Christopher Sneeder, Steven Gresh
University of Maryland College Park
csneeder@terpmail.umd.edu
stvngrsh@gmail.com

Monday 24, 2014

Dear Consumer 3D Printer User,

We are two mechanical engineering undergraduates with a combined 6 years of experience using 3D printing technology in the classroom, at home, and in our workplaces. It has allowed us to bring our CAD modeled designs to life, creating custom parts quickly and at an affordable cost. 3D printing has changed the way we design things as engineers. We can come up with a new idea and test it in hours. This accelerates the design cycle and ensures that our concepts will work as planned. Consumer access to 3D printing is obviously a revolutionary advancement.

However, because 3D printing is such a new technology, there are still kinks to be worked out. The tools available at a price point hobbyists can afford don't always work out of the box and are notoriously unreliable. Extruders can jam, your plastic won't stick to the build plate, and layers might become misaligned as they're put down. Printer manufacturers don't feel comfortable when owners fiddle with their complicated machines so they rarely include more than basic instruction manuals. If you turn to the internet for help, information and troubleshooting tips are scattered and incomplete. These are problems we've encountered far too often in our experience with 3D printing, but we have a solution. We've produced the first comprehensive operation, advice, and troubleshooting manual for consumer 3D printers. This guide includes everything a hobbyist, student, or engineer will need in their work. It begins with general setup and calibration instructions for your new tool. This will help you ensure your printer is working optimally from the start. Next you'll find a list of best practices: techniques and guidelines we've discovered over the years or learned from experts. These will help you design better parts, use appropriate printer settings for your needs, and achieve long life and reliability from the printer. Finally, we've included step-by-step instructions to diagnose and correct printing errors, malfunctions, and damages. To ensure the guide addresses what's important to you, we conducted fact-finding interviews with fellow engineers and hobbyists. This provided us with unique perspectives and novel tricks of the trade. This manual provides the information you'll need to reduce downtime, headaches, and repair costs while consistently producing the best 3D printed parts possible.

We are passionate about using 3D printing for new and innovative applications, and we want to give back to the community by providing a reliable source of information to new and experienced users. Our manual is the result of experience gained from years of work to understand and put to use a promising new technology. We hope you find this document to be a useful addition to your workflow. If you have any questions or suggestions, please feel free to reach out to us.

Sincerely,

Christopher Sneeder

Steven Gresh

Enclosure: A User's Manual for Consumer 3D Printing

Consumer 3D Printing: Reference and Troubleshooting Guide

A Tableside Handbook for Consumer FDM Printers

www.pcr-online.biz/news/read/3d-printing-a-new-dimension/032481

Prepared by: Christopher Sneeder & Steven Gresh

University of Maryland Professional Writing Program

UNIVERSITY OF MARYLAND

TABLE OF CONTENTS.

INTRODUCTION

BASICS

GETTING STARTED

BEST PRACTICES

TROUBLESHOOTING

APENDIX

PREFACE

Until a few years ago, 3D printing was reserved for engineers and researchers with the resources and backing of a large company or university. Now that patents on the fundamental technology have expired, countless affordable printers have entered the market. This has opened the field to hobbyists and students, and sparked a revolution in the maker community.

Because consumer-level 3D printing is such a recent development, there are very few resources with advice and troubleshooting guidance for new users. Manufacturers rarely provide maintenance instructions as to avoid the liability of customers damaging their printer while trying to take it apart. Online forums and blogs answer some common questions, but the information is spread across the web without much organization. We decided it was time for a better option.

This guide is intended as a comprehensive reference for anyone using a consumer 3D printer. It includes general information, setup and calibration instructions, an overview of printing software, best practices advice, and guides for troubleshooting and maintenance. The contents are a combination of our personal experience as well as information gathered from friends, colleagues, and internet resources. We hope you find it to be a useful addition to your printer.

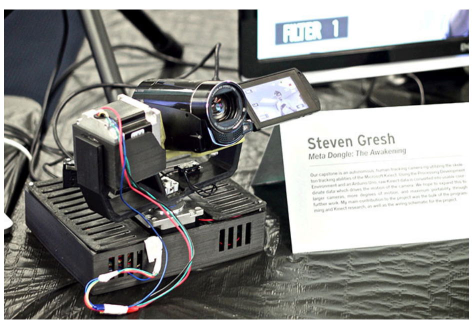
Happy printing!

Steven and Chris

ABOUT THE AUTHORS

Chris Sneeder is a junior mechanical engineering student at the University of Maryland, College Park. He first started using a 3D printer in 2010 to fabricate components for his high school rocketry club. Since then, Chris has built experience using the technology during several research and product development internships. His expertise is in designing functional structural and mechanical components that are optimized for 3D printing.

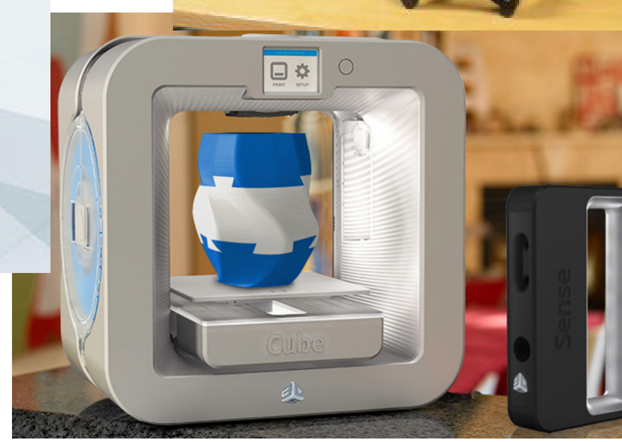
Steven Gresh is also a junior mechanical engineering student at the University of Maryland, College Park. He began his 3D printing career several years ago by using university owned MakerBot printers for school projects. Since then, he's purchased his own printer and uses it for hobby projects, home improvement and prop design. He is currently working for a 3D printing start-up as a engineering intern. His expertise is in slicing software, printer hardware and troubleshooting.



HARDWARE ▸ Common 3D Printers

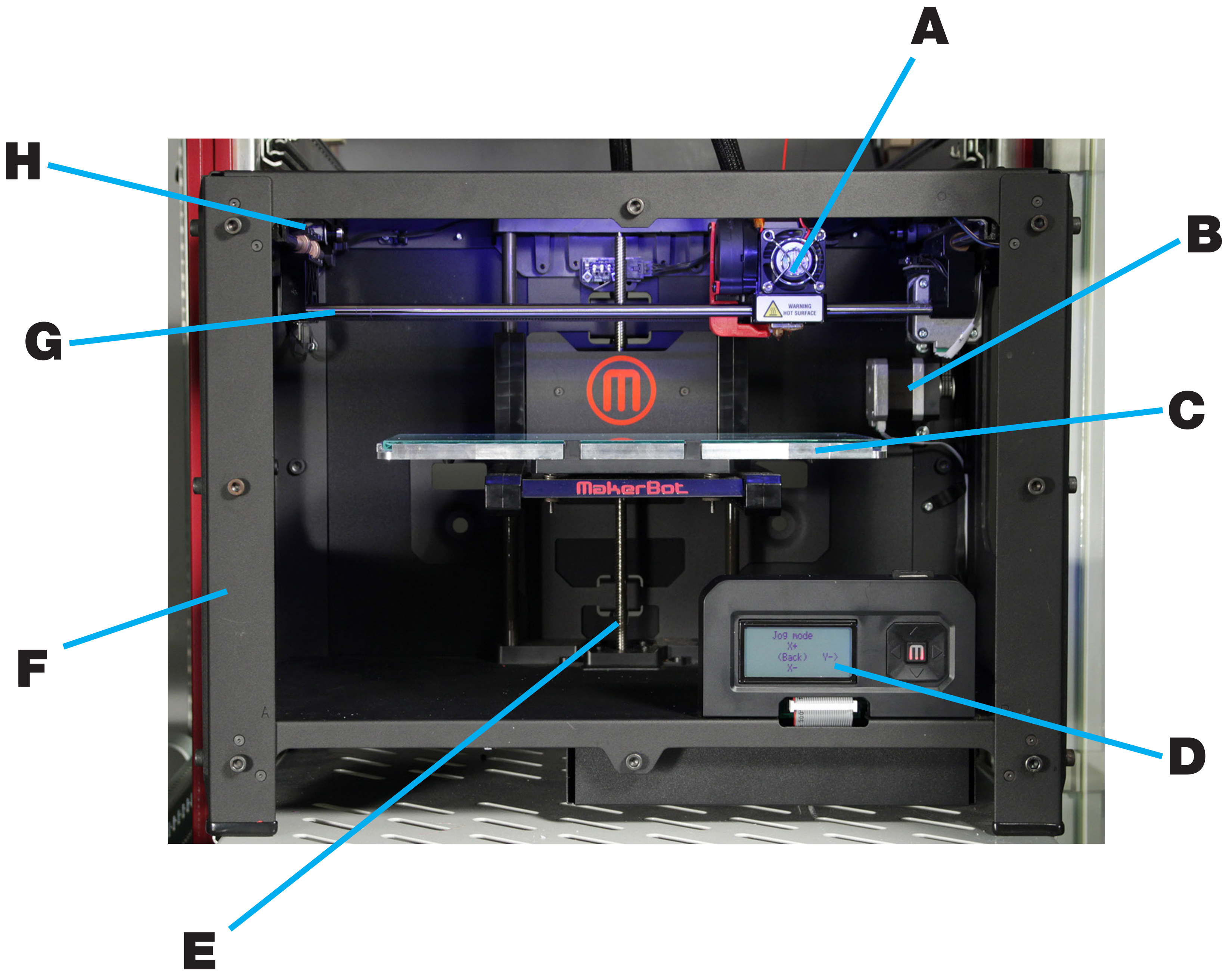
While 3D printers come in all shapes and sizes, most consumer 3D printers rely on a technology called FDM or Fused Deposition Modeling. FDM printers are characterized by the line-by-line extrusion of plastic layers by a print head. FDM printers may look different to the untrained eye, but they are all very similar in terms of operation. Below is a list of common models.

> PrintrBot Simple
> XYZ Printing Da Vinci
> Mendel (RepRap)
> Prusa Mendel (RepRap)
> Solidoodle 4
> 3D Systems Cube
> Rostock MAX
> Flashforge Creator 2
> Afina H-Series
> Ultimaker
> Makerbot Replicator 2
> Lulzbot Taz
> Makergear M2
> UP! Mini



*RepRap is a term for a free, public domain printer model. Essentially a "build it yourself" printer.

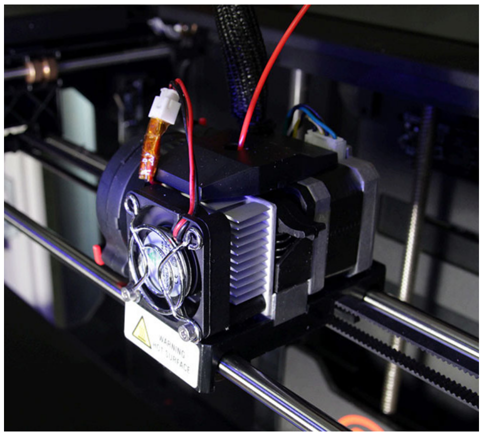
Top Left: MakerBot Replicator 2
Top Right: Lulzbot TAZ 4
Bottom Left: Flashforge Creator 3D
Bottom Right: 3D Systems Cube

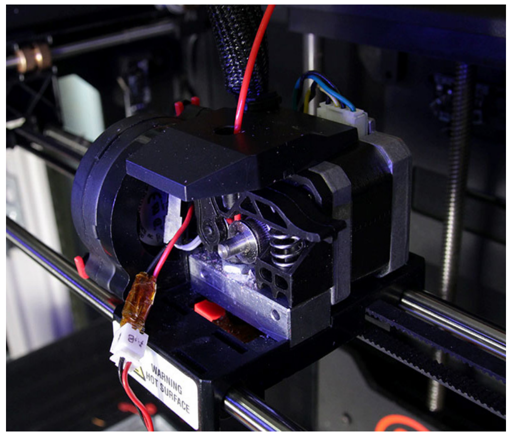


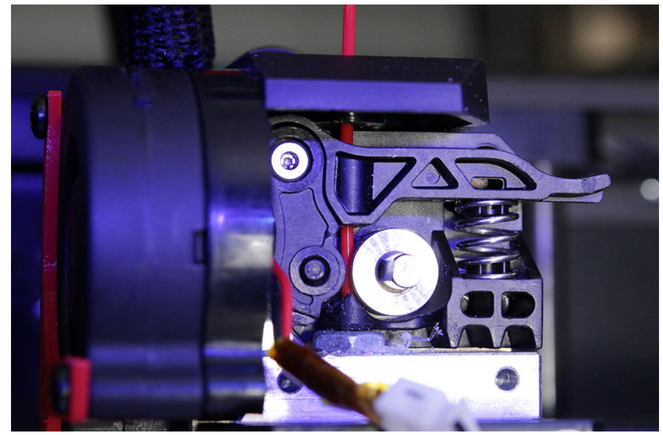
Shown is a MakerBot Replicator 2. Your printer may vary in appearance and form.

A. Extruder

The part of the printer that actually "prints". The extruder houses the print head or nozzle and uses a system of gears and motors to pull the filament in through the top and extrude it out the the nozzle. The extruder also houses a heating block which heats the filament to its melting point. Some extruders have a fan that is directed at the nozzle to cool filament after it is extruded.







B. Stepper Motor

3D printers use a special type of motor called a **stepper motor.** They get their name from the fact that they move in tiny increments or "steps". This is how 3D printers are able to print with extreme precision. There are usually 4 motors on a 3D printer. Three for the X, Y and Z axis movement and one for the extruder.

C. Build Platform

Also referred to as the **build plate** or simply "the bed", this platform is where the 3D printed object is formed. On most printers, the bed rises and lowers in the Z-axis while the extruder moves in the X and Y direction.

HARDWARE ▸ 3D Printer Anatomy

D. LCD Screen

If your printer is designed to print from an SD card and without a connection to a computer, it should have an LCD Screen and a set of controls. This allows you to read information about the printer, move the extruder/bed, and execute various maintenance and utility actions. If your printer does not have an LCD Screen, all of these functions are controlled by the software on the host computer.

E. Z-axis Threaded Rod

Most consumer FDM printers move the build plate in the vertical Z-axis via a threaded motor shaft. When this rod rotates, the build plate rides along the threads and moves up or down

F. Case/Frame

The structrual exterior of the printer provides the stability and rigidness to keep the printer stable and intact during a print. Some printer frames will have solid walls and fully enclose the print area. In that case, the frame would also be reffered to as an **enclosure.**

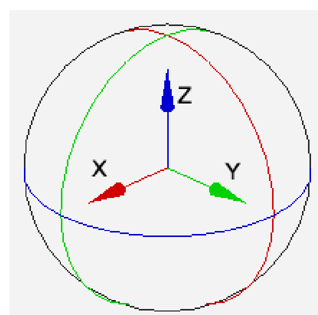
G. X-axis Rods

These rods allow for linear motion in the X-axis. The extruder is usually mounted directly to these rods. The motion of the extruder along these rods is actuated by a stepper motor and a belt.

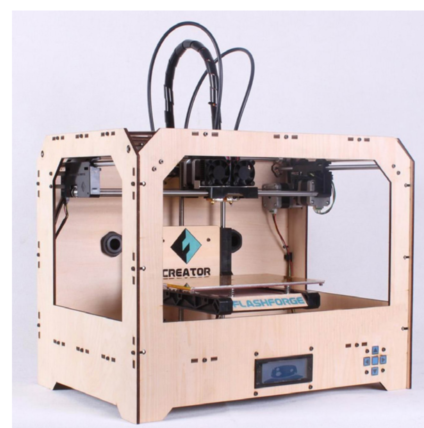
H. Y-axis Rods

These 2 rods run parallel on both sides of the printer and allow for linear motion in the Y-axis. The X-axis rods and extruder move along these rods via a stepper motor and 2 belts. The entire X-axis/Y-axis assembly is referred to as the "Gantry".

Standard coordinate axes for a consumer FDM printer.



Leocad.org



Flashforge Creator 3D

SOFTWARE ▸ Common Software

Before you can print a 3D model, the 3D part file must be converted into a file that can be read by a printer. This new file is called the “g-code” and is essentially a set of directions that the 3D printer will follow. A process called “slicing” refers to breaking down the model into printable layers or “slices”. Some printers read these files from an SD memory card and are independent of the computer with the slicing software, while other printers require a connection to the host computer in order to run the print. We will focus on three common softwares: MakerBot Desktop, Cura, and Repetier Host.

MakerBot Desktop - MakerBot Printers **-** https://www.makerbot.com/desktop

Propriotary software for MakerBot Printers. Slices using MakerBot-exclusive slicer. Includes presets for all Makerbot models. Much more limited in terms of advanced slicing features than Cura or Repetier Host.

Cura - Designed for Ultimaker, can be used universally **-** http://software.ultimaker.com/

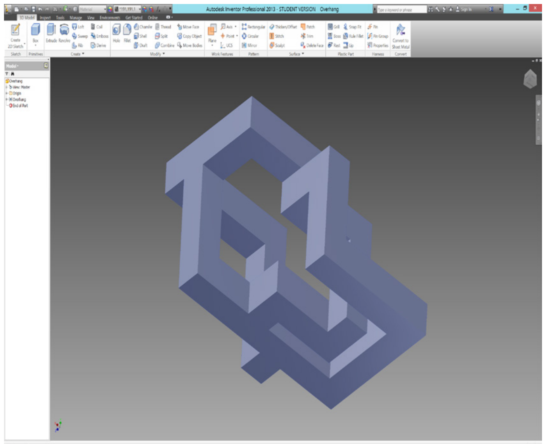
Software designed by Ultimaker, can be used with non-Ultimaker printers. Slices using *Cura-Engine*. Includes presets for many common 3D printers. Very simple user interface.

Repetier Host - Universal Software **-** http://www.repetier.com/download/

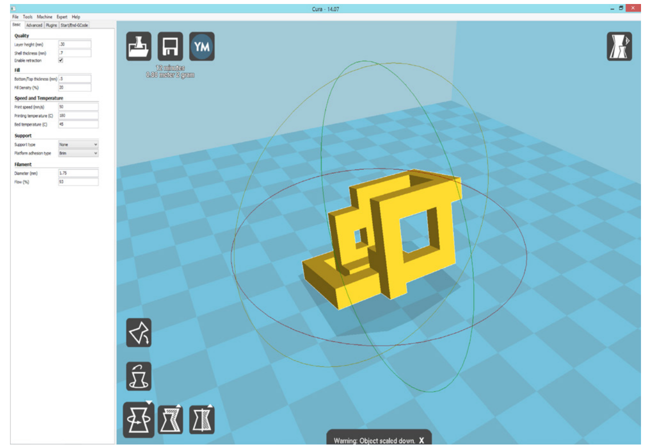
Universal control software that can be used for almost any FDM printer. Slices using third-party slicers that can be downloaded from the web. Included slicers are *Slic3r* and *Cura-Engine.* Control interface gives you full motion control of the printer when it is not printing a part.

SOFTWARE ▸ Overview

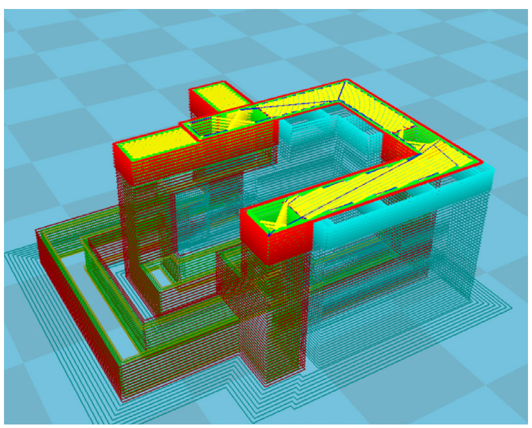
1. Design or Download
3D Modeling software or website
Shown: Autodesk Inventor



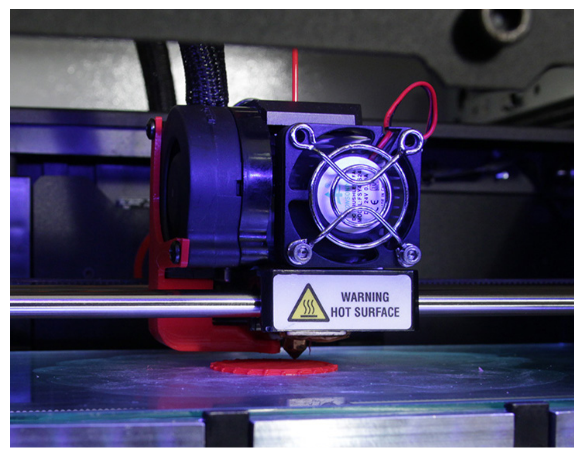
2. Position/Scale
Control Software
Shown: Cura



3. Slice
Control Software
Shown: Cura



4. Print
Control Software or Printer SD Card
Shown: MakerBot Replicator 2



HELPFUL EQUIPMENT

The following is a short list of equipment that should be kept nearby your printer. Many of these tools will be referenced later in this guide.

Paint scraper - Used to remove parts from print bed.

Toothbrush - Useful for cleaning print especially with acetone and ABS.

Tweezers - Good for removing filament from nozzle head and print

Screwdrivers/Allen Wrenches - Necessary for servicing parts on the printer.

Pliers - Best tool for peeling off support material. Also useful for removing parts stuck to print bed.

Acetone - For ABS printing, good for cleaning print bed and nozzle

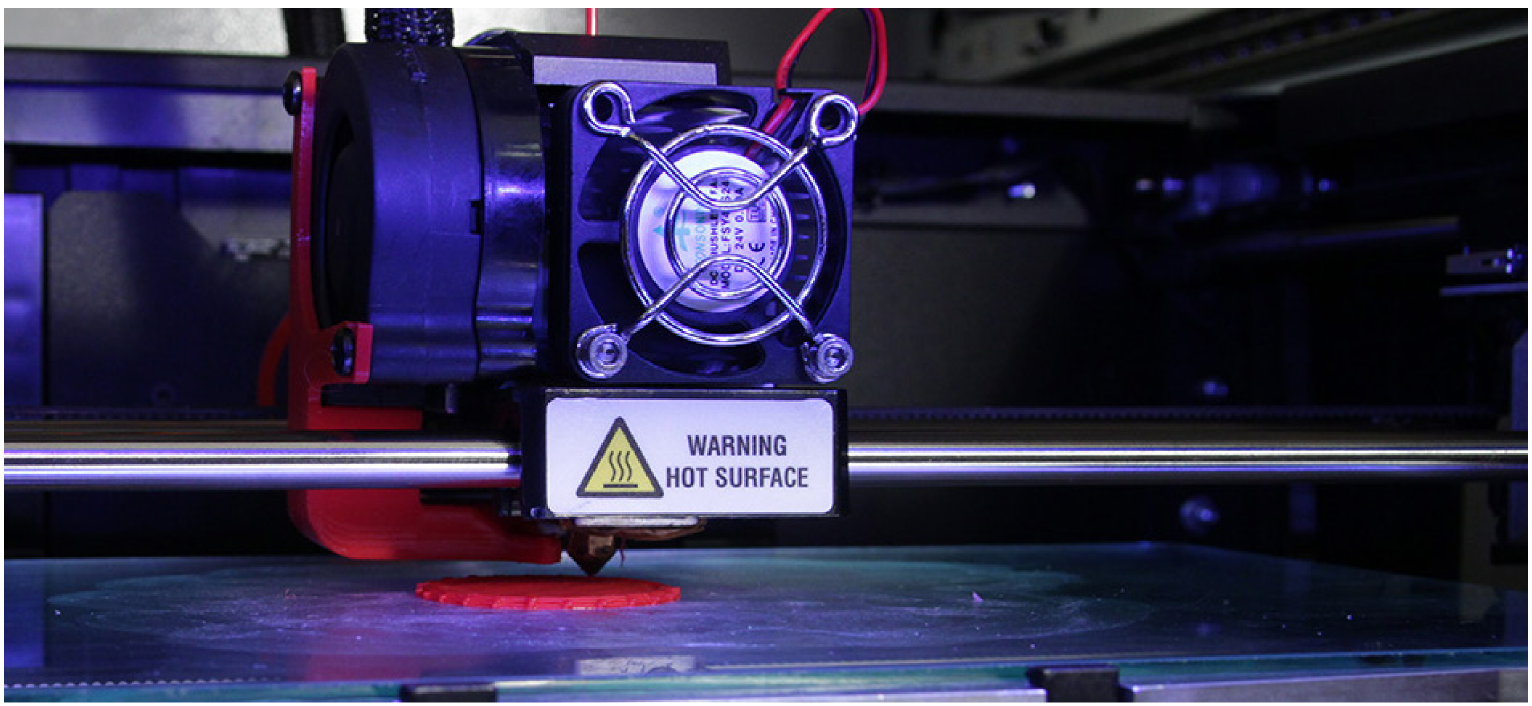
CALIBRATION ▸ Bed Leveling

One of the biggest considerations for reducing future problems is build plate levelness. A level build plate will ensure equal filament distribution for the entire part. This will help prints stick to the bed and reduce warping, as well as improve the visual appearance and accuracy of the part.

After shipment and assembly of a printer, the bed will often start out in a very un-level state. Leveling your bed is an ABSOLUTE must before using a 3D printer for the first time. Over time and extensive usage, the bed will tend to require regular readjustment.

Some 3D printers offer automatic bed-leveling or software assisted bed-leveling. If your printer does not offer these features, or you find that the features are not leveling the bed to the accuracy that you want, the following steps will guide you through a manual leveling process.

Tools needed: piece of paper, allen wrench set



CALIBRATION ▸ Bed Leveling

Note: For most bed leveling setups, tightening a screw lowers the print bed, while loosening a screw raises it.

1. Boot up your control software and printer.

2. If you are going to use a heated bed for printing, it is recommended to set the bed to about 90˚C to account for thermal expansion of the bed surface.

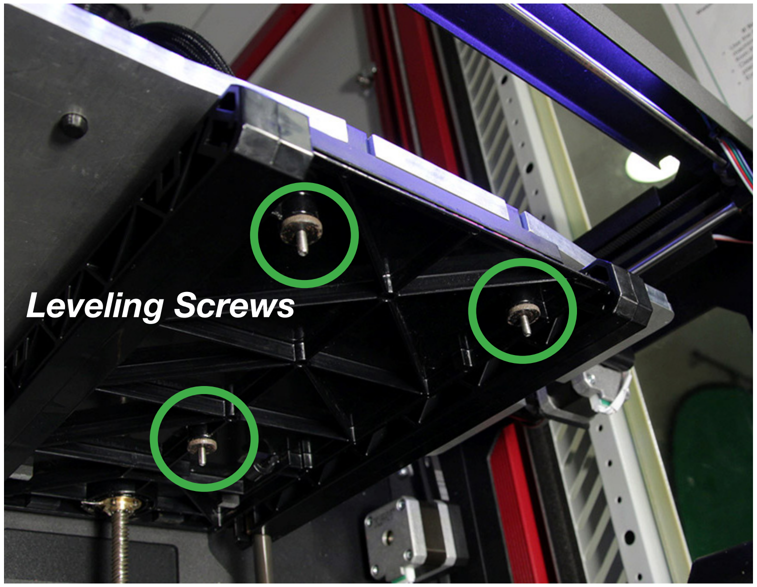
3. Tighten your bed leveling screws about 2 or 3 turns to lower the bed.

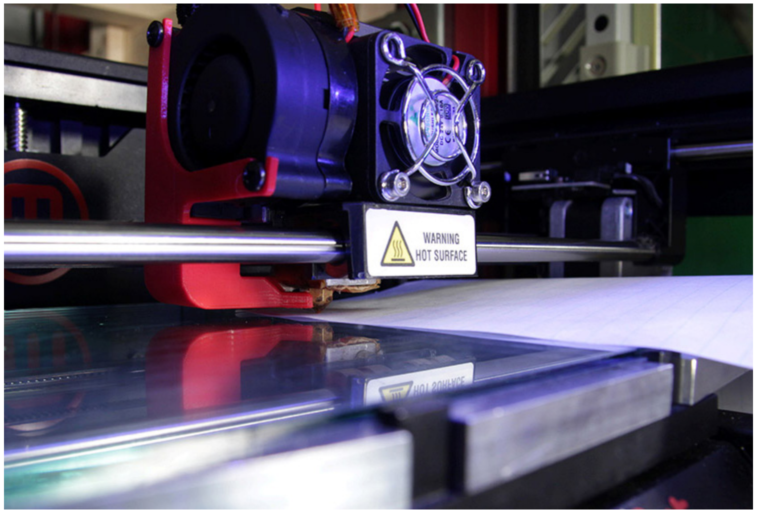
4. Using your control software, “Home” your axes.

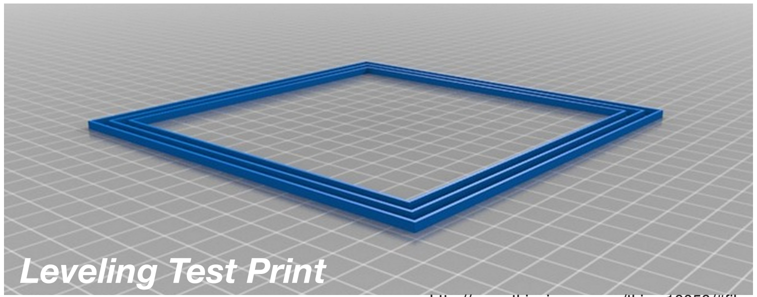
5. Position the nozzle over one of the bed leveling screws and loosen the screw until the bed is just below the nozzle. You should be able to slide a piece of paper between the gap and feel a slight amount of friction. Repeat this step for each remaining leveling screw. Warning: If you heated bed is on, do not leave the paper on the bed for more than a few seconds.

6. You may need to redo step 5 one or two more times to really fine-tune the leveling.

7. To do a full test, print a few layers of a hollow rectangle that runs the perimeter of the bed. Check for consistent flow and bed adherence over the rectangle.







http://www.thingiverse.com/thing:13053/#files

CALIBRATION ▸ Extruder Calibration

The amount of filament dispensed is controlled by the turning of a gear inside the printer's extruder. Ideally, the printer pulls through and extrudes the exact amount of filament as is instructed by the software. However, in many cases the extruder might over or under-extrude due to mechanical or filament imperfections. When setting up a new printer, you may want to calibrate your extruder. Improperly calibrated extruders can be very problematic when printing parts where precise dimensions are important. Note: MakerWare does not allow for the calibration of the extruder.

1. Start by booting up your printer and control software. Heat up the extruder to the proper temperature for the filament you will be using, and remove any filament currently in the extruder.

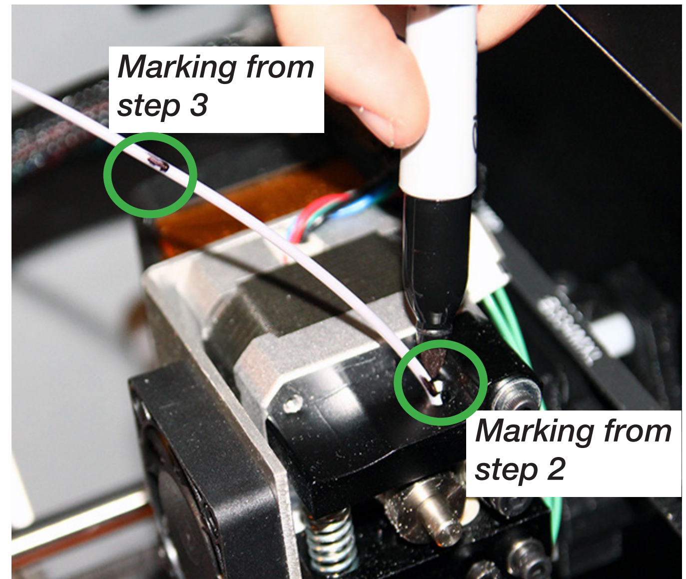
2. Take the end of your filament and make a small marking about 10cm up from the end of the filament.

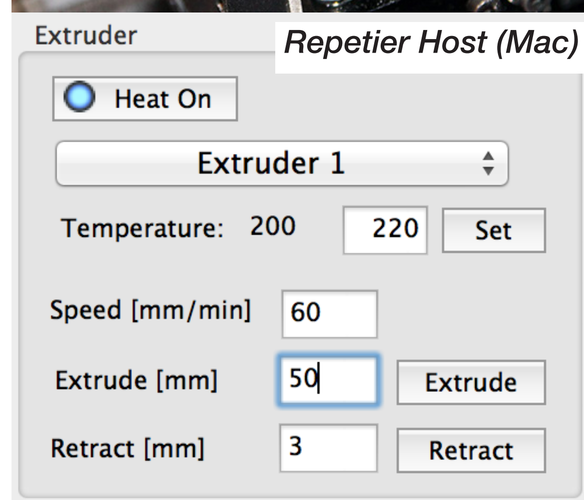
3. Using a pair of calipers or a ruler, make another marking 50mm up from the first marking.

4. Feed the filament into the extruder and carefully extrude the filament in increments of 1mm or less until the first marking is lined up with the surface of your extruder.

5. Extrude a value of 50mm of filament. Watch the second marking to see where it ends up. Make a third marking at the base of the extruder.

6. Remove the filament from the extruder and measure the difference in length between the second and third markings. If the third marking was under your second marking, your value will be positive and your extruder is UNDER-extruding. If the third marking was above the second marking, your value will be negative and your extruder is OVER-extruding.





CALIBRATION ▸ Extruder Calibration

For Cura users:

7a. Divide the value you obtained in step 6 by 50mm to get the percentage that your extruder is over or under extruding by. For example, if your step 6 value was -8mm, your percentage would be -8mm/50mm = -0.16 = -16%

8a. Add the value obtained in step 7a to 100% to get your adjusted flow rate. For example, our step 7a value of -16% + 100% = 84%.

9a. Use the value from step 8a as the value for "Flowrate". This will tell your printer to extrude a rate that is 84% of the rate it would normally extrude.

For Repetier-Host users:

7b. Go into *Printer > EEPROM Settings* and write down the value you for "E Steps per mm". This is your printers current flow rate. For example, this value will read something like 150 steps/mm.

8b. Multiply this E steps per mm value by 50mm. For example: 50mm x 150steps/mm = 7500 steps.

9b. Add the value from step 6 to 50mm to get the total amount extruded. For example, if your step 6 value was -8mm, your total amount would be -8mm + 50mm = 42mm.

10b. Divide the value from step 8b with the value from step 9b. For example, 7500 steps / 42mm = 178.57steps/mm.

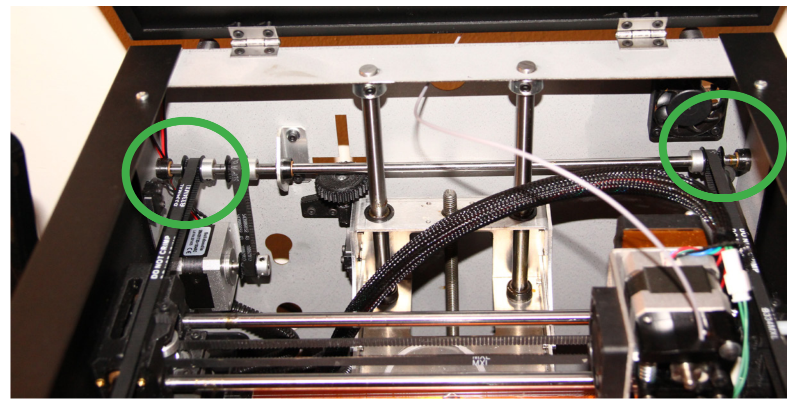
11b. Replace the value in the EEPROM settings with the new value from step 10b.

CALIBRATION ▸ Belt Alignment

WARNING: This calibration step can be delicate and requires partial disassembly of the machine. Improper handling of the machine may result in irreversible damage to the machine.

If you notice that your printer is printing lopsided or deformed curves and circles, it may be helpful to re-align the printer's Y-axis belts. Most printers have two Y-axis belts running parallel to each other, one along either side of the printer. If these belts are not parallel, slight deformations can occur when printing curves. Due to the varying layout of 3D printer models, this guide will cover a basic method of realigning belts that has been tested on MakerBot and Solidoodle printers. It is advised that you consult your printer's customer support if this guide does not provide sufficient assistance.

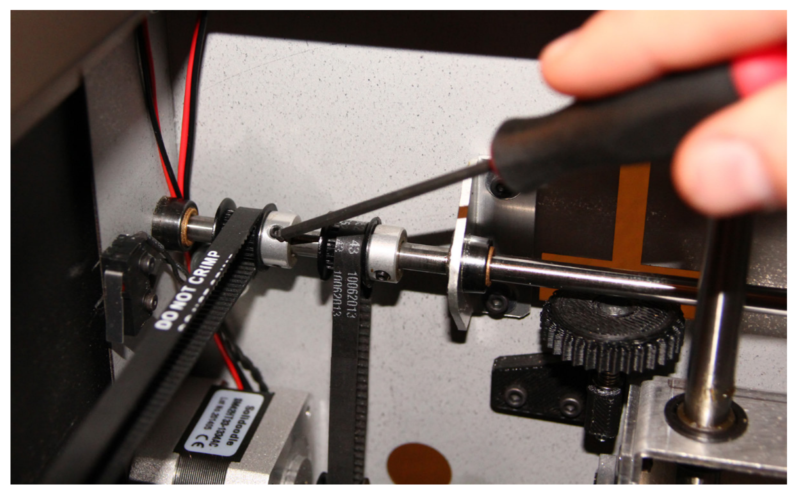
Tools needed: Allen wrench set



1. Locate the shaft containing the pulleys for the two Y-axis belts.

2. Loosen the set-screw for each pulley. You should be able to slide the pulleys left and right on the shaft.

4. Manually move the extruder/gantry up and down the Y-axis. Watch the two pulleys to see if they move during this action. This action alone should be enough to align the belts.



5. Find a point where the belts appear to be parallel and tighten down one of the pulleys.

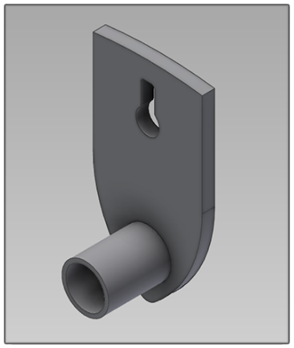
6. Manually move the gantry up and down the Y-axis.
   > If the other belt moves left or right, loosen the tightened pulley. Return to step 4. You may need to try this a few times to get it just right.
   > If the belt doesn't move, tighten the other pulley and close up your printer.

MODELING ▸ Modeling Suggestions

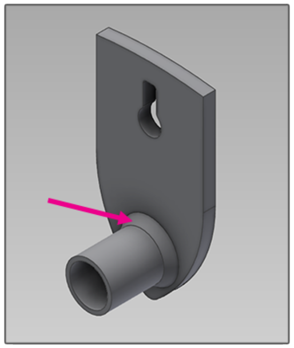
3D printing is unlike traditional manufacturing processes, so designing functional parts takes some careful thought and experimentation. While modeling a part intended to be printed, consider how the printer will construct the part layer by layer. It is often useful to examine a potential model by slicing it in a printer control software to get an idea of the final printed structure. This provides a chance to catch potential problems and redesign before beginning a print. Some other suggestions include:

Reinforce Hard Corners

Because of the layered structure of a 3D printed part, hard corners result in stress concentration points where the layers may split apart. This problem can be reduced by using fillets or chamfers to reinforce the corner.



Cylinder will snap from the backplate easily



Cylinder reinforced with a chamfer at the base

Divide the Model

Some parts will require a long print time or extensive overhang supports if they printed in one piece. Consider dividing a model into smaller sections and then assembling it after printing.

Use a plastic solvent weld, acetone (for ABS), or a thin layer of epoxy or superglue to adhere the parts together with an inconspicuous seam.

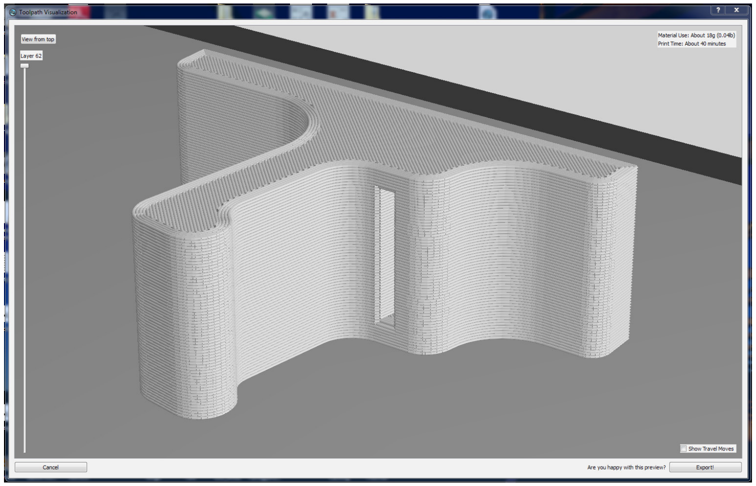
OR

Design parts with pins or clips that allow for mechanical assembly of components after printing.

rchut.co.uk

Orienting for Strength

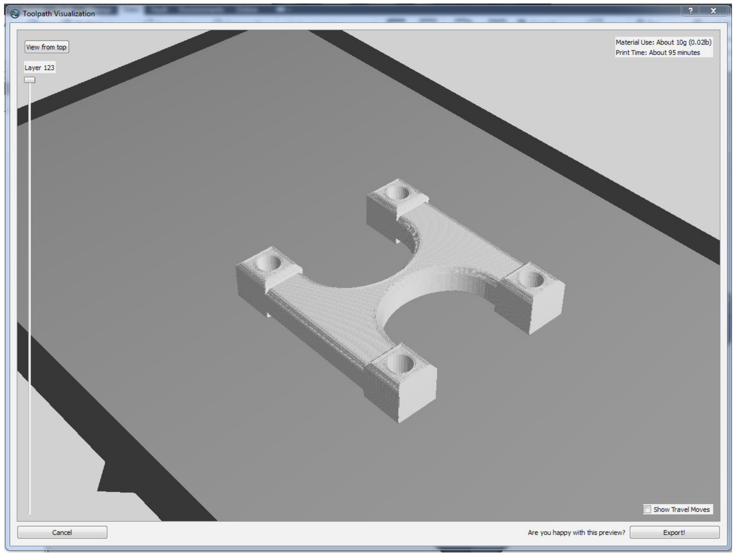
If you know how a functional 3D printed part will be used, you can increase its strength by printing so that the layers are optimally oriented. Parts often fail by splitting along the divide between layers, which is the weakest direction in the material. Orient the part to be printed so that the build layers are perpendicular or at least at an angle with the shearing force it will experience.



This bottle opener was printed with optimal layer orientation to resist the bending force it would experience

Limit Small or Slender Features

A printer's minimum resolution and the mechanical properties of printed plastic result in design limitations. Familiarize yourself with your printer's resolution capability and avoid adding geometries or cosmetic details to your design that are too small to print. Additionally, watch out for parts that have slender or thin features. Printed plastic is less durable than injection molded or milled materials, and functional parts will require a sturdy design.



The slender feature in the center of this mounting bracket is likely to snap if it isn't reinforced

FILAMENT ▸ PLA vs. ABS

While filaments may seem indistinguishable at first glance, your choice of material can be crucial to the success of a print. The two most commonly used filaments are **Acrylonitrile butadiene styrene** (ABS) and **PolyLactic Acid** (PLA). Choosing between the two will depend on several factors.

	Acrylonitrile butadiene styrene (ABS)	**PolyLactic Acid** (PLA)
Material Properties	Synthetic polymer made from a combination of chemicals	Plastic made from corn, sugarcane, or other plant sources
Material Strength	Mildly flexible: can withstand slight deformations without breaking	Very rigid: can endure higher overall forces but only limited deformation
Printing Temperature	220C - 230C	180C - 190C May be damaged by direct sun exposure
Bed Conditions	Very prone to warping, requires heated bed and/or bed adhesives	Less prone to warping, can be printed on blue painters tape with no additonal prep
Physical Appearance	Naturally a milky-beige color, colored spools are often found in opaque colors	Naturally clear, can be found in virtually any color, opaque or translucent
Printing Smell	Enclosure reccomended, ABS gives off a strong “burnt plastic” smell when printing	Gives off an almost unnoticible “sweet” smell when printing

Lonestarfilament.com

A recent study by the Illinois Institute of Technology has raised concern of possible health risks associated with 3D printing.

The study performed tests on the amount of gaseous particles given off by the hot plastic during 3D printing. Known as UltraFine Particles, or UFP's, these particles can be inhaled and absorb into the respiratory and cardiovascular system. The data from the study indicated that the concentration of UFP's in an enclosed area rises dramatically during 3D printer operation.

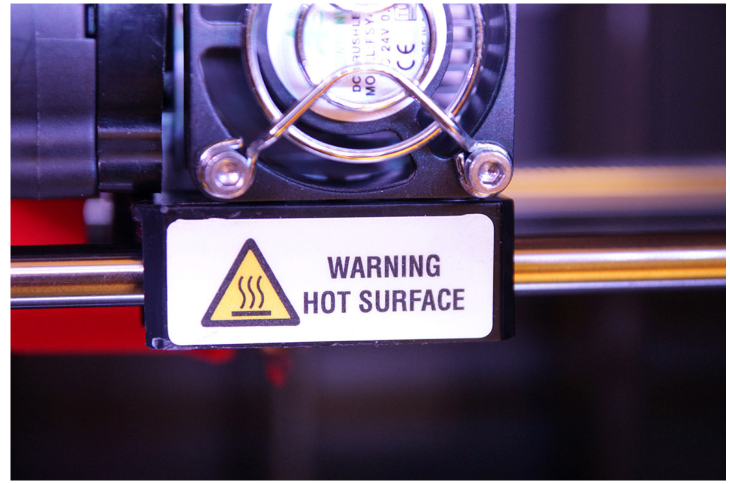
While this news may be alarming, UFP's are not necessarily toxic by nature. The chemical content of the UFP is what determines if it is harmful. There is very little data regarding the toxicity of ABS or PLA when inhaled.

To minimize possible health risks, take the following precautions when using 3D printers:

> Print in a well ventillated area
> Purchase or build an enclosure for the printer if one is not already present
> Minimize the time spent in the room in which the 3D printer is operating
> Purchase filament from reputable sources where the material makeup is published
> Be extra careful when printing with ABS, which is produced from multiple chemicals, several of which have been shown to be toxic to human health.

Link to full study: http://www.sciencedirect.com/science/article/pii/S1352231013005086

Print Temperature



The temp of your filament will usually be specified by the manufacturer but here is a list of common temperatures for each material.

ABS: 220˚C +/- 10˚C

PETT: 220˚C +/- 5˚C

PLA: 190˚C +/- 10˚C

Nylon: 245˚C +/- 10˚C

Heated Bed Temperature

Whiteclouds.com

Heated beds help minimize warping and are almost essential for printing with ABS. You will want to set your heated bed to the temperatures listed below for the specific filaments.

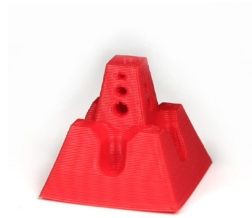
ABS: 95-100˚C

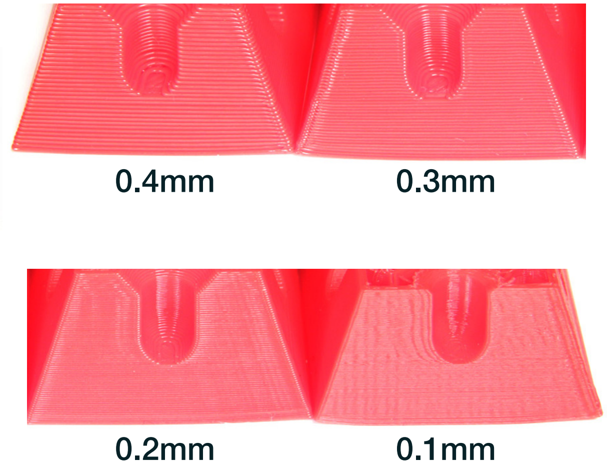
PLA: 60-70˚C

SLICING ▸ Part Structure

Layer Height

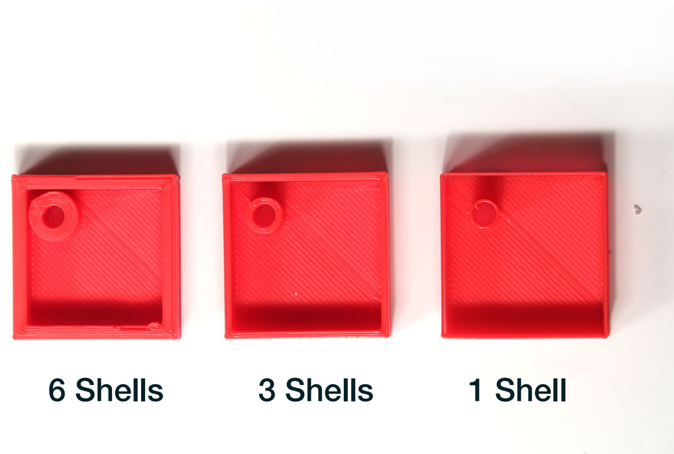
This is the physical thickness of each individual layer of your print. The smaller this value, the greater the vertical resolution of your print. Larger layer heights drastically reduce print duration but affect the appearance of the part.





Shell Thickness / Number of Shells

The shell of your print is the visible outer surface of the part. This parameter allows you to control how thick the walls of your part will be. Slicer software will let you control thickness in terms of width (in millimeters) or the numerical count of shell layers. Thicker walls often result in stronger parts but may extend print time and filament usage.



Infill Density

3D printed parts are usually semi-hollow. Infill density allows you to decide on how “hollow” the parts are. The interior will be filled with a grid or honeycomb pattern, with the density determined by a percentage. Higher values will often result in stronger parts but may extend print time and filament usage.

0% 15% 50%

SLICING ▸ Support Structures

Support Material

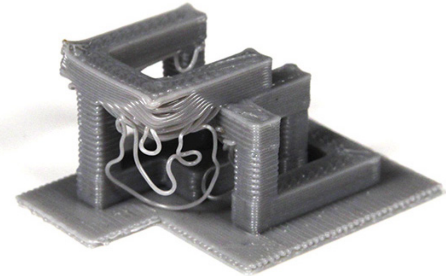
In the event that overhanging features are unavoidable in your design, your printer may need to print support material to provide a base to print the overhangs on top of. There are two main methods for support:

Breakaway Support:
This support is made by printing the regular filament in a very thin pattern. Your printer will fill areas under overhangs with a sparse scaffolding of filament that can be snapped away by hand.

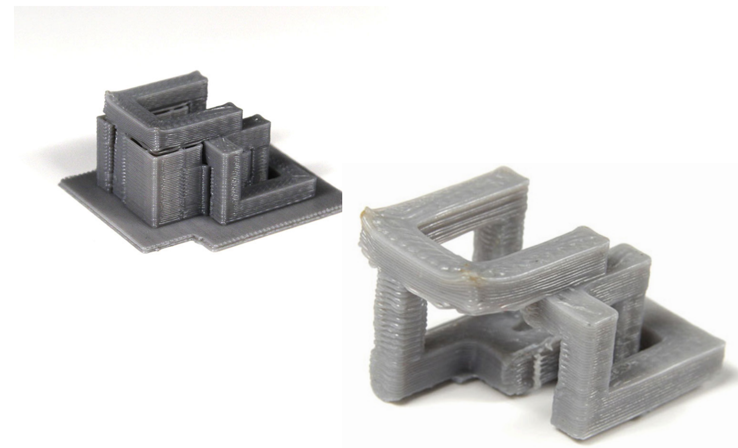
Soluble Support:
Dual-head printers allow you to print supports in a different material that can be dissolved in a solution that will not affect your primary filament. This can allow you to print very elaborate parts and removing the support is as easy as leaving the part submerged in a chemical for several hours. Some choices are listed below:

>PVA - Dissolvable in water
>HIPS - Dissolvable in citric acid
>ABS - Dissolvable in acetone

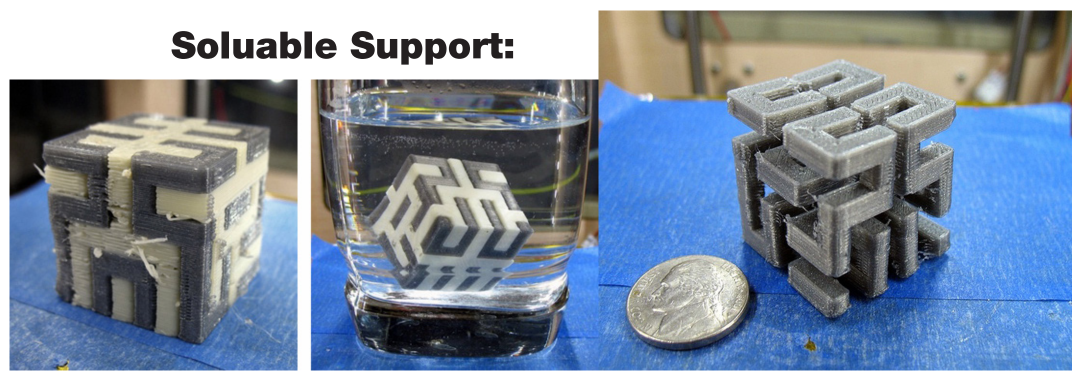
No Support:



Breakaway Support:



Soluable Support:

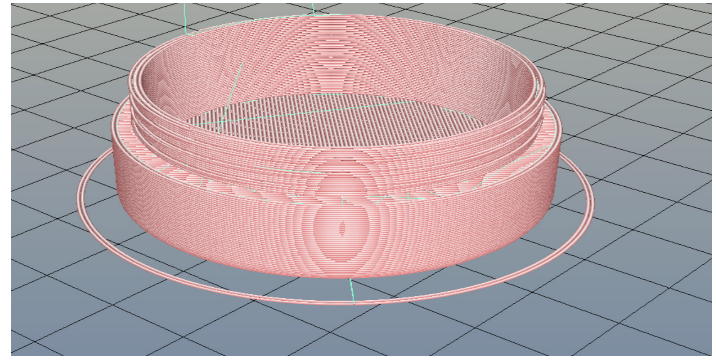


3ders.org

SLICING ▸ Bed Adhearance Structures

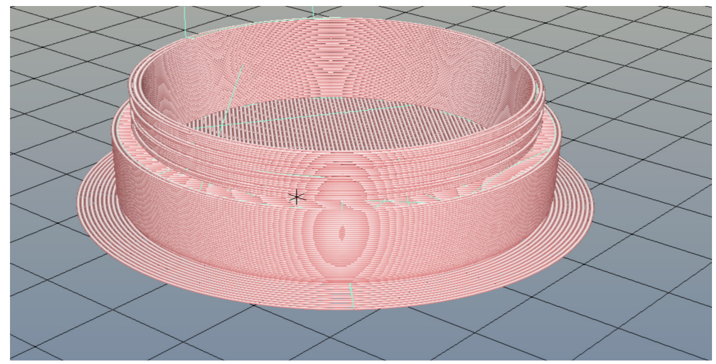
Skirt

The skirt provides the function of clearing and preparing your nozzle before beginning the print. Printing a few outlines around your part area before beginning allows you to verify that your print head is level and the filament is sticking to the bed.



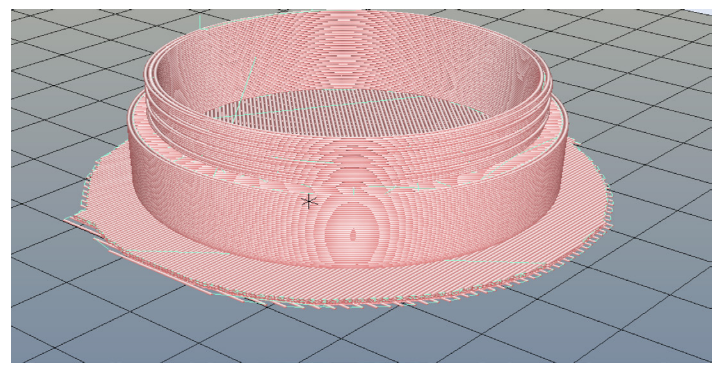
Brim

Similar to the skirt, a brim prints outlines around your part area before beginning the part. The difference is that the Brim continues printing outlines that get closer and closer to your part area until the innermost brim outline becomes the outermost part outline. The brim provides additional adherence to the bed in the event that warping becomes a problem and can be peeled away after the part is complete.



Raft

When printing small parts, you may have trouble getting the part to stick to the bed or the friction of the print head may shift the part on the bed during print. A raft can help by creating a large area under the part to print on top of. Filament sticks to itself very easily so printing a small platform for your part can help the print stick to the bed.



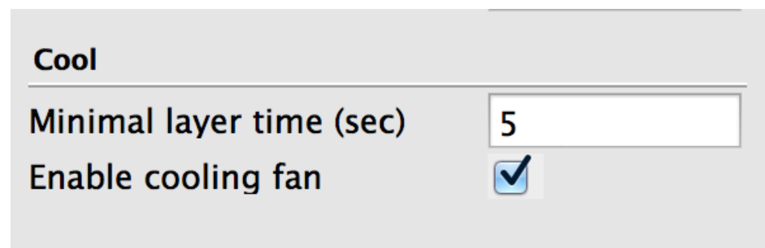
SLICING ▸ Other Settings

Retraction

During retraction, the extruder pulls the filament back away from the nozzle during periods of nozzle movement where no extrusion is desired. This can help prevent small amounts of filament from leaking out of the nozzle when the print head moves around your part. Too much retraction can damage the filament in the nozzle and reduce the quality of your print.

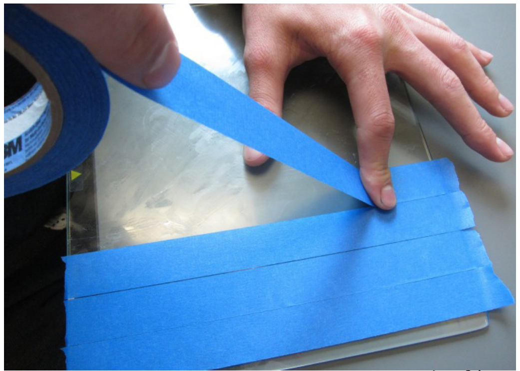
Cooling

When the printer finishes a large layer and moves up to the next one, the layer below it should have had time to sufficiently cool and solidify. With smaller part layers, this is not always the case. The print head may have trouble printing on top of a still melted layer and this can cause problems for your part. The cooling time parameter is the minimum time allowed for a single layer to take to print. If your printer finishes a layer in only 3 seconds, and you set your cooling time to 5 seconds, the printer will stop and wait 2 seconds before moving on the next layer. This ensures each layer is sufficiently cooled.



Cura Cooling Setting

BED PREPARATION ▸ Surfaces


spectrom3d.com

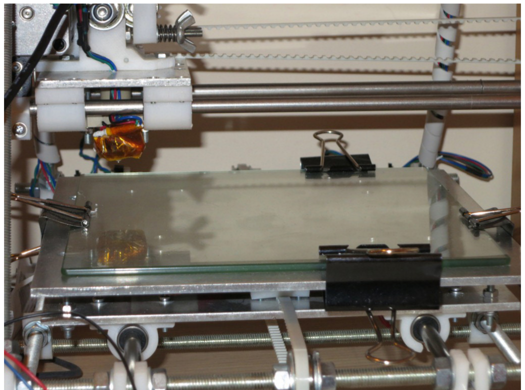
Blue Painters Tape (PLA)

The tried and true solution to PLA printing. Blue painters tape (or any color) is a cheap solution for PLA bed adhearance issues. Put down a single layer of tape evenly and smoothly on the build platform.
WARNING: It is not reccomended that you use Painters Tape along with a heated bed as the tape could ignite.


3dprinterprices.net

Kapton Tape

While this tape can be expensive, it is an excellent surface for both ABS and PLA. When used with a heated bed, this surface conducts even evenly though its surface while providing a smooth surface for printing. You may find that PLA sticks almosts too well to the Kapton however. Be careful when scraping a part off of the tape as a metal scraper could damage the expensive tape.


fabshed.com

Glass Bed

If the stock bed of your printer is not producing great results, a glass bed can be a quick alternative. Most hardware stores will custom cut glass panes for under $10. The pane can be easily fixed to the existing bed with binder clips. Combine glass with the adhesive methods on the next page for best results. Glass behaves well with the adhesives and it can be easily cleaned after the print.
WARNING: A glass pane will increase the height of your bed. To avoid a collison with the nozzle and the bed, lower your bed using the leveling screws by at least the thickness of the glass, and re-level your bed.

pencils.com

Glue Stick

For use with both ABS and PLA. Applying one to two layers of a washable glue stick prior to the print is one of the fastest, cheapest, and most effective ways to ensure print adherence to the build plate. Glue works best on a removable plate so that it can be cleaned after printing. To remove the part after the print, you may need to run the plate under hot water so that the glue dissolves.

3dsupplyworld.com

ABS Slurry (ABS Only)

If you happen to have some ABS print scraps lying around, you can make your own adhesive using acetone. Mix acetone and ABS plastic in a closed glass jar and let it sit for 6-8 hours. You can paint this ahesive onto the build plate using a small brush, cloth or cotton ball.

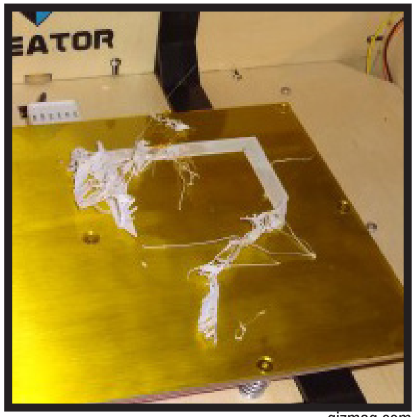
3dprintingatgphs.blogspot.com

Hairspray (ABS Only)

First, determine that the hairspray you are using contains acetone (most aerosol ones do, but check to be sure). If it does, you can spray a little onto your bed prior to a print. It is reccomended that you remove the build plate prior to spraying the hairspray. Spraying any form of a liquid inside the printer or near the printer could cause damage or fire.

TROUBLESHOOTING ▸ Visual Glossary

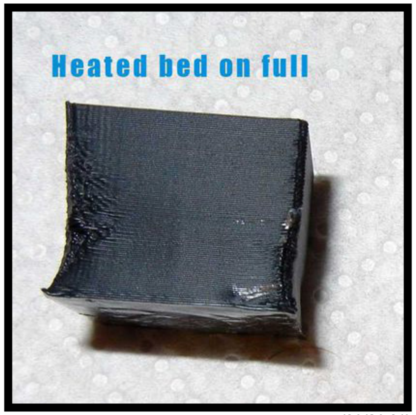
Under-Adhearance - 30
Print not sticking to bed



gizmag.com

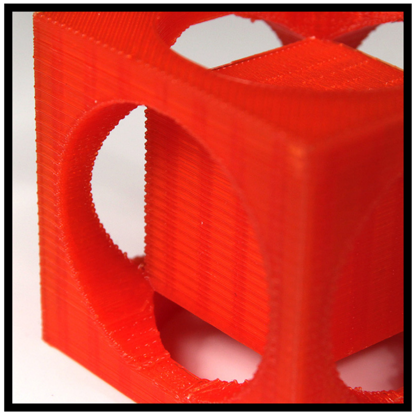
Software Failure - 30
Print stops midway

Bed Overheating - 30
Part caves in the middle

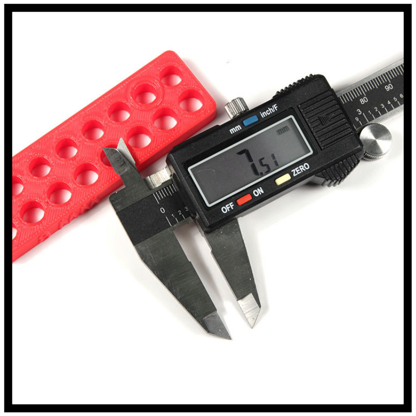


reprap.org

Z-Wobble - 31
Jagged layer pattern



Over Extrusion - 31
Part dimensions are wrong



Part cools too fast - 31
Part is splitting across layer

reprap.org

Motor stall - 32
Dramatic layer shift

Motor creep - 32
Gradual layer shift

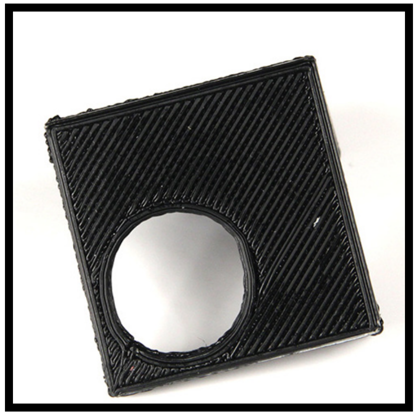
support.3dverkstan.se

TROUBLESHOOTING ▸ Visual Glossary

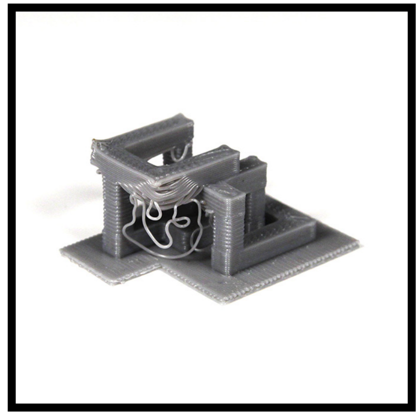
Not enough cooling - 32
Skinny sections deforming

reprap.org

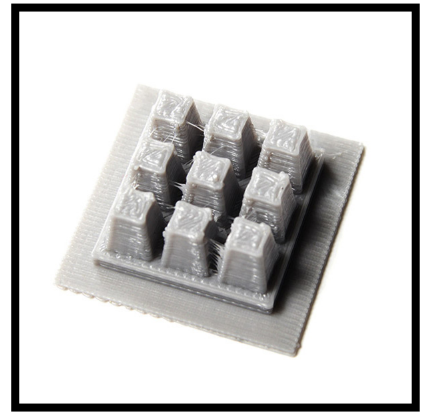
Belt Tension - 33
Circles printing oblong



Overhang Drooping - 33
Stringing and drooping

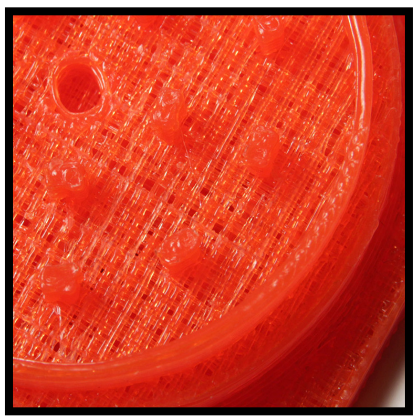


Nozzle Ooze - 33
Stringy ooze between gaps



Jagged Corners - 34
Choppy corners and edges

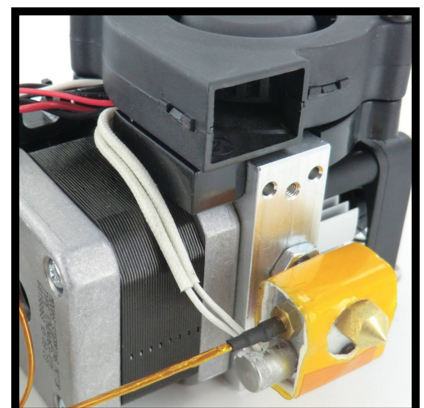
Under Extrusion - 34
Gaps on surface layers



Base Warping - 34
Base of part curls upwards

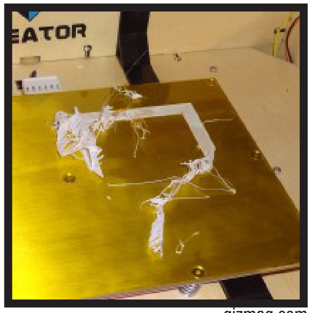
support.3dverkstan.se

Extruder Failure - 35
Little to no filament prints



sihra.com

TROUBLESHOOTING ► Part A

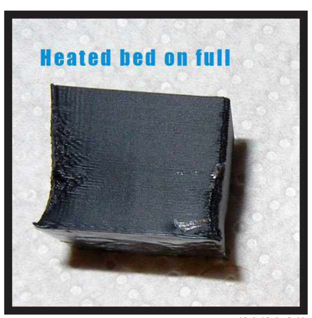

gizmag.com

Under-Adhearance: Occurs when the material is not bonding fast enough to the bed surface. The filament is dragged away from its intended position by the movement of the print head.

> Make sure bed is level and about a paper thin distance from the nozzle at “0” height
> If using a heated bed, try turning up the bed temperature by 5 to 10˚C
> Slow down the printing (motor) speed
> See page # for tips on bed preparation. Some options may work better for your printer than others.

Software Failure: Occurs when the connection between the computer and the printer is interuppted momentairily.

> Turn off or pause any back ground processes such as automatic updates, cloud storage syncing, or antivirus programs
> Turn off any automatic “sleep” timers in your computers power settings
> Try rolling back any recent updates to your software or using a different software
> Your building may have unsteady power. If these options do not work, try minimizing the amount of electronics plugged into the outlet or power strip the 3D printer is using.

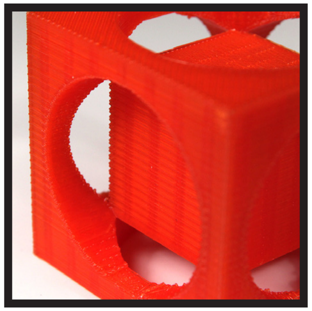


reprap.org

Bed Overheating: Occurs when the heat from the bed seeps up into the part and causes it to cool too slowly. The parts will tend to melt inwards.

> Turn down the heated bed by increments of 3-5˚C until results are satisfactory
> Your build plate may have an uneven distribution of heat. Try printing on glass or kapton tape which are better at conducting the heat evenly across the build plate.
> If glass or kapton tape are not available, try printing the part on a different section of the build plate.

TROUBLESHOOTING ► Part B



Z-wobble: Mechanical imperfections on the Z-axis threaded rod can cause patterns of misaligned layers along the Z-axis.

> The Z-wobble pattern is dependent on the pitch and threads per inch of the threaded rod. The patterns become more or less prevalant depending on your layer height. You can find working layer heights by trial-and-error. Try changing layer heights in increments of .01mm to find optimal heights.
> Certain printers have community created solutions to Z-wobble. You may be able to find 3D models for parts you can 3D print that will help restrict Z-wobble movement.

Over Extrusion: Occurs when your extruder is pulling filament at a higher rate than needed.

> See calibration guide for “Extruder Calibration” on page #
> If you’ve already done this, try turning down your flow rate by increments of 1-2%
> Slightly off dimensions may be unavoidable. You may compensate this by altering your part dimensions by a fraction of a millimeter when creating the part in your modeling software.


Reprap.org

Part Cools too Fast: Cracking can occur if you part cools too fast. Plastic shrinks when cooling so a rapid shrinking can cause a split between layers.

> Turn your heated bed temperature up by 5-10˚C. Make sure you don’t cause overheating however.
> If your printer does not have an enclosure, turn off any fans or open windows that may be blowing air across your printer. Also make sure the room is at least 21˚C or 70˚F.
> You may want to build an enclosure for your printer. This can be done cheaply using acrylic or glass panes found at any hardware store.

Motor Stall: If the motors motion is blocked for any reason, it will stall and will not move. The printer has no way of knowing if it stalled and will continue printing assuming the motor head is where it should be. This can cause a dramatic shift in layer position.

> Check your filament spool for a tangle. This is the most common source of motor stalling.
> Make sure there are no objects in the printer that may be sticking out near the gantry
> Check the Y and X-axis rods for any hard or sticky substance that may impede motion

http://support.3dverkstan.se/

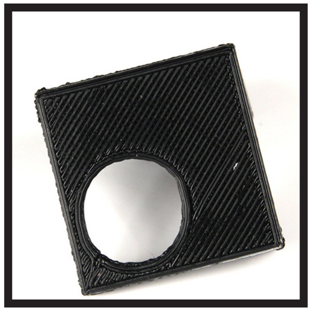
Motor Creep: Also caused by motor stalling, but is a result of slightly too much friction or resistiance, rather than several large blockages. This causes a gradual shift in layer postion.

> Clean and lubricate your rods with a silicone based machine to ensure low friction movement
> Make sure your filament spool does't require a lot of force to rotate. Depending on the spools mounting orientation, fliping the spool may make it easier on the printer.

Reprap.org

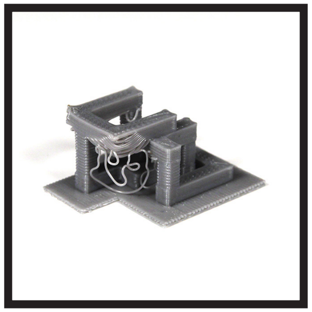
Not enough cooling: Occurs when the printer moves to the next layer before the previous layer had enough time to cool. This results in deformation of small, narrow features.

> Turn up the minimum cooling time in your slicing settings.
> If your extruder has a fan that is oriented to blow air on the part, check to see if this fan is operation and unblocked.



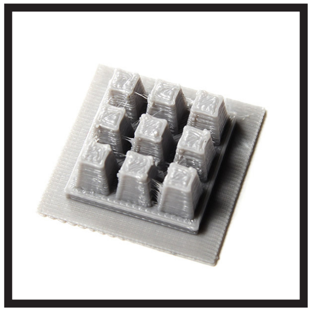
Belt Tension: Oblong or ovular circles can occur as a result of misaligned Y-axis belts. Many FDM printers have 2 parallel belts that move the extruder in the Y-direction. If these belts are misaligned, or pulling too hard or too little in comparison to your X-axis belt, circles and curves can come out lopsided.

> Check the calibration page # for instructions on aligning your Y-axis belts.
> You may need to consult manufacturer's customer support for more information about adjusting the belt tension for your specific printer.



Overhang Drooping: Most 3D printers can print overhangs over 45˚ to the build plate. Anything over that and you will need to print support material.

> Enable support material in your slicer settings.
> If you are still experiencing drooping after enabling support, try increasing the density and thickness of your support material in your slicer. (Not all slicers support this)

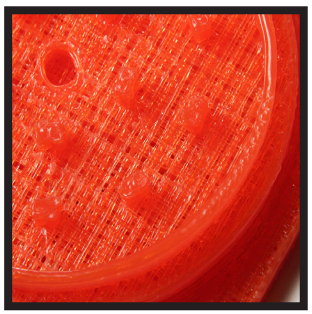


Nozzle Ooze: This occurs when liquid filament leaks out of the nozzle during travel moves, or movement where the nozzle isn't supposed to be extruding.

> Increase Retraction Speed setting in your slicer.
> Increase Travel Speed (Non-extruding speed) in your slicer.
> Lower print temperature in increments of 3-5˚C until ooze is reduced

Messy Corners: Print quality on corners can decrease with a number of factors.

> Lower print speed. If your slicer supports specific speeds, lower perimeter printing speed.
> Make sure your printer head is level and close enough to the bed at height "0". If your print head is too high, the filament may shift slightly before bonding to the part.
> Your filament may be of low quality and



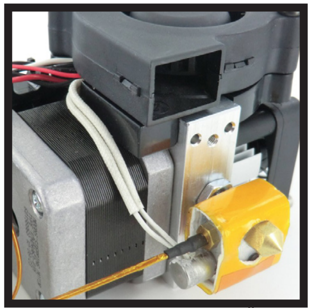
Under Extrusion: Also caused by motor stalling, but is a result of slightly too much friction or resistance, rather than several large blockages. This causes a gradual shift in layer position.

> Clean and lubricate your rods with a silicone based machine to ensure low friction movement
> Make sure your filament spool doesn't require a lot of force to rotate. Depending on the spools mounting orientation, flipping the spool may make it easier on the printer.

http://support.3dverkstan.se/

Warping: Occurs when the printer moves to the next layer before the previous layer had enough time to cool. This results in deformation of small, narrow features.

> Turn up the minimum cooling time in your slicing settings.
> If your extruder has a fan that is oriented to blow air on the part, check to see if this fan is operation and unblocked.



Extruder Failure: If little to no filament is being extruded, your extruder may be clogged.

> First try raising your print temp by 10-20˚C. Your filament may just not be hot enough.
> If you've recently switched filament types, try clearing your nozzle by extruding 50-100 mm of the new filament.
> Check to see if your extruder is gripping the filament. You may need to clean the teeth on the extruder gear with a brush.
> If these methods do not work, you may need to remove the nozzle and clean it. You may want to consult manufacturer support for information on how to remove the nozzle for you specific printer. Once the nozzle is removed, one or more of the following methods can be used:

Blowtorch Method - Requires: Blowtorch, flame/heat resistant gloves, pliers
1. Holding the nozzle with the pliers, apply 3-4 second bursts of the blowtorch down the hole of the nozzle.
2. Continue this until you can see clearly through the nozzle.
3. Place the nozzle down and allow it to cool.
4. Using a cloth, wipe away any ash on the nozzle.

"Flossing" Method - Requires: Drill bit, metal rod or wire with diameter equal to the that of your nozzle
1. If you have calipers, verify the diameter of your chosen tool.
2. Manually insert the chosen tool into the hole of the nozzle and slowly "floss" the tool in and out of the nozzle hole.
2. Brush away any removed debris with your fingers.
3. Repeat until you can see clearly through the nozzle.

Acetone Method (ABS Only) - Requires: Glass jar with metal lid, Acetone, cloth
1. Pour about a quarter cup of acetone in the jar
2. Submerge the nozzle in acetone and seal the jar.
3. After at least an hour, swirl the jar and remove the nozzle.
4. Quickly clean the nozzle with a cloth and wipe away debris. (The acetone evaporates quickly)
5. Repeat steps 2 through 4 several more times.

GLOSSARY

3D model
A computer generated 3D object. A 3D model could be as simple as a cube or as complex as a robot for a hollywood movie. A 3D model can be designed with computer modeling programs.

ABS
A synthetic plastic that is used in many consumer products. Its melting properties make it very suitable for 3D printing.

Bed ahearance
The ability for the first printed layer to stick to the print bed. If the first layer does not adhere to the bed, the part will not print correctly.

Belt
A tight rubber loop that the rotation of a motor to be converted into linear motion.

Build plate
The flat surface that the part is built on. Also referred to as the “bed” or the “build platform”.

Calipers
A tool that is capable of providing very accurate length measurements.

Chamfer
A 3D modeling term used to descibe a beveled edge that connects 2 walls. A chamfer is typically used to strentghen the joint betwwen 2 perpendicualr surfaces.

Enclosure
A 3D printer casing that fully surrounds the printer. An enclosure blocks physical access to the printer and the user must typically open a door to reach inside the printer.

Extruder
The aparatus that pulls in the solid filament from the spool, heats it up, and expels hot liquid filament out the nozzle tip. Compare the extruder to the print head aparatus on a typical injet printer.

FDM
“Fused Deposition Modeling”: The type of 3D printing technology that relys on the line-by-line extrusion of filament. FDM printers build parts from the ground up, printing one layer at a time.

Filament
The plastic material used by 3D printers to create objects. Filament is analogous to ink in a 2D inkjet printer.

GLOSSARY

Fillet
Similar to a chamfer, a fillet is a rounded surface rather than a flat, beveled edge.

Flowrate
The rate at which filament is extruded from the nozzle. It is usually represented as a percentage. If you find your printer is extruding too much or too little filament per part, you may want to tweak this value.

G-code
The code read by a printer that tells it exactly what movement actions to perform in order to create a physical part. G-code is generated by a slicing program.

Gantry
The term used to describe the entire mechanical system that controls the X and Y axis movemnt of a 3D printer. This includes the extruder.

Home Axes
A function on 3D printers that moves the print head to its minimum value in the X, Y and Z directions. This allows the printer to recalibrate the location of its print head. This is automatically performed before every print.

Infil
The gridlike mesh that makes up the interior of a 3D printed part. To reduce filament use, 3D printed parts are not solid and are semi hollow.

Kapton tape
An adhesive sheet or tape that conducts heat well. Kapton tape is a popular choice for a build surface in 3D printers.

Layer
A single vertical sheet that makes up the 3D printed part. FDM printers print one layer at a time, moving up the z-axis by a tiny amount after the completion of a layer.

Nozzle
The component of the extruder that the filament is ejected from. The diameter of the nozzle determines the speed and accuracy that a printer can print.

Overhang
The term to describe any part of a 3D model that does not have a solid surface under it. The arms of a “T” or an awning on a building would be considered “overhangs”

GLOSSARY

PLA
Similar to ABS, PLA is a cornbased plastic that is popular in 3D printing due to its melting properties.

Pulley
A round component attached to the motor that grips and turns the belts.

Retraction
The term for the reverse motion of filament in the extruder. When the extruder head moves across a gap, the extruder may pull the filament back away from the nozzle tip to reduce unwanted leakage.

Shaft
A long, smooth cylinder that makes up the skeleton of the gantry. The components of the gantry slide along the shafts.

Shearing Force
A force that is applied parallel to and along a surface. Poking your palm with your index finger would not generate a shearing force, but the friction of sliding your palms together will.

Shell
The outer, visible walls of a 3D printed part. The thickness of the shell can be increased for more strength.

Slicer
The computer program that breaks down a 3D model into “G-code” that a printer can read.

Slicing
The process of breaking down a 3D model into layers or “slices”. The resolution of a part depends on the thickness of the individual slices.

Stall
What happens when a stepper motor cannot provide enough power to overcome the force to move its load. A stall will result in the motor remaning motionless while the computer or printer still registers movement occuring.

Stepper Motor
A special motor that rotates in very small increments or “steps”. This is how 3D printers can be precise down to the fraction of a milimeter.

Support material
Addiontal materail that is printed along with the 3D model to provide a base for overhangs. Without support under an overhang, a printer would just be extruding filament into thin air.

GLOSSARY

UPF
UltraFine Particle. Tiny particles given off by the melting or heating of a material. These particles are essentailly suspended in a gasseous state and can be inhaled.

X-axis
The direction in a 3D printer that is generally recognized as “left and right” if you were facing the printer dead on.

Y-axis
The direction in a 3D printer that is generally recognized as “forward and backward” if you were facing the printer dead on.

Z-axis
The direction in a 3D printer that is generally recognized as “up and down” if you were facing the printer dead on.

Audience Analysis

Our audience consists of anybody who interacts with 3D printers in some manner. Primarily, we're focusing on the hobbyists, students, and engineers who frequently operate a 3D printer firsthand. They might use the technology for school, work, or personal projects. We provide information in our manual that may also be useful to managers overseeing a lab with 3D printers or to manufacturers looking for a new perspective on their product.

The manual is written in moderately technical terms, such that an engineering student or experienced hobbyist would easily understand it. However, the guide is not intended for a layman with no technical skills. The primary audience either knows how to create their own 3D models on a computer or is familiar with places on the internet to download models that others have created. The guide contains some limited tips on 3D modeling but assumes the user is already at the point where they're ready to print. Our audience has likely used 3D printers in the past and will be using them in the future. They have probably encountered issues with their printer at least once or experienced confusion at some point while operating it. We believe they will appreciate the source of information our manual provides.

Much of our audience is frustrated at the difficulty they experience when searching for information on best practices, operation, and troubleshooting their 3D printer. New users without extensive experience are especially affected by the lack of guidance. The audience may not readily trust the information in our manual because we are undergraduate hobbyists rather than industry experts or representatives from a manufacturer. However, like our audience, we have experience using 3D printers for a variety of applications. We have both experienced the difficulties inherent in the new technology and have had trouble finding advice online or from the manufacturer. Our information is credible because it is drawn from:

- Personal experience with using 3D printers (6 years combined) for work and enjoyment
- Personal experience setting up a new 3D printer
- Personal experience designing functional parts to be 3D printed
- Personal experience searching the internet for information
- Information gathered from 3D printing forums and blogs, and verified by the authors
- Official information from manufacturers and our personal experience with its limitations
- Conversations with other students and professionals who use 3D printing regularly
- Steven's internship at M3D, a 3D printing startup company

Fact-Finding Interviews

We conducted interviews to aid in creating a manual that is appropriately targeted to our audience. We wanted to know what printing problems operators most frequently encounter. We also wanted to know what 3D printing topics they've had trouble finding information and guidance on in the past. This will allowed us to put together a manual that is useful for our audience and that doesn't rely entirely on our own experiences. We interviewed several fellow students who use 3D printing regularly, as well as managers of the Digital Cultures and Creativity lab. The questions we asked are shown below:

Operator Questions

1. How many years of experience do you have with 3D printing? Where did you first experience the technology? How often do you use it?
2. In what context do you use 3D printing? At work? For hobby projects? What are some projects you have worked on?
3. What type of printer do you usually work with? What brand/model? Do you use ABS, PLA, or another type of filament? What type of build plate does your printer have? Is it plastic or glass? Do you use any kind of treatment to prepare the plate to aid printing?
4. Think back to the projects you've worked on recently. What problems did you encounter? Did the print fail at any point? Were there defects in your part? Did you have issues with warping away from the build plate? Did the filament ever jam in the extruder or fail to adhere on the first layer? Was your part weaker than you expected when you were designing it?
5. When you encounter these sorts of problems, what do you do to fix them? Do you consult the internet for advice? Does your printer have a helpful manual? Do you attempt maintenance yourself or do you call the manufacturer? If you had a reliable and complete source of information, would you be more likely to attempt fixing the printer by yourself?

Manager Questions

1. How many printers do you oversee? Who is authorized to use them? Do they receive any training before using a printer?
2. Do you have any experience using 3D printers? Have you ever used the printers you are responsible for?
3. What is your lab's procedure for dealing with maintenance issues? Do you fix them yourself? Is there a representative from the manufacturer who provides support or performs maintenance? Do you ever rely on the product's warranty?
4. On average, how much printer downtime does your lab experience? Do you feel this significantly reduces the usefulness of your lab? What problems do the operators in your lab report when using the printers? Are there any common issues that result in downtime or replacement costs?
5. If we provided a comprehensive manual of best practices and maintenance tutorials, would you be willing to make it available to the staff and operators in your lab? Would you consider paying for this product?

Works Consulted

Brubaker, Lars. "Troubleshooting Common Challenges with 3d Printers." 2014 3D Printer World Expo. Lecture.

Chilson, Luke. "The Difference Between ABS and PLA for 3D Printing." *ProtoParadigm*. Web. <http://www.protoparadigm.com/news-updates/the-difference-between-abs-and-pla-for-3d-printing/>.

Gupta, Bhuvanesh, Nilesh Revagade, and Jons Hilborn. "Poly(lactic Acid) Fiber: An Overview." *Progress in Polymer Science* 32.4 (2007): 455-82. *Science Direct*. Web.
PLA and ABS Strength Data. MakerBot. Web. <http://eu.makerbot.com/fileadmin/Inhalte/Support/Datenblatt/MakerBot_R__PLA_and_ABS_Strength_Data.pdf>.

"Print Troubleshooting Pictorial Guide." *RepRap Wiki*. Web. <http://reprap.org/wiki/Print_Troubleshooting_Pictorial_Guide>.

Replicator 2X Experimental 3D Printer Troubleshooting and Maintenance. MakerBot. Web. <http://download.makerbot.com/replicator2x/MakerBot_Replicator_2X_Troubleshooting___Maintenance.pdf>.

Stephens, Brent, Parham Azimi, Seineb El Orch, and Tiffanie Ramos. "Ultrafine Particle Emissions from Desktop 3D Printers." *Atmospheric Environment* 79 (2013): 334-39. *ScienceDirect*. Elsevier, 6 July 2013. Web. <http://www.sciencedirect.com/science/article/pii/S1352231013005086>.

Stratasys. Stratasys. *ABS*. Natural Resources Research Institute, 2007. Web. <http://www.nrri.umn.edu/NLTC/ABS07.pdf>.

"A Visual Ultimaker Troubleshooting Guide." *3DVerkstan Knowledge Base*. Web. <http://support.3dverkstan.se/article/23-a-visual-ultimaker-troubleshooting-guide>.

"3D Printing Basics." *3ders.org*. Web. <http://www.3ders.org/3d-printing-basics.html>.

"3D Printing Guide." *Ultimaker Wiki*. Web. <http://wiki.ultimaker.com/3D_printing_guide>.