5-Axis
AIN'T
THAT
SCARY...

Customer Quote

“You just position and cut. It makes every operation just one operation. If you’re not doing this [5-sided machining on a 5-axis CNC] , you’re going to get left behind.” - Tim Friedman, Triangle Precision

Why 5-axis?

…challenges driving this technology

The Challenges we Face

Batch sizes are getting smaller: shops are seeing a higher mix of lower volume orders. To keep up, they are being forced to look for more efficient ways of producing these types of parts to stay competitive.

Delivery times are getting shorter: in the days of J.I.T. manufacturing, shops are being forced to adapt with a much faster turnaround time. Because orders are being placed later, and delivery times are sooner, shops must find technology that allows them flexibility.

Lead-times can change: needs change for all of us, and our customers are no different. As their needs change – sometimes daily – shops need to be able to adapt quickly to those changes to survive.

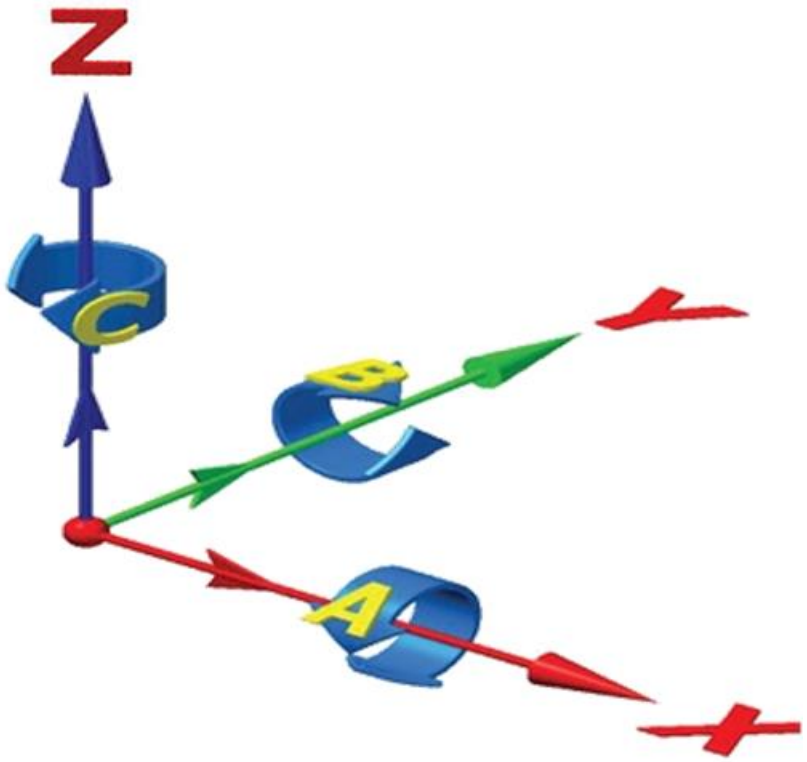
Machine Configurations

…which is which?

Axis Configuration

Machine Configurations

- A/C
- A/B
- B/C



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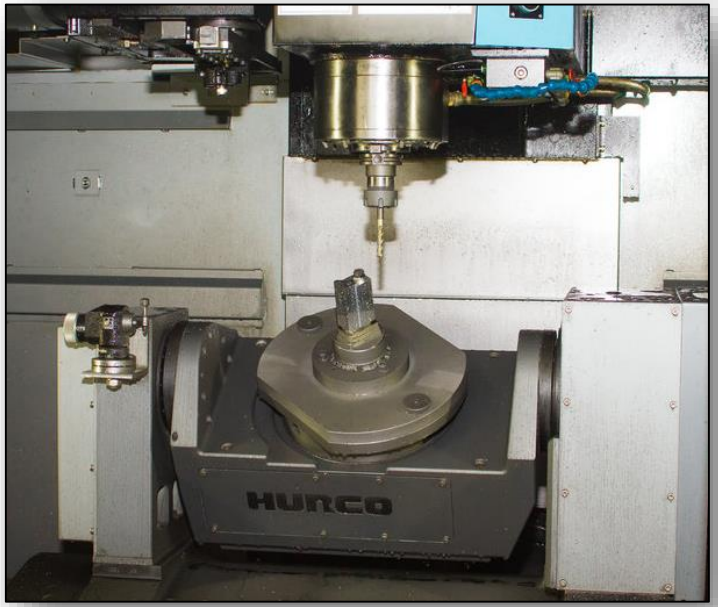
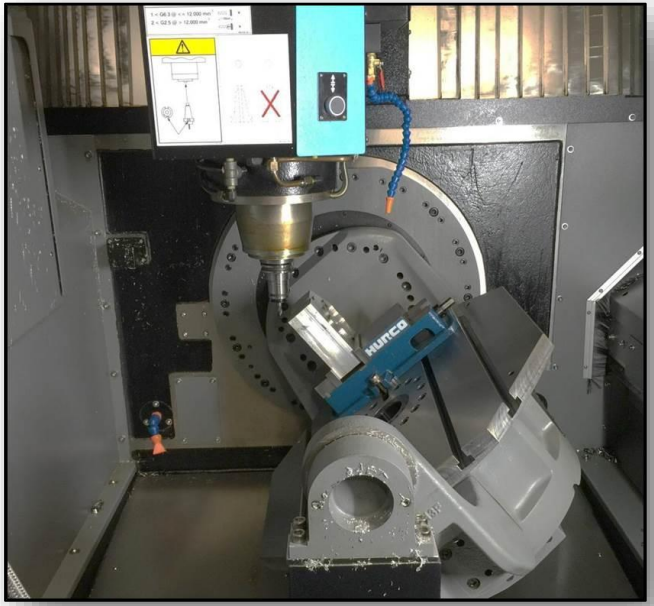
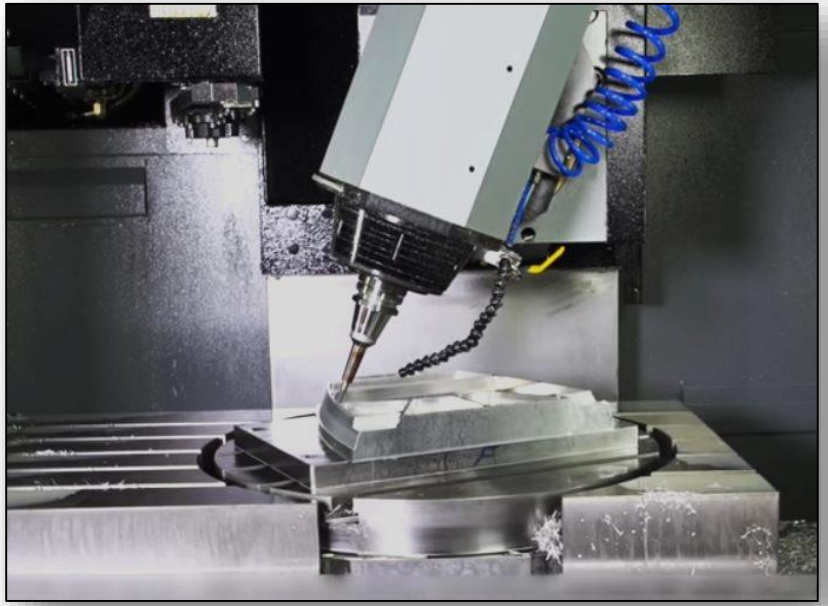


Trunion Machines (A/C)

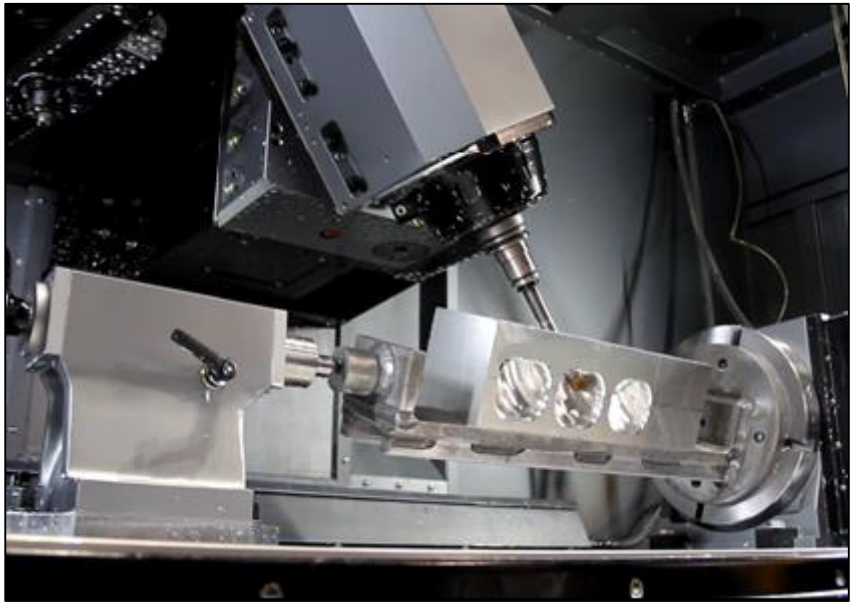


Trunion Machine (B/C)

Machine Configurations

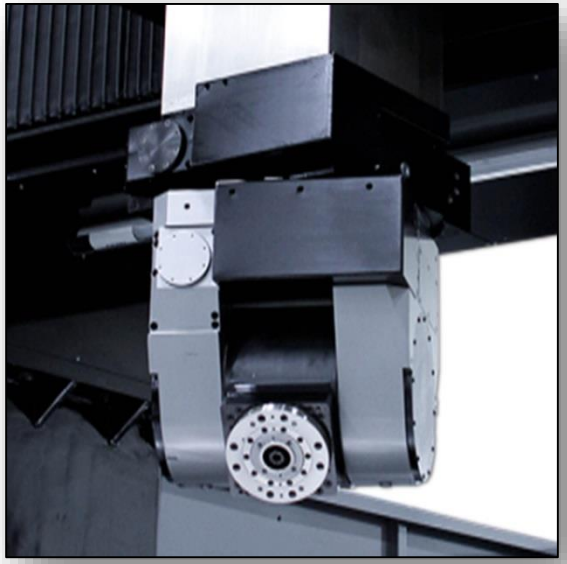


Swivel Head (B/C)



Swivel Head (A/B)

Machine Configurations



Articulating Head
(A/C) or (B/C)

Add-On Tables
(A/B) or (A/C) or (B/C)

Benefits of 5-Axis

…what's in it for me?

The Major Benefits of 5-Axis

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- **Provides ability to machine multiple operations in a single setup**

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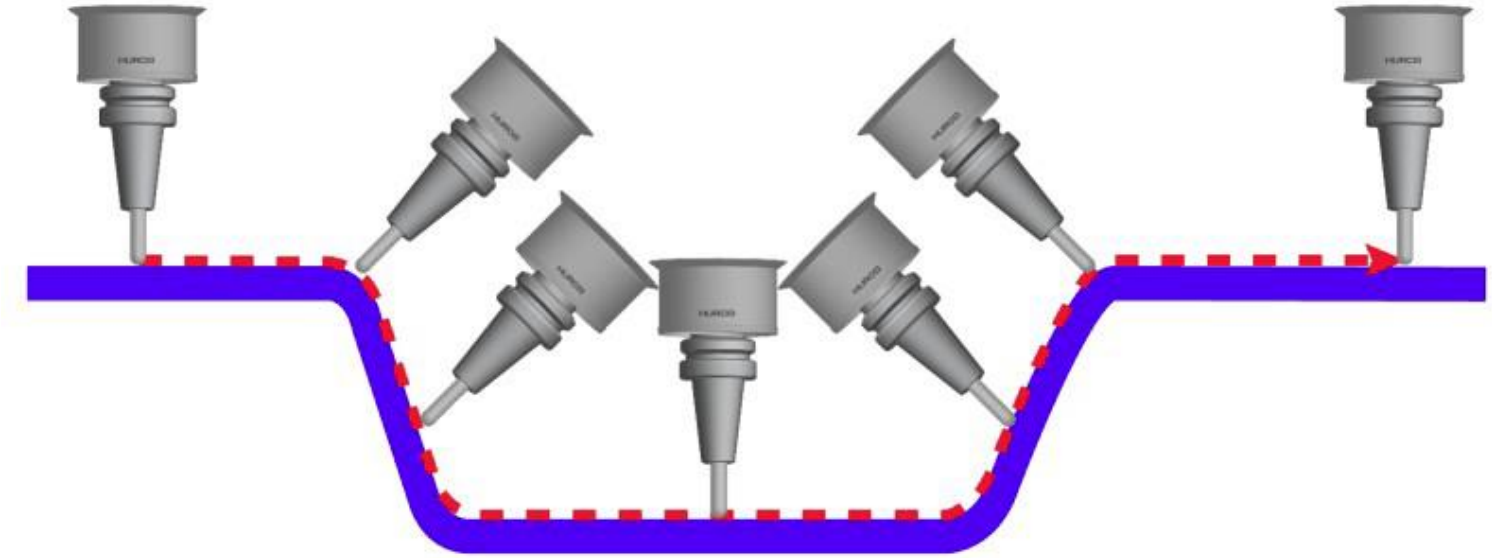
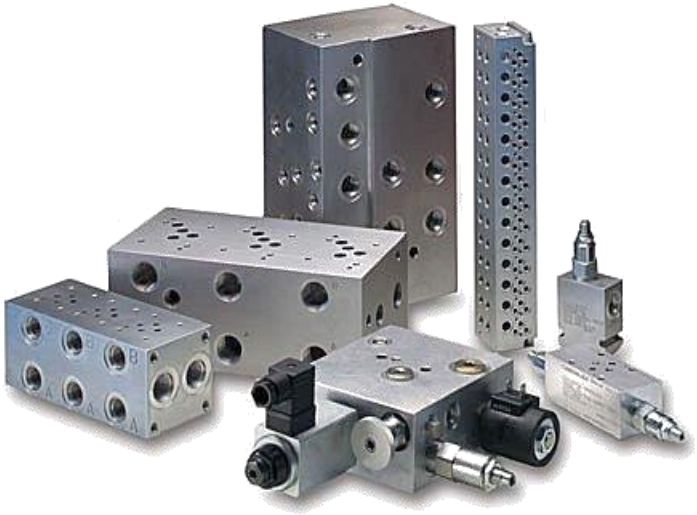
- **Machine complex parts from solid billet instead of castings**
- **Enables the use of shorter cutting tools in deep cavity features**

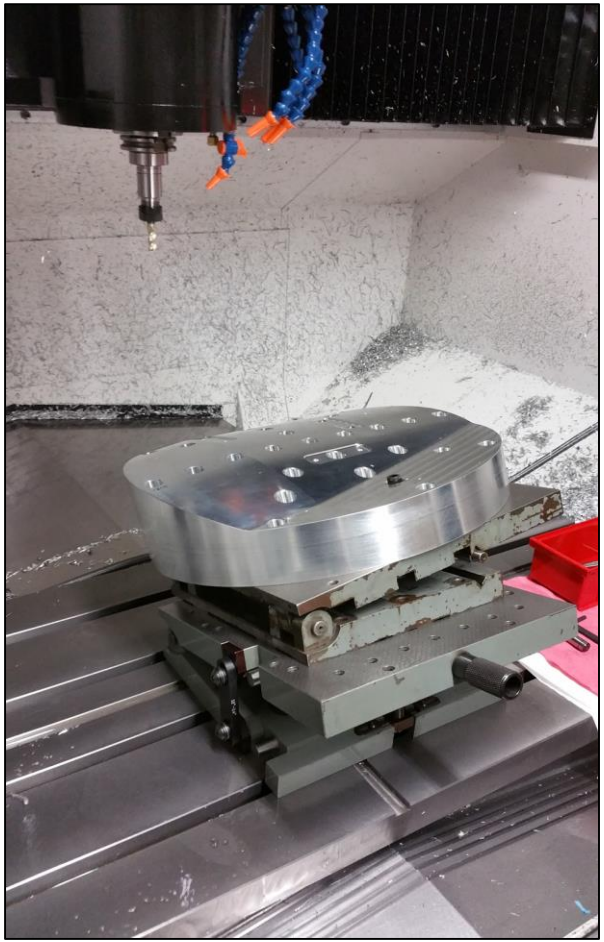
Deep Core & Cavity Mold Machining

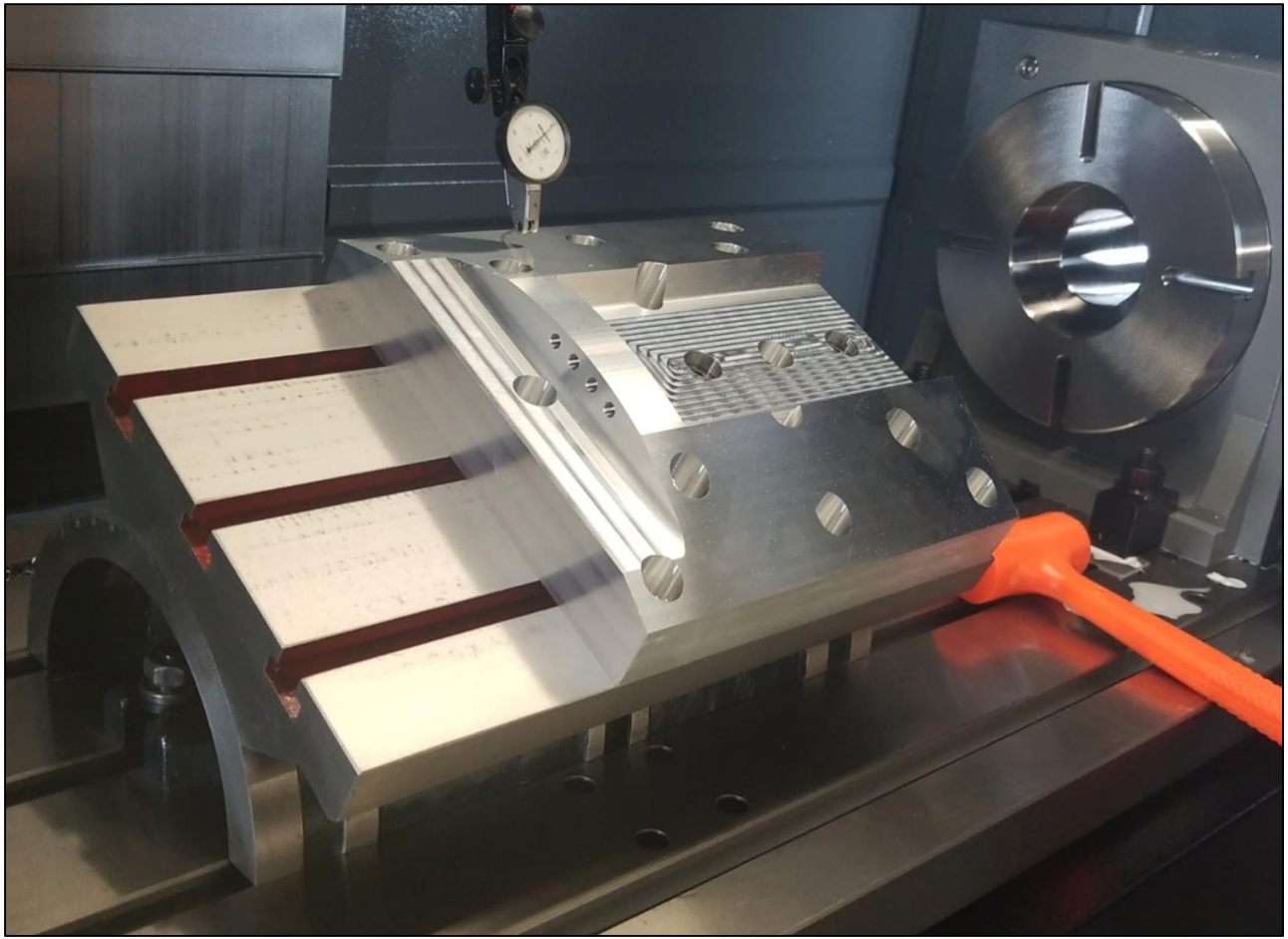


There are 2 ways to talk about five axis…

- 3+2 (also known as 5-axis positioning or 5-sided machining)
- Simultaneous five axis







5-sided vs. Simultaneous 5-axis

There are pros and cons to both 5-sided machining and Simultaneous 5-axis machining. Even though 5-axis machining is impressive to watch, it is slow. If you can create a part with 5-sided machining instead of simultaneous 5-axis, you should.

Benefits
5-sided (also called 3+2)

Benefits
simultaneous 5-axis

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- Allows tool to reach difficult places smoothly

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- Easy to program

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- Cuts faster

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- Easy to program
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- Fewer tool interference issues

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Benefits 5-sided (also called 3+2)

- Easy to program
- Cuts faster
- Fewer tool interference issues
- Excellent roughing strategy

Benefits simultaneous 5-axis

- Better surface finish
- Longer tool life
- Allows tool to reach difficult places smoothly

3-Axis vs. 5-Sided

…old vs. new

Let's Compare…

3-Axis Machining

5-Sided Machining

Let's Compare…

3-Axis Machining

- Multiple setups for each side of the same part

5-Sided Machining

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3-Axis Machining

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- Reduces setup times
- Improves part accuracy

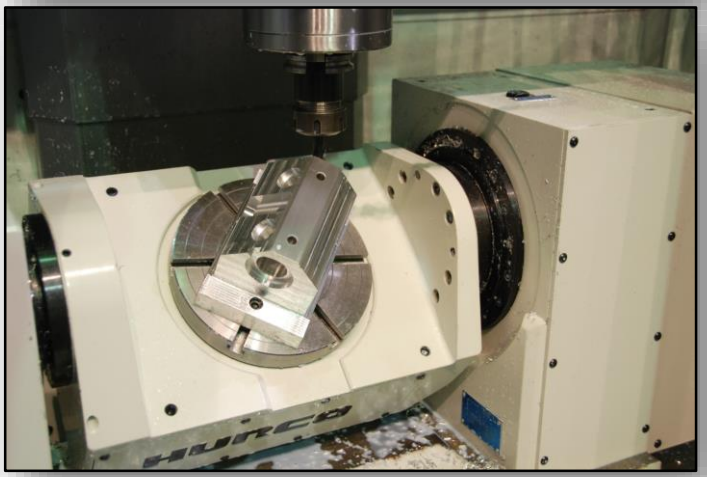
Let's Compare…

3-Axis Machining

- Multiple setups for each side of the same part
- Increased setup time
- Decreased accuracy

5-Sided Machining

- Reduces setup times
- Improves part accuracy
- Increases shop capability



Traditional Setup

- Standard 6” Vise
- Typical Vise Stop
- Multiple Operations

5-Sided Setup

- Bolted directly to fixture
- No Stop necessary
- Two Operations

Standard 3 Axis				
Operation	**Setup Time**	**Load Time**	**Cycle Time**	**Description**
1	30 min	20 sec	3 min 58 sec	Drill top holes and C'bore
2	30 min	20 sec	0 min 42 sec	Facemill back side
3	30 min	20 sec	1 min 07 sec	Facemill front & mill pockt
4	30 min	20 sec	2 min 29 sec	Mill, drill & notch right side
5	30 min	20 sec	2 min 23 sec	Mill & drill left side
6	1 hr 30 min	20 sec	5 min 05 sec	Mill front angle, drill & C'bore - built fixture to cut angle
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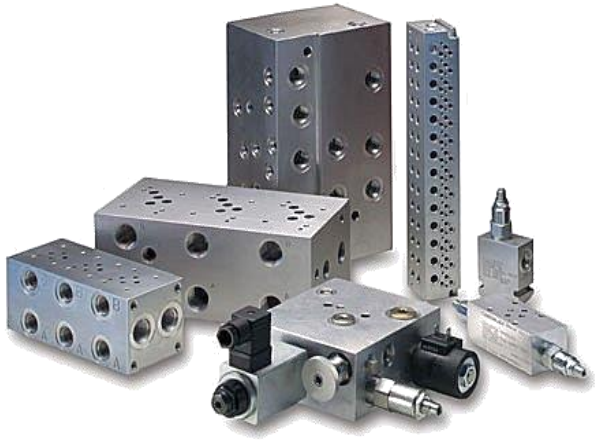
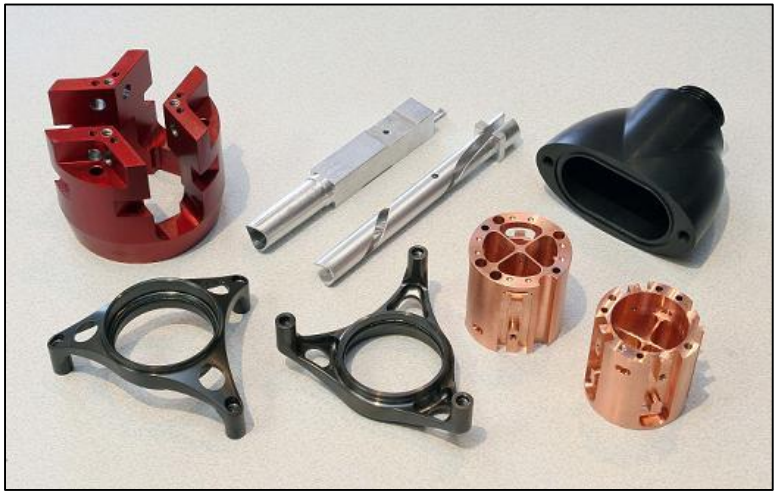
Due to optimized tool changes

Real-World Applications

…time is money

Real World Parts





Machining Techniques

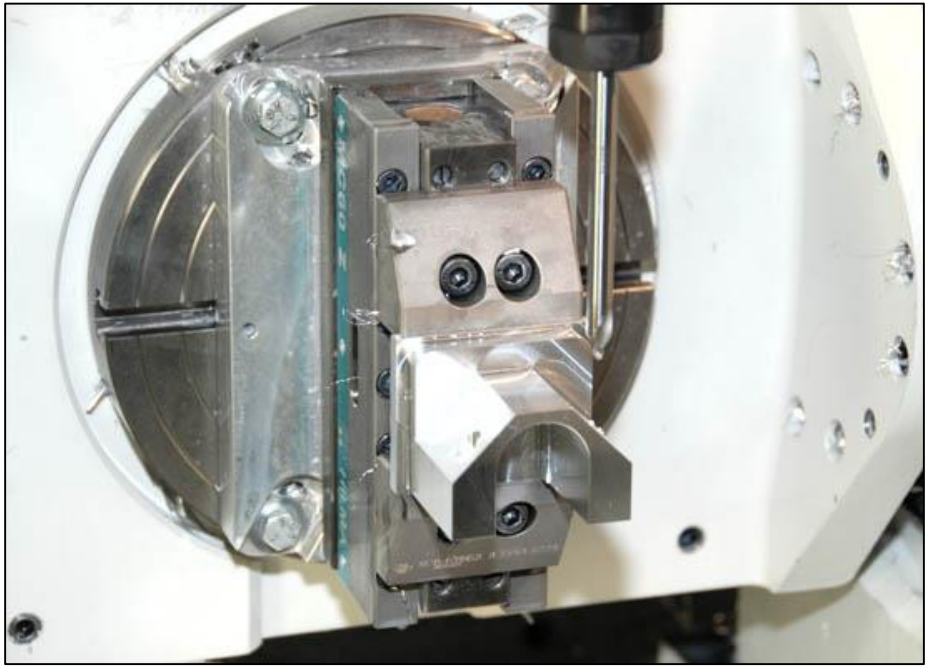
This shop's early adoption of 5-axis machining pays big dividends

"many of our jobs are now turned around one-third (33%) faster"

Gregor Technology

5-Axis Helped This Shop Go Lean

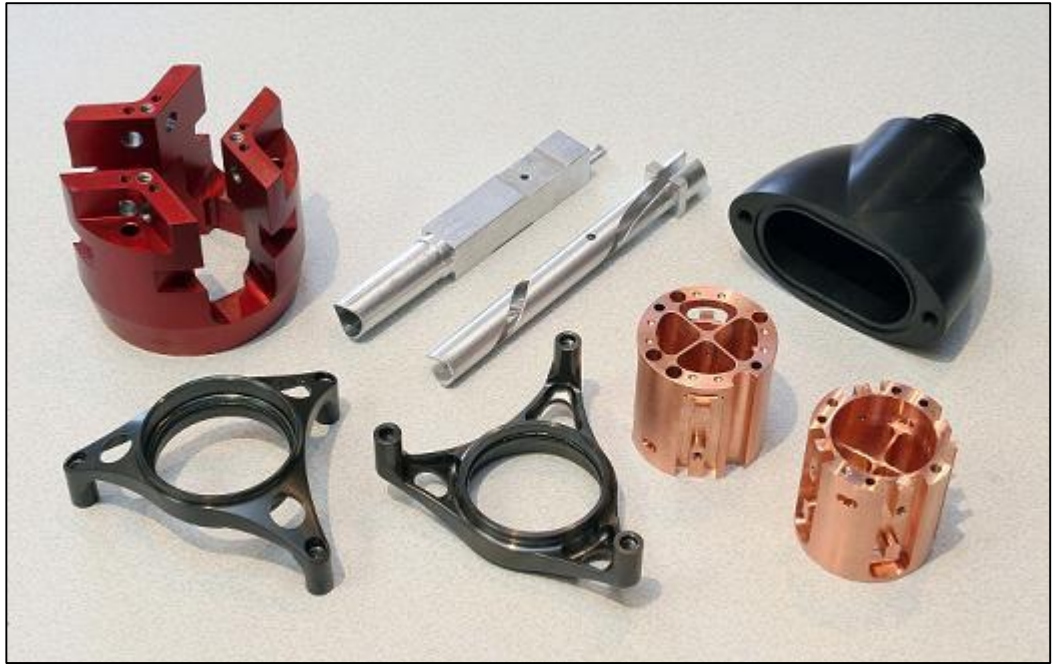
"*The five-sided software is very easy to use. On our 3-axis machines we had six separate setups. On our new 5-axis VM10U, we only have two setups.*"



Acrona Engineering

Hurco's Smallest 5-Axis Machine Makes a Big Impact

"*We are winning more and more contracts from first-tier suppliers to the aerospace industry. Our plan is to move further into this type of high value-added work, for which the 5-axis machine is ideal"*



Switching from 3-axis to 5-sided

VM 10Ui

VMX 42 SRTi

VM 10i

Switching from 3-axis to 5-sided

- ✓Easy transition to 5-sided work

VM 10Ui

VMX 42 SRTi

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- ✓Easy transition to 5-sided work
- ✓Increases shop capability

VM 10Ui

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VM 10i

Switching from 3-axis to 5-sided

- ✓Easy transition to 5-sided work
- ✓Increases shop capability
- ✓Makes the jump to full 5-axis easier & less scary

VM 10Ui

VMX 42 SRTi

VM 10i

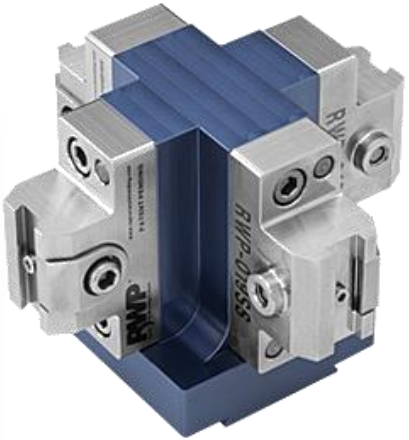
Workholding

…but I can only hold one part at a time

5th AXIS®
V75100

Good

Better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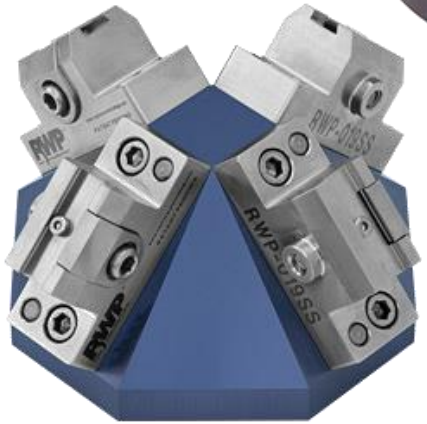
RWP

RWP-003
RWP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PATENT US 8,672,310 B2

5th AXIS
5th AXIS
5th AXIS

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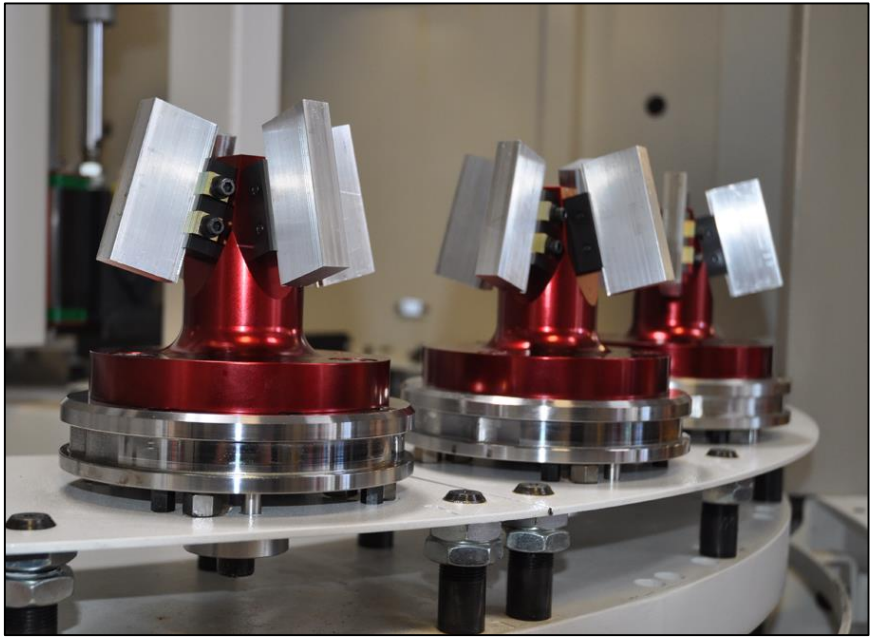
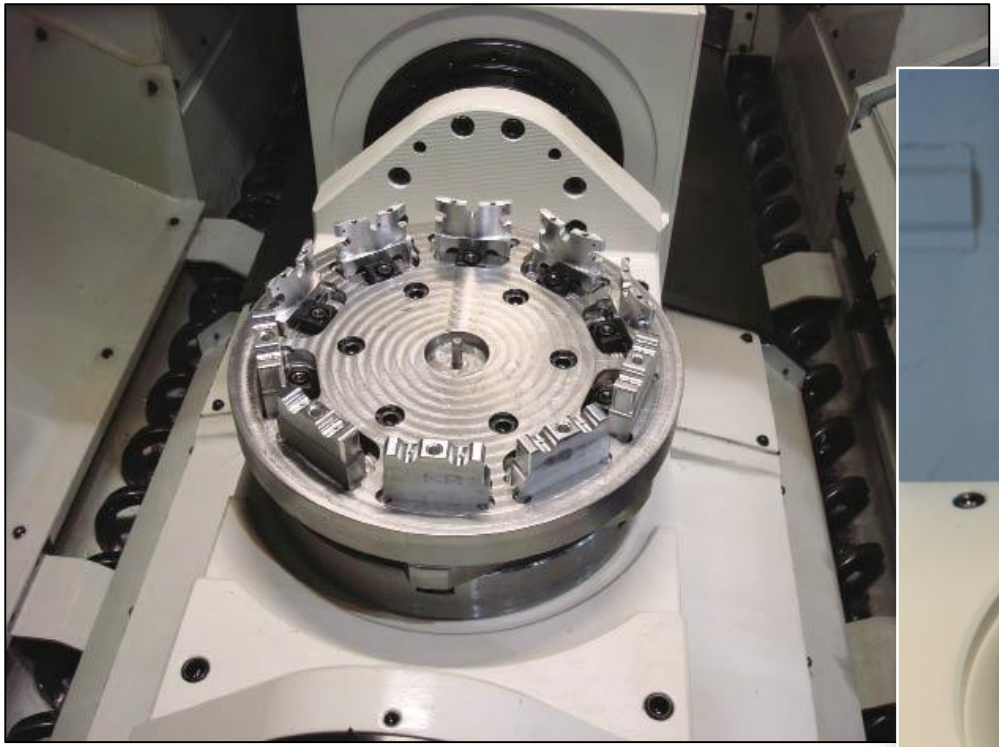
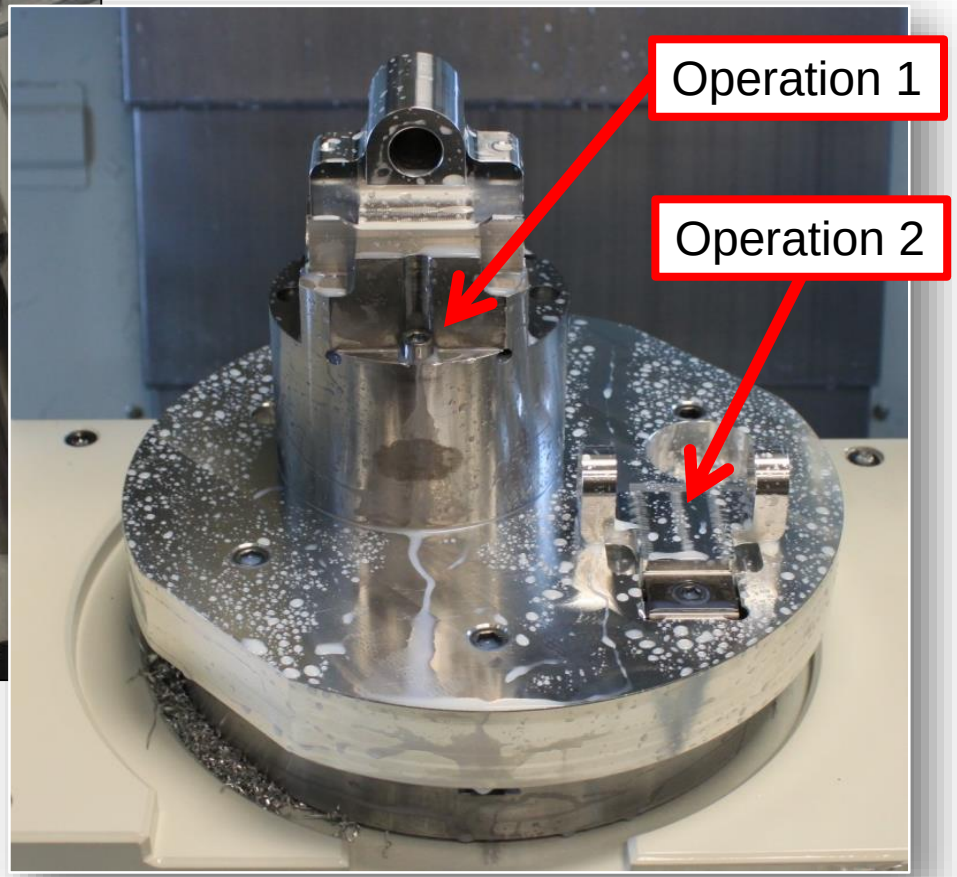
5th AXIS.

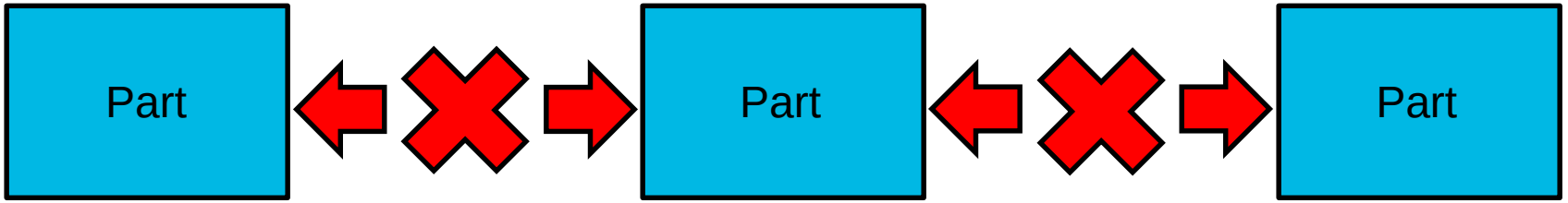






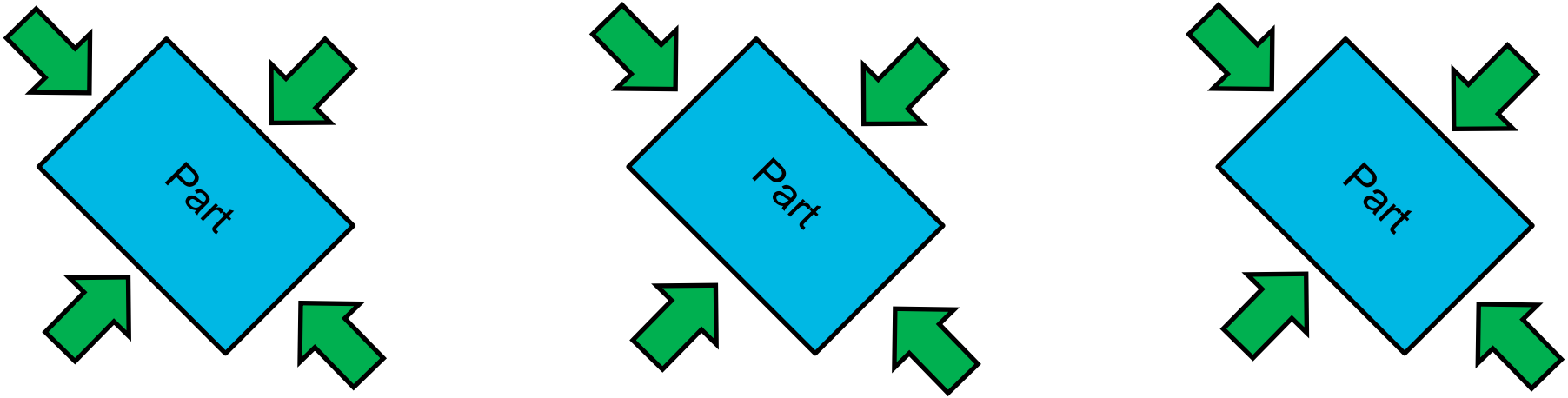
…be creative

Traditional Workholding



Tools can’t reach the inside faces of the parts due to interference issues

Creative Workholding



Simply rotating the parts 45° allows access to all five sides of all parts

Purchasing Considerations

…bigger is not always better

Pre-Purchase Checklist

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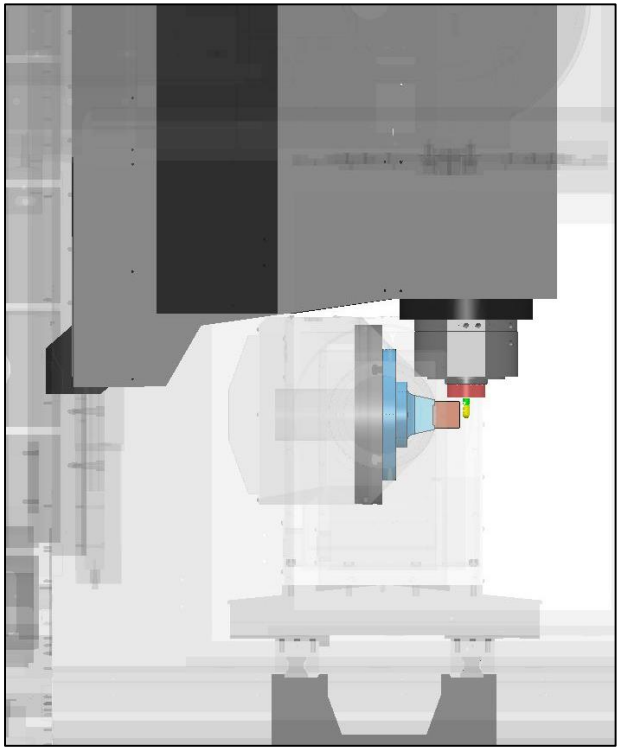
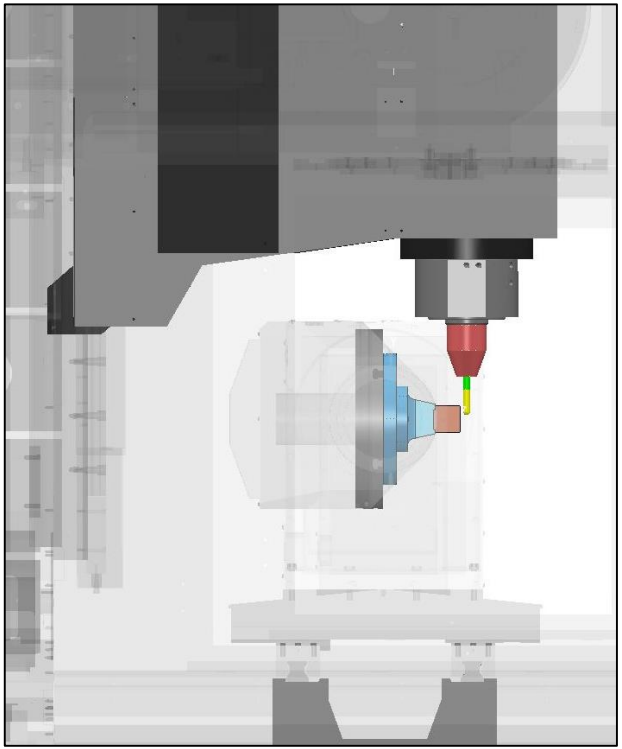
- ✓ **Consider the individual part size - or part family**
  - Trunion Table Diameter - which machine best suits ALL of the parts without being too large or too small

Tool Length

…is this the correct size of trunion table for me?





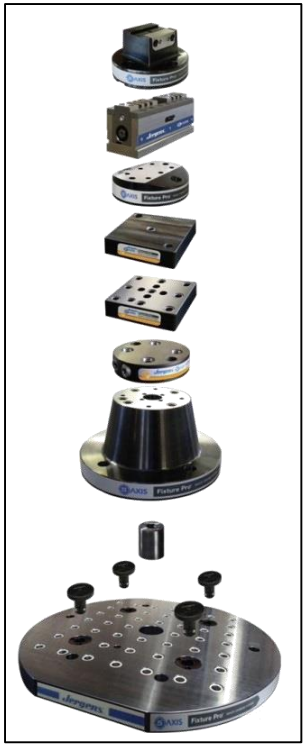
Pre-Purchase Checklist

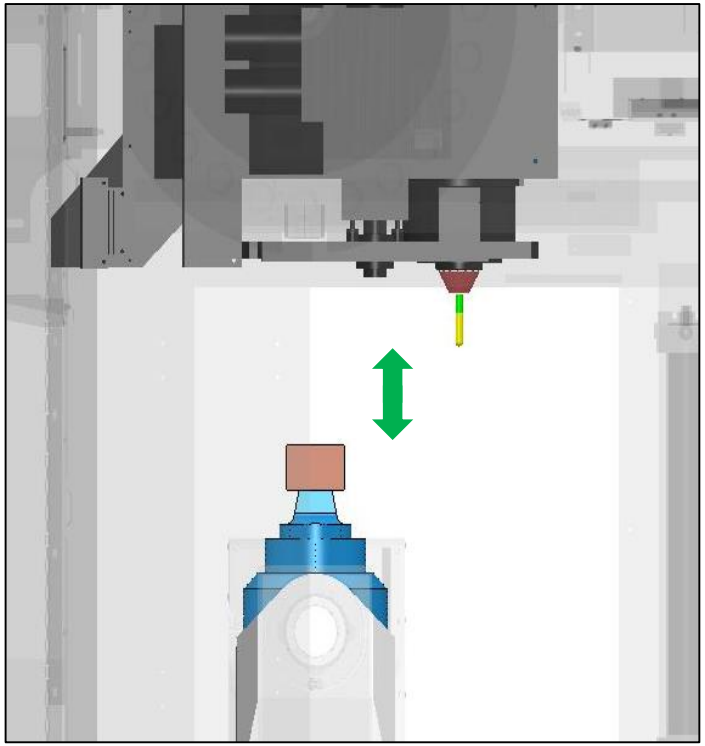
- ✓ **Consider the individual part size - or part family**
  - Trunion Table Diameter - which machine best suits ALL of the parts without being too large or too small

- ✓ **Review the part setup or fixture design**
  - Height off Table - make sure the selected machine will accommodate not only the parts, but the desired fixture (Y-axis travel)

Fixture Height

…do I have enough axis travel for my setup?

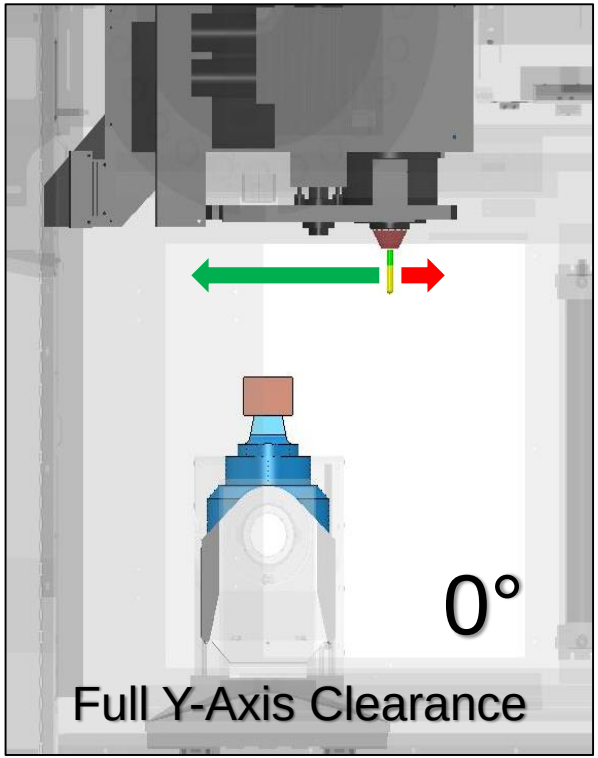


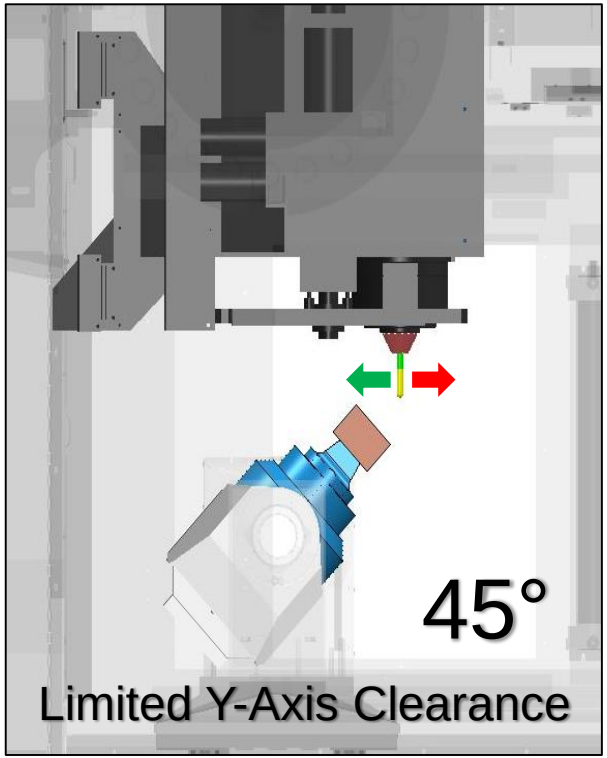


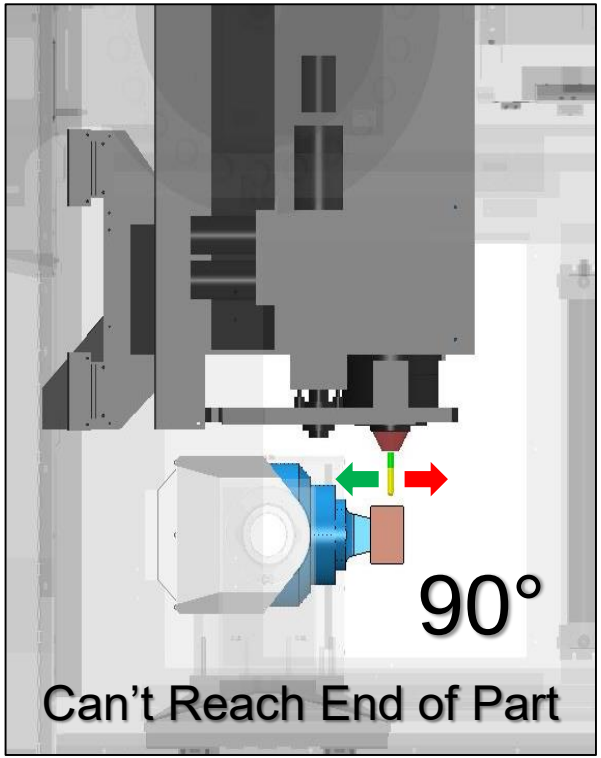
- Modular fixturing makes setup easy but excess height may cause problems
- Plenty of Z-axis clearance at 0º
- The closer to 90º the more Y-axis travel will be affected

Fixture Height

…do I have enough axis travel for my setup?







Pre-Purchase Checklist

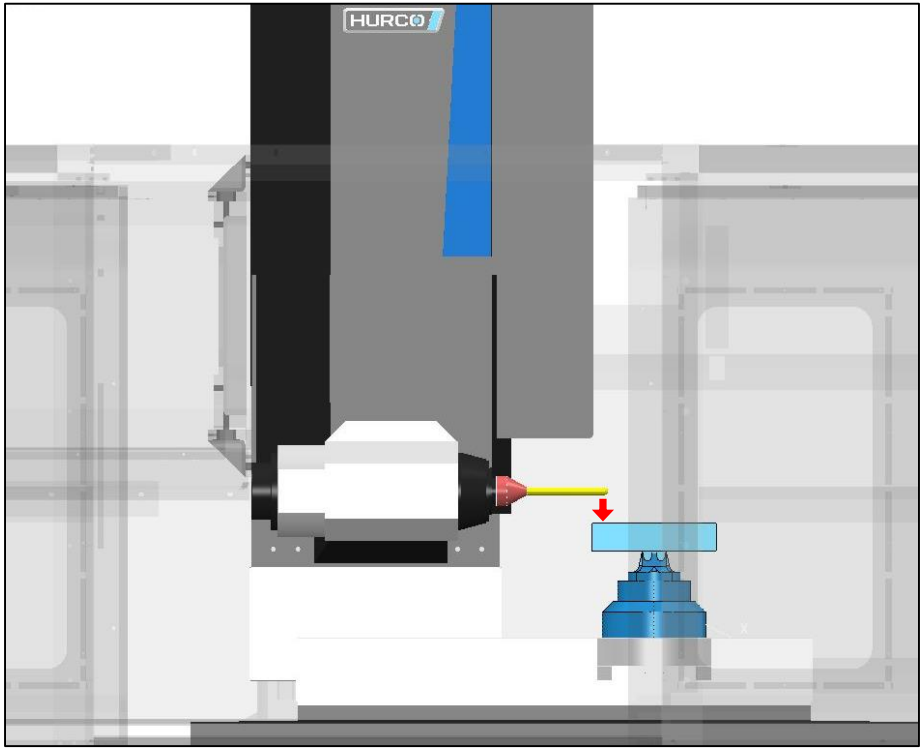
- ✓ **Consider the individual part size - or part family**
  - Trunion Table Diameter - which machine best suits ALL of the parts without being too large or too small

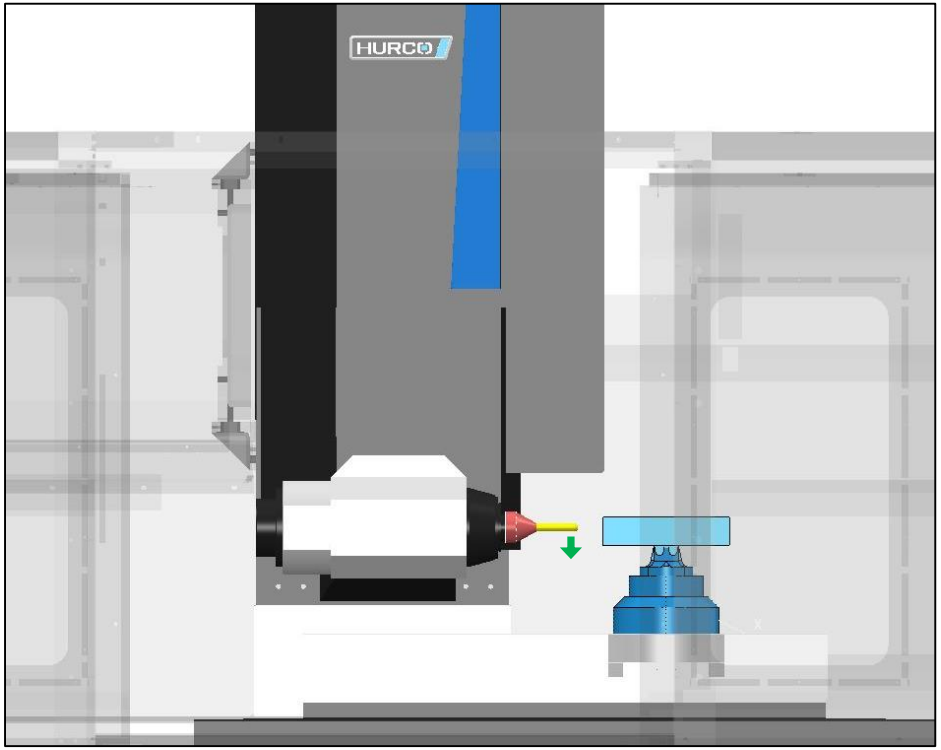
- ✓ **Review the part setup or fixture design**
  - Height off Table - make sure the selected machine will accommodate not only the parts, but the desired fixture (Y-axis travel)

- ✓ **Consider the length of all necessary tooling**
  - Axis Travel – longer tool lengths can be a significant deciding factor that will drive the machine size and type selected

Axis Travel

…will this size machine accommodate my tooling?





Terminology

…learn the buzz words

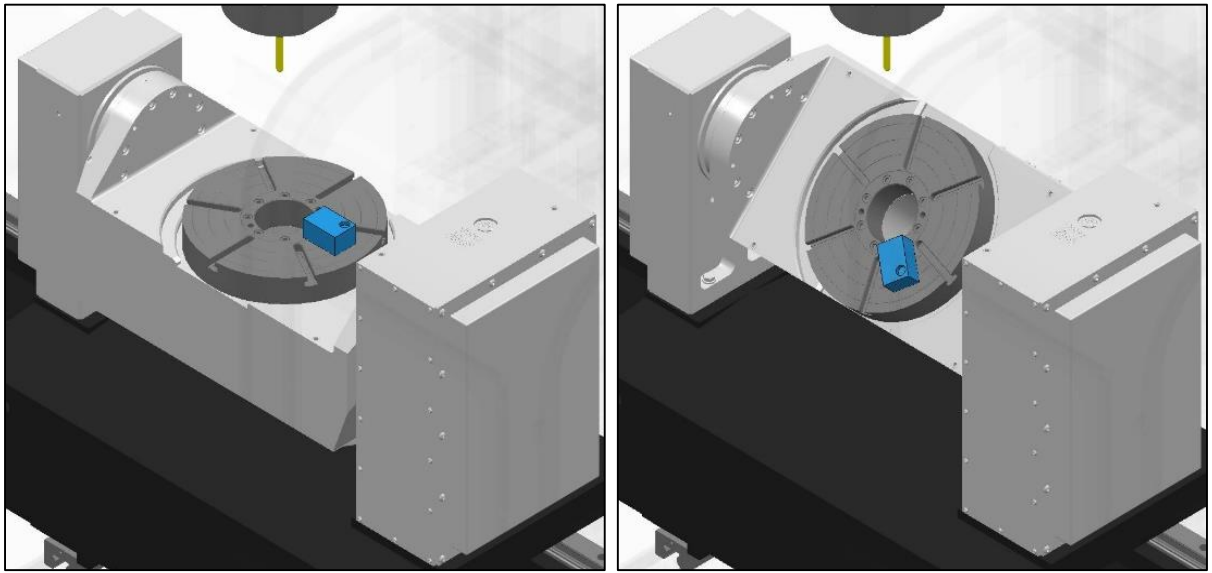
Important 5-Axis Terms

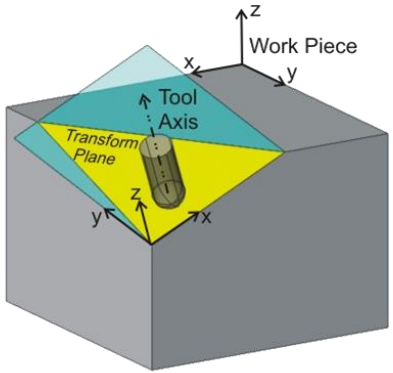
- Tool Center Point Management (TCPM)
- Transform Plane
- Surface Normal
- Tool Vector
- 5-Axis Toolpath Linearization

Tool Center Point Management (TCPM)

Simply program the part using the workpiece zero location. No need to account for the distance from part zero to the axes centerlines of rotation.

- **Program in workpiece coordinate system**
- **Makes program and part setup independent from machine setup and configuration**
- **Allows for less complex post-processor**





Transform Plane

```
%
T1M6
G68.2 X50 Y-50 Z-100 A90 C90
G00 X50 Y50 Z0
```

- A new workplane is defined with a Transform Plane command
- Z-axis is perpendicular to newly transformed work plane
- Program features using any 3-axis strategy
- NC or Conversational

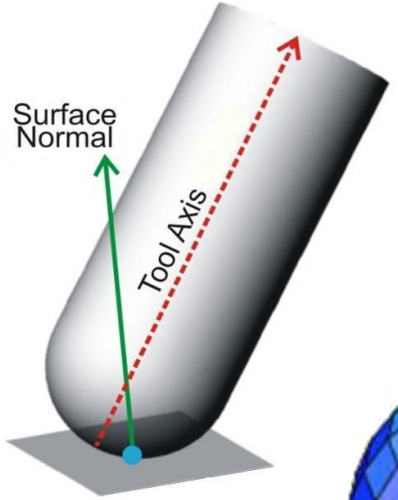
BLOCK 2 TRANSFORM PLANE

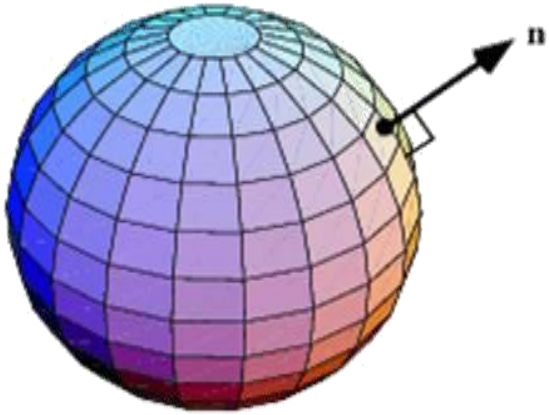
ORIENT METHOD ANGLES

ORIGIN POINT		ROTATION ANGLES	
X	50.000	R(X)	90.000
Y	-50.000	R(Y)	0.000
Z	-100.000	R(Z)	90.000

Surfaces & Surface Normals

- **Neither is exclusive to 5-axis machining**
- **All solids are made up of a multitude of surfaces**
- **A surface normal is an axial vector that is perpendicular to any given surface**
- **5-axis programs use the surface normal as a reference for tool tilt angles**

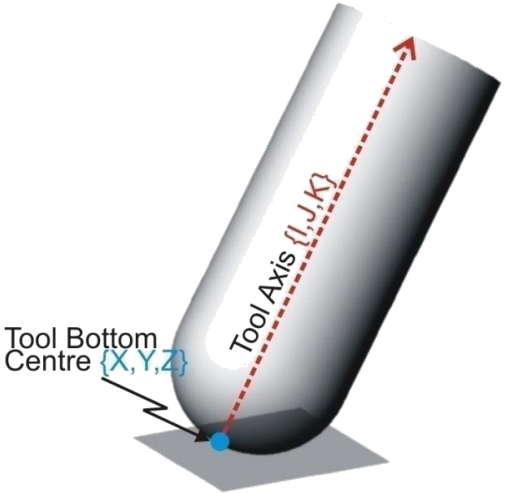


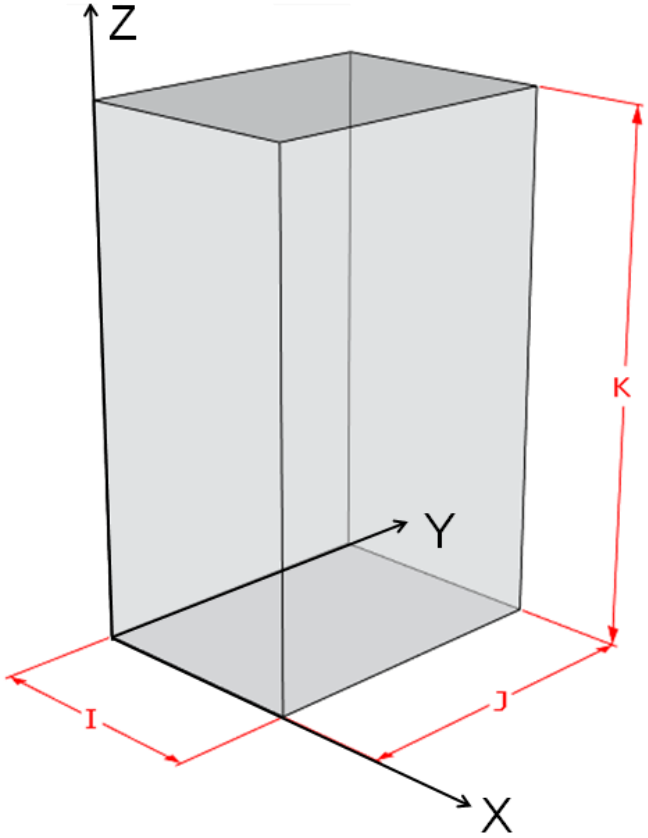


Tool Vector

Tool tilt angle & direction away from surface contact point

G01 X10. Y10. Z10. I0.5 J0.5 K0.707106





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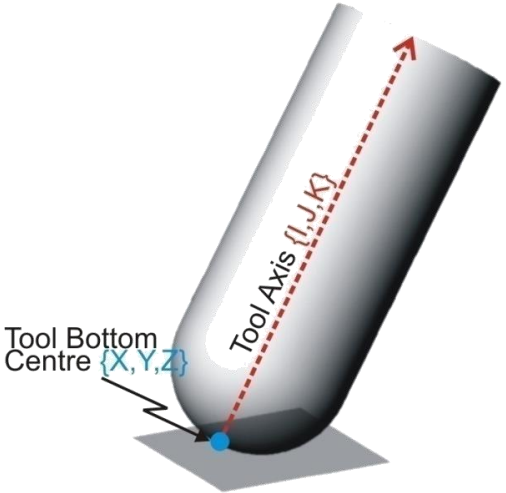
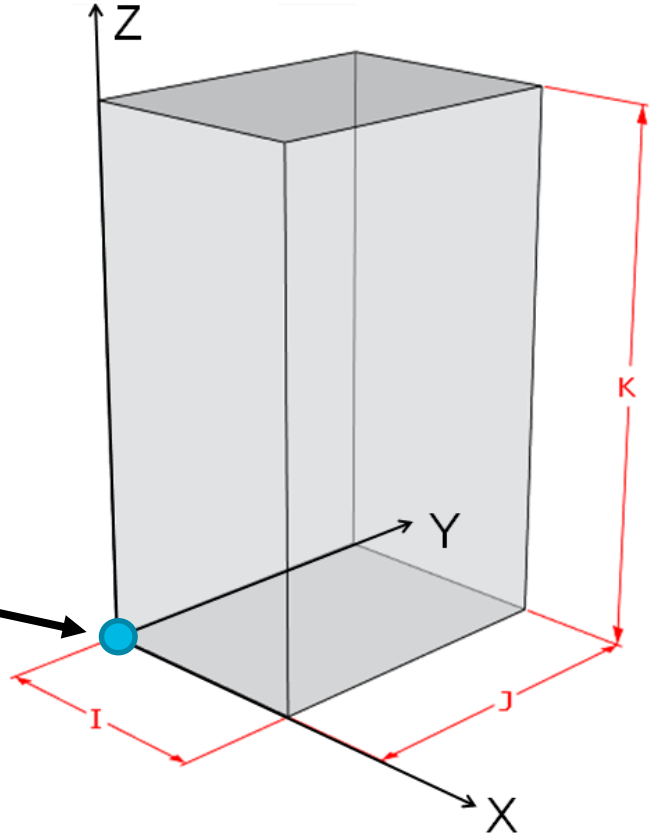
G01 X10. Y10. Z10. I0.5 J0.5 K0.707106



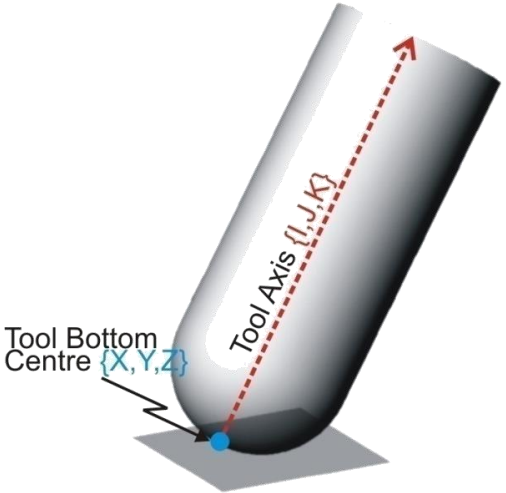
XYZ Contact Point



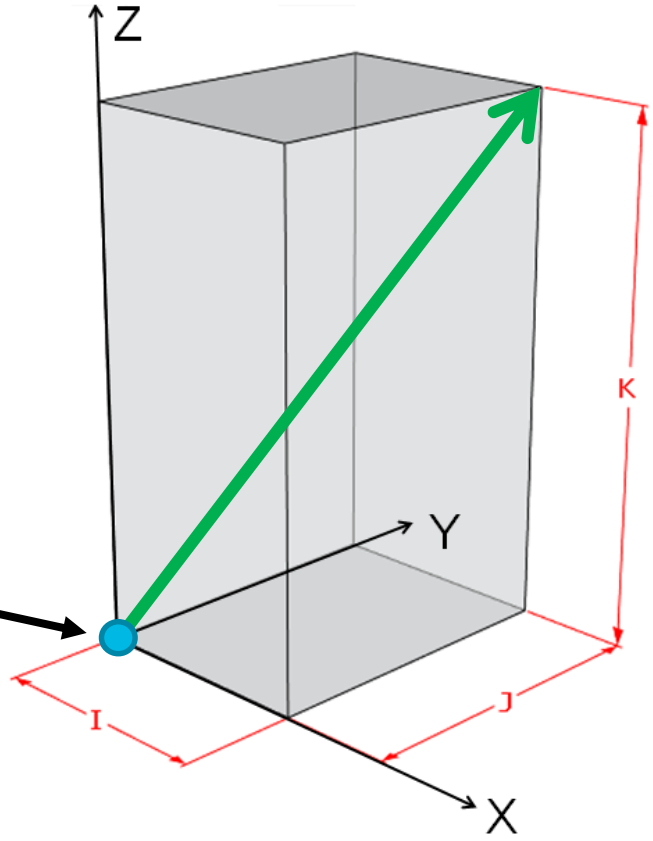
Tool Vector

Tool tilt angle & direction away from surface contact point

G01 X10. Y10. Z10. I0.5 J0.5 K0.707106



XYZ Contact Point



Tool Vector

Tool tilt angle & direction away from surface contact point

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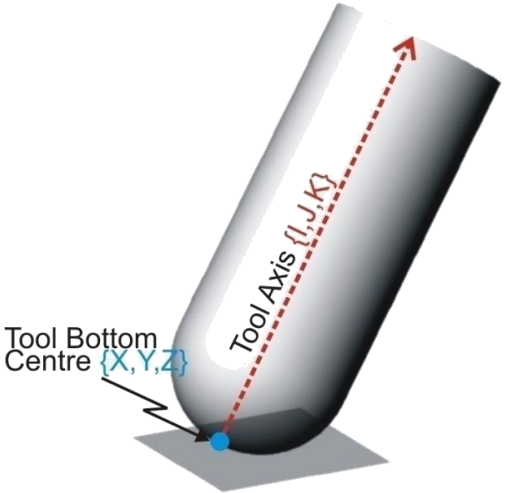
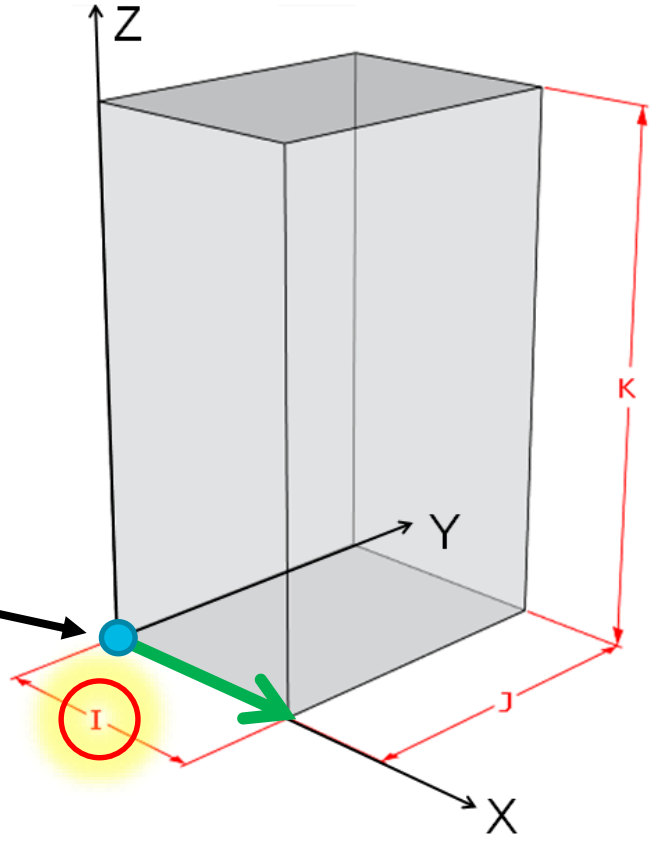


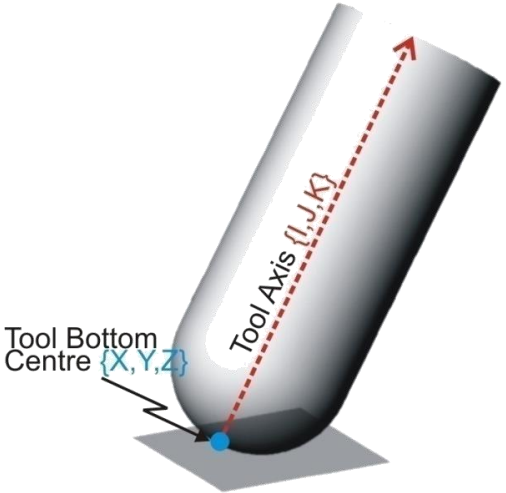
XYZ Contact Point



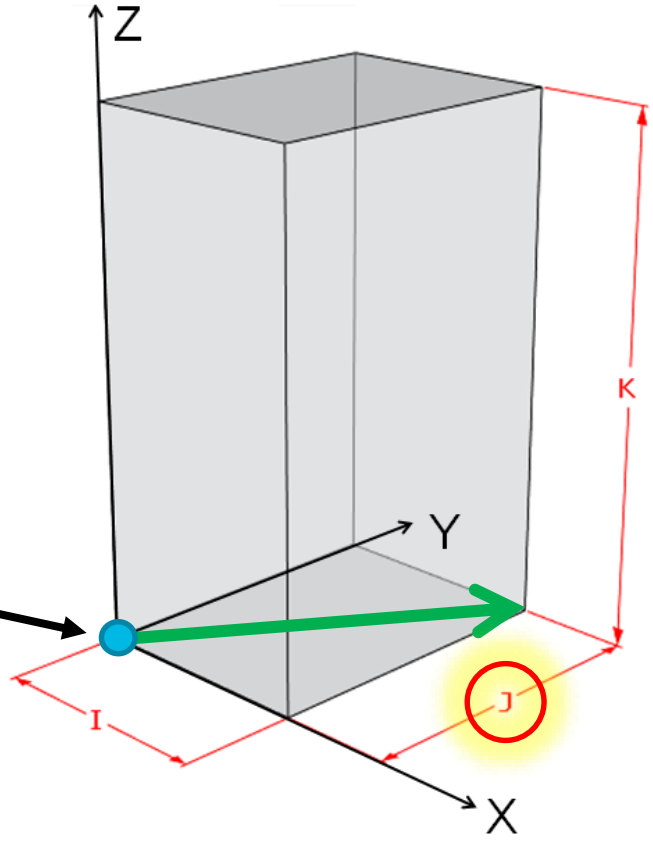
Tool Vector

Tool tilt angle & direction away from surface contact point

G01 X10. Y10. Z10. I0.5 J0.5 K0.707106



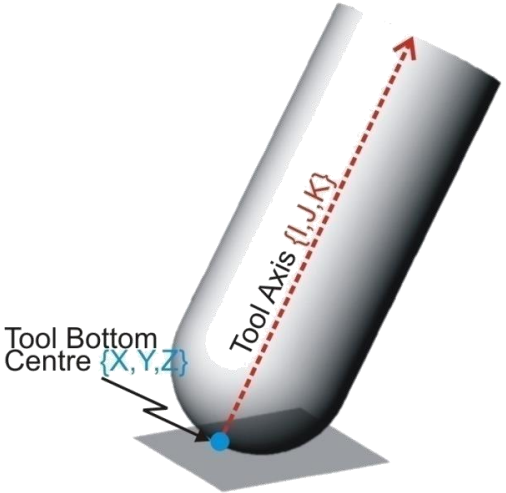
XYZ Contact Point



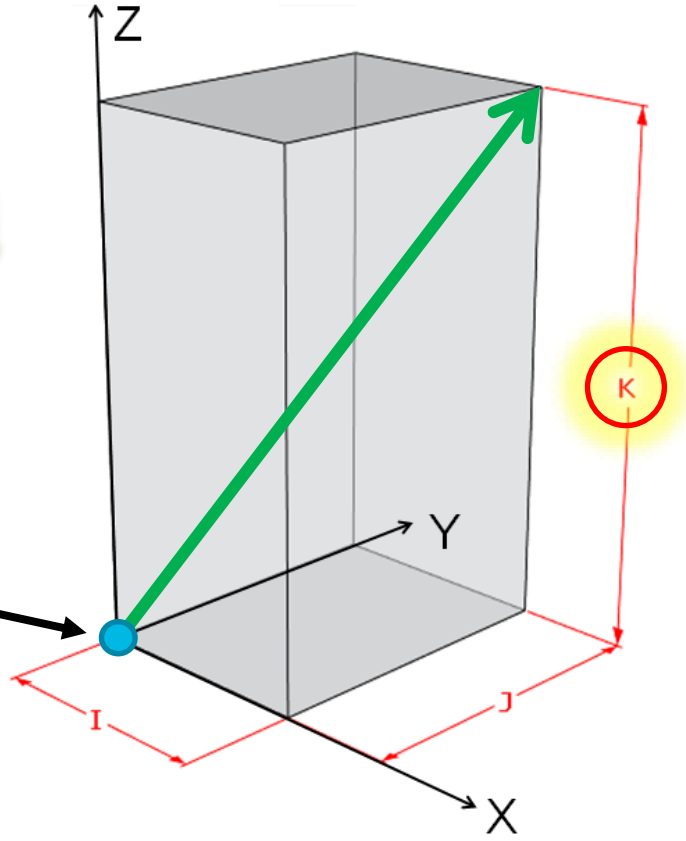
Tool Vector

Tool tilt angle & direction away from surface contact point

G01 X10. Y10. Z10. I0.5 J0.5 K0.707106



XYZ Contact Point



Tool Vector Input

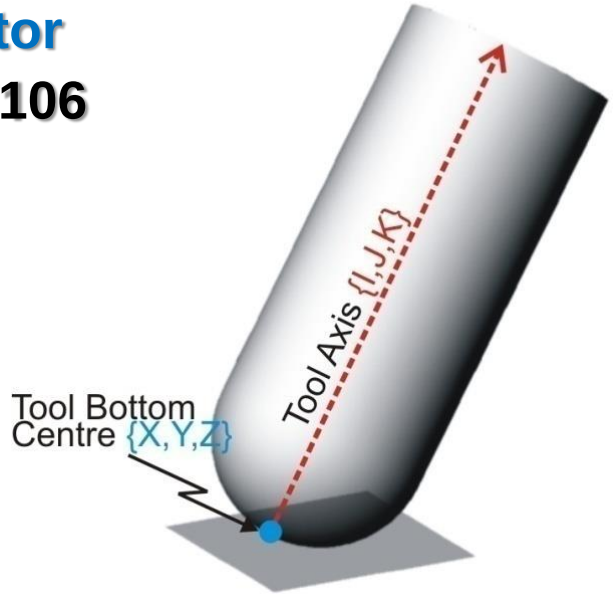
Allows a program to run on any five axis machine - regardless of axis configuration.

Workpiece coordinates + tool vector

G01 X10. Y10. Z10. I0.5 J0.5 K0.707106

- the same as -

G01 X10. Y10. Z10. B45. C45

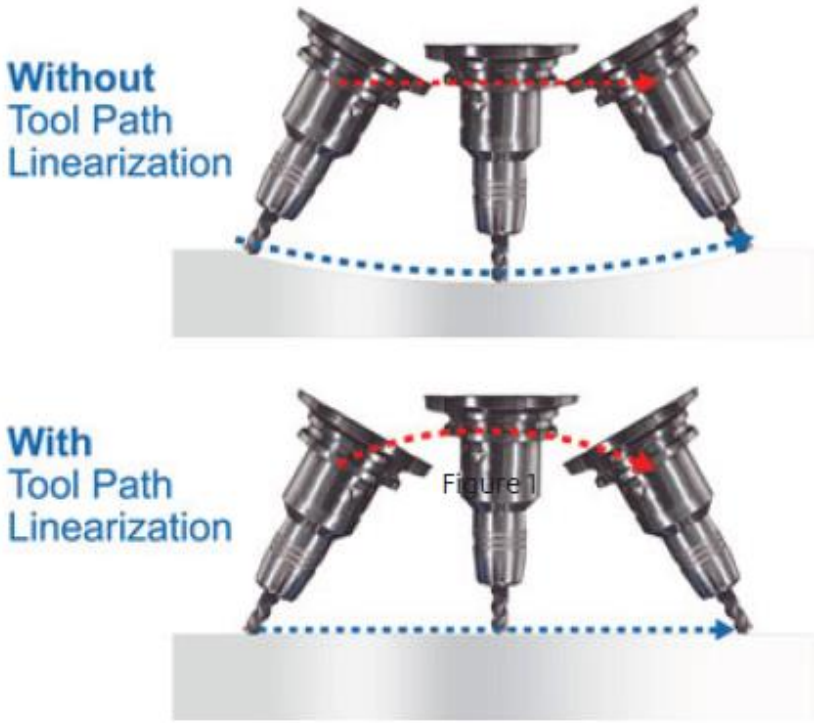


- **Tool Vector input makes programs machine independent**
- **Control computes necessary machine angles and positions**

5-Axis Toolpath Linearization

Benefits of G43.4 Linearization:

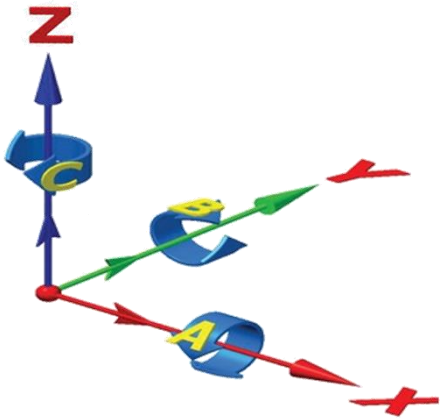
- **Eliminates gouging on the workpiece**
- **Tool tip “attaches” itself to the workpiece**
- **Doesn’t “blindly” follow rotations**
- **Results in smaller NC programs – due to fewer points required**



Rotation Directions

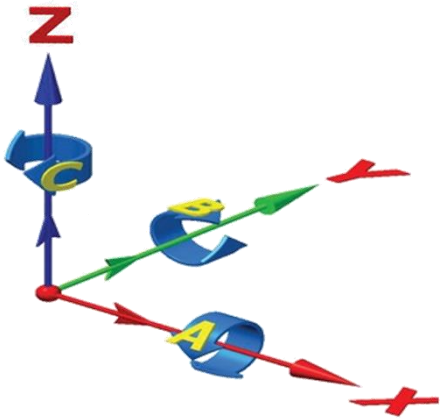
…ISO standard & the right hand rule

ISO vs. Non-ISO Rotary



- There are two expressions that determine positive and negative rotations when programming rotary movements: ISO Standard & Non-ISO
- ISO is an Acronym for the International Organization for Standardization (ISO 841:2001)
- Non-ISO is the exact opposite
- Always imagine the tool moving when programming, and not the machine

ISO vs. Non-ISO Rotary



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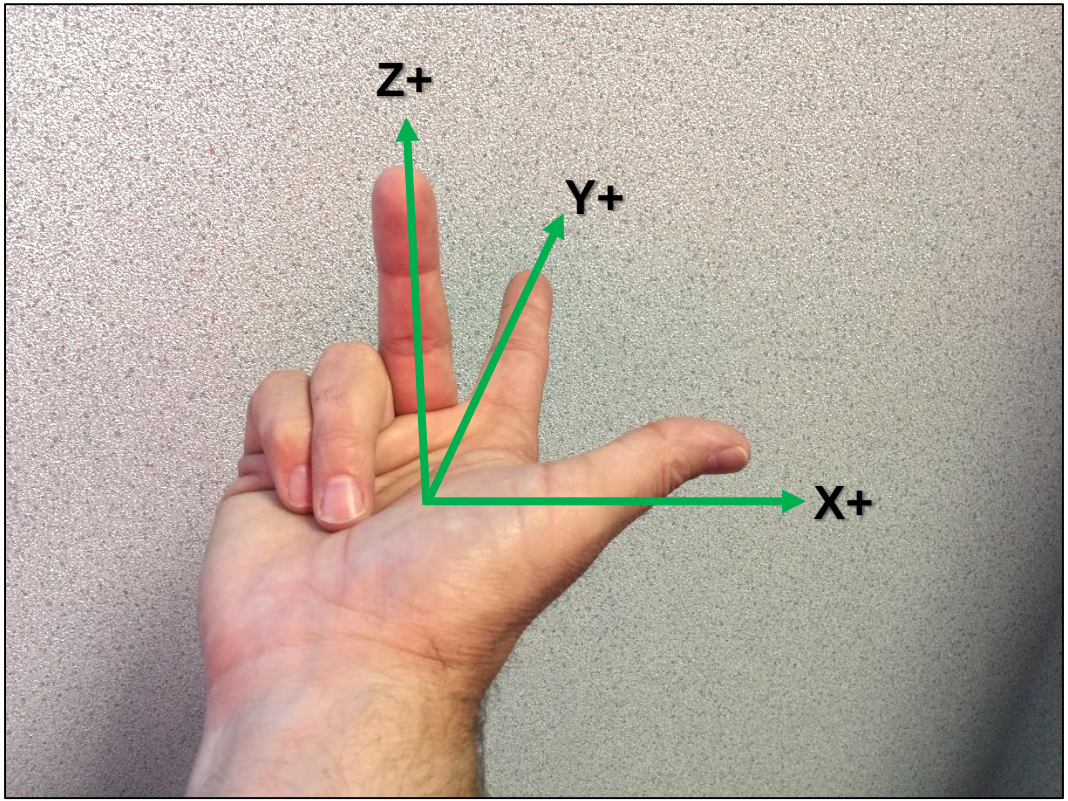
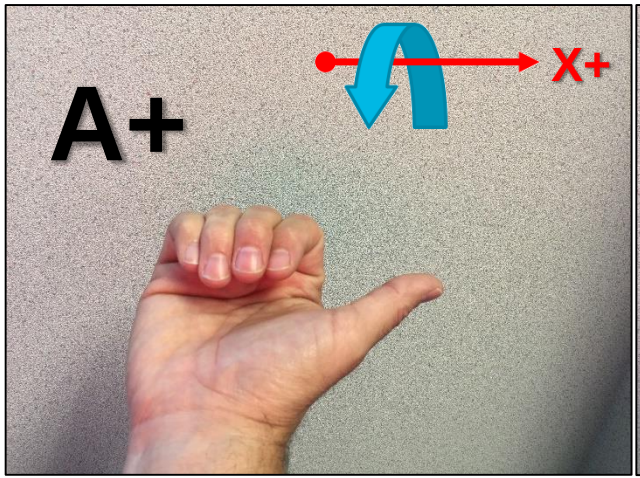
The Right Hand Rule

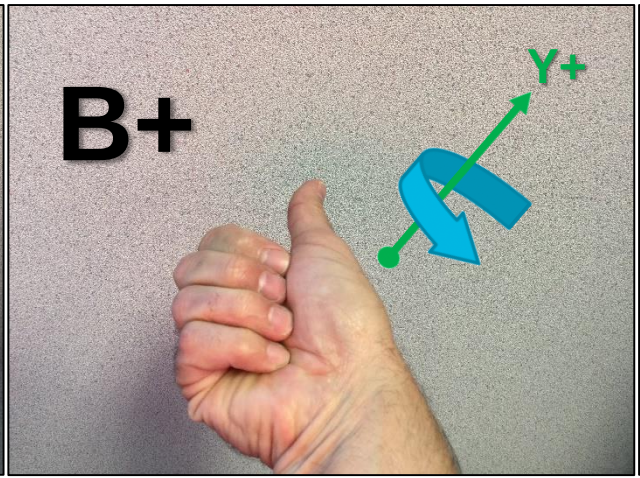


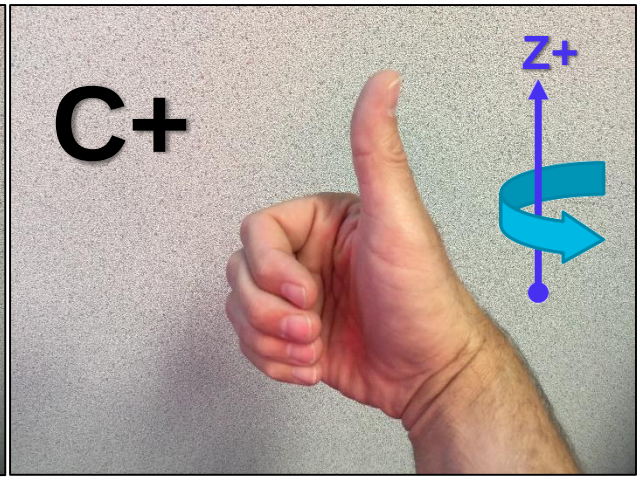
The Right Hand Rule

Lay the thumb along the positive direction of the linear axis, and the fingers wrap in the positive direction of rotation of the tool.

The right hand rule always describes the ISO Standard rotary direction



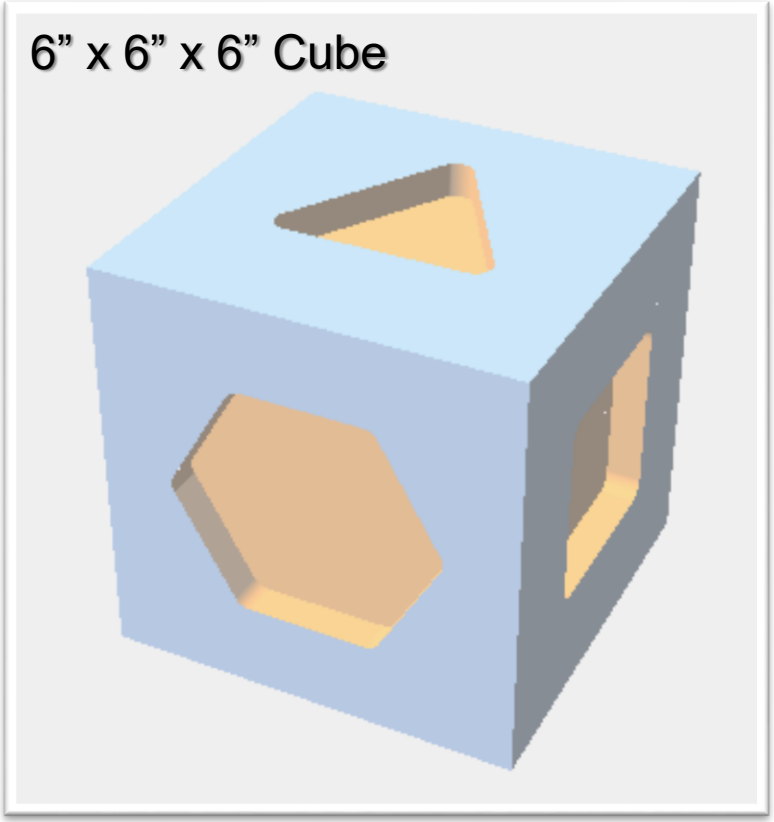




Programming *5-sided*

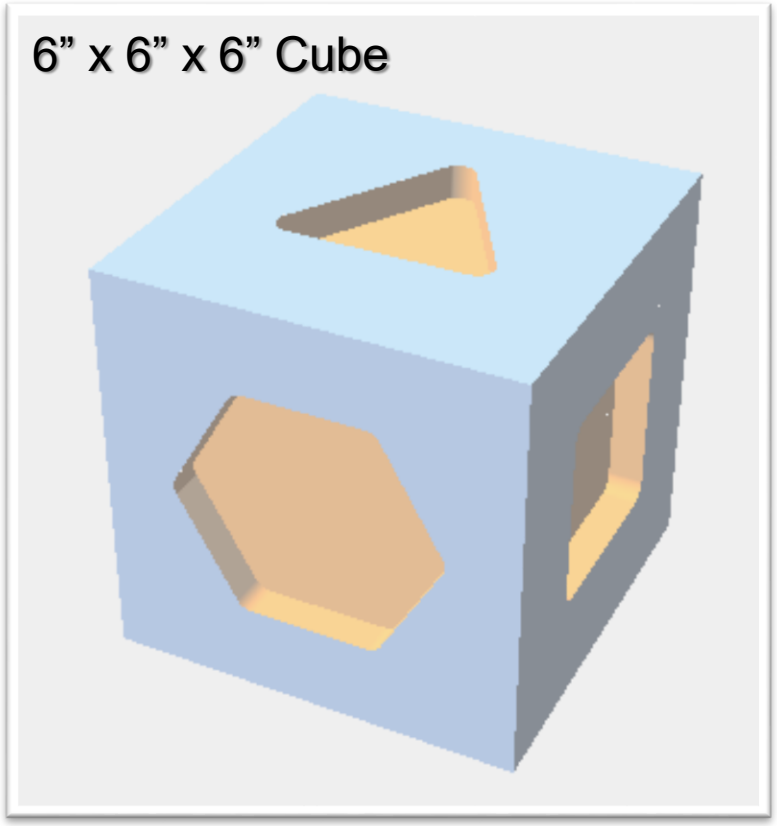
…how easy is it? …can I do it?

…It's as easy as 1-2-3



Right Side

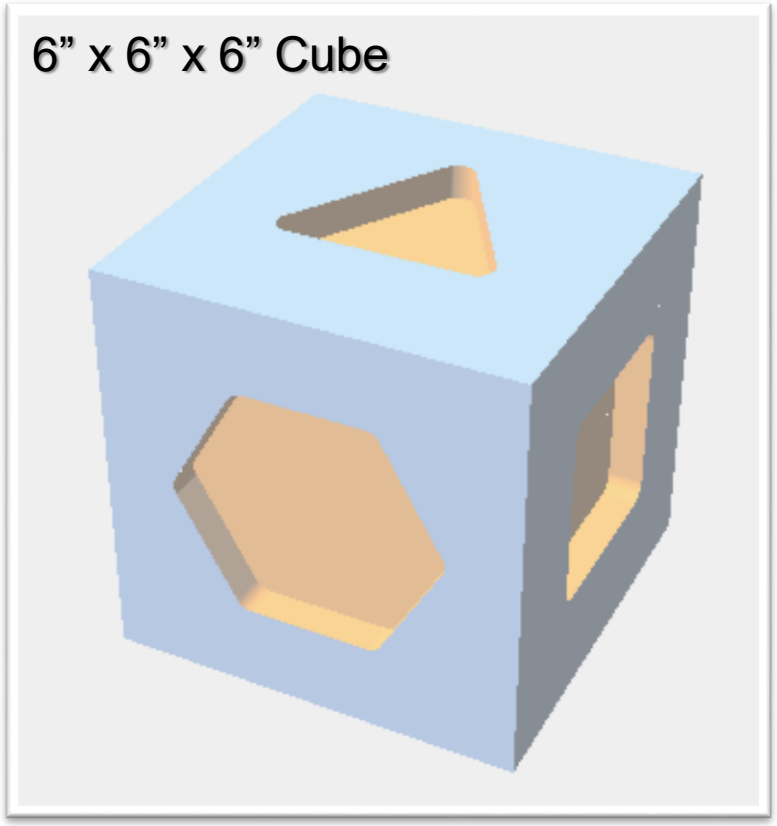
…It's as easy as 1-2-3



Right Side

1. Move the origin point

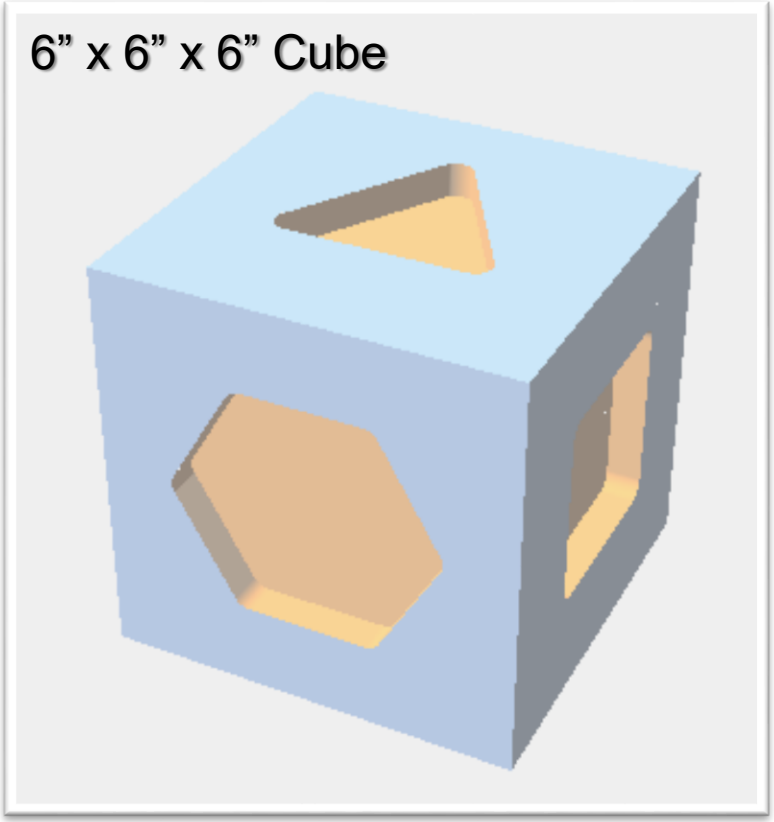
…It's as easy as 1-2-3



Right Side

1. Move the origin point
2. Rotate the workplane

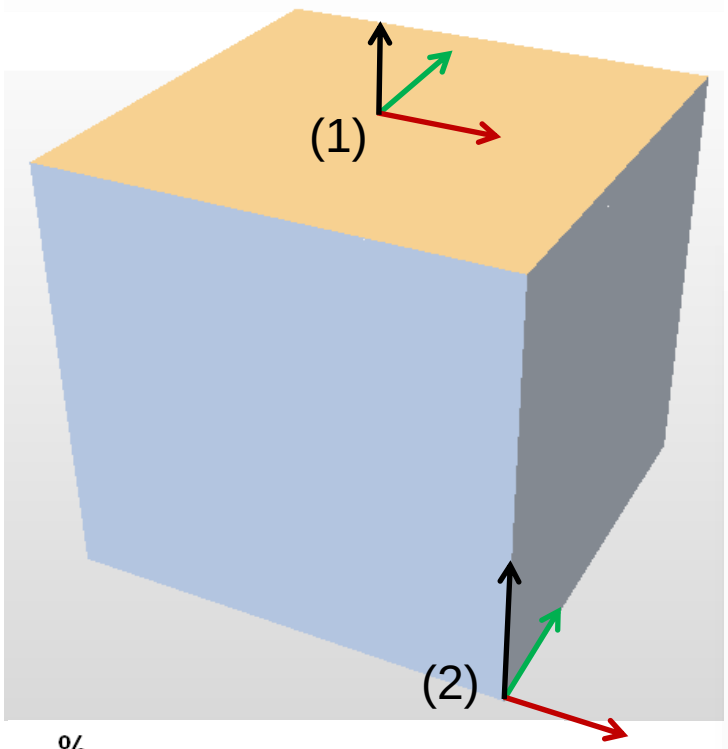
…It's as easy as 1-2-3



Right Side

1. Move the origin point
2. Rotate the workplane
3. Program 3-axis features

Right Side



1. Move the origin point

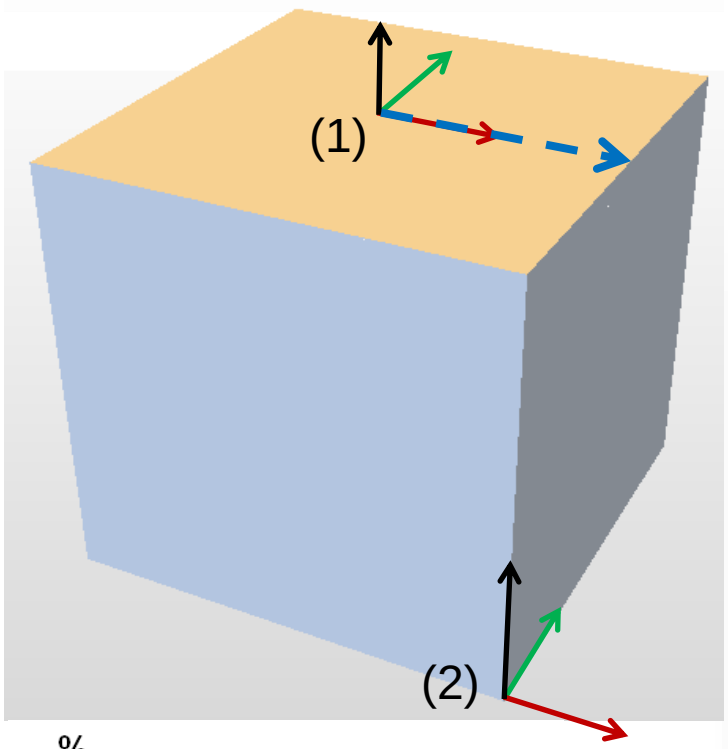
BLOCK 3 TRANSFORM PLANE

ORIENT METHOD ANGLES

ORIGIN POINT		ROTATION ANGLES	
X	3.0000	R(X)	0.000
Y	-3.0000	R(Y)	90.000
Z	-6.0000	R(Z)	0.000

```
%
T1M6
G68.2 X3.0 Y-3.0 Z-6.0 B90
G0 X2.566 Y1.3582
```

Right Side



1. Move the origin point

BLOCK 3 TRANSFORM PLANE

ORIENT METHOD ANGLES

ORIGIN POINT

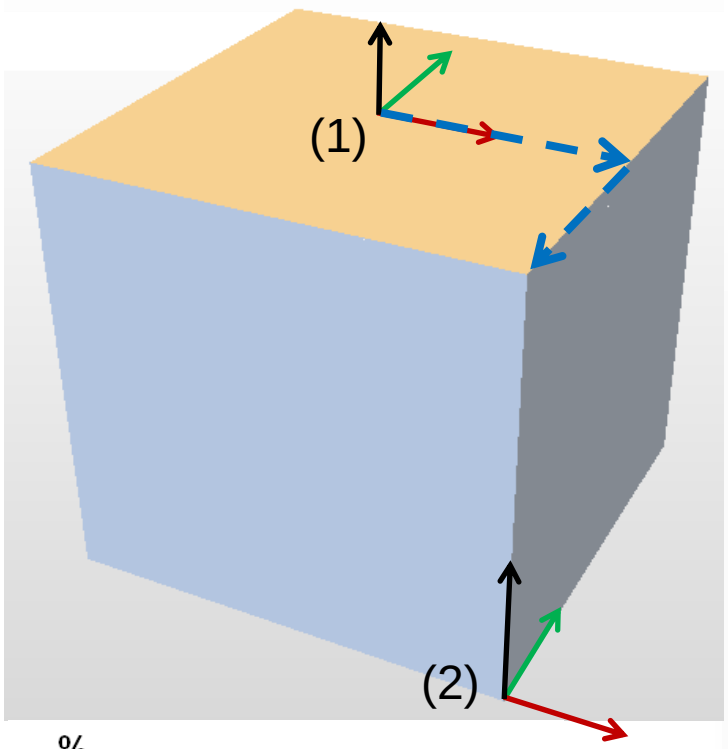
X	3.0000
Y	-3.0000
Z	-6.0000

ROTATION ANGLES

R(X)	0.000
R(Y)	90.000
R(Z)	0.000

```
%
T1M6
G68.2 X3.0 Y-3.0 Z-6.0 B90
G0 X2.566 Y1.3582
```

Right Side



1. Move the origin point

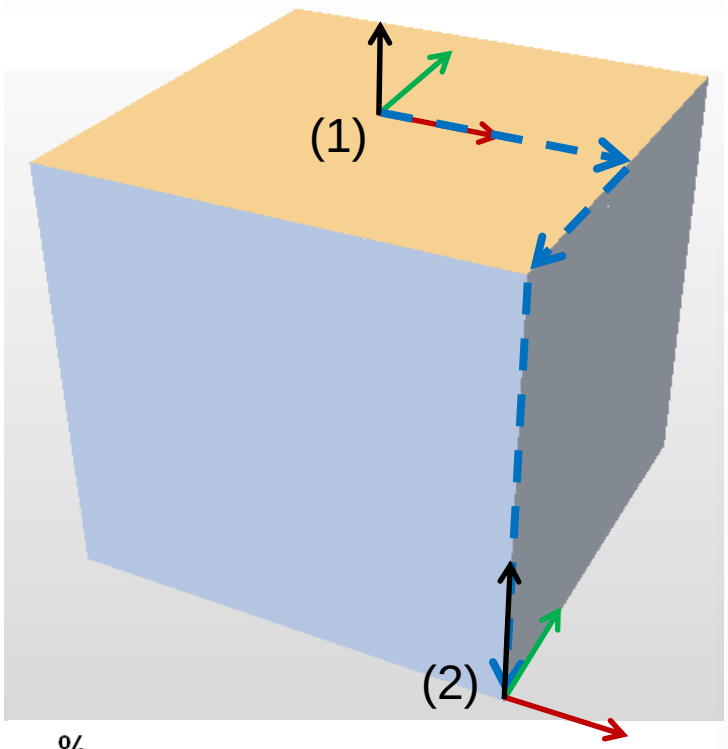
BLOCK 3 TRANSFORM PLANE

ORIENT METHOD ANGLES

ORIGIN POINT		ROTATION ANGLES	
X	3.0000	R(X)	0.000
Y	-3.0000	R(Y)	90.000
Z	-6.0000	R(Z)	0.000

```
%
T1M6
G68.2 X3.0 Y-3.0 Z-6.0 B90
G0 X2.566 Y1.3582
```

Right Side



%
T1M6
G68.2 X3.0 Y-3.0 Z-6.0 B90
G0 X2.566 Y1.3582

1. Move the origin point

BLOCK 3 TRANSFORM PLANE

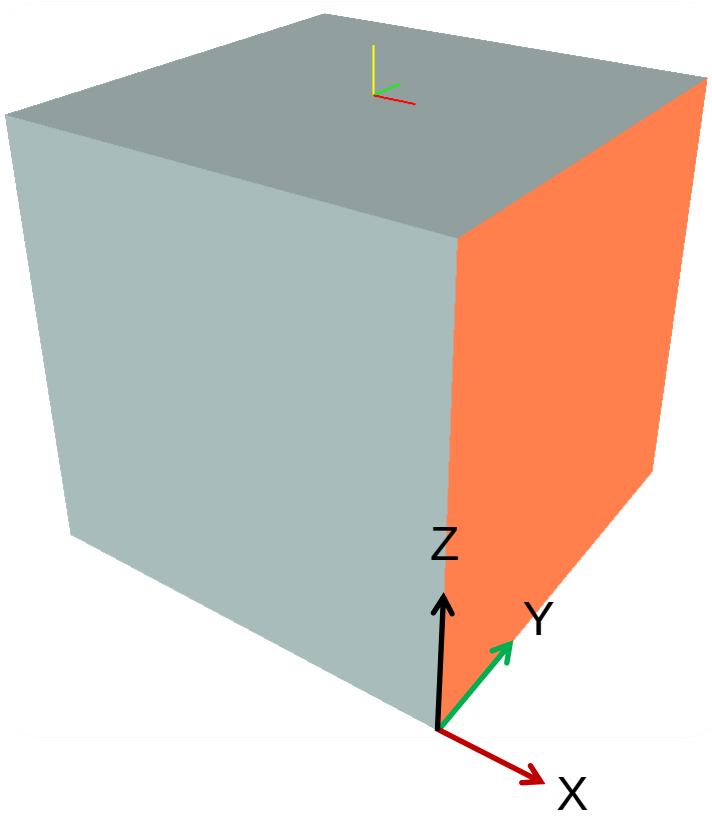
ORIENT METHOD ANGLES

ORIGIN POINT

X	3.0000
Y	-3.0000
Z	-6.0000

ROTATION ANGLES

R(X)	0.000
R(Y)	90.000
R(Z)	0.000



Right Side

2. Rotate the workplane

BLOCK 3 TRANSFORM PLANE

ORIENT METHOD ANGLES

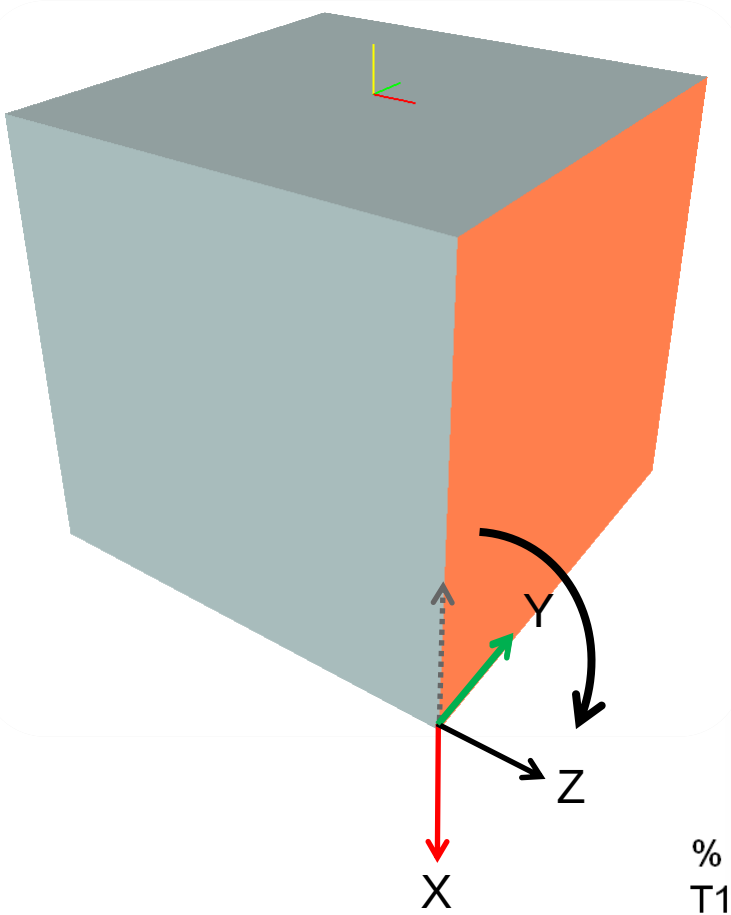
ORIGIN POINT

X	3.0000
Y	-3.0000
Z	-6.0000

ROTATION ANGLES

R(X)	0.000
R(Y)	90.000
R(Z)	0.000

```
%
T1M6
G68.2 X3.0 Y-3.0 Z-6.0 B90
G0 X2.566 Y1.3582
```



Right Side

2. Rotate the workplane

BLOCK 3 TRANSFORM PLANE

ORIENT METHOD ANGLES

ORIGIN POINT

X	3.0000
Y	-3.0000
Z	-6.0000

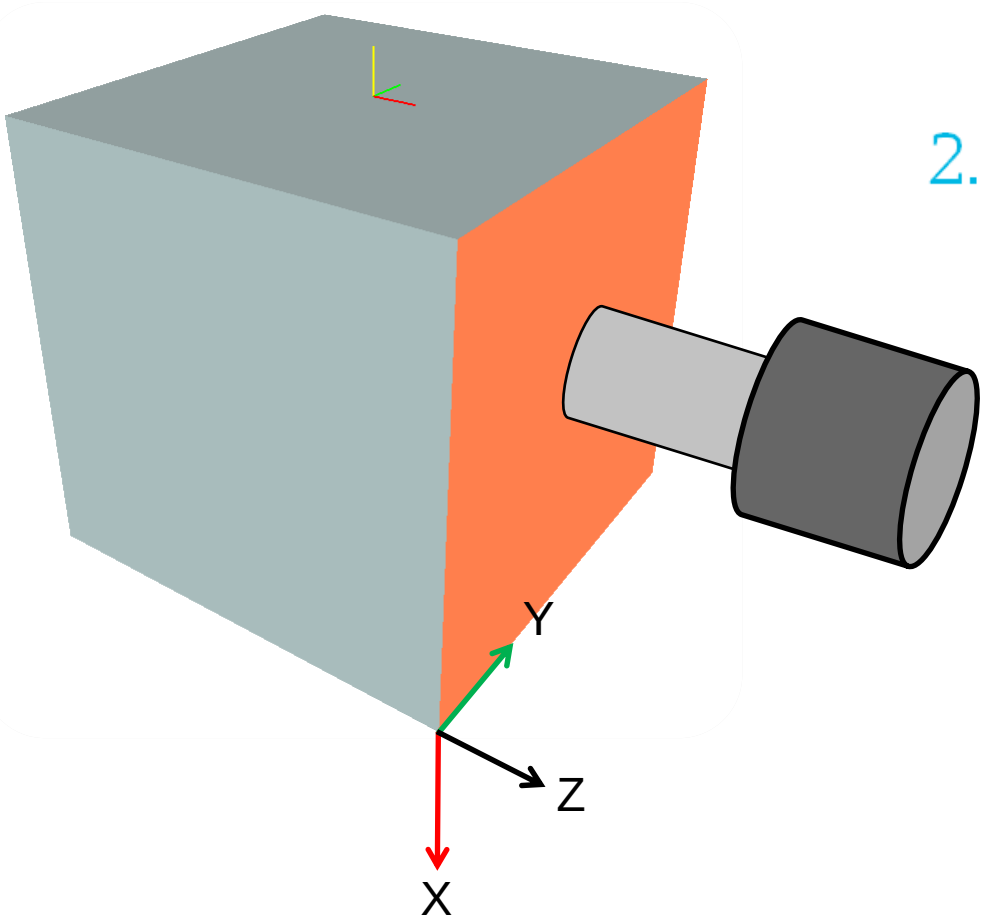
ROTATION ANGLES

R(X)	0.000
R(Y)	90.000
R(Z)	0.000

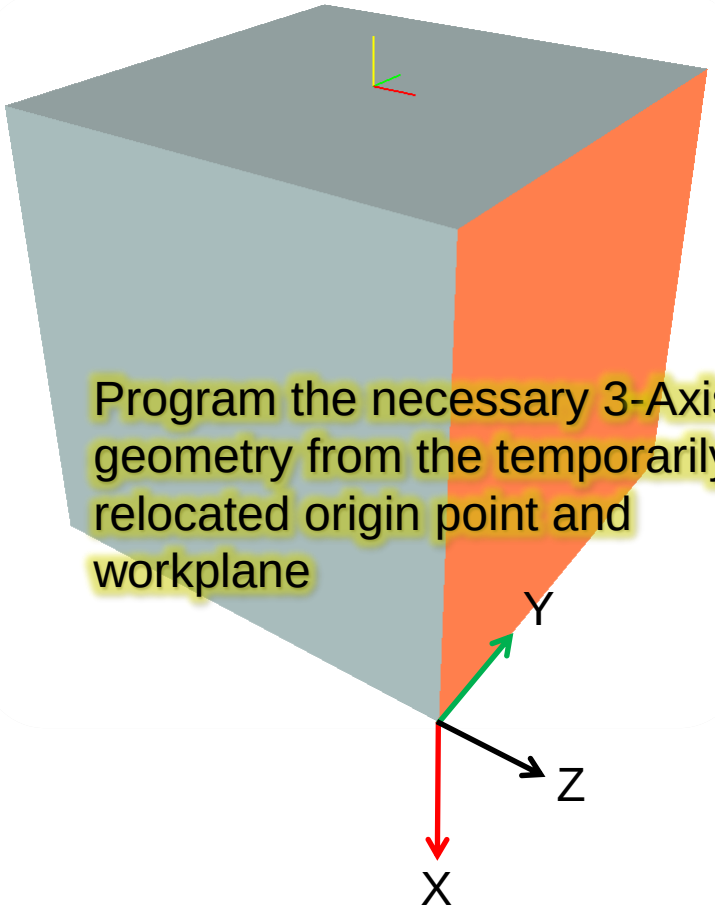
```
%
T1M6
G68.2 X3.0 Y-3.0 Z-6.0 B90
G0 X2.566 Y1.3582
```

Right Side

2. Rotate the workplane



The tool axis is now perpendicular to the newly created workplane



Program the necessary 3-Axis geometry from the temporarily relocated origin point and workplane

Right Side

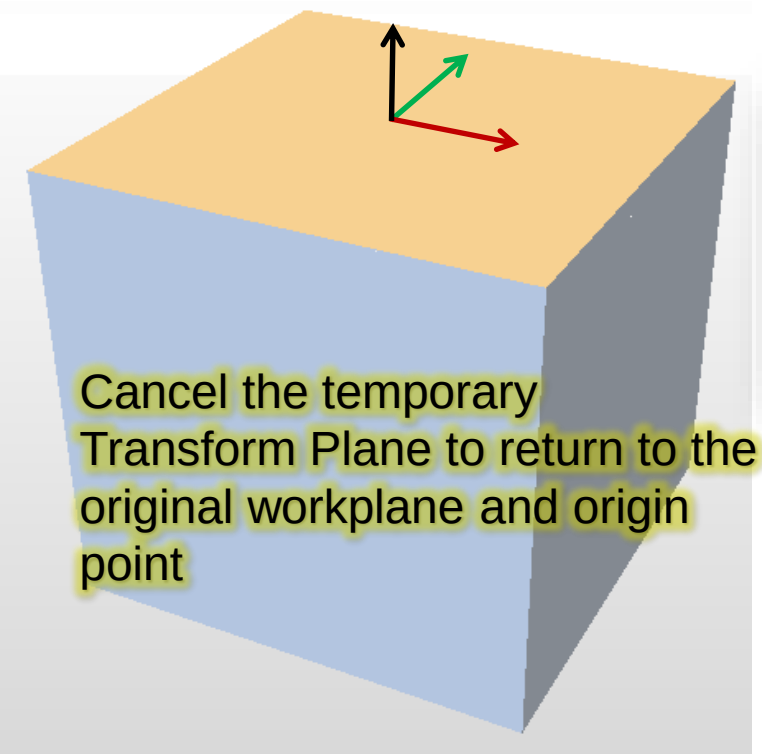
3. Program 3-axis features

BLOCK	5	MILL CIRCLE	
X CENTER	-3.0000	Z START	0.1000
Y CENTER	3.0000	Z BOTTOM	-0.5000
RADIUS	2.5000		

Conversational - OR – G Code

```
%
O2012(HURCO ENGRAVE)
(MATERIAL - ALUMINUM INCH - 2024)
( T1000 |  1/8 BALL ENDMILL )
N100 G20
N102 G0 G17 G40 G49 G80 G90
N104 T1000 M6
```

Right Side



Cancel the temporary Transform Plane to return to the original workplane and origin point

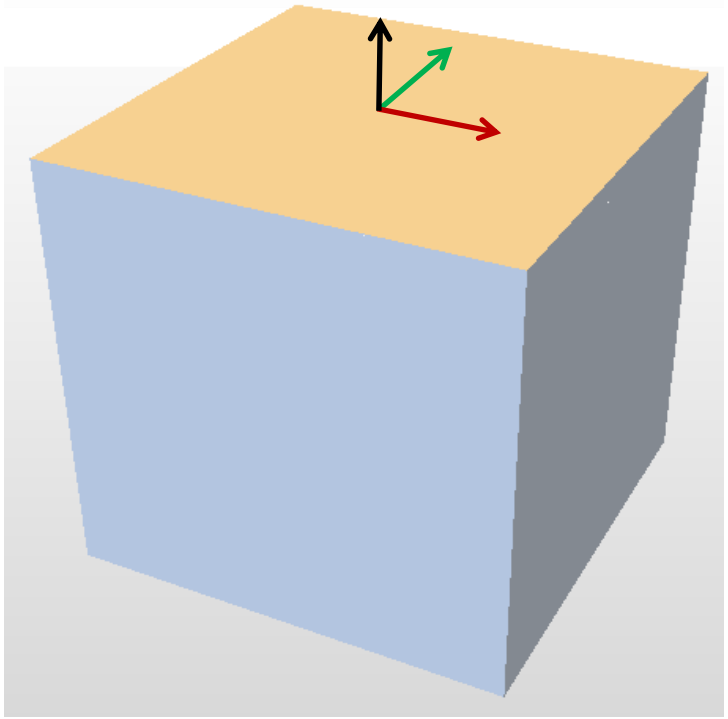
PROGRAM REVIEW SCREEN

DATA BLOCKS	SUB BLOCKS
1. TRANSFORM PLANE	
2. MILL CIRCLE (POCKET BOUNDARY)	
3. TRANSFORM PLANE END	
END OF PROGRAM	

Conversational - OR – G Code

```
X1.56 Y2.1224
G53 Z0
G69
G0 A0 B0
M30
```

…It's as easy as 1-2-3



Wash…

Rinse…

Repeat…

mind over metal℠