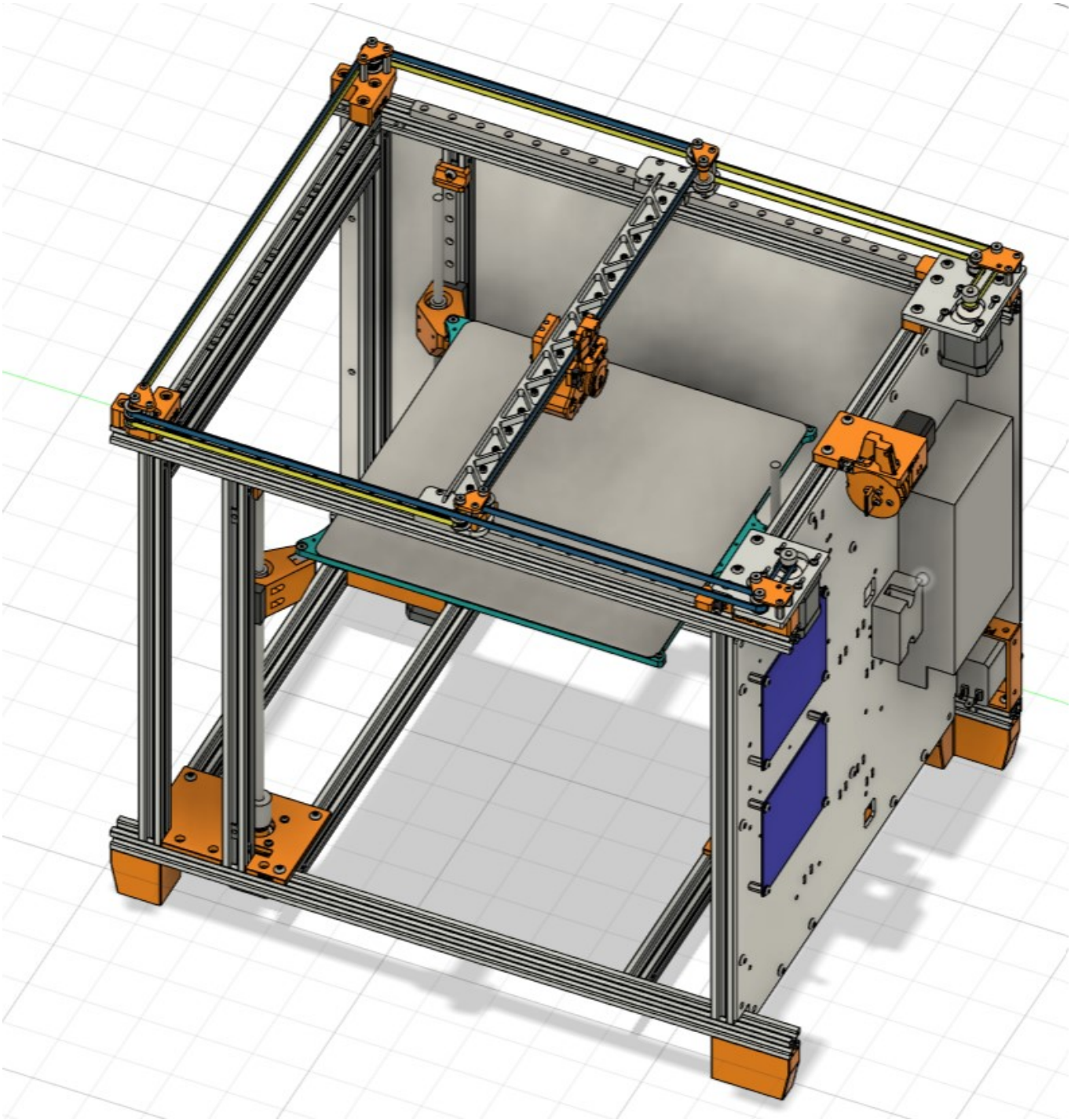
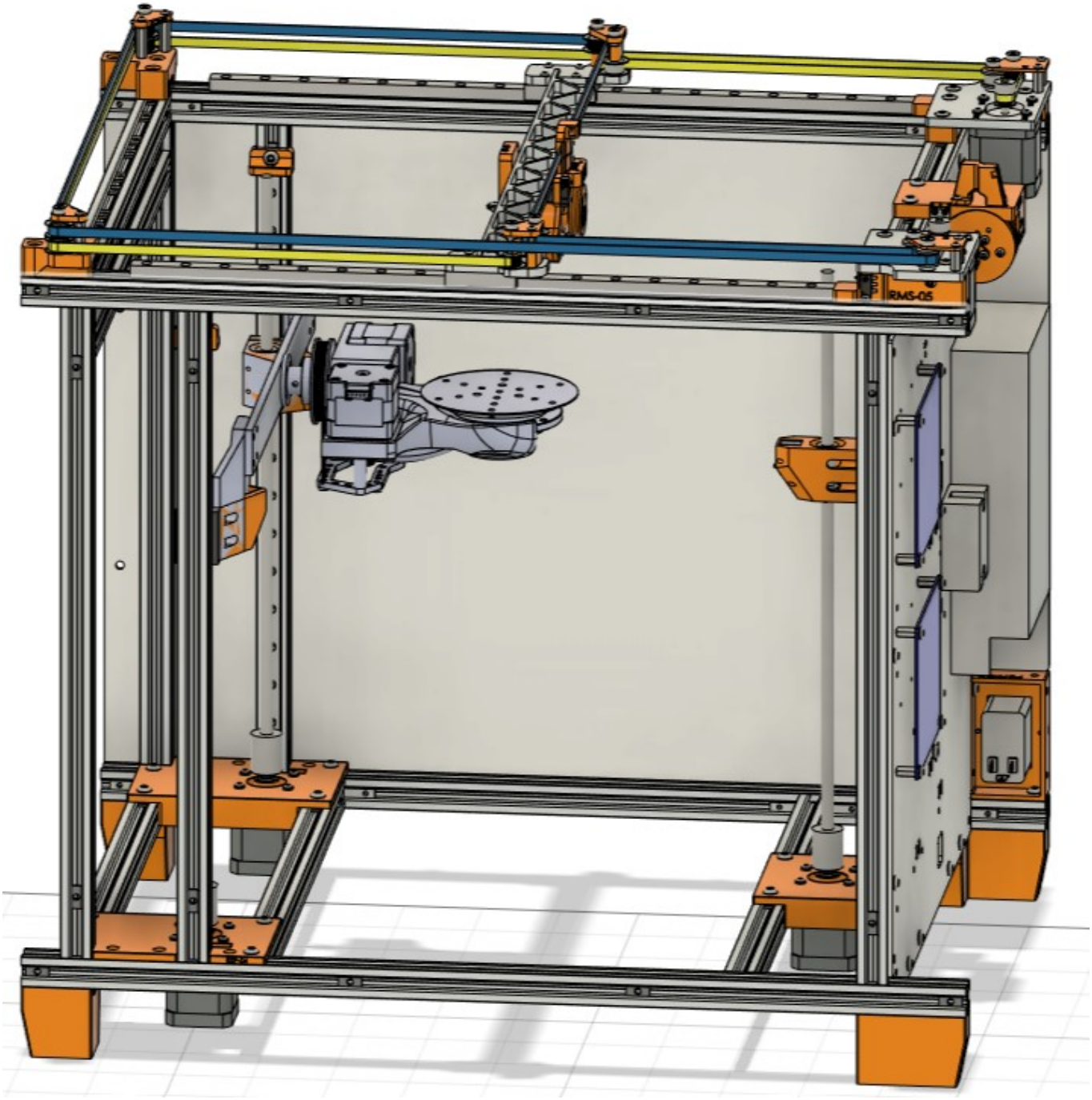
Guide to 5 Axis on the Jubilee

Your goal will be to replace the standard 305 x 305mm rectangular bed on a Jubilee with a circular 100mm, 5 axis enabled bed:
This:



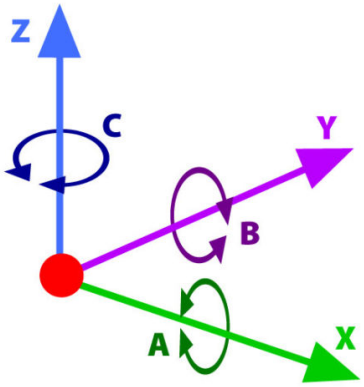
> (Poofjunior, jubilee.step from Jubilee github)

To this:



> (above with Garth42's Jubilee-Open5x-assembly.step in place of bed)

Which adds a B & C axis, that is rotation around the Y and Z axes:



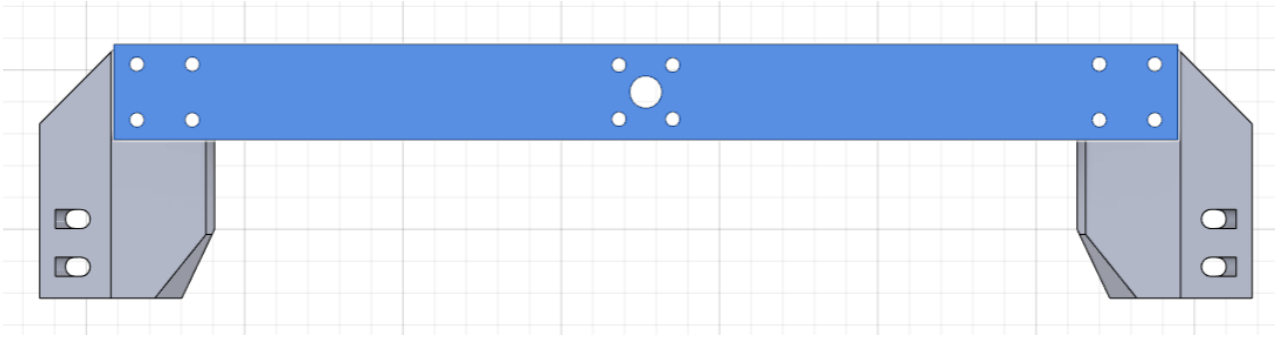
> (Winndeavor, 5-Axis CNC Machining Explained)

You need to:

- Download all files in the Jubilee folder (hell, download the E3D ones too)
- Assemble materials
- Build the stage
- Install the stage
- Update your configuration files

Assembling Materials

1. Acquire all items on the 5 Axis Jubilee BOM
   Machining: you need this simple bridge:



> (Garth42's Jubilee-Open5x-assembly.step on the Open5x Github)

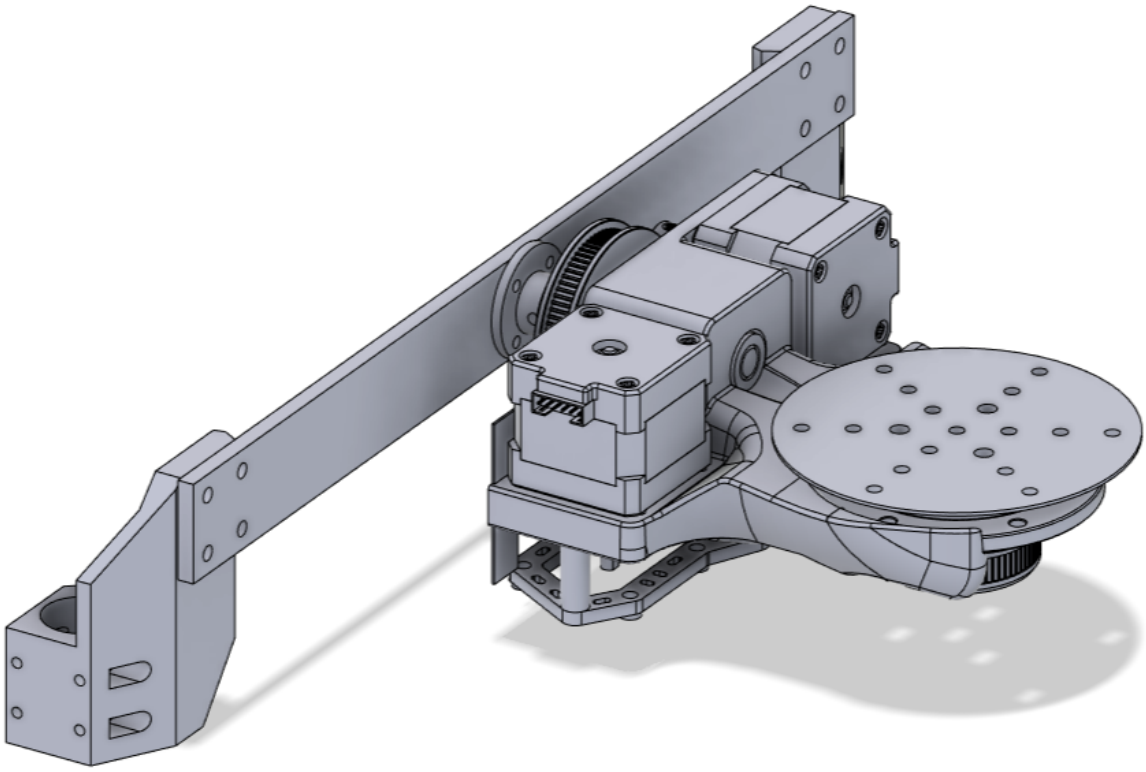
Any material that can hold about 1 kg hanging a foot forward from the large middle hole will suffice. However, **aluminum or steel** is recommended.

Printing: Print two versions: one in PLA, then one in engineering plastics. Similarly, do a test build in PLA, then one in the pricey material.

Building the Stage

Process:

- Open the Jubilee Open5x Assembly and refer to it throughout the build.



> (Garth42's Jubilee-Open5x-assembly.step on the Open5x Github)

- Add heat set inserts:
  - Watch this video from Markforged
  - Bed: M4 in the three big holes, M3 everywhere else. Be sure to keep the top of the bed clean, using short heat set inserts may be helpful here.
  - Body: M4x5 in the turntable connector, M3x2 in the harness connection points.
  - Bracket: M4x4 in the holes connecting to the bridge.

- Pound the flanged sleeve bearings into the main body with a deadblow hammer
- Slide in the 10-mm shaft
- Slide on the 80-tooth pulley, secure with grub screws
- Stepper motor 1: spindle pointing towards Z bridge
    - Place into slot, wiring socket facing away from main body
    - Add 20-tooth pulley, align with 80-tooth, secure with grub screws
    - Slide on the 200mm Gates belt
    - Pull the motor to tighten belt, secure with M3x8 (or x10) bolts.
- Bed:
    - Place the Igus ring onto the hole in the main body
    - Secure with M4x12
    - Push resin gear into the bottom of the Igus ring, place 100 mm bed on top
    - Connect all three with M4x40
- Stepper motor 2: pointing downwards. Follow same process as stepper motor 1, with the 280mm Gates belt and M3x12 (or 16).
- Wiring harness:
    - Position the aluminum spacers over the M3 heat set inserts and the wiring harness over the spacers, with flat surface facing upwards
    - Secure with M3x30.
- Brackets:
    - Screw universal mounting hub onto bridge with M4x8 (or so)
    - Attach bridge to brackets with M4xas long as you want, but 20-25 should do just fine.

Install the Stage

- Take photos of your printer with the ordinary bed, including of all wiring and boards, for reference later.
- Take off 305mm rectangular bed and place on the floor

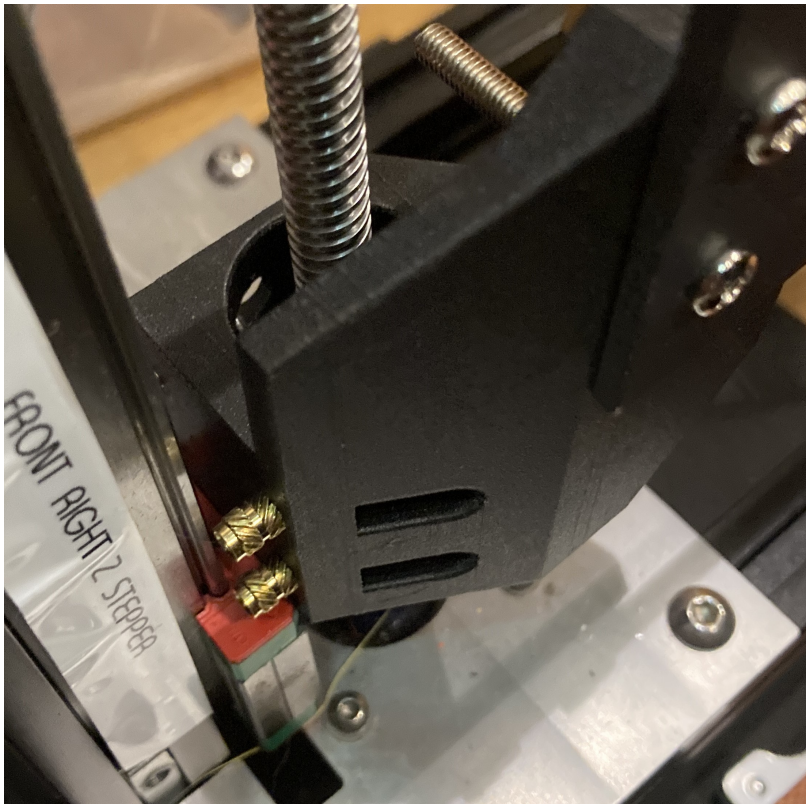
- Remove the aluminum yokes:
  - Take off the 4 short M3 screws connecting yoke (the big aluminum bit) to the plunger.

  - Take off the 4 long M3 screws connecting the yoke to the green and red linear carriage. Keep a finger on the carriage because it will drop when the last screw is removed.

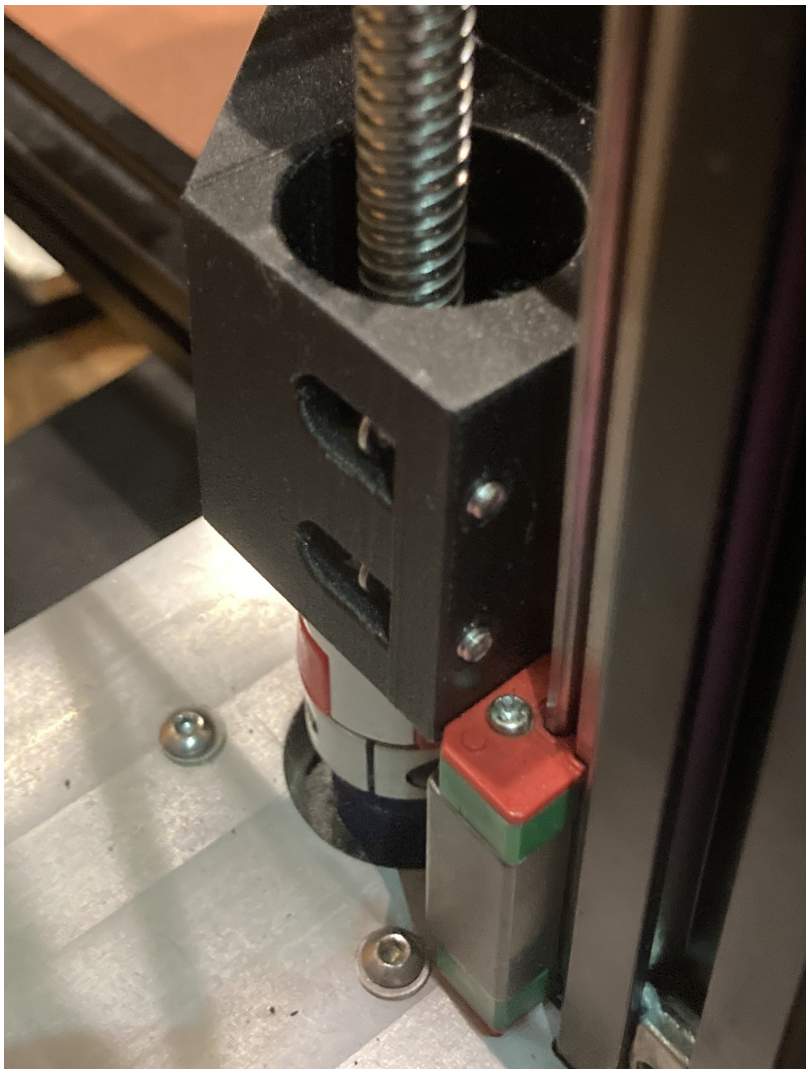
- On the 5 axis bed, the plungers are installed upside-down. Thus, unscrew the plungers from the leadscrews.
  Install the 5 axis stage:
- We will swap the position of the short and long M3 screws to accommodate the tight tolerances on the brackets.
- With the carriage off the printer, push all 8 **short** M3 screws into the holes facing away from the bracket. This is tricky: I pushed the screw into its side-

loading hole, then dug at it with a thin allen key to get it through the hole.

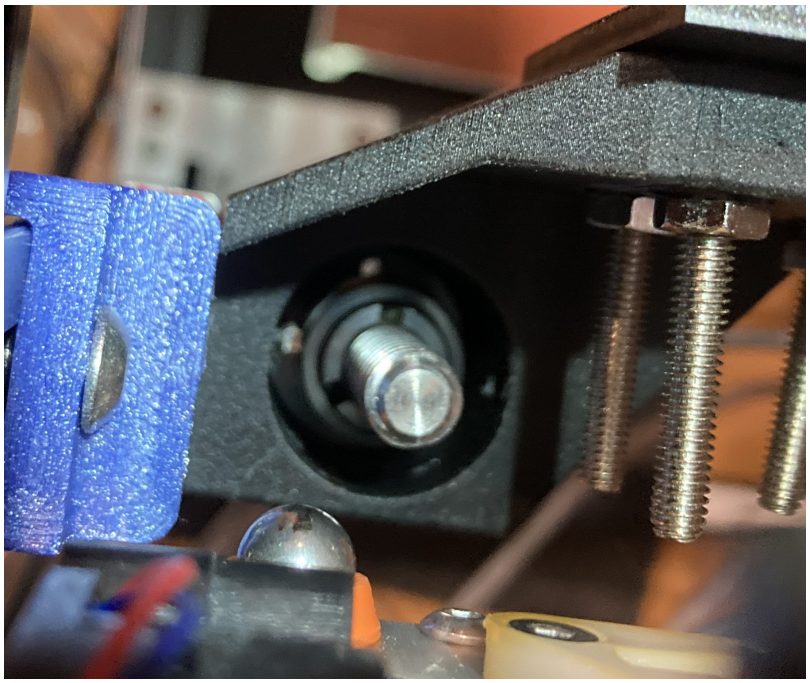
- As you get each screw into its hole, **screw on a nut** so it doesn't fall back out.



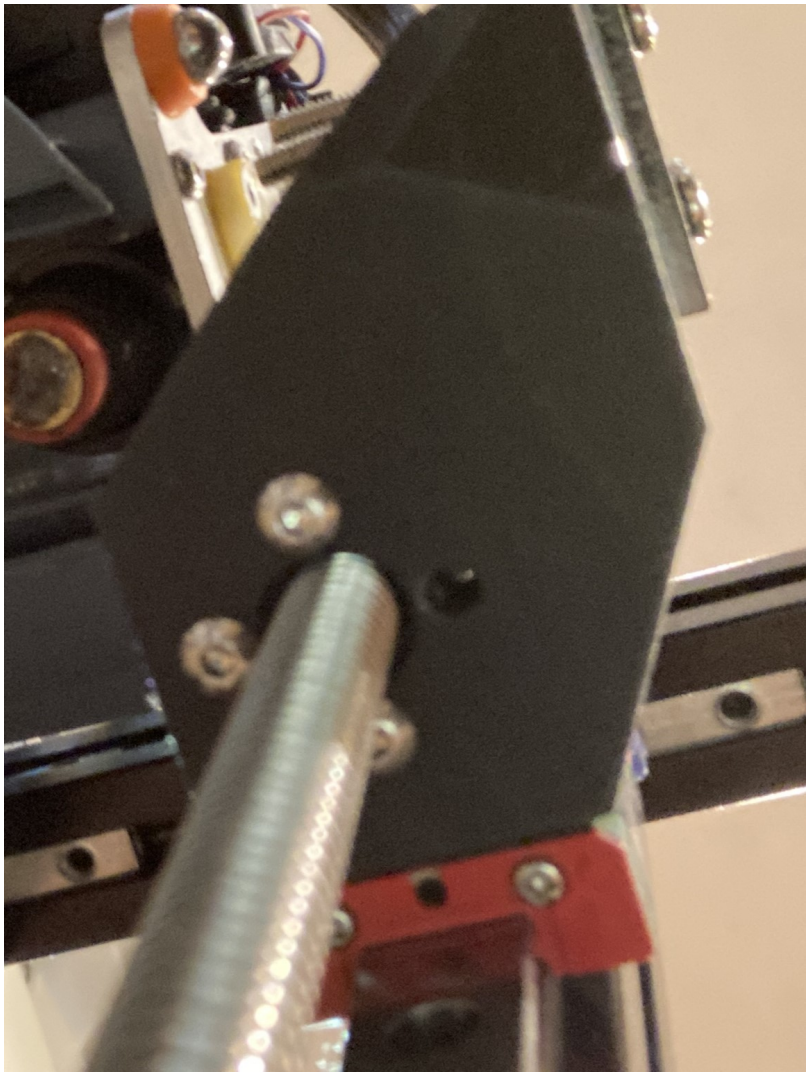
- Put the stage onto the two front Z axis screws. We will attach the linear carriages first, then the plunger.
- Unscrew the nuts and push the screws backwards into the bracket just enough so that the linear carriage can be aligned with all four.



- Align and screw into carriage. Be patient; this takes some time.
- Screw the plungers back onto the leadscrews, wide part facing down.
- Move the stage up the rail and push plunger into the hole.



- Screw in the long M3s from the bottom



- Stage is attached, congratulations!

Run the wiring

- Wiring Diagram for the Duet 3 Mini 5+
- You need two free Driver ports, and can disconnect the Driver port for your back Z axis motor.
- The Duet 3 Mini 5+ uses 4-pin KK connectors, the expansion board uses 4-pin JST VH connectors.
    - If using the TwoTrees motors linked in the 5 Axis Jubilee BOM, they will fit into the 4-pin KK connectors but not easily.
- Ground the motors to the frame.
- Before connecting to the driver ports, check the phase on your motors' cables so it aligns with the wiring diagram.

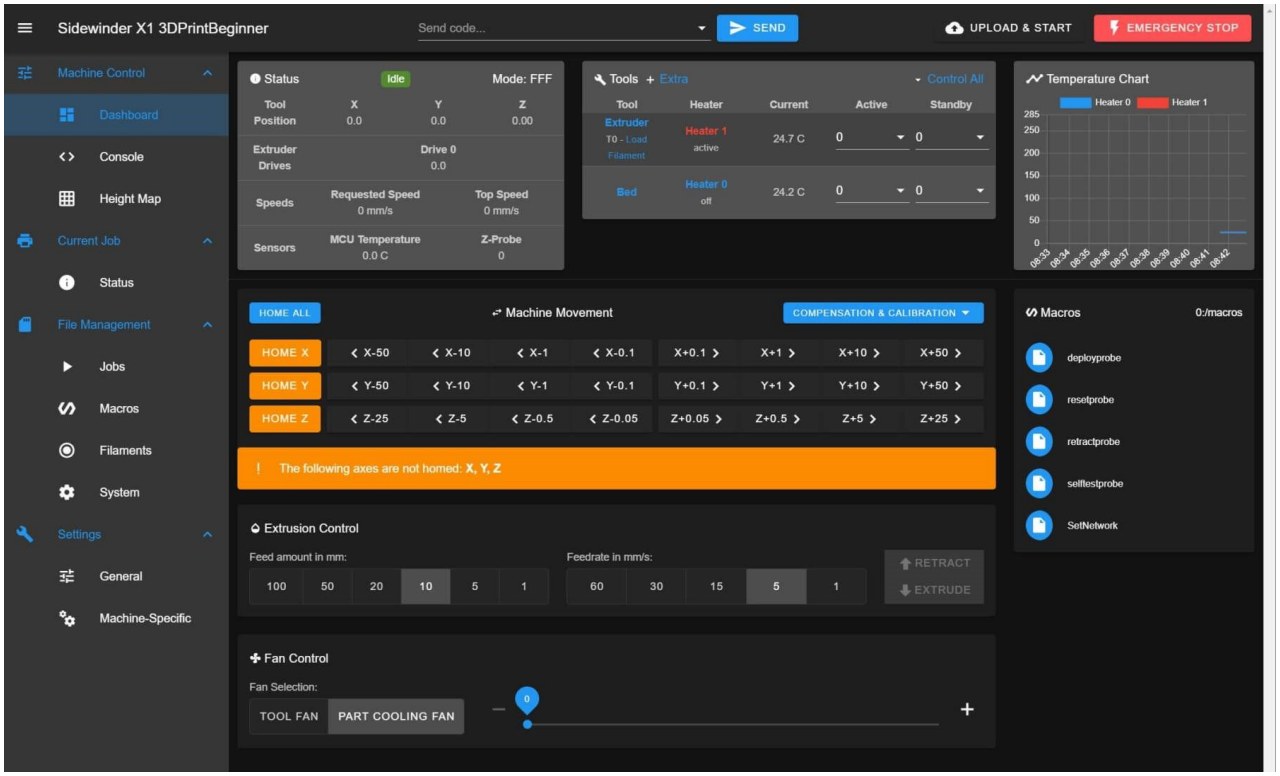
- Run the wiring through the wiring holder underneath the main body so you can feel like there's a point to the piece.

Update Configuration

Alright, this is the hardest part. Up till this point, if you have standard Jubilee hardware the instructions can be followed rigidly. Now you'll need to understand your config and do a fair bit of testing on your own.

There are two main parts: editing the config file and editing other system files. Examine all files in Post-Open5X Files. They break down into:

- **Config.g**: your machine model in software. Most important, will take the most edits.
- **Homeb/c/y/x....g**: describes the homing routine which will run when you hit the Home buttons on your Duet 3 interface. **Homeall.g** notes the order in which they run.



> (from 3D Print Beginner, this is for a Sidewinder X1 but Jubilee looks similar)

- All files starting with **t...** (Toffset.g, tfree1.g, ...): have to do with tools.

    - **Toffsets.g** describes the delta between the Z-axis probe on the underside of the tool carriage and the nozzle of each tool.
    - **TfreeX.g**: selects Tool X when no tool is equipped
    - **TpostX.g**: once Tool X has been locked to the carriage, removes Tool X from the parking post and to last printed location
    - **TpreX.g**: returns Tool X to its parking post, unlocks it from carriage.
- **meshLevel.g** and **bed.g**: runs before each print. **Bed.g** probes each side of the stage and levels by adjusting the Z axis leadscrews. It then runs **meshLevel.g**
- **pause.g**: self-explanatory

I have attempted to note my thought process in each file, and preserved the original content of each file by commenting it out with `;`. Additional notes:

- Download and upload files through Duet Web Control: Files -> System
- Make a backup of all your system files before editing
- In testing, keep your finger on the off switch. Interrupts through GCODE (e.g. `M0`) will wait until the current move is completed.
- Duet3D GCODE Dictionary: M-codes are largely used in config files, G-codes in printing.
- Skim the guide once, then work through the instructions one-by-one while referencing the GCODE Dictionary and the given files. Soon, you'll likely not need my directions.
- There's no easy way to disconnect your heated bed, so you will keep all wires attached and place the old bed at the base of the printer.
- It will take multiple attempts for a config to work properly, your carriage will crash into things. I have likely made mistakes in places, trust your gut.

Semi in-depth guidance

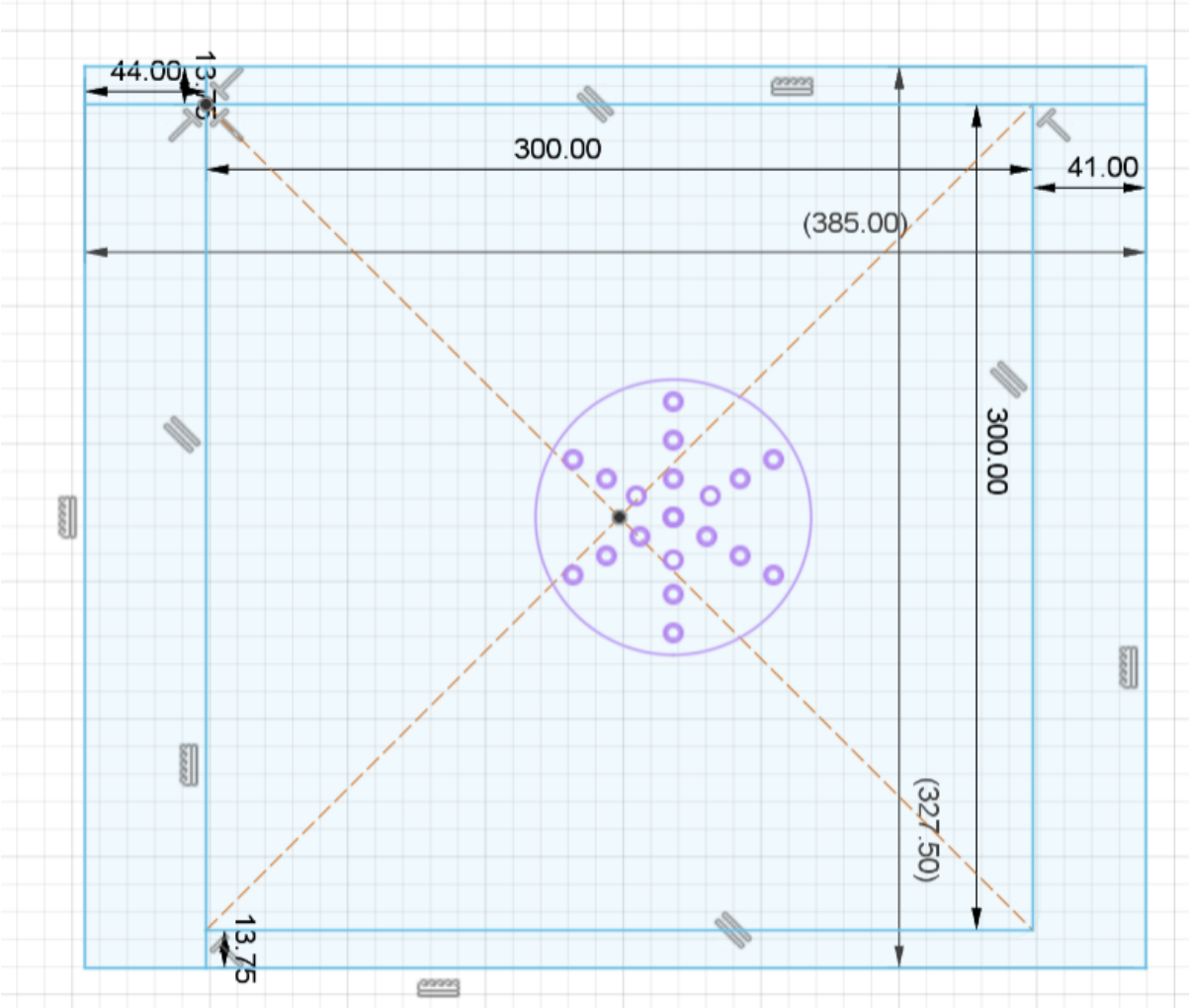
Config.g, you must:

- M569 B and C: sets the properties of physical driver ports on your boards (Px.x) to run forwards or backwards, etc.

- M584 (set drive mapping) for B and C axis: maps the physical driver ports to axis.
    - E.g. `M569 P0.0 S0` and `M584 C0.0` first sets the Driver 0 port on my Duet 3 Mini 5+ to run clockwise, then assign the letter "C" to use the Driver 0 port.
- M569 only two Z screws
- M584 only two Z screws (remove the 3rd)
- M906 B and C: set current to 70% of peak current, which should be listed in the motors' specs.
- M669 (kinematics profile): used Garth's, `M669 K8 X1:1:0:0:0 Y1:-1:0:0:0 Z0:0:1:0:0:0 B0:0:0:0:1:0 C0:0:0:0:0:1 U0:0:0:1:0:0`. The kinematics profile defines which motors move to produce a carriage movement in each direction.
    - E.g. the Jubilee uses two motors connected by belts to move in X and Y, so if you want to move straight along Y you must turn Motor 1 clockwise and Motor 2 counterclockwise.
- M92 (set axis steps per unit length) B and C axes: since we move rotationally, we are calculating steps per degree of motion in the bed / main body. The formula is therefore `1/[motor step angle]) * (gear ratio) * [microstepping factor]`.
    - If you are using the TwoTrees from the BOM, there are 200 steps / revolution, so I came out to `M92 B{{(200/360)*(80/20)}*16}` and `M92 C{{(200/360) * (72/20)} * 16}`.
- M350 (set microstepping) on B and C: 16x microstepping, `M350 B16 C16 I1`.
- Speed, Acceleration, and Jerk values: it is difficult to find max acceleration or jerk, so I used a conservative 1000 mm/s^2 and 300 mm/s^3 for each, respectively. Speed is max degrees / minute, calculated as `[max rev / minute] * [steps per rev] / [steps per degree]`.
    - For the TwoTrees, max revs/minute is 570, so I ended up with roughly 2800 for B and 3125 for C.
- M208 (sets axis origin, max travel) for B and C: C may be arbitrarily large, B can rotate until the wires get tangled, so I set `M208 B-200:200` and `M208`

`C-99999:99999`.

- M208 X, Y, Z to change new origin point so (0,0) is center of the bed: using the Jubilee model, I calculated the delta between the corner of the 305x305mm bed and the center of the 100mm bed:



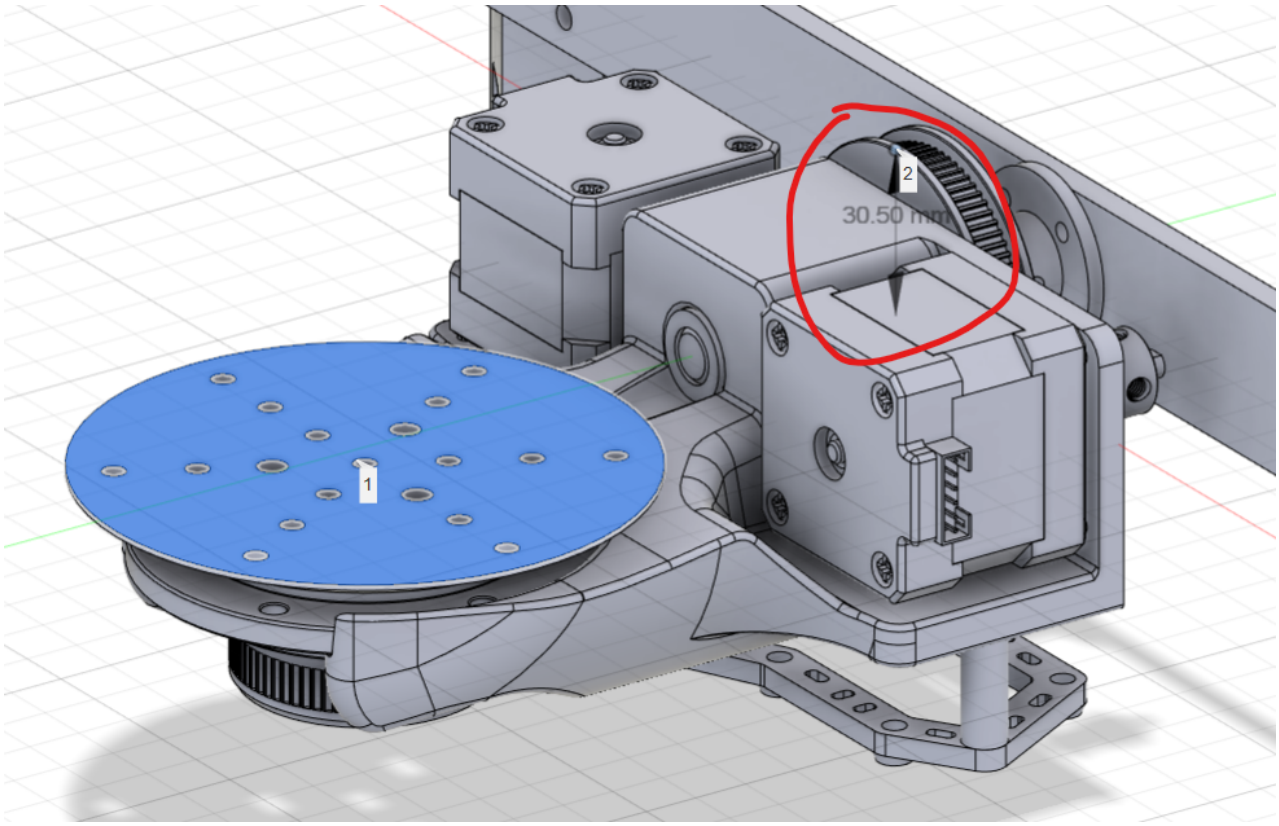
  and found that the new XYZ movement envelope was `X-163.75:-163.75`, `Y-213.548:171.452`, `Z-14.5:280.5` with `-50:50` in XY being on the bed, and the translation from rectangular to circular coordinates to be **(-150, -169.548, -14.34)**. Yours may differ.
- M143 (set heater maximum) your bed so that it cannot heat above 40C. This is for safety, since we don't disconnect the bed.

Other file changes: aside from tool files, hopefully can be copied over as-is. My edits were:

- **bed.g**: now probes only two points on the far sides of the bed and adjusts the leadscrews. I placed a limit on how far each leadscrew can adjust (`S2`

= 2mm), because these brackets connect leadscrew to stage rigidly vs the ball and groove connectors of the rectangular bed.

- **homeall.g**: Homing order is U (tool lock), Y, X, B, C, and Z. B and C don't have limit switches, so both **homeb.g** and **homec.g** simply assign the current position of the B and C axes as the homed (origin) position. This is ok on the C axis (as a circle, it is identical at any rotation before printing), and the B axis can be manually aligned with a bubble level before homing.
- **pause.g**: When printing on the rectangular bed, the print surface is the highest point being carriage by the Z leadscrews. On the circular stage, however, the 80-tooth pulley is significantly above the print surface:



> (Garth42's Jubilee-Open5x-assembly.step on the Open5x Github)

- Thus we drop the bed 33mm when pausing, stopping, returning tools, etc.
- **All other .g**: go through *every one* of your config files and compare to the ones given to be sure none use rectangular coordinates, lack a sufficient Z dive, use the old tool offsets, etc.

Important info:

- Translation between rectangular and circular coordinates: **(-150, -169.548, -14.34)**
- Safe Y: below **Y45** with no tool selected. The carriage does not know anything above the print area exists (the motors, the pulley, etc.) and can collide with it. Thus, any movement more positive than Y45 requires a Z dive to be done safely.
- Z dive: **33mm** to clear the 80-tooth pulley
- Though the bed is 100mm, I use a printable area of 98mm to allow for a margin. This area is defined by your slicer or in mesh leveling: there is nowhere in the config you need to say, "My machine has a 100mm circular bed".

Printing

- Use Full Control GCODE, install locally or use on the web. Play with the 5 axis demo.
- I have not found a suitable GCODE viewer, so GCODE validation is done by trial and error. You could explore using NCViewer.
- You will need custom start / end GCODE. To start, I used:

```
G1 Z1 F900      ; Drop bed a little
G90
T-1                     ; deselect any tool
G1 X0 Y0 C0 F9000
M558 F500  ; Set the probing speed
G30 ; Do a single probe
M558 F50 ; Set a slower probing speed
G30 ; Do a second probe
M557 R49 S15 ; mesh level a 98mm bed every 15mm
G29 S1 P"/sys/heightmap.csv"; load the heightmap from mesh
leveling
T1
M109 S210 ; set temperature and wait for it to be reached
G21 ; set units to millimeters
G90 ; use absolute coordinates
M83 ; relative extrusion
```

```
;Purge line
G1 Z0
G0 X-22 Y22
G1 X22 E45 F300
G1 Z5
```

- To End:

```
G91
G1 Z33 F5000
G90
G1 B0                   ; home B axis
G92 C0                  ; declare current C position as 0
T-1                             ; return tool
```

And a second congratulations is due -- you have a working 5 axis printer!!

Credit

Thanks to Freddie Hong and the Open5X team for making this project.
Thanks to Brendon Builds for the port to the E3D toolchanger, the assembly used throughout is his.
Thanks to Garth42 for his adaptation of the E3D toolchanger version to the Jubilee platform.
Thanks to PoofJunior for the base Jubilee model and config and to the excellent Jubilee community.
All mistakes are mine.