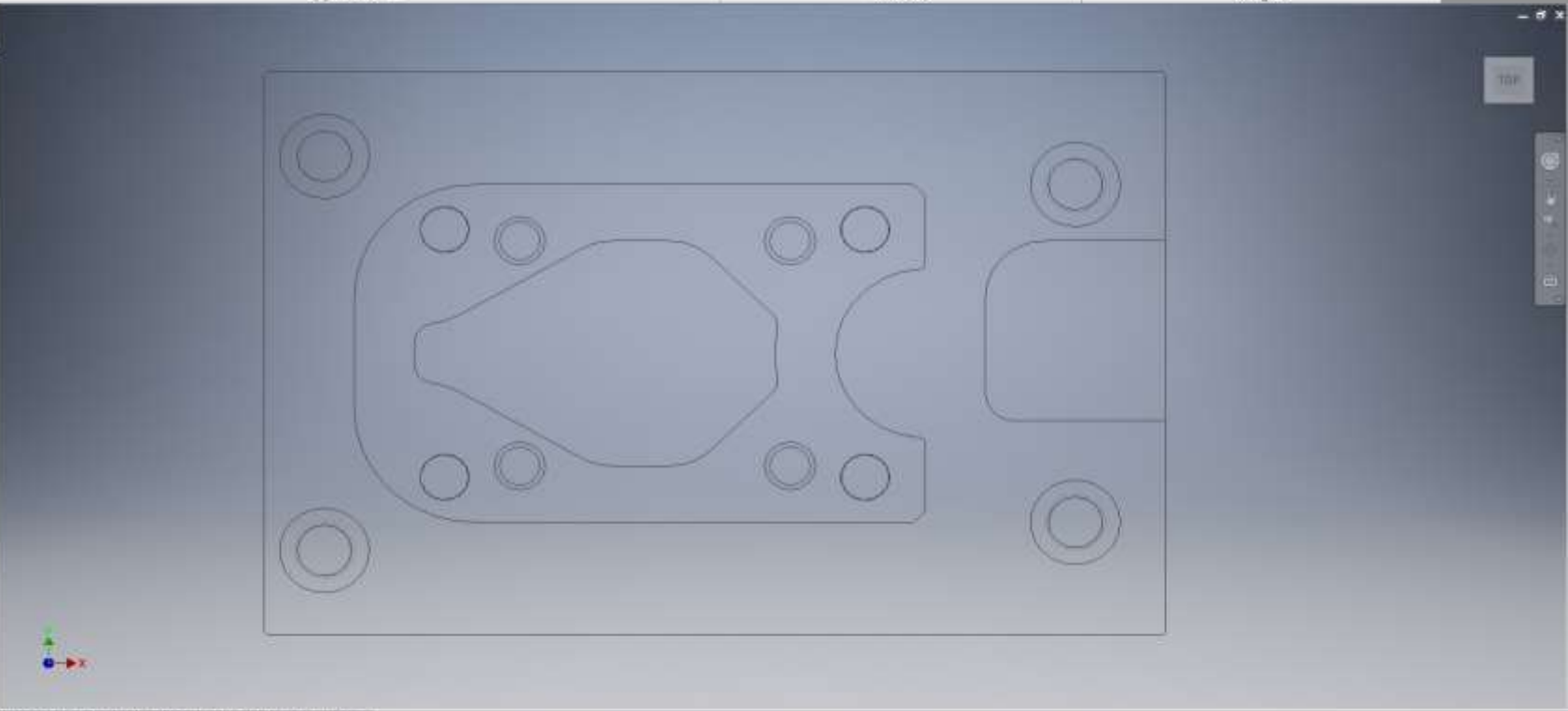


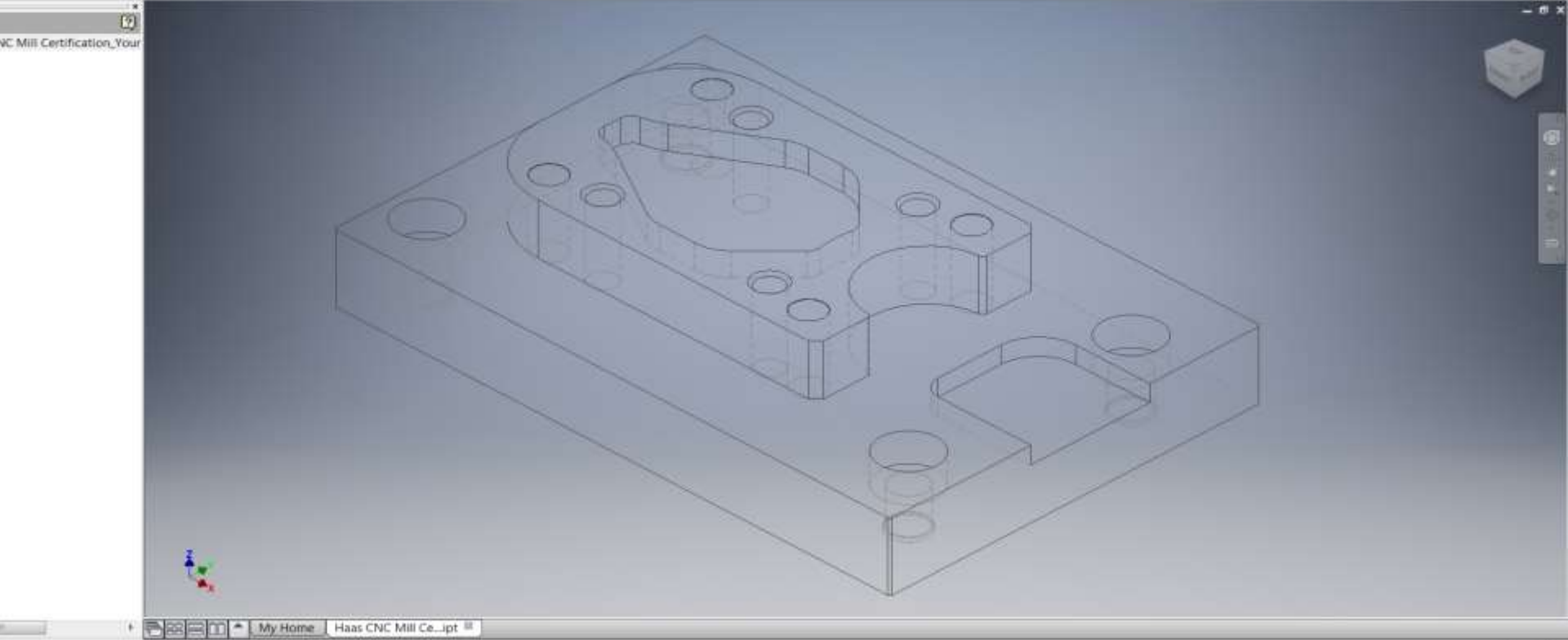
Toolpaths

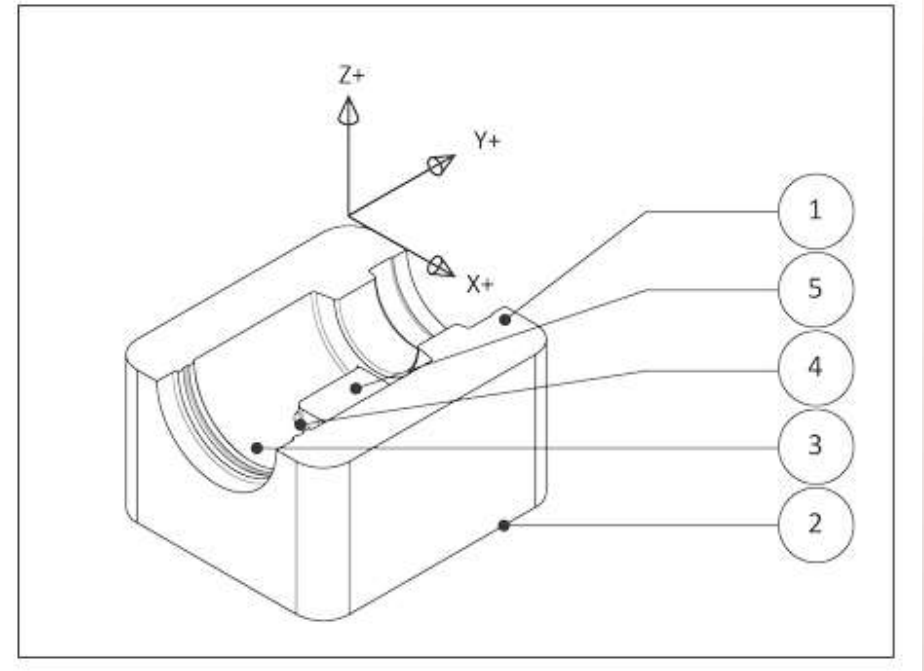
2.5D



CAM -  
Haas CNC Mill Certification\_Your







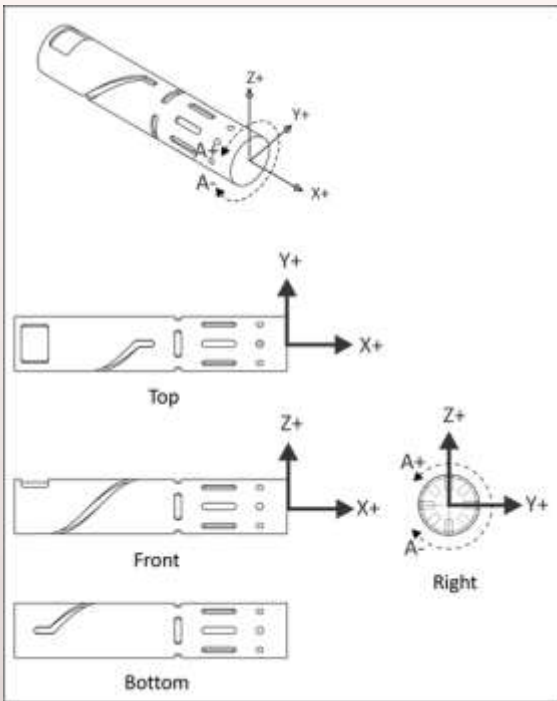
Toolpaths

## 3D

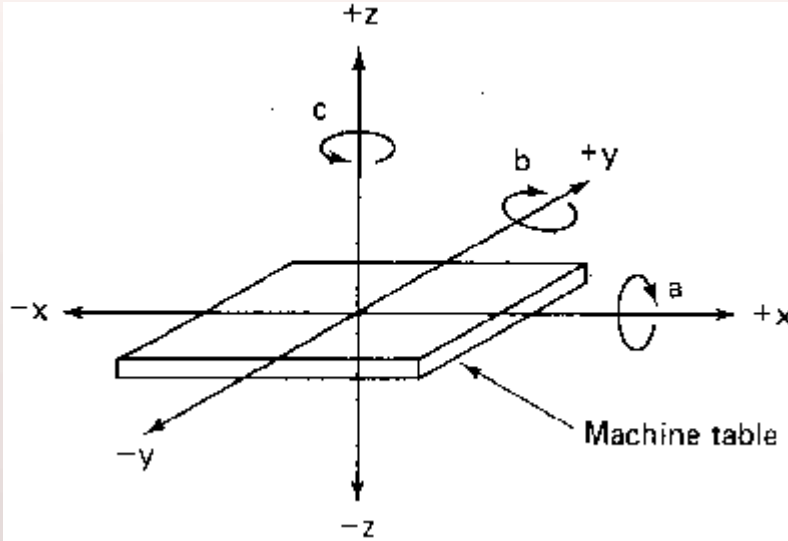






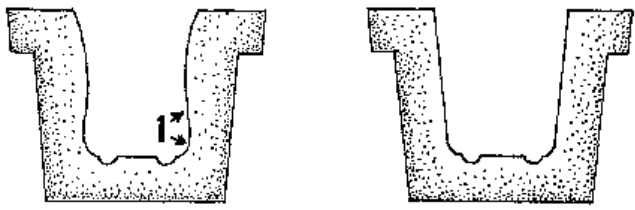


## Toolpaths 4-axis

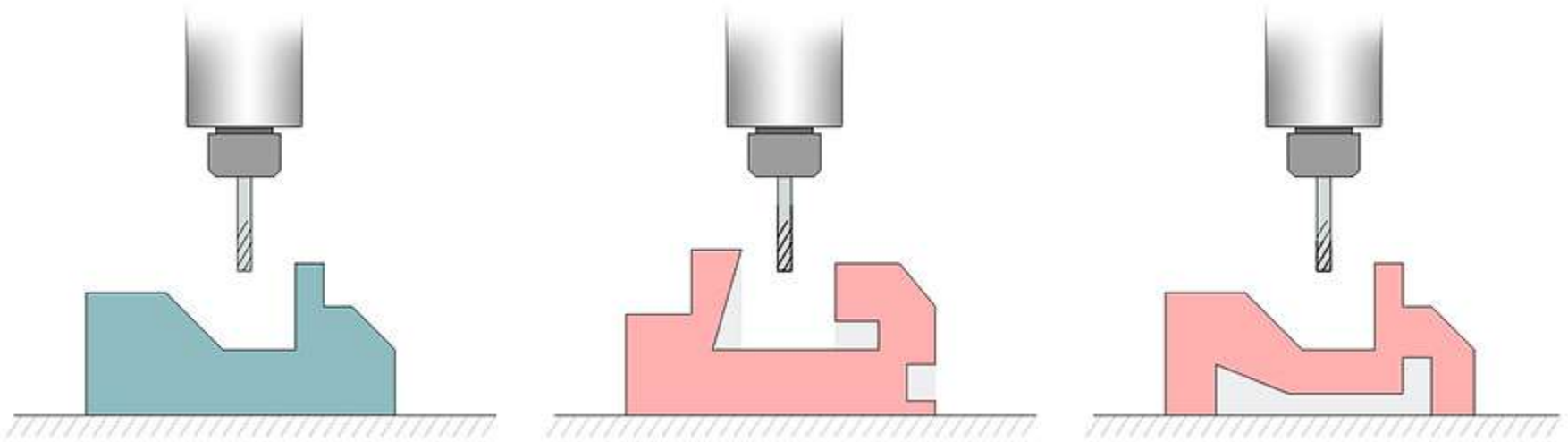


Toolpaths  
**5-axis**





# Undercuts example



Machinable/Unmachinable Features using a 3-Axis CNC Machine





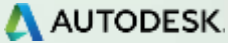


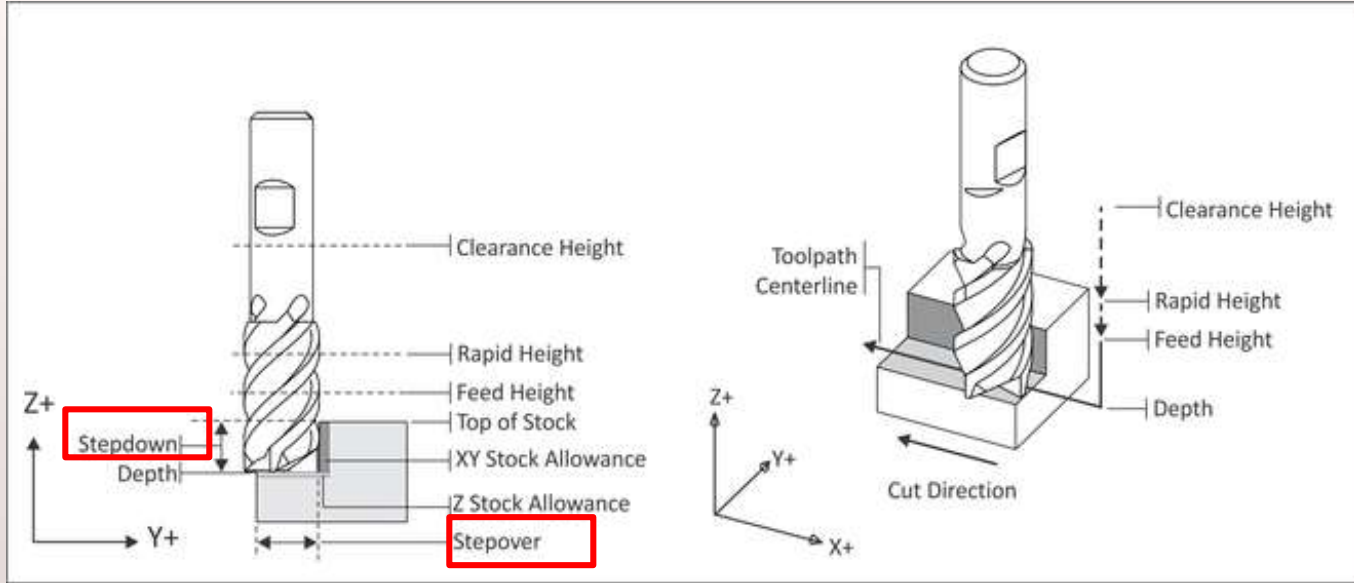


# Key Terms Review

- CNC
- Subtractive/Additive Processes
- NC
- CAD to CAM
- Three steps in CAM
- Post Processor
- Solid Model
- 2D Toolpaths
- 2.5D Toolpaths
- 3D Toolpaths
- 4-axis Toolpaths
- 5-axis Toolpaths
- Undercuts
- Setup
- Toolpath
- Simulate

# Toolpath Terminology

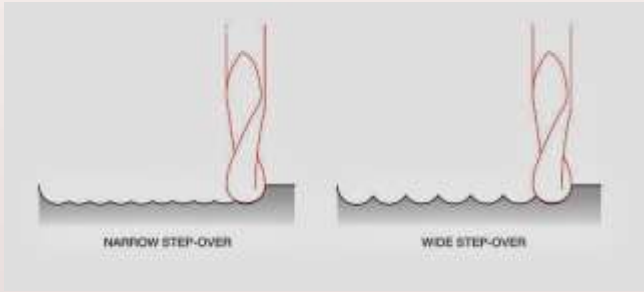
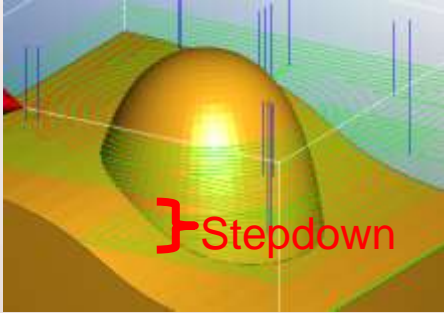
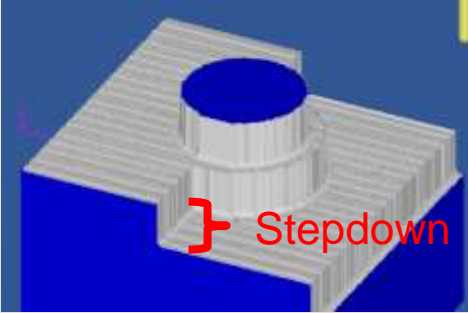




## Toolpaths

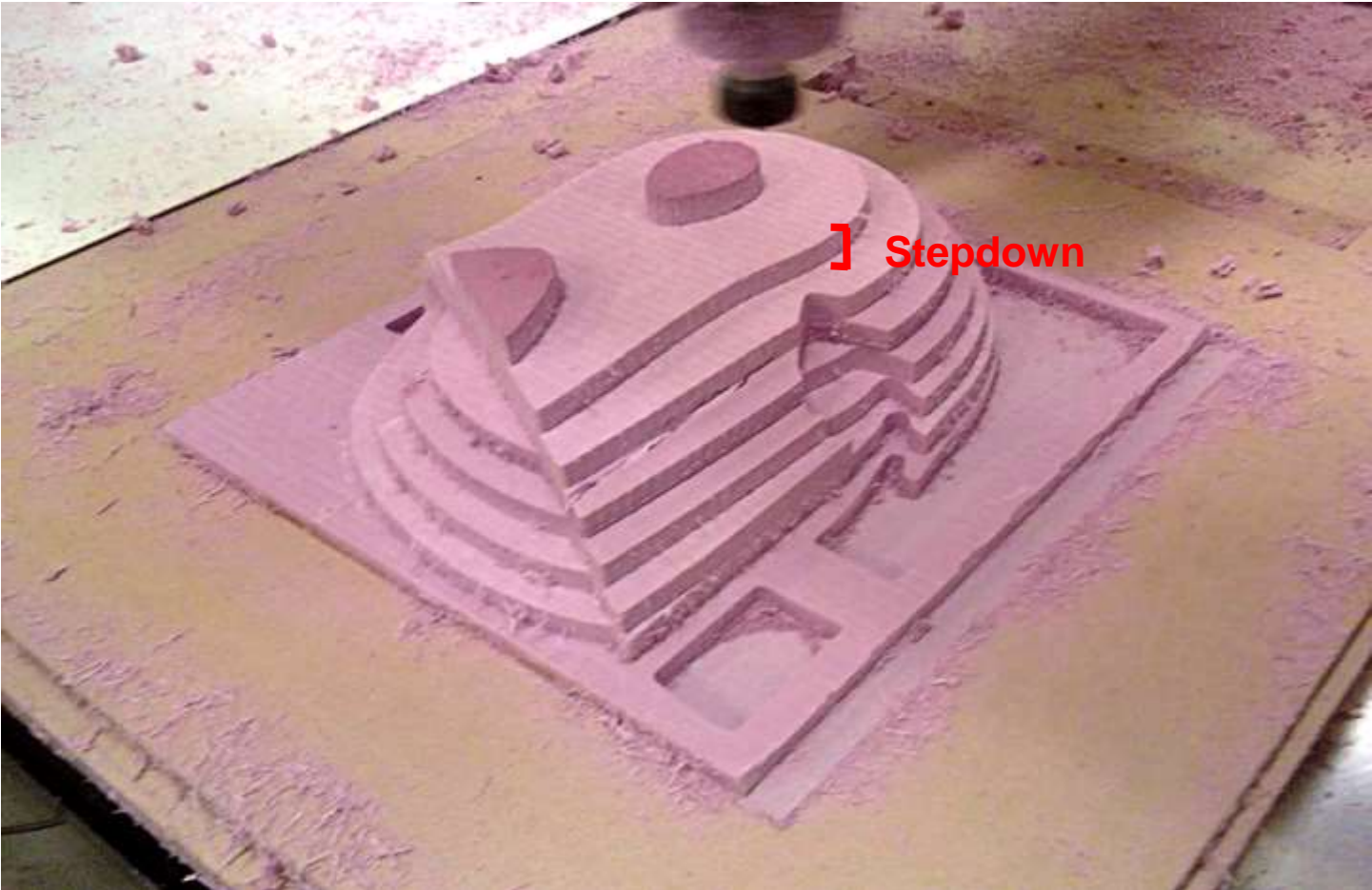
# 2D Toolpath Terminology

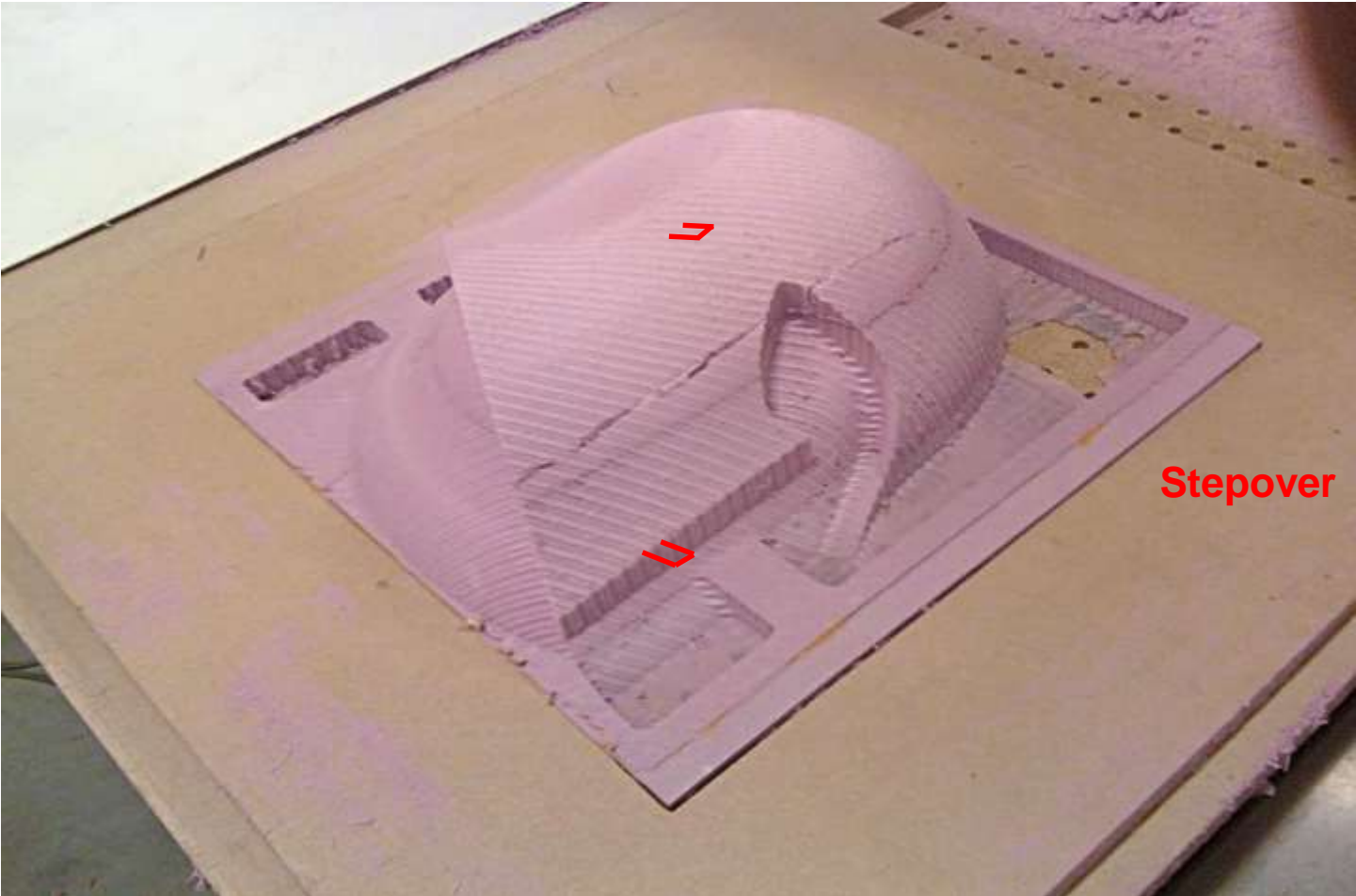


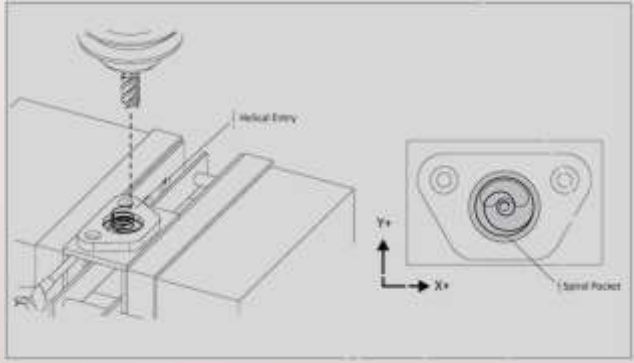
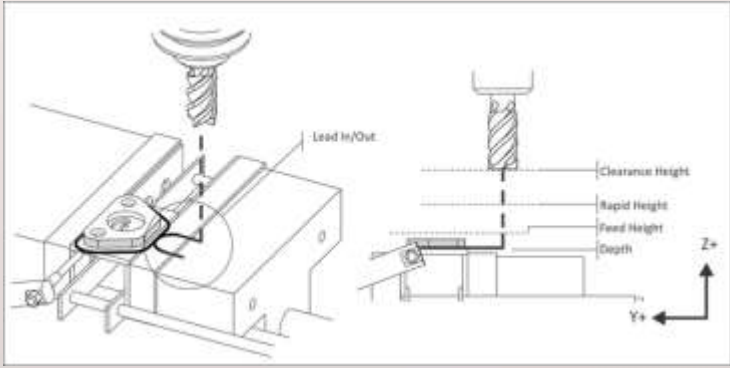
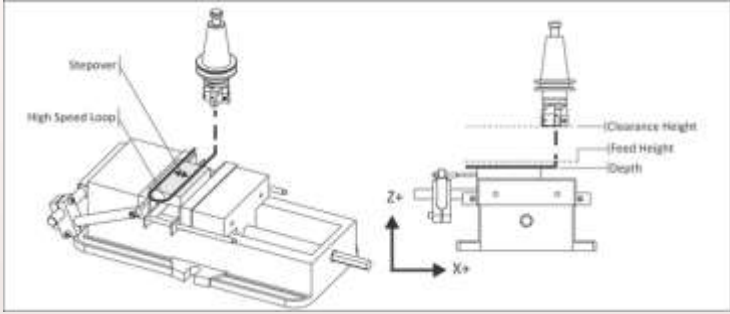


Toolpaths

# 2D Toolpath Terminology

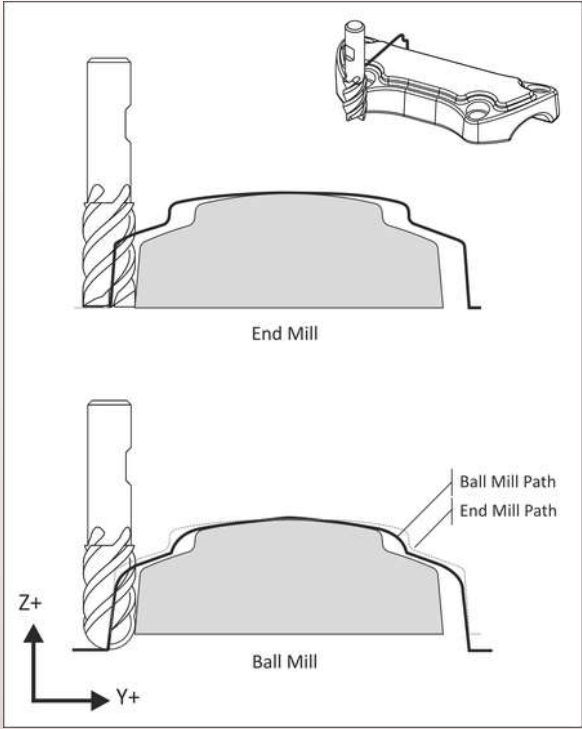






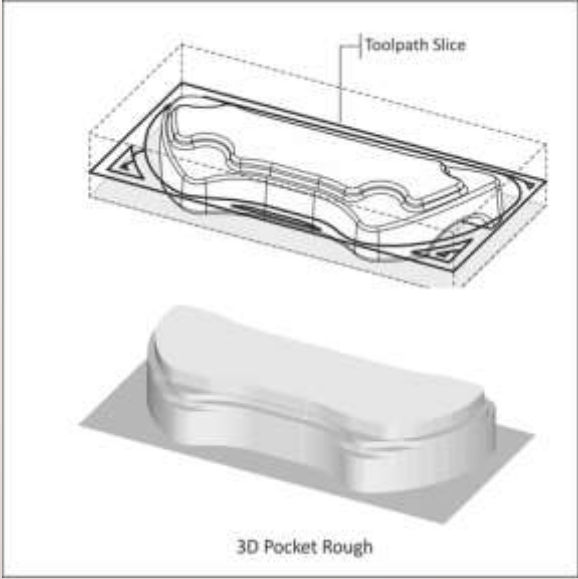
## Toolpaths

# 2D Toolpaths: Facing, Contour, Pocket



Toolpaths

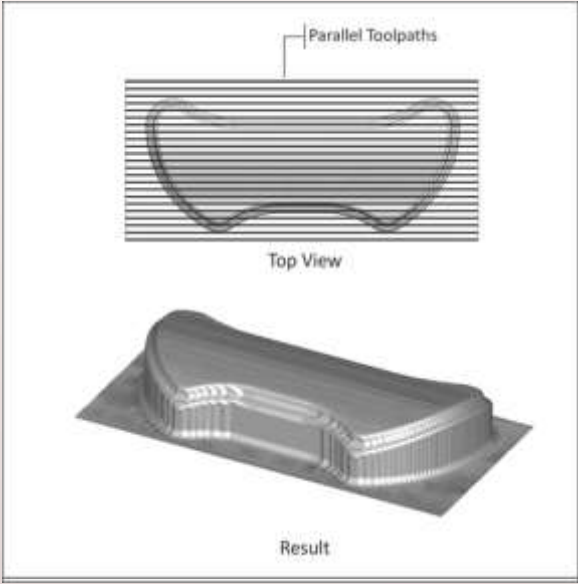
# 3D Toolpaths



Toolpaths

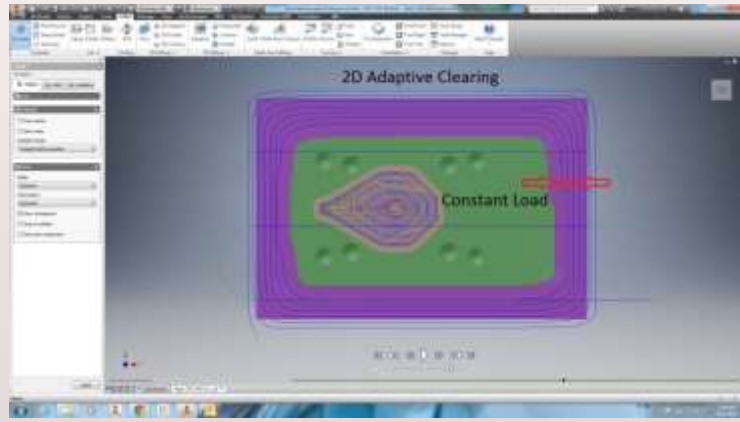
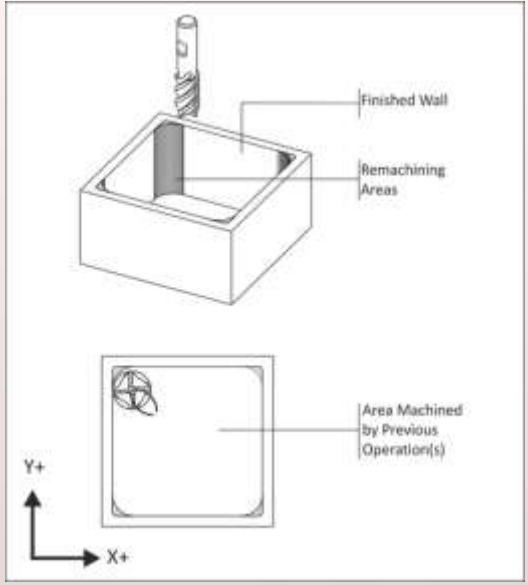
# 3D Toolpath: Roughing





Toolpaths

# 3D Toolpath: Finishing



Toolpaths

# 3D Toolpaths: REST and Adaptive

# Key Terms Review

- CNC
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- NC
- CAD to CAM
- Three steps in CAM
- Post Processor
- Solid Model
- 2D Toolpaths
- 2.5D Toolpaths
- 3D Toolpaths
- 4-axis Toolpaths
- 5-axis Toolpaths
- Undercuts
- Setup
- Toolpath
- Simulate
- Stepdown
- Stepover
- Facing toolpath
- Contour toolpath
- Pocket toolpath
- 3D Toolpath: Roughing
- 3D Toolpath: Finishing
- REST machining
- Adaptive machining
- HSM

CNC Overview

# The CNC Shop at Pier 9





## CNC Shop

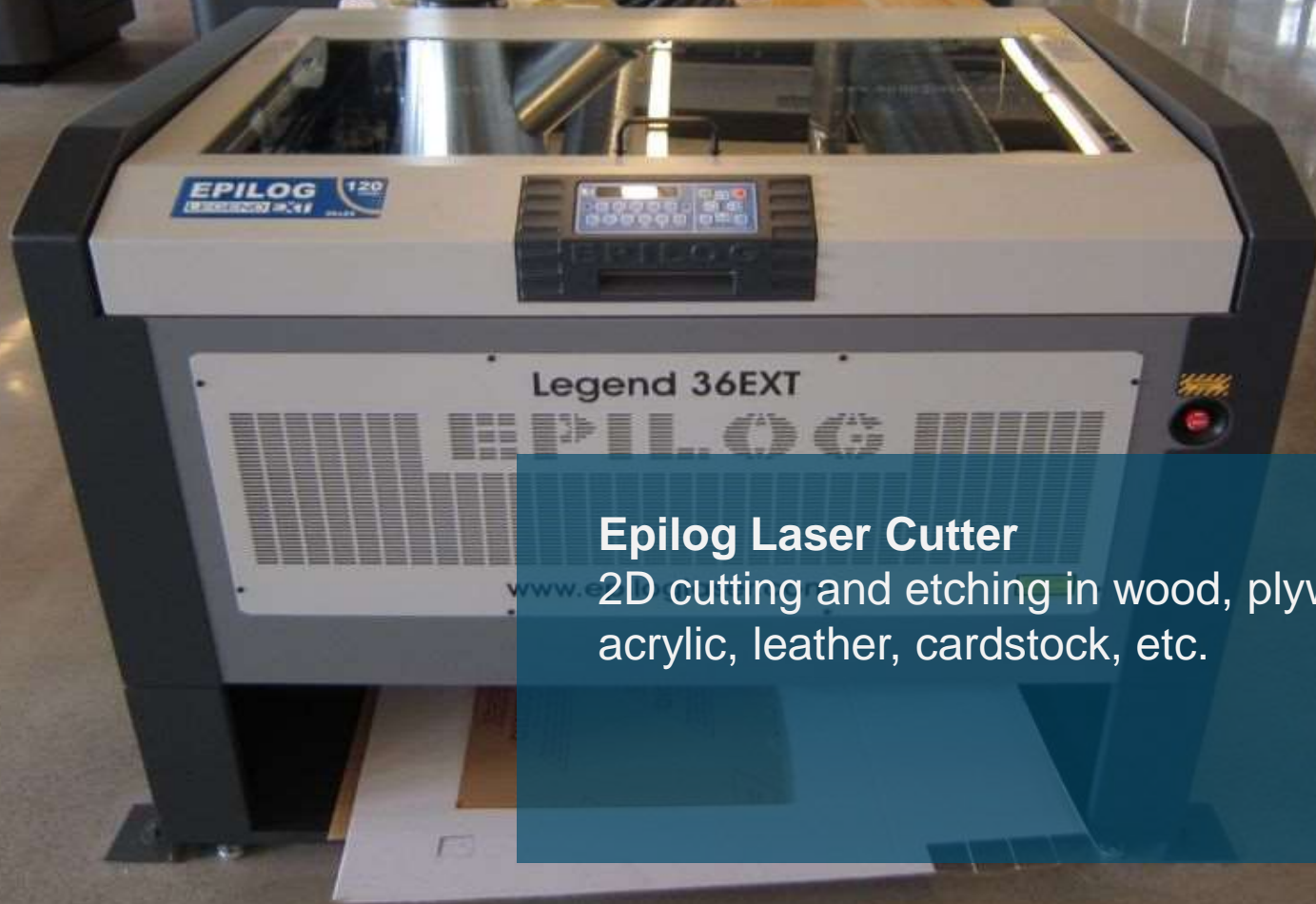
- Equipment
- 1,000 visitors/month
- 820 registered users
- “Pier 9 University”—50 classes/month



CNC Overview

**What are typical workflows for CNC machines at Pier 9?**  
**What Autodesk software should I use?**





## Epilog Laser Cutter

2D cutting and etching in wood, plywood, acrylic, leather, cardstock, etc.

# WORKFLOW for Epilog Laser Cutters

- Scan a hand-drawn image or use bitmap in any design software for raster etching
- Draw vectors for cutting in any design software, including Fusion 360 or AutoCAD
- Can trace bitmap to make vectors
- Corel, Illustrator, or Fusion 360 straight to machine

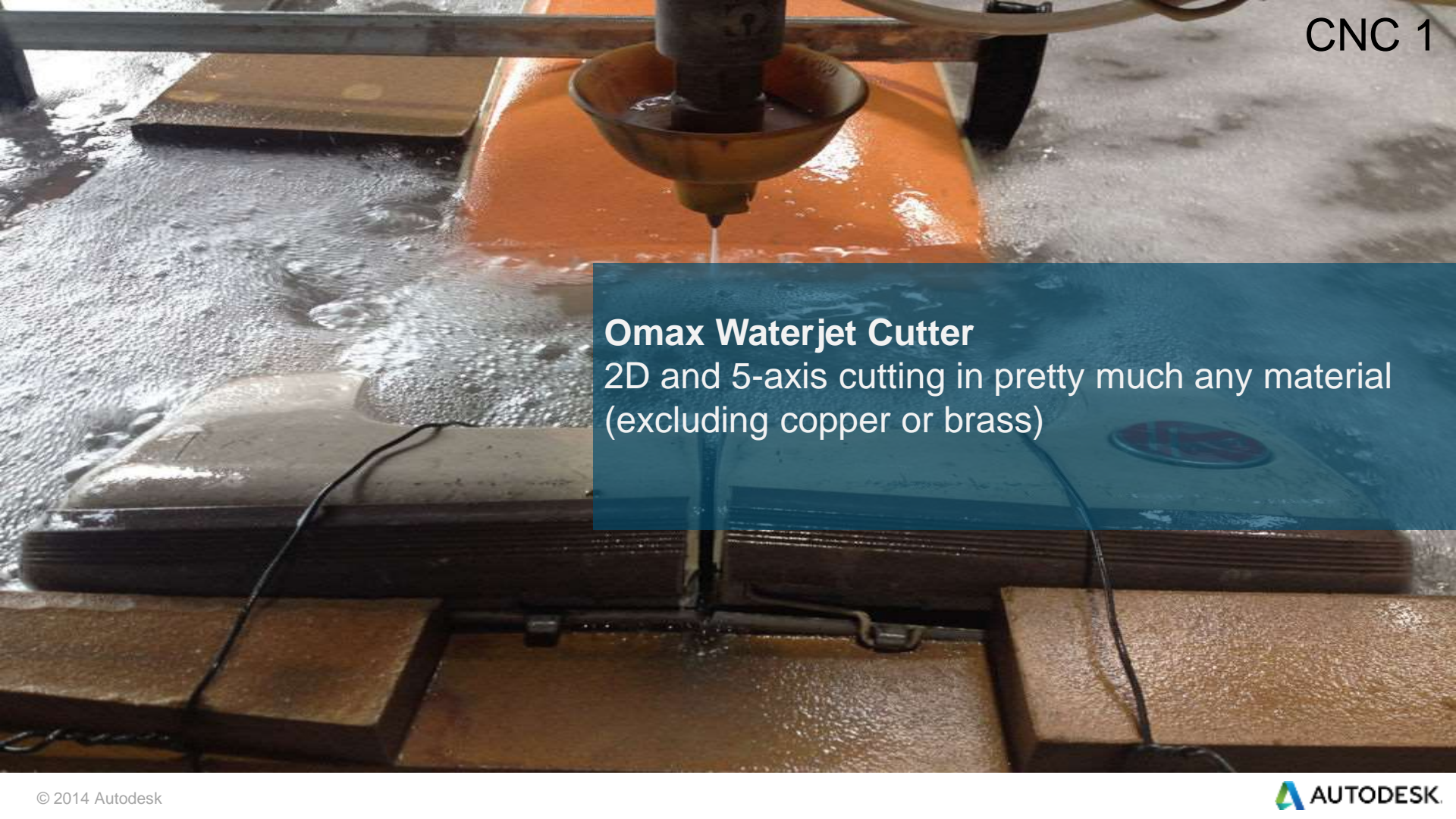


**Roland Vinyl Cutter**  
2D cutting and color printing

# WORKFLOW for Roland Vinyl Cutter

- Create bitmaps in any design software
- Use Illustrator to create cut lines in artwork
- Import to Roland VersaWorks software
- Cut and print
- Instructable: [Roland VersaCAMM Vinyl Printer](#)





**Omax Waterjet Cutter**  
2D and 5-axis cutting in pretty much any material  
(excluding copper or brass)

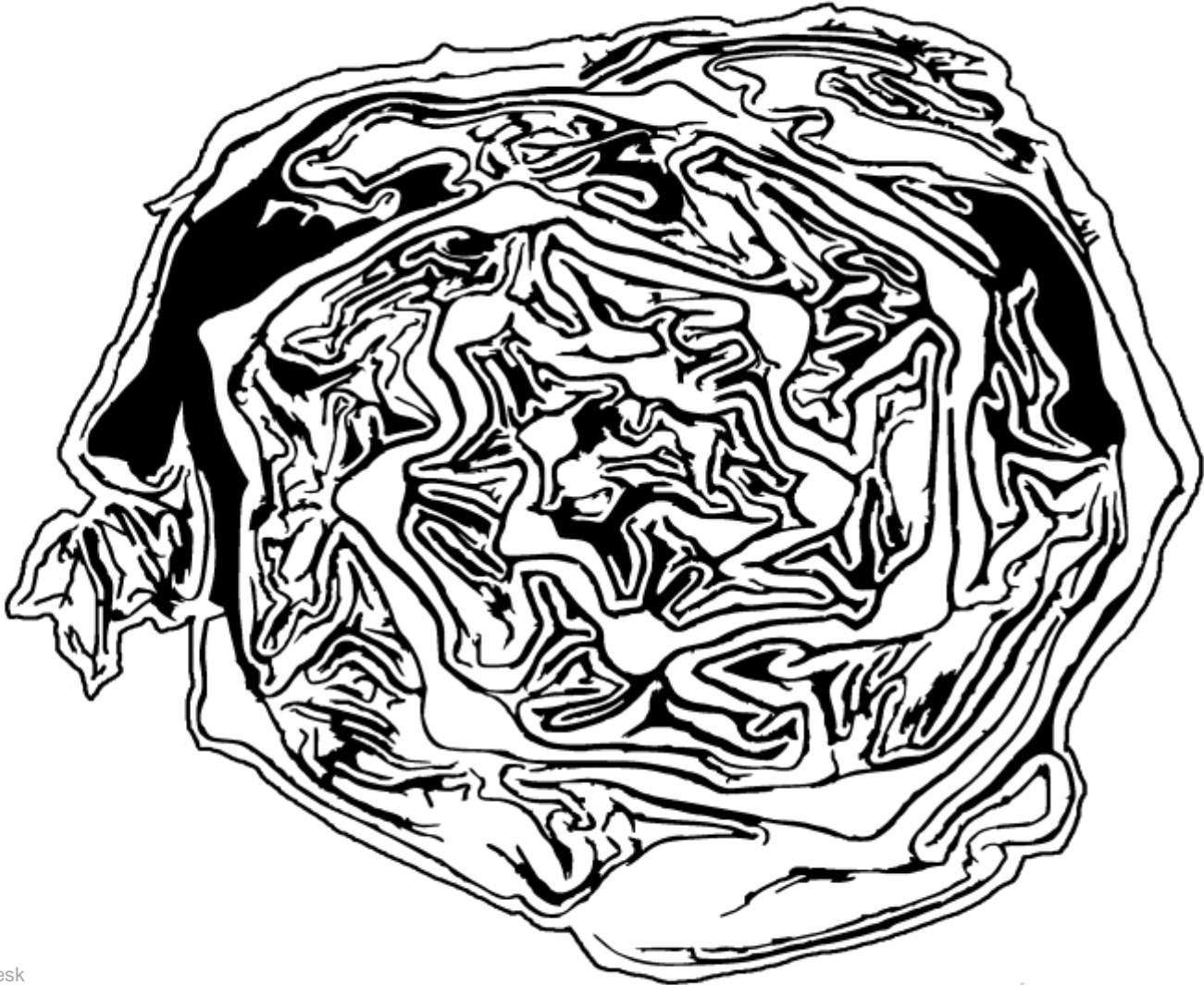




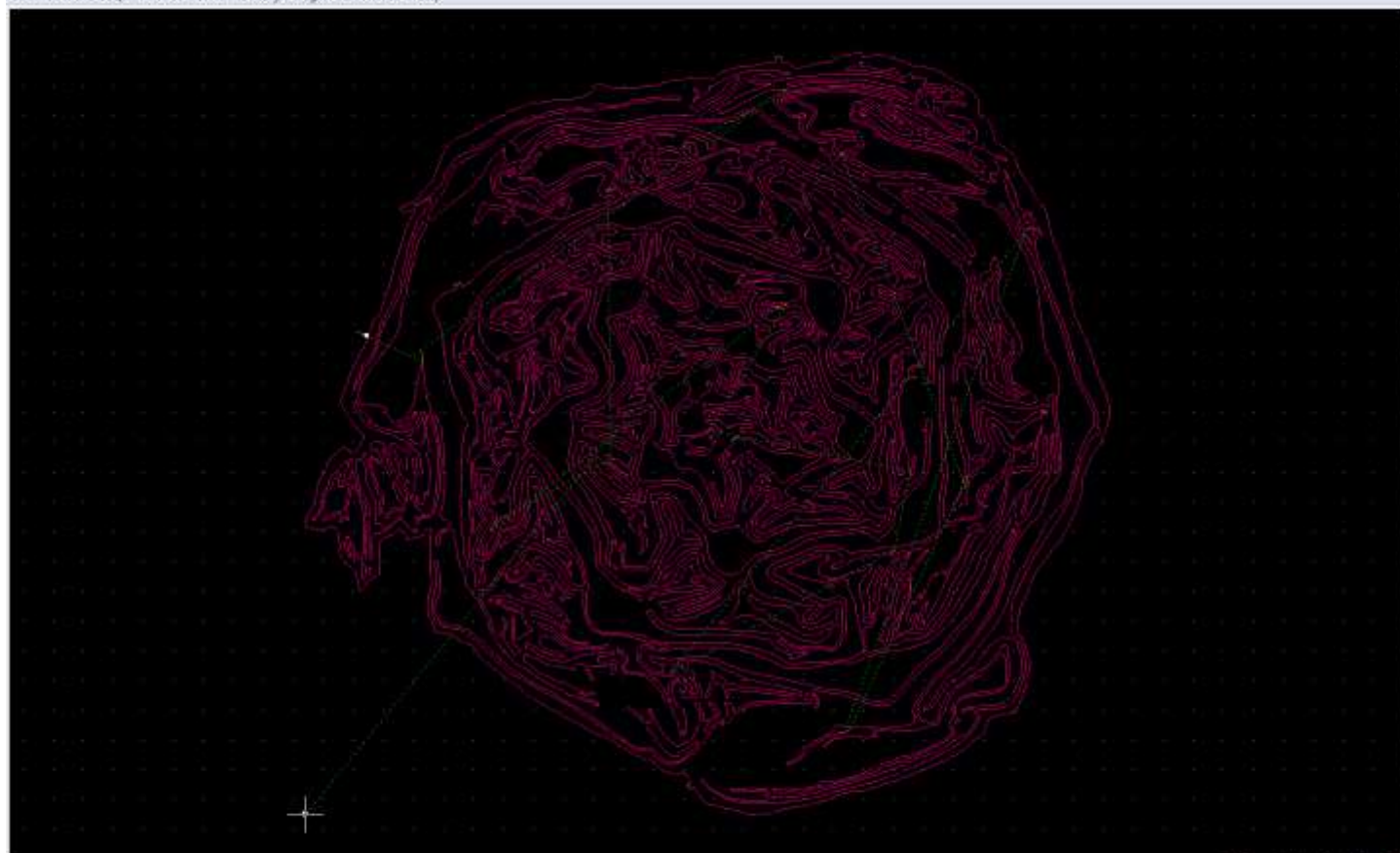
# WORKFLOW for Omax Waterjet Cutter

- Draw/trace vectors
- Import into Omax Layout
  - Register for access to product key [here](#)—use Autodesk email
- Create toolpaths, tabs, and traverses
- Save and open in Omax Make
- Specify material, thickness, offset
- Cut part









Nozzle Position

|      |                            |        |        |
|------|----------------------------|--------|--------|
| 000+ | Distance from "User Home"  | 0.0000 | 0.0000 |
| 000+ | Distance from "Path Start" | 0.0000 | 0.0000 |

Vector Move X Jog Left Jog Right Jog Up Jog Down Show V Locate

Status  
**Ready to begin machining.** Soft Limits Disabled

Action

Statistics

Material: Mild Steel A36 (80 85-3)  
 Machinability: 81.3 (Meral)  
 Thickness: 2.0000 inches  
 Tool offset: 0.0125 inches  
 Rotation: 0°

Estimated time to make this part: <H/A>  
 Estimated cost to make this part: <H/A>  
 Estimated abrasive needed: <H/A>

Contract: OMAX to register software and enable part time estimates and other features...  
 Call (800) 298 6038 or (253) 872 2300

Piercing: High pressure / Install-PIERCE  
 Pierces: 19 (0 are wiggle pierces)  
 Cutting: High pressure

Width of path: 26.7747 (inches)  
 Height of path: 25.6446  
 Length of tool path: 2179.5530  
 Length of cutting: 2009.6030

(Values reported after tool offset applied.)

Pressure and nozzle setup:

High pressure setting: 80000.00 PSI  
 Low pressure setting: 20000.00 PSI  
 Mixing tube diameter: 0.0000 inches  
 Jewel diameter: 0.0140 inches  
 Abrasive flow rate: 1.0000 Lb/Min  
 Abrasive size: 90.00 Mesh (US Std.)  
 Abrasive index: 1.00


**OMAX Make Precision Velocity Controller**  
 Copyright © 1998-2012 OMAX Corporation All Rights Reserved  
 Covered in the United States by the following hardware and software patents: 5,472,367 and 5,530,550. Foreign and other patents pending.





## ShopBot CNC Router

2.5D or 3D cutting in plywood, MDF, wood, acrylic, resin, corian, foam, mixed media





# WORKFLOW for Shopbot

- CAD Design
  - Create vectors or solid model in any software
- Transmit to Fusion 360 or Inventor HSM
- CAM
  - Setup, Toolpath, Simulate
- Post Process
- Transmit to ShopBot software, Dry Run, Cut Part



## DMS Router

2.5D, 3D, or 5-axis cutting in wood, MDF, plywood, acrylic, cast resin, corian, foam, etc.

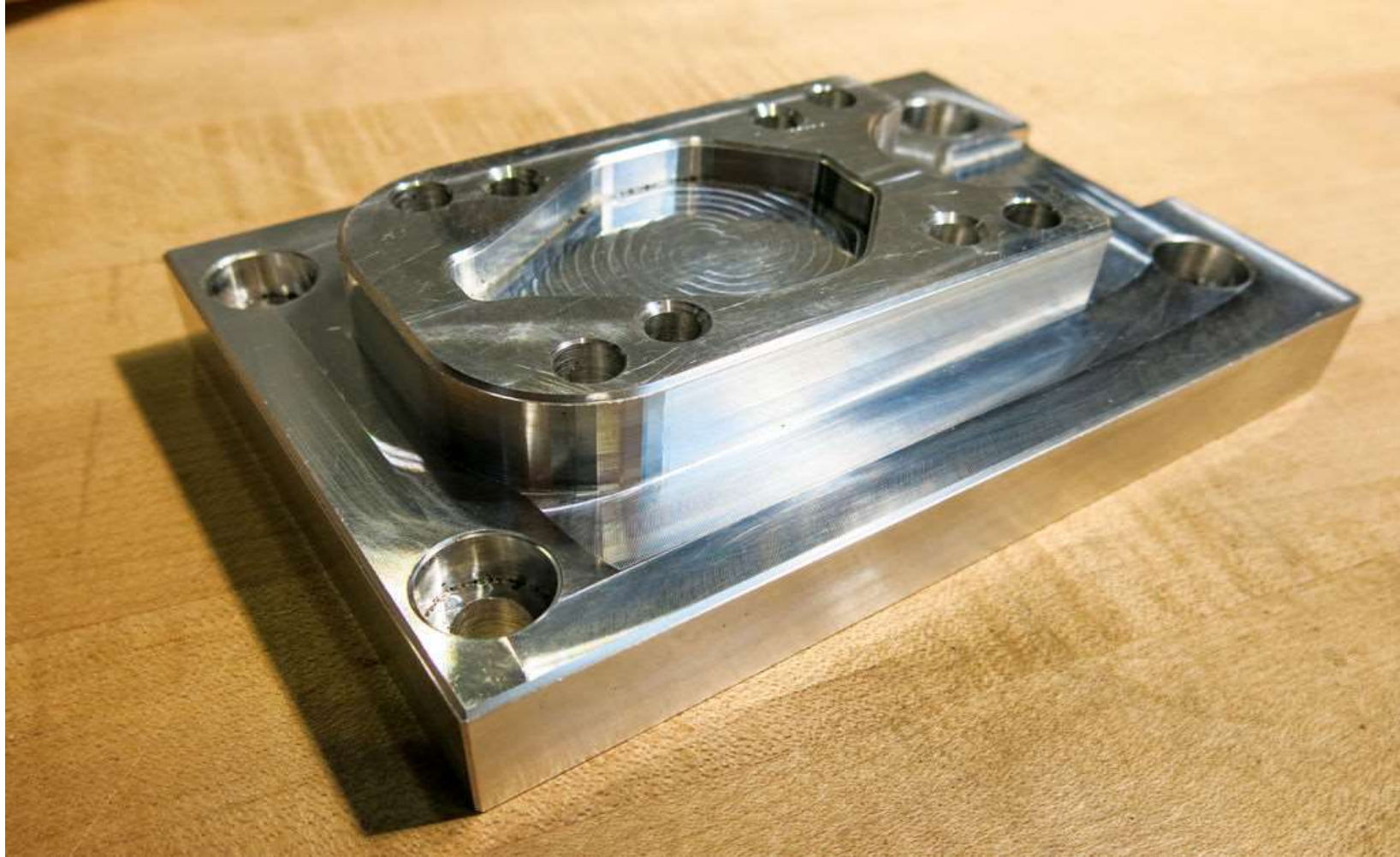
# WORKFLOW for DMS CNC Router

- Follow Pier 9 CNC Learning Path
  - Classes and programming
- Use ShopBot first—software workflow is the same
- Start with 2.5D before trying 3D or 5-axis



**Haas CNC Mill**  
2.5D or 3D cutting in metal  
High precision—less forgiving





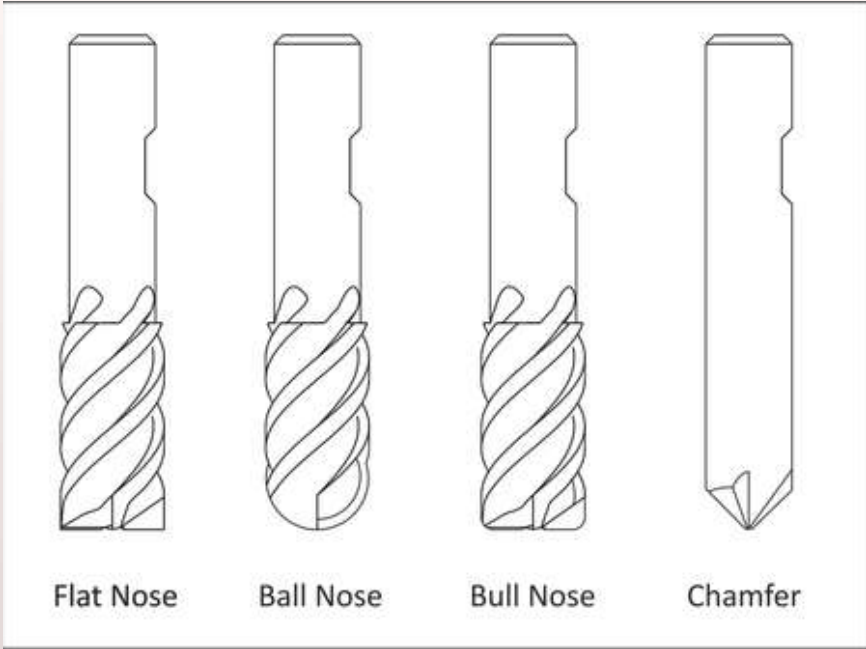
# WORKFLOW for Haas CNC Mill

- Follow the Pier 9 CNC Learning Path!
  - Classes and programming



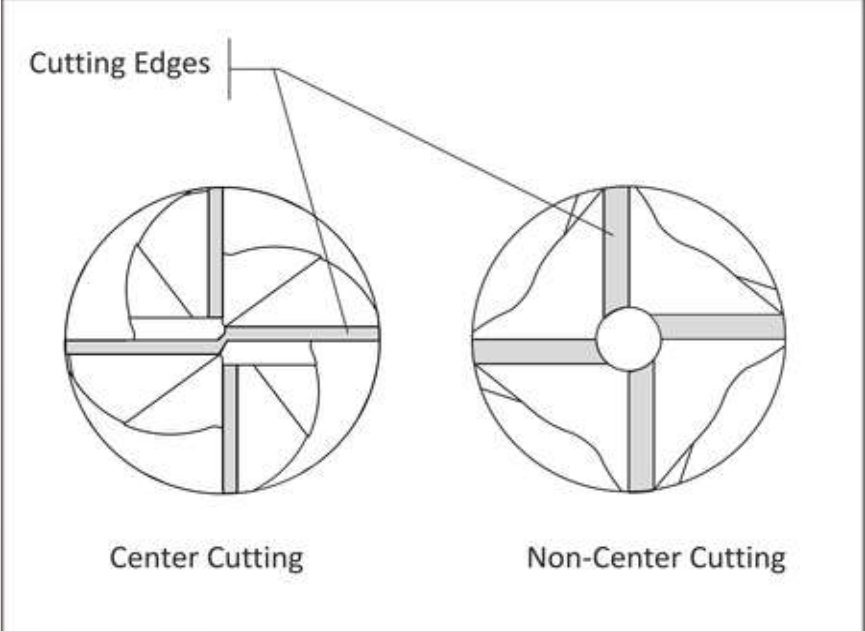
CNC Overview

# CNC Milling Tools



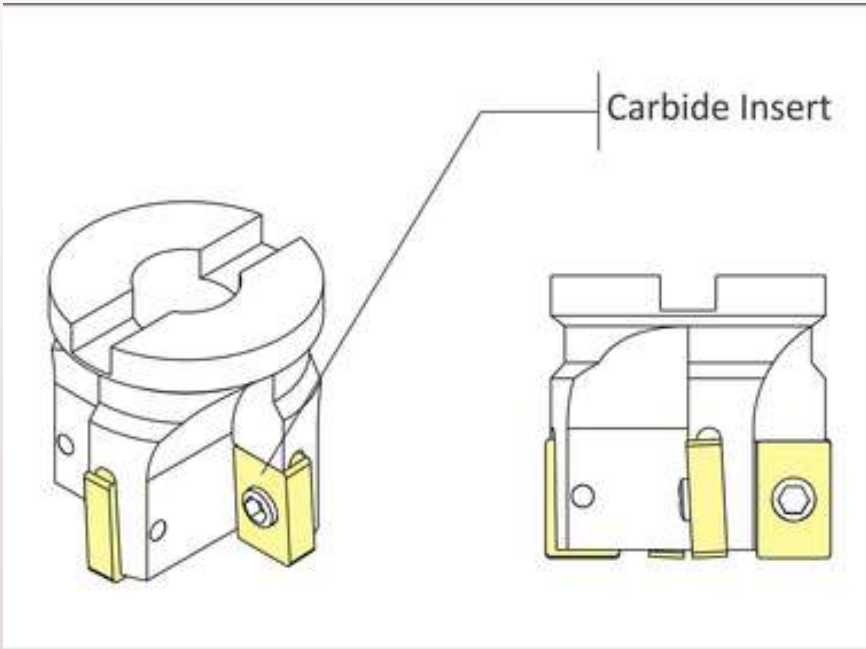
CNC Milling Tools

CNC End Mills



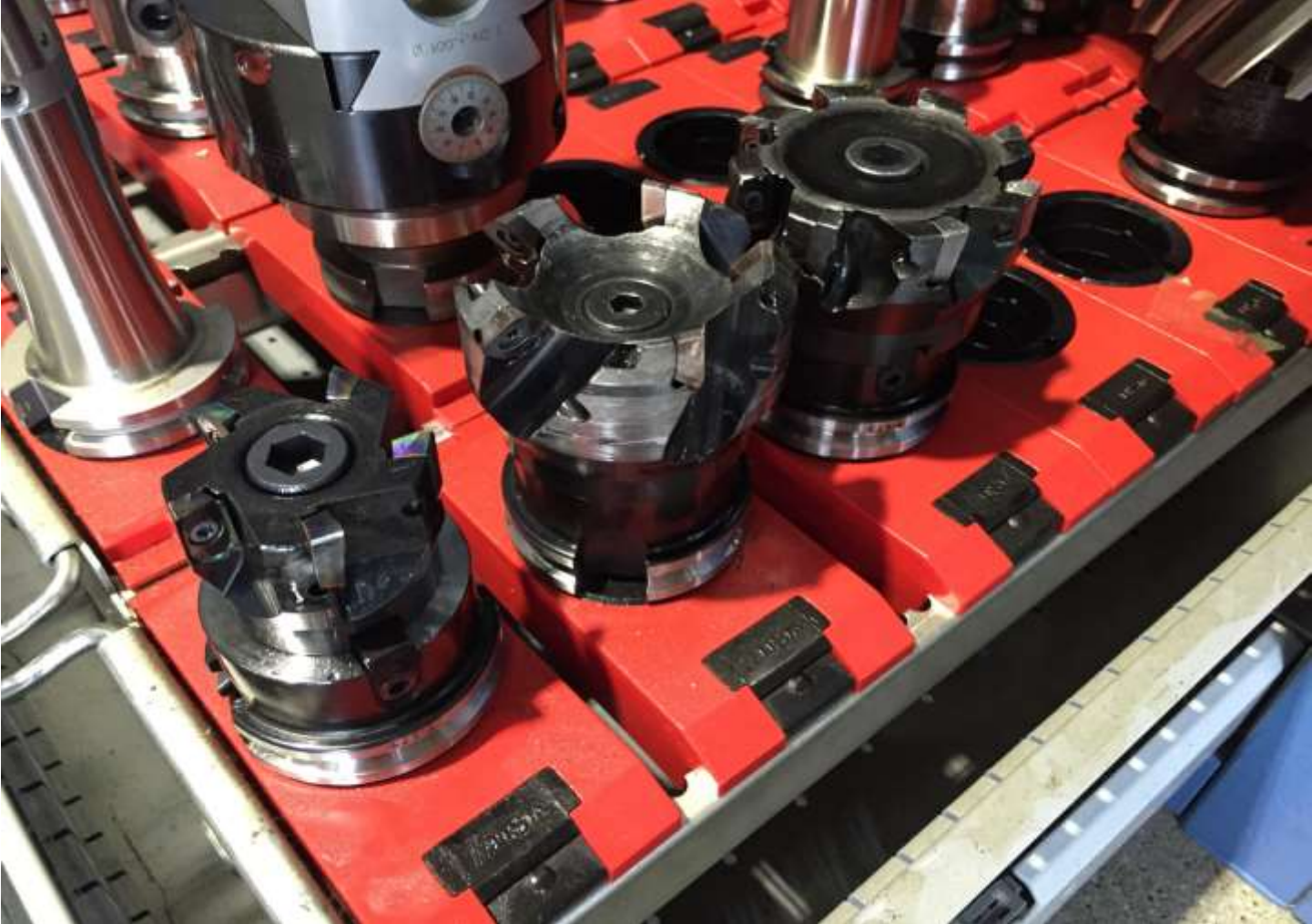
CNC Milling Tools

# Center and Non-center Cutting End Mills



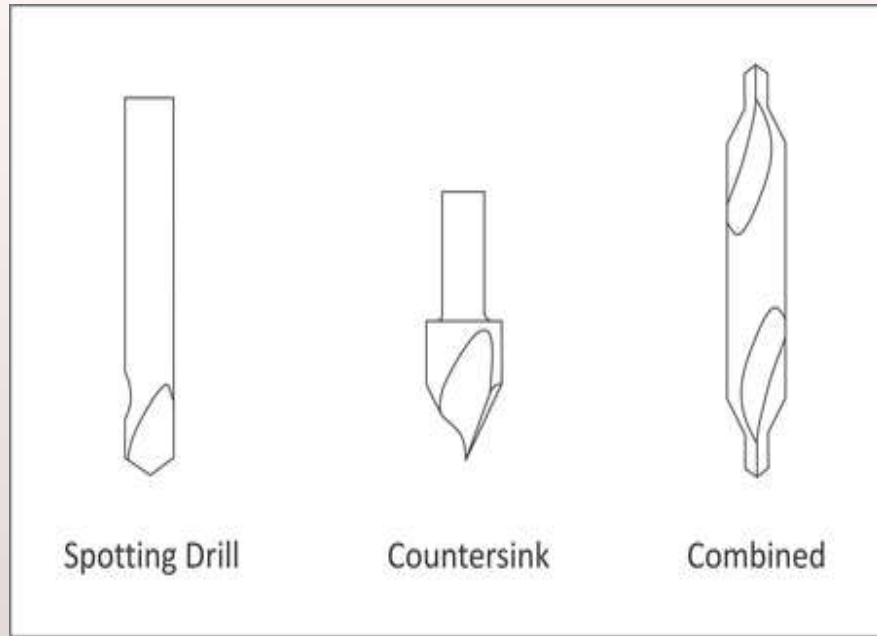
CNC Milling Tools

CNC Face Mills



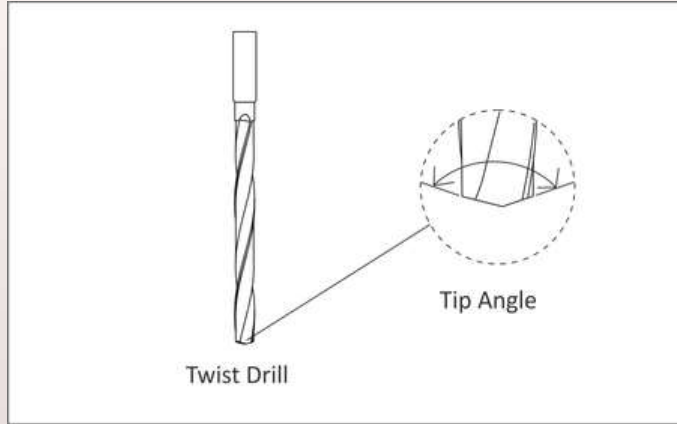






## CNC Milling Tools

# Hole Making Tools: Spotting Drills

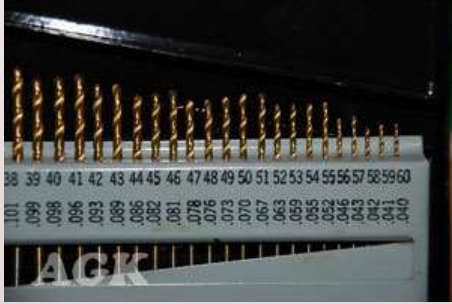


CNC Milling Tools

# Hole Making Tools: Twist Drills



METRIC



SAE/  
IMPERIAL/  
ENGLISH/  
STANDARD

CNC Milling Tools

Four Kinds of Drills



CNC Milling Tools

# Hole Making Tools: Taps



## Tap Drill Chart

| Tap Drill Chart (Standard 28) |               |       |                |       |             |         |          |               |       |                |         |           |      |
|-------------------------------|---------------|-------|----------------|-------|-------------|---------|----------|---------------|-------|----------------|---------|-----------|------|
| Tap Size                      | Cut Tap Drill |       | Roll Tap Drill |       | Minor Ø     | Major Ø | Tap Size | Cut Tap Drill |       | Roll Tap Drill | Minor Ø | Major Ø   |      |
| 0-80                          | 3/64          | .0469 | 1.35mm         | .0531 | .0465/.0514 | .060    | 7/16-14  | U             | .3680 | 13/32          | .4062   | .360/.380 | .437 |
| 1-72                          | #53           | .0595 | 1.7mm          | .0669 | .0580/.0635 | .073    | 7/16-20  | 25/64         | .3906 | Z              | .4130   | .383/.395 | .437 |
| 1-64                          | #53           | .0595 | 1.65mm         | .0650 | .0561/.0623 | .073    | 7/16-28  | Y             | .4040 | *              | *       | .299/.407 | .437 |
| 2-64                          | #50           | .070  | 2.0mm          | .0787 | .0691/.0753 | .086    | 1/2-13   | 27/64         | .4219 | 15/32          | .4688   | .417/.434 | .500 |
| 2-56                          | #50           | .070  | 5/64           | .0781 | .0667/.0737 | .086    | 1/2-20   | 29/64         | .4531 | 12.25mm        | .4823   | .446/.457 | .500 |
| 3-48                          | #47           | .0785 | #43            | .089  | .0764/.0845 | .099    | 1/2-28   | 15/32         | .4688 | *              | *       | .461/.470 | .500 |
| 3-56                          | #45           | .0820 | 2.3mm          | .0906 | .0797/.0865 | .099    | 9/16-12  | 31/64         | .4844 | 17/32          | .5312   | .472/.490 | .562 |
| 4-40                          | #43           | .0890 | #39            | .0995 | .0849/.0939 | .112    | 9/16-18  | 1/2           | .500  | 13.5mm         | .5315   | .502/.515 | .562 |
| 4-48                          | #42           | .0935 | 2.6mm          | .1024 | .0894/.0968 | .112    | 9/16-24  | 33/64         | .5156 | *              | *       | .517/.527 | .562 |
| 5-40                          | #38           | .1015 | #33            | .1130 | .0979/.1062 | .125    | 5/8-11   | 17/32         | .5313 | 14.75mm        | .5807   | .527/.546 | .625 |
| 5-44                          | #37           | .1040 | 2.9mm          | .1142 | .1004/.1079 | .125    | 5/8-18   | 9/16          | .5625 | 15.25mm        | .6004   | .565/.578 | .625 |
| 6-32                          | #36           | .1065 | 3.1mm          | .1220 | .104/.114   | .138    | 5/8-24   | 37/64         | .5781 | *              | *       | .580/.590 | .625 |
| 6-40                          | #33           | .1130 | 3.2mm          | .1260 | .111/.119   | .138    | 11/16-12 | 39/64         | .6094 | *              | *       | .597/.615 | .687 |
| 8-36                          | #29           | .1360 | #26            | .1520 | .134/.142   | .164    | 11/16-24 | 41/64         | .6406 | *              | *       | .642/.652 | .687 |
| 8-32                          | #29           | .1360 | #25            | .1495 | .130/.139   | .164    | 3/4-10   | 21/32         | .6563 | 45/64          | .7031   | .642/.663 | .750 |
| 10-24                         | #25           | .1495 | 11/64          | .1719 | .145/.156   | .190    | 3/4-16   | 11/16         | .6875 | 23/32          | .7188   | .682/.696 | .750 |
| 10-32                         | #21           | .1590 | #16            | .1770 | .156/.164   | .190    | 3/4-20   | 45/64         | .7031 | *              | *       | .696/.707 | .750 |
| 12-24                         | #16           | .1770 | 5.0mm          | .1968 | .171/.181   | .216    | 13/16-12 | 47/64         | .7344 | *              | *       | .722/.740 | .812 |
| 12-28                         | #14           | .1820 | #8             | .1990 | .177/.186   | .216    | 13/16-16 | 3/4           | .750  | *              | *       | .745/.759 | .812 |
| 12-32                         | 3/16          | .1875 | *              | *     | .182/.190   | .216    | 13/16-20 | 49/64         | .7656 | *              | *       | .758/.770 | .812 |
| 1/4-20                        | #7            | .2010 | #1             | .2280 | .196/.207   | .250    | 7/8-9    | 49/64         | .7656 | *              | *       | .755/.778 | .875 |
| 1/4-28                        | #3            | .2130 | A              | .2340 | .211/.220   | .250    | 7/8-14   | 51/64         | .7969 | *              | *       | .798/.814 | .875 |
| 1/4-32                        | 7/32          | .2188 | *              | *     | .216/.224   | .250    | 7/8-20   | 53/64         | .8281 | *              | *       | .821/.832 | .875 |
| 5/16-18                       | F             | .2570 | L              | .2880 | .252/.265   | .312    | 15/16-12 | 55/64         | .8594 | *              | *       | .847/.865 | .937 |
| 5/16-24                       | I             | .2720 | M              | .2950 | .267/.277   | .312    | 15/16-16 | 7/8           | .8750 | *              | *       | .870/.884 | .937 |
| 5/16-32                       | 9/32          | .2813 | *              | *     | .279/.286   | .312    | 15/16-20 | 57/64         | .8906 | *              | *       | .883/.895 | .937 |
| 3/8-16                        | 5/16          | .3120 | S              | .3480 | .307/.321   | .375    | 1 - 8    | 7/8           | .8750 | *              | *       | .865/.890 | 1    |
| 3/8-24                        | Q             | .3320 | T              | .3580 | .330/.340   | .375    | 1 - 12   | 59/64         | .9219 | *              | *       | .910/.928 | 1    |
| 3/8-32                        | 11/32         | .3438 | *              | *     | .341/.349   | .375    | 1 - 20   | 61/64         | .9531 | *              | *       | .946/.957 | 1    |

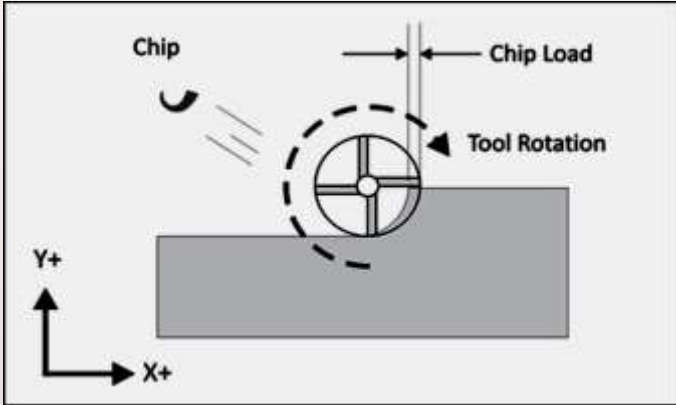
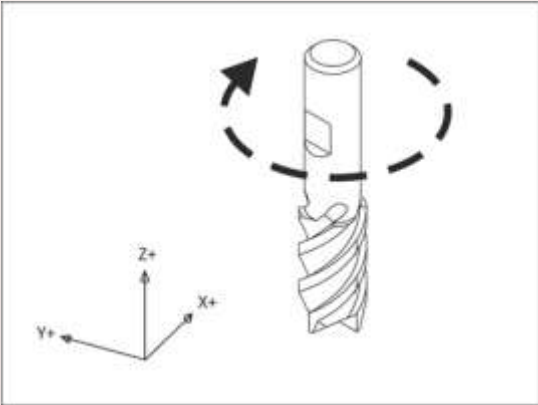


# Key Terms Review

- CNC
- Subtractive/Additive Processes
- NC
- CAD to CAM
- Three steps in CAM
- Post Processor
- Solid Model
- 2D Toolpaths
- 2.5D Toolpaths
- 3D Toolpaths
- 4-axis Toolpaths
- 5-axis Toolpaths
- Undercuts
- Setup
- Toolpath
- Simulate
- Stepdown
- Stepover
- Facing toolpath
- Contour toolpath
- Pocket toolpath
- 3D Toolpath: Roughing
- 3D Toolpath: Finishing
- REST machining
- Adaptive machining
- HSM
- Flat nose end mill
- Ball nose end mill
- Bull nose end mill
- Chamfer end mill
- Center cutting end mill
- Non-center cutting end mill
- Face mill
- Spot drill
- Twist drill
- Form taps/Roll taps
- Cutting taps

CNC Overview

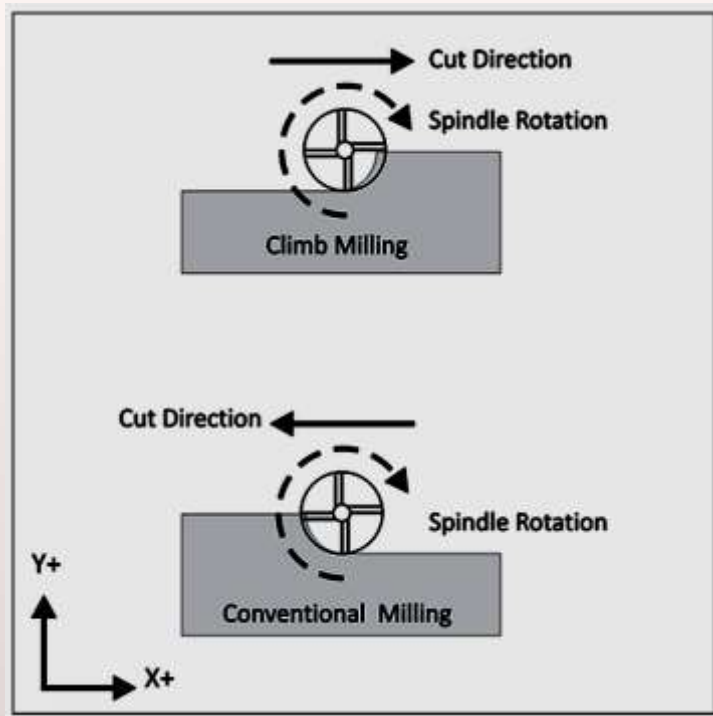
# CNC Cutting Fundamentals



CNC Cutting Fundamentals

Rotation Direction and Chip Load

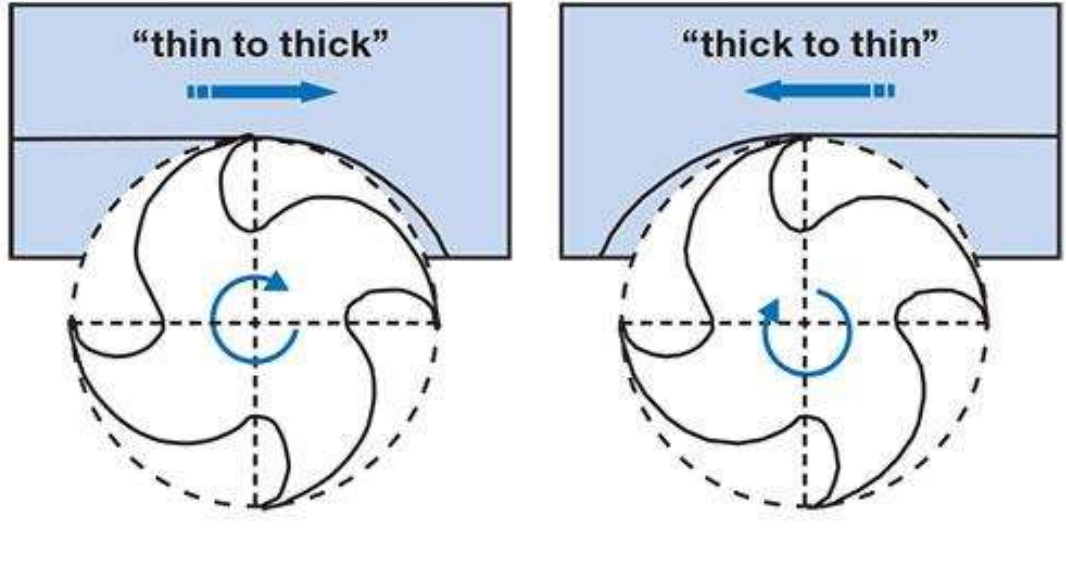




## CNC Cutting Fundamentals

# Climb versus Conventional Milling

# Chip Creation

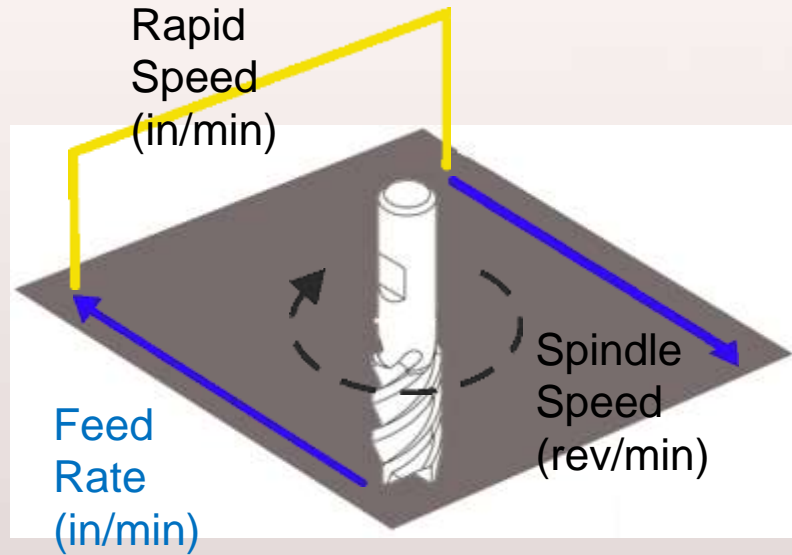


CNC Cutting Fundamentals

## Climb versus Conventional Milling

CNC Overview

# Feeds and Speeds



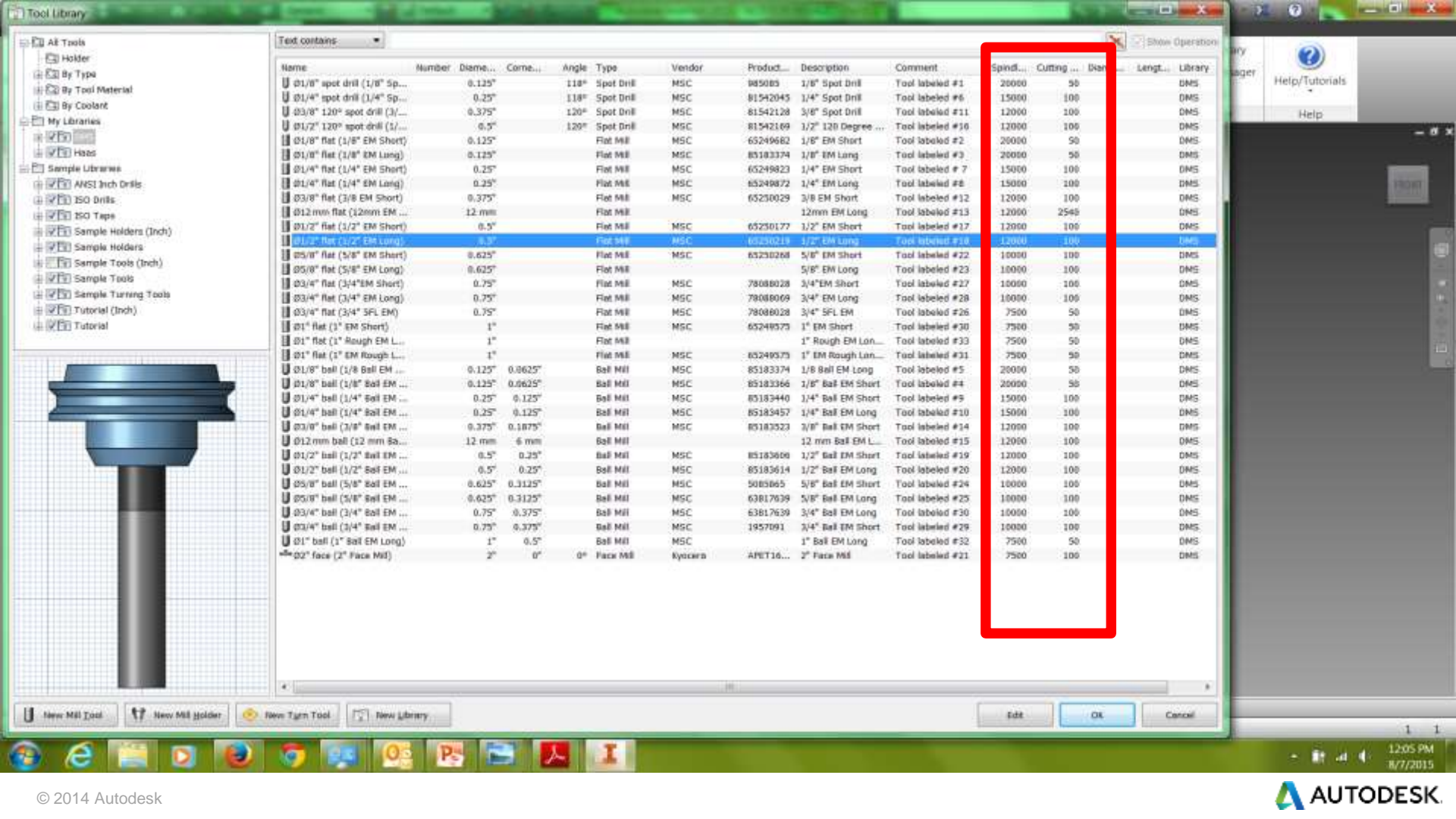
## Feeds and Speeds

# Spindle Speed and Feed Rate



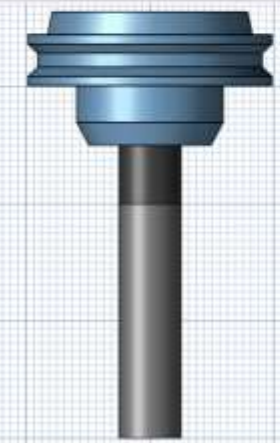






Text contains

| Name                          | Number | Diams. | Corne... | Angle | Type       | Vendor  | Product... | Description         | Comment          | Spind... | Cutting ... | Depth... | Length... | Library |
|-------------------------------|--------|--------|----------|-------|------------|---------|------------|---------------------|------------------|----------|-------------|----------|-----------|---------|
| Ø1/8" spot drill (1/8" Sp...  |        | 0.125" |          | 118°  | Spot Drill | MSC     | 885085     | 1/8" Spot Drill     | Tool labeled #1  | 20000    | 90          |          |           | DMS     |
| Ø1/4" spot drill (1/4" Sp...  |        | 0.25"  |          | 118°  | Spot Drill | MSC     | 81542045   | 1/4" Spot Drill     | Tool labeled #6  | 15000    | 100         |          |           | DMS     |
| Ø3/8" 120° spot drill (3/...  |        | 0.375" |          | 120°  | Spot Drill | MSC     | 81542128   | 3/8" Spot Drill     | Tool labeled #11 | 12000    | 100         |          |           | DMS     |
| Ø1/2" 120° spot drill (1/...  |        | 0.5"   |          | 120°  | Spot Drill | MSC     | 81542169   | 1/2" 120 Degree ... | Tool labeled #16 | 12000    | 100         |          |           | DMS     |
| Ø1/8" flat (1/8" EM Short)    |        | 0.125" |          |       | Flat Mill  | MSC     | 65249682   | 1/8" EM Short       | Tool labeled #2  | 20000    | 90          |          |           | DMS     |
| Ø1/8" flat (1/8" EM Long)     |        | 0.125" |          |       | Flat Mill  | MSC     | 85183374   | 1/8" EM Long        | Tool labeled #3  | 20000    | 90          |          |           | DMS     |
| Ø1/4" flat (1/4" EM Short)    |        | 0.25"  |          |       | Flat Mill  | MSC     | 65249823   | 1/4" EM Short       | Tool labeled #7  | 15000    | 100         |          |           | DMS     |
| Ø1/4" flat (1/4" EM Long)     |        | 0.25"  |          |       | Flat Mill  | MSC     | 65249872   | 1/4" EM Long        | Tool labeled #8  | 15000    | 100         |          |           | DMS     |
| Ø3/8" flat (3/8 EM Short)     |        | 0.375" |          |       | Flat Mill  | MSC     | 65250029   | 3/8 EM Short        | Tool labeled #12 | 12000    | 100         |          |           | DMS     |
| Ø12 mm flat (12mm EM ...)     |        | 12 mm  |          |       | Flat Mill  |         |            | 12mm EM Long        | Tool labeled #13 | 12000    | 2548        |          |           | DMS     |
| Ø1/2" flat (1/2" EM Short)    |        | 0.5"   |          |       | Flat Mill  | MSC     | 65250177   | 1/2" EM Short       | Tool labeled #17 | 12000    | 100         |          |           | DMS     |
| Ø1/2" flat (1/2" EM Long)     |        | 0.5"   |          |       | Flat Mill  | MSC     | 65250219   | 1/2" EM Long        | Tool labeled #18 | 12000    | 100         |          |           | DMS     |
| Ø5/8" flat (5/8" EM Short)    |        | 0.625" |          |       | Flat Mill  | MSC     | 65250268   | 5/8" EM Short       | Tool labeled #22 | 10000    | 100         |          |           | DMS     |
| Ø5/8" flat (5/8" EM Long)     |        | 0.625" |          |       | Flat Mill  |         |            | 5/8" EM Long        | Tool labeled #23 | 10000    | 100         |          |           | DMS     |
| Ø3/4" flat (3/4"EM Short)     |        | 0.75"  |          |       | Flat Mill  | MSC     | 78088028   | 3/4"EM Short        | Tool labeled #27 | 10000    | 100         |          |           | DMS     |
| Ø3/4" flat (3/4" EM Long)     |        | 0.75"  |          |       | Flat Mill  | MSC     | 78088069   | 3/4" EM Long        | Tool labeled #28 | 10000    | 100         |          |           | DMS     |
| Ø3/4" flat (3/4" SFL EM)      |        | 0.75"  |          |       | Flat Mill  | MSC     | 78088028   | 3/4" SFL EM         | Tool labeled #26 | 7500     | 90          |          |           | DMS     |
| Ø1" flat (1" EM Short)        |        | 1"     |          |       | Flat Mill  | MSC     | 65249573   | 1" EM Short         | Tool labeled #30 | 7500     | 90          |          |           | DMS     |
| Ø1" flat (1" Rough EM L...    |        | 1"     |          |       | Flat Mill  |         |            | 1" Rough EM Lon...  | Tool labeled #33 | 7500     | 90          |          |           | DMS     |
| Ø1" flat (1" EM Rough L...    |        | 1"     |          |       | Flat Mill  | MSC     | 65249573   | 1" EM Rough Lon...  | Tool labeled #31 | 7500     | 90          |          |           | DMS     |
| Ø1/8" ball (1/8 ball EM ...)  |        | 0.125" | 0.0625"  |       | Ball Mill  | MSC     | 85183374   | 1/8 Ball EM Long    | Tool labeled #5  | 20000    | 90          |          |           | DMS     |
| Ø1/8" ball (1/8" ball EM ...) |        | 0.125" | 0.0625"  |       | Ball Mill  | MSC     | 85183366   | 1/8" Ball EM Short  | Tool labeled #4  | 20000    | 90          |          |           | DMS     |
| Ø1/4" ball (1/4" ball EM ...) |        | 0.25"  | 0.125"   |       | Ball Mill  | MSC     | 85183440   | 1/4" ball EM Short  | Tool labeled #9  | 15000    | 100         |          |           | DMS     |
| Ø1/4" ball (1/4" ball EM ...) |        | 0.25"  | 0.125"   |       | Ball Mill  | MSC     | 85183457   | 1/4" Ball EM Long   | Tool labeled #10 | 15000    | 100         |          |           | DMS     |
| Ø3/8" ball (3/8" ball EM ...) |        | 0.375" | 0.1875"  |       | Ball Mill  | MSC     | 85183523   | 3/8" Ball EM Short  | Tool labeled #14 | 12000    | 100         |          |           | DMS     |
| Ø12 mm ball (12 mm Ba...      |        | 12 mm  | 6 mm     |       | Ball Mill  |         |            | 12 mm Ball EM L...  | Tool labeled #15 | 12000    | 100         |          |           | DMS     |
| Ø1/2" ball (1/2" ball EM ...) |        | 0.5"   | 0.25"    |       | Ball Mill  | MSC     | 85183608   | 1/2" Ball EM Short  | Tool labeled #19 | 12000    | 100         |          |           | DMS     |
| Ø1/2" ball (1/2" Ball EM ...) |        | 0.5"   | 0.25"    |       | Ball Mill  | MSC     | 85183614   | 1/2" Ball EM Long   | Tool labeled #20 | 12000    | 100         |          |           | DMS     |
| Ø5/8" ball (5/8" ball EM ...) |        | 0.625" | 0.3125"  |       | Ball Mill  | MSC     | 5085065    | 5/8" Ball EM Short  | Tool labeled #24 | 10000    | 100         |          |           | DMS     |
| Ø5/8" ball (5/8" ball EM ...) |        | 0.625" | 0.3125"  |       | Ball Mill  | MSC     | 63817639   | 5/8" Ball EM Long   | Tool labeled #25 | 10000    | 100         |          |           | DMS     |
| Ø3/4" ball (3/4" ball EM ...) |        | 0.75"  | 0.375"   |       | Ball Mill  | MSC     | 63817639   | 3/4" Ball EM Long   | Tool labeled #30 | 10000    | 100         |          |           | DMS     |
| Ø3/4" ball (3/4" ball EM ...) |        | 0.75"  | 0.375"   |       | Ball Mill  | MSC     | 1957091    | 3/4" Ball EM Short  | Tool labeled #29 | 10000    | 100         |          |           | DMS     |
| Ø1" ball (1" Ball EM Long)    |        | 1"     | 0.5"     |       | Ball Mill  | MSC     |            | 1" Ball EM Long     | Tool labeled #32 | 7500     | 90          |          |           | DMS     |
| Ø2" face (2" Face Mill)       |        | 2"     | 0"       | 0°    | Face Mill  | Kyocera | APET16...  | 2" Face Mill        | Tool labeled #21 | 7500     | 100         |          |           | DMS     |



New Mill Tool New Mill Holder New Turn Tool New Library Edit OK Cancel

$$Speed \left( \frac{rev}{min} \right) = \frac{SFM \left( \frac{ft}{min} \right) \times 3.82}{Dia(in)}$$

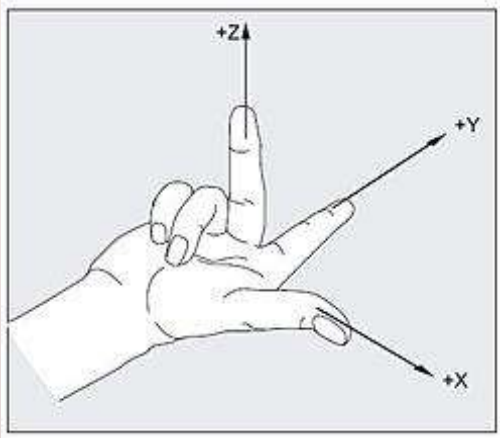
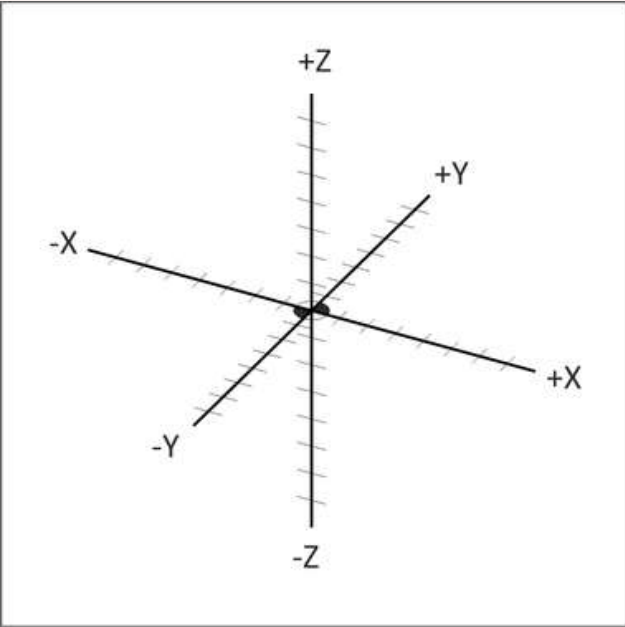
$$Feed \left( \frac{in}{min} \right) = Speed \left( \frac{rev}{min} \right) \times CL \left( \frac{in}{rev \text{ flute}} \right) \times NumFlutes$$

## Feeds and Speeds

# Formulas: Spindle Speed and Feed Rate

CNC Overview

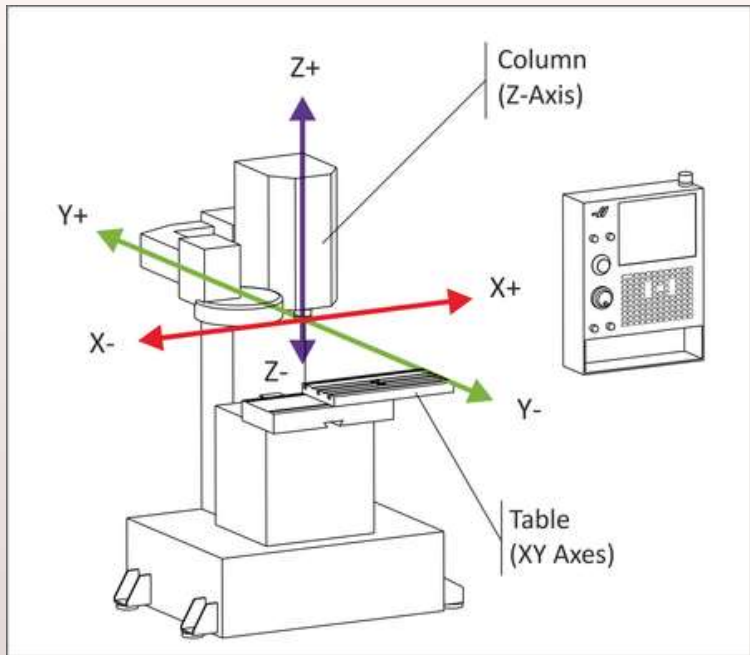
# Coordinate System



Coordinate System

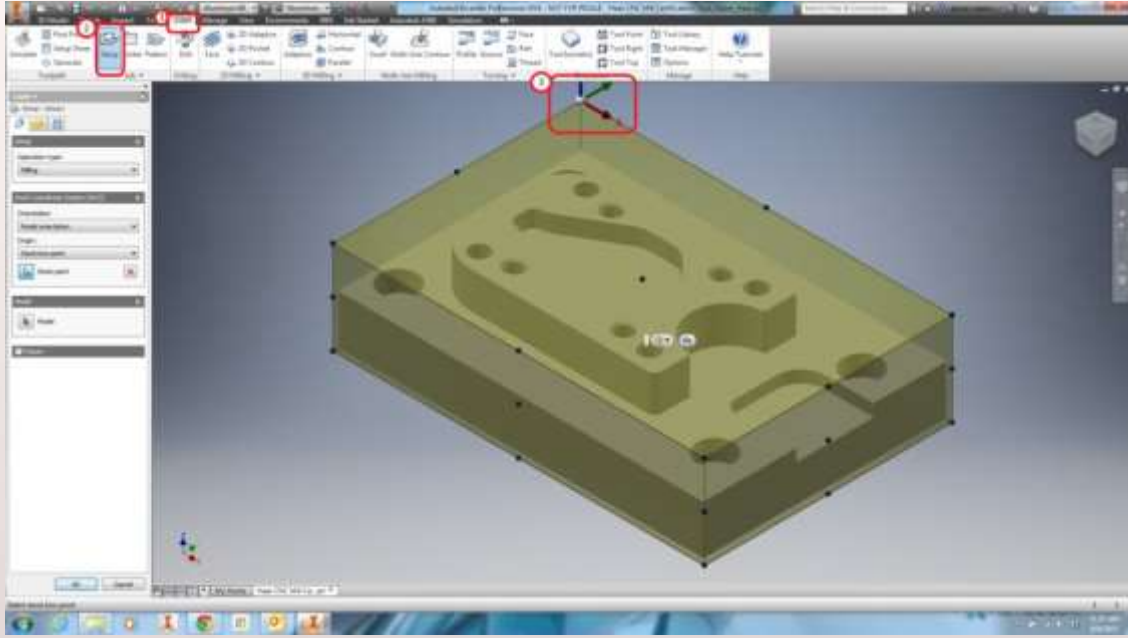
# Cartesian Coordinates and Right Hand Rule





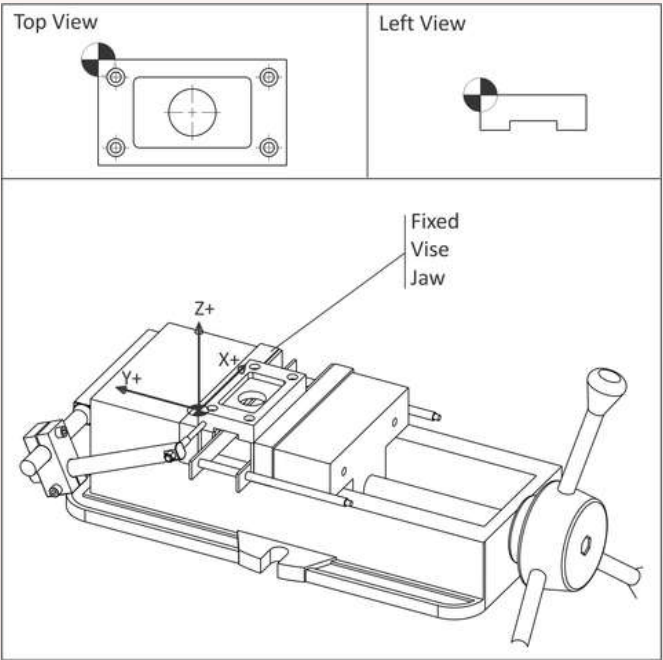
## Coordinate System

# Machine Coordinate System



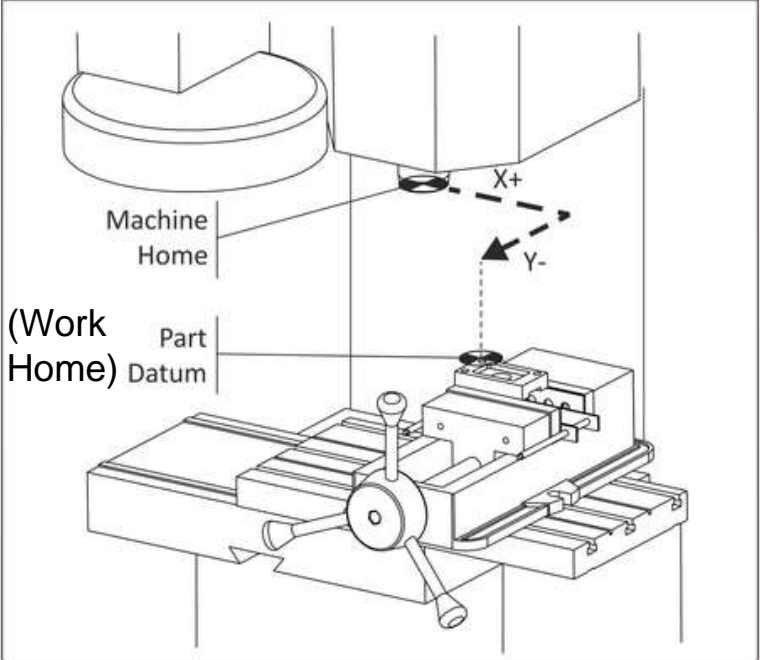
Coordinate System

# Work Coordinate System



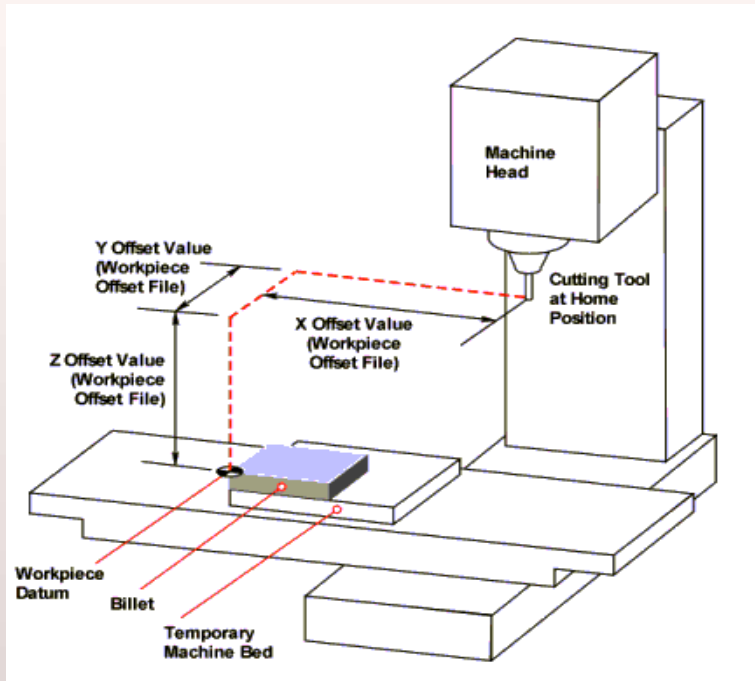
## Coordinate System

# Work Coordinate System



Coordinate System

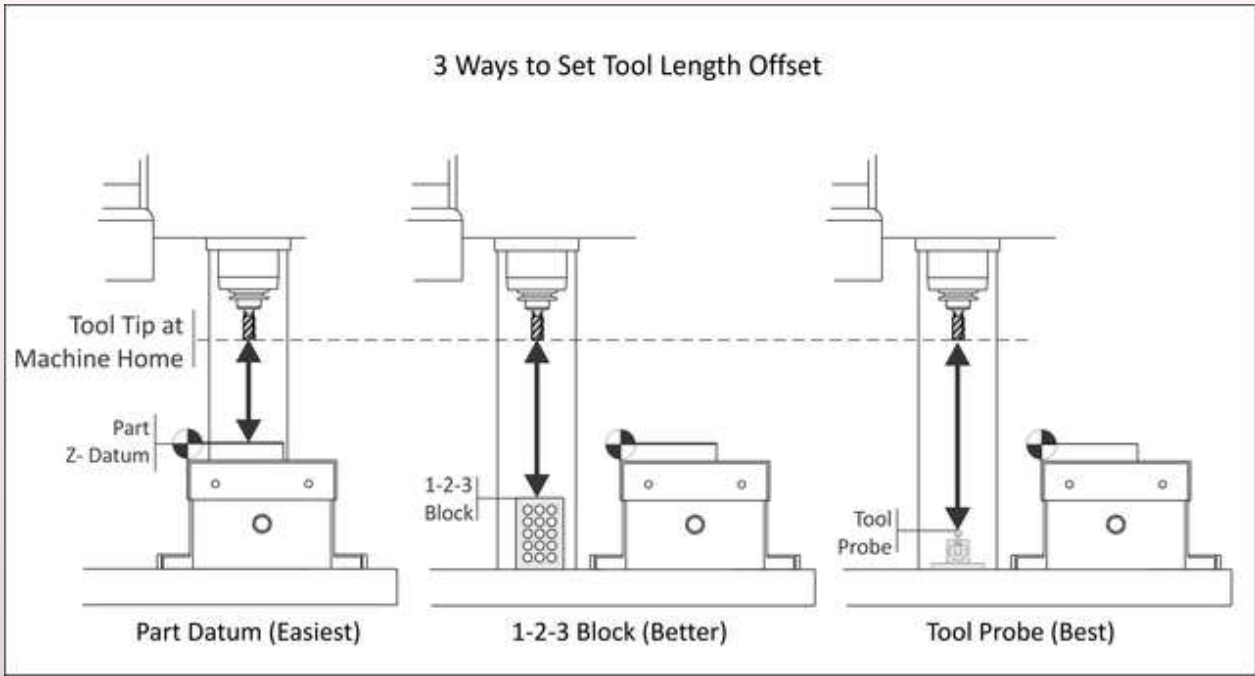
# Tool and Fixture Offsets



## Coordinate System

# Tool and Fixture Offsets





Coordinate System

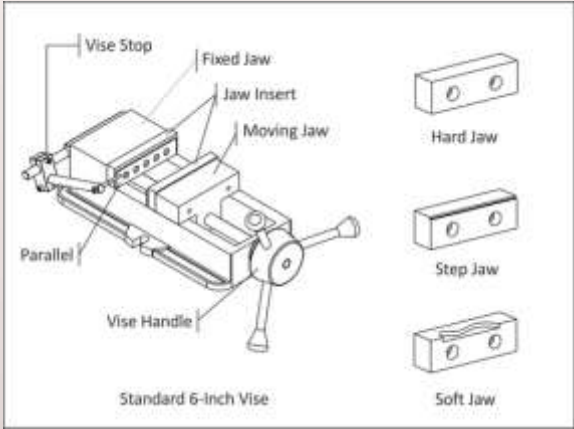
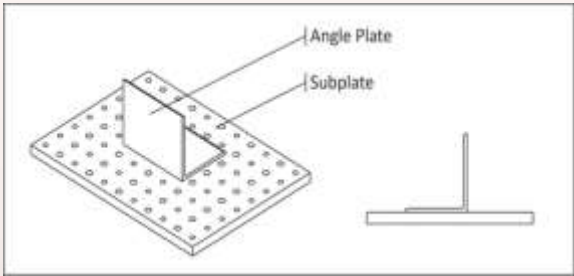
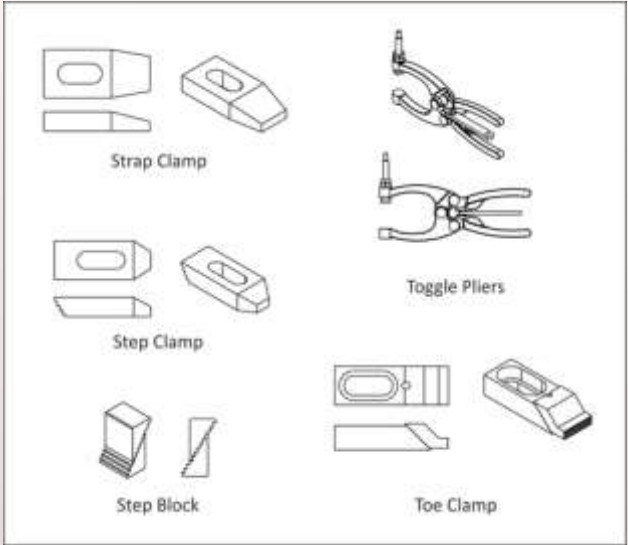
# Tool Length Offset

# Key Terms Review

- CNC
- Subtractive Processes
- NC
- CAD to CAM
- Three steps in CAM
- Post Processor
- Solid Model
- 2D Toolpaths
- 2.5D Toolpaths
- 3D Toolpaths
- 4-axis Toolpaths
- 5-axis Toolpaths
- Undercuts
- Setup
- Toolpath
- Simulate
- Stepdown
- Stepover
- Facing toolpath
- Contour toolpath
- Pocket toolpath
- 3D Toolpath: Roughing
- 3D Toolpath: Finishing
- REST machining
- Adaptive machining
- HSM
- Flat nose end mill
- Ball nose end mill
- Bull nose end mill
- Chamfer end mill
- Center cutting end mill
- Non-center cutting end mill
- Face mill
- Spot drill
- Twist drill
- Form taps/Roll taps
- Cutting taps
- Rotation Direction
- Chip Load
- Climb Milling
- Conventional Milling
- Spindle Speed
- Feed Rate
- Rapid Speed
- Right Hand Rule
- Machine Coordinate System
- Work Coordinate System
- Tool Length Offsets
- Fixture Offsets

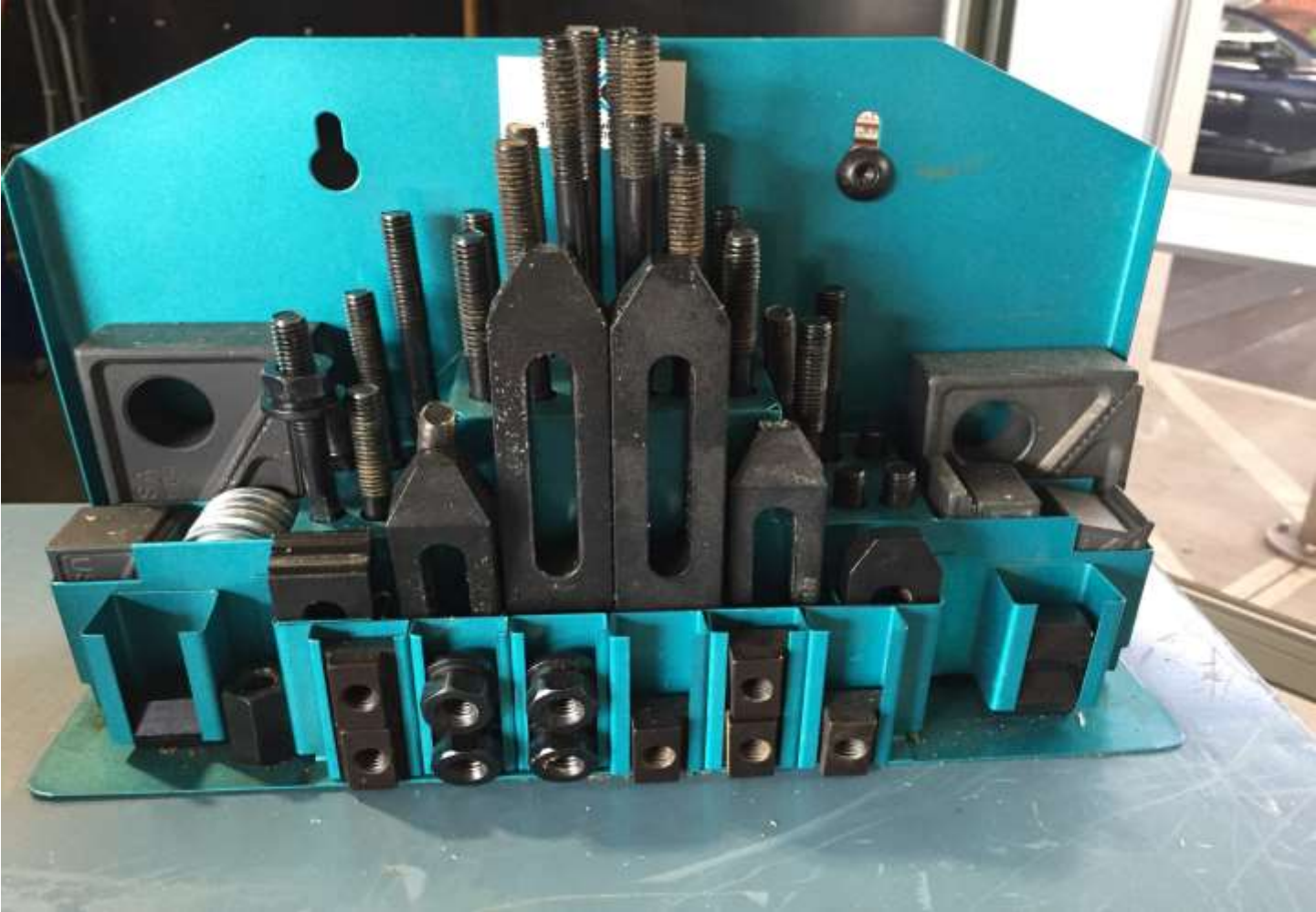
CNC Overview

# Fixturing/Workholding



Fixturing

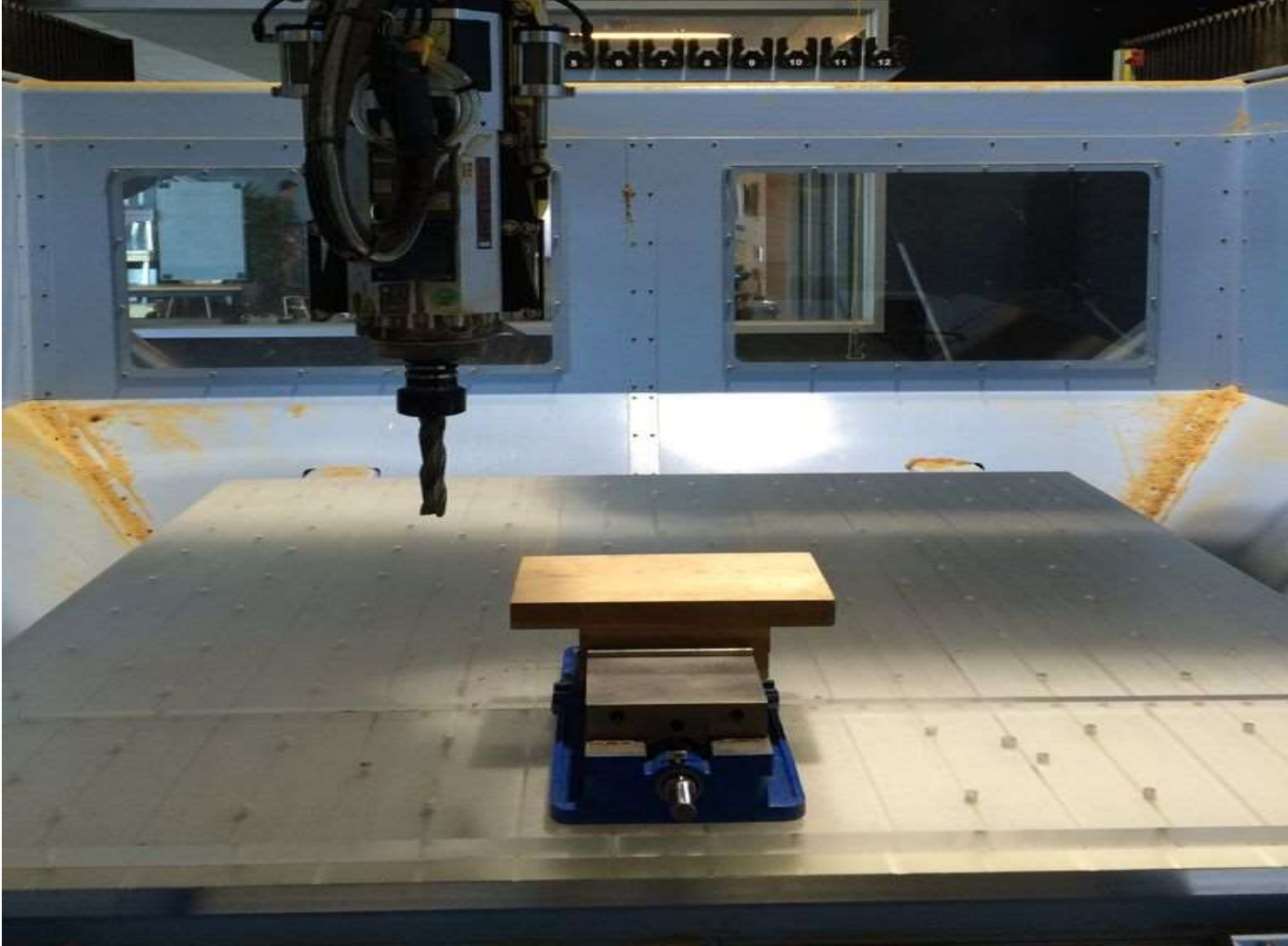
# Clamps, Subplates, and Vices

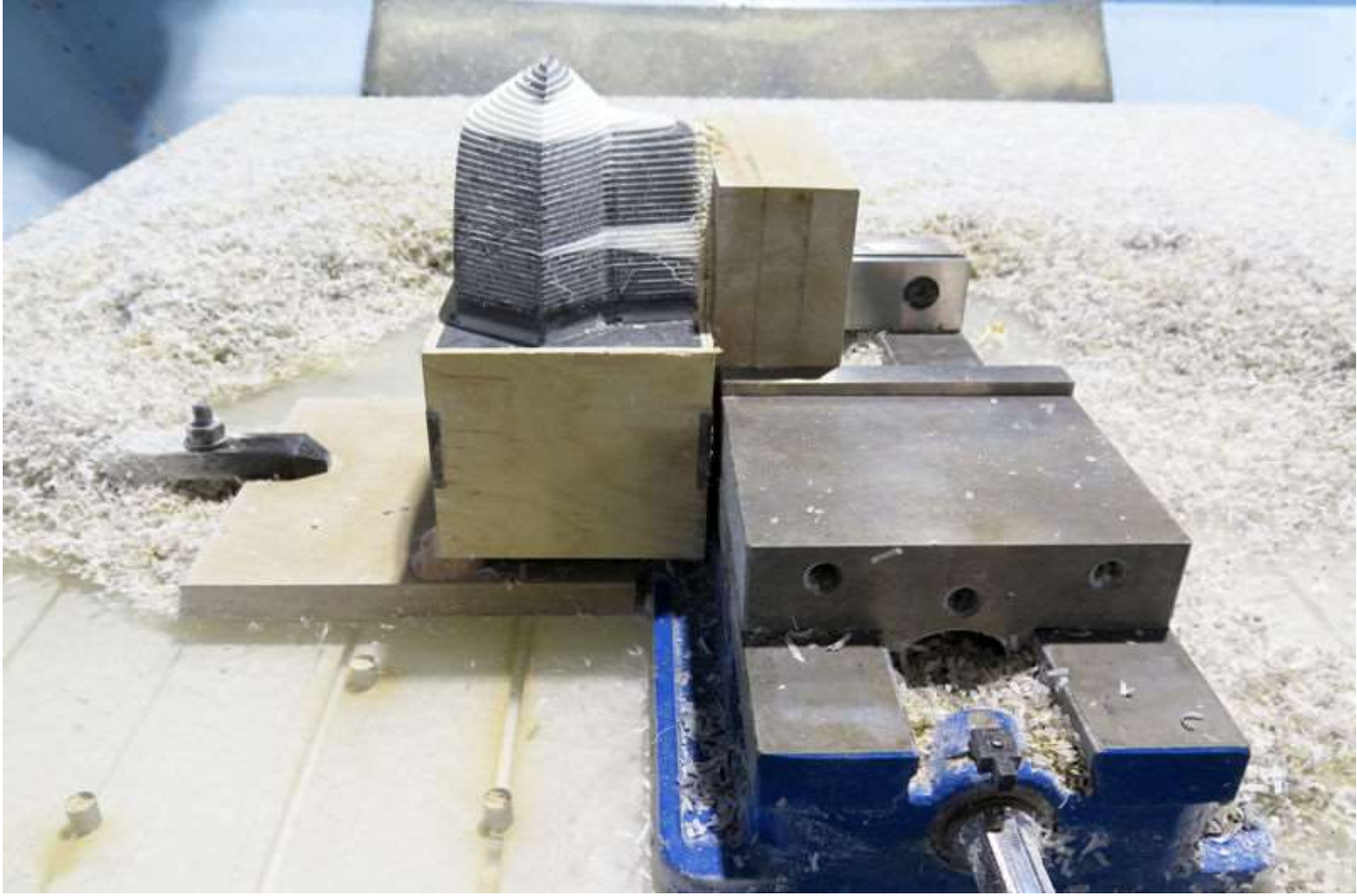






# CNC 1













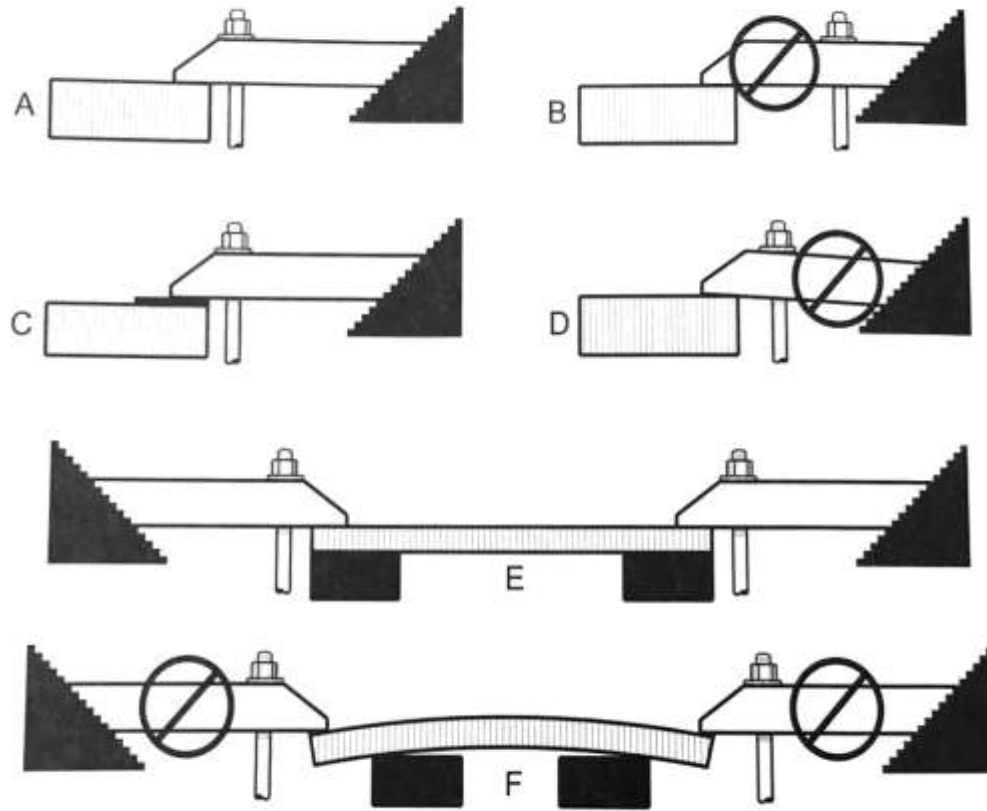


Figure 8-40. Correct (A, C & E) and incorrect ways (B, D & F) to use table clamps.



# Marlow, Frank. Machine Shop Essentials: Questions and Answers

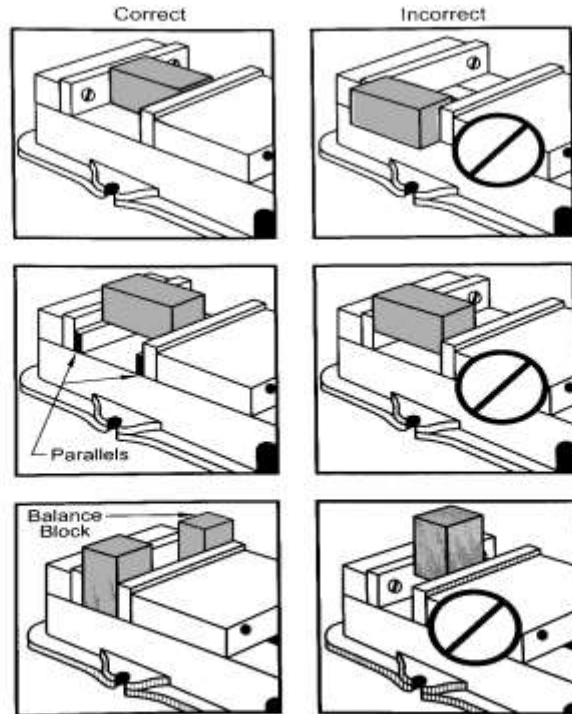
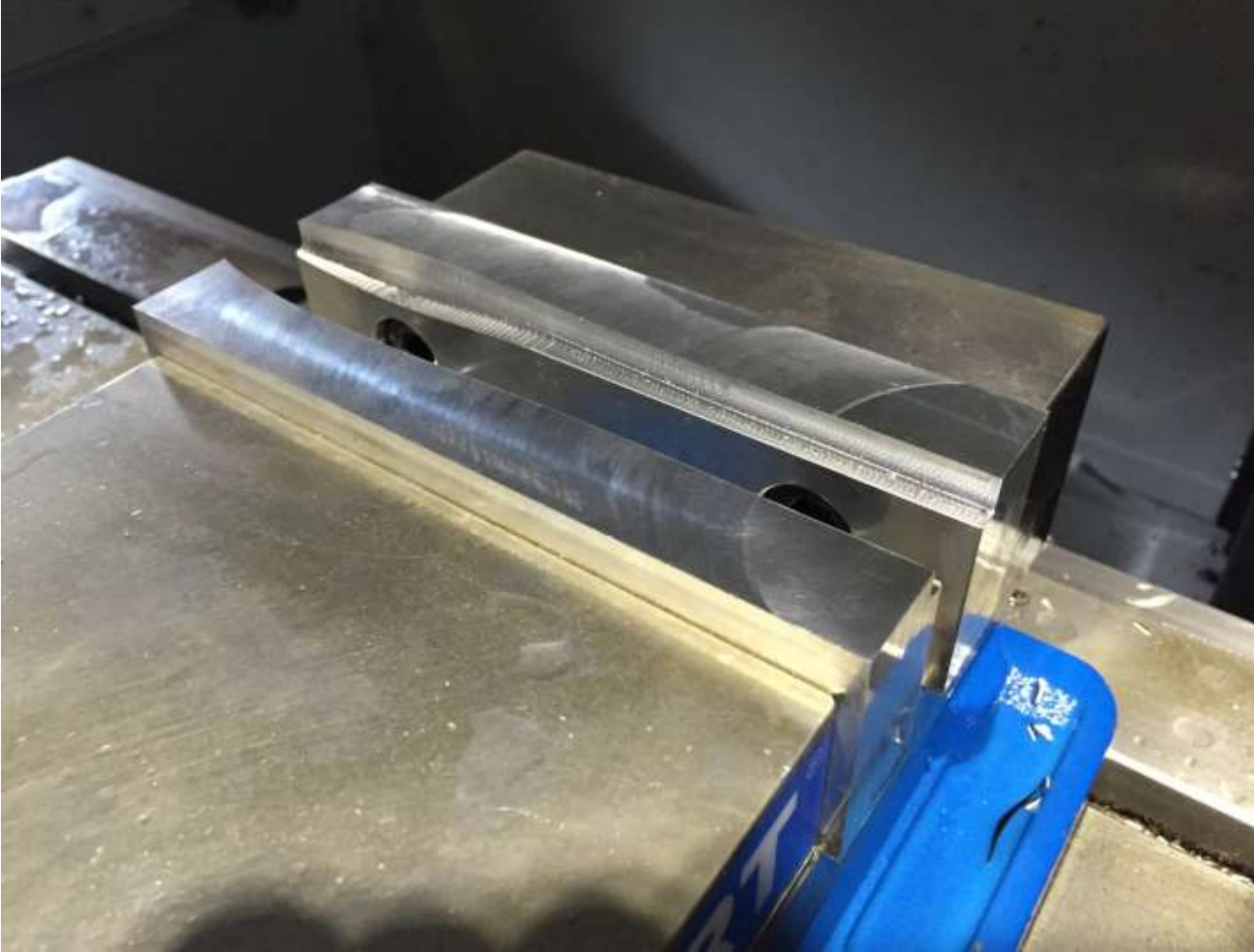


Figure 8-44. Correct and incorrect ways of clamping work in a milling vise.

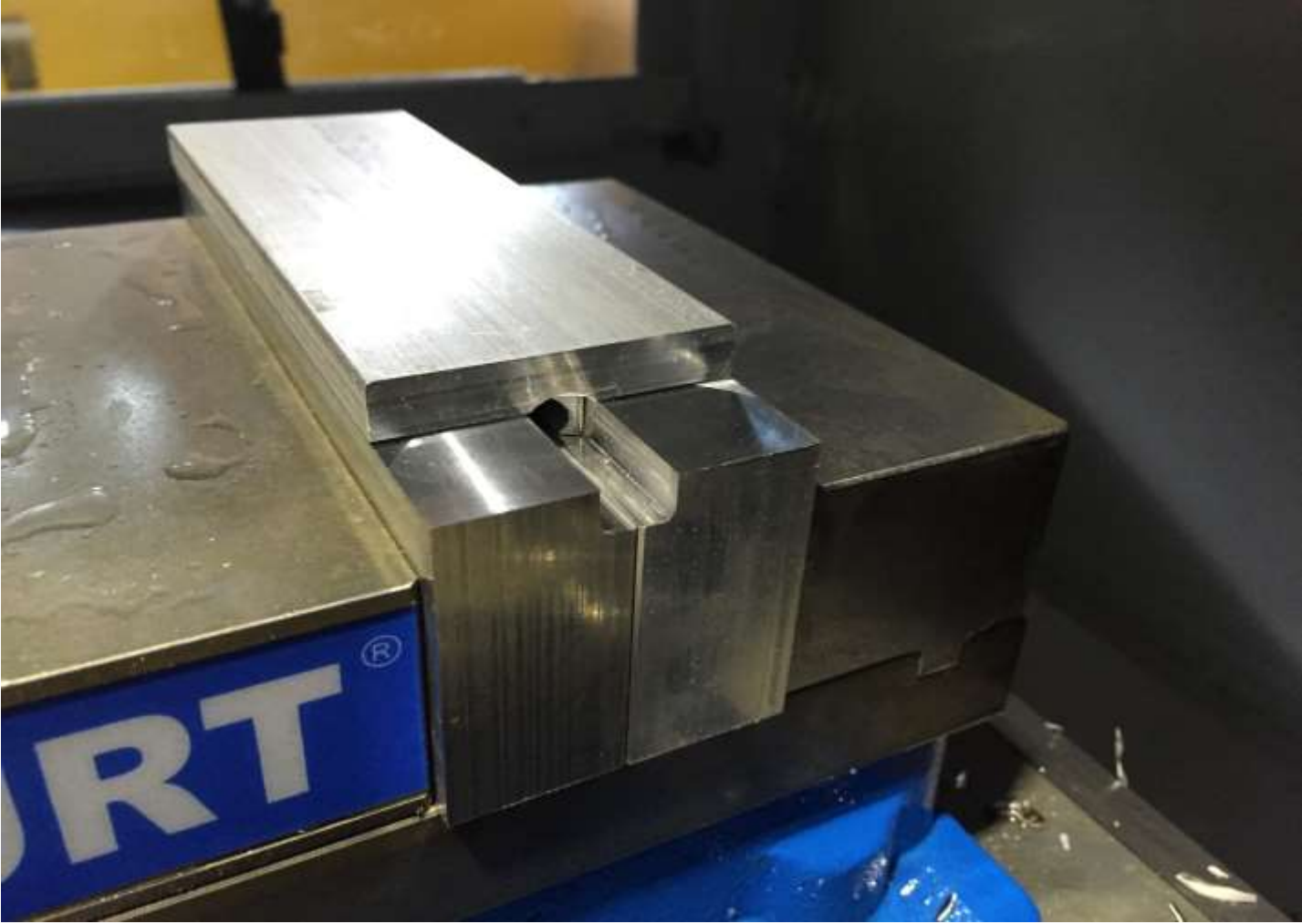










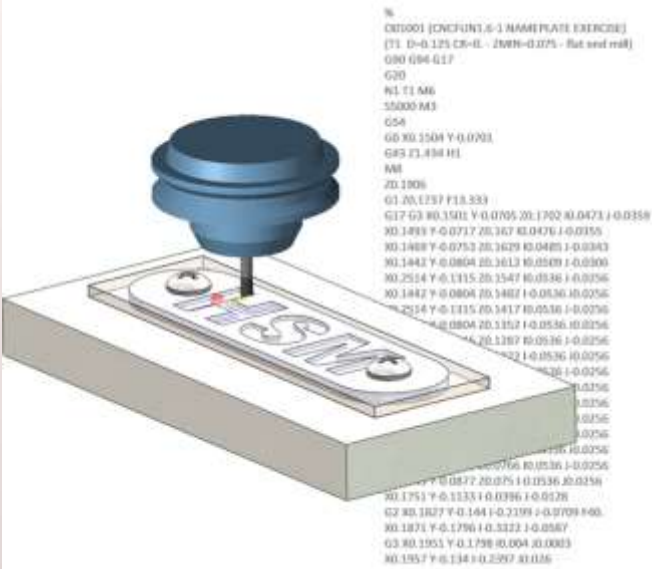








# Overview: CNC Operation



## CNC Operation

CNC Learning

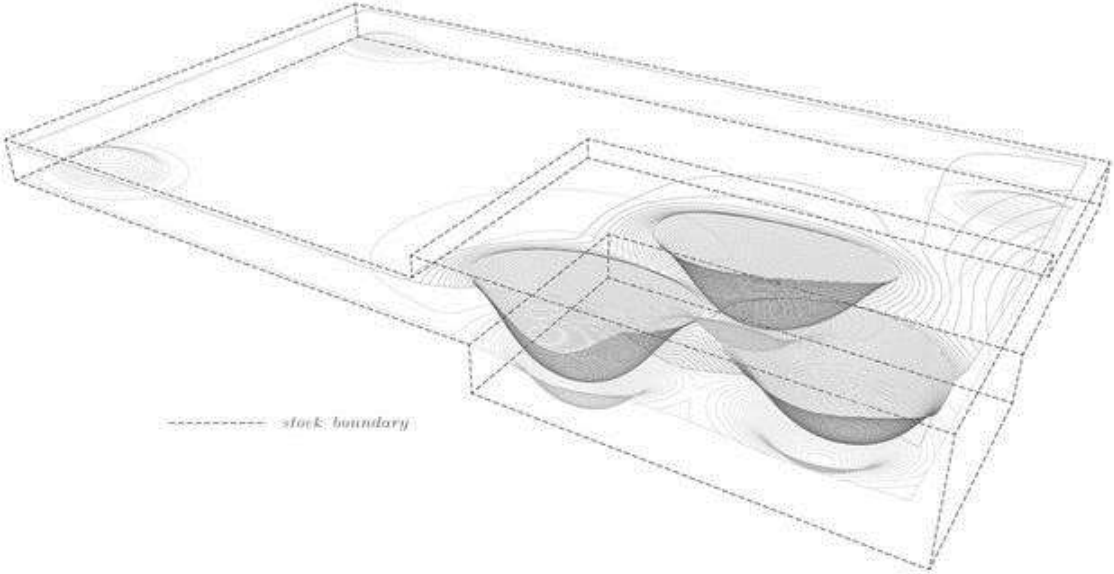
# Starter/Intermediate/Advanced Projects...

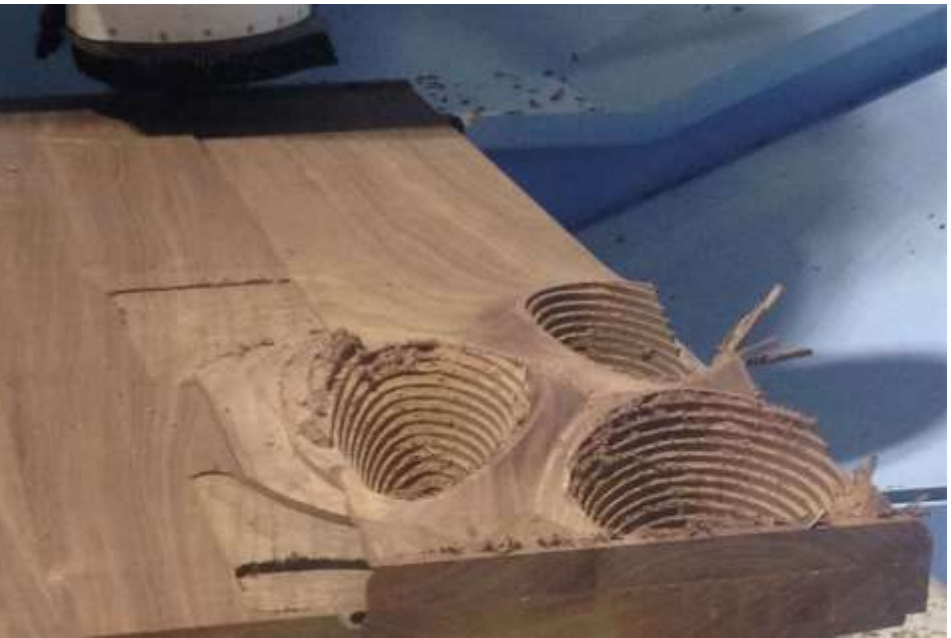












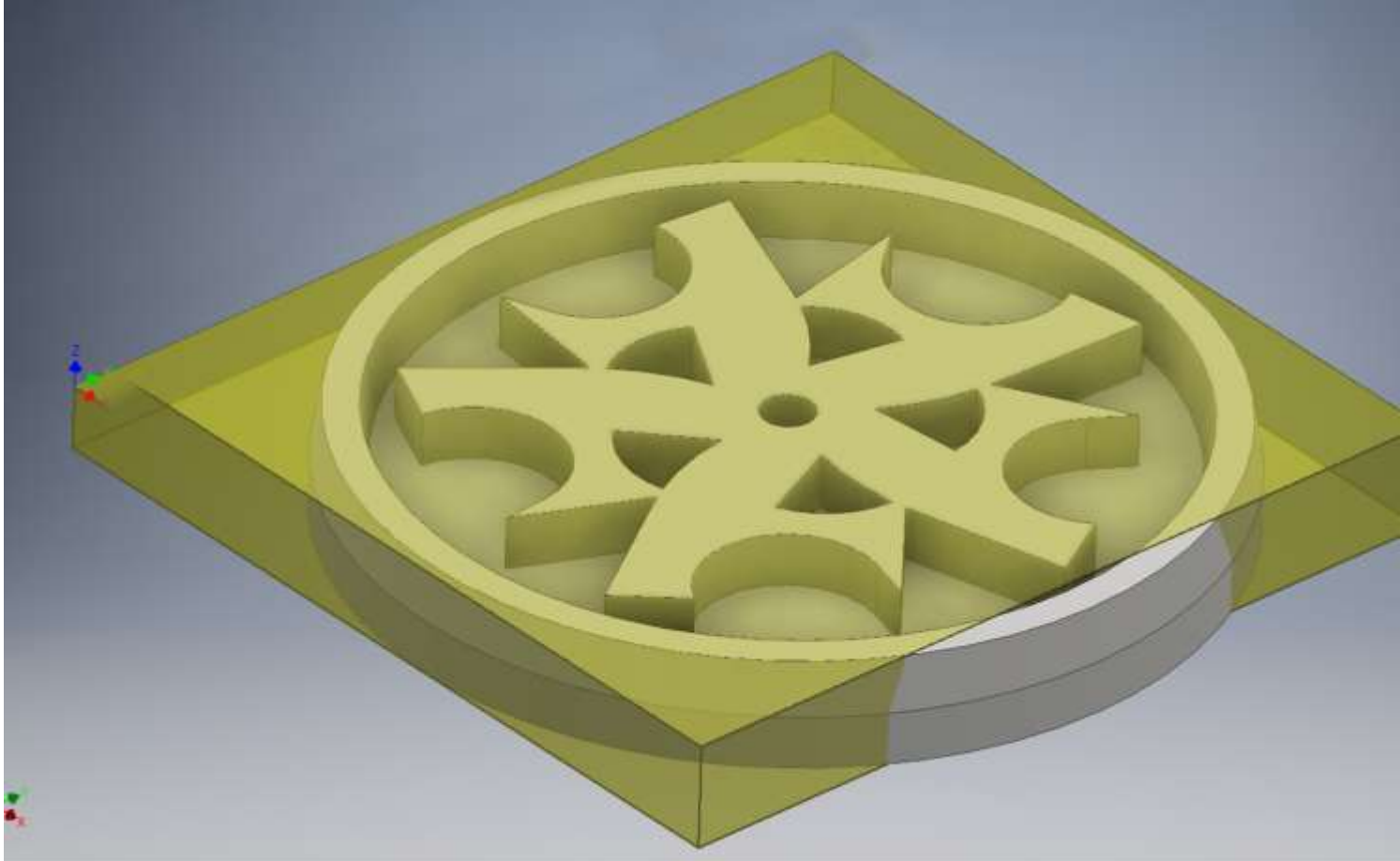


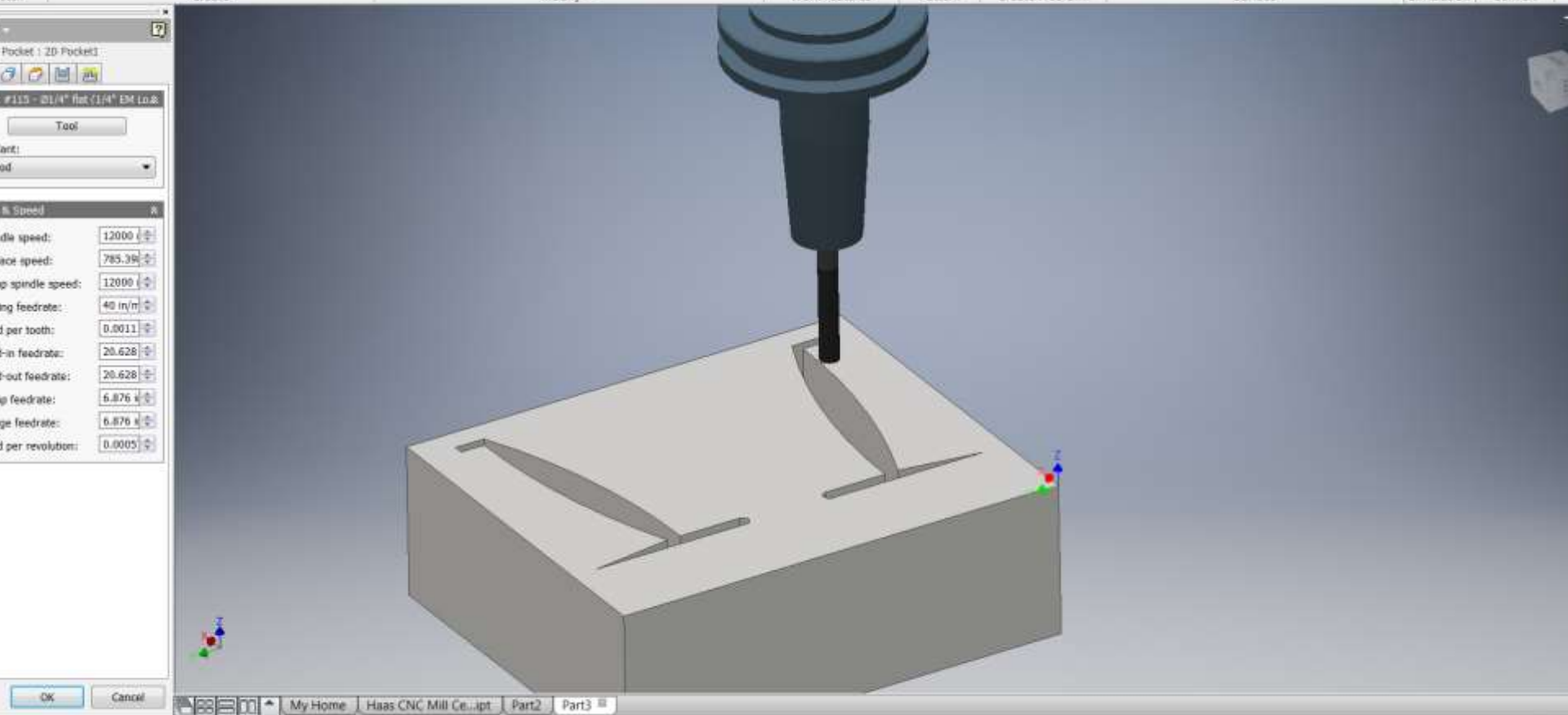






# Considerations during CAD phase





Simulation

Tool

- Show shaft
- Show holder
- Show transparent

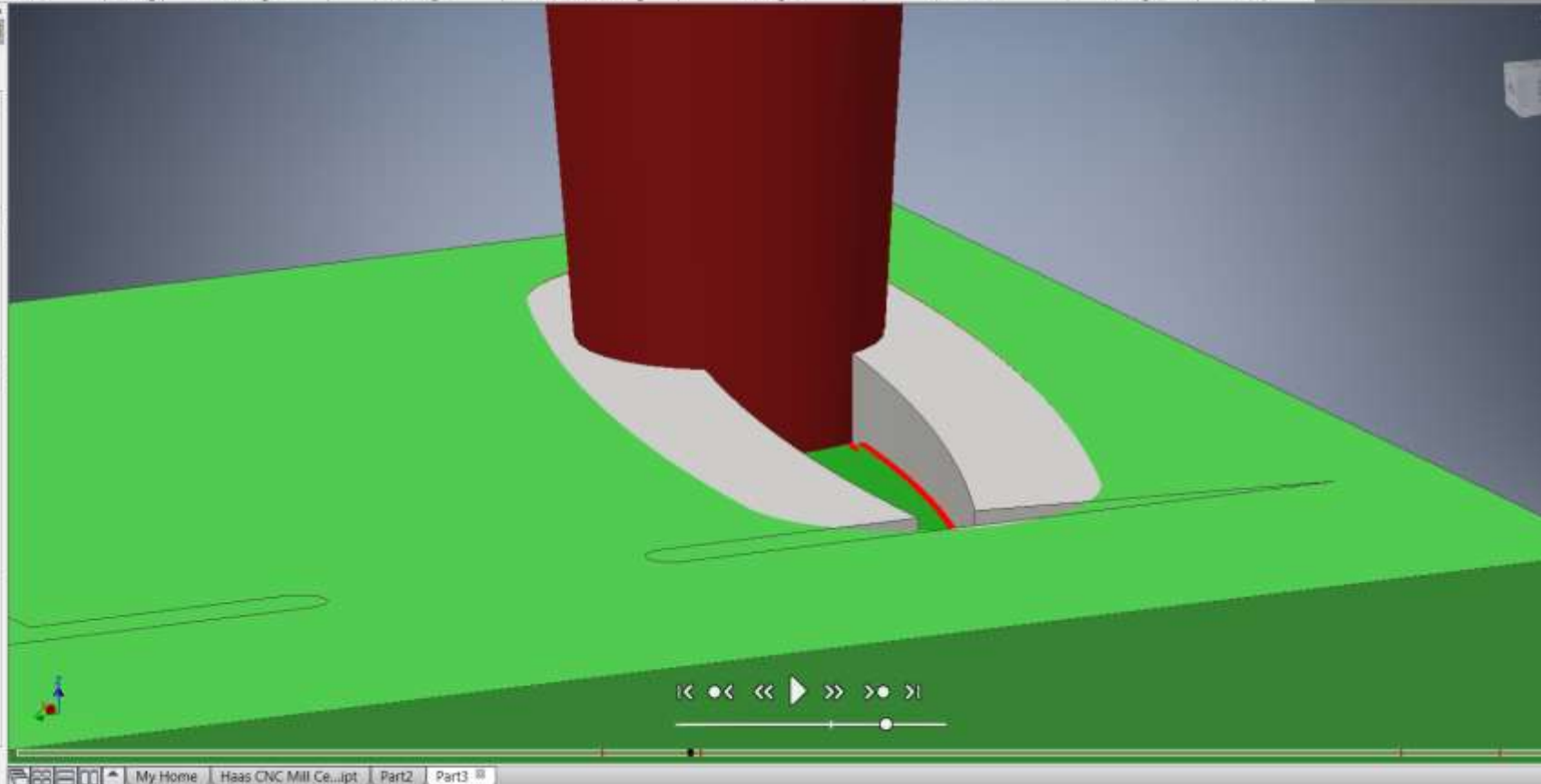
Toolpath

- Show points
- Show axes
- Toolpath mode: Tail

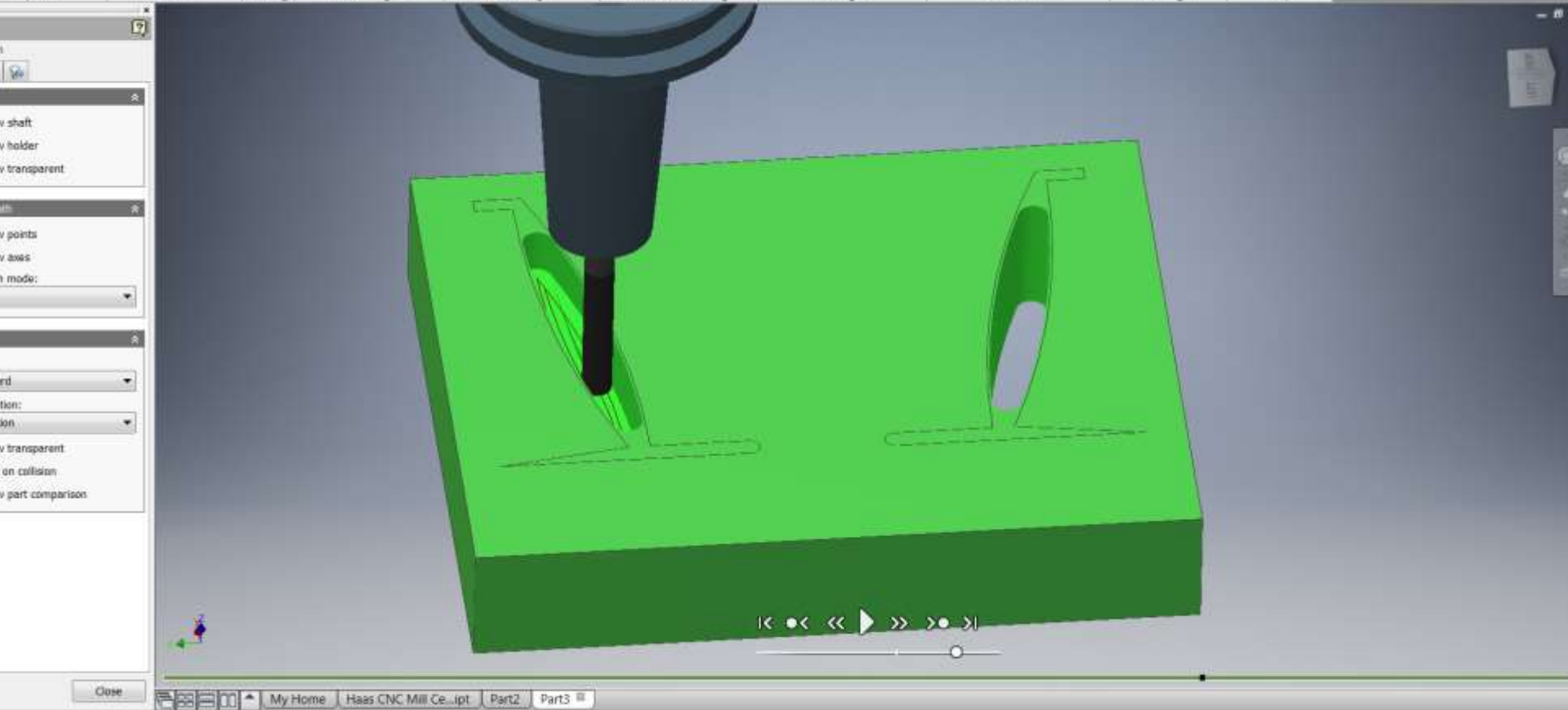
Stock

- Mode: Standard
- Colorization: Operation
- Show transparent
- Stop on collision
- Show part comparison

Close







# Review of Considerations During CAD Phase CNC 1

- Stock
- Tools
  - Collisions, Design resolution
- Workholding
- Materials

## And Remember...

- Use inches as units
- Simulations are accurate
- For DMS/Haas: Take a picture of your Machine Coordinates at Work Home (0,0,0)
- As you machine, go slowly and visualize what you're going to do before you do it

CNC Learning

# Pier 9 CNC Learning Path

**Goal: Train new CNC users in CNC concepts, High Speed Machining (HSM) CAM programming, Haas mill operation, and machine room layout through a series of regularly occurring classes, one-on-one skill checks, and hands-on practical application.**



# Pier 9 CNC Learning Path

- Haas CNC Mill
  - CNC 1: Concepts of CNC
    - Chapters 1-4 in [Autodesk CNC Handbook](#)
  - CNC 2: Beginner CAM Programming
    - Steps 1-22 in [Beginner and Advanced CAM](#)
  - CNC 3: Advanced CAM Programming
    - Steps 23-51 in [Beginner and Advanced CAM](#)



# Pier 9 CNC Learning Path

- Haas CNC Mill (continued)
  - Skill Check #1
    - Program certification part in presence of instructor
  - Haas CNC Mill Safety Basic Use Course
    - Sign up on ELC after Skill Check #1 complete
  - Skill Check #2
    - Machine certification part

# Follow Through: How to be Prepared

- Take classes again as needed
- Start with 2.5D projects
- Watch videos; Take notes; Read the CNC Handbook
- CAM Setup, Toolpath, Simulate at your desk

# Getting Ready to Use DMS or Haas

- Get CAM program/toolpaths checked by shop staff
- Email Julie to reserve machine
- Red notebook with notes, CNC Handouts, etc. are required when using machines

# The first time you're on the DMS or Haas...

- Get plenty of rest the night before
- Distractions while CNC machining
- Machine rapid speeds: 5% rapid at all times
- Enjoy the process & take your time

# CNC Concepts: Where is this in the CNC Handbook?

- Chapter 3
  - CNC Milling Tools, pages 3-1 to 3-7
  - CNC Cutting Fundamentals, pages 3-8 to 3-10
  - Speeds and Feeds, pages 3-10 to 3-18
- Chapter 4
  - Coordinate Systems, pages 4-1 to 4-14
- Chapter 6
  - CNC Operation, page 6-3



# CNC Concepts: Where is this in the CNC Handbook?

- Chapters 7 and 9
  - Toolpaths
- Chapter 10
  - Workholding and Fixturing, pages 10-3 to 10-7

# Software Links and Downloads

- Autodesk Inventor HSM Pro 2016
  - Download on the [Autodesk Sharepoint Site](#)
- Fusion 360
  - Download on the [Fusion 360 Pricing Page](#) and activate educational licensing
- Post Processors, Certification parts, and Tool Libraries
  - [Dropbox folder](#)

# Learning Links

- [cam.autodesk.com](http://cam.autodesk.com)
  - CAM Forums
  - CNC Handbook
- Instructables
  - [Beginner and Advanced CAM](#)
  - [Pier 9 Tool Library](#)
  - [Inventor HSM to Shopbot Workflow](#)

# Video Tutorials

- nextgencam.com
  - Good for 3D Toolpath techniques
- Machine training
  - [vimeo.com/channels/shoptraining](https://vimeo.com/channels/shoptraining)



[julie.kumar@autodesk.com](mailto:julie.kumar@autodesk.com)