Design Supplement Document
Autodesk Escher Collaborative Control Printer Design
Revision 1.1
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Purpose of DESIGN SUPPLEMENT

Multi-gantry printers have different design constraints and considerations than single gantry printers. They are inherently more complex and they bring a unique set of engineering challenges. This *Design Supplement* contains topics and discussion that we deem outside the scope of the *Functional Recommendations Document*. The comments and discussion contained here stem from our learnings and insights gleaned from building, testing, redesigning and rebuilding several generations of multiple gantry printer prototypes at Autodesk. We have included these comments to help accelerate your development of high-quality hardware compatible with the Netfabb multi-gantry "Project Escher" control system.

Some of the discussion herein includes multiple strategies for approaching the same design challenge. ***Some of these strategies can be combined and some are mutually exclusive.*** Some strategies may be "better" engineering practice than others. All of them should be used at your discretion, based on your own good judgement.

We hope that this document will aid and speed you on your path to designing and building high-quality multi-gantry 3D printers.

Sincerely,

The Autodesk "Project Escher" Team

Design Considerations, Recommendations and Notes

Definition of Axes

Figure 1 *Coordinate System Definition. The long axis (X) is shared by all bots with on-board, independent Y and Z motion.*

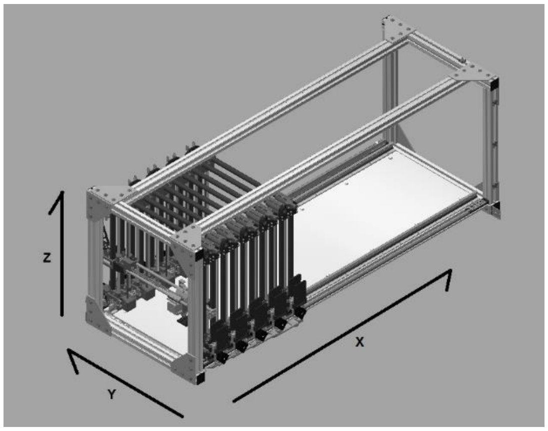
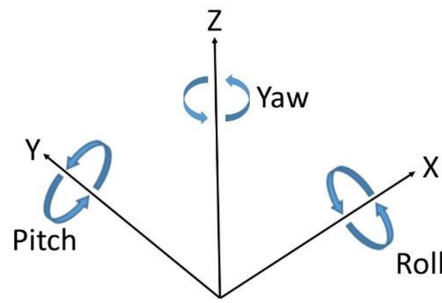


Figure 2 *For clarity we will use standard aircraft terminology to discuss rotation or "skew" around coordinate axes. Rotation around the Z axis is "YAW," rotation around X is "ROLL," and rotation around Y is "PITCH."*



Definition of Terms

1. Bot: a gantry or other type of movable frame within a 3D Printer that contains independent controllable X,Y, Z, and Extrude axes.

Gantry Alignment

1. In multi-gantry printers all gantries must be aligned to a shared coordinate system.
   a. For a number of reasons including compounding error, gantries are less tolerant to poor axis alignment than traditional 3D printers.
   b. Gantries can be physically aligned or alignment can be done in software if deviation from coordinate system is known.
   c. Non-planar gantry movement, even if detected, cannot currently be corrected in software.

Individual Bot YAW

1. Overview:
   a. For some printer geometries, optimal bot packing along the X axis often requires bot gantries that are substantially shorter in the X direction than in the Y direction (see Figure 1 for axis definition). This high Y:X aspect ratio may result in gantries that are more likely to experience unintended yaw than typical FDM printer gantries (Figure 2).
   b. The misalignment from yaw can affect both the relative position of the bots to the build platform and the relative position between individual bots.
   c. Yaw errors reduce print quality.
   d. Yaw can cause undesirable mechanical loading.

    e. The purpose of this section is to mitigate movement-related problems that can arise from unintended bot yaw.
2. Recommendations and Considerations:
    a. Make bot footprints longer than minimum bot nozzle to bot nozzle distance (aka packing distance).
    b. Make bots as rigid as possible to counteract yaw.
        i. The portion of the gantry structure connecting opposing X rail/carriage system components should be as rigid as possible.
        ii. Open-loop synchronized drives in +Y and –Y locations may not be sufficient to eliminate yaw on high aspect ratio gantries, even with seemingly rigid structure.
    c. Make bot yaw mechanically adjustable, then lockable.
        i. Enables aligning all bots on a printer to the same coordinate system and to each other.
    d. Make bot yaw adjustable with automation
        i. Use electronic datum system or other system to detect yaw errors.
        ii. Use printed test pattern to detect yaw errors between bots.
        iii. Use control system to correct yaw errors based on detected misalignments.
            1. Either physically correct structural misalignment (e.g. independently adjust both sides of bot) or use correction factor in software or firmware.

<u>Individual Bot ROLL</u>

1. Overview:
    a. In a Collaborative Control printer multiple gantries must be parallel to one build surface.
    b. An adjustable build surface can only be made parallel to one gantry.
    c. Roll can cause layer misalignment and/or nozzle-part contact.
2. Recommendations and Considerations
    a. Design bot structure to counteract roll.
        i. Structure connecting opposing Z rail/carriage system components as rigid as possible
        ii. Open-loop Synchronized drives in +Y and –Y locations may not be sufficient to eliminate roll, even on very rigid structures.
    b. Make bot roll mechanically adjustable (e.g. using a mechanical fastener etc.), then lockable.
        i. Enables procedure to align all bots on a printer to build platform, then lock all bots in alignment.
    c. Make bot roll adjustable with automation
        i. Use electronic datum system or sensor to detect misalignments.
        ii. Use physical adjustment to correct misalignments.
        iii. Use control system to correct misalignments based on detected misalignment
            1. Either physically correct structural misalignment (e.g. independently move motors) or use correction factor in software or firmware to compensate for roll errors in physical structure.

<u>Individual Bot PITCH</u>

1. Overview:
    a. Pitch errors can cause reduction in print quality, particularly at seams.

                i. Bots should be as parallel as possible in Y-Z plane (see Fig. 2).

Motor Orientation

1. Overview:
    a. Collaborative Control bots may have motors in mirrored positions driving a single axis
2. Recommendation:
    a. Check to ensure proper motor polarity for opposing motors.

Filament/Material Routing

1. Overview:
    a. Collaborative Control Printer toolpaths often require more and larger back-and-forth printing and travel moves than traditional 3D printers.
    b. There is more than one moving gantry that requires filament/material. As a result, material routing in a Collaborative Control printer has a unique set of design requirements.
2. Recommendations and Considerations:
    a. Pay particular attention to minimizing risk of filament/material/material handling system snags.
        i. Back-and-forth (X) and up-down movements (Z) of gantries can result in filament/material/material handling system slack.
        ii. A given bot's slack can cause problems with adjacent bots and with itself.
            1. Minimize "out of bot" (XY plane) slack.
            2. Pay attention to potential snag points on bots and on printer frame.
    b. If using filament, consider running filament in guide tubes.
        i. Fixed length tubes may be easier to control and present less slack.
    c. Consider carrying filament spool onboard each gantry.
    d. Consider moving filament spool *with* gantry but not *on* gantry.
    e. Consider retracting filament slack back onto spool.
    f. Consider retracting filament slack, but not back onto spool.
    g. Consider retracting guide tube slack.
    h. Consider containing filament and/or guide tube in area that permits slack without risk of snags.

Reliability

1. Collaborative Control printers are inherently more subject to failure than simpler printers because failure probability is multiplicative.
    a. For instance, if each bot has a print success rate of 99%, then for a printer with two bots the success rate probability is .99 * .99, or 98%.
2. Recommendations:

    a. Taking steps to maximize reliability have a greater impact on print success rate than taking the same steps in single gantry 3D printers.

3. Note: failure-reducing features may be added to control system in the future.