Alex Mous
2 April 2019

Bigger, Better, Faster

Designing and Building and Improved Budget 3D Printer

Engineering Goal

To design and build an improved easy to run budget 3D printer costing less than $750 for home users to create high quality, high speed prints with a minimum print volume of 275x275x325mm ($2.475x10^7 mm^3$, approximately the size of a 6 gallon wastebasket).

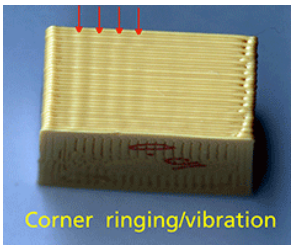
Criteria and Constraints

- Parts and materials must cost less than $750
- At a print speed of 60mm/s, ringing must be less than a 3 on a ringing scale of 1-6 (1 is negligible, 6 is significant) and roughness must be less than a 3 on a roughness scale of 1-6 (1 is smooth, 6 is rough)
- Print tolerance of ±0.2mm on a 25mm cube
- A minimum print volume of 275x275x325mm (2.475x107mm3)
- Sturdy frame and design
- Powerful heat bed capable of quickly heating to more than 110°C

Background Research

In 2016, I built an Anet A8 budget 3D printer from a kit. During two years of use, the following issues became evident:

- Print quality (surface quality and amount of ringing (see picture to right for illustration of ringing)) rapidly degraded with an increase in print speed
- A lack in frame sturdiness caused low quality parts from shaking induced by the moving axes
- Bolts loosened with use causing rapid degradation in calibration, giving rise to repeated long setup times
- The heat bed was underpowered and could not heat up quickly or reach temperatures above 95°C (required to print certain plastics)
- Print volume was limited to 220x220x230mm
-



Picture of ringing. Photo credit: cubicdesk.com

Design Execution

- Research parts needed to build 3D printer
- Build aluminum cube frame and assemble IKEA Lack tables (see Picture 1)
- Create V1 of X and Y axes (see Picture 2)
- Assemble electronics (see Picture 3)
- Build Filament Storage (see Picture 4)
- Make X axis carriage (see Picture 5)
- Make Z axis and Bed Supporting Frame (see Picture 6)
- After determining that axes do not work with current design, create V2 of X and Y Axes (see Picture 7)
- Create Bed Plate (see Picture 8)
- Finish Wiring 3D printer (see Picture 9)
- Hotend Tested (see Picture 10)
- Perform first prints (see Picture 11)

- Add further improvements, including V3 of the Hotend Carriage (see Picture 12)

Parts and Materials List

Qty	Part Description, Dimensions and Selection	Cost	Supplier
2	Linear Shafts 10mm OD 500mm L	$15.20	Aliexpress
2	Linear Shafts 12mm OD 500mm L	$19.10	Aliexpress
4	Linear Bearings LM10LUU	$8.28	Aliexpress
4	Linear Bearings LM12LUU	$8.91	Aliexpress
2	Anti-Backlash Nut Tr8x8x2	$7.64	Aliexpress
1	Stepper Motor for Z with Lead Screw 500mm L	$23.91	Aliexpress
3	Nema 17 Stepper Motor 48 Ncm	$30.66	Aliexpress
30	Aluminum 3030 Corner Brackets	$20.64	Aliexpress
4	Locking Caster 30mmx30mm base 15kg load supporting	$11.14	Aliexpress
10	GT2 Idler 20T W6 B3 With T 5 per lot	$8.47	Aliexpress
2	GT2 Pulley 16 teeth 5mm bore	$1.06	Aliexpress

Qty	Part Description, Dimensions and Selection	Cost	Supplier
100	M3x4 Screws for Thermistor	$2.48	Gamut
25	M3x10x0.5 for Motors	$4.57	Gamut
4	PVC Pipe 20mm D 50cm L White	$10.79	Aliexpress
1	Power Supply 12V 20A	$15.25	Aliexpress
1	Switch and C14 Socket 10A fuse Red	$0.93	Aliexpress
3	Silica Gel Yellow	$7.25	Aliexpress
1	Arduino Mega RAMPS 1.4 A4988 Stepper Drivers Endstops LCD	$36.85	Aliexpress
1	Silicone Wire Flexible 10m 16AWG half of red black	$12.92	Aliexpress
1	Acrylic Offset for Hinges 100x100x3mm A2	$3.28	Aliexpress
10	Acrylic Hinges 25 x 33 x 3mm	$2.42	Aliexpress
1	Titan Extruder and V6 Hotend and Motor Type 3	$25.04	Aliexpress

4	Anti-Vibration Pads for Table 77x77x7mm LxWxH	$1.51	Aliexpress
1	Fiberglass GT2 Belt 5m L	$5.22	Aliexpress
8	Table Mounting Brackets	$3.89	Aliexpress
10	T Slot Nuts M6 m6 100pcs	$10.99	Aliexpress
50	More T-slot nuts	$9.99	Amazon
4	Aluminum Extrusion 3030 Frame 440mm L HFS	$17.60	Misumi
8	Aluminum Extrusion 3030 Frame 470mm L HFS	$37.60	Misumi
4	Aluminum Extrusion 3030 Bed 280mm L	$17.88	Misumi
1	Anodized Aluminum Tubing 3/8”ODx29/200"IDx72"L	$12.14	McMaster-Carr
2	LACK Side table 550x550x450mm Feet: ~50x50mm	$29.98	IKEA
100	M3x25x0.5 for Pulleys	$3.80	Gamut
100	M3x0.5 Nut for Pulley 5.5mm W 2.41mm H	$0.62	Gamut
100	M6x20x1.0 for Mounting	$10.15	Gamut
50	M3 Set Screws 25mm L M3X25(50pcs)	$6.99	Aliexpress
10	Aluminum 3030 2-Hole Connector Plates for Bed 30s 10pcs	$8.99	Aliexpress

1	PTFE Tube and Pneumatic Couplers 2mm ID 4mm OD 1m L Type C	$3.28	Aliexpress
20	M3 Wing Nuts	$1.93	Aliexpress
1	Power Cord 10A NEMA 5-15P to C13	$7.50	Amazon
1	Seal Strip 5mmx12mmx10m	$12.59	Amazon
2	Acrylic Knob for Door	$1.10	Tap Plastics
1	TAP Acrylic Cement 4oz	$7.25	Tap Plastics
1	Acrylic Cement Applicator Small Bottle	$3.50	Tap Plastics
4	Acrylic Sheet 19 7/8 x 18 x 3/32	$42.52	Tap Plastics
1	Solvent Funnel	$0.95	TAP Plastics
3	Bunting Bearings EF060812 Flanged Bearing 3/8” bore, 3/4” L, 11/16” Flange OD, 1/16” Flange	$4.64	Amazon
1	Gulfcoast Robotics E3D V6 Clone Hotend 1.75mm All-metal	$18.99	Amazon
(approximate amount of filament used in fi			
2	HATCHBOX PLA 3D Printer Filament 1 kg Spool 1.75 mm Blue	$39.98	Amazon
Parts Already Owned			
1	Heat Shrink Tube	$0.00	

1	Silicone Heating Pad 300x300mm 120V 750W	$24.62	Aliexpress
10	M3 Knurled Thumb Nuts	$0.99	Aliexpress
50	M3 Washers for Thermistor Mount	$3.36	Aliexpress
1	SSR for Silicone Heat Pad SSR 40DA	$5.86	Aliexpress
10	100k NTC Thermistor	$2.83	Aliexpress
1	Cast Aluminum Bed 1/4" H 13" L 13" W	$54.48	Midwest Steel and Aluminum
100	M6x12x1.0mm Screws For Bed Mounting	$8.08	Gamut
10	M3 Nylon Spacers For Bed 10mm L 5mm OD	$1.75	Gamut

1	4-Core Cable	$0.00	
1	Wire wrap	$0.00	
1	Solder	$0.00	
1	Hot glue	$0.00	
1	Stronger Glue (Hobby cement/super glue)	$0.00	
1	Tape for insulating low-voltage wires	$0.00	
1	Light Motor Oil for oiling rods on both old and new printers	$0.00	
1	1-1/4” Coarse Drywall Screws	$0.00	

3D Printed Parts

Part Name	Version Number	Part Name	Version Number
Acrylic Panel Clamp	2.4	Z axis Adjustable Screw	1.1
Acrylic Toggle Clamp Base	3.1	Z Bearing to Bed Part 1	3.1
Acrylic Toggle Clamp Connector	2.0	Z Lead Screw Restraint	1.0
Acrylic Toggle Clamp Lever	3.0	Z Lead Screw Nut to Bed Mount	1.1
Acrylic Toggle Clamp Handle	4.2	Z Motor Mount	1.0
Acrylic Toggle Clamp Moving Clamp	1.1	Z axis 10mm Rod Clamp Front-Left	1.2
Bronze Bushing Holder from Bushing Holder V5.1	5.1	Z axis 10mm Rod Clamp Front-Right	1.2
Caster Adapter for IKEA Lack	1.0	Z axis 10mm Rod Clamp Back-Right	1.0
Endstop Mount 9.525mm (X axis clamp rotated)	6.0	**V2 of X and Y**	
Endstop Mount 10mm	3.5	12mm Steel Rod Clamp Type 1	2.3
Endstop Mount 10mm (opposite orientation of endstop)	5.1	12mm Steel Rod Clamp Type 2	2.4
Endstop Mount 12mm	3.5	Carriage Main for X axis	3.0
Extruder Mount	1.0	Fan Air Vent/Director	2.0
Filament Runout Sensor Clip	4.0	GT2 Belt Clamp	1.0
LCD and Controls Case	3.1	Hotend Clamp Top for V3 of Hotend Carriage	1.0
M6x8.5 Spacer, wider	1.0	Hotend Mount Plate for V3 of Hotend Carriage	3.0
PVC Pipe Clamp	2.0	Hotend Wire Clamp Part 1	2.0
PVC Pipes Joiner	1.1	Hotend Wire Clamp Part 2	2.0
Reinforcement and Mounting Bracket for IKEA Lack Type 1	2.0	Idler Bearing Mount	1.3
Reinforcement and Mounting Bracket for IKEA Lack Type 2	2.0	Motor Mount	1.5
Switch Holder	1.0	XY Joiner	1.5
Wire Clamp	1.0		

Test Plan

The following tests were printed on both the Anet A8 and the new printer. The test prints were then compared and analyzed.

1. Calibration cubes (25x25x25mm) at print speeds from 30-80mm/s in 10mm/s steps with an acceleration of 1250mm/s^2 testing for:
    a. Ringing
    b. Surface quality
    c. Tolerance
2. #3DBenchys to test the ability to print difficult features (such as overhangs, bridges, complex rounded shapes, etc.)
3. Paper Basket Torture Tests to verify the maximum practical print volumes and identify any additional common printing issues

Test Results

Figure 1: 25mm Calibration Cube Test

Print Speed (mm/s)	New 3D Printer		Anet A8	
	Actual (XxYxZ, mm)	Deviation from Model (mm)	Actual (XxYxZ, mm)	Deviation from Model
30	24.9x25.1x25.1	-0.1,+0.1,+0.1	25.0x24.9x24.8	0.0,-0.1,-0.2
40	24.9x25.1x25.2	-0.1,+0.1,+0.2	25.0x25.0x24.8	0.0,0.0,-0.2
50	24.9x25.1x25.2	-0.1,+0.1,+0.2	25.1x25.0x24.8	+0.1,0.0,-0.2
60	24.9x25.1x25.1	-0.1,+0.1,+0.1	24.9x25.2x24.9	-0.1,+0.2,-0.1
70	24.9x25.1x25.1	-0.1,+0.1,+0.1	24.9x25.0x24.8	-0.1,0.0,-0.2
80	24.9x25.1x25.1	-0.1,+0.1,+0.1	24.9x24.9x24.9	-0.1,-0.1,-0.1

This table shows that the accuracy of the 25mm calibration cubes printed by the Anet A8 varies randomly between -0.1 and +0.1mm in the X and Y axes and between -0.1 and -0.2mm in the Z axis. The new 3D printer showed a constant offset of -0.1mm (X axis) and +0.1mm (Y axis). This constant offset is far easier to compensate for than the random variation of the Anet A8. The Z axis of the new 3D printer varied between +0.1 and +0.2mm.

Print Quality vs. Print Speed of 25mm Calibration Cubes

Figure 2: Ringing vs. Print Speed

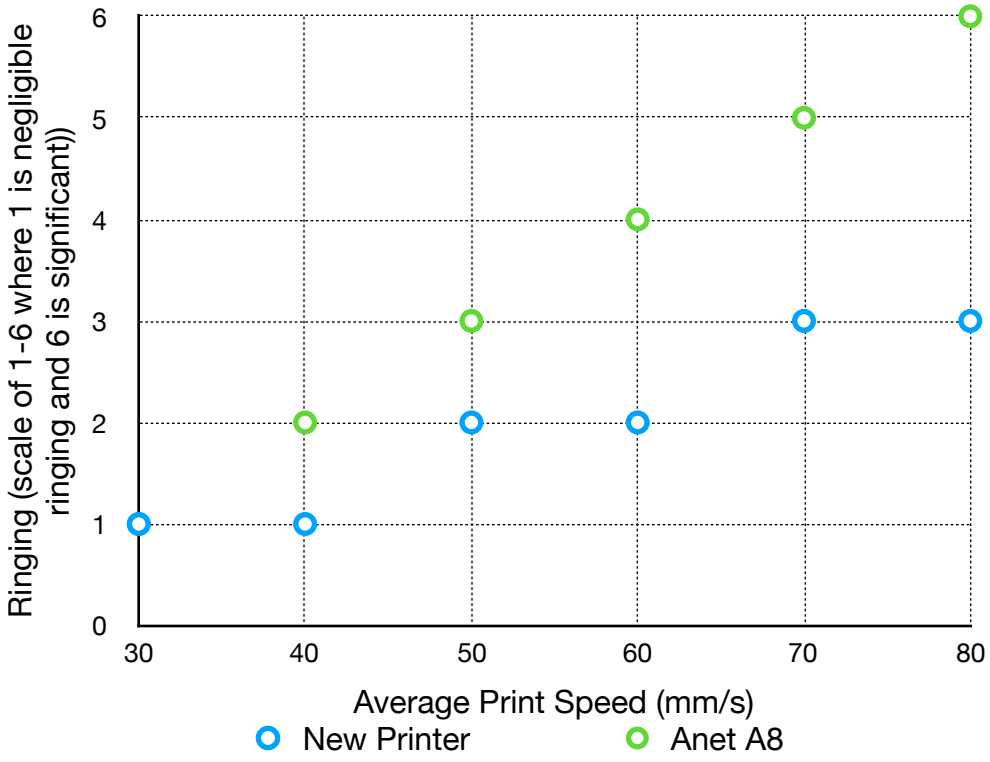


Figure 2 shows that ringing significantly increases with print speed on the Anet A8. Ringing on the new 3D printer still increases, but at a slower rate.

Figure 3: Roughness vs. Print Speed

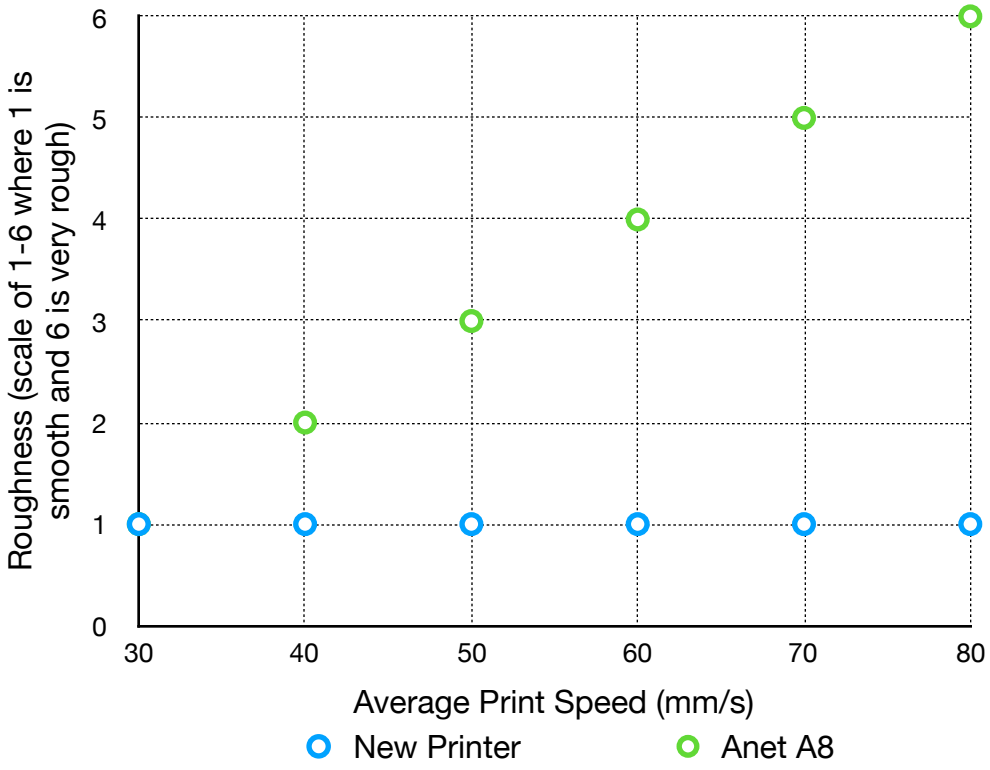


Figure 3 shows that the roughness increases quickly with print speed on the Anet A8. However, the roughness on the new 3D printer remains at a constant low rating with rising print speed.

Figure 4: #3DBenchy Torture Test

Features	Anet A8	New 3D Printer
Hull Surface	Not smooth, uneven layers (not straight), surface imperfections, ringing throughtout	Hull nearly perfectly smooth, with a few minor imperfections.
Symmetry	Not symmetrical in hull from left to right	Perfect symmetry
Tiny Surface Details	“#3DBenchy” text is not legible	“#3DBenchy” text is not legible but clearer than Anet A8
Cylindrical Shapes	Chimney not completely round (6.9x7.0 (length x width) instead of 7.0x7.0) and inner circle 2.5mm in diameter (instead of 3.0mm)	Chimney not completely round (6.9x7.0 (length x width) instead of 7.0x7.0) and inner circle 2.5mm in diameter (instead of 3.0mm)
Overhang Surfaces	Slight drooping in front of boat’s bridge but holes seem pretty good	Nearly no drooping and perfect holes
Large Horizontal	Window seems round but layers/edge not very smooth and also has a lot of ringing	Window seems round and layers/edge very smooth but has some ringing around edges
Small Horizontal	Good details and very round but with ringing before and after	Good details and very round but with a little ringing before and after
Slanted Small Holes	Relatively smooth layers but size of cylinder changes above hull	Even layers and same size above and below hull
First Layer Details	Text on bottom of boat is legible but a little squashed	Text very clear
Walls of bridge	Significant ringing and large variations in thickness and smoothness	Some ringing but walls very smooth and equally thick
Stringing	Little stringing	Slightly more stringing

This table shows that the #3DBenchy printed by the new 3D printer performed better in categories Hull Surface, Symmetry, Tiny Surface Details, Overhang Surfaces, Large Horizontal Holes, Small Horizontal Holes, Slanted Small Holes, First Layer Details and Walls of Bridge. Further, the #3DBenchy printed by the new 3D printer performed the same as the Anet A8 in category Cylindrical Shapes. However, the #3DBenchy printed by the new 3D printer performed worse in the category Stringing than the Anet A8.

Figure 5: Paper Basket Torture Test - Size

Printed with V2 Hotend Carriage		
Features	**Anet A8**	**New 3D Printer**
Print Size X, Theoretical (mm)	220	307
Print Size Y, Theoretical (mm)	220	272
Print Size Z, Theoretical (mm)	220	298
Print Volume (mm^3), Theoretical	10648000	24884192
Percent Larger (New 3D Printer/ Anet A8), Theoretical	N/A	234
Paper Basket Print Size X (mm)	200	260
Paper Basket Print Size Y (mm)	200	260
Paper Basket Print Size Z (mm)	210	295
Paper Basket Print Volume (mm^3)	8400000	19942000
Basket Percent Larger (New 3D Printer/Anet A8)	N/A	237

The Paper Basket Torture Test demonstrated that the new 3D printer has a print volume of more than twice as large as the Anet A8. The new 3D printer performed better in the Top and Bottom Rims category and scored the same as the Anet A8 in the Main Frame Layer Quality, Bridging Between Columns at Top and Stringing categories. Note: this test was performed before adding V3 of the Hotend Carriage (V3 was created to decrease ringing and improve surface quality), so the basket print size for the new 3D printer is larger than it can print with the V3 Hotend Carriage.

Figure 6: Paper Basket Torture Test - Quality

Printed with V2 Hotend Carriage		
Features	**Anet A8**	**New 3D Printer**
Top and Bottom Rims	Significant ringing and very low surface quality	Some ringing but smooth surfaces compared to Anet A8
Main Frame Layer Quality	Terrible surface quality and significant ringing	Terrible surface quality and significant ringing
Bridging between Columns	Noticeable drooping between columns	Noticeable drooping between columns
Stringing	Fine, hairlike strings removed with heat gun	Thick strings removed with utility knife

Figure 7: Hotend Carriage V3

Features	Anet A8	New 3D Printer
X Print Size (mm)	220	307
Y Print Size (mm)	220	231
Z Print Size (mm)	220	334
Print Volume (mm^3)	10648000	23686278
Percent Larger (New 3D Printer/Anet A8)	N/A	222

Conclusion

Criteria and Constraints	
Parts and materials must cost less than $750	✓
At a print speed of 60mm/s, ringing must be less than a 3 on a ringing scale of 1-6 (1 is negligible, 6 is significant) and roughness must be less than a 3 on a roughness scale of 1-6 (1 is smooth, 6 is rough)	✓
Print tolerance of ±0.2mm on a 25mm cube	✓
A minimum print volume of 275x275x325mm ($2.475x10^7 mm^3$)	4% less than theoretical
Sturdy frame and design	✓
Powerful heat bed capable of quickly heating to more than 110℃	✓

Future Improvements

- Reduce stringing by fine tuning retraction distance for Bowden setup without clogging hotend
- Add another Z motor to reduce strain on current one and reduce oscillation in bed when moving up and down
- Fine tune slicer settings to improve printer accuracy
- Add a 10W laser head to turn into powerful laser cutter
- Add spindle head to turn into CNC mill

Bibliography

- “All3DP.Com.” All3DP, all3dp.com/.
- Tech2C. “HyperCube 3D Printer/CNC by Tech2C.” Thingiverse, Thingiverse, 4 Sept. 2016, www.thingiverse.com/thing:1752766.
- “Marlin.” Marlin Firmware, marlinfw.org/.
- “RepRap.” RepRap, reprap.org/wiki/RepRap.
- “MatterHackers.” MatterHackers, www.matterhackers.com/.
- Sanladerer, Thomas. “Tom's 3D.” Tom's 3D Printing Guides and Reviews, New Media Thomas Sanladerer, toms3d.org/.
- Cauldwell, Rex. Wiring a House. The Taunton Press, 2014.