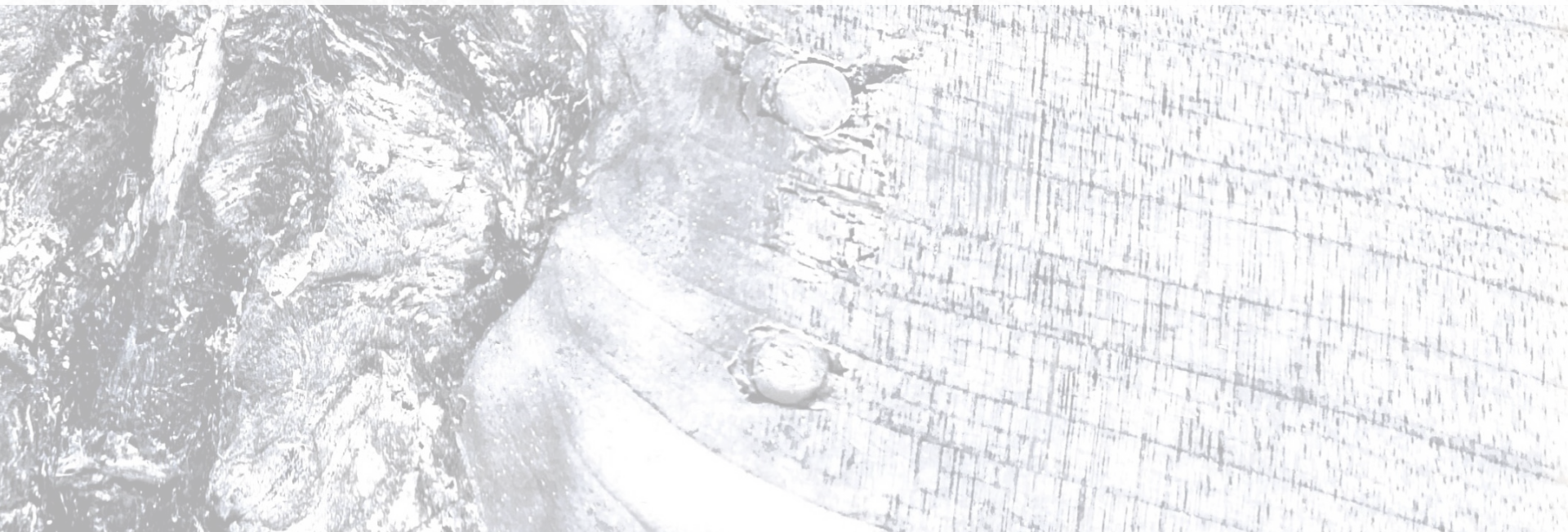
Digital Media Fab Lab

CNC MACHINING DEMONSTRATION

ADVANCED PROTOTYPING: Reverse/Flip Machining for Two-Sided Objects



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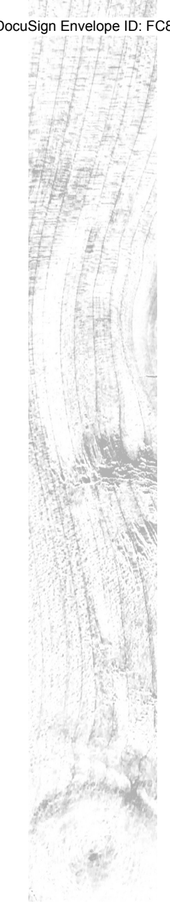
ADVANCED PROTOTYPING: Reverse/Flip Machining for Two-Sided Objects

CONTENTS



One way to create a multi-sided object through automated Reductive Manufacturing is by designing a single program that includes a material part reversal. The following information demonstrates the process of programming with Autodesk Fusion360 for rapid prototyping with a Carbide3D Nomad 883 Pro CNC Machine.

To create the Demonstration Object, we (1) set a design objective, (2) designed an object, (3) programmed toolpaths with Autodesk Fusion 360, (4) prepared the material stock, (5) processed material stock with a Carbide3D Nomad 883 Pro CNC Machine, (6) refined toolpaths, and (7) created the final prototype object.

- Design Objective: To efficiently create a sustainable fabrication process for a multi-sided one-off object, intended for rapid design evolution.

  - Minimal Material Investment and Waste
    - 100% biodegradable/clean/sustainable/plant-based prototype material
    - Closed-Loop Waste Stream
  - Minimal Effort Towards Unnecessary Action
    - Create a Version 01 Prototype without fabricating a material stock jig

Toolpath Programming in Autodesk Fusion360 for Machining with a Carbide3D Nomad 883 Pro CNC Machine

- Open a 3D Model in Autodesk Fusion360

  - Setup the Program with Machine and Material Information
    - Change Workspace to < Manufacture >
    - On the top toolbar, choose Setup < New Setup >
    - On the Setup toolbar, < Setup > Tab, select the machine < 3-axis–Gantry with Moving-Table >
    - Choose and Set, Setup parameters, Work Coordinate System, and Select Model
    - On the Setup toolbar, < Stock > Tab, set the Material Stock Size
    - On the Setup toolbar, < Post Process > Tab, specify Program identity, and Machine Work Coordinate System settings

The Demonstration Object program has two Setups, one for each side of the object. The difference between the two Setups is the point on the material stock that the Work Coordinate System is aligned to. The placement of the Work Coordinate System defines the (0,0) reference point location on the material to be cut.

Side 00 – Setup 12

- On the Setup toolbar < Setup > Tab, < Work Coordinate System > setting, we chose to place the (0,0) location at the top, bottom left corner of the material stock image 1
- On the Setup toolbar < Stock > Tab, we set the stock size to the size of the material to be cut and set the model to be centered within the material stock image 2 page 12
- On the Setup toolbar < Post Process > Tab, we wrote a descriptive Program Name and Comment to reference during future iterations image 3 page 12

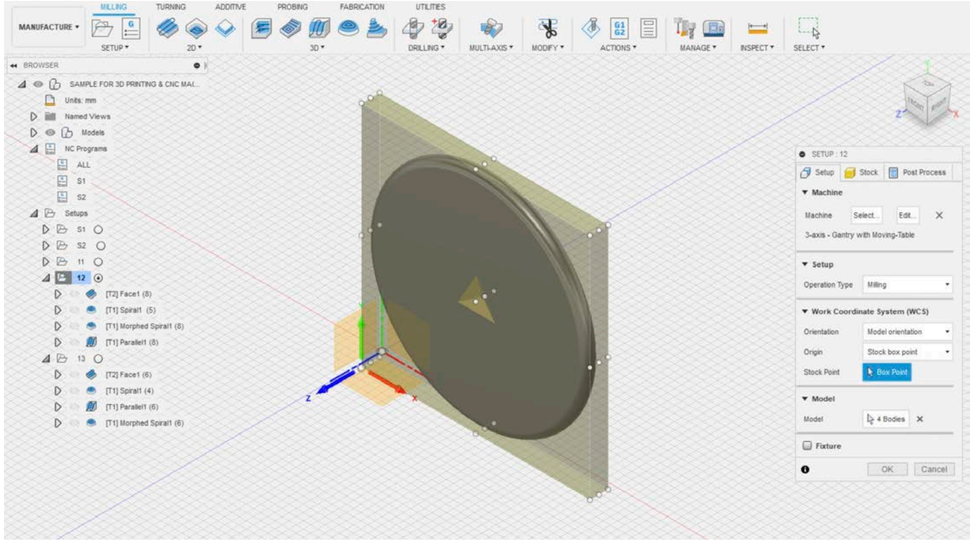


image 1 - Side 00 _ Setup 12, detail of Setup Tab. Autodesk Fusion 360.

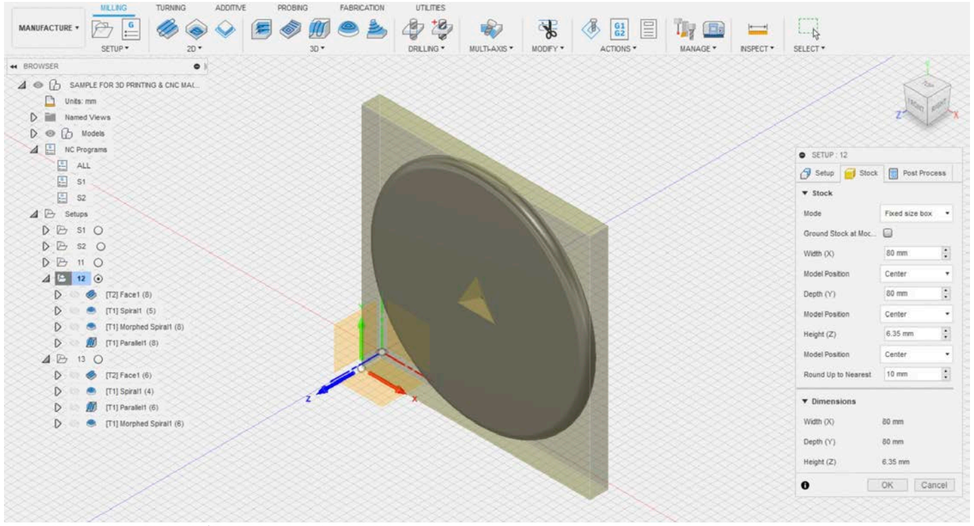


image 2 - Side 00 _ Setup 12, detail of Stock Tab. Autodesk Fusion 360.

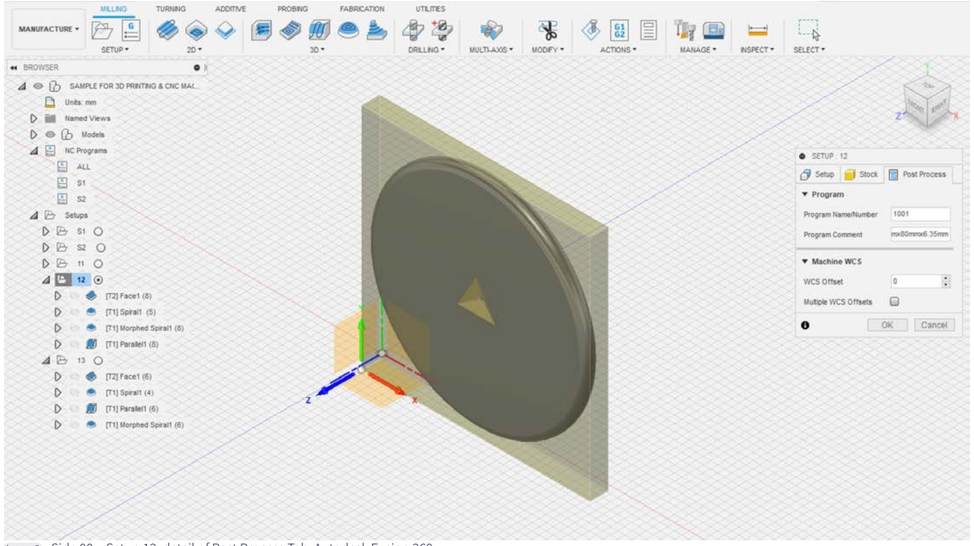


image 3 - Side 00 _ Setup 12, detail of Post Process Tab. Autodesk Fusion 360.

Side 01 – Setup 13

Side 01 has a different Work Coordinate System. We chose to flip the material along the x-axis. To maintain the orientation of the geometry on each side of the object, we programmed the top right corner of the material stock to be the (0,0) location. The < Stock > Tab information is identical to Side 00, and the < Post Process > Tab Program Name/Number is adjusted slightly image 4 image 5 , image 6 page 14

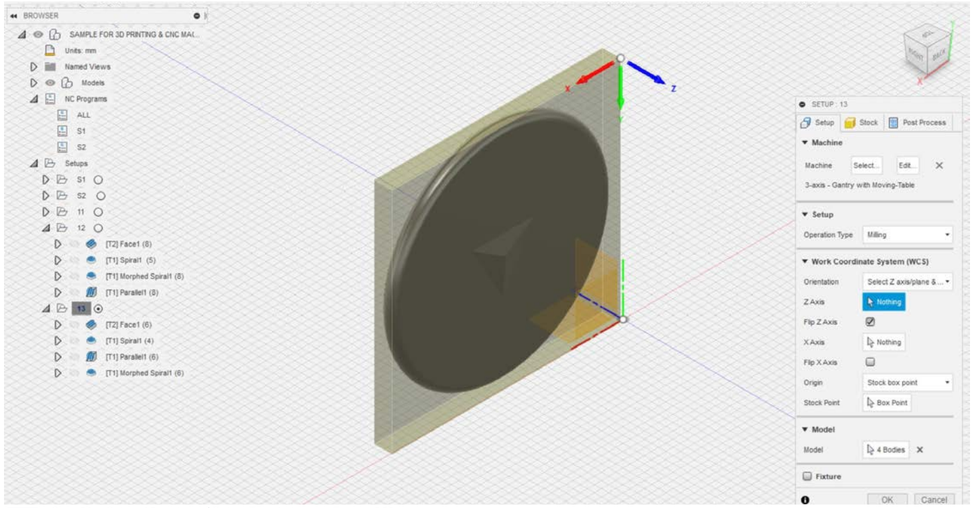


image 4 - Side 01 _ Setup 13, detail of Setup Tab. Autodesk Fusion 360.

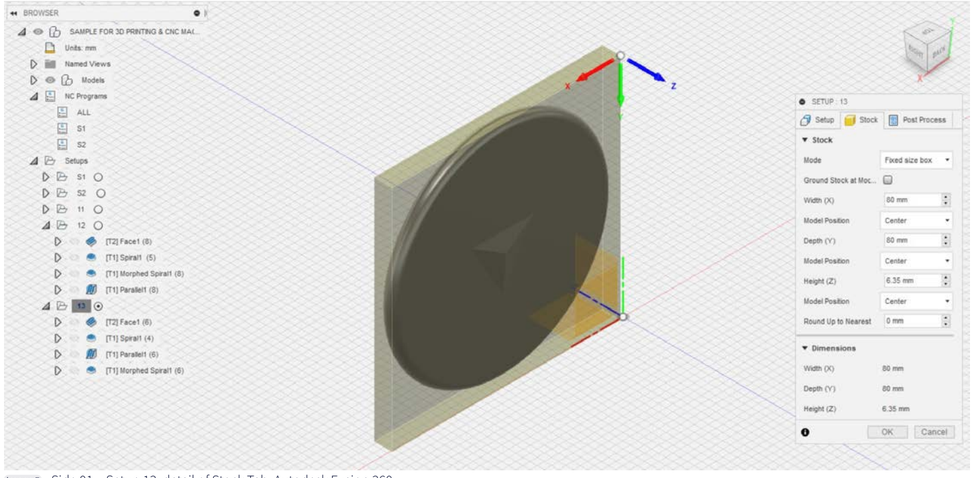


image 5 - Side 01 _ Setup 13, detail of Stock Tab. Autodesk Fusion 360.

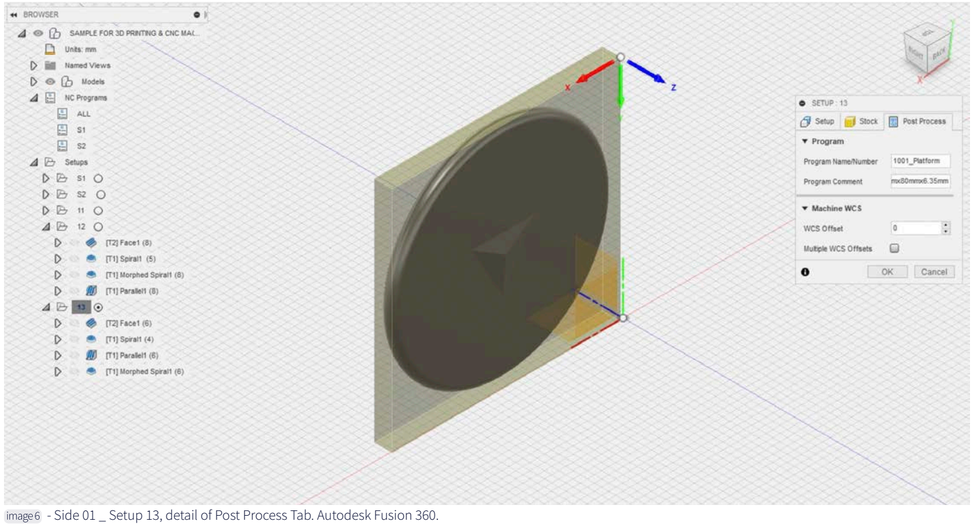


image 6 - Side 01 _ Setup 13, detail of Post Process Tab. Autodesk Fusion 360.

While working towards the ideal settings, toolpaths, and simulations, we created several Setups. The Side 00 _ Setup 12, and Side 01 _ Setup 13 are those contained within the code utilized for the creation of the Demonstration Object Basswood Prototype. Information about previous Setups and prototyping iterations are contained within the Prototype section of this demonstration page 45

▼ Create a Custom Tool Bit or Choose one from the Tool Library

There are several ways within Autodesk Fusion360 to access the tool library for the creation of a Tool Bit. You can either do this before programming the toolpaths, or during the Setup unique to the model.

Before Toolpath Program

- Open the Tool Library by choosing Manufacture < Manage < Tool Library
- On the left side toolbar, select All < Local < Library
  - On the interior panel, click the New Tool (“+”) icon
    - Choose the end mill type and define the Tool Bit specifications in the General, Cutter, and Shaft Tabs image 1 image 2 & image 3 page 16

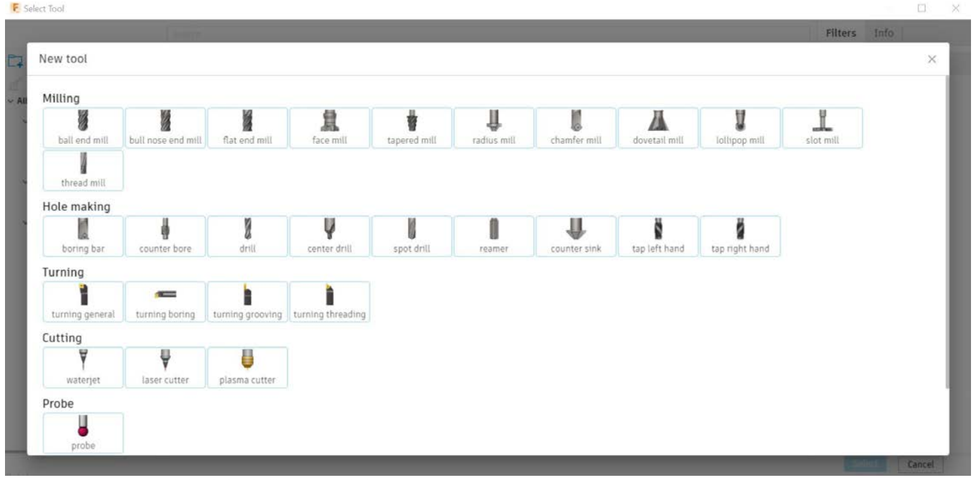


image 1 - Tool Library, New Tool, detail of End Mill types. Autodesk Fusion 360.

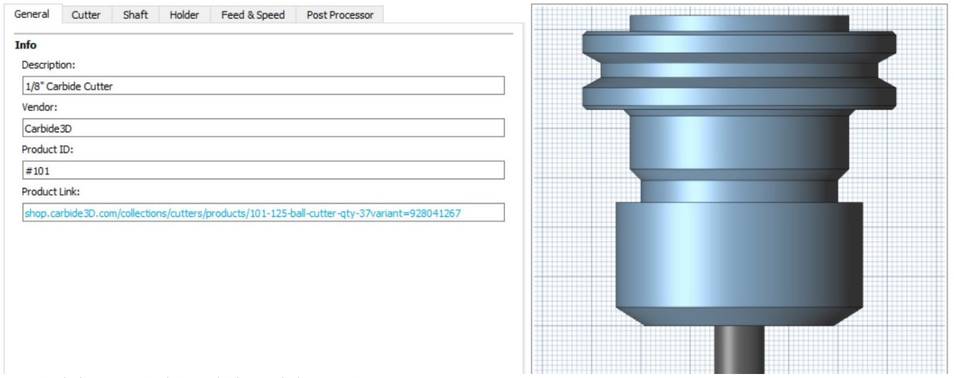


image 2 - Tool Library, New Tool, General Tab. Autodesk Fusion 360.

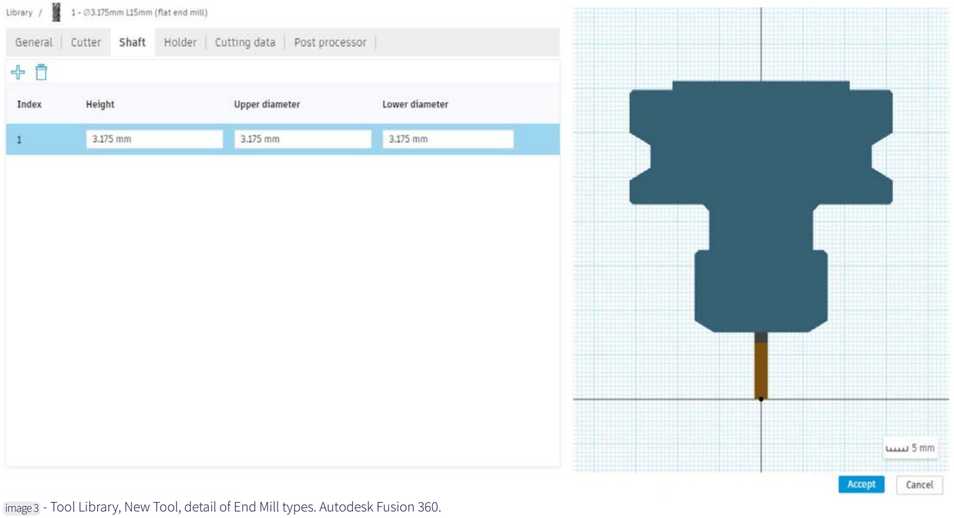


image 3 - Tool Library, New Tool, detail of End Mill types. Autodesk Fusion 360.

- Custom Tool Bits can be modified while managing the Tool Library. Open the Tool Library by choosing Manufacture < Manage < Tool Library. On the left side toolbar, select All < Local < Library. Select the Tool Bit, right click, for < Edit Tool >, < Copy Tool >, < Duplicate Tool >, < Renumber Tool >, < Delete Tool > image 4

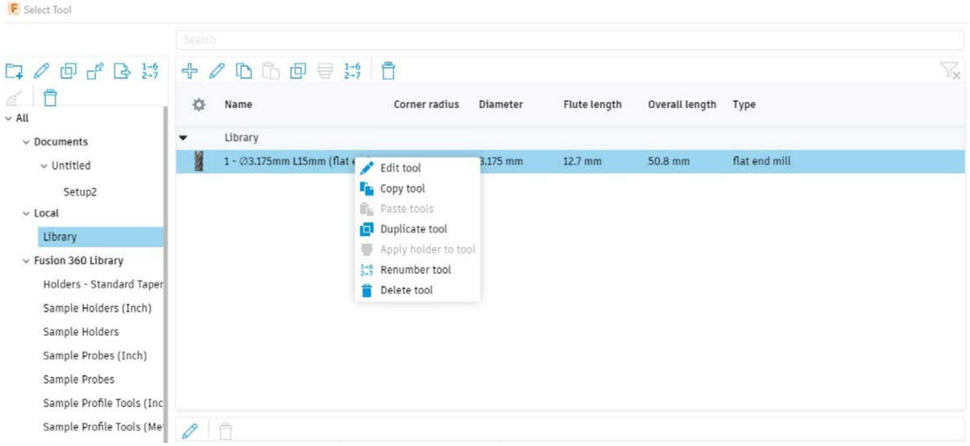


image 4 - Tool Library, Local, Library, detail of possible Tool Bit modifications. Autodesk Fusion 360.

- In the Holder Tab < set Holder image 5

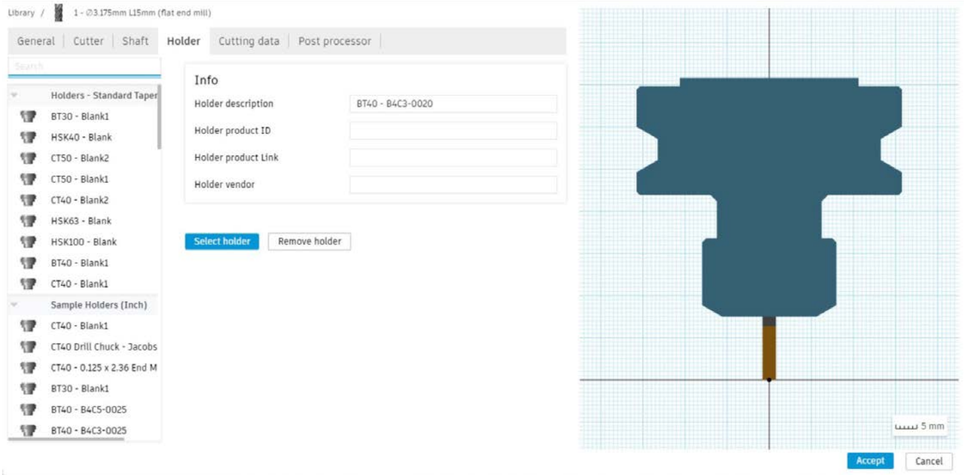


image 5 - Tool Library, New Tool, Holder Tab. Autodesk Fusion 360.

- In the Feed & Speed Tab < set Spindle speed and Cutting feedrate image 6
  - References
    - Carbide3D Nomad 883 Pro Machine Specifications
    - Carbide3D Nomad 883 Pro Feeds & Speeds Chart

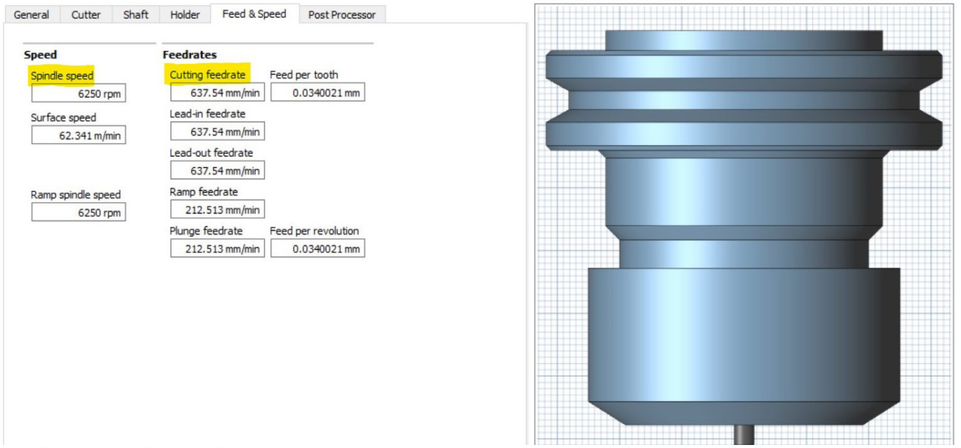


image 6 - Tool Library, New Tool, Holder Tab. Autodesk Fusion 360.

- *During Toolpath Program*
- Begin a toolpath program by choosing Manufacture < (2D/3D/Drilling/Multi-Axis) < choose a tool process
- On the toolpath menu < Tool > tab, choose < Select… > to open the Tool Library
- On the left side toolbar, select All < Local < Library
  - On the interior panel, click the New Tool (“+”) icon
    - Choose the end mill type and define the Tool Bit specifications in the General, Cutter, and Shaft Tabs image 1 image 2 & image 3 page 19

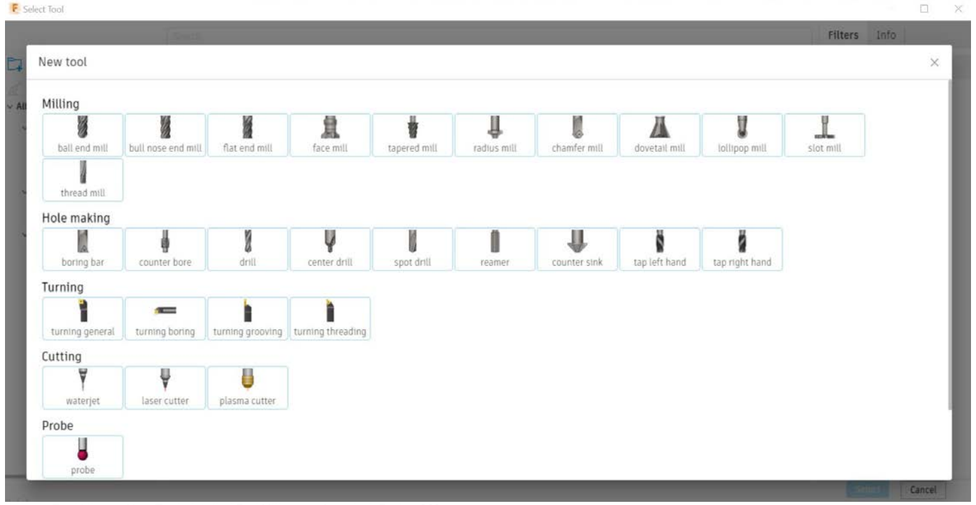


image 1 - Tool Library, New Tool, detail of End Mill types. Autodesk Fusion 360.

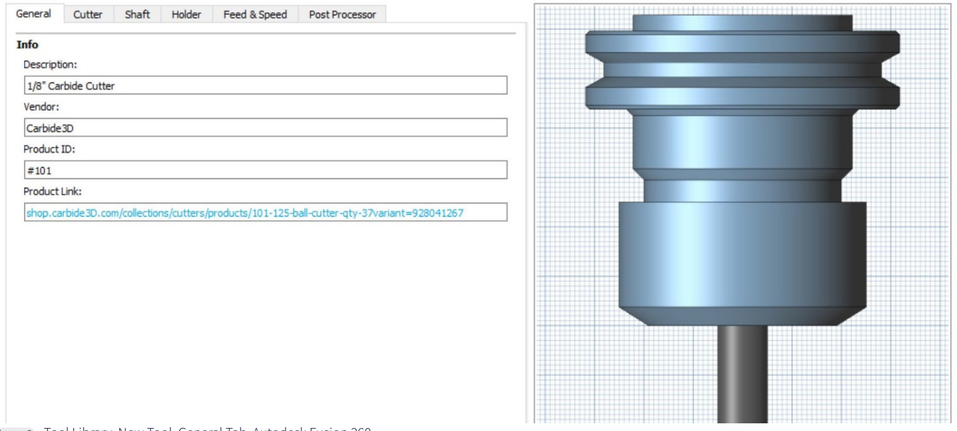


image 2 - Tool Library, New Tool, General Tab. Autodesk Fusion 360.

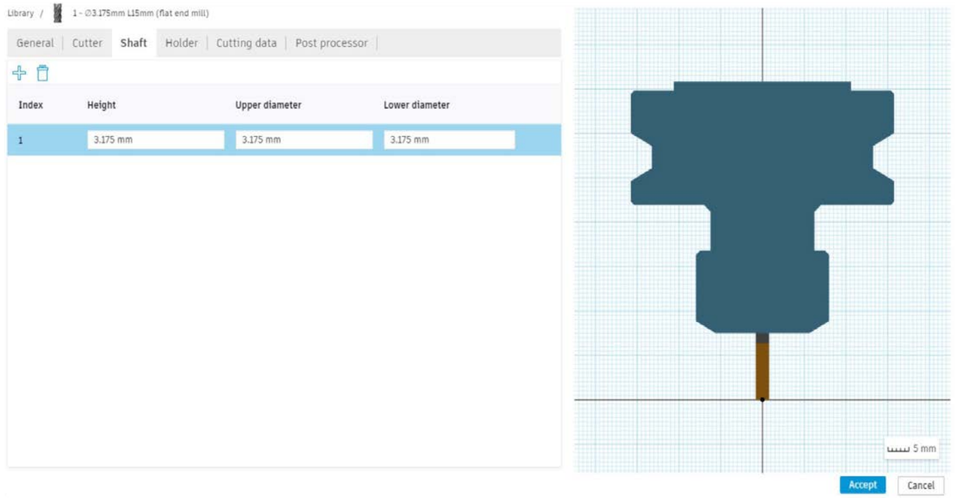


image 3 - Tool Library, New Tool, detail of End Mill types. Autodesk Fusion 360.

- Custom Tool Bits can be modified while managing the Tool Library. Open the Tool Library by choosing Manufacture < Manage < Tool Library. On the left side toolbar, select All < Local < Library. Select the Tool Bit, right click, for < Edit Tool >, < Copy Tool >, < Duplicate Tool >, < Renumber Tool >, < Delete Tool > image 4 .

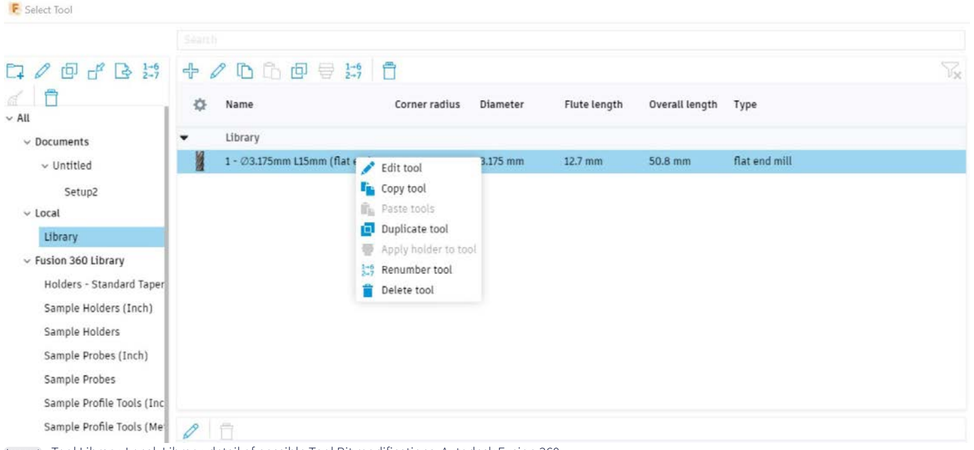


image 4 - Tool Library, Local, Library, detail of possible Tool Bit modifications. Autodesk Fusion 360.

- In the Holder Tab < set Holder image 5

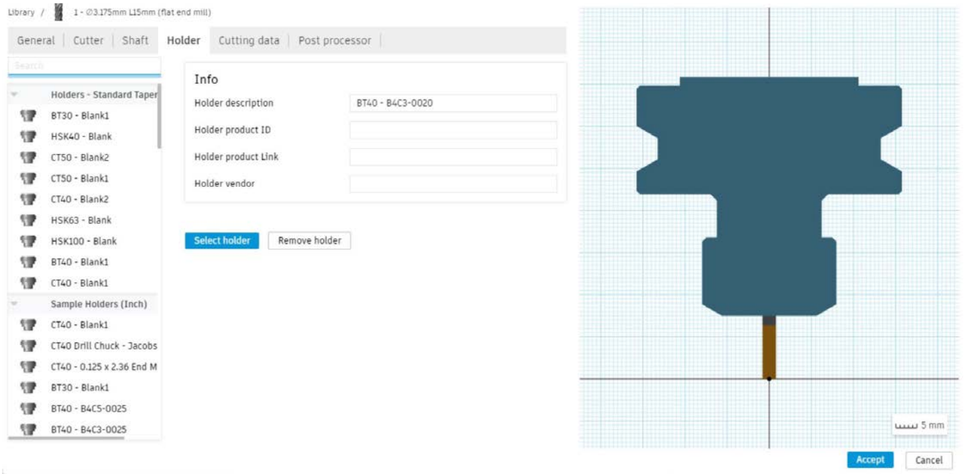


image 5 - Tool Library, New Tool, Holder Tab. Autodesk Fusion 360.

- In the Feed & Speed Tab < set Spindle speed and Cutting feedrate image 6
  - References
    - Carbide3D Nomad 883 Pro Machine Specifications
    - Carbide3D Nomad 883 Pro Feeds & Speeds Chart

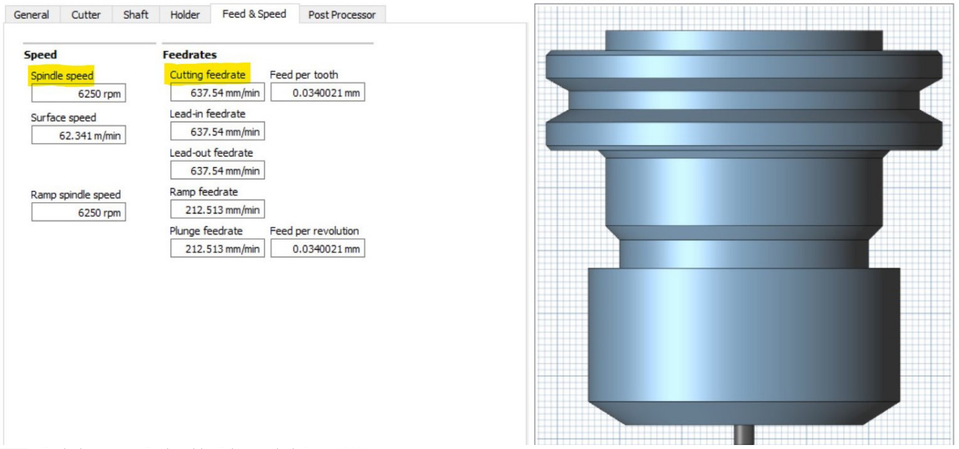


image 6 - Tool Library, New Tool, Holder Tab. Autodesk Fusion 360.

- Program a Toolpath
  - Begin a toolpath program by choosing Manufacture < (2D/3D/Drilling/Multi-Axis) < choose a toolpath process
  - On the toolpath menu < Tool > tab, choose < Select… > to open the Tool Library
  - Choose a Tool Bit from the Tool Library OR program a custom Tool Bit
  - Set the Speeds & Feeds. Speeds & Feeds will automatically set to the Tool Bit's settings. To modify a preset Speed or Feed, enter adjustments on the < Tool > tab
  - On the toolpath menu < Geometry > tab, select the area to be machined, and specify any other additional parameters (Stock Contours, Tool Containment, Offset Distance, Contact Point Boundary, Rest Machining, Tool Orientation, etc.)
  - On the Toolpath menu < Heights > tab, set distance values for the Tool Bit movement between processes, processing heights and depths
  - On the Toolpath menu < Passes > tab, set the variables while taking into consideration the Tool Bit's workload and the desired aesthetic
  - On the Toolpath menu < Linking > tab, optimize the machining process, leads, and transitions

The Toolpath Program for the Demonstration Object contains eight toolpaths; four on each side. To decide on a toolpath process, consider the desired form and material finish. Namely, A PCB circuit board may require a single toolpath on each side for the formation of channels but, a three-dimensional metal object with holes may require clearing, drilling, finishing, and profiling. Beyond functionality, toolpath processes can add aesthetic and conceptual value to the object produced.

- Stock Contours, Tool Containment, Offset Distance, Contact Point Boundary, Rest Machining, Tool Orientation

Side 00 – Setup 12's Spiral toolpath contains precise edge settings. Notice the differences in the two simulated machining processes:

- Tool Containment – Tool center on boundary image 1 & image 2 image 3 on page 22
- Tool Containment – Tool center on boundary + .04mm Offset Distance image 4 image 5 on page 23 & image 6 page 24

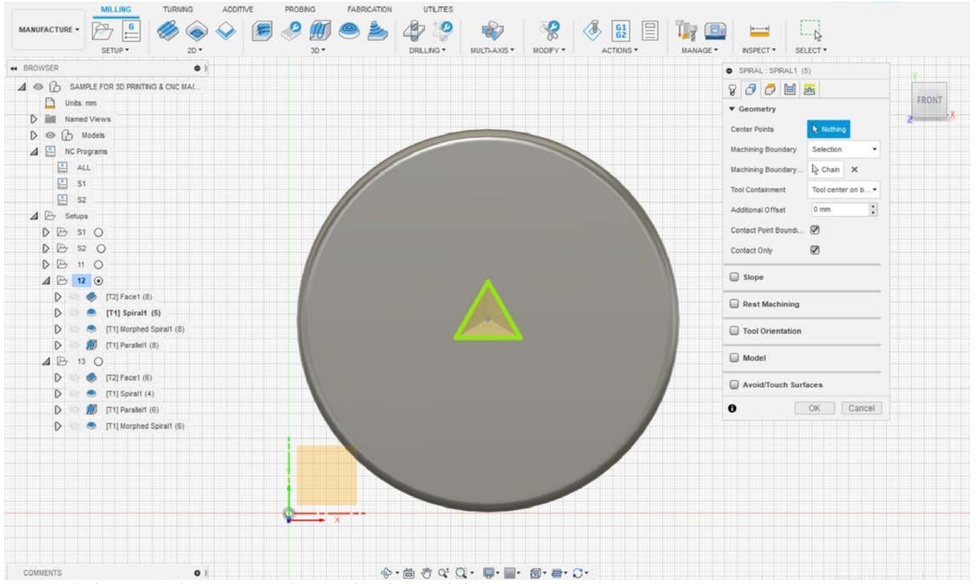


image 1 - Toolpath Settings, Tool Containment: Tool center on boundary. Autodesk Fusion 360.

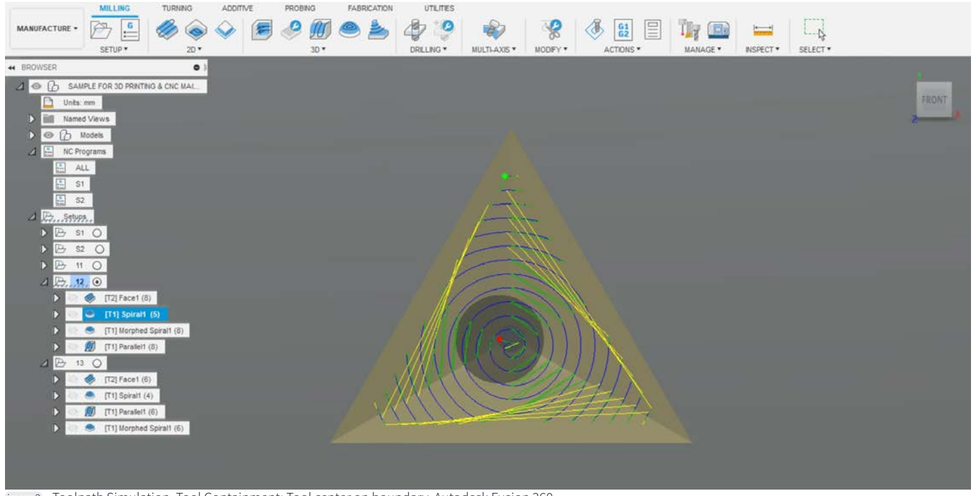


image 2 - Toolpath Simulation, Tool Containment: Tool center on boundary. Autodesk Fusion 360.

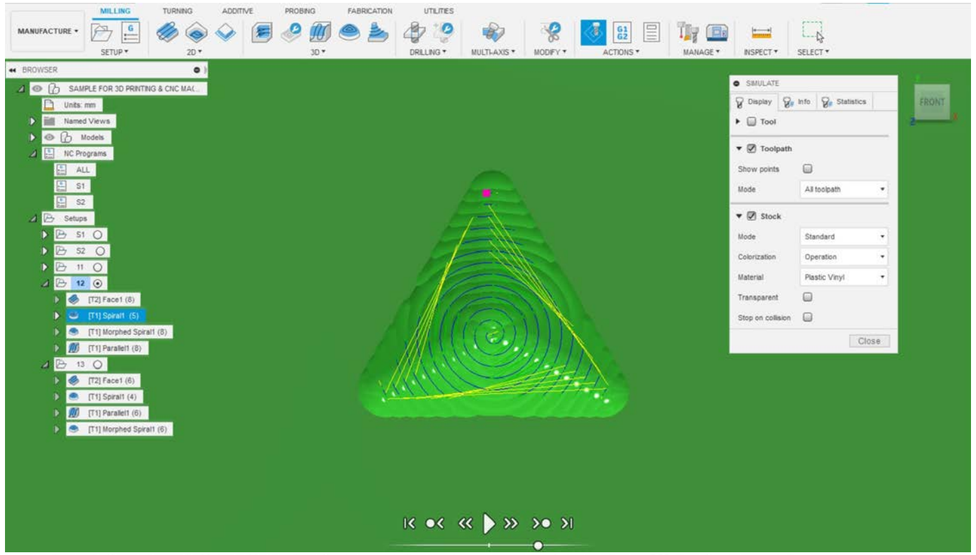


image 3 - Toolpath Simulation with Material Visible, Tool Containment: Tool center on boundary. Autodesk Fusion 360. Tool Containment. Tool center on boundary. Autodesk Fusion 360.

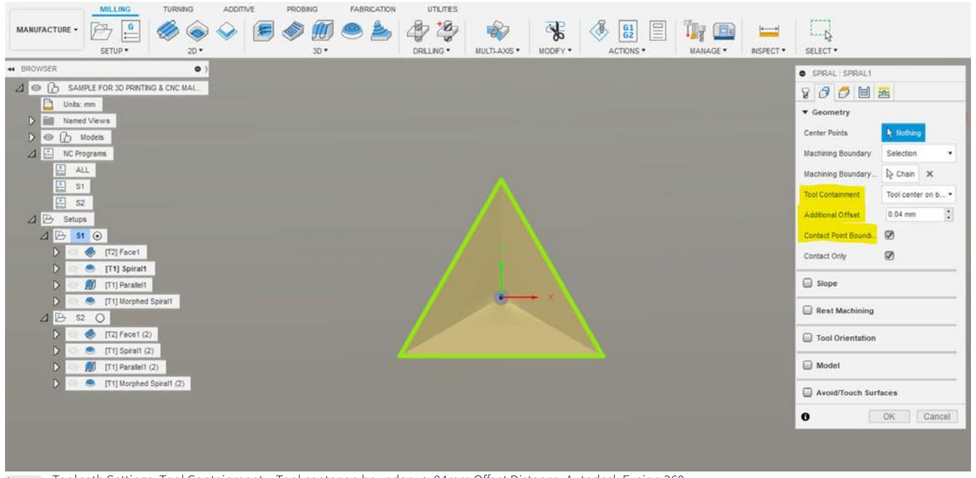


image 4 - Toolpath Settings, Tool Containment – Tool center on boundary + .04mm Offset Distance. Autodesk Fusion 360.

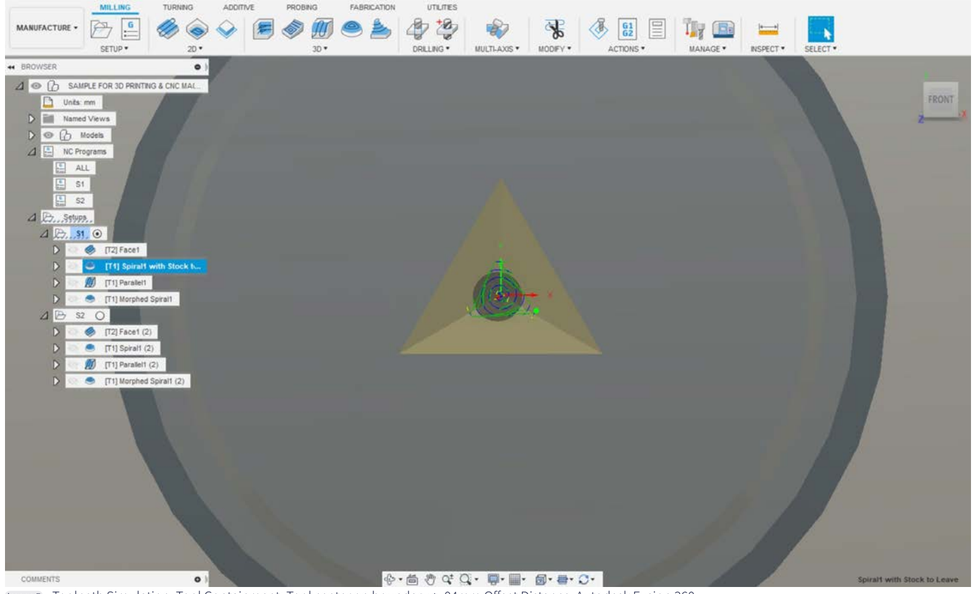


image 5 - Toolpath Simulation, Tool Containment: Tool center on boundary + .04mm Offset Distance. Autodesk Fusion 360.

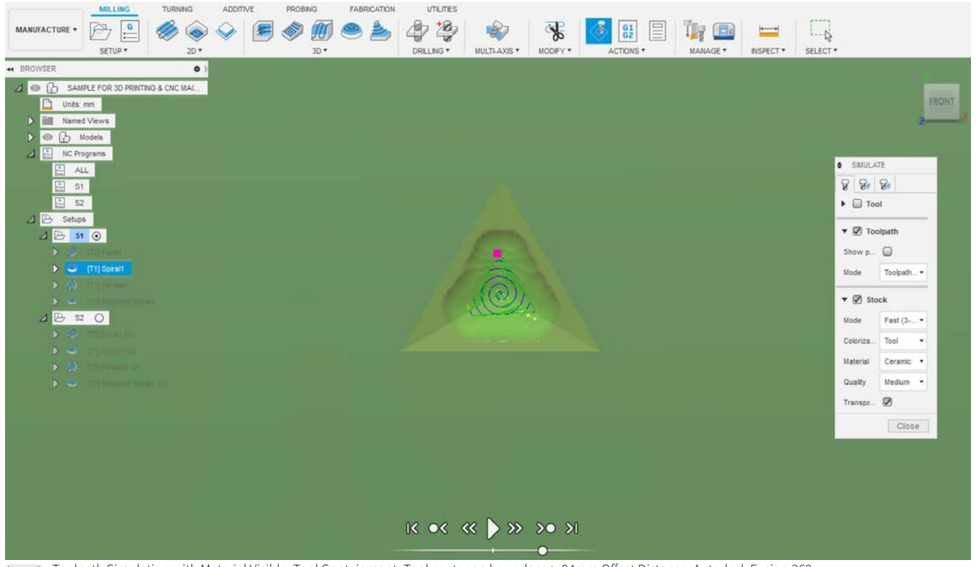


image 6 - Toolpath Simulation with Material Visible, Tool Containment: Tool center on boundary + .04mm Offset Distance. Autodesk Fusion 360.

- Choose to set settings according to the intended aesthetic. To smooth transitions between surfaces on an object, consider adding a finishing toolpath. The Demonstration Object's Side 00 – Setup 12's program contains three "roughing" toolpaths (Face, Spiral, Morphed Spiral) that remove material bulk, before a final "finishing" toolpath (Parallel image 7). The finishing toolpath cleans and refines the edges on the surface. An ideal finishing toolpath will prepare the surface for a minimal amount of hand finishing.

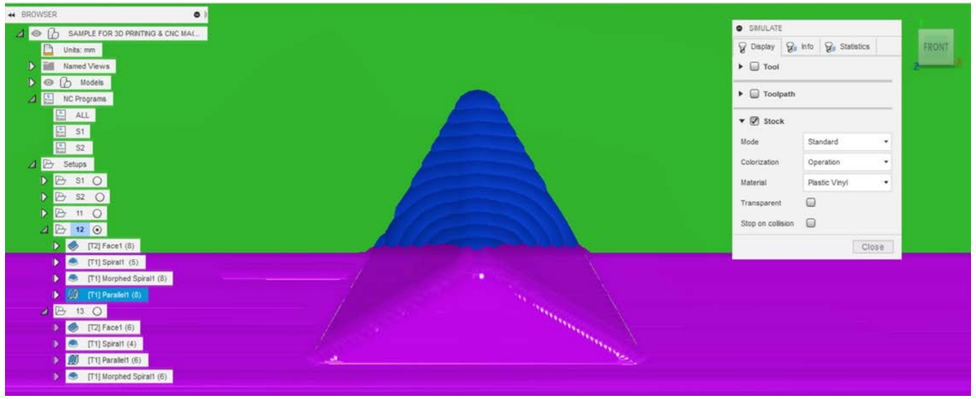


image 7 - Paused Toolpath Simulation with material stock visible, and colorization set to code by operation. Green; Facing. Blue; Spiral. Purple; Parallel. Autodesk Fusion 360.

▼ Generate Toolpaths

- Choose the Setup or Toolpath to be generated
- In the < Manufacture > Workspace, < Actions > Tab, choose < Generate >

For the Demonstration Object, we refined settings, toolpaths, and simulations multiple times in order to maintain the integrity of the 3D Model design. Toolpaths can be generated individually or as a group. Generating toolpaths individually may become necessary as the need to refine variables within the toolpath arise (see Prototype section, page 45).

▼ Simulate Toolpaths

- Choose the Toolpath or Setup to simulate
- On the < Manufacture > toolbar, < Actions > Tab, choose < Simulate >
- On the Simulate Menu < Display > Tab, set the Tool, Toolpath, and Stock visibility
- On the Simulate Menu < Info > Tab, view Tool Bit position during simulation, Toolpath Information, Machining Time, Machining Distance, Operations, and Tool Changes
- Located at the bottom of the Workspace above the < Navigation Toolbar >, controls to < Start > the simulation, < Move > between toolpaths, and change < Speed > are available

Demonstration Object toolpath previews and toolpath simulations image 1 - image 8 on page 25 - page 29

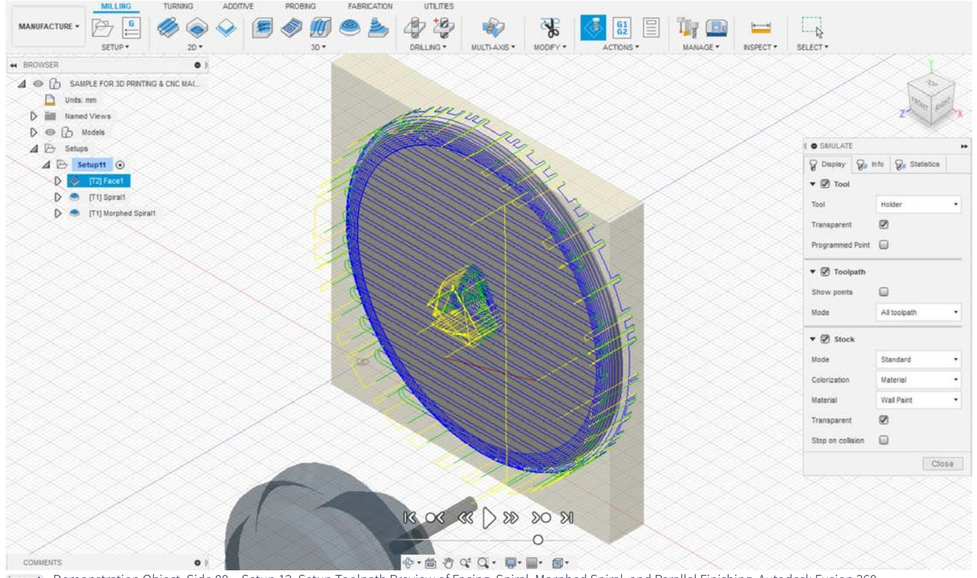


image 1 - Demonstration Object, Side 00 _ Setup 12, Setup Toolpath Preview of Facing, Spiral, Morphed Spiral, and Parallel Finishing. Autodesk Fusion 360.

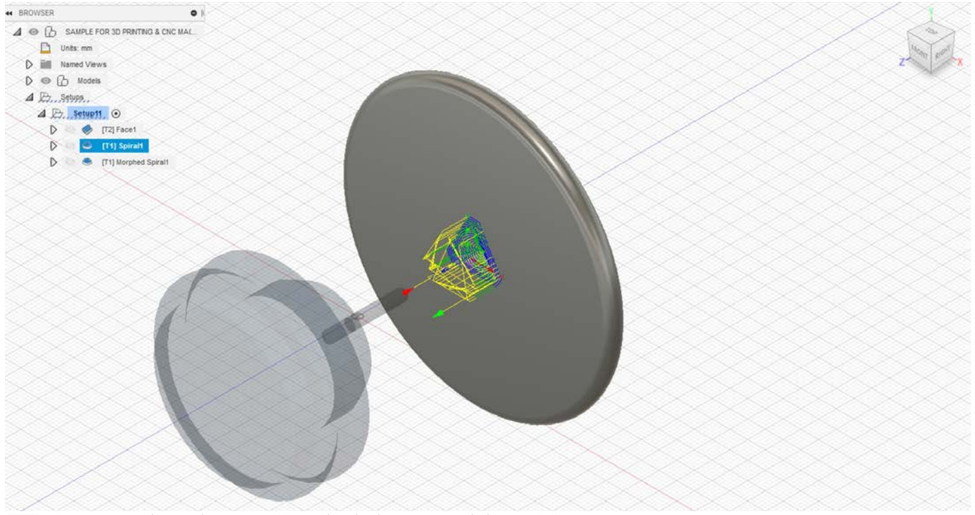


image 2 - Demonstration Object, Side 00 _ Setup 12, Spiral Toolpath Preview. Autodesk Fusion 360.

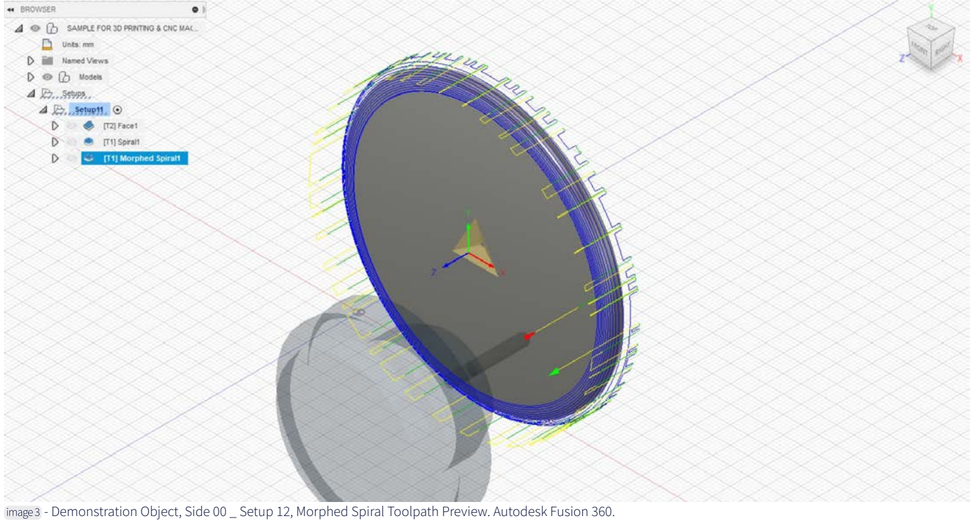


image 3 - Demonstration Object, Side 00 _ Setup 12, Morphed Spiral Toolpath Preview. Autodesk Fusion 360.

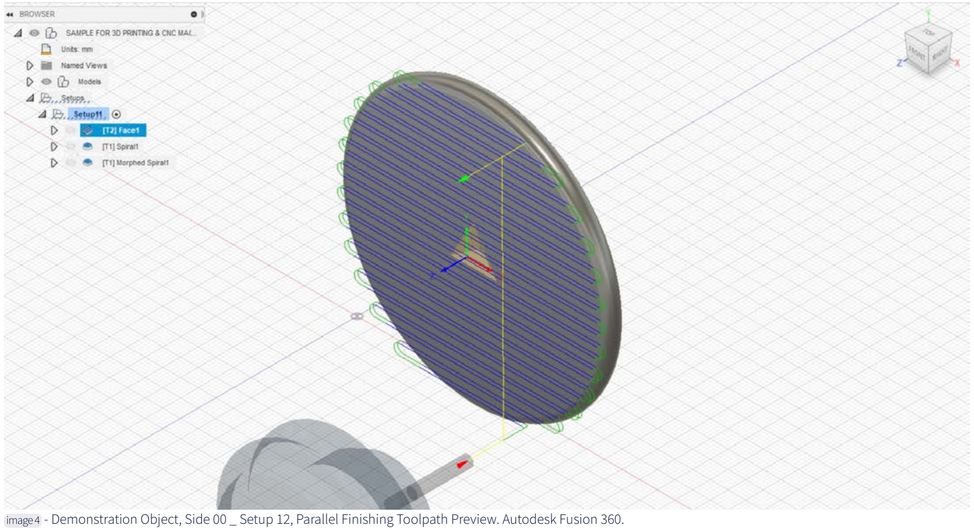


image 4 - Demonstration Object, Side 00 _ Setup 12, Parallel Finishing Toolpath Preview. Autodesk Fusion 360.

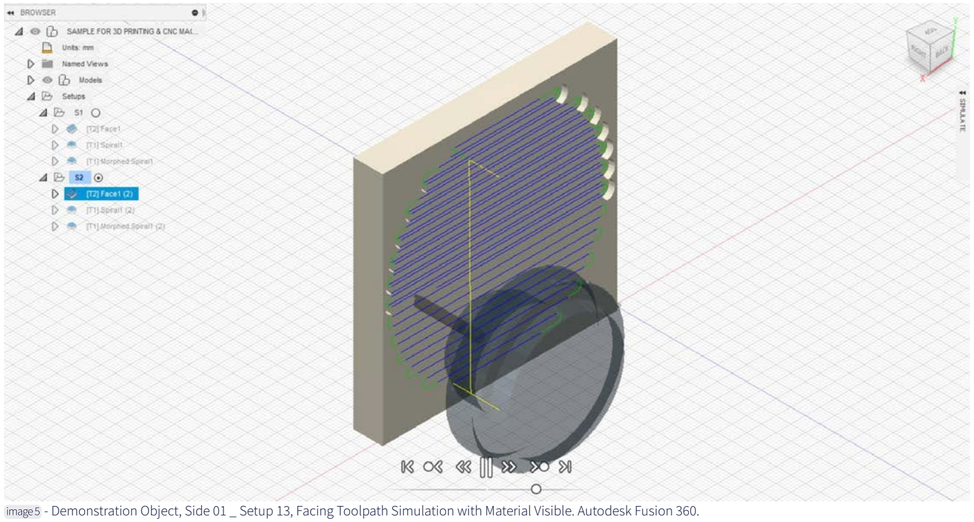


image 5 - Demonstration Object, Side 01 _ Setup 13, Facing Toolpath Simulation with Material Visible. Autodesk Fusion 360.

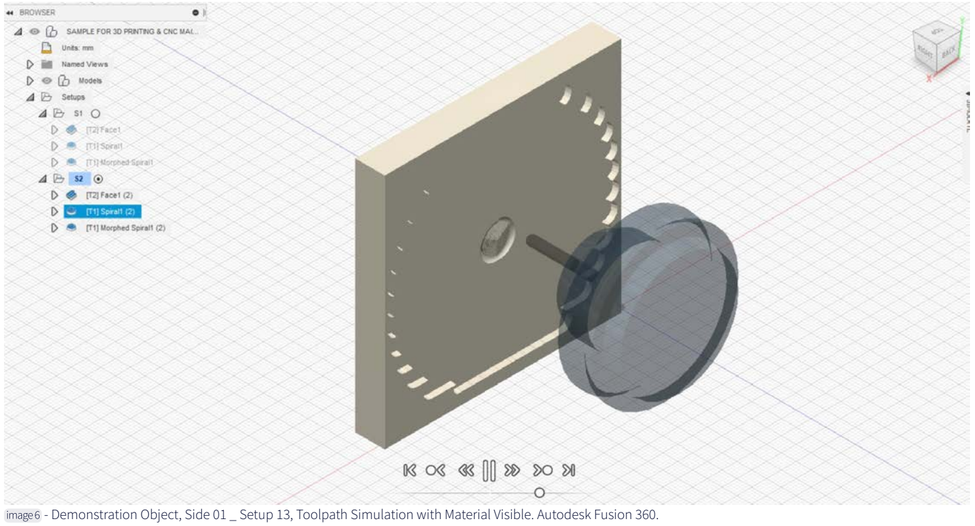


image 6 - Demonstration Object, Side 01 _ Setup 13, Toolpath Simulation with Material Visible. Autodesk Fusion 360.

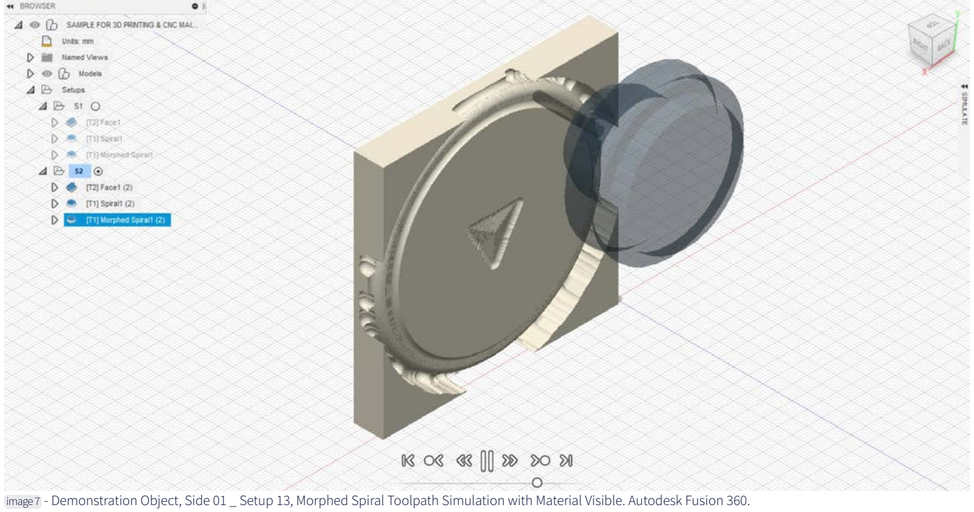


image 7 - Demonstration Object, Side 01 _ Setup 13, Morphed Spiral Toolpath Simulation with Material Visible. Autodesk Fusion 360.

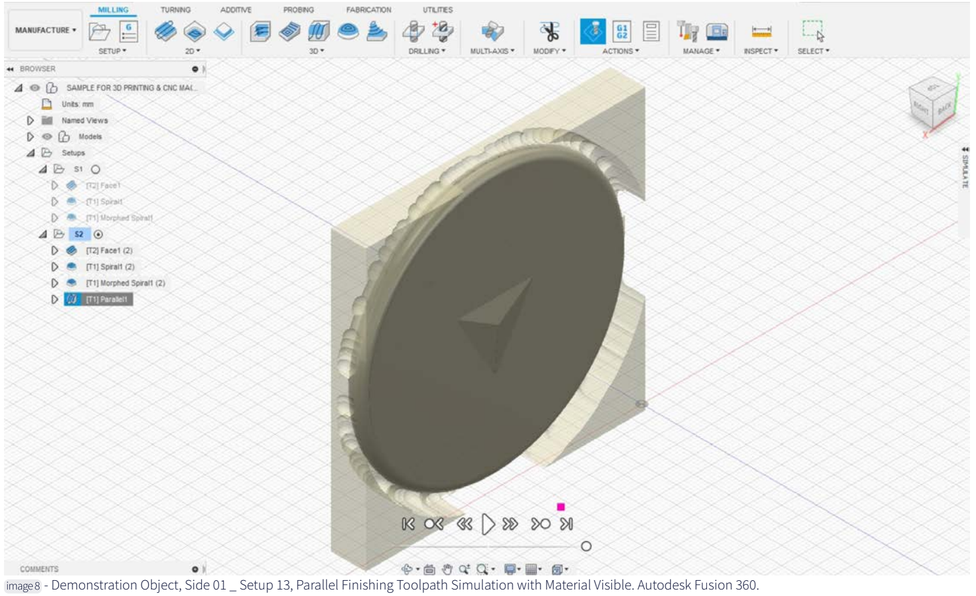


image 8 - Demonstration Object, Side 01 _ Setup 13, Parallel Finishing Toolpath Simulation with Material Visible. Autodesk Fusion 360.

▼ Post Process

- Create the Program
- Choose the Setup or Toolpath to Post Process
- On the < Manufacture > toolbar, < Actions > Tab, choose < Post Process >
- In the < Post Process > window, set < Post Configuration > to < Carbide 3D (Grbl) / Carbide3D > image 1 page 30
- Choose the < Output folder >
- Set < Program Settings >
- < Post >

■ Setup or Toolpath

Programs that contain multiple WCS (Work Coordinate System) locations, will require separate code files for each WCS location. The Demonstration Object program has two WCS locations; Side 00 – Setup 12, and Side 01 – Setup 13. After refining the toolpaths, we chose to post the program for Side 00 – Setup 12, as a single program to include all four toolpaths. Posting all four toolpaths for one side optimizes the efficiency of transitions (retraction, plunge, and travel) between machining operations (see Toolpath Preview, yellow and red lines image 1 page 25 .

■ < Output Folder >

It is recommended to choose a folder that can be transferred to the desktop of the computer attached to the Carbide3D Nomad 883 Pro. For the Demonstration Object, code was saved locally, transferred to a external drive, transferred to the computer attached to the Carbide3D Nomad 883 Pro, and deleted when complete.

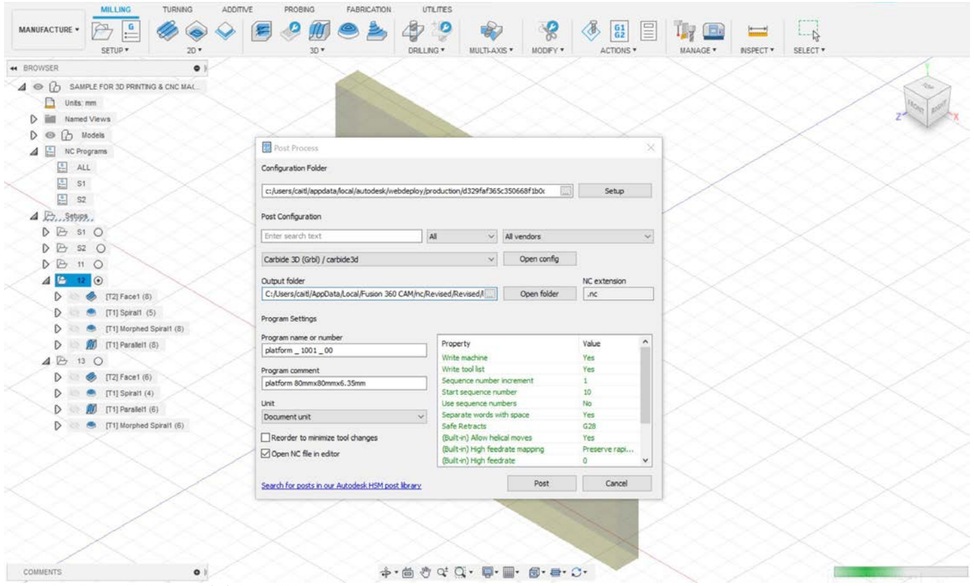


image 1 - Post Process Settings. Autodesk Fusion 360.

File Organization

There is value in organizing files clearly, especially when developing a new process or prototyping something for the first time that may inform other projects. The Demonstration Object program files are nested; revised code is contained within the previous file folder, image 2 & image 3 .

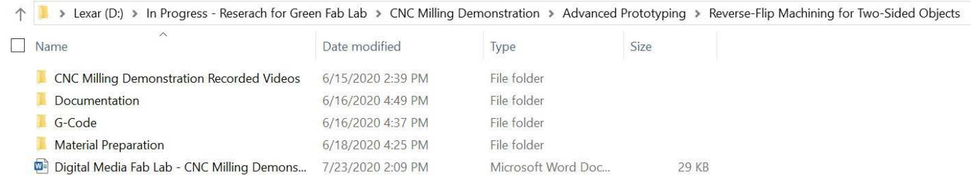


image 2 - Demonstration Object Program File Folders

image 3 - Demonstration Object Program File Folders, detail of nesting revised code

Source Code Errors

The computer system we choose to utilize while programming toolpaths has Visual Studio Code installed for viewing code. While refining settings and toolpaths, it is helpful to reference an external code editor to see errors or make modifications to the .nc file image 4 .

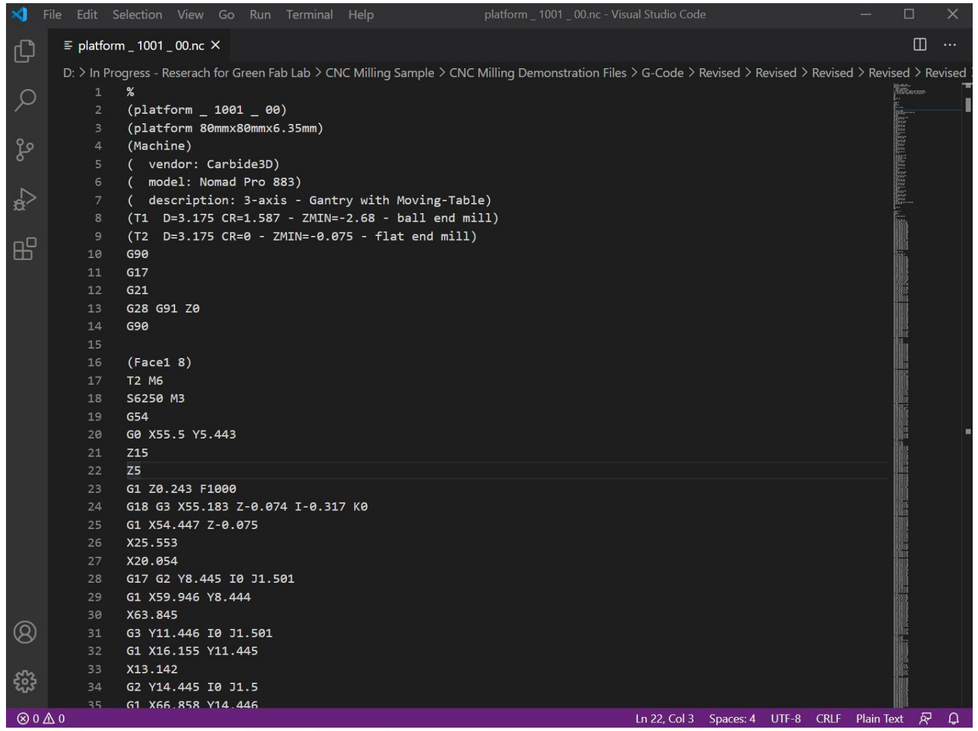


image 4 - The Demonstration Object's Side 00 _ Setup 12, Toolpath Program. Visual Studio Code.

To maintain alignment with the Design Objectives of the Demonstration Object, the material stock for the prototype was created from a piece of basswood material, found in the Digital Media Fab Lab, and intended for use during prototyping by Florida State University, Department of Art, Students, Faculty, and Staff.

To prepare the material for CNC Machining, we (1) designed a material stock contour and positioning box with Adobe Illustrator, then (2) processed material with a Universal Laser Systems PLS6.75 CO_2 Laser Cutter.

- **Universal Laser Systems PLS6.75**
  - The information on Material Preparation (pages 35 - 38) functions as a supplemental resource to the Digital Media Fab Lab, Universal Laser Systems PLS6.75, Machine Demonstration and Training. Understanding the safety information and receiving a Machine Demonstration and Training from a qualified Digital Media Fab Lab staff is mandatory prior to engaging any and all technology, equipment, and machines within the Digital Media Fab Lab, Department of Art, 530 W Call Street, Fine Arts Building 422, Tallahassee, Florida 32306-1150.

- **References**
  - Schedule a Machine Demonstration and Training
  - Digital Media Fab Lab Scheduling Calendar
  - Universal Laser Systems PLS6.75
  - Digital Media Fab Lab — How To — Setup a File for Laser Cutting
  - Approved Materials

Material Preparation: Adobe Illustrator, **Universal Control Panel,** Universal Laser Systems PLS6.75

To prepare material stock for the Demonstration Object, we chose to design a square in Adobe Illustrator to be laser cut out of a ¼" piece of basswood with the Universal Laser Systems PLS6.75. The dimensions of the square are 80mm x 80mm x 6.5mm; at this scale, the material stock is approximately 1mm larger than the Demonstration Object 3D model on all sides. This tolerance aligns with the Demonstration Object Design Objective, Minimal Material Investment and Waste.

- **Open Adobe Illustrator**

  - Set Artboard size to material size image 1

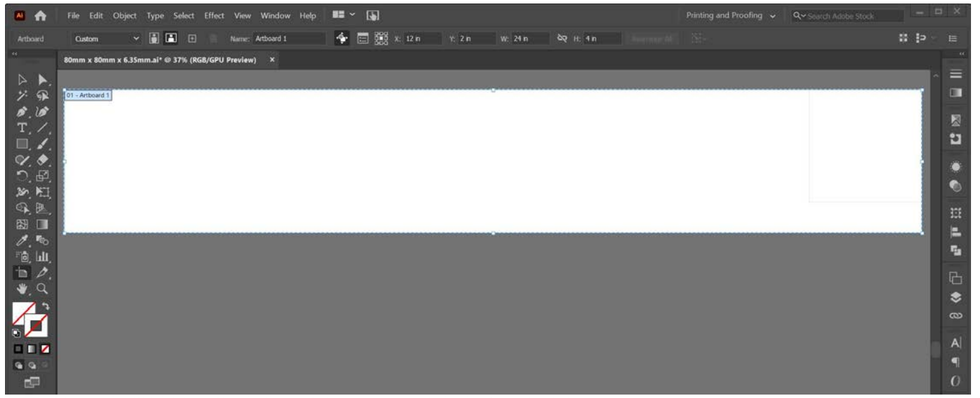


image 1 - Artboard size, W (width) and H (height) equal to the basswood material size. Adobe Illustrator.

  - Create a Positioning Box < Rectangle Tool > set dimensions to material size image 2
  - Set the stroke to .001
  - Set the stroke color to R: 255 G: 255 B: 0

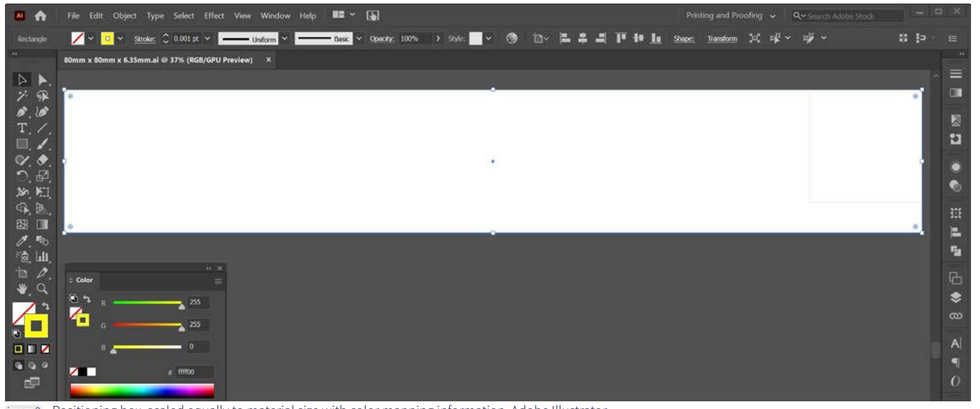


image 2 - Positioning box, scaled equally to material size with color mapping information. Adobe Illustrator.

▼ Create the stock contour to be cut image 3
- Set the stroke to .001
- Set the stroke color to R: 255 G: 0 B: 0

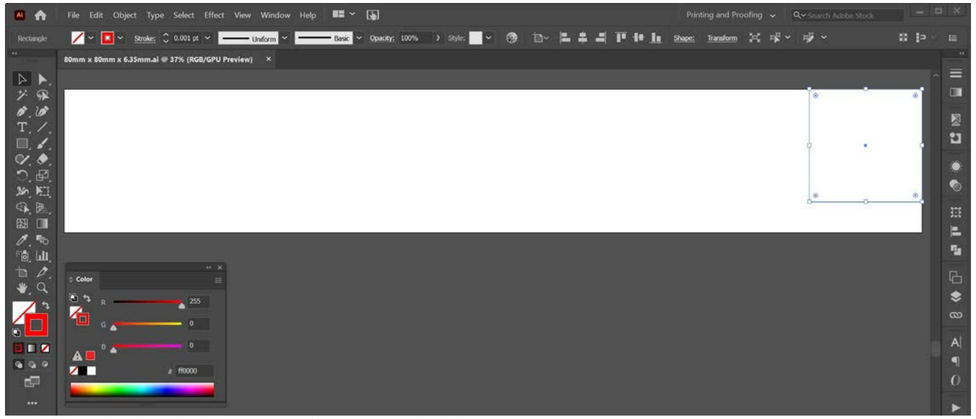


image 3 - Stock contour to be cut with color mapping information. Adobe Illustrator.

▼ File < Save to External Drive

● Open a vector file in Adobe Illustrator on the computer attached to the Universal Laser Systems PLS6.75

▼ File < Print
- Set the < Media Size > to < Defined by Driver >
- Set the < Printer > as < ULS 6.75 >
- Choose < Print >

● Open Universal Control Panel

▼ Align material stock onto the honeycomb inside the Universal Laser Systems PLS6.75
- Focus the material to the laser
- Switch the Air Compressor and Exhaust to < ON >

▼ Reposition the design to the location of the material stock with the < Relocate Tool > image 1
- Check material stock boundaries with the < Focus Tool >
- Set < Material Settings > image 2
- Press < Start >

▼ Complete
- Before removing material from the Universal Laser Systems PLS6.75, wait 30 seconds
- Remove stock and scrap material from the Universal Laser Systems PLS6.75 image 3 page 38
- Switch the Air Compressor, Exhaust, and Universal Laser Systems PLS6.75, to < OFF >

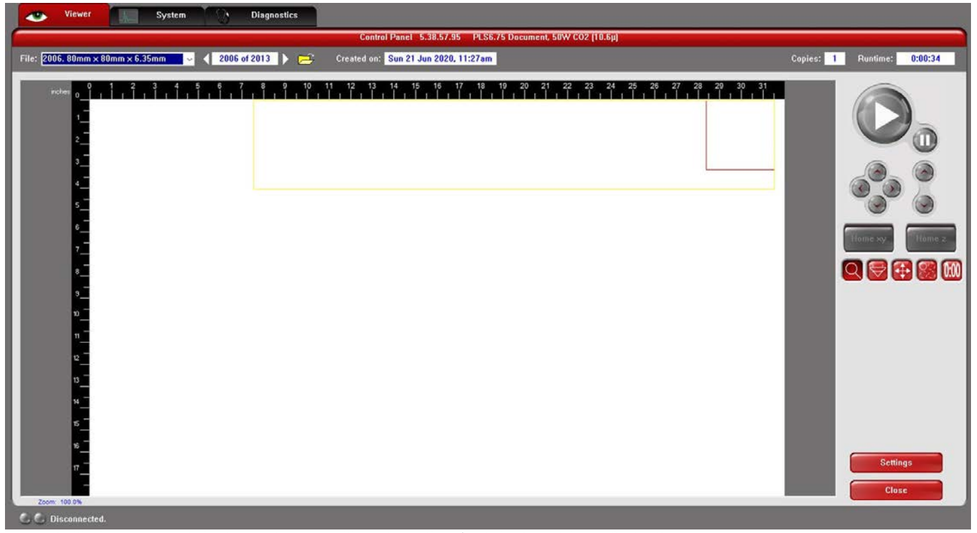


image 1 - Positioning box and material stock contours, repositioned to location of material stock. Universal Control Panel.

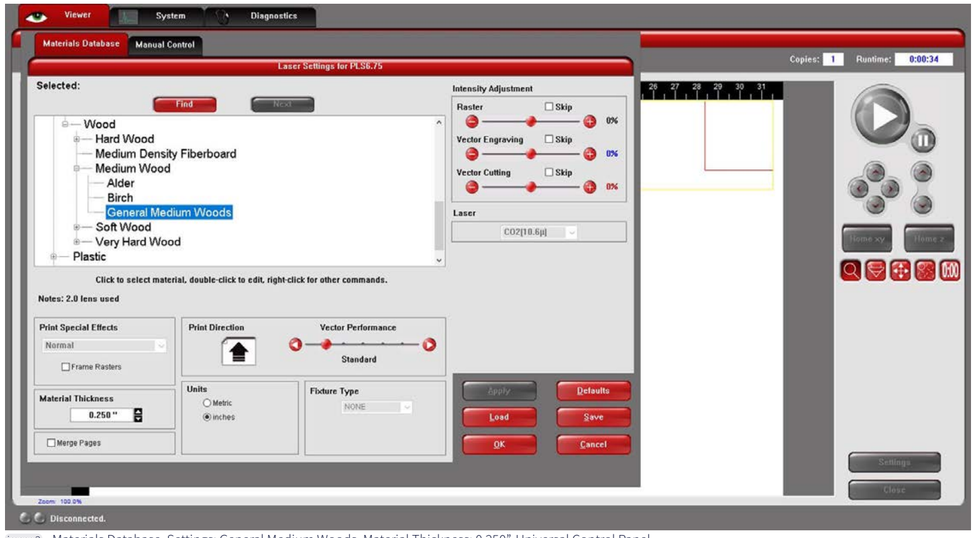


image 2 - Materials Database. Settings: General Medium Woods, Material Thickness: 0.250". Universal Control Panel.

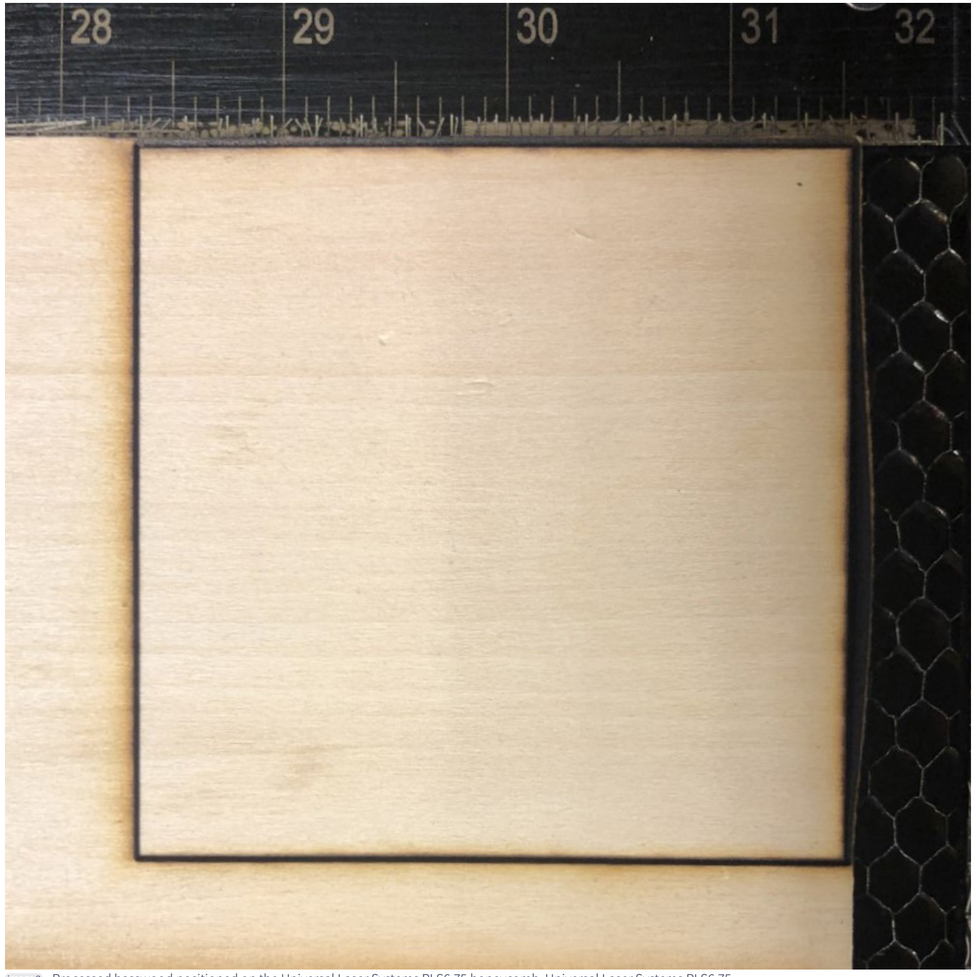


image 3 - Processed basswood positioned on the Universal Laser Systems PLS6.75 honeycomb. Universal Laser Systems PLS6.75.

▼ Carbide3D Nomad 883 Pro

- The information on Machine Setup and Software page 43 functions as a supplemental resource to the Digital Media Fab Lab, Carbide3D Nomad 883 Pro, Machine Demonstration and Training. Understanding the safety information and receiving a Machine Demonstration and Training from a qualified Digital Media Fab Lab Staff is mandatory prior to engaging any and all technology, equipment, and machines within the Digital Media Fab Lab, Department of Art, 530 W Call Street, Fine Arts Building 422, Tallahassee, Florida 32306-1150.

▼ References

- Schedule a Machine Demonstration and Training
- Digital Media Fab Lab Scheduling Calendar
- Carbide3D Nomad 883 Pro
- Carbide3D — CNC Basics
- Carbide3D Nomad 883 Pro Machine Safety Instructions
- Carbide3D Nomad 883 Pro — Carbide Motion — User Guide

Machine Setup and Software: Carbide3D Nomad 883 Pro, Carbide Motion

▼ Follow the Carbide3D Nomad 883 Machine Safety Instructions

- Secure long hair back, secure loose-fitting clothing into position, tuck-in drawstrings, remove scarves and dangling jewelry, etc.
- Always wear safety glasses while operating the machine, even when the protective door is closed.
- Always keep the protective door closed unless the machine is stopped and you need to change the Tool Bit or material stock.
- Tool Bits are sharp and should be treated with care, even before they are mounted in the machine.
- Never reach into the machine while it is running — it is possible to pinch your hand as the Holder moves around, or badly cut yourself if you touch the Spindle or Tool Bit.

  - While setting a Work Coordinate System (WCS) zero location one may need to open the protective door to observe the location of the spindle and end of the Tool Bit. While the door is open, keep all appendages at a safe distance away from moving Axes and Spindle to ensure safety.

● Carbide3D Nomad 883 Pro

▼ Securely attach material stock to Y-platform

For the Demonstration Object, we chose to attach the material stock to the Carbide3D Nomad 883 Pro's y-platform with double-sided carpet tape and outlined the material stock with a graphite pencil. Depending on the material stock to be machined, other methods of attachment may be necessary.

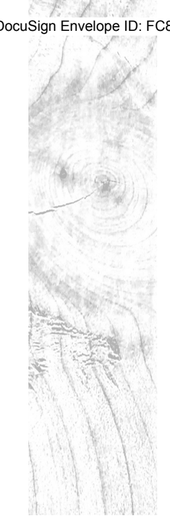
▼ Power < ON > the Carbide Nomad 883 Pro CNC Machine

- Press the button on the front, right, bottom corner

▼ Open < Carbide Motion > Software on the computer

- Choose < Connect to Cutter >
- Choose < Load New File >
- Locate and Select the .nc file exported from Autodesk Fusion360, choose < OK >
- Choose < Jog > Tab
- Secure the Tool Bit into the jaws of the chuck at the Tool Bit's shoulder height
- Choose < Spindle On >, set the < Increment > to < Fast >
- Set the World Coordinate System (WCS) Location, or set the Work Coordinate System (WCS) Location
  - Choose < X+ >, < X- >, < Y+ >, < Y- >, < Z+ >, < Z- >, to move the Tool Bit towards the WCS (0,0) location defined within the Program file, reducing increment speed as the Tool Bit approaches the platform and material stock
  - When the Tool Bit arrives at the correct WCS location, in < Carbide Motion >, < Jog > Tab, choose < Set Zero >
  - Choose < Set Current Position >
  - Choose the axis/axes to zero, < Zero X >, < Zero Y >, < Zero Z >, < Zero All >
  - Retract the spindle away from the material by choosing < Z+ >, then select < Done >
- Choose the < Run > Tab
- Choose < Start Job >
  - Reduce the < Feedrate > to 20% temporarily
  - When operating a Toolpath for the first time it is wise to reduce the feedrate as the Tool Bit is approaching material stock. This allows one to verify the code is programmed correctly, prevent damage to Tool Bits, and preserve material stock
- Choose < Start >, to begin the program
  - As the spindle moves the Tool Bit towards the material, observe for correct action, alignment, and machining process. To discontinue the machine movement, choose < Pause >, or < Stop >
  - After observing correct action, alignment and machining process, On the < Run > Tab, choose < Reset Feedrate >
- Observe the machining process throughout the duration of the Program
- Complete
  - After the Program is complete, power < OFF > the machine by pressing the button on the front, right, bottom corner, remove the material stock, clean machine of material debris with a dust pan, brush, and vacuum, remove the Tool Bit from the Tool Holder, return all Tools and Tool Bits to the designated storage location, and engage the appropriate lab approved waste stream for the disposal of any scrap material debris.

Prototype



Demonstration Object Basswood Prototype, detail of Side 00

Demonstration Object Basswood Prototype, detail of Side 01

Prototype: Autodesk Fusion360, Carbide3D Nomad 883 Pro

To create the Demonstration Object several modifications were made during the fabrication process. The following information details the specific design challenges and the resulting changes that were made to the 3D Model geometry and Toolpath Programming.

- Splitting Geometry

The Demonstration Object was designed from a fileted primitive solid cylinder. Before programming the toolpaths, we split the geometry and added a v-curve for the machining boundary with the < Split Body > command image 4 page 50 . To prepare for the < Split Body > command, we added a sketch curve around the Demonstration Object at the level of the intended split image 1 . Splitting the geometry facilitated the accurate selection of machining boundaries during Toolpath Programming.

▼ Draw a Sketch Curve
- < Design > Workspace
- Choose < Sketch >
- < Create >
- < Circle >
- Set < Circle Diameter >

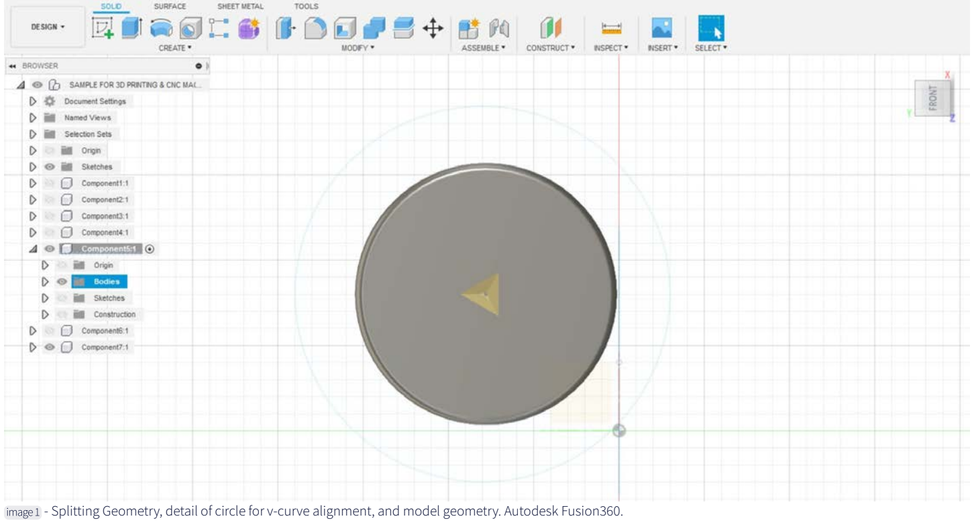


image 1 - Splitting Geometry, detail of circle for v-curve alignment, and model geometry. Autodesk Fusion360.

▼ Split Body
- < Design > Workspace
- Choose < Modify >
- < Split Body >
- Select the < Body to Split > and the < Splitting Tool > image 2 page 49
- Select < OK > to split body image 3 page 49

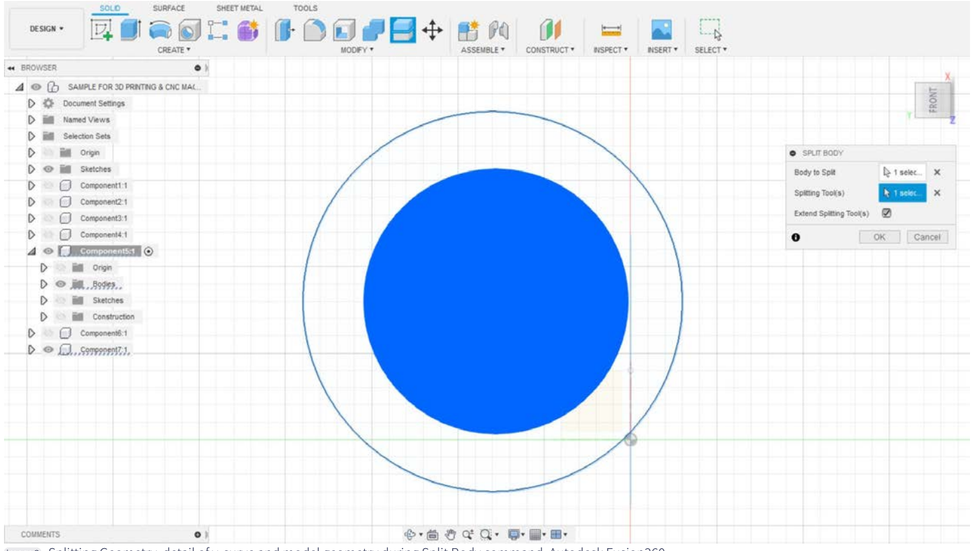


image 2 - Splitting Geometry, detail of v-curve and model geometry during Split Body command. Autodesk Fusion360.

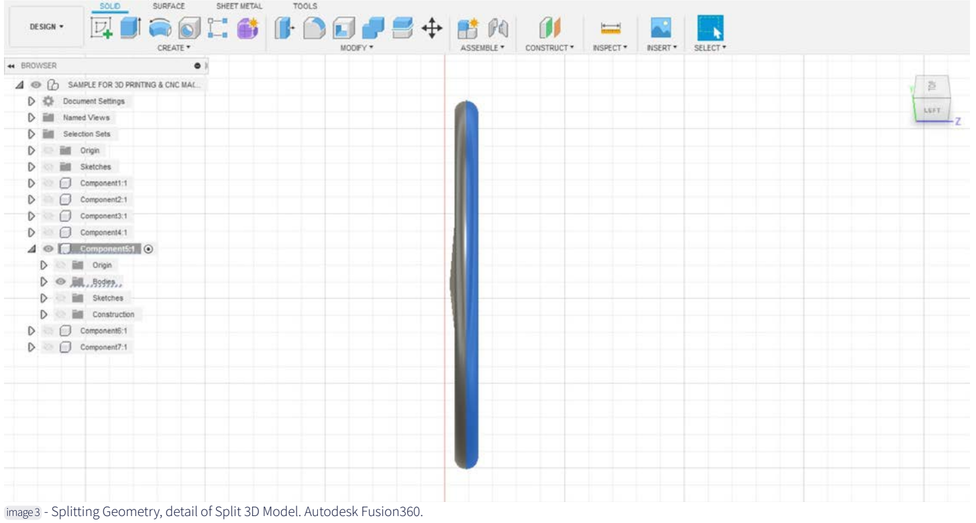


image 3 - Splitting Geometry, detail of Split 3D Model. Autodesk Fusion360.

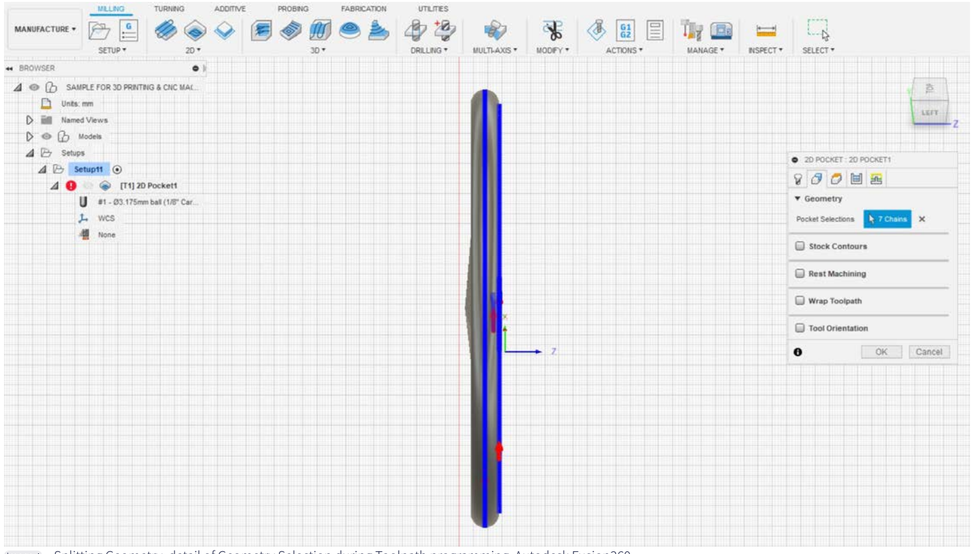


image 4 - Splitting Geometry, detail of Geometry Selection during Toolpath programming. Autodesk Fusion360.

- World Coordinate Systems and Work Coordinate Systems

For the Demonstration Object, several Setups were programmed while working towards precise settings, parameters, and simulations. We have documented the three attempts at manufacturing the basswood prototype, detailing the different Setups and Toolpath Programs.

One of the attempts at manufacturing the basswood prototype of the Demonstration Object, included a Toolpath Program with a World Coordinate System at the origin (0,0) and a Work Coordinate System centered on the material stock's top surface. To create a Setup with a Work Coordinate System location, centered on the material stock;

- Open the 3D Model in Fusion360

- Setup the Program with Machine and Material Information
  - Change Workspace to < Manufacture >
  - On the top toolbar, choose Setup < New Setup >
  - On the Setup toolbar, < Setup > Tab, select the machine < 3-axis–Gantry with Moving-Table >
  - Choose and Set Setup parameters, Work Coordinate System, and Select Model
    - Work Coordinate System
      - Set Orientation as < Model Orientation >
      - Set Origin as < Stock Box Point >
      - Set Stock Point as < Box Point >, and choose the front, center, point on model stock box image 5 page 51
      - On the Setup toolbar, < Stock > Tab, set the Material Stock Size
      - On the Setup toolbar, < Post Process > Tab, specify Program identity, and Machine Work Coordinate System settings

The Carbide Motion program requires machine and material calibration for each program uploaded, meaning (1) Individual Toolpath program files require the WCS location to be set once, and also (2) program files containing a full Setup with multiple Toolpaths require the WCS location to be set once.

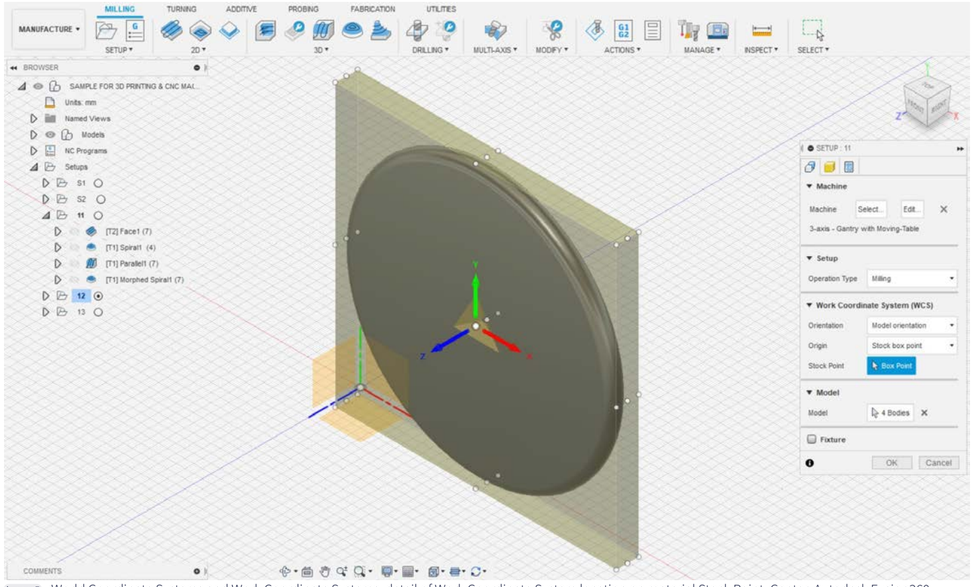


image 5 - World Coordinate Systems and Work Coordinate Systems, detail of Work Coordinate System location on material Stock Point, Center. Autodesk Fusion360.

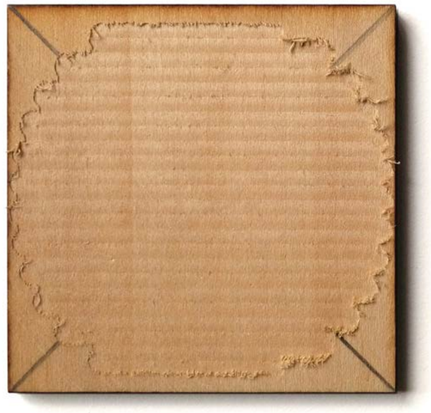


image 6 - World Coordinate Systems and Work Coordinate Systems, detail of Facing Toolpath and graphite on basswood.

image 6 (above) details the results of the first Toolpath in Side 00 _ Setup 12, Facing. To facilitate aligning the Tool Bit to the Work Coordinate System, the center of the basswood material was found with a graphite pencil and ruler.

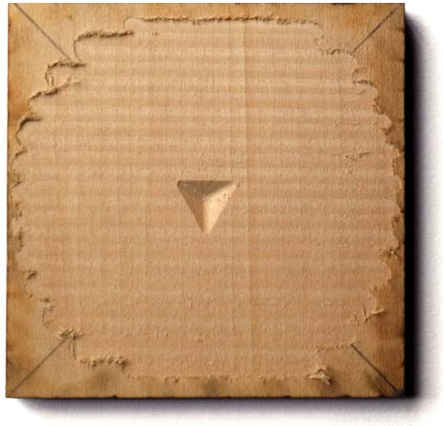


image 7 - World Coordinate Systems and Work Coordinate Systems, detail of Facing Toolpath, Spiral Toolpath and graphite on basswood.

image 7 (above) details the first and second Toolpath style within the Demonstration Object's sequence of Toolpaths: Facing, Spiral. When creating this version of the Demonstration Object, basswood prototype, the Toolpath Programs were run individually, so at the beginning of each program the Work Coordinate System was set.

image 8 - World Coordinate Systems and Work Coordinate Systems, detail of Facing Toolpath, Spiral Toolpath, Morphed Spiral Toolpath and graphite on basswood.

image 8 (above) details the first, second, and third Toolpath style within the Demonstration Object's sequence of Toolpaths: Facing, Spiral, Morphed Spiral. Each Toolpath Program was run individually.

While it is proven useful for certain geometry and fully developed/fail-safe code, the combination of a centered WCS and individual toolpath programs was ineffective for this stage in the development of the program design, as the second toolpath style removes the WCS zero location. Removing the zero location

removes the ability to align individual Toolpath programs within a sequence and create a precisely machined object. After creating the basswood prototype of the Demonstration Object image 8 , we chose to maintain the World Coordinate System at the origin (0,0), and relocate the Work Coordinate System at the top, bottom left corner of the material stock; this final revision of the code created the Demonstration Object Basswood Prototype images page 47 . Ease and success during prototyping is insured by making the choice to maintain the integrity of the material stock at the Work Coordinate System location when aligning toolpaths individually.

Design Review
Evaluation of the Demonstration Object Design Objectives and Basswood Prototype

- Efficiency
  - Time
    - Variations in programming of toolpaths will change manufacturing time. The Demonstration Object's manufacturing time is approximately 4 – 5 hours in duration, and when aligned precisely the program creates a smooth surface finish. The toolpath tolerances within the program are ideal for manufacturing materials that reveal tooling marks, like precision-milled aluminum. To modify the surface finish or manufacturing time for other materials, one could adjust the Tool Bit stepover tolerances within the finishing toolpaths.
- Material Sustainability
  - Minimal Material Investment
    - The variable costs to be factored into a thorough investment analysis of the Demonstration Object prototyping process are: (1) basswood material, (2) double-sided tape, (3) eXacto blade, (4) pencil graphite, (5) Tool Bit wear, (6) Tool and Machine Investment; Carbide3D Nomad 883 Pro, vacuum, hand tools, safety equipment, (7) energy consumption; Carbide3D Nomad 883 Pro, computer, vacuum, lab electricity, (8) exhaust, and other facility costs.

      Because the Demonstration Object was created in the Digital Media Fab Lab, variable costs (2), (3), (4), (5), (6), (7), and (8), were paid for by student fees, tuition costs, grant funding, and other University resources. Variable (1) basswood material, could be considered a zero-cost investment, as the original source of funding is unknown – a gift!
  - Minimal Material Waste
    - A Closed-Loop Waste Stream is one that takes into consideration material by-products and establishes plans for end-of-life release. Often in manufacturing, a producer of an object with a Closed-Loop Waste Stream will reuse, remanufacture, or recycle materials utilized during the creation of the object, and the object itself. Reusing, remanufacturing, or recycling materials preserves energy and material resources.
      - Energy Consumption: Materials and Processes
        - Basswood Material
          - Manufacturing materials with the intention to preserve resources creates minimal material waste/by-product. While utilizing the Universal Laser Systems PLS6.75 and Carbide3D Nomad 883 Pro machines for the Demonstration Object, carving dust and pieces of scrap wood were collected. The carving dust and scrap wood can be remanufactured into a particle board material, or wood glue. Examples of particle board materials are, Taskboard, MDF, and Masonite. This process of remanufacturing wood resources is known as Cascading. Cascading maximizes resource effectiveness and extends the life of biological and technical nutrients. The Demonstration Object and material by-product, in time, will be remanufactured. For now, the materials live as an Educational Tool. Note: More attention to separate out what was already within the shop-vac before utilizing the device to collect wood dust would facilitate ease and integrity during any reuse/remanufacturing /recycling process.
        - Double-Sided Tape
          - Current local business infrastructure supports the disposal of this material through a landfill waste stream. However, Precycling the double-sided tape by formulating a predetermined outcome for the used portion is the most ideal solution for the environment. Example of Precycling: Having a purpose for, intention to, and follow through on blending used adhesive with water to create a liquid paste for securing other materials. Note: During the creation of the Demonstration Object, the double-sided tape was disposed of through the landfill waste stream.
        - eXacto Blade
          - This resource can be renewed by sharpening. By utilizing an alundum stone or sanding the blade carefully on an angle with sandpaper can restore the edge.
        - Pencil Graphite
          - Harvesting this material as a substance to remanufacture, reuse, or recycle is possible. One could also consider the graphite as an additive to the MDF material attached to the y-platform, to be remanufactured or reused when the y-platform is replaced.

- Tool Bit
  - This resource can be renewed through a sharpening service or sharpened by hand. Companies that sell Tool Bits will sometimes offer Tool Bit recutting as a service. Local sharpening services may exist depending on the area.

- Energy Consumption
  - Machine energy is calculated by factoring the power supply wattage, the number of hours a machine is powered, and the local utility rate:

    (Machine Watts) multiplied by (Hours Powered) equals (Watts Consumed)
    (Watts Consumed) divided by (1000) equals (Kilowatts kWh Consumed)
    (Kilowatts kWh Consumed) multiplied by (Local Utility Rate kWh) equals the rate of Energy Consumption

    The **Universal Laser Systems PLS6.75** has a 240-watt power supply, taking this into consideration with the > 15 minutes of manufacturing time, and the Local Utility Rate in Florida 10.12¢/kWh, the minimal Energy Consumption cost per prototype is .06 kWh, > $.01.

    The desktop **Computer** attached to the Universal Laser Systems PLS6.75 has a 275-watt power supply. The minimal Energy Consumption cost per prototype is .07 kWh, or > $.01.

    The **Carbide3D Nomad 883 Pro** has a 240-watt power supply, taking this into consideration with the 4 - 5 hours of manufacturing time, and the Local Utility Rate in Florida 10.12¢/kWh, the minimal Energy Consumption cost per prototype is 1.2 kWh, or $.13.

    The desktop **Computer** attached to the Carbide3D Nomad 883 Pro has a 275-watt power supply. The minimal Energy Consumption cost per prototype is 1.375 kWh, or $0.15.

    The **Shop-Vac 87732-56 Vacuum** has a 120-watt power supply. The minimal Energy Consumption cost per prototype if utilized for < 1 hour is .12 kWh, or $0.01.

    The **Digital Media Fab Lab Minimal Energy Consumption** (air distribution, chill water load, and steam load) cost per prototype is $1.05 ($.21/hour).

    The **Digital Media Fab Lab Electrical Cost** is $.10 kWh, making the minimal cost per prototype $.50.

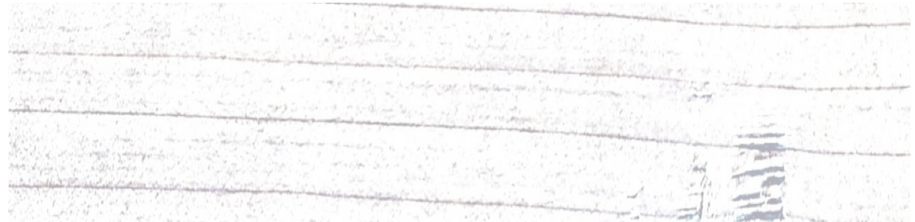
    When produced in the way outlined in this tutorial, the Demonstration Object has an Energy Consumption/Investment Cost of approximately $1.86 per prototype.

- Minimal Effort Towards Unnecessary Action

  - Material Stock Jig
    - For a first iteration two-sided prototype, fabricating a customized material stock jig, or investing in a material stock holder, could be considered a waste of resources. The Demonstration Object process explores one possibility for creating a two-sided prototype through precise material stock alignment. The process for creating the Demonstration Object produced an accurate prototype, however, depending on one's ability to precisely place material on the y-platform the outcome may yield different results.

    - To prepare an object like the Demonstration Object for mass manufacturing, one may choose to continue iterating on the design until fully satisfied with the form and material stock size, then create a customized material stock jig or invest in a stock holder for rapid placement of material stock during the production process.

The Demonstration Object Basswood Prototype is one possible materialization of the Design Objectives. The information and experience collected during the entire process, creates a strong and stable foundation for attaining efficiency, and creating sustainable prototypes, through automated Digital Fabrication processes.



- Open a 3D Model in Autodesk Fusion360

▼ Setup the Program with Machine and Material Information

- Change Workspace to < Manufacture >
- On the top toolbar, choose Setup < New Setup
- On the Setup toolbar, < Setup > Tab, select the machine < 3-axis–Gantry with Moving-Table >
- Choose and Set Setup parameters, Work Coordinate System, and Select Model
- On the Setup toolbar, < Stock > Tab, set the Material Stock Size
- On the Setup toolbar, < Post Process > Tab, specify Program identity, and Machine Work Coordinate System settings

▼ Create a Custom Tool Bit or Choose one from the Tool Library

There are several ways within Autodesk Fusion360 to access the tool library for the creation of a Tool Bit. You can either do this before programming the toolpaths, or during the Setup unique to the model.

▮▮ *Before Toolpath Program*

- Open the Tool Library by choosing Manufacture < Manage < Tool Library
- On the left side toolbar, select All < Local < Library
  - On the interior panel, click the New Tool (“+”) icon
    - Choose the end mill type and define the Tool Bit specifications in the General, Cutter, and Shaft Tabs
    - In the Holder Tab < set Holder
    - In the Feed & Speed Tab < set Spindle speed and Cutting feedrate.
      - ▾ References
        - Carbide3D Nomad 883 Pro Machine Specifications
        - Carbide3D Nomad 883 Pro Feeds & Speeds Chart

▮▮ *During Toolpath Program*

- Begin a toolpath program by choosing Manufacture < (2D/3D/Drilling/Multi-Axis) < choose a tool process
- On the toolpath menu < Tool > tab, choose < Select… > to open the Tool Library
- On the left side toolbar, select All < Local < Library
  - On the interior panel, click the New Tool (“+”) icon
    - Choose the end mill type and define the Tool Bit specifications in the General, Cutter, and Shaft Tabs
      - Reference the Tool Bit manufacturer for any unknowns about the Tool Bit
      - Custom Tool Bits can be modified while managing the Tool Library. Open the Tool Library by choosing Manufacture < Manage < Tool Library. On the left side toolbar, select All < Local < Library. Select the Tool Bit, right click, for < Edit Tool >, < Copy Tool >, < Duplicate Tool >, < Renumber Tool >, < Delete Tool >
    - On the Holder Tab < set Holder
      - If possible, choose the Holder identical to what is on the machine being utilized for the process. The default Holder that most closely resembles the holder on the Carbide3D Nomad 883 Pro is the Holder BT40 – B4C3-0020
    - In the Feed & Speed Tab < set Spindle speed and Cutting feedrate.
      - ▾ References
        - Carbide3D Nomad 883 Pro Machine Specifications
        - Carbide3D Nomad 883 Pro Feeds & Speeds Chart

▼ Program a Toolpath

- Begin a toolpath program by choosing Manufacture < (2D/3D/Drilling/Multi-Axis) < choose a toolpath process
- On the toolpath menu < Tool > tab, choose < Select… > to open the Tool Library
- Choose a Tool Bit from the Tool Library OR program a custom Tool Bit
- Set the Speeds & Feeds. Speeds & Feeds will automatically set to the Tool Bit’s settings. To modify a preset Speed or Feed, enter adjustments on the < Tool > tab

- On the toolpath menu < Geometry > tab, select the area to be machined, and specify any other additional parameters (ex. Stock Contours, Tool Containment, Offset Distance, Contact Point Boundary, Rest Machining, Tool Orientation, etc.)
- On the Toolpath menu < Heights > tab, set distance values for the Tool Bit movement between processes, processing heights and depths
- On the Toolpath menu < Passes > tab, set the variables while taking into consideration the Tool Bit's workload, and the desired aesthetic
- On the Toolpath menu < Linking > tab, optimize the machining process, leads, and transitions

▼ Generate Toolpaths

- Choose the Setup or Toolpath to be generated
- In the < Manufacture > Workspace, < Actions > Tab, choose < Generate >

▼ Simulate Toolpaths

- Choose the Toolpath or Setup to Simulate
- On the < Manufacture > toolbar, < Actions > Tab, choose < Simulate >
- On the Simulate Menu < Display > Tab, set the Tool, Toolpath, and Stock visibility
- On the Simulate Menu < Info > Tab, view Tool Bit position during simulation, Toolpath Information, Machining Time, Machining Distance, Operations, and Tool Changes
- Located at the bottom of the Workspace above the < Navigation Toolbar >, controls to < Start > the simulation, < Move > between toolpaths, and change < Speed > are available

▼ Post Process

- Create the Program
- Choose the Setup or Toolpath to Post Process
- On the < Manufacture > toolbar, < Actions > Tab, choose < Post Process >
- In the < Post Process > window, set < Post Configuration > to < Carbide 3D (Grbl) / Carbide3D >
- Choose the < Output folder >
- Set < Program Settings >
- < Post >

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Toolpath Programming in Autodesk Fusion360 for Machining with a Carbide 3D Nomad 883 Pro CNC Machine

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