Apollo Documentation

HUA 3910 Practicum with Professor Manzo

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Overview

Background

Guitars are fretted string instruments that are featured in many musical styles and are favored for their versatility, range, and portability. Due to the number of interacting components on the instrument, there are many ways to alter the configuration of the guitar to change its playability, tonal characteristics, and utility.

The strings of a guitar are held between the bridge and the headstock, with the pitch of different tones being performed by manipulating the length of the string being struck. These strings resonate against the body material of the instrument, typically a species of wood chosen for its resonance, sustain, and impact on attack quality, among others. In the case of a standard acoustic guitar, this sound is projected from a sound hole, while in an electric guitar electromagnetic pickups are most commonly used to send the signal to an amplifier.

Guitars are usually purchased fully-constructed and are later customized to meet the needs of the end user as they become apparent. Customization is typically a labor of trial and error, with the musician extensively researching each component before rolling the dice on whether it will perform as expected when installed into their own instrument. Installation of new parts is often expensive and time-consuming, and there is still a possibility that the new modifications won't meet expectations. This frustrating process is motivation for the design of a modular guitar that can be used to more rapidly audition electric guitar components, starting first with two parts of the guitar that drastically influence the tone and sustain of the instrument: the pickups and the bridge.

Modular Guitar Inspiration

Fern Guitars modular all-wood guitar: https://www.fernguitars.com/

"The Fern Phoenix is the only modular guitar that retains the feel of a traditional guitar while offering numerous pickup and control setups. Without having to disassemble or alter strings, modules can be swapped in seconds. The design prioritizes portability; each module has the capabilities of a whole guitar while fitting conveniently into a backpack."

Boaz One modular guitar:

https://www.kickstarter.com/projects/boazinstruments/boaz-one-one-modular-guitar-50-combinations

“The Boaz modular guitar is a high-end guitar with modular pickups, body, and bridge. Boaz allows you to choose any style for a fair price. The movable bridge allows you to fine-tune each string for the exact movement and intonations you desire. The built-in wheel and screw make tuning a breeze. The height of the strings may be adjusted with six wheels, and the length of the strings can be fine-tuned with a screw at the back. The adjustable bridge comes in two styles. The goal in the future is to create an adjustable bridge made of plastic with more fibers.”

What is Apollo

The goal of this project was to develop a modular component testing rig that would allow our team to independently develop an electric guitar component (pickup, bridge, etc.), install that component into a module block, and then integrate the block into the larger working system for testing and analysis.

Requirements for Apollo

- Headstock and tuners are built into the headstock module; the rig has the ability to adjust the break angle
- Nut is built into a vertically-adjustable module
- Pickups are built into horizontally-adjustable module boxes
- Bridge is built into a horizontally-adjustable module box
- All boxes are able to be secured tightly to an underlying structure; it is vitally important that all modules are secured tightly with **absolutely no** flex or other subtle movement with tension in excess of 250lbs

Benefits of Apollo

The advantage of this approach is that we can better isolate variables during testing, assessment, and development; a particular component can be tested independently alongside known working modules. For example, if developing a pickup, the pickup can be built into a “pickup module” template and then attached to the system where a headstock, nut, strings, and bridge are already in place.

The Guitar Body

Designing and Creating the Desktop Testing Rig

The following is an overview of the work completed by the previous Apollo team.

Requirements

- The underlying structure must be made of a metal, delrin, or another non-wood material
- The module component boxes must be made of delrin or another non-wood material
- Guitar strings stretch from the tuners to the bridge, so the underlying structure should be designed so that modules can be "installed" from the bottom or sides thereby allowing the strings to remain connected whenever possible; particularly when changing the pickup or nut modules.
- We must standardize the module box sizes so that components can be integrated into modules rapidly; module materials must be able to be modified with hand tools
- The underlying structure should be tall enough so that 1) the modules themselves are roughly the same thickness of a guitar body (about 2"), and 2) installing/removing modules is not a difficult process, and 3) the entire structure is rigid

Bill of Materials

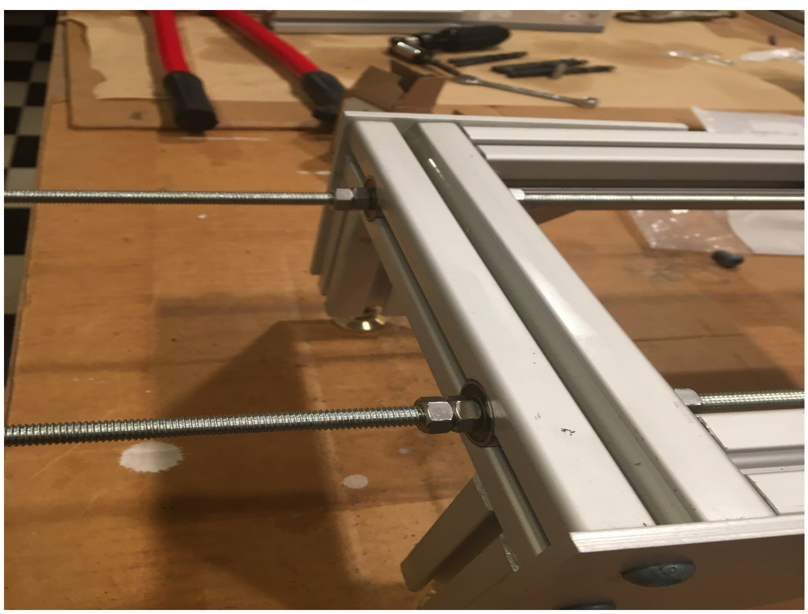
Part	Part # (Grainger)	Notes	Number of Parts
Pivot Joint, 40 Series, Width 1-9/16 In	16U367		2
80/20 Framing Extrusion (4m)	5JRY5	40-4040-LITE-4M	2
Straight Flute Tap, Thread Size M8x1.25	5EWF4		2
BHSCS & Economy T-Nut, PK15	5JRH6	For all attachments and mounting	2

Fully Threaded Rod, Steel, M8-1.25mm, 1 m	10P805		4
Leveling Feet	16U348		4
5 Hole Tee Joining Plate	5JRR1	For attaching the modules	10
5 Hole 90 Degree Joining Plate	5JRR8	For all corner mounts and for attaching the legs - Needs to be sturdy	8
Button, Metric Socket Head Cap Screw, M8-1.25, Steel, Alloy Steel, Metric Blue, 16 mm Length	5YMK8	25 pack	2
Hex Nut, Hex Nut, Stainless Steel, A4, 50 PK	6CA34	https://www.grainger.com/product/FABORY-Hex-Nut-6CA34	1
m8 Barrel Nut 10 pack		Not from Grainger - https://www.amazon.com/Metric-Barrel-Dowels-Slotted-Furniture/dp/B01M67UGC8	1
1KG - Spool of black PLA		https://www.amazon.com/HATCHBOX-3D-Filament-Dimensional-A	1

		ccuracy/dp/B00J0ECR5I	
10pcs 629-2RS Mini Ball Bearing 9x26x8 Sealed 629DDU	10 pack	https://bearingsdirect.com/ball-bearings/miniature-ball-bearing-metric-sizes/620-series-mini-ball-bearings/10lot-629-2rs-miniature-ball-bearing-9x26x8-sealed?/?_vsrefdom=ppcgoogle&utm_source=google&utm_medium=cpc&utm_campaign=Smart%20Shopping&gclid=CjwKCAjw5Kv7BRBSEiwAXGDEIXvVWHYI9C6jiZeMEBfGRBmA9Hhgj0mbdvw446azJjPI8xcfbIHDaxoC1kcQAvD_BwE	1
Post-Assembly Fitting Spring Nuts for HFS8 Series Aluminum Extrusions (MISUMI)	HNTPV8-8	https://us.misumi-ec.com/vona2/detail/110302257620/?CategorySpec=00000042754::b%09unitType::1	46
Cylindrical, Metric Socket Head Cap Screw, M8-1.25, Steel, Class 12.9, Black Oxide	26LG49	replacement for previous too long screws https://www.grainger.com/product/FABORY-Cylindrical-26LG49 (100 pack)	1

Procedure for Construction

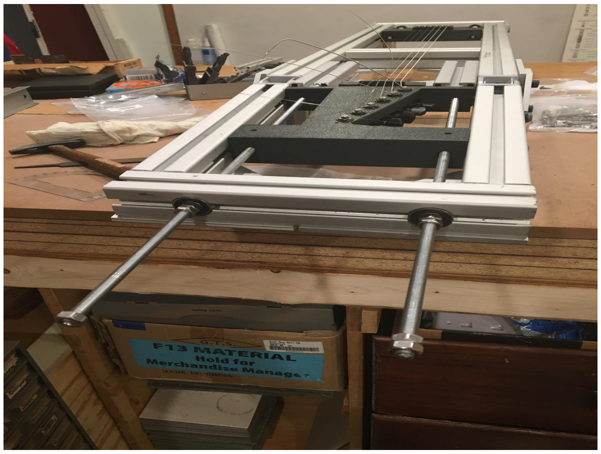
1. Cut Bars to desired length (2 long sidebars, 2 headstock bars, 4 module bars, 2 cap bars (one headstock cap and one bridge cap), central support bar)
    a. You can make more modules and cap bars (headstock or bridge) if you want to have extras to hot-swap in and out.
2. One end of the sidebars and headstock bars then need to be tapped with an m8x1.25 thread. This thread size can only frequently be found in shorter tap lengths as a longer tap has a higher chance of snapping at this size. As the tap depth was a limitation for the first build we needed to use shorter 25 mm M8 bolts to mount the hinges. This is shorter than the recommended 40mm bolts from the original spec sheet. However, this shouldn't be a structural issue as all the forces are going into the hinge at relatively low angles. There should be minimal risks of any tear-out or deflection due to small tangential forces. The base of the feet and both ends of the headstock cap bar also need to be tapped.
3. The base of the feet and both ends of the headstock cap bar also need to be tapped.
4. Headstock Bar and Bridge bars require some additional machining. This can be done on a CNC (not CADed anywhere yet) or manually. If doing manually, mark and center punch the guide rod locations by lining up the block with the bar and tapping with a drill bit. Then drill a through-hole for the m8 rods and two recessed holes for mounting the bearings. The bearing holes should be 1 inch in diameter and the bearings are then press fit in.

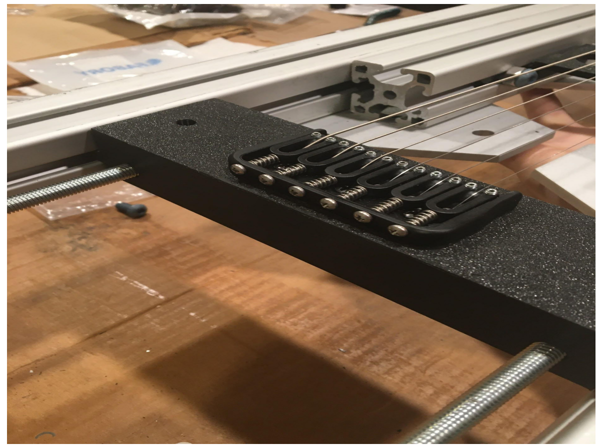


5. The main frame is made in an H pattern with the central support bar in the middle connected with two T-plates.
6. The leg bars then have the feet threaded in and are attached with 90-degree plates. To level the system, turn the feet to extend or retract them accordingly.

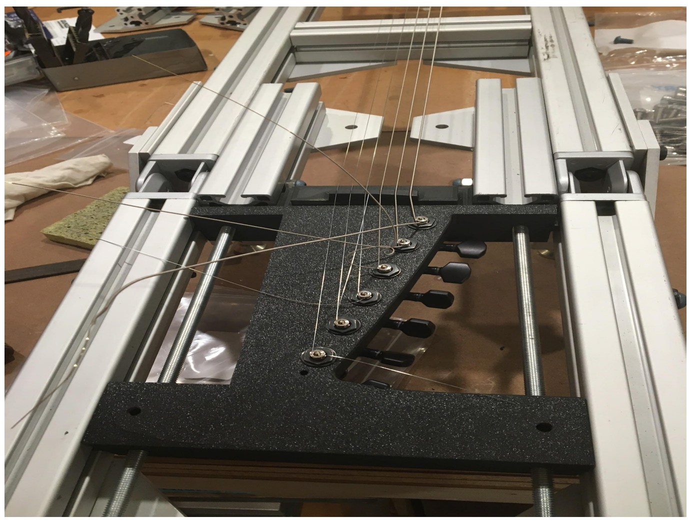
7. The hinge can now be attached to the main assembly and the support bracket and bar attached as well.

8. Once the hinge is assembled the headstock bar and bridge bar can be attached and the guide rods can be threaded into the desired blocks

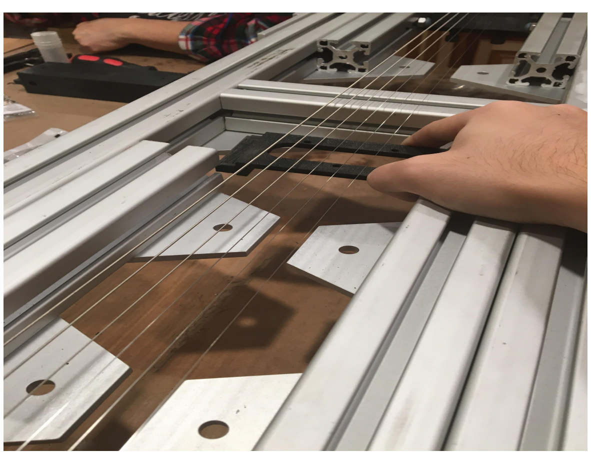




9. Once the blocks are in place and locked in with rods the nut module can be put in place and the system strung



10. Pickup modules can now be place in from the bottom and locked into place as desired or slid into already inserted guide rails




Pictures of Completed Testing Rig

Next Steps

- The testing rig is working, but the guitarist needs to make sure the components are working properly when playing.
- Create a more playable version of the testing equipment.
- CNC a wooden body that houses all of the tested modules .

Designing and Creating the Playable Rig

Requirements

- Design the guitar body using an existing Parker Nitefly template (body and neck) in Solidworks. This model should allow cavities for the attachment of pickup and bridge modules and include a pocket for the neck to be bolted on.
- The toolpath for the body must be developed using Fusion 360, and must be easily modifiable so it can be used on different CNC machines or construction materials. It is of utmost importance that the toolpath is reviewed when making any changes to configuration, as not doing so can cause damage to machines or personally injury
- The body must be CNC'd from a wood body blank in order to assess the quality of the design and effectiveness of the tool path.
- After review, revisions will likely need to be made to the body and/or toolpath to perfect the design

Tools Used

CNC Drill Bits		
Drill Bits	Link	Cost
¼” Flat end Mill	=======	15.68
¼” Ball end mill	=======	16.99

CNC Router			
CNC Options	Tools/Contacts	Link	Cost ($)
WPI Washburn	Talk to Prof. Bergstrom		Free

Laboratorios			
Other WPI Services	CollabLab (maybe??)	https://wpi.campuslabs.com/engage/organization/collablab	Free (possibly)
	Individual WPI Students		Free (possibly)
Technicopia (Worcester)	ShopBot PRStandard 96” x 48” CNC Router	https://technocopia.org/tools	Variable (104-173/mo)
	Probotix v90 Mk2 Desktop CNC Router	https://technocopia.org/tools	Variable (104-173/mo)
Buy your Own	Carbide 3D Shapeoko 4 CNC Router (XL)	https://shop.carbide3d.com/collections/machines/products/shapeoko4?variant=39337291939901	1775.00
	Carbide 3D Shapeoko 4 CNC Router (XXL)	https://shop.carbide3d.com/collections/machines/products/shapeoko4?variant=39337291808829	1970.00
Other Routing Services	AM 3D & CNC Fabrication	https://www.am3dprocam.com/	Not sure (depends on project)

Bill Of Materials

Bill of Materials				
Parts	Links	Amount	Cost per part ($)	Cost of materials ($)
Sliding Mechanism w/ locking screws	---------	2	13.99 (pack of 4)	13.99
Neck	Ken Parker	1	-	-
Hinge mechanism	---------	1	6.98 (pack of 6)	6.98
Metal Snap fasteners	---------	1	6.99 (pack of 100)	6.99
Screws + Bolts	---------	4	5.69 (pack of 4)	5.69
Wood (Blanks)		Size	Cost ($)	
Mahogany	---------	20"x14"x1.75" Minimum		90
Poplar	---------	20"x14"x1.75" Minimum		55
Basswood	---------	20"x14"x1.75" Minimum		45
Cherry	---------	3/4" Thick and 16x32		65.49
			Total cost (no tax or shipping) ($):	289.14

Body Files and Toolpath Code

All Files on Autodesk Group	
Type of File	Specific File Name
Body File without Bridge	TestingRigV3.sldprt
Body File with Bridge	TestingRigV3.sldprt
Part File for Bridge Cover	PlateForBack.sldprt
Toolpath code with Bridge Cutout	CAM Testing Version 3 (work together)
Toolpath code without Bridge Cutout	CAM Toolpath (without Bridge cutout)
Toolpath code for Fixture (includes Body File)	CAM Testing Fixture Version 1

Procedure For Construction

1) Gather materials

- These materials are outlined in the bill of materials above and will vary depending on which version of the guitar is being assembled.
- *Check the availability of equipment, the method of development is based solely on which machine is available. Some machines will require a drastic change to certain settings.*

2) Download CAD files and make necessary adjustments to the end user parameters based on the machine and parts you have

Download the Code

- Download Fusion 360 from Autodesk
- Use your school email to get the educational license
- Request access to connect to the Autodesk Group called “EGIL”
- Once in the group, find the desired files and download

End User Parameters

The table below lists end user parameters that may be necessary for different machines or materials. Occasionally, edits to the model or operation will break the succeeding operations. When this happens, it is usually possible to simply open each operation in the tree and click *OK* to correct it. It may also be necessary to toggle active layers and visibility of fixtures of operations while editing to ensure the toolpath is not being broken.

End User Parameters		
Customization	**Notes**	**Pictures**

<table>
<tr>
<td>Stock offset</td>
<td>

These offsets should be determined on a case-by-case basis depending on the size of the stock being used. Subsequent facing operations will reduce the stock to the appropriate thickness for the body model.
End user must measure their body blank and modify these parameters in the EDIT menu of the TOP process tree

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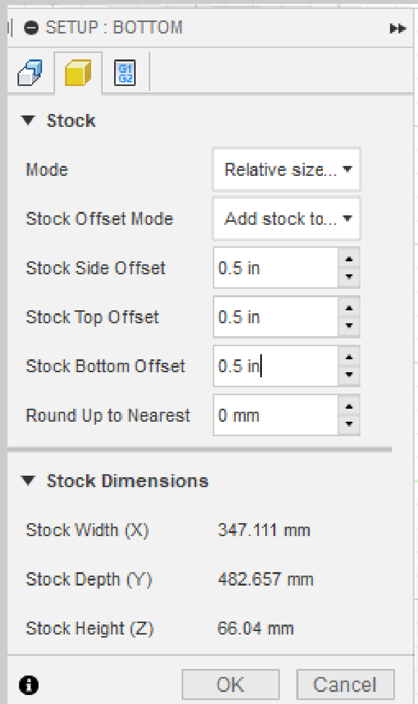

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<tr>
<td>Custom Drill bits</td>
<td>

Cutting speeds and feed rate depend on the CNC machine and will need to be updated for each operation
Stepover should be at most half the diameter of the bit being used. This will need to be updated in all operations if a bit wider than ¼” diameter is used (not recommended)
To use a different bit, it is easiest to make these edits in the tool library. This should automatically update the tool in all operations.

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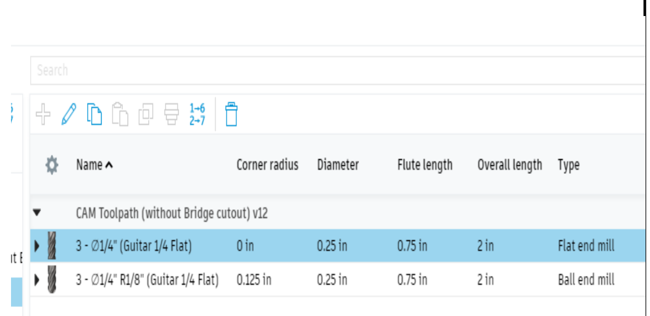

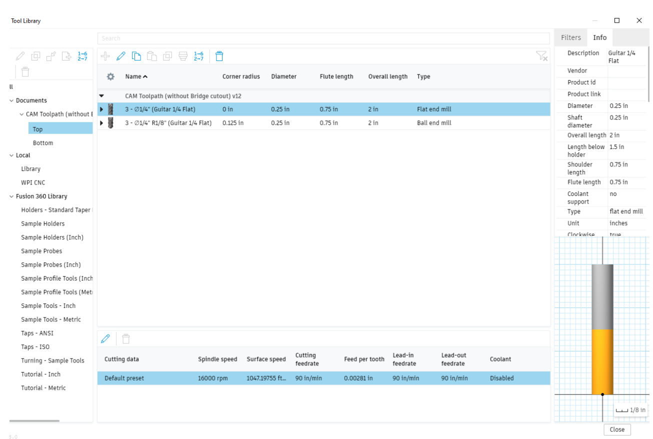
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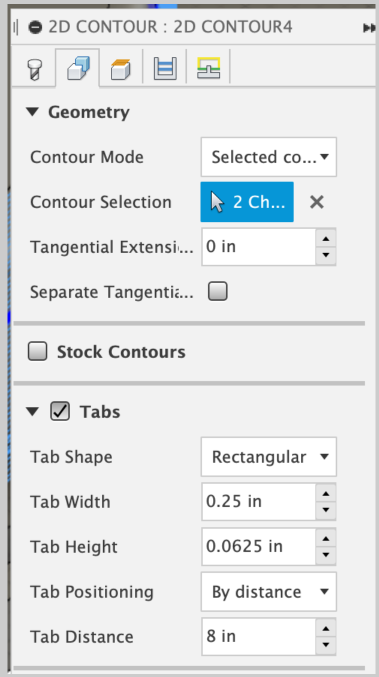
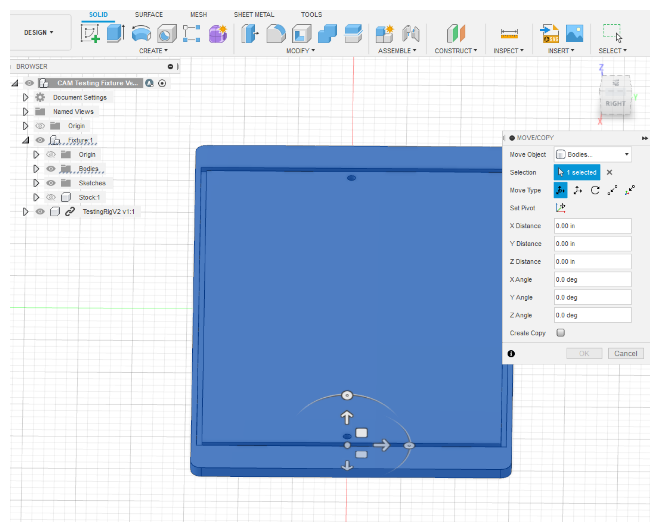
Adjust Tabs	• Tabs are used during contouring operations to keep the stock stable and prevent loose cutouts from becoming entangled in the machine. These can be edited in the *TOP > 2D Contour4* menu, if it is found that more tabs are required.	
Fixture and Dowels	• The fixture and dowel positions will need to be changed depending on the stock used. These changes will need to be made by editing the fixture file itself. • Be cognizant of the positioning of the dowels with respect to the tool path to avoid drilling through them.	

Note 1: The following steps are theoretical and will need to be changed based on future updates on the project

Note 2: Make sure to watch the CAM tutorials under “Links and Resources”, in order to understand how the toolpaths were made, and how to revise the toolpaths if needed

3) Export the toolpath code to the CNC router by right-clicking on each of the setups in the tree and clicking on *post process*. This is what allows the CAM file to be converted into G-code that can be read by the machine.

4) If the fixture has not been made, CNC the fixture. This fixture will be used to locate the origin of the tooling operation while the body is being machined. This allows for the toolpath to be aligned when switching between tooling the asymmetrical features at the top and bottom of the body, as well as making it easier to create subsequent iterations of the design on the same machine. As the fixture is currently designed, the CNC machine will use the right angled corner of the fixture as the origin.

5) Once the fixture is completed, CNC the guitar body using the fixture as the base for the stock to be on, securing the stock using dowels.

6) After everything is CNC'd, the body can be sanded and assembled. The neck and bridge should be attached and aligned first to ensure that the path of the strings passes correctly over the area where the pickup module will rest. It should be possible to easily attach the sliding rails for the bridge unit using screws perpendicularly into the body (via the cavity cutout), similar to the configuration used in the prototype desktop rig. This mechanism should hold the bridge steady in the plane parallel to the face of the body, and the tensions of the strings should hold this bridge module in its appropriate position when tuned to pitch.

Next Steps

- Review provided documentation and get a understanding of where the project is left of and what has been accomplished so far
- Evaluate and audition CNC options, revising the toolpath as necessary to suit the capabilities of the machines at the chosen facility.
- Create a prototype using procedures delineated above
- Edit the prototype and make necessary changes to fine-tune playability and testing performance
- Thoroughly document updates throughout the process to enable smooth transitioning into the project for the next team

The Modules

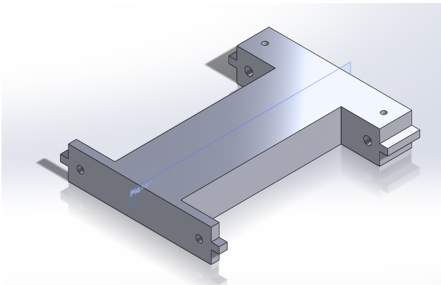
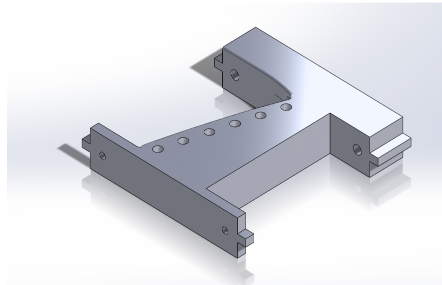
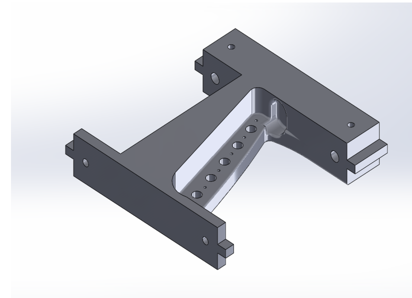
Overview

- Modules should require no more than 2 screws each to be fixed in place
- Module blocks shall have registration features (e.g. a vertical dowel-pin based system) for repeatable locating within 0.010”
- All modules should be able to install without tools (using knurled thumb screws, etc., that are easy to grip and turn)
- The nut module should be able to adjust vertically
- The bridge module should be able to slide forward or backward up to N” and then be locked down
- The pickup module should be able to slide forward or backward up to N” and then be locked down **Screw terminals to allow for quick-connection of pickups without damaging wires; a 1/4" output should be built into the structure and easily "patched" to the individual pickup module boxes
    - With regards to the pickup module, the jig should allow for continuous adjustment of locations within the range (rather than a few fixed locations)
- The headstock (w/tuners) shall be a removable module as well to allow for changing of the bridge module without having to scrap the set of strings currently loaded. The headstock is not intended to be a developmental module, but rather is intended to allow for enhanced interchangeability on the bridge. Also, such a design can allow for quick changes from a conventional to a “headless” setup.

Components

Headstock modules

- The headstock module is essentially similar to the Bridge module, except it includes channels on the side for tuner access.
- A new module may be simply created by importing the main guide block into Solidworks and cutting it away using a typical headstock design. It is recommended that as many thick pieces as possible be used for support, as it will be subjected to the same amount of force as the Bridge module.
- Solidworks assembly with cuts and other features is demonstrated in the supplied files.
- For strength, at least 50% infill and enlarged perimeters should be printed (7-8 perimeters)

Pickup Modules

- Single Coil Pickup Module (Seymour Duncan)
  - 3 hole mounting pattern
  - Holes in module are thru holes for 3x 6-32 screws
  - Use the smaller,helical springs, wider end contact underside of the module
  - One module is a straight setup, the other is angled for a bridge location
  - Screws should thread into the pickup
- Single Coil Pickup Module(Lace)
  - This module should fit any other single coil with only two mounting holes
  - Holes in module are thru hole for 2x 6-32 screws
  - Use the smaller helical springs, wider end should contact underside of the module
  - Can be mounted straight or at an angle
  - Screws should thread into the pickup
- Humbucker Pickup (Seymour Duncan)
  - Should fit any humbucker on the market (fingers crossed)
  - Holes in module are thru holes for 2x 3-48 screws
  - Use longer, straight springs
  - Screws should thread into the pickup

Nut Modules

- The nut module is composed of two components: a nut holding block and a sleeve. The sleeve includes two holes with embedded nuts inside to press on the block's bottom, raising and lowering the block to get the appropriate nut height.
- Because the only thing that has to be changed are the nuts, they may be cemented into or removed from the block as needed. If the nut only has to be replaced at the same height, simply leave the sleeve screws in their original position and insert a new block through the top.

- The nut overhang block was intended to keep the nut 17mm from the center of the first tuner hole while the headstock is angled at 4.5 degrees. When the headstock is absolutely level and at no angle, the straight block nut module will only hold at 17mm.
- Should be printed with at least 50% infill and larger perimeters for strength (7-8 perimeters)

Bridge Modules

- The bridge module is built around a big block that has two internal rails for M8 threaded rods. These rods connect to a barrel nut inserted in the block. All that needs to be retained for redesigns are the side rail slots, the thickness around the guiding holes for strength, and the guide holes themselves. The length of the block may be adjusted to reduce the amount of material utilized. Should be printed with at least 50% infill and larger perimeters for strength (7-8 perimeters)
- The bridge models can be 3D printed or, ideally, machined from Delrin. If you need to create another bridge module, use the Stock block as a reference to trim pockets and eliminate any unnecessary materials.
- Maintain the position of the guide rod holes, barrel nut holes, side tabs, and top surface. This guarantees that the strings pass over the frame's center support bar.
- There is some wiggle room in that measurement since the bridge (in the module) may be vertically movable, and the nut module is likewise vertically adjustable; eventually, with regard to the top plane standard mentioned above, the string height for any bridge will be roughly the same.
- Hipshot Fixed Bridge
    - The three smaller holes are 5/64” in diameter and are used for the bridge's mounting screws. They will use the Delrin on their own.
    - The six 18-inch THRU holes allow the strings to travel through the bottom of the module and up through the bridge.
    - Six counterbored holes are located on the bottom. Six string retention ferreles will be pressed into these counterbored holes.
    - A 5/64” drill bit and collet tool, as well as an 18” drill bit and collet tool, will be required.
- Parker Fly Fixed Bridge - UNFINISHED
    - Three holes in the module must be tapped using a RH 10-32 tap.
    - The bridge will be mounted using double-sided threaded screws.
    - For this CAM, you'll need a drill bit with a diameter of.159" and a collet.
- Parker Fly Vibrato Bridge - UNFINISHED
    - Speak with someone at Washburn about utilizing an extra long 38" end mill that is at least 1.5" long.
    - A 12" drill bit and collet must be made.
    - For op 3, laser cut handmade parallels from scrap plastic or wood in washburn at a +4 degree angle off the horizontal.
    - Talk to Prof. Manzo regarding assembly.

Next Steps

- However we design the component modules to lock into the rig, we need to think of a way to get those components to *also* lock into a a second rig that is a "wooden guitar body" type design that has a guitar neck attached to it; the goal, then, is that component module blocks can go transferred from the component testing rig to a more “playable” guitar rig.

Other Links and Resources

Project Resources

- Wiki Page: https://vjmedia.wpi.edu/Private:Guitar_Component_Testing_Rig
- Testing Rig Video: https://www.youtube.com/watch?v=lOk9m2ms3Rc
- Solidworks Model Video: https://www.youtube.com/watch?v=6mRaFAJDCNk&t=1s

Tutorial Resources

- CAM Tutorials for Step by Step Process:
  - Basics: https://www.youtube.com/watch?v=VPMvnzmuTOw
  - Order of Operations: https://www.youtube.com/watch?v=APK0zo1nIeU
  - Guitar Body: https://www.youtube.com/watch?v=7gshKzKdbb4