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?

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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…

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

KTNC

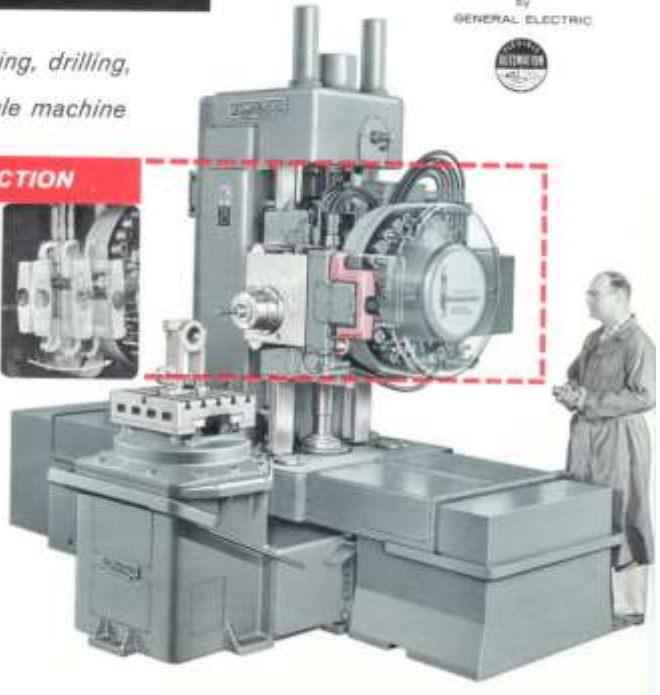
*a machine that harnesses the **full** potential of numerical control:*

***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

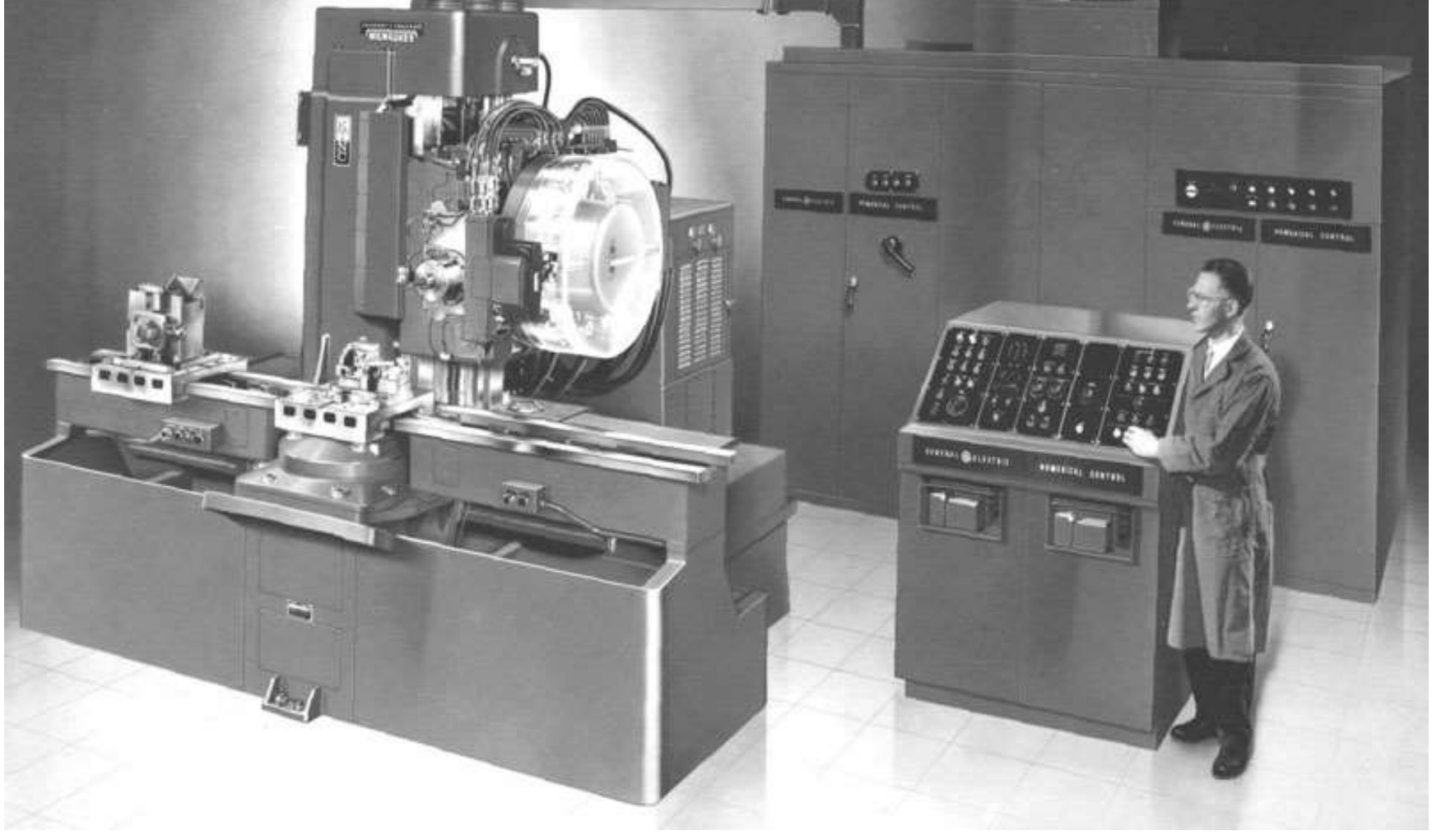
The MILWAUKEE-MATIC is the *most significant achievement* of the machine tool industry in the last 50 years. Briefly, it is a single machine that performs the many operations that are normally accomplished on several other machines to complete a part. MILWAUKEE-MATIC will improve almost every aspect 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, arcs and slopes, tool selection, indexing and speeds and feeds.
- Cuts working capital requirements . . . balances 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 MILWAUKEE

KEARNEY & TRECKER CORPORATION, Dept. KTNC
5680 W. National Ave., Milwaukee 14, Wisconsin
Designers and Builders of Precision and Production Machine Tools Since 1898

See Back Page . . .
FOR FANTASTIC SAVINGS!



CNC 1

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Advantages of using CNC Machines

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

Disadvantages of using CNC Machines

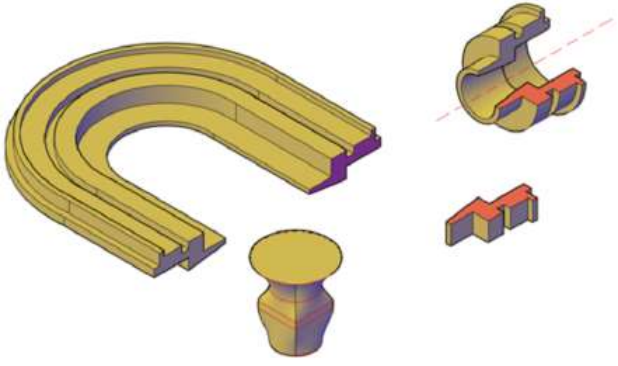
- Price
- Programming Skillset
  - They only do what they're told to do
- Space/Electricity/Maintenance
- Slower to make a single part

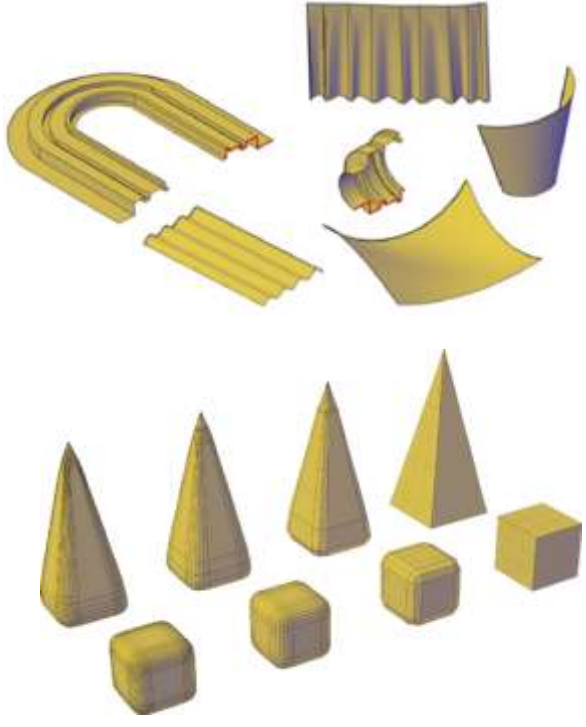
How do you prepare a file for CNC machines?

- 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

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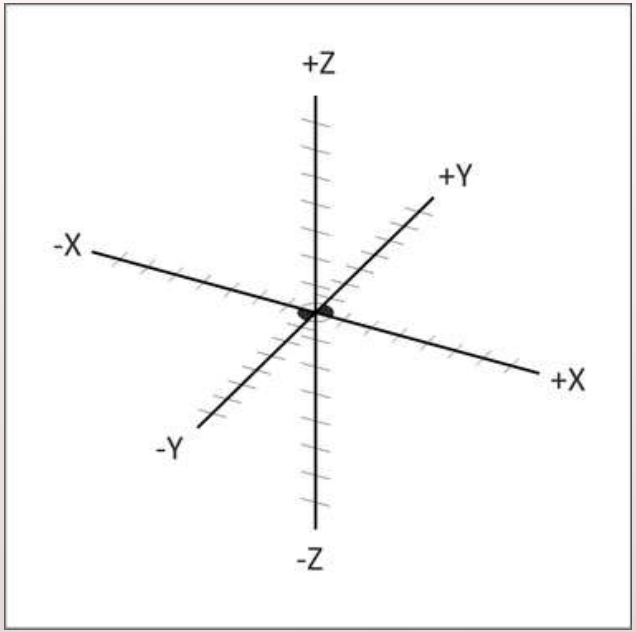
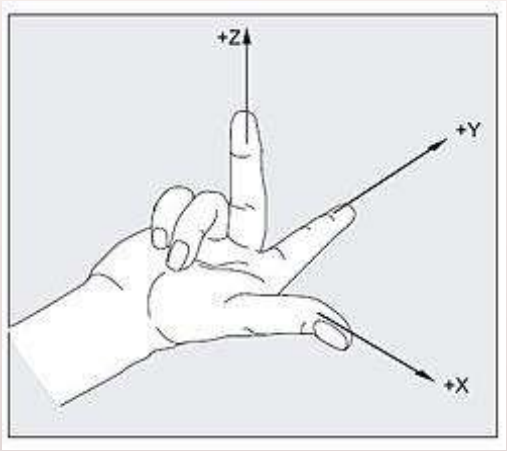
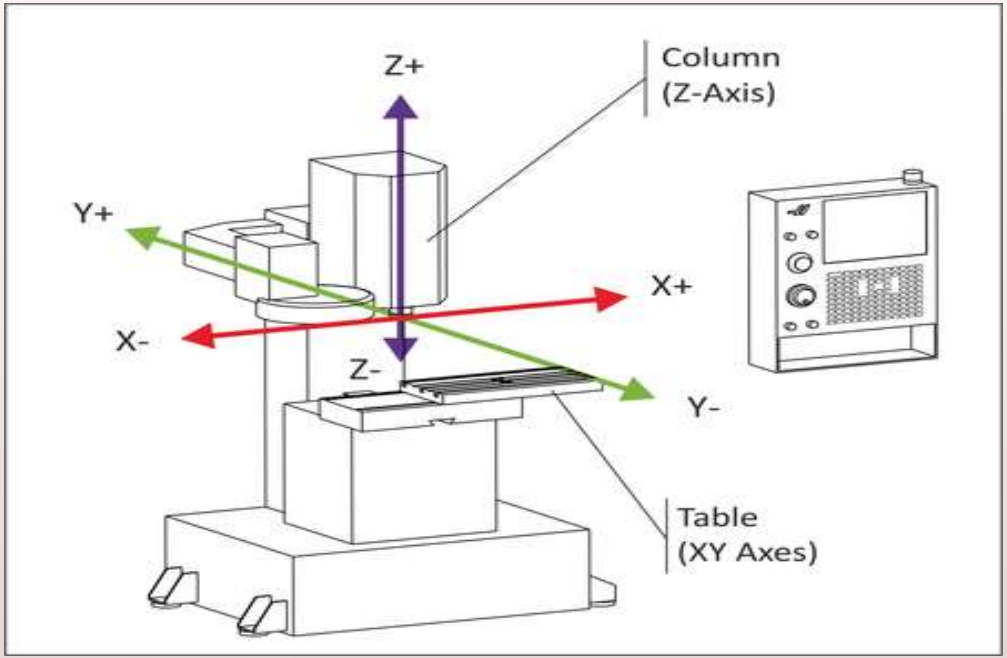




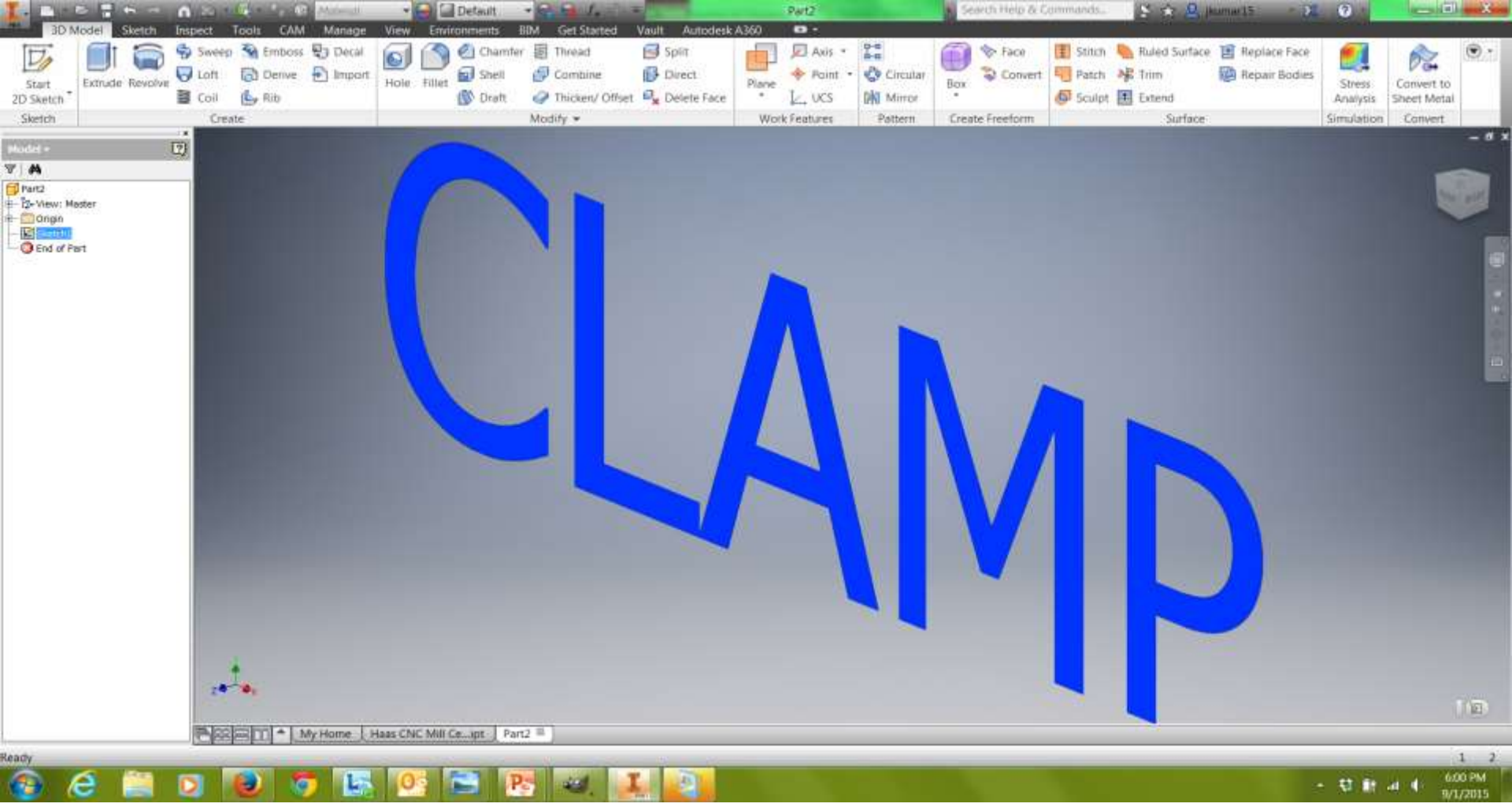
Coordinate System

Cartesian Coordinates and the Right Hand Rule



Coordinate System

Machine Coordinate System



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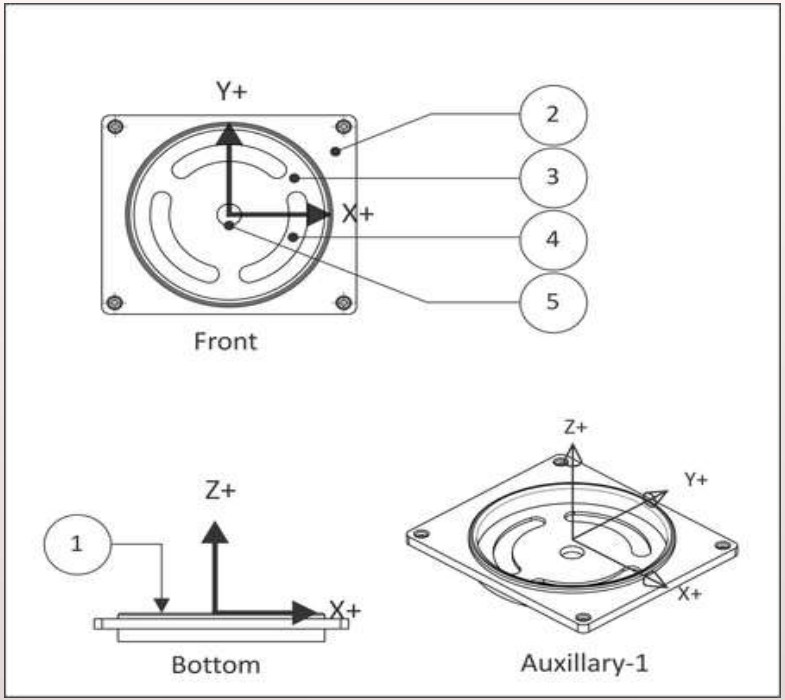
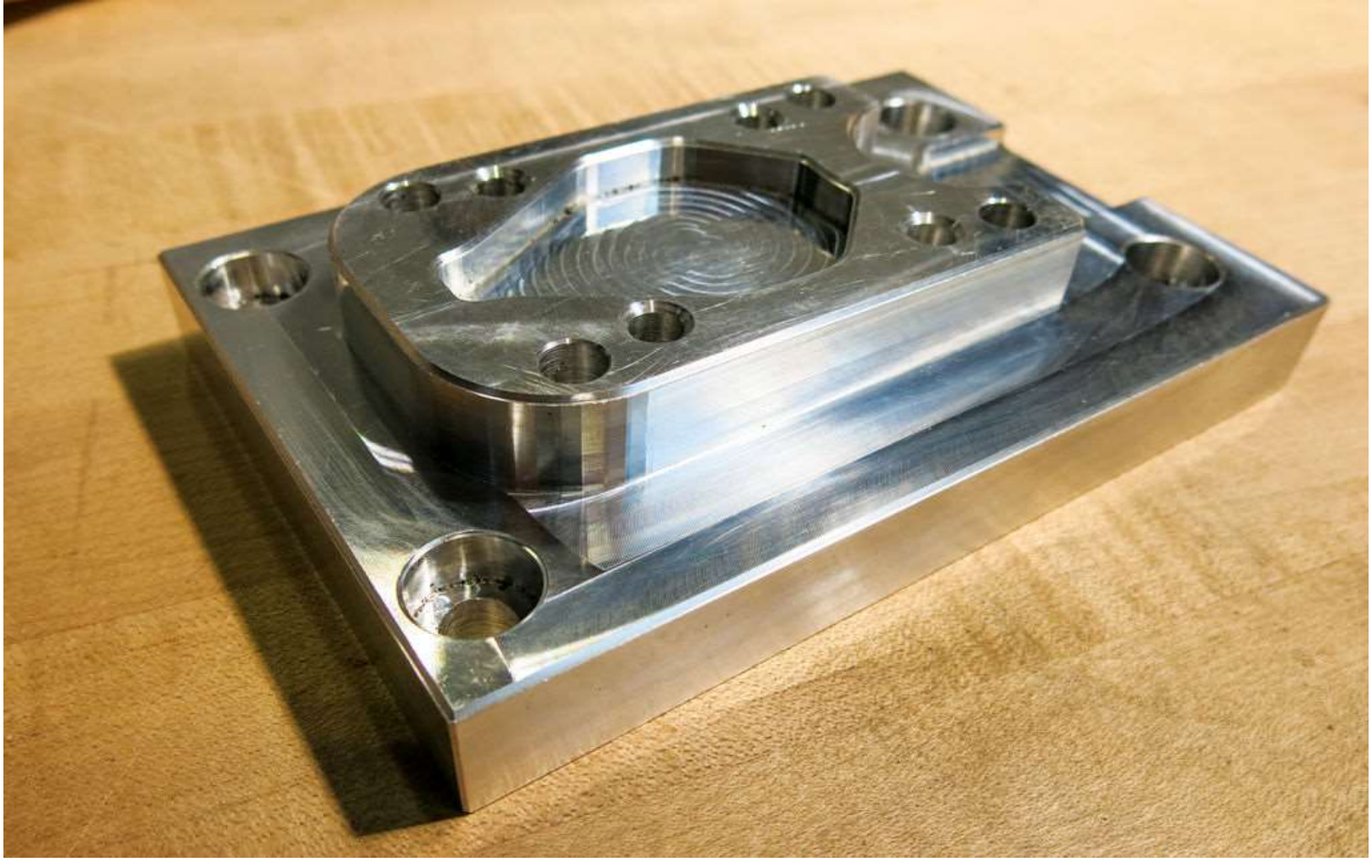
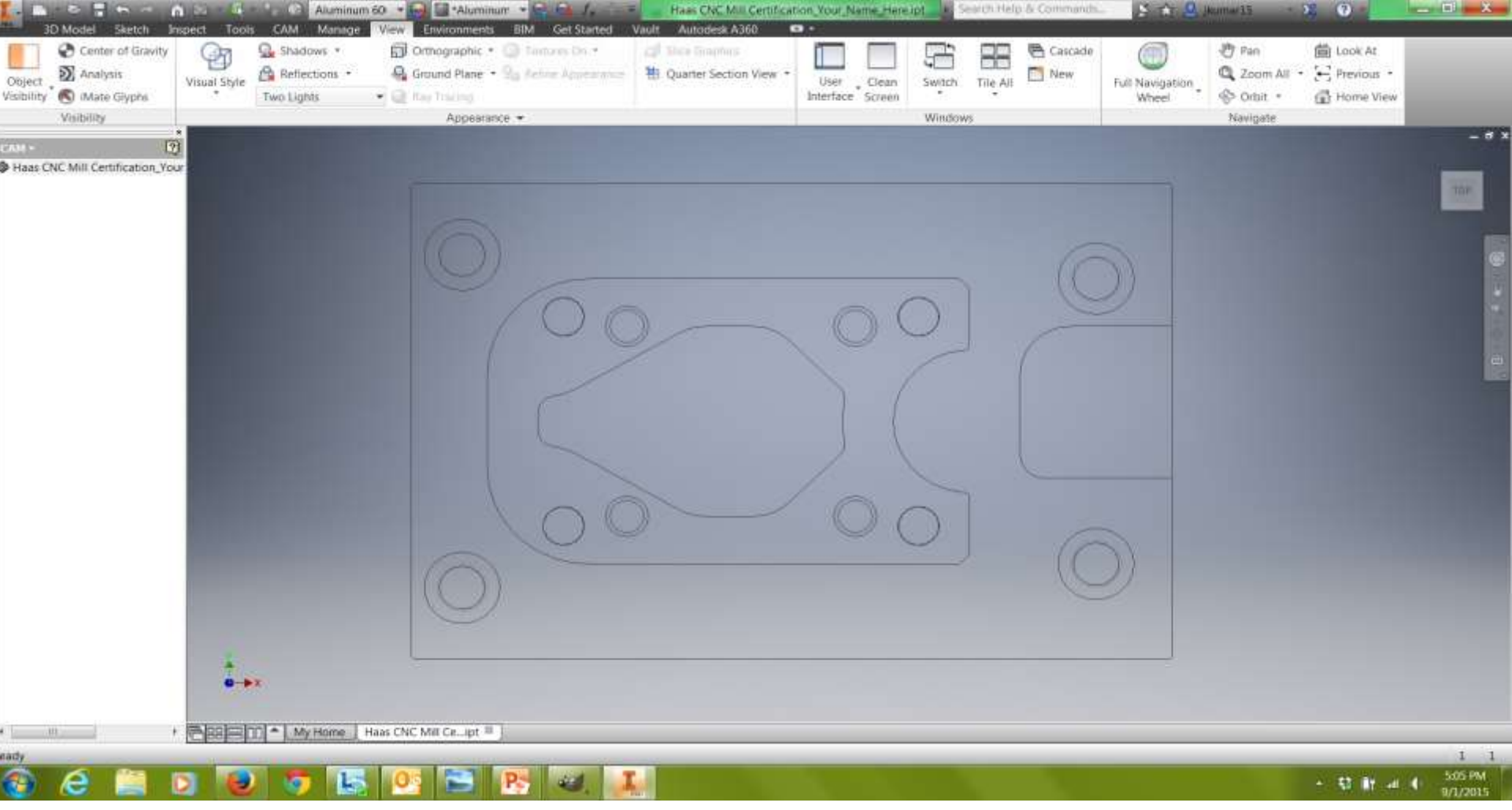


Toolpaths

2.5D



CNC 1



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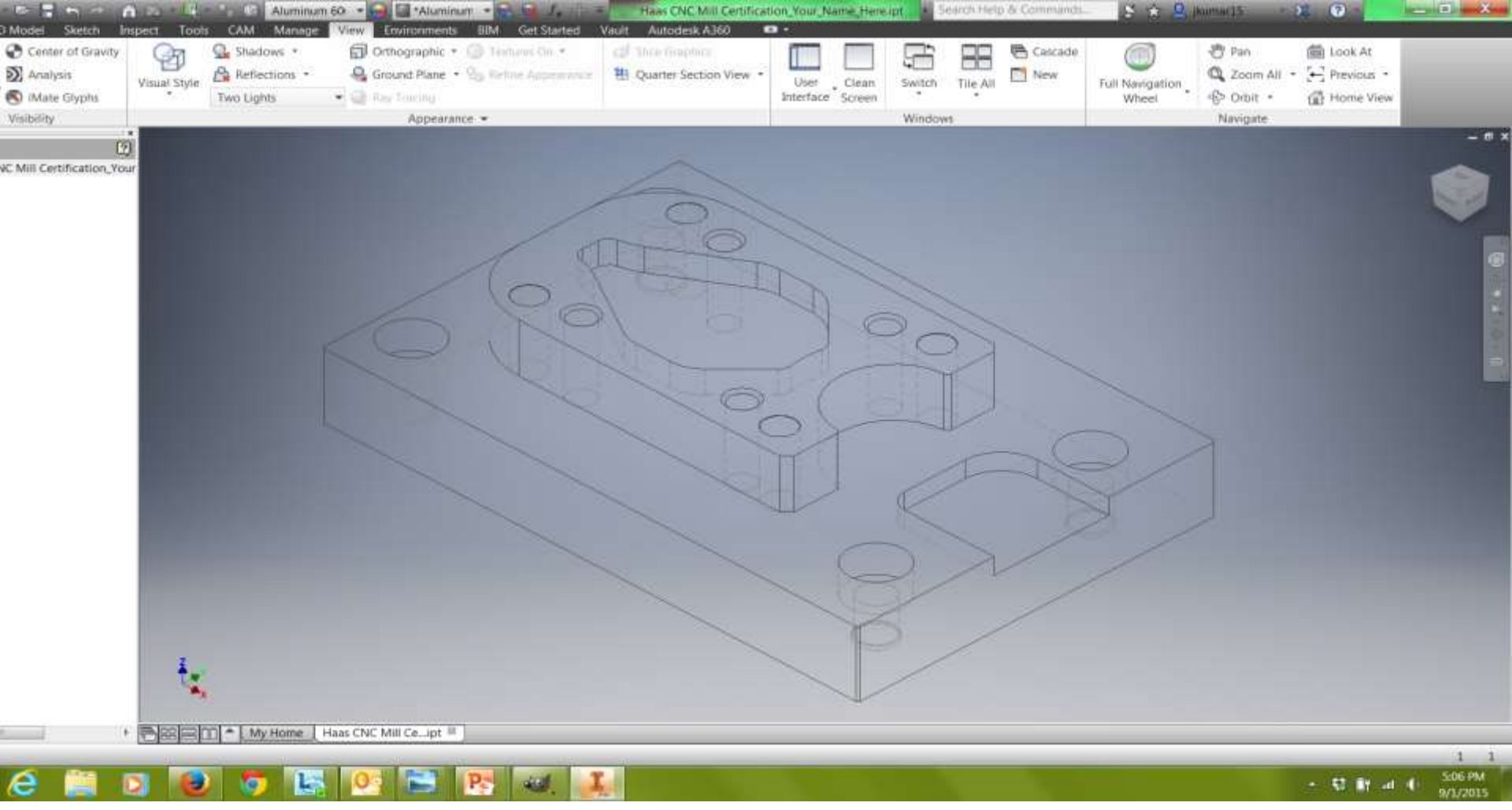

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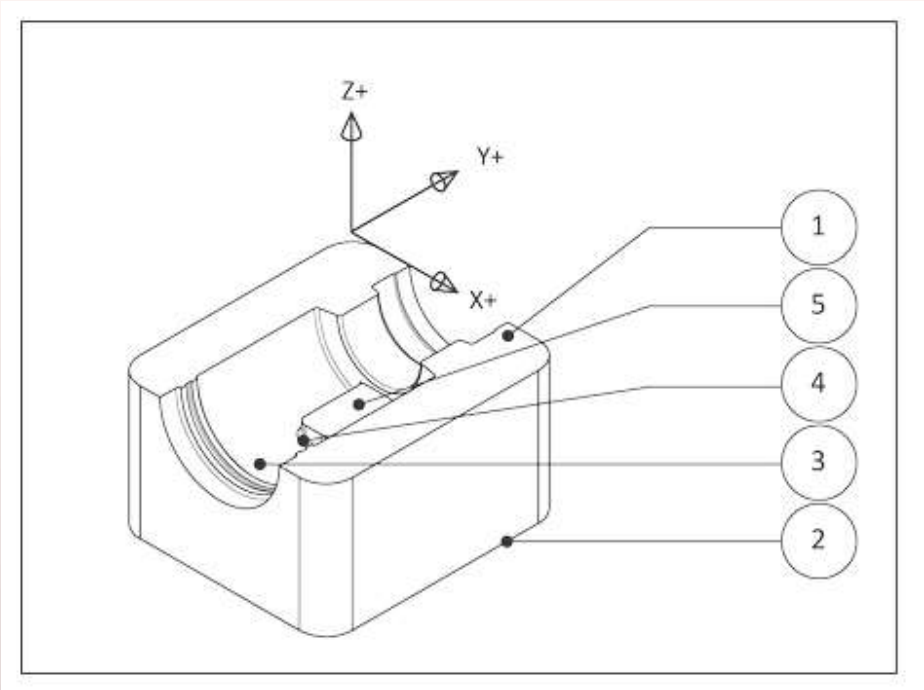
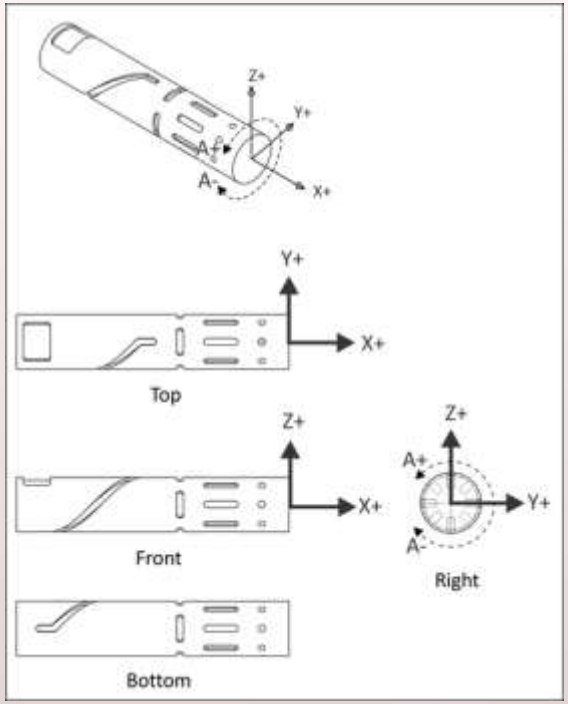
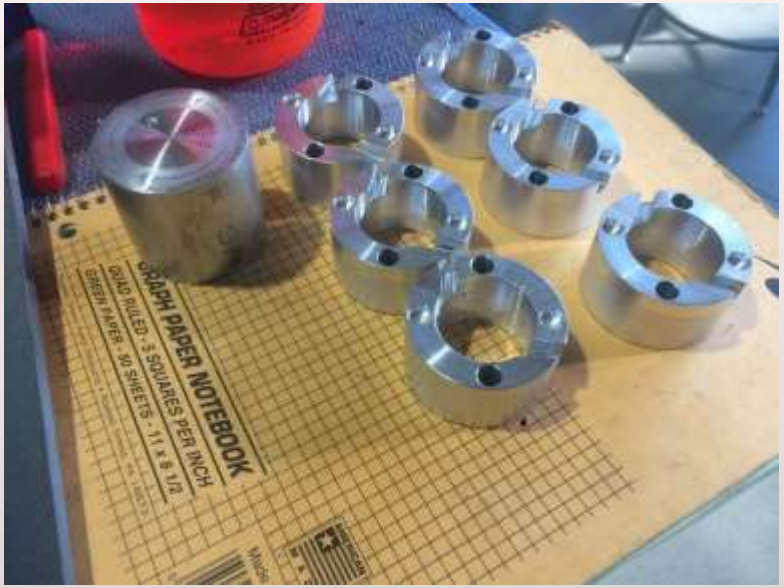


Toolpaths

3D

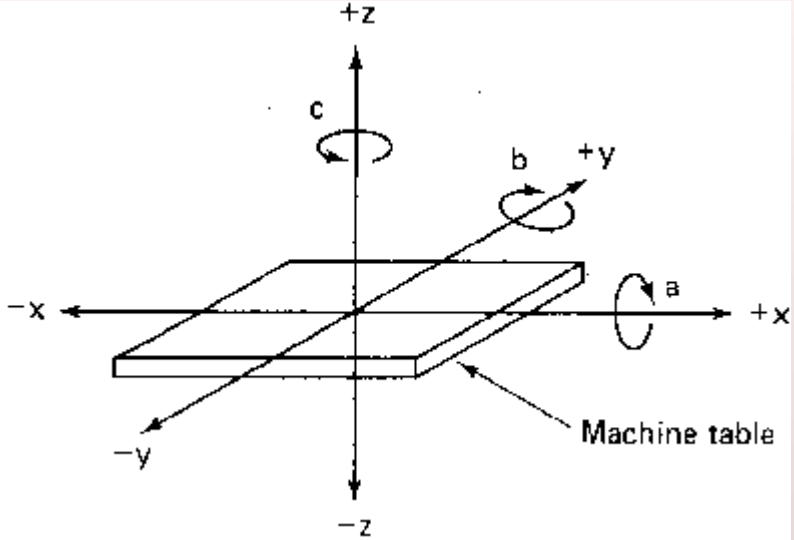
CNC 1





Toolpaths

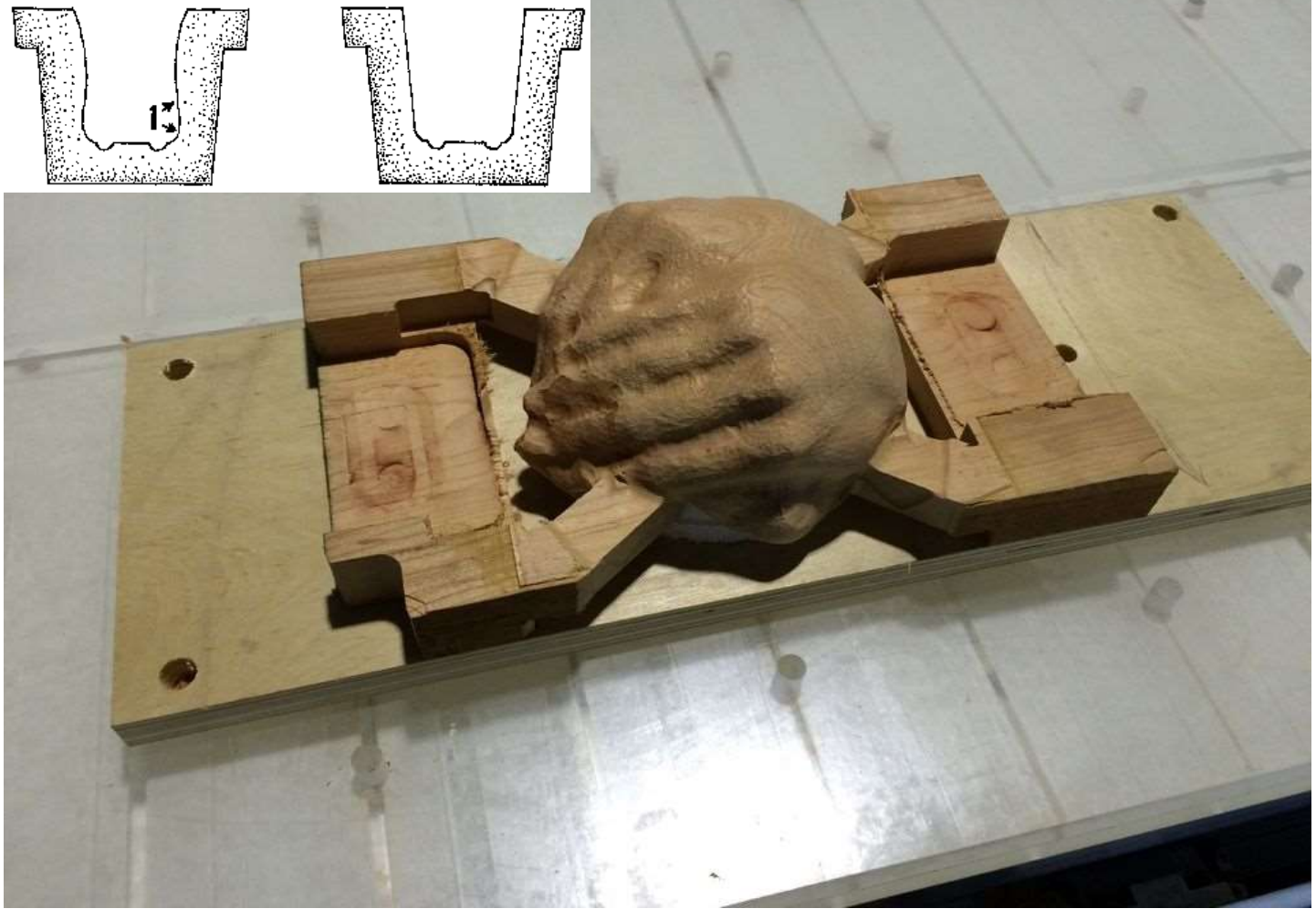
4-axis



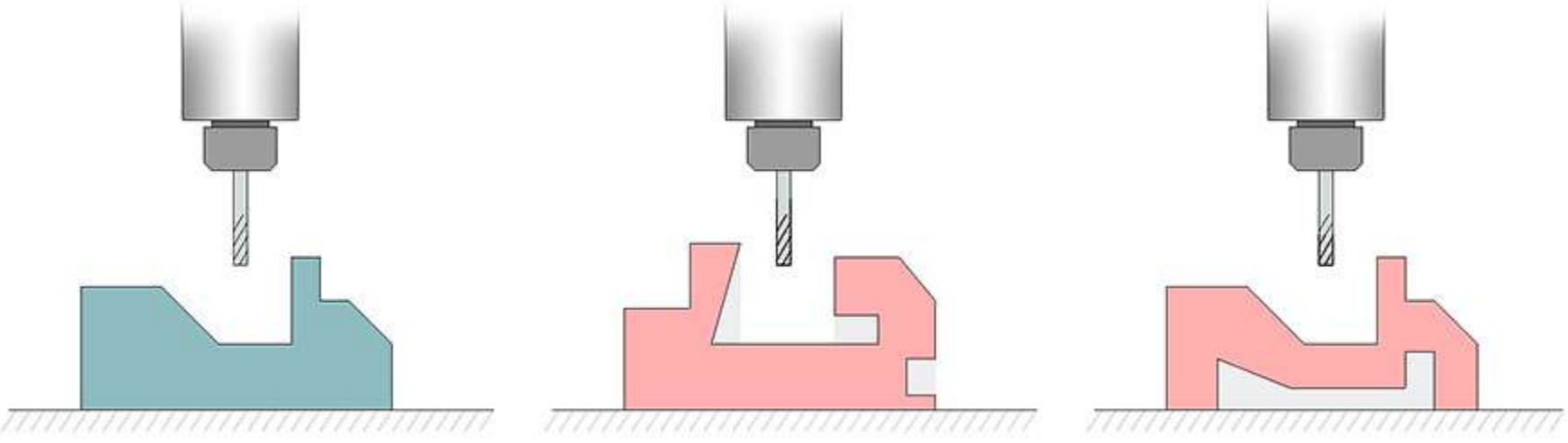
Toolpaths

5-axis

CNC 1

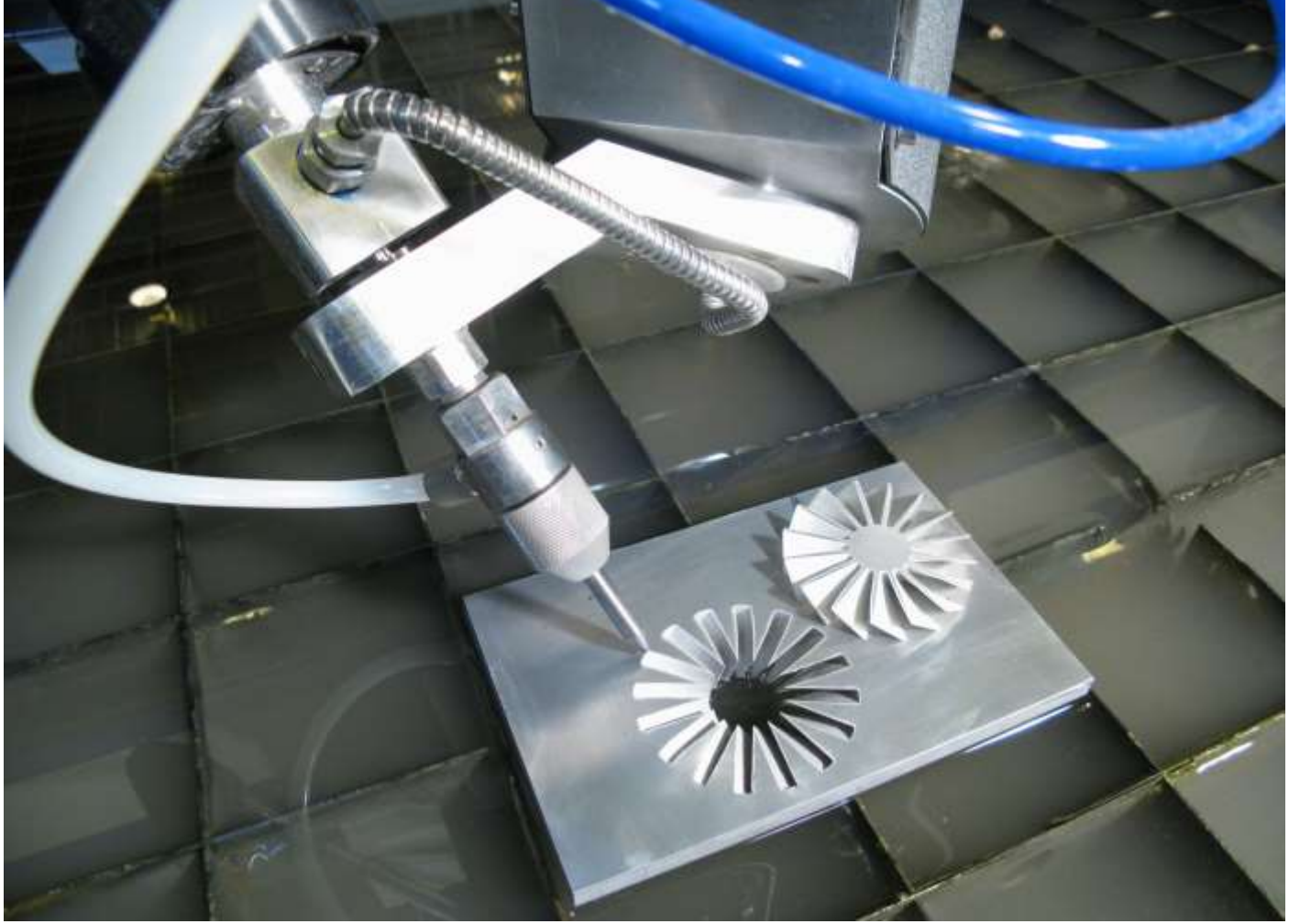


Undercuts example



Machinable/Unmachinable Features using a 3-Axis CNC Machine

CNC 1



CNC 1

CNC 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

Toolpath Terminology

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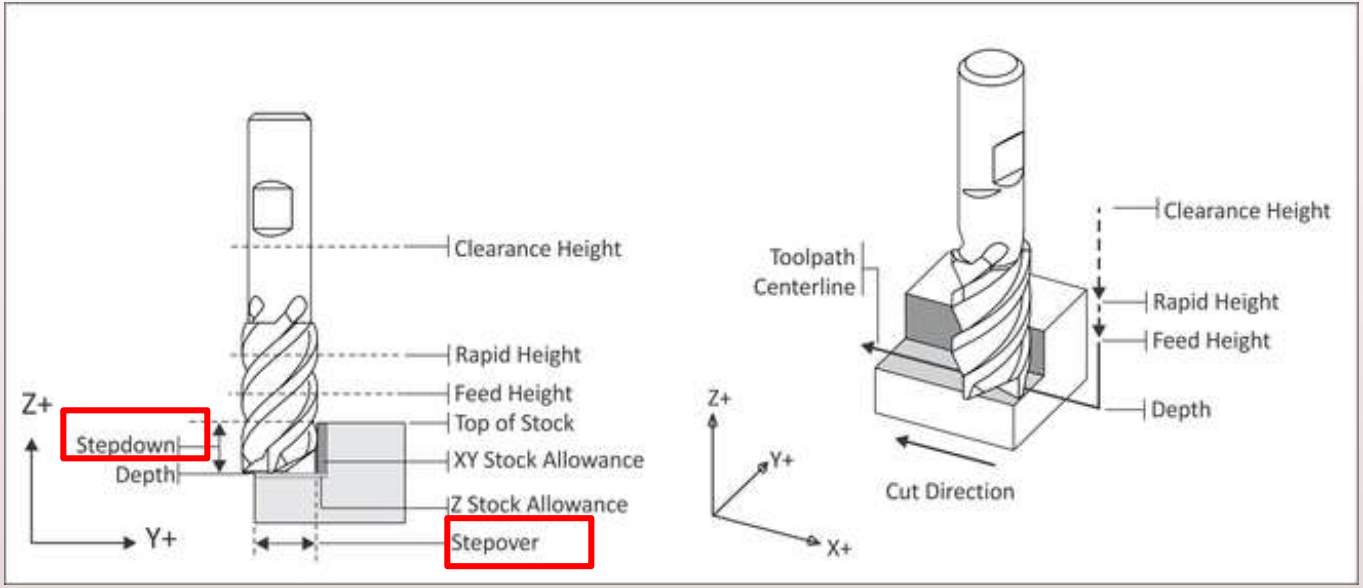
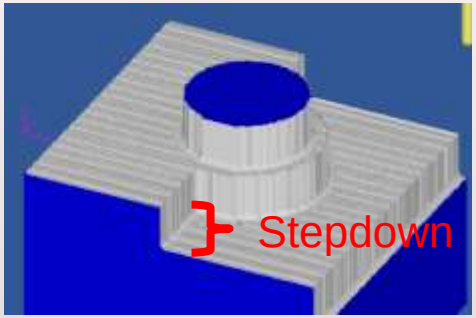
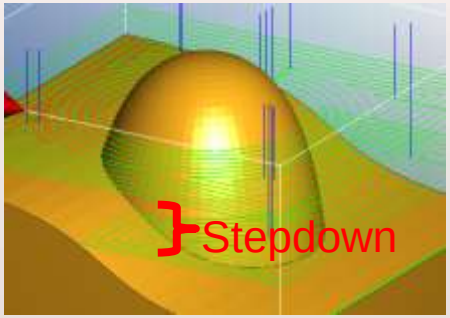
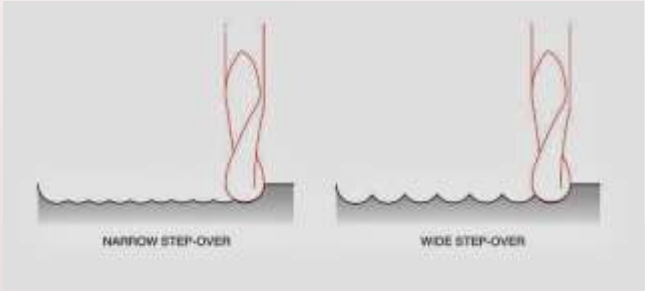


Toolpaths

2D Toolpath Terminology



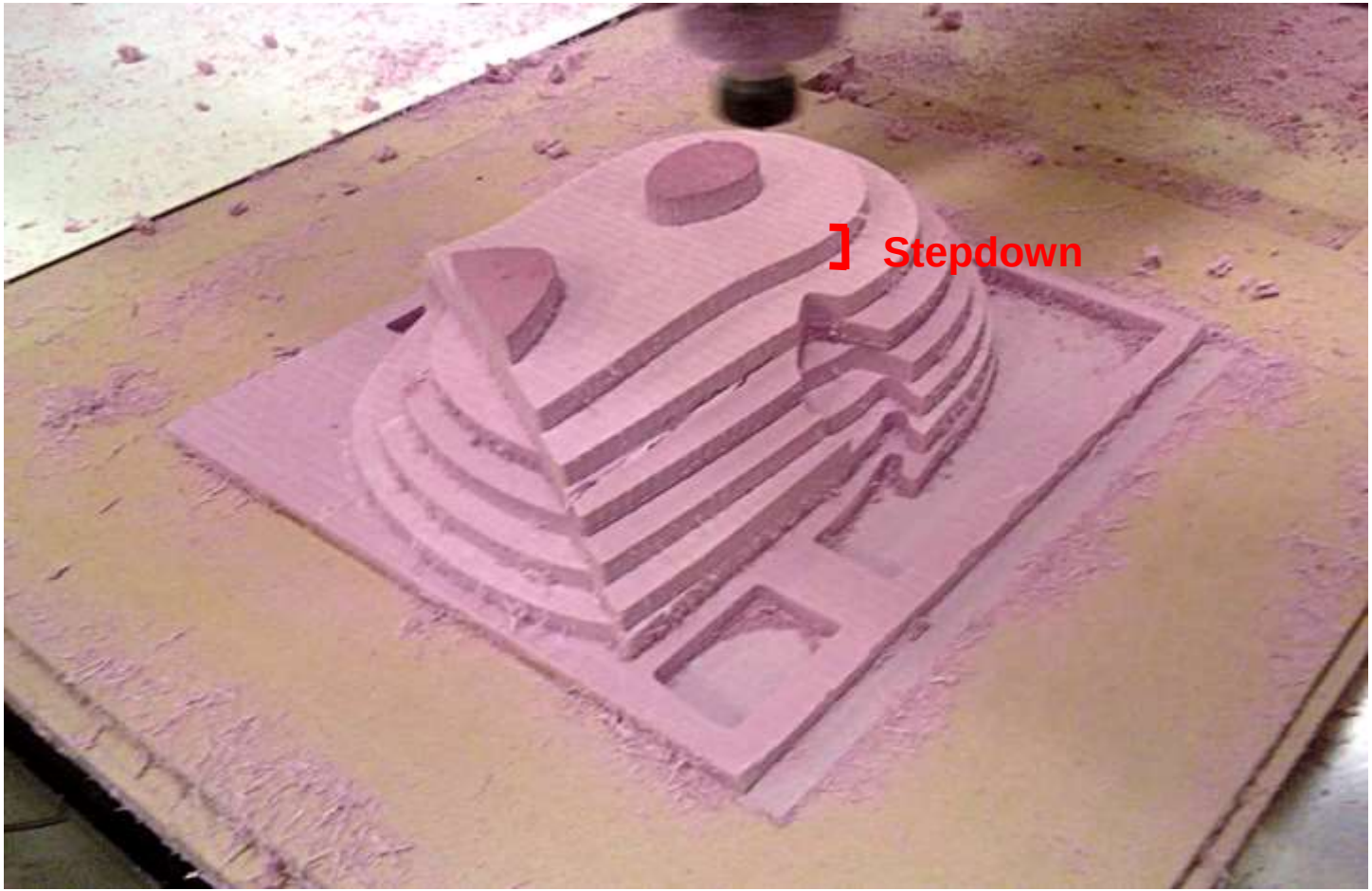




Toolpaths

2D Toolpath Terminology

CNC 1



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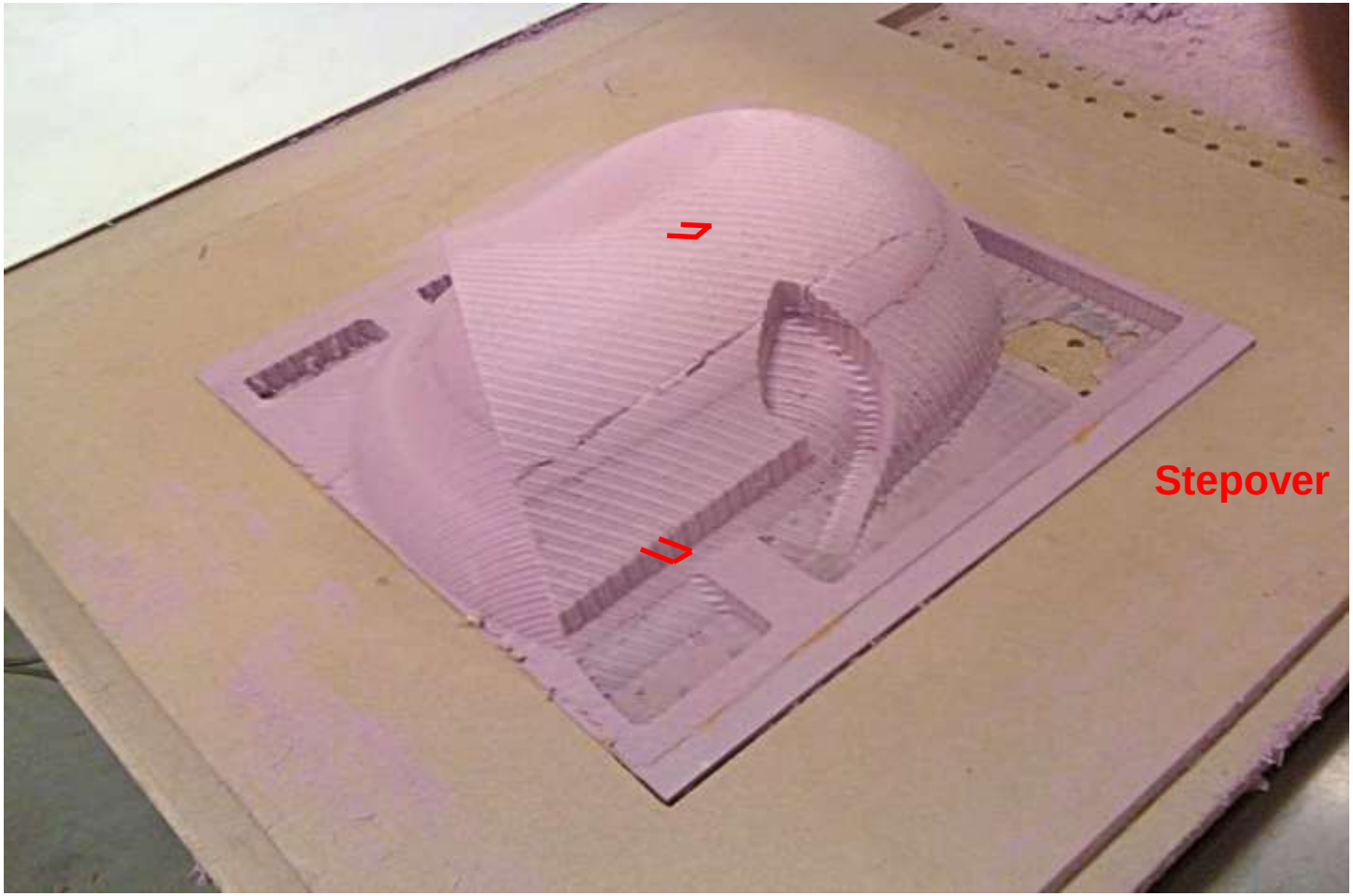
CNC 1



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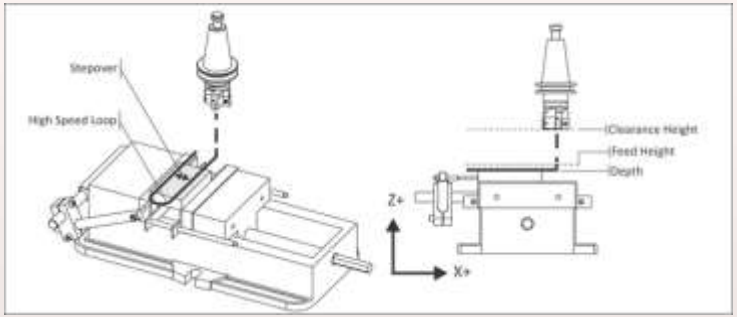
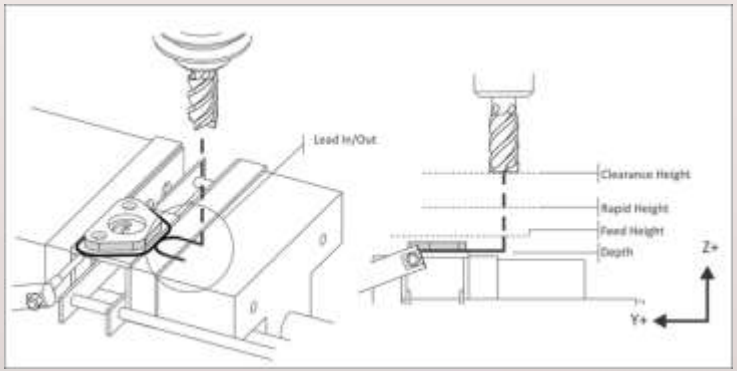
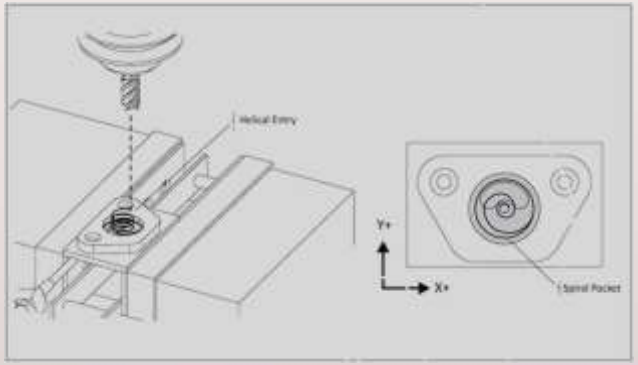
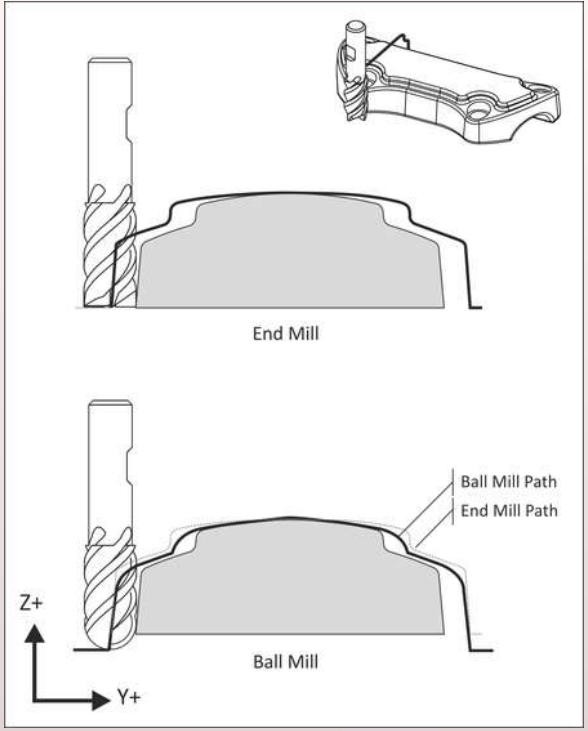






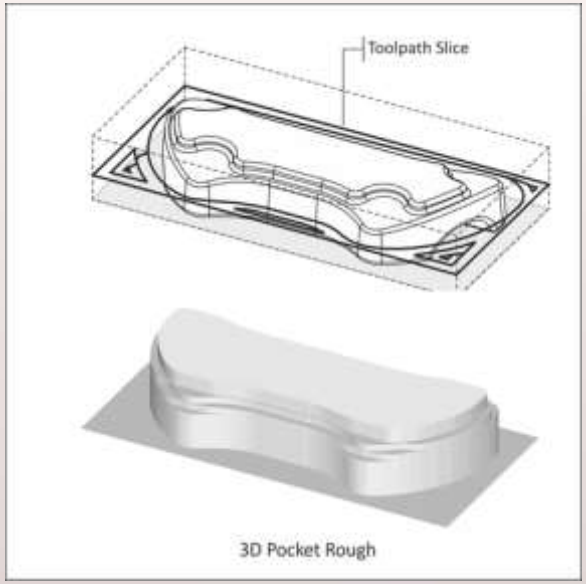
Toolpaths

2D Toolpaths: Facing, Contour, Pocket



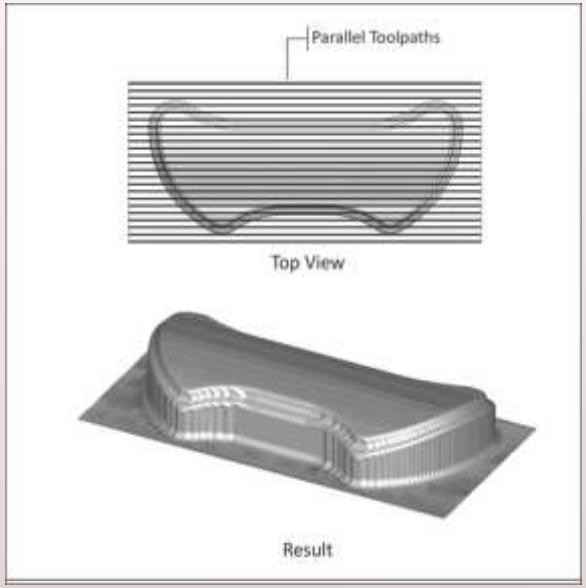
Toolpaths

3D Toolpaths



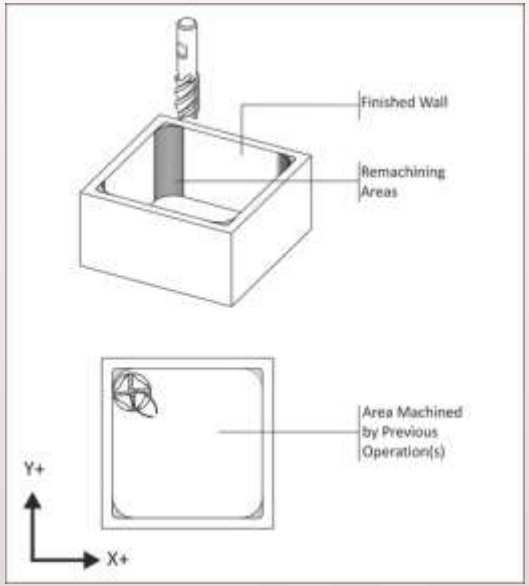
Toolpaths

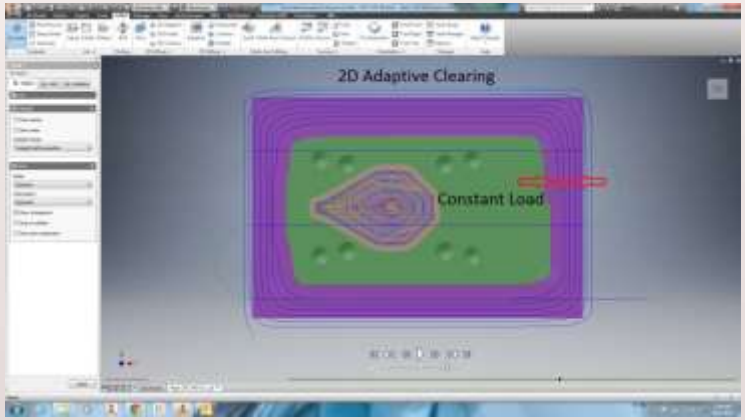
3D Toolpath: Roughing



Toolpaths

3D Toolpath: Finishing





Toolpaths

3D Toolpaths: REST and Adaptive

Key Terms Review

- CNC
- 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

CNC Overview

The CNC Shop at Pier 9

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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?

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Epilog Laser Cutter

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

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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

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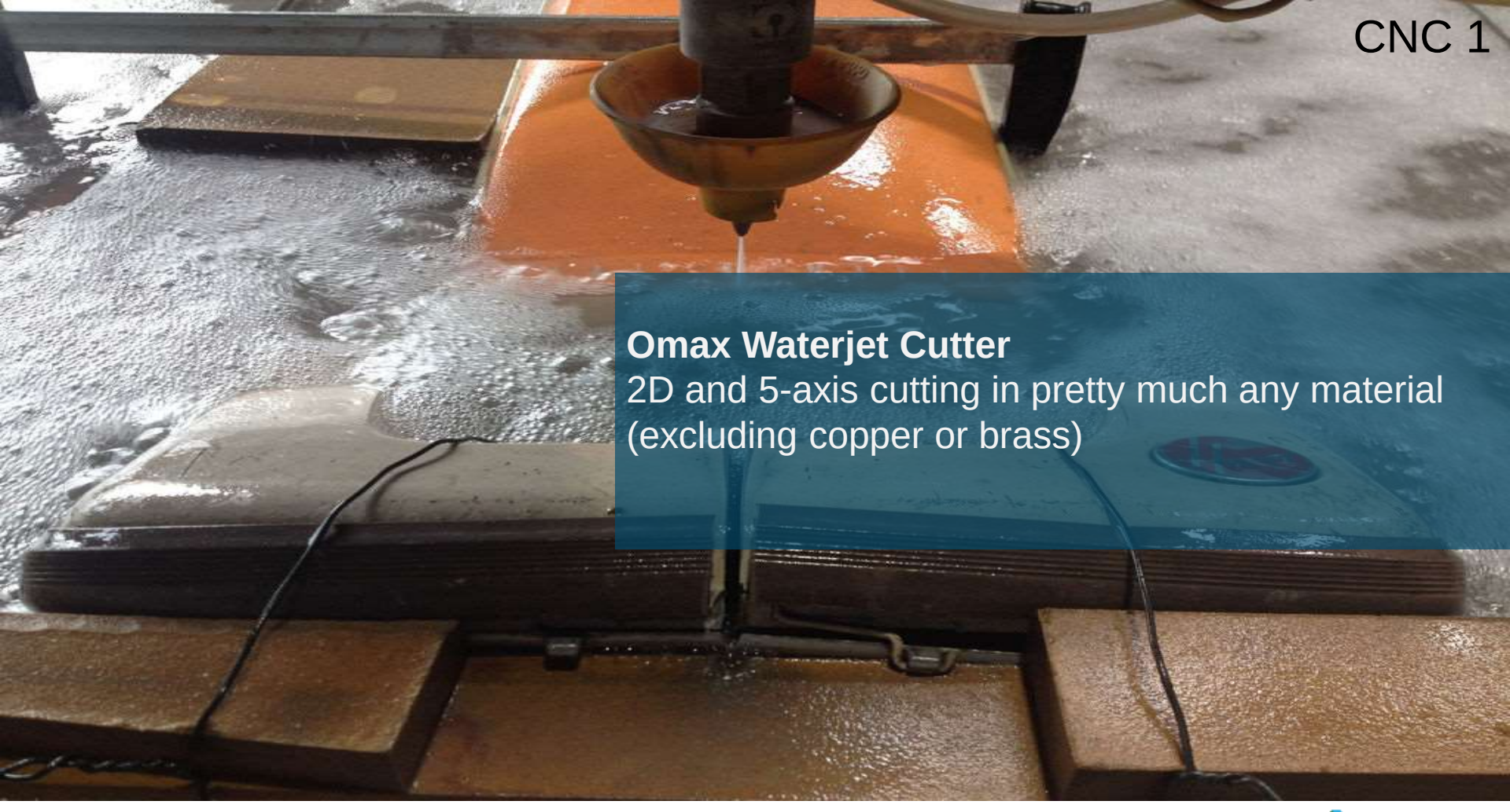
WORKFLOW for Roland Vinyl Cutter

- 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



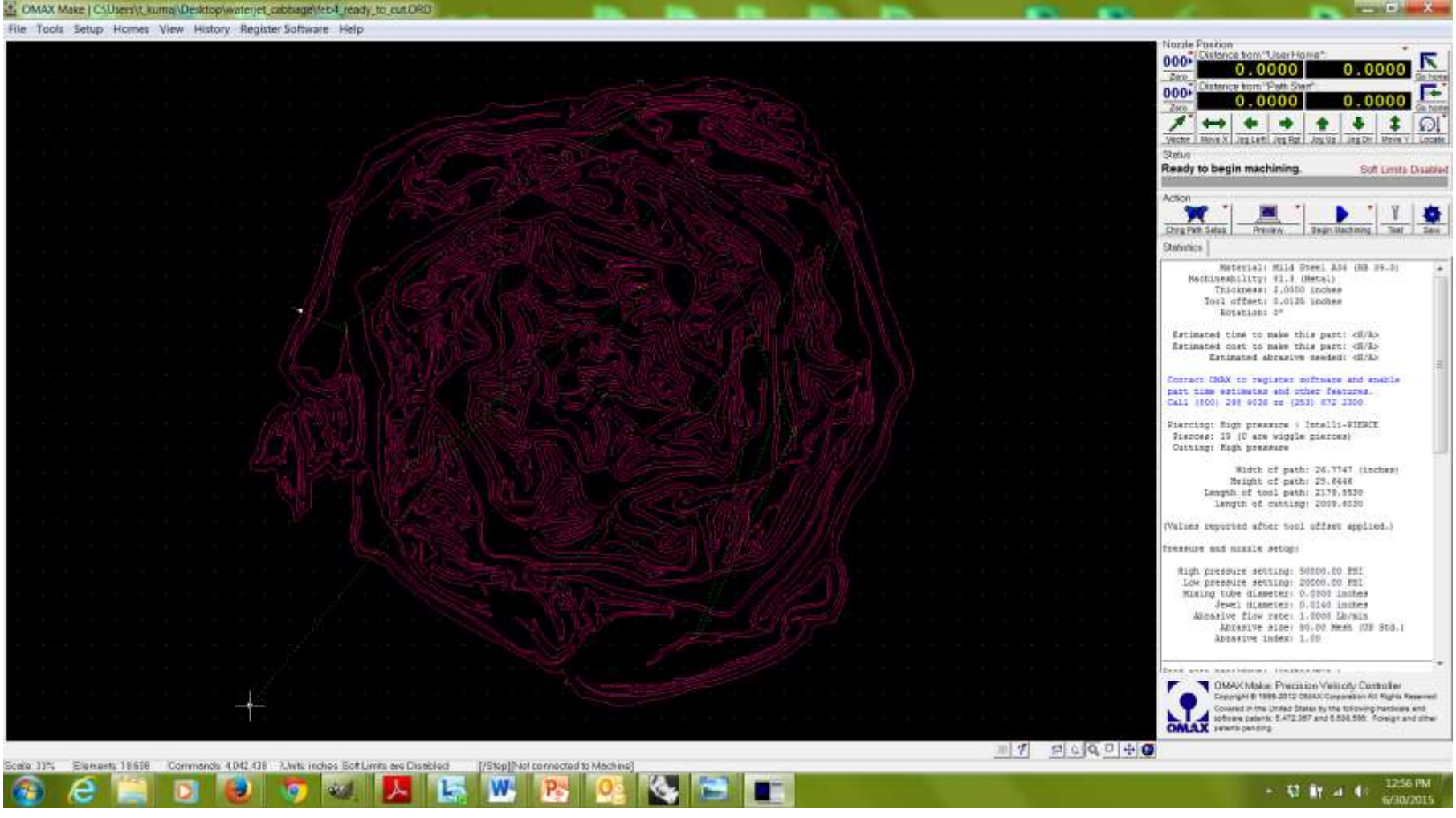
Omax Waterjet Cutter
2D and 5-axis cutting in pretty much any material (excluding copper or brass)

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

CNC 1

CNC 1



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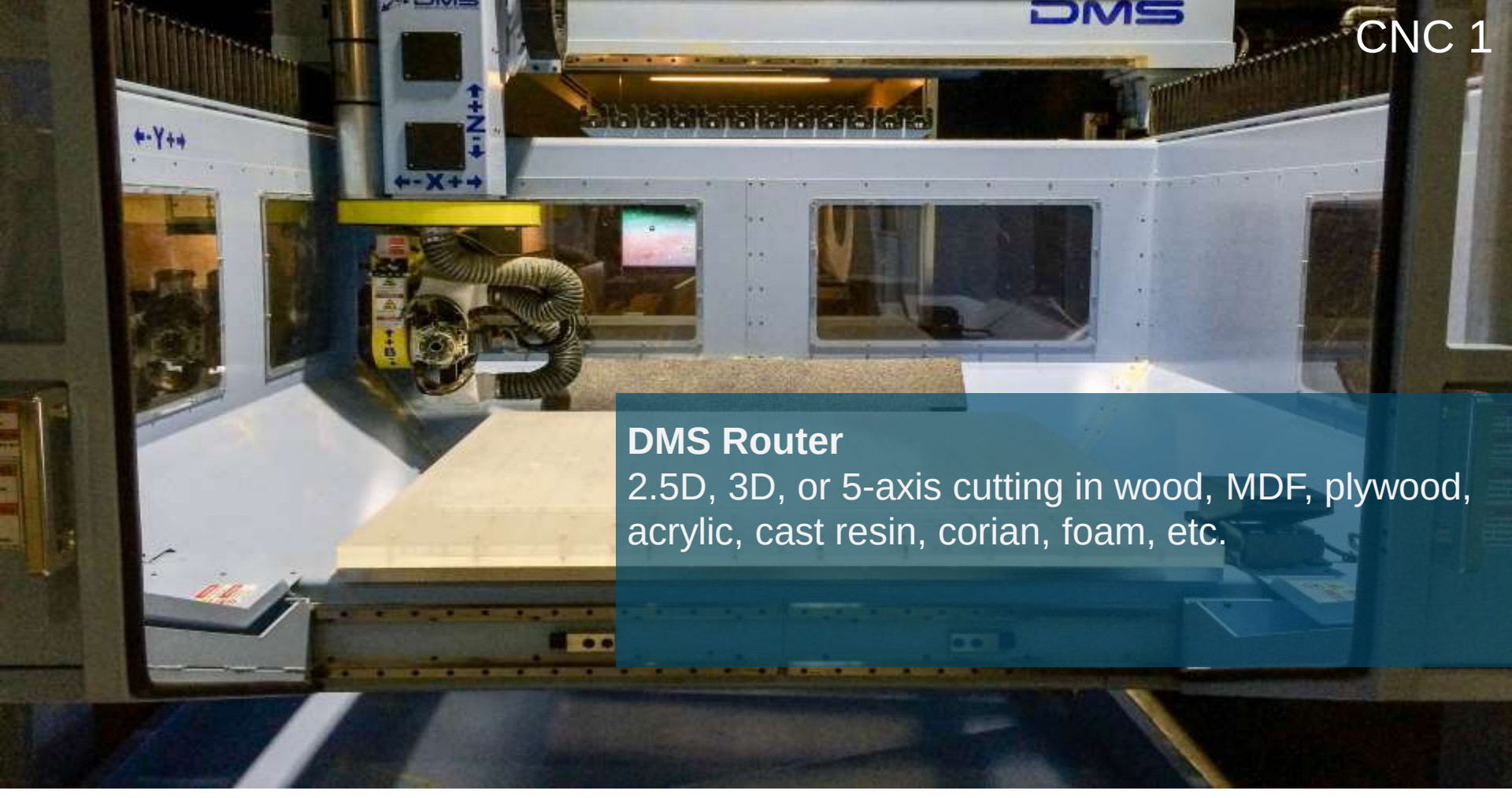
ShopBot CNC Router

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

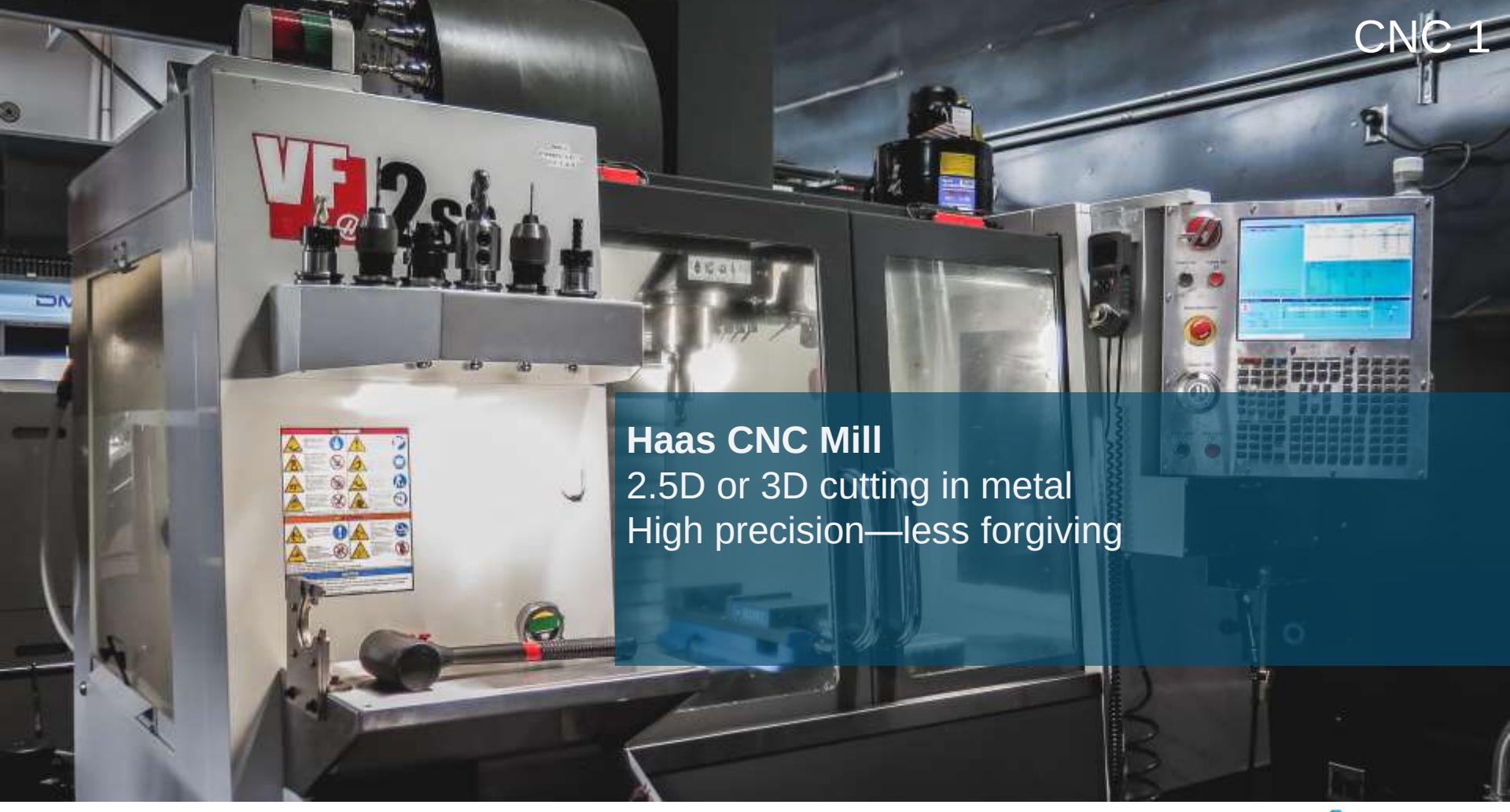


DMS Router

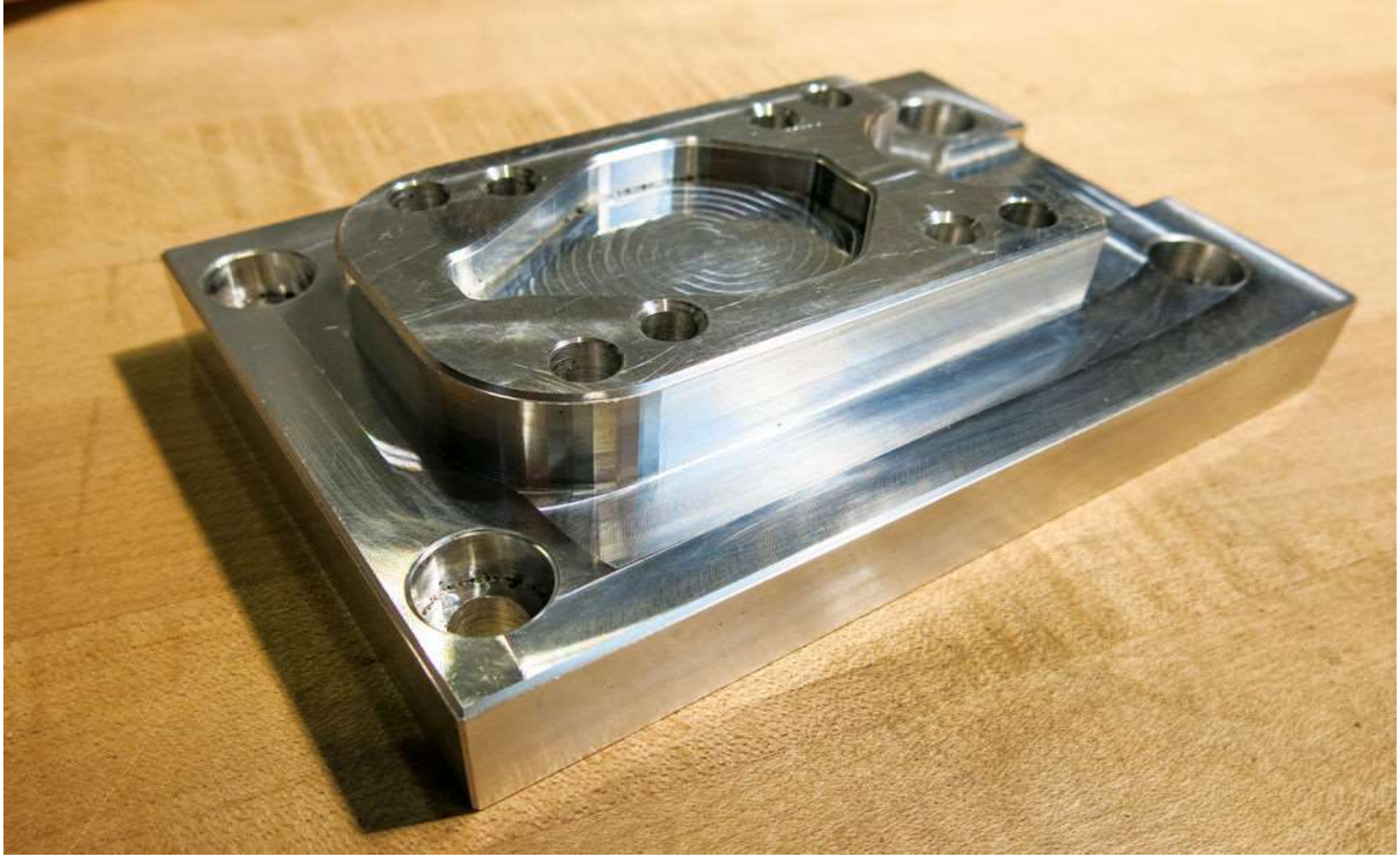
2.5D, 3D, or 5-axis cutting in wood, MDF, plywood, acrylic, cast resin, corian, foam, etc.

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

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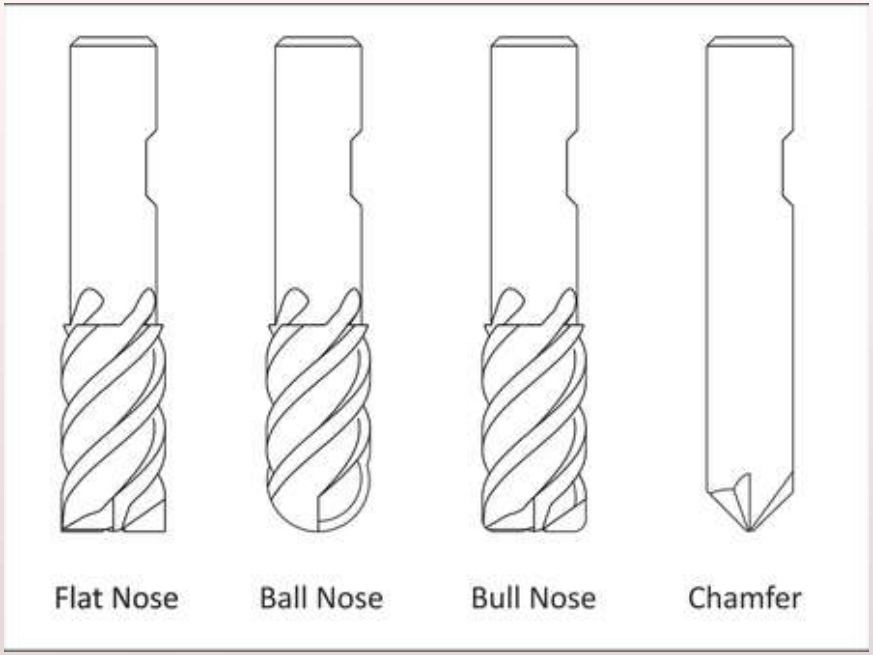
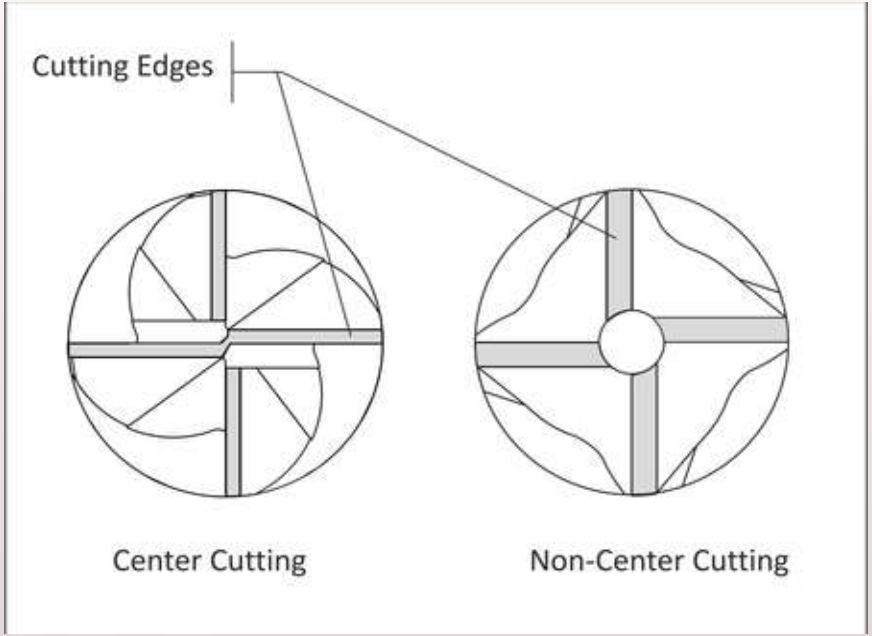


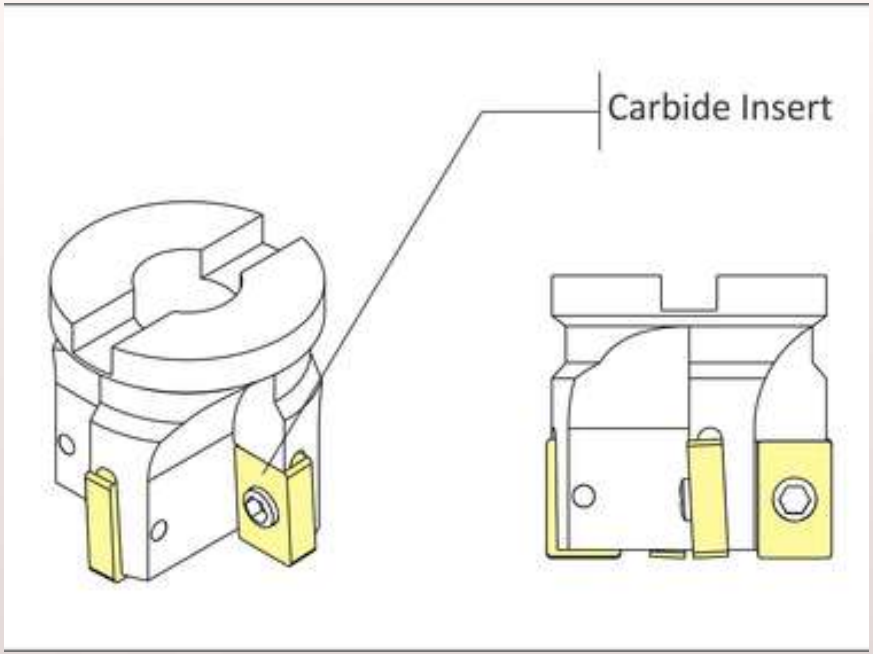
CNC Milling Tools

CNC End Mills



CNC Milling Tools

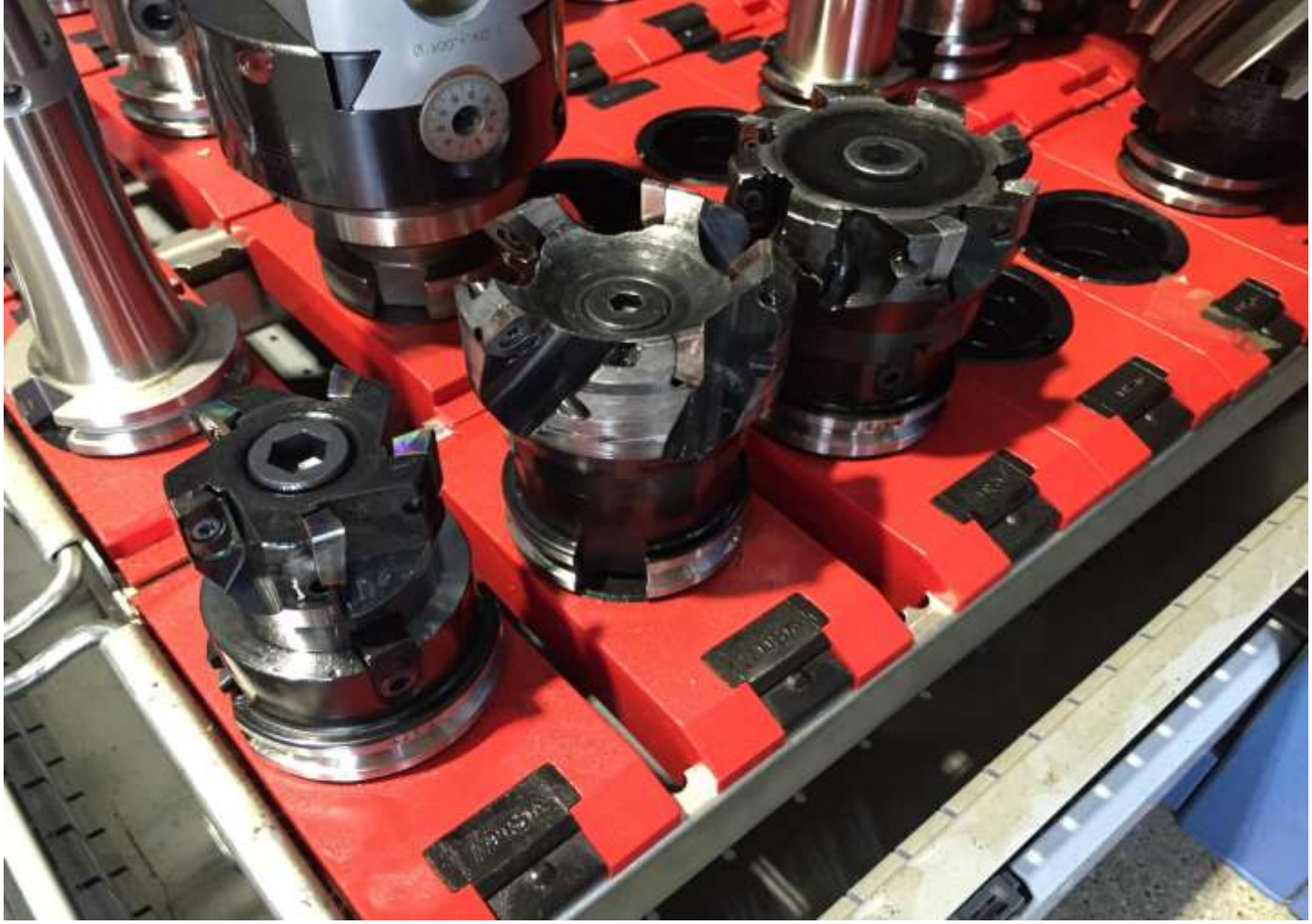
Center and Non-center Cutting End Mills



CNC Milling Tools

CNC Face Mills

CNC 1



CNC 1

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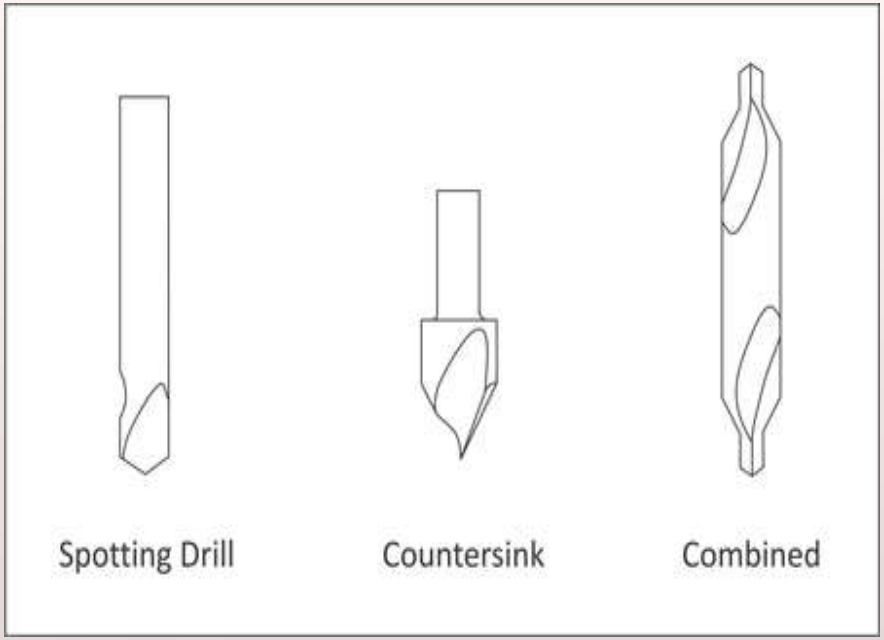
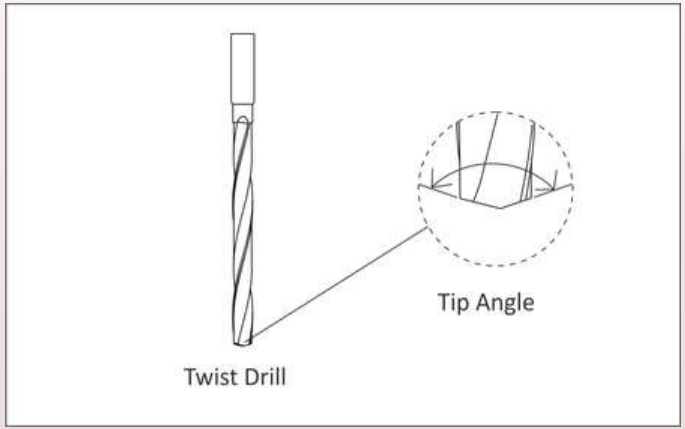


CNC Milling Tools

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 2B)

Tap Size	Cut Tap Drill		Roll Tap Drill		Minor Ø	Major Ø
0-80	3/64	.0469	1.35mm	.0531	.0465/.0514	.060
1-72	#53	.0595	1.7mm	.0669	.0580/.0635	.073
1-64	#53	.0595	1.65mm	.0650	.0561/.0623	.073
2-64	#50	.070	2.0mm	.0787	.0691/.0753	.086
2-56	#50	.070	5/64	.0781	.0667/.0737	.086
3-48	#47	.0785	#43	.089	.0764/.0845	.099
3-56	#45	.0820	2.3mm	.0906	.0797/.0865	.099
4-40	#43	.0890	#39	.0995	.0849/.0939	.112
4-48	#42	.0935	2.6mm	.1024	.0894/.0968	.112
5-40	#38	.1015	#33	.1130	.0979/.1062	.125
5-44	#37	.1040	2.9mm	.1142	.1004/.1079	.125
6-32	#36	.1065	3.1mm	.1220	.104/.114	.138
6-40	#33	.1130	3.2mm	.1260	.111/.119	.138
8-36	#29	.1360	#26	.1520	.134/.142	.164
8-32	#29	.1360	#25	.1495	.130/.139	.164
10-24	#25	.1495	11/64	.1719	.145/.156	.190
10-32	#21	.1590	#16	.1770	.156/.164	.190
12-24	#16	.1770	5.0mm	.1968	.171/.181	.216
12-28	#14	.1820	#8	.1990	.177/.186	.216
12-32	3/16	.1875	"	"	.182/.190	.216
1/4-20	#7	.2010	#1	.2280	.196/.207	.250
1/4-28	#3	.2130	A	.2340	.211/.220	.250
1/4-32	7/32	.2188	"	"	.216/.224	.250
5/16-18	F	.2570	L	.2880	.252/.265	.312
5/16-24	I	.2720	M	.2950	.267/.277	.312
5/16-32	9/32	.2813	"	"	.279/.286	.312
3/8-16	5/16	.3120	S	.3480	.307/.321	.375
3/8-24	Q	.3320	T	.3580	.330/.340	.375
3/8-32	11/32	.3438	"	"	.341/.349	.375

Tap Size	Cut Tap Drill		Roll Tap Drill		Minor Ø	Major Ø
7/16-14	U	.3680	13/32	.4062	.360/.380	.437
7/16-20	25/64	.3906	Z	.4130	.383/.395	.437
7/16-28	Y	.4040	"	"	.299/.407	.437
1/2-13	27/64	.4219	15/32	.4688	.417/.434	.500
1/2-20	29/64	.4531	12.25mm	.4823	.446/.457	.500
1/2-28	15/32	.4688	"	"	.461/.470	.500
9/16-12	31/64	.4844	17/32	.5312	.472/.490	.562
9/16-18	1/2	.500	13.5mm	.5315	.502/.515	.562
9/16-24	33/64	.5156	"	"	.517/.527	.562
5/8-11	17/32	.5313	14.75mm	.5807	.527/.546	.625
5/8-18	9/16	.5625	15.25mm	.6004	.565/.578	.625
5/8-24	37/64	.5781	"	"	.580/.590	.625
11/16-12	39/64	.6094	"	"	.597/.615	.687
11/16-24	41/64	.6406	"	"	.642/.652	.687
3/4-10	21/32	.6563	45/64	.7031	.642/.663	.750
3/4-16	11/16	.6875	23/32	.7188	.682/.696	.750
3/4-20	45/64	.7031	"	"	.696/.707	.750
13/16-12	47/64	.7344	"	"	.722/.740	.812
13/16-16	3/4	.750	"	"	.745/.759	.812
13/16-20	49/64	.7656	"	"	.758/.770	.812
7/8-9	49/64	.7656	"	"	.755/.778	.875
7/8-14	51/64	.7969	"	"	.798/.814	.875
7/8-20	53/64	.8281	"	"	.821/.832	.875
15/16-12	55/64	.8594	"	"	.847/.865	.937
15/16-16	7/8	.8750	"	"	.870/.884	.937
15/16-20	57/64	.8906	"	"	.883/.895	.937
1 - 8	7/8	.8750	"	"	.865/.890	1
1 - 12	59/64	.9219	"	"	.910/.928	1
1 - 20	61/64	.9531	"	"	.946/.957	1

CNC 1

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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

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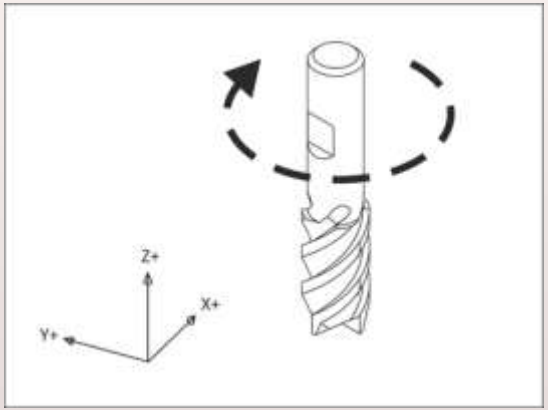
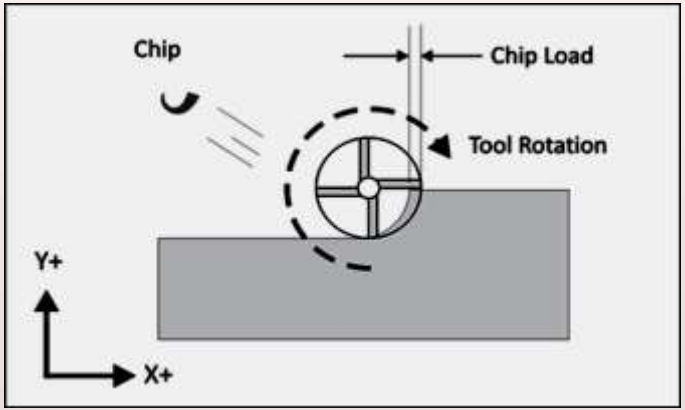
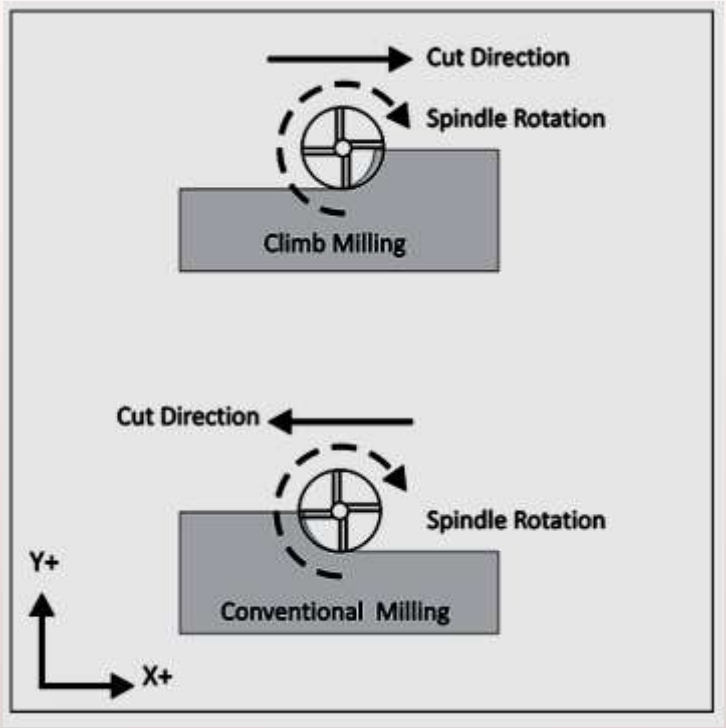




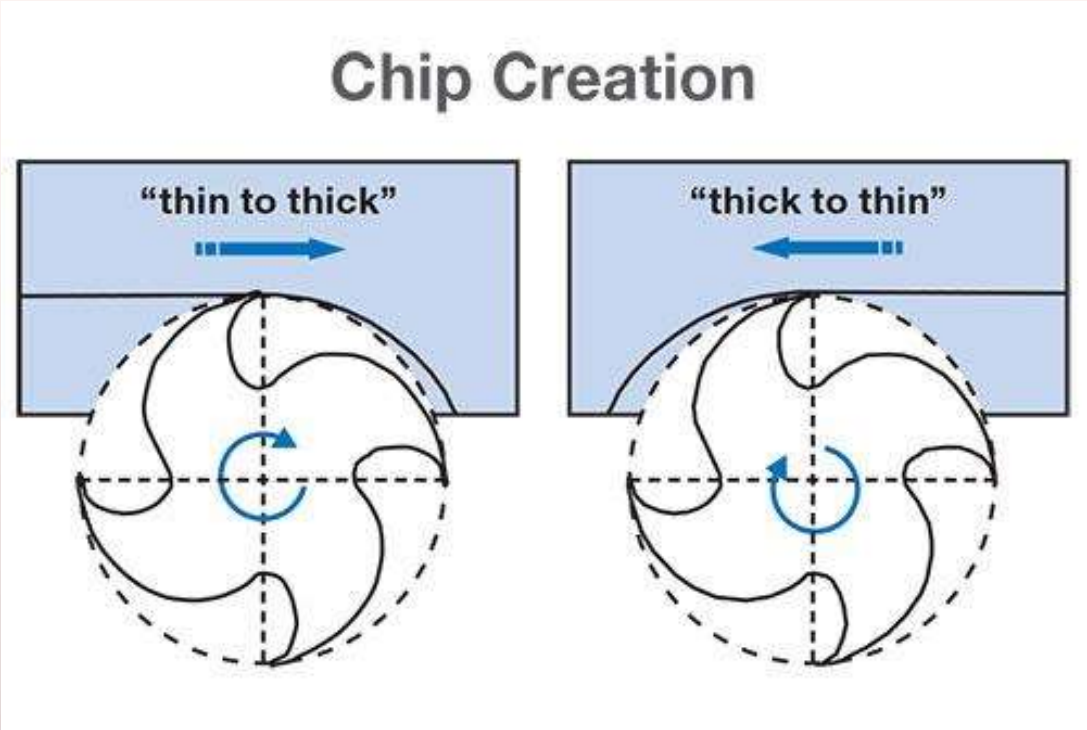
CNC Cutting Fundamentals

Rotation Direction and Chip Load



CNC Cutting Fundamentals

Climb versus Conventional Milling



CNC Cutting Fundamentals

Climb versus Conventional Milling

CNC Overview

Feeds and Speeds

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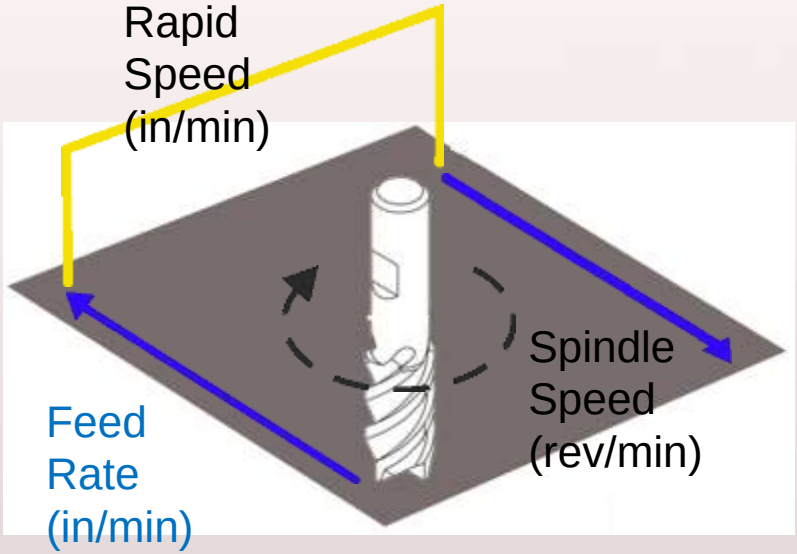

Feeds and Speeds

Spindle Speed and Feed Rate

CNC 1

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CNC 1

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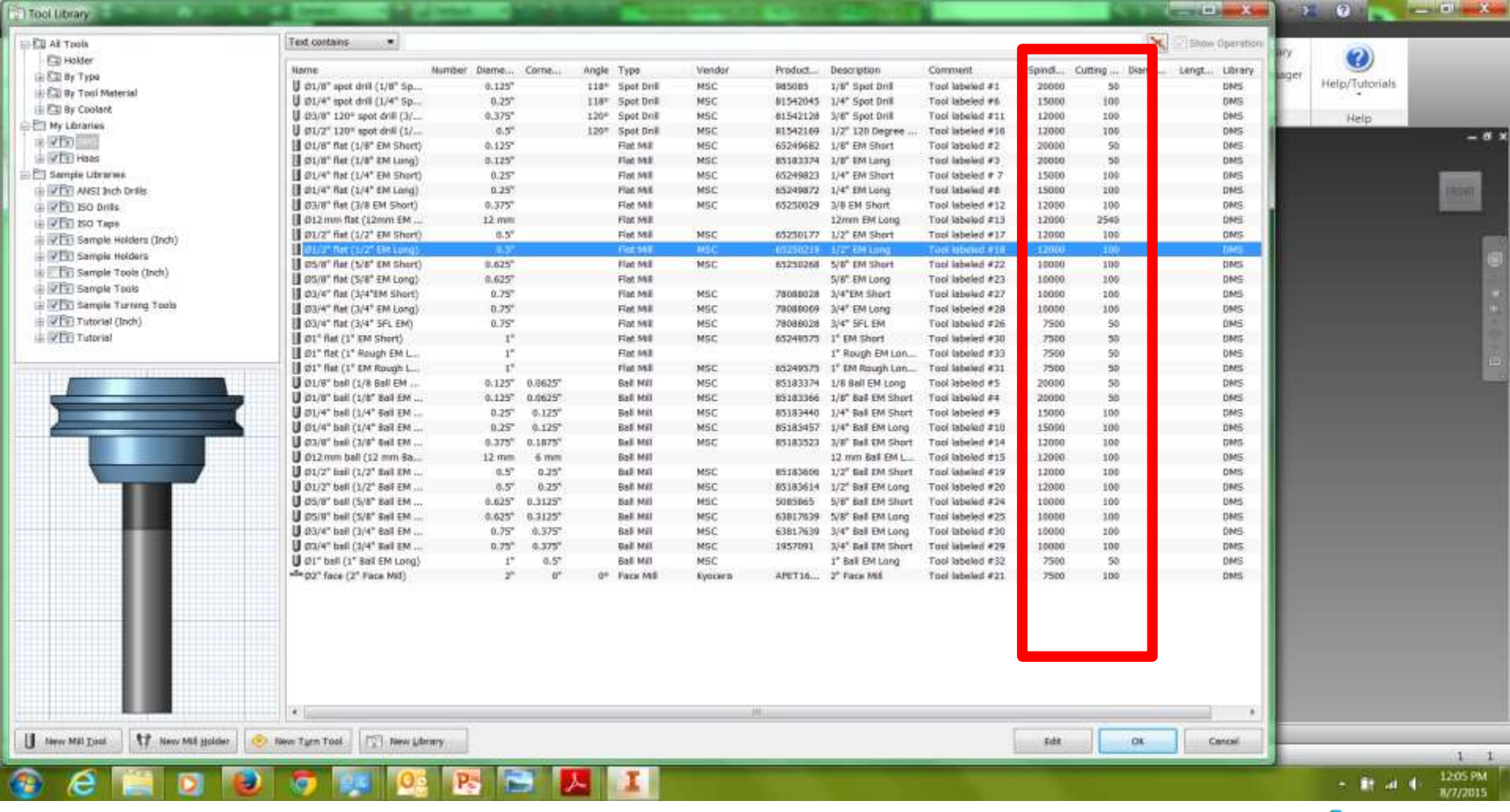

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$$Speed\left(\frac{rev}{min}\right) = \frac{SFM\left(\frac{ft}{min}\right) \times 3.82}{Dia(in)}$$

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

Feeds and Speeds

Formulas: Spindle Speed and Feed Rate

CNC Overview

Coordinate System

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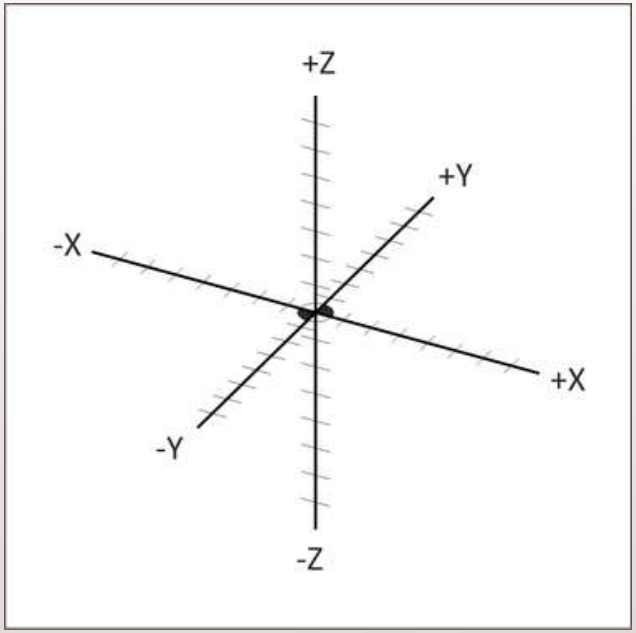
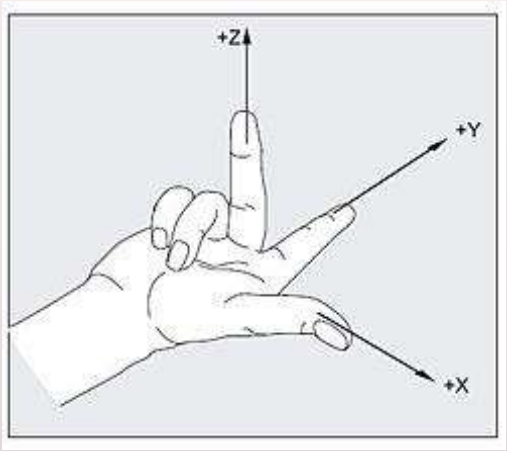
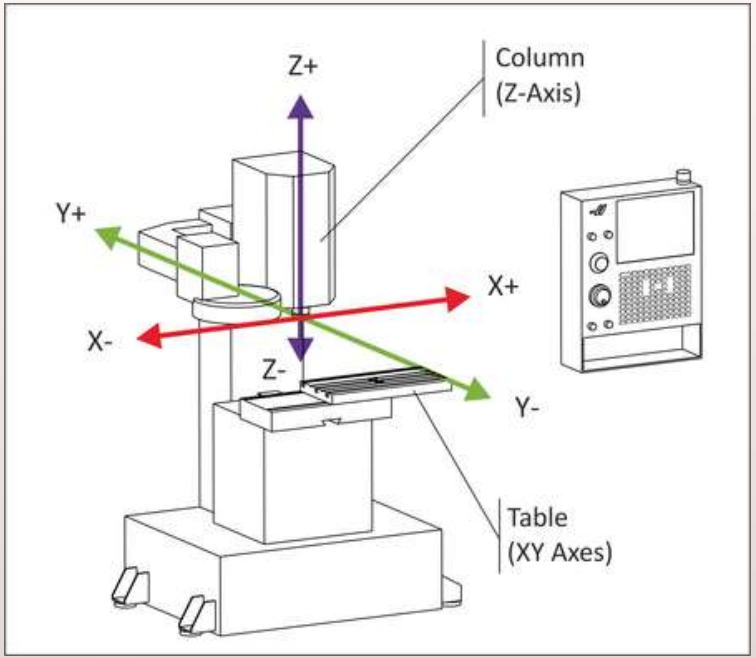




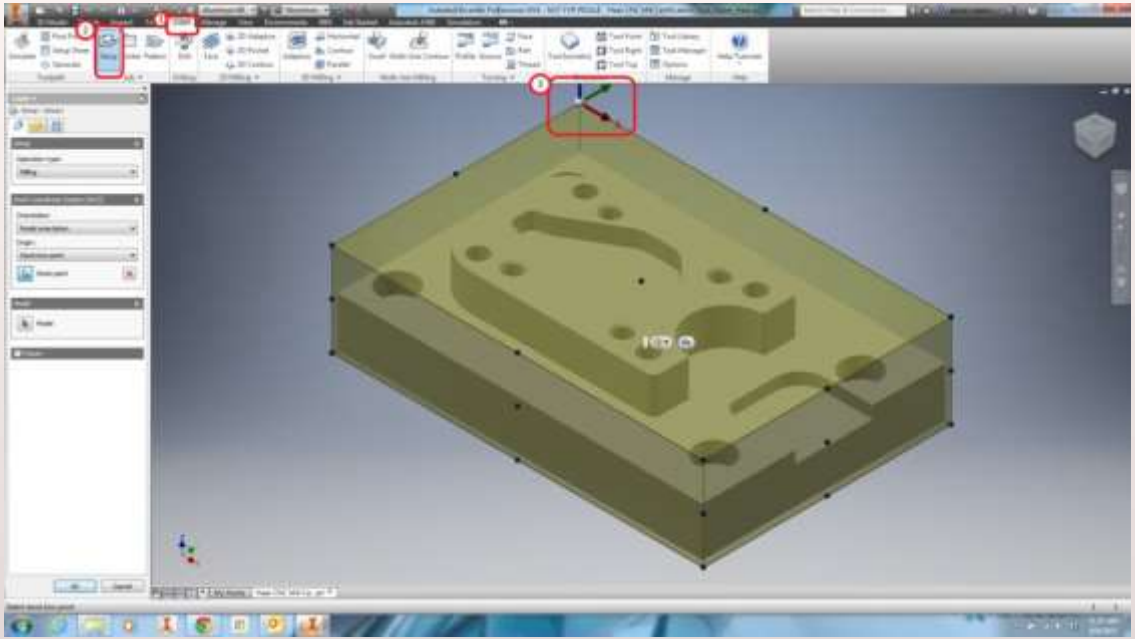
Coordinate System

Cartesian Coordinates and Right Hand Rule



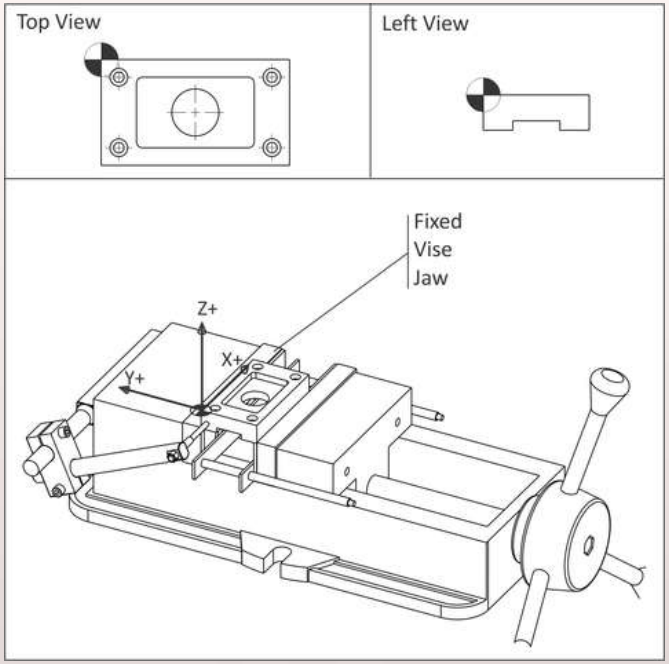
Coordinate System

Machine Coordinate System



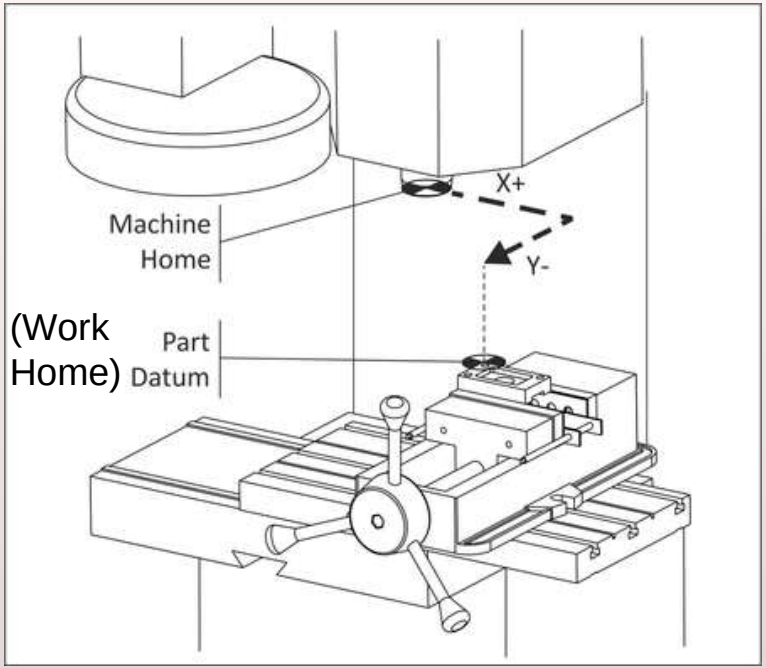
Coordinate System

Work Coordinate System



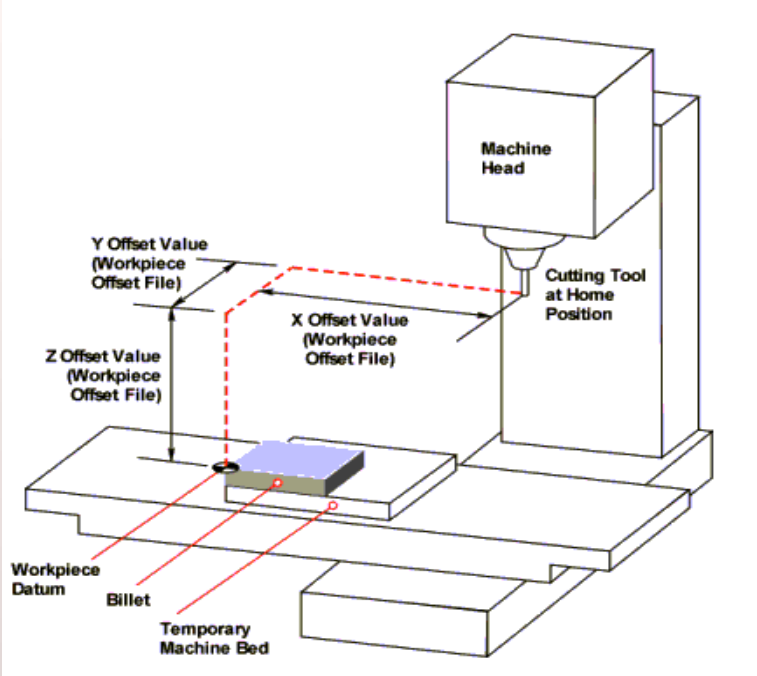
Coordinate System

Work Coordinate System



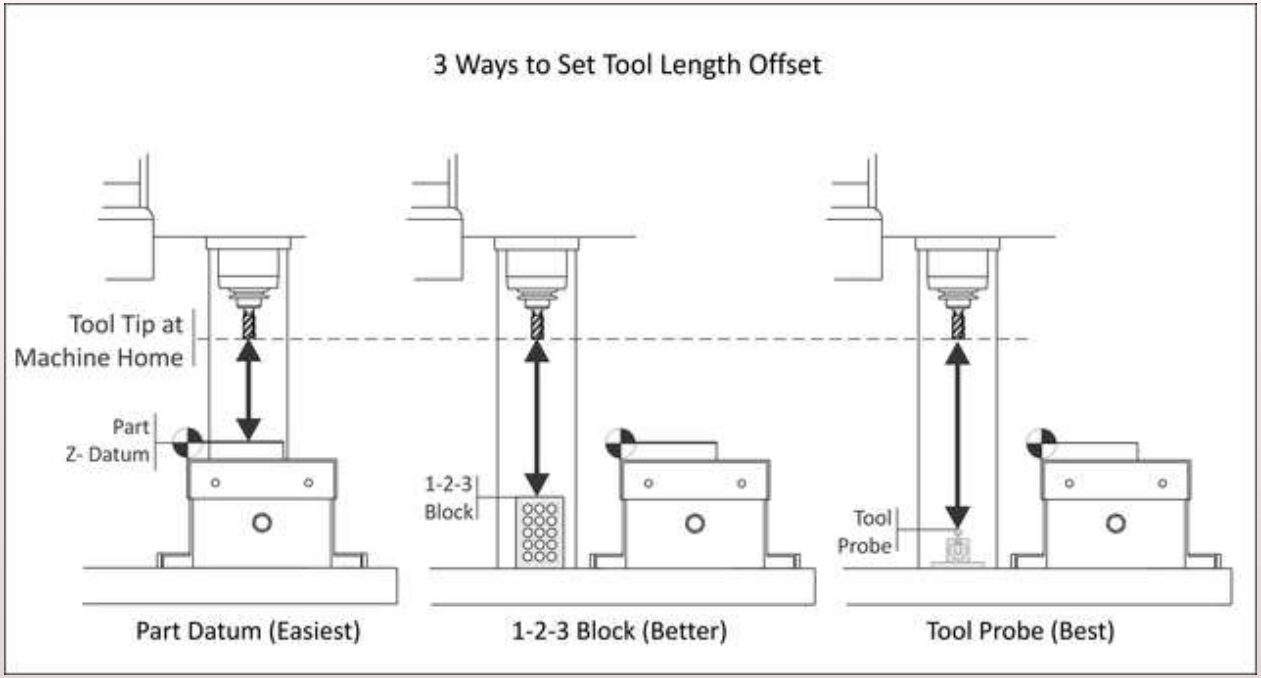
Coordinate System

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
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- Undercuts
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- 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

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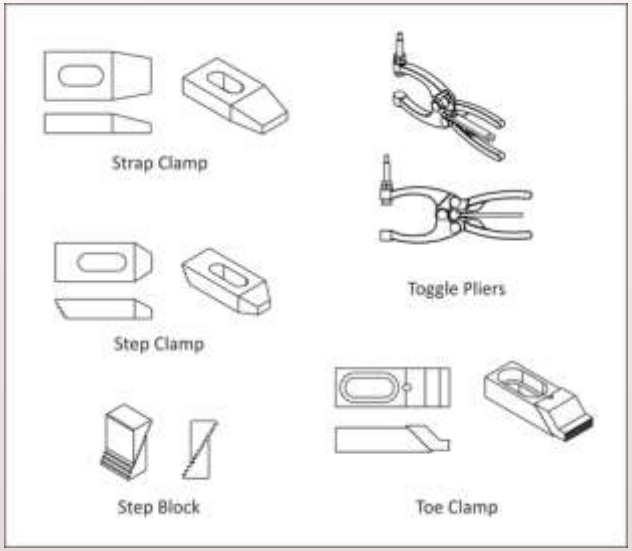
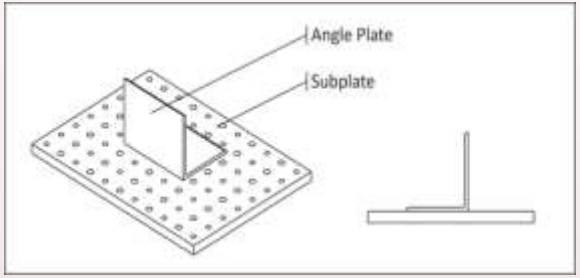
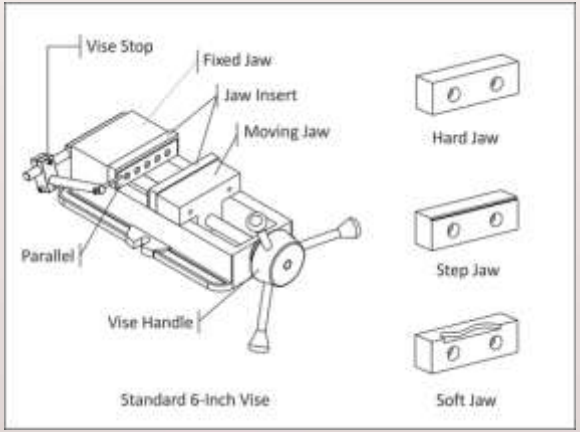


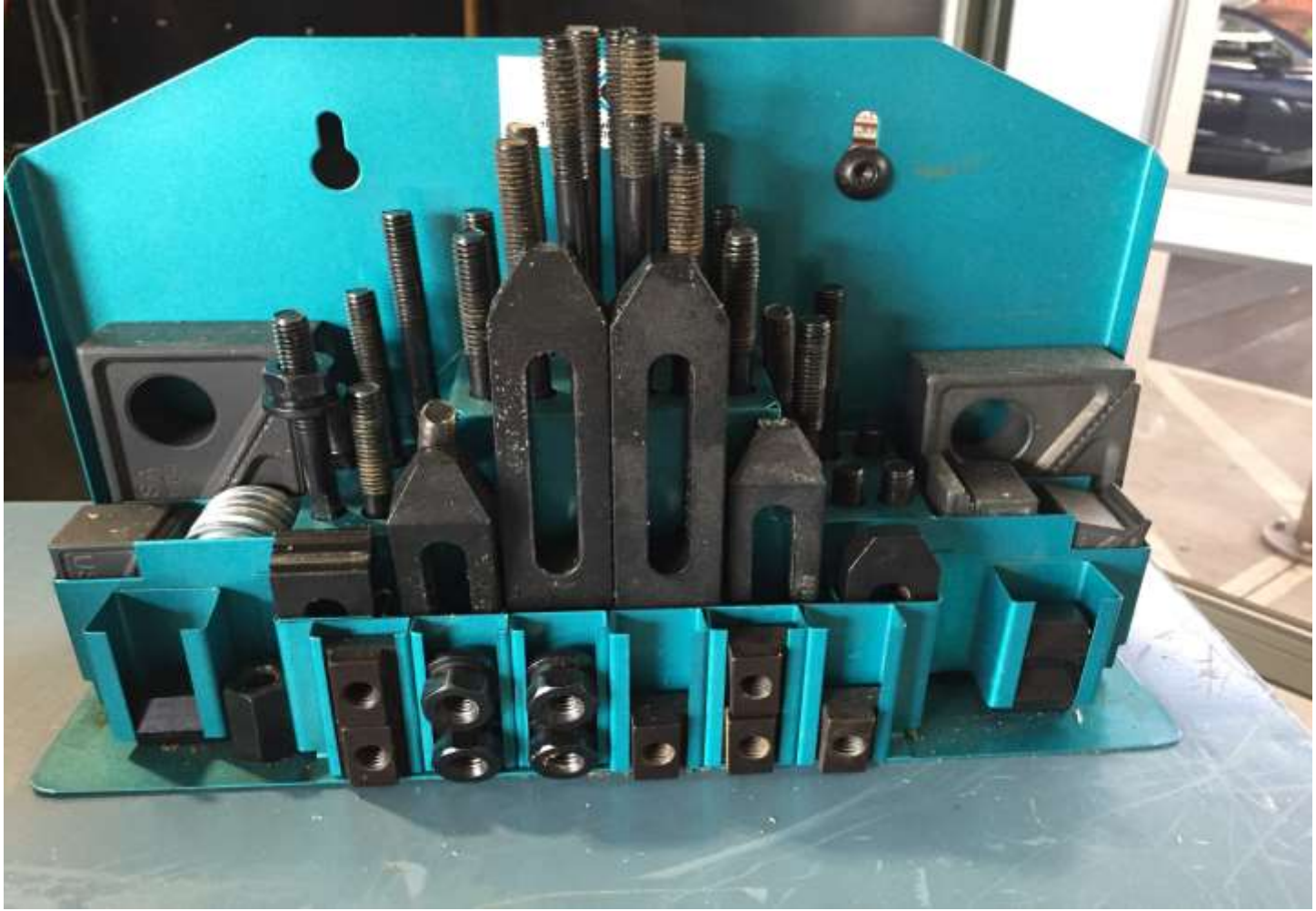




Fixturing

Clamps, Subplates, and Vices

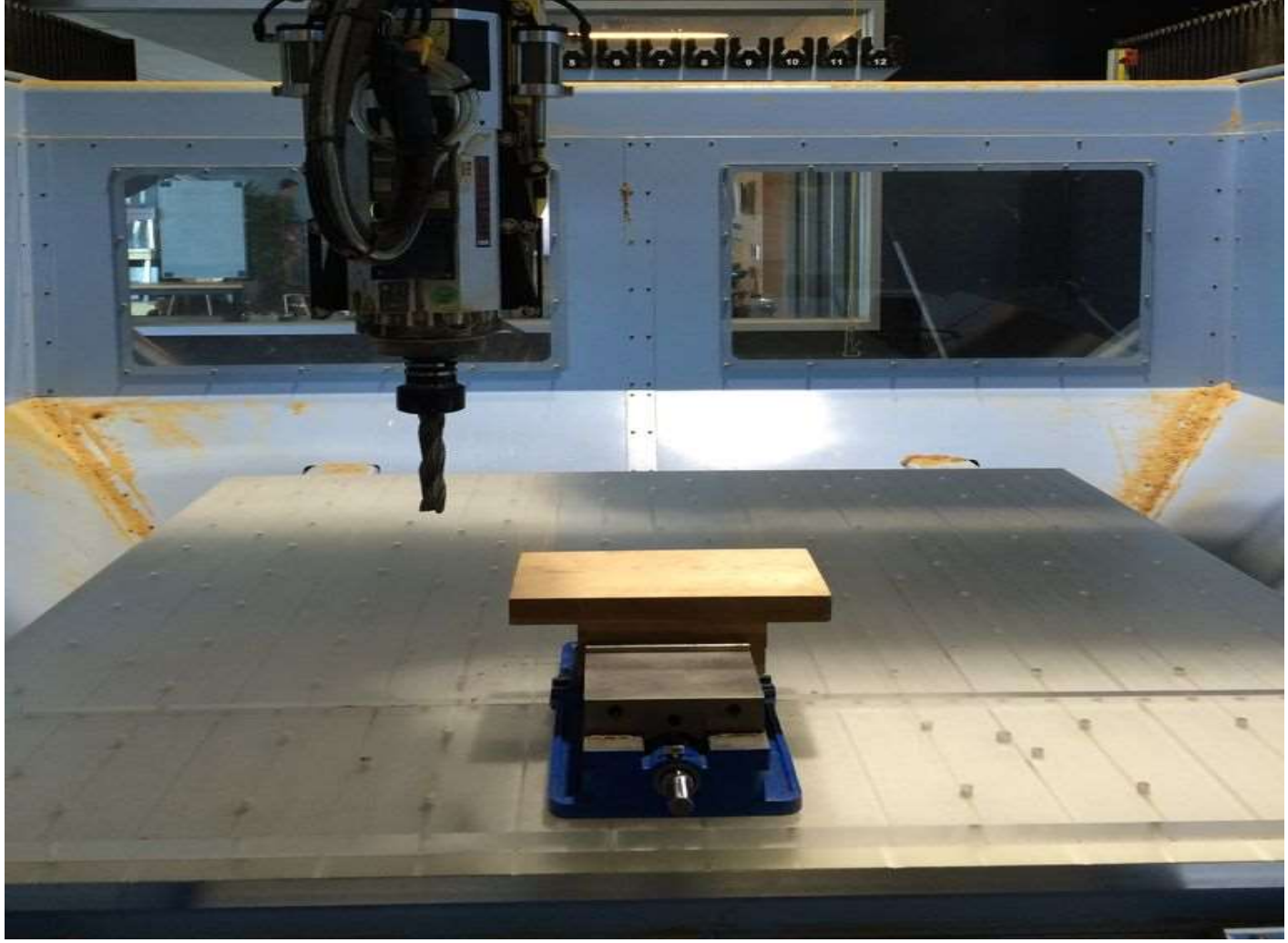
CNC 1



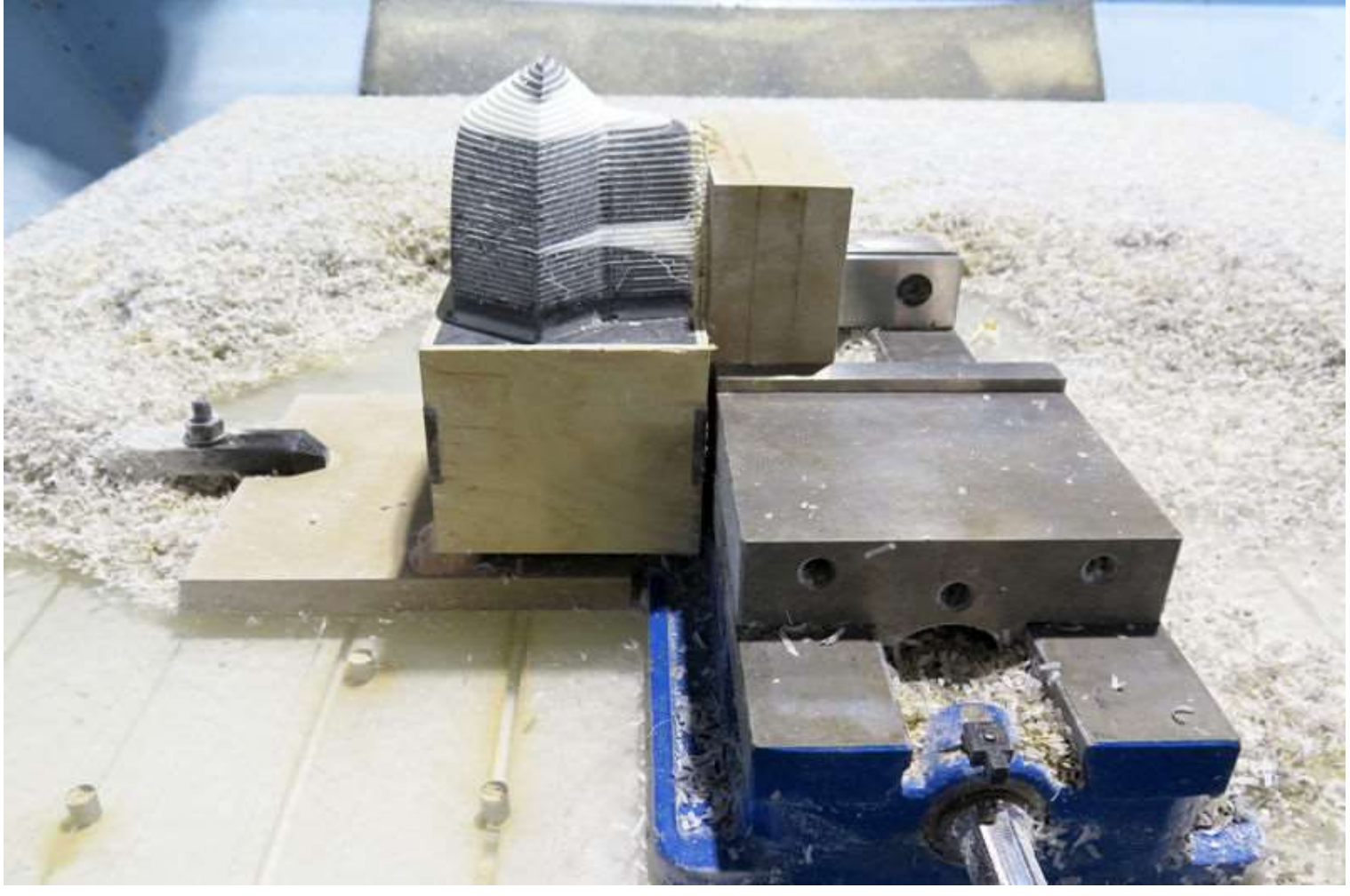
CNC 1

AUTODESK.

CNC 1



CNC 1



CNC 1

CNC 1

CNC 1

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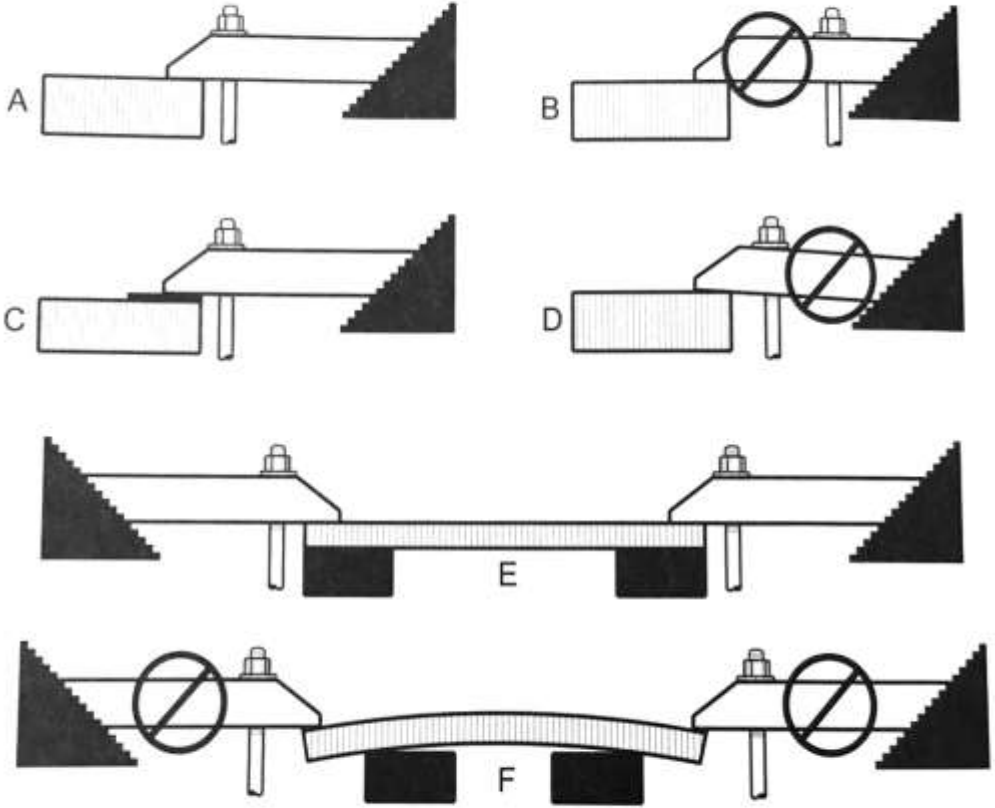

Figure 8–40. Correct (A, C & E) and incorrect ways (B, D & F) to use table clamps.

Marlow, Frank. Machine Shop Essentials: Questions and Answers

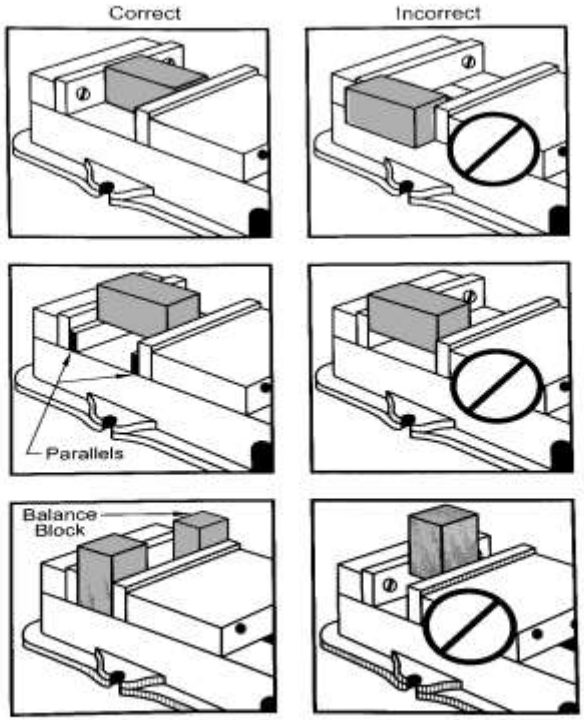

Figure 8–44. Correct and incorrect ways of clamping work in a milling vise.

CNC 1

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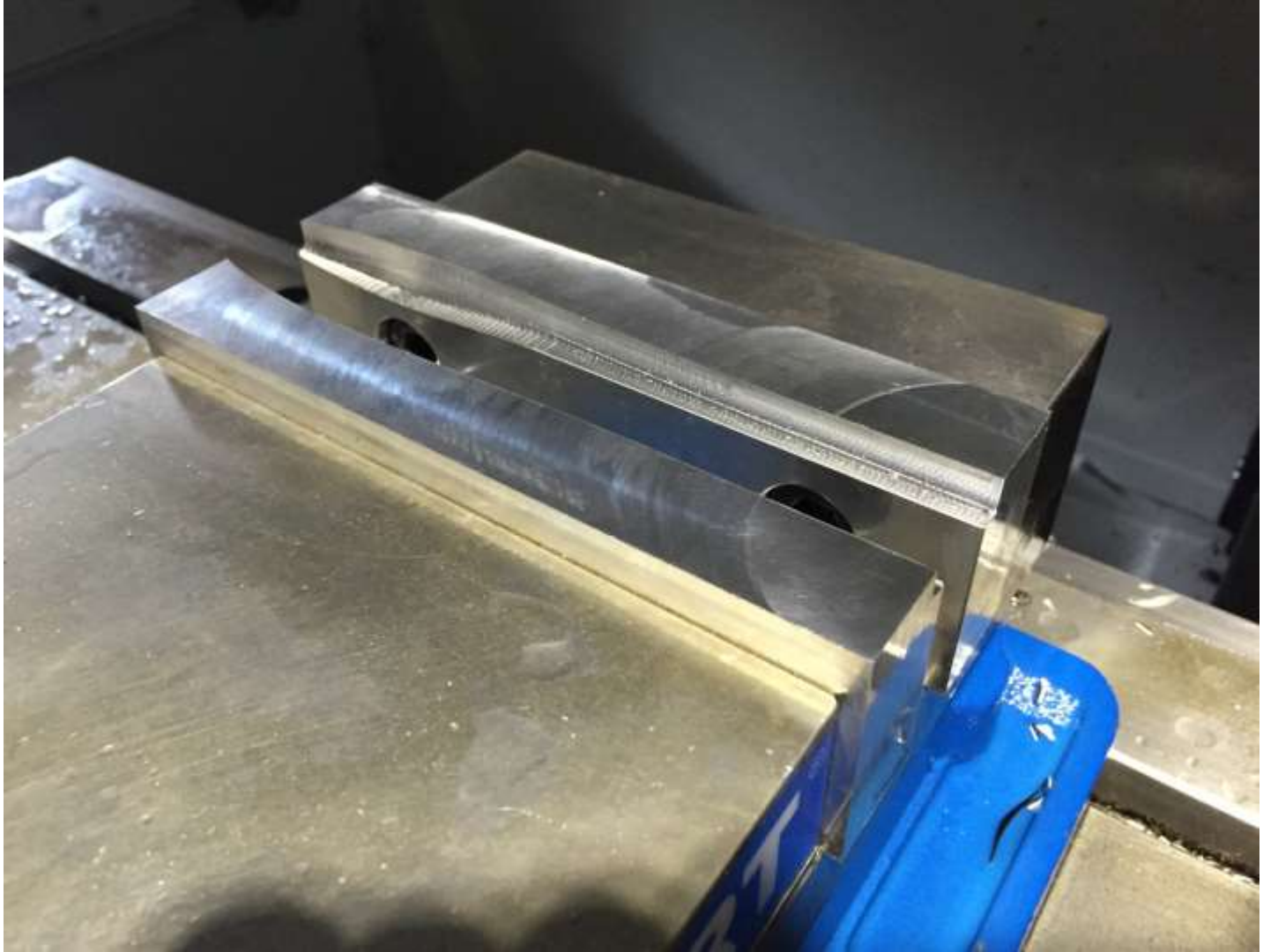
CNC 1



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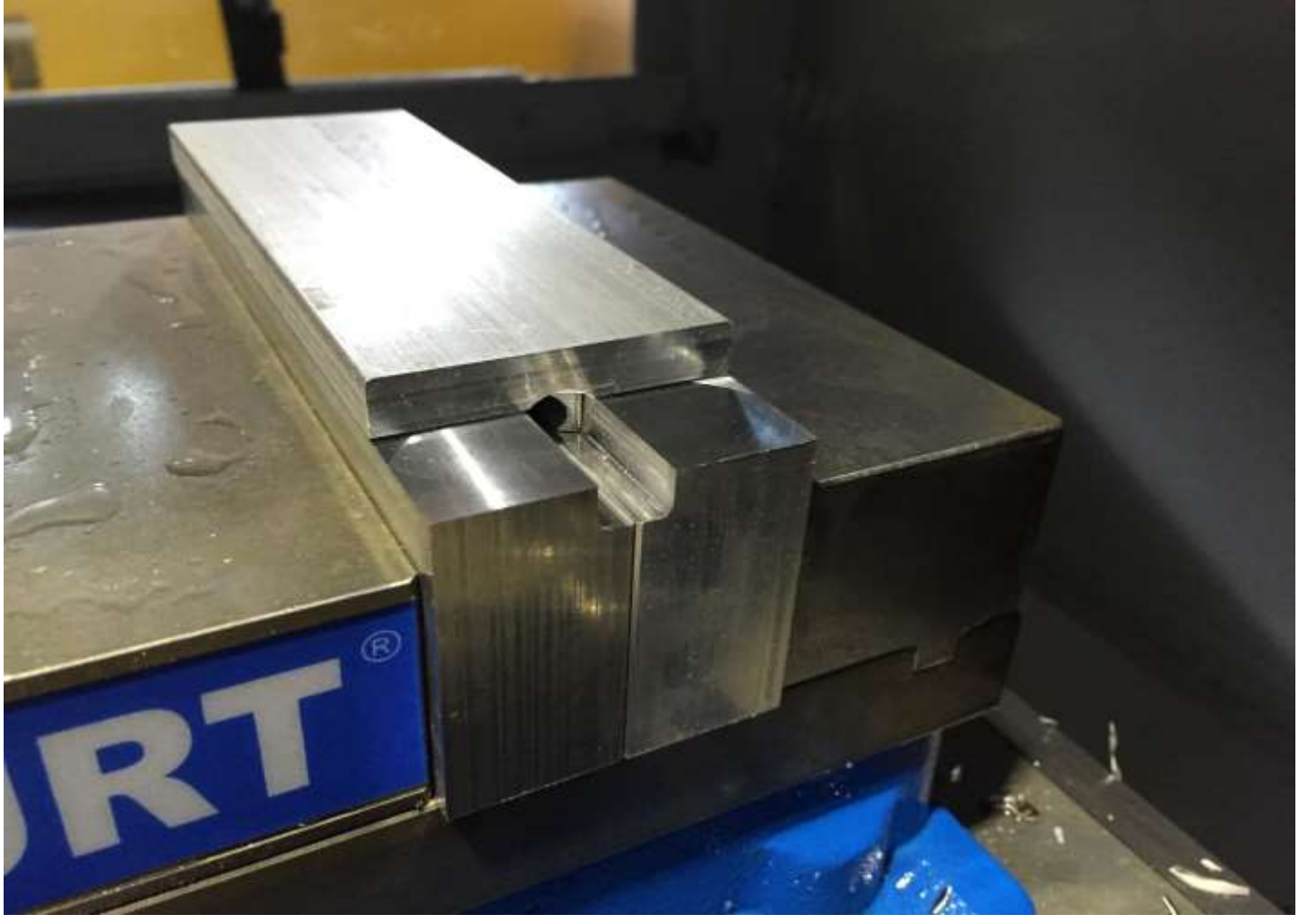
CNC 1

CNC 1



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CNC 1

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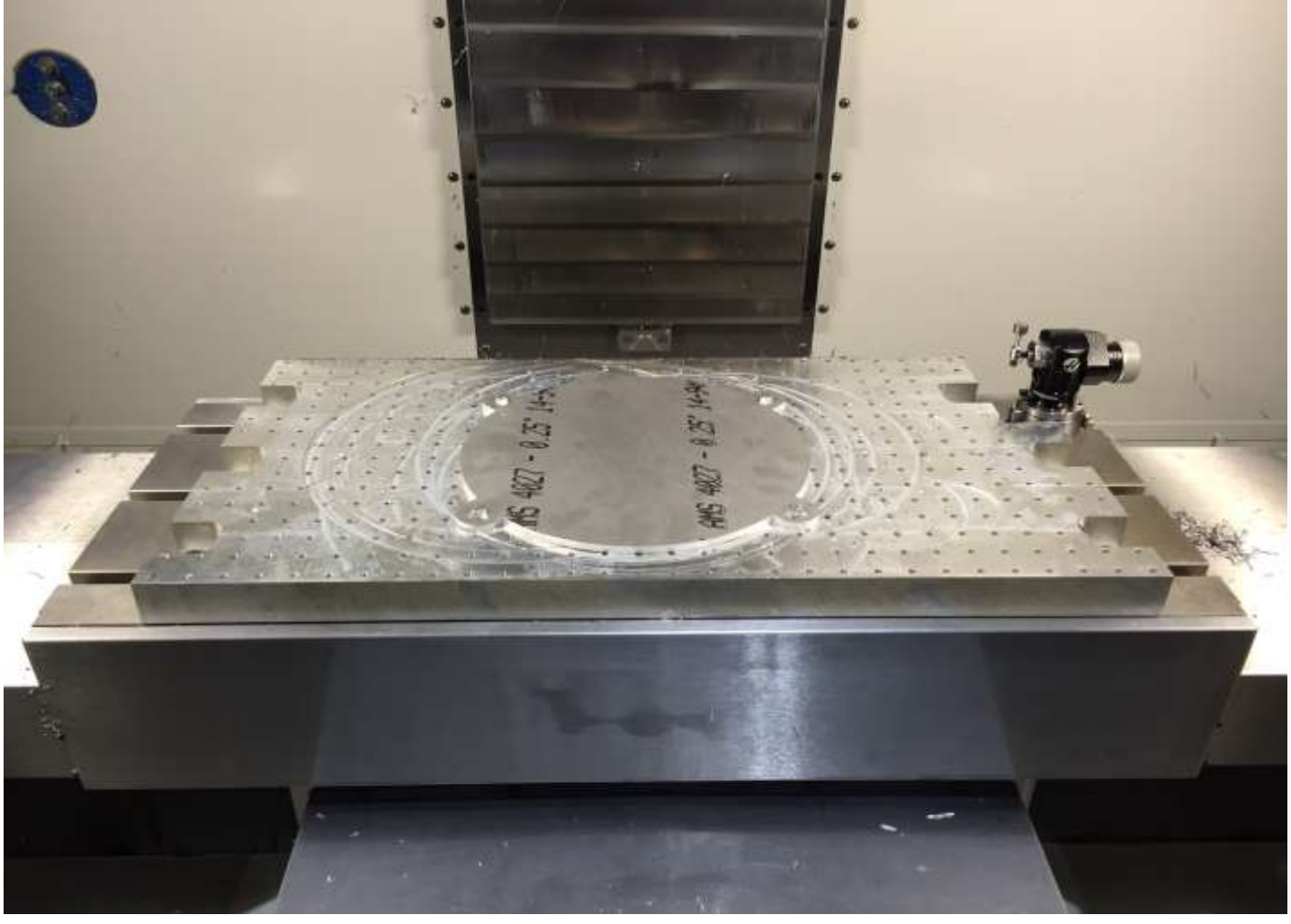
CNC 1



Overview: CNC Operation

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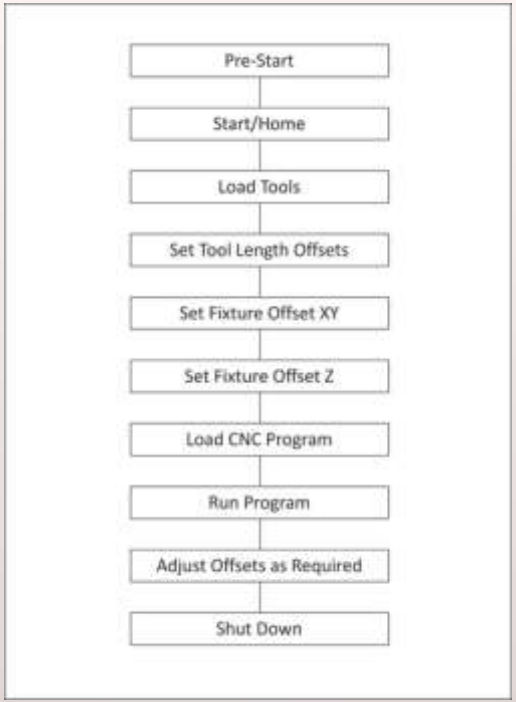

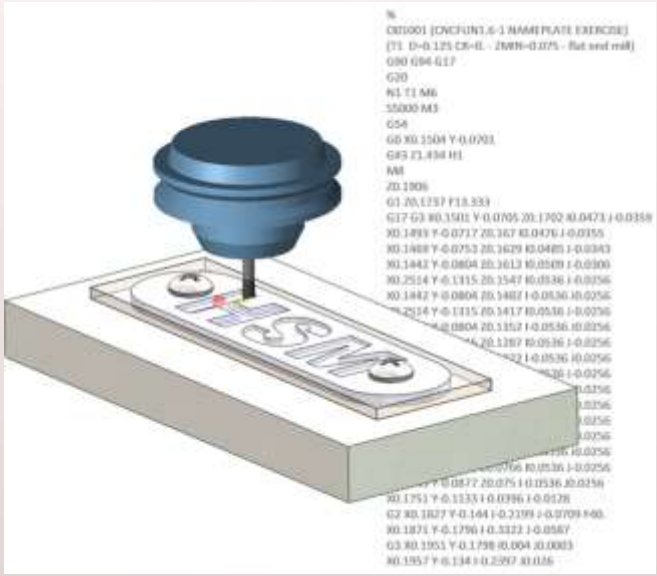

CNC Operation

CNC Learning

Starter/Intermediate/Advanced Projects…

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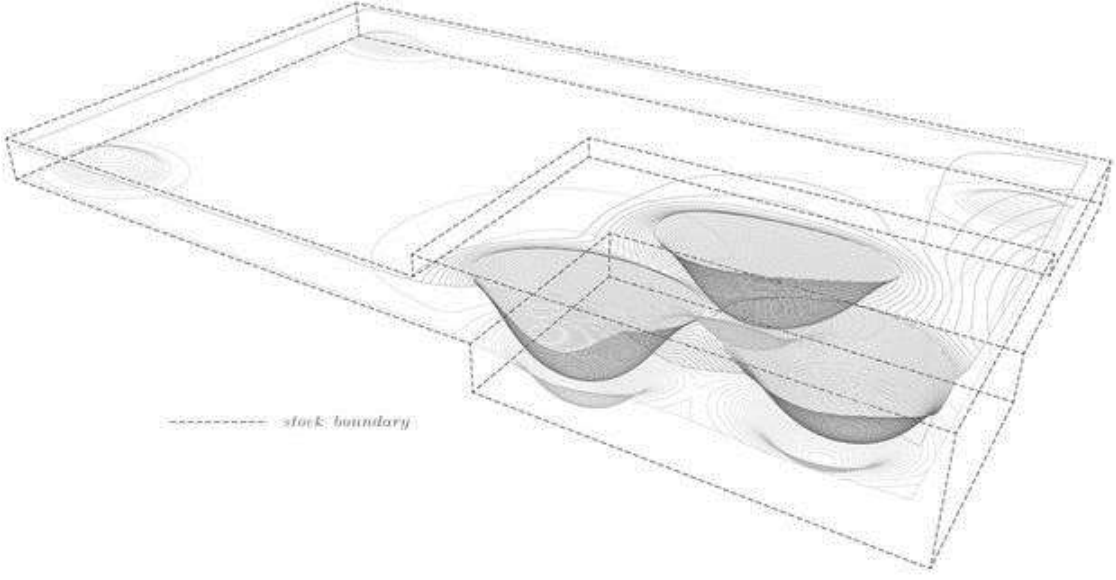
CNC 1

CNC 1

AUTODESK.

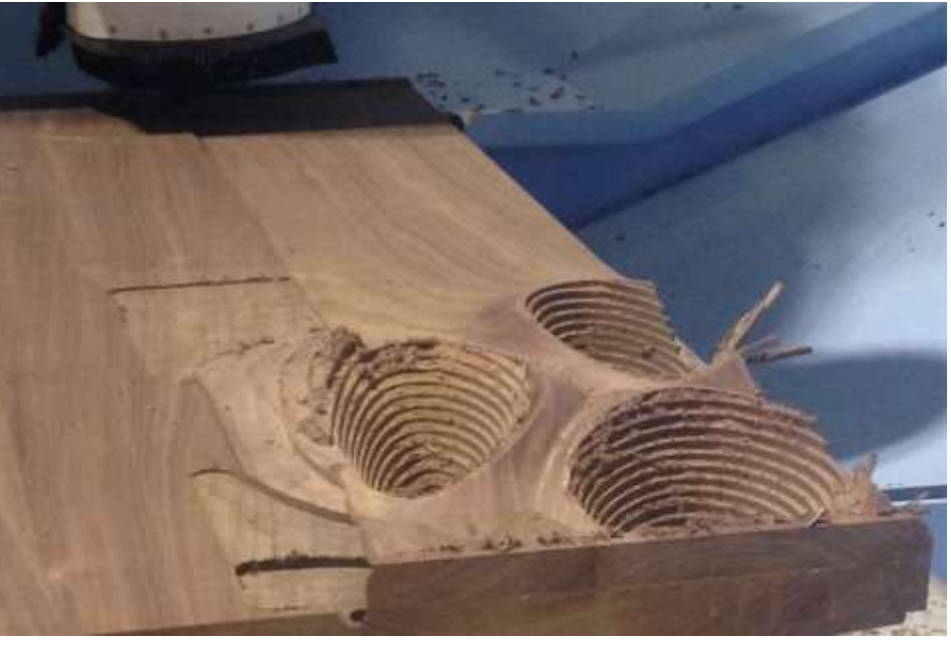
CNC 1

CNC 1



AUTODESK.

CNC 1



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CNC 1

Considerations during CAD phase

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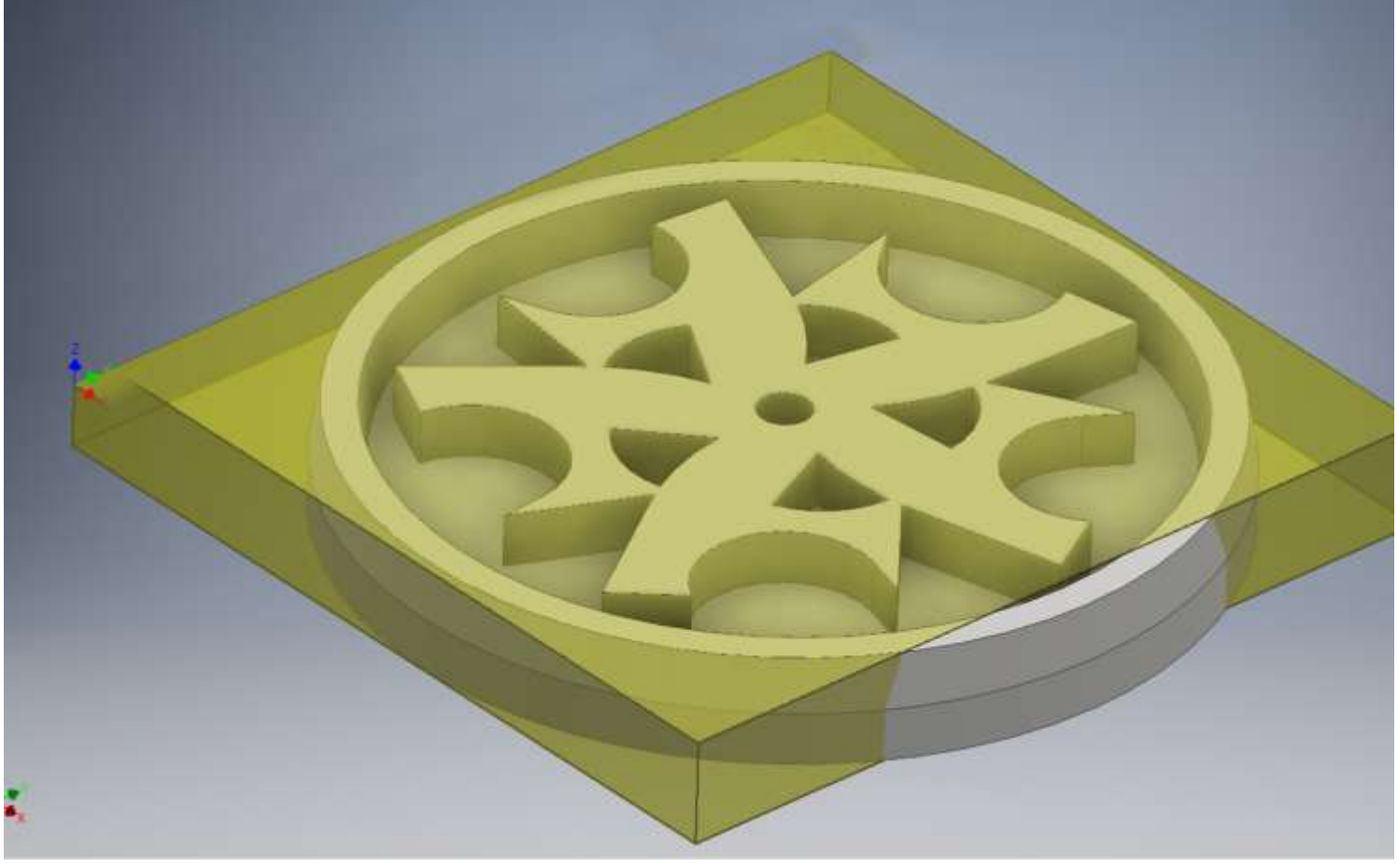
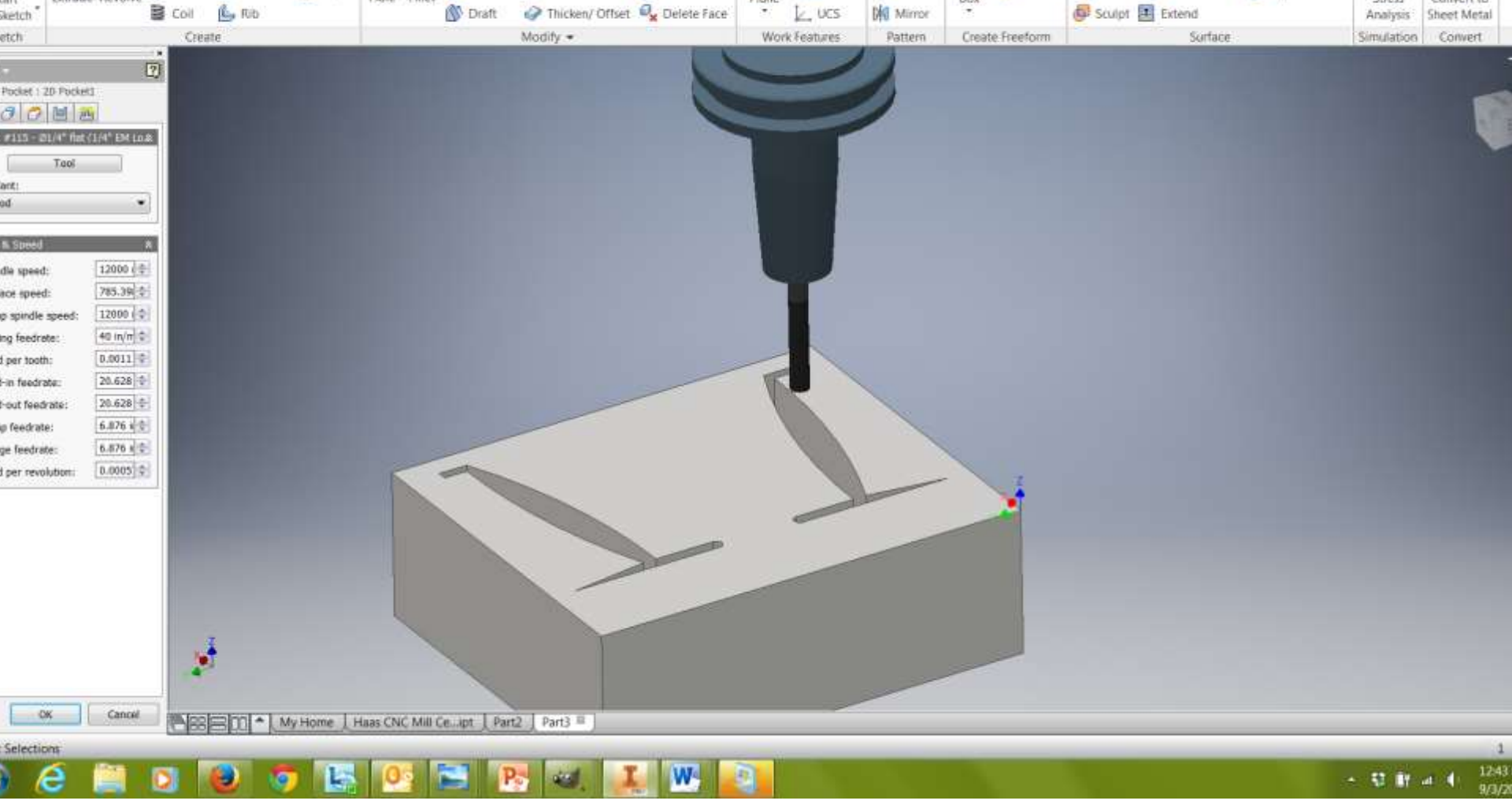
CNC 1





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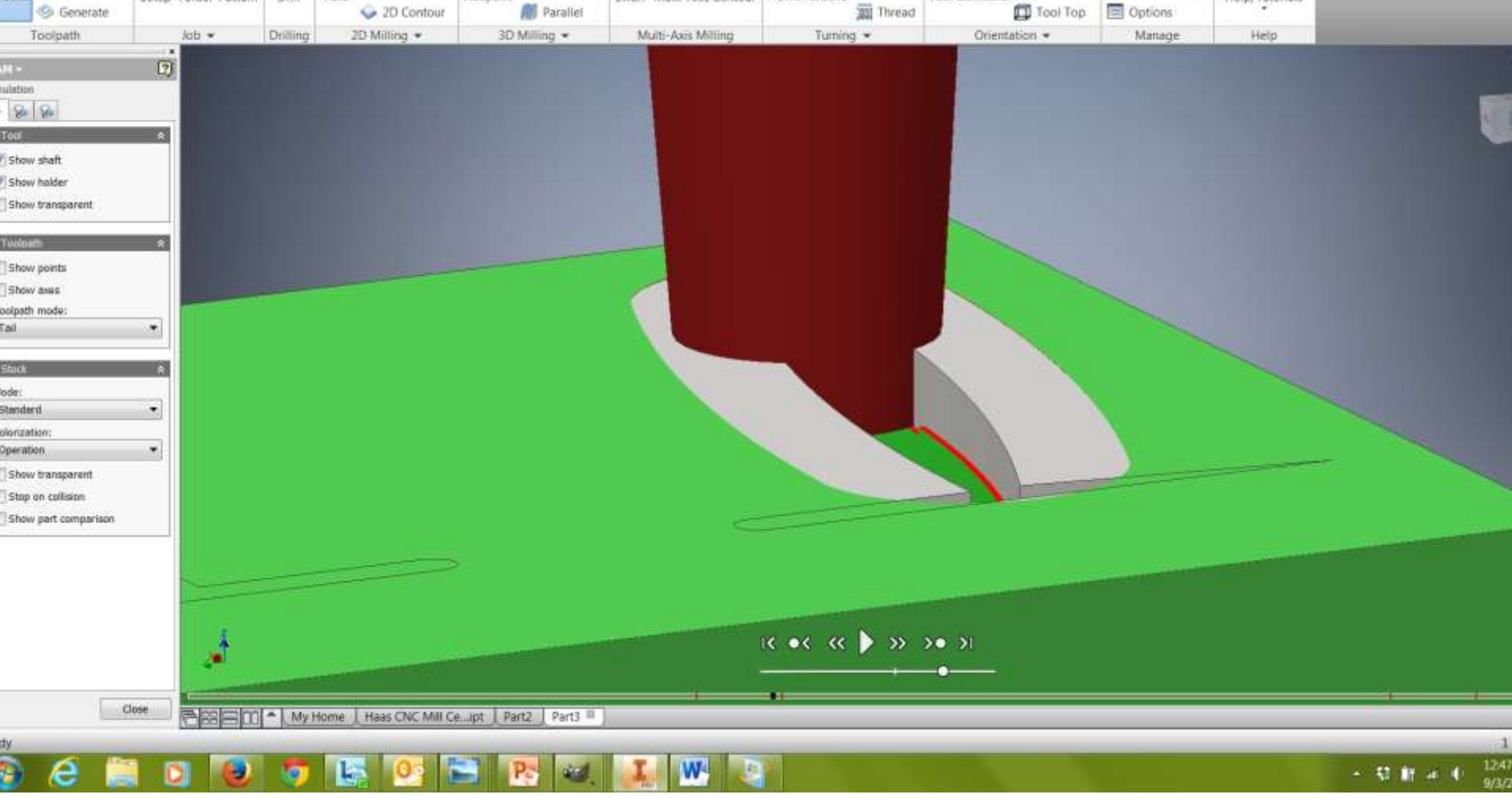

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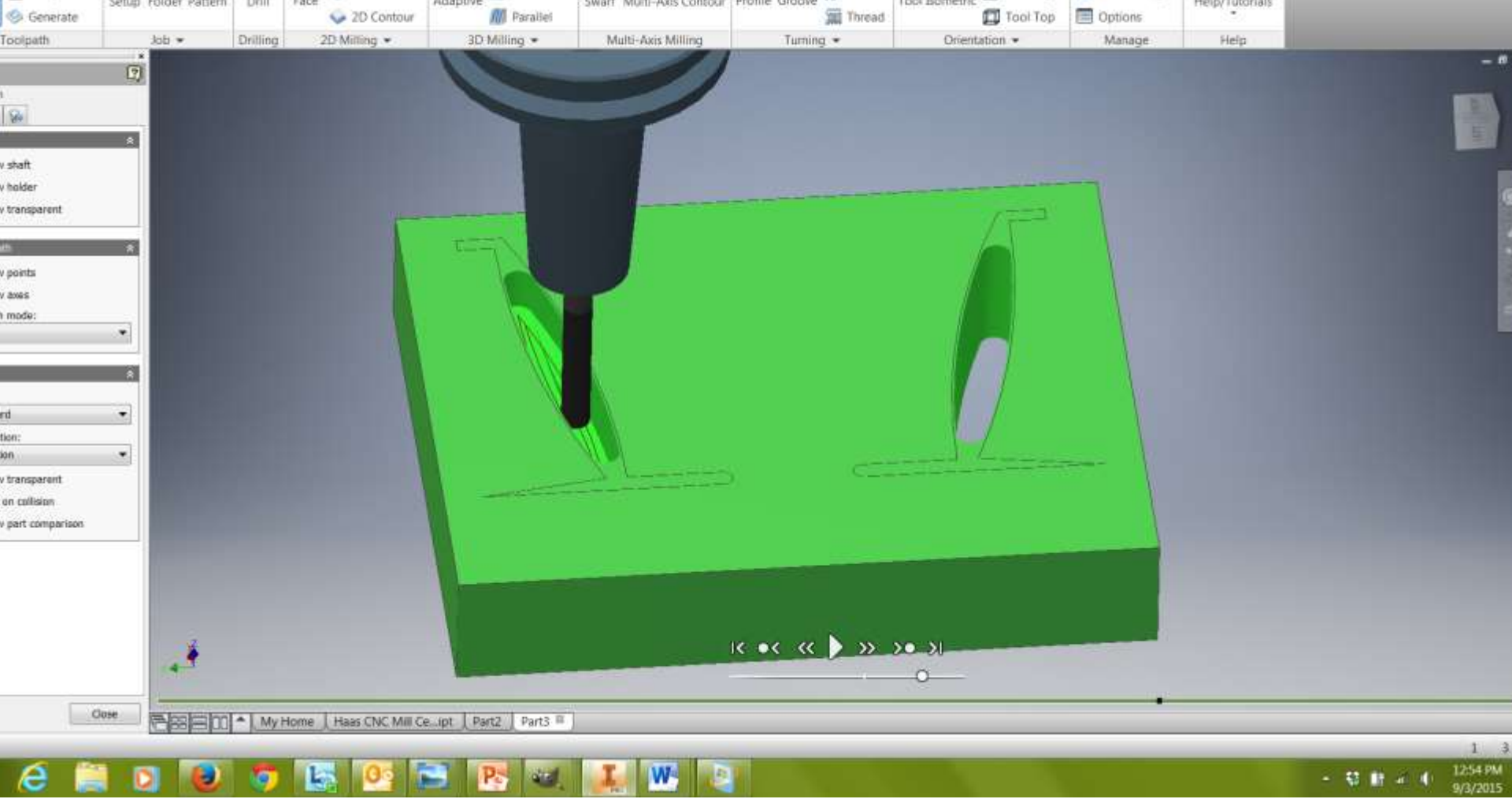

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Review of Considerations During CAD Phase

- 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.

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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
  - 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

julie.kumar@autodesk.com