



Skill Badge Guide: 3D Printing

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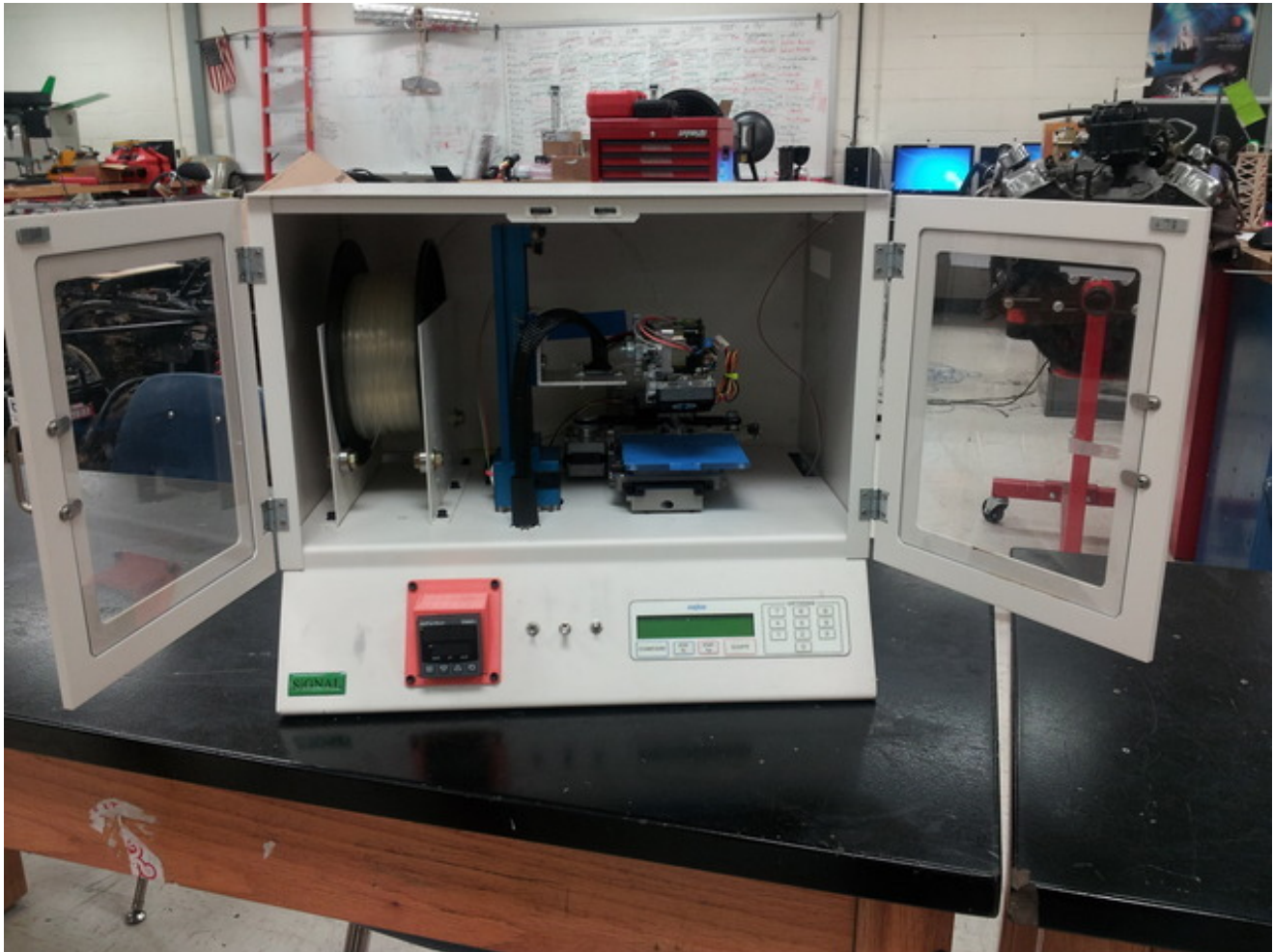


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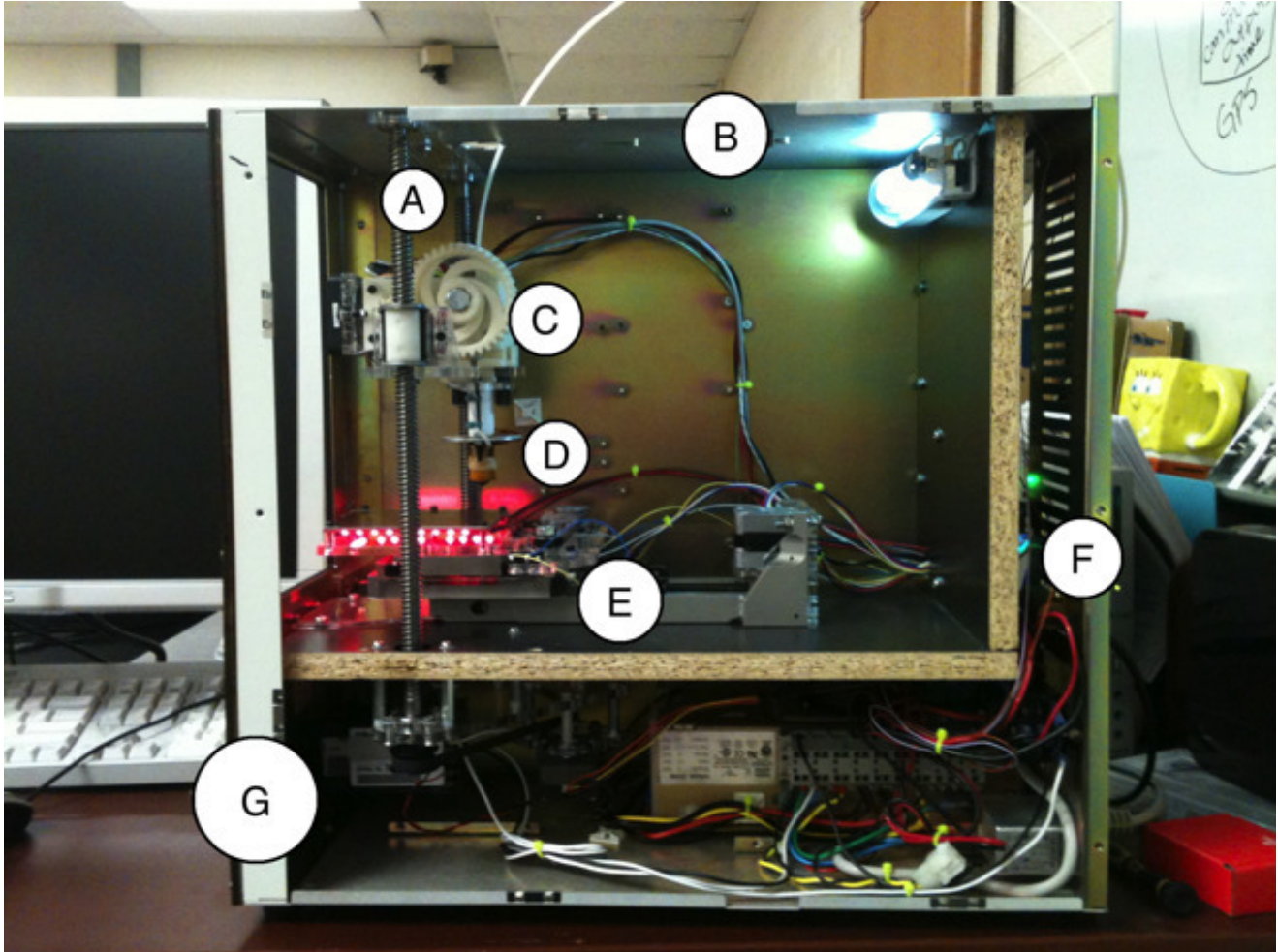
3D Printing Overview



The 3D printer uses a process called *fused deposition modeling* to construct a solid object from a virtual model. This process involves the controlled deposition of a molten feed stock, typically ABS or PLA plastic, onto a build surface where layer-by-layer the model emerges. Each 3D printer features a series of motors to move the three axis and the extruder, and a controller to move the motors and manage the build process.

Understanding the technology

Today's 3D printers are typically made up of 6 main components. There are multiple methods for configuring the machine and this guide features a machine whose build platform moves on the X and Y, and the Z carries the extruder.



The Structure (B):

The role of the structure is to provide a rigid platform for the machines components to be secured to. The material of the structure can be as unique as the machine itself. Some common materials are plywood, acrylic, and metal.

The XY axis (E):

The XY axis provides stable, linear movement in the X & Y directions. This mechanism is controlled by either a belt or screw interface to a stepper or servo motor. The amount of XY movement per step correlates to the machines resolution.

The Z axis (A):

The Z axis elevates the extruder above the build platform and moves perpendicular to the XY axis. This mechanism is typically controlled by a linear screw interface to a stepper or servo motor. The amount of +Z movement correlates to the thickness of each layer. Some machines move the extruder with the XY axis and the Z axis moves the build platform. Regardless of the configuration, all three axis are required to construct a 3D object.

The Build Platform (D):

The build platform is the surface that supports the extruded material while the machine completes each layer. There are two types of build platforms, heated and not heated. A heated platform is optimal for larger parts as it helps to eliminate the problem of thermal contraction of the extruded material which leads to part deformation and warping. Printers that print ABS often require a heated platform while those that use PLA do not.

The Extruder (C):

The extruder is the heart of the 3D printer. This mechanism is responsible for accurately depositing the desired feed stock onto the build platform. There are numerous designs and types of materials the extruder can handle. If it is extruding plastic feed stock, the extruder relies on a toothed feed wheel that feeds the plastic filament into a heated chamber. This chamber is thermally regulated to the desired melting point of the plastic and once molten, the filament is forced through a small nozzle. The diameter of the nozzle dictates the detail that can be replicated by the machine and are generally ~0.4mm - 0.5mm in diameter.

The Electronics & Software (F, G):

The electronics and software make up the brain of the 3D printer. Designs are produced on a computer as a solid model and are deconstructed by a G-Code processor (Skeinforge, Slicr, Miracle Grue, etc.). This piece of software takes the solid model and "slices" it into a series of layers. Each layer is then converted into a series of coordinate movements that are fed into the machines controller by the control software (ReplicatorG, MakerWare, Repeater-Host, Pronterface, etc.).

Filament types



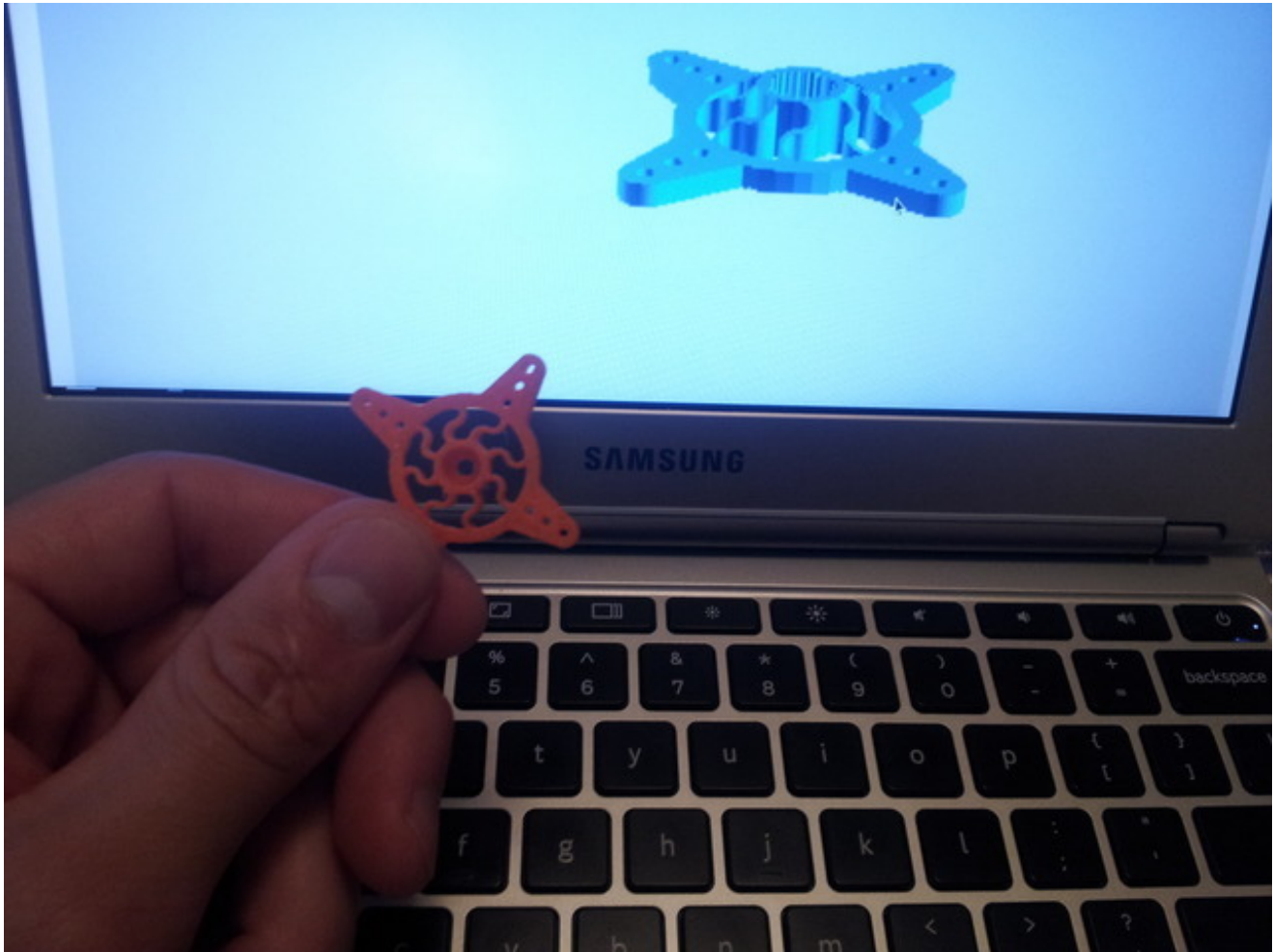
Although there is a wide range of filament types a 3D printer can handle, ABS and PLA plastics are by far the most popular. These two plastics are readily available in a staggering amount of colors, even glow-in-the-dark!

- **PLA** (<http://adafru.it/cop>) - Is a thermoplastic derived from natural sources and has excellent print qualities. It flows at a relatively low temperature, starting at $\sim 220^{\circ}\text{C}$, and does not require a heated build platform. Objects made out of PLA are rigid and more brittle than ABS. PLA is also preferred over ABS when used in areas with poor ventilation due to its relatively non-offensive smell.
- **ABS** (<http://adafru.it/coq>) - Is a synthetic thermoplastic commonly used in the automotive industry and also has excellent print qualities. It flows at a temperature starting at $\sim 230^{\circ}\text{C}$, but can be extruded at higher temperatures than PLA due to its chemical stability, but requires a heated build platform. Objects made out of ABS are rigid and tend to bend before breaking, unlike PLA. Lastly, proper ventilation is a must due to the offensive fumes generated when printing ABS.
- **PLA/PHA** (<http://adafru.it/2063>) - A compromise between PLA and ABS at an affordable price. Like PLA, PLA/PHA is made from renewable resources and is biodegradable. Polyhydroxyalkanoate (PHA) adds toughness to the PLA, making it more malleable and giving it a feel similar to ABS. The colors are opaque and remain vibrant after printing. However, unlike ABS, it is not prone to warping and can be printed easily on an unheated printer bed. It flows at a relatively low temperature, starting at $\sim 220^{\circ}\text{C}$.
- **NinjaFlex** (<http://adafru.it/1690>) - Specially formulated thermoplastic elastomer (TPE) that

produces flexible prints with elastic properties. Perfect for wearables, LED Diffusers, Bumpers, Insulation, Grips, Buttons and Buoyancy. It flows at temperatures starting at ~240°C, but can be extruded at higher temperatures.

- **SemiFlex** (<http://adafru.it/2321>) - boasts half the flexibility, more strength and reliability for your 3D printing projects. It's slightly more rigid with a higher level of detail and with added shock-absorption. It can also handle unsupported vertical printing. Flows at temperatures around ~230°C
- **BambooFill** (<http://adafru.it/2475>) - Made with actual recycled bamboo! This material can be stained and sanded. Smells and feels like wood! Works well on both heated and non-heated build platforms. Flows at a temperatures starting at ~220°C.
- **BronzeFill** (<http://adafru.it/1830>) - Print with **actual bronze** at home! Straight from the printer parts look almost laser sintered with a matte finish but with a bit of sanding and polishing the bronze particles will start to shine and shimmer unlike any 3D printing filament you have seen before. The weight of the material is something special, about 3x heavier than regular PLA filament. Prints easily on an unheated printer bed. It flows at a temperatures starting at ~220°C.
- **CopperFill** (<http://adafru.it/2128>) - Same properties as BronzeFill but with a gold color after polishing!
- **Magnetic Iron** (<http://adafru.it/2797>) - This filament behaves similarly to iron - even to the point of rusting - making it a great choice for costumes and props. It's actually "ferromagnetic" as opposed to magnetic. This means that magnets will stick to items printed with this filament but 3D Printed items will not behave as magnets. Prints easily on an unheated bed. It flows at temperatures starting at ~220°C.
- **Conductive PLA** (<http://adafru.it/27032703>) - A great way to make something with an LED, touch sensor, or some other electronics through your 3D printer. The filament is great for low-voltage circuitry. A great way to think of it is that anything you can run through a 1K resistor should work with this filament. Prints easily on an unheated bed. It flows at temperatures starting at ~220°C.
- **Glow in Dark** (<http://adafru.it/2338>) - Literally make your work glow! During the day it's a beautiful creamy color which prints to a perfect smooth finish. Phosphorescent pigment is matched with PLA/PHA compound to make prints glow in the dark. For a better and longer lasting glow time print your models with 100% infill and charge up your models with UV LEDs or high power lights, or just let them enjoy the sunlight for a bit. Prints easily on an unheated bed. It flows at temperatures starting at ~220°C

Designing for the printer



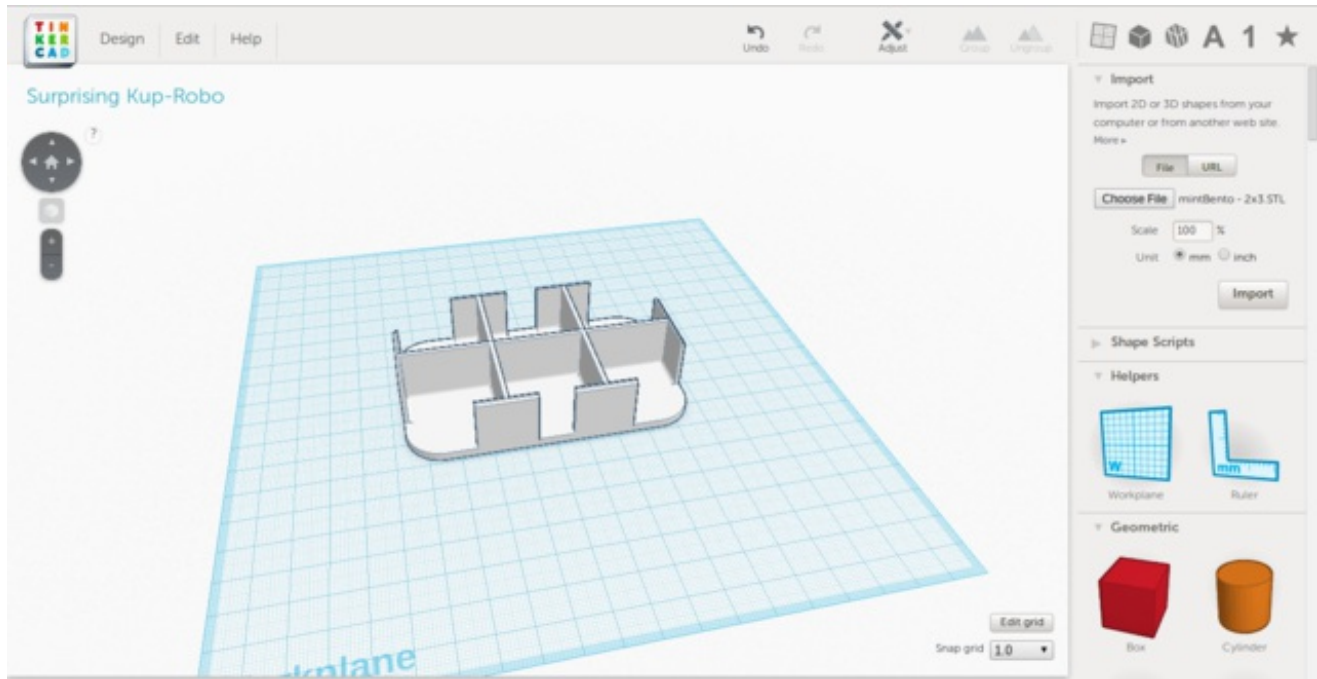
In order to produce 3D printer compatible objects, it is important to understand its limits. I like to think of a 3D printer as a spaghetti machine. It carefully stacks noodles on top of each other, and if there isn't enough noodle to stack on, it droops. The following three design elements can be implemented to help prevent drooping and will allow you to successfully print overhangs.

1. **The 45° Rule:** In general, 3D printers are restricted to overhangs that are under 45°. This allows for enough material to be present under the new extrusion and helps to prevent drooping.
2. **Peaked circles:** If you need to create a circular feature that is perpendicular to the build platform, taper the top of the circle with two tangential lines so that the 45° rule is not broken.
3. **Support structure:** Many slicing engines will detect overhangs and can generate a brittle support structure that provides support for overhangs over 45°. This is a nice feature to use, especially when overhangs are unavoidable, but usually uses a ton of filament in the process.

Check out [Makerbot Thingiverse \(http://adafru.it/cor\)](http://adafru.it/cor) for models and design ideas for your next

project. Their friendly community has a ton of 3D printer compatible models to share.

Free 3D CAD



There are many FREE CAD suites that make designing for the 3D printer a breeze. Each one has its strengths, so try 'em all and see which works best for you!

- **123D Design** (<http://adafru.it/aVV>): Autodesk's 123D Design provides a very capable solid modeling environment that operates on Mac and PC. The 123D tool set is similar to commercial suites making it a good free alternative to software such as Solidworks and Fusion 360.
- **Blender** (<http://adafru.it/aVR>): This feature rich software can create everything from solid models for printing to full fledged, cinema quality, video. Although the learning curve is a bit steep, there is a huge amount of support available in their community forum and elsewhere online.
- **Tinkercad** (<http://adafru.it/aVU>): Revived by Autodesk, Tinkercad provides an easy to learn solid modeling environment that links directly to your Thingiverse account. Unlike 123D Design, Thinkercad is capable of importing and manipulating existing solid models and runs entirely "in the cloud."

Setting up the machine

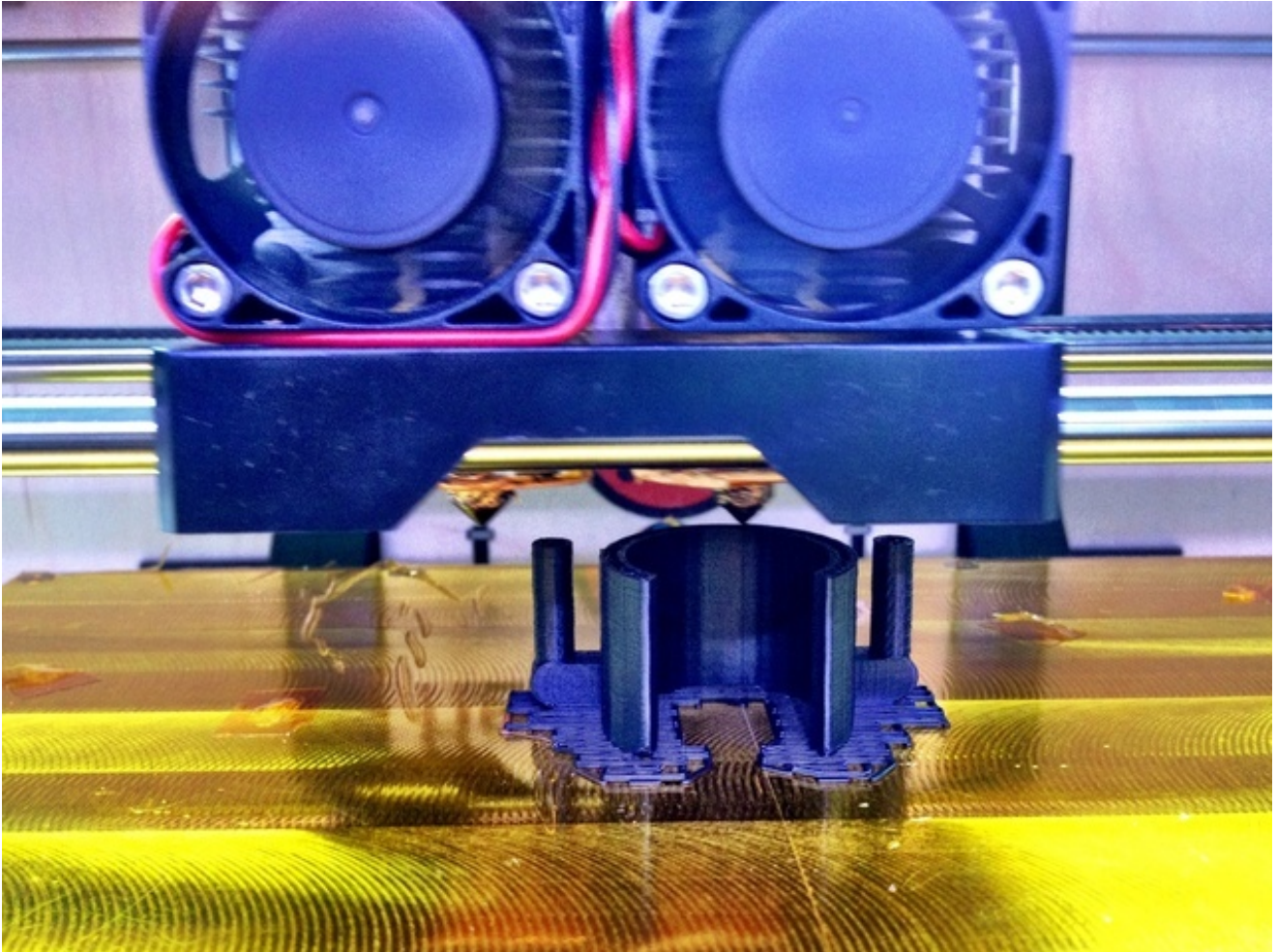


Before you operate your machine, check the following to ensure its proper operation:

1. Make sure the filament spool is installed properly and turns freely.
2. Gently move each axis and ensure they move smoothly.
3. Check that the build platform is level.

These three checks will help to eliminate many of the problems that inhibit a good print job. If the spool sticks while it unravels it will pull up on the extruder and may prevent it from extruding. If the axis don't move freely, they may need to be greased or realigned. This will help prevent the stepper from skipping a step, resulting in a shifted print job. Finally, if the build platform is not level the first layer will most likely not stick evenly and will cause distortion or warping of the printed model.

Bed leveling



The build surface needs to be level to ensure the filament properly sticks to the surface and to provide a secure foundation for the print job. The bed can be leveled by either mechanically leveling the bed or using a raft to accommodate for unevenness.

- **Mechanical Leveling** - The easiest way to check this is to command the printer to "zero" the axis and move the extruder to its lowest position. You should be able to insert a sheet of paper between the build platform and the tip of the nozzle. If there is a gap, gently raise that side of the build platform using the adjustment screw or a shim and continue checking the remaining corners of the build area.
- **Extrusion Raft** - If the build platform is warped, or cannot be leveled, try printing your next object with the "raft" feature enabled. This will deposit a thick grid of material onto the bed at the beginning of each print and will eliminate most adhesion problems.

Scale calibration

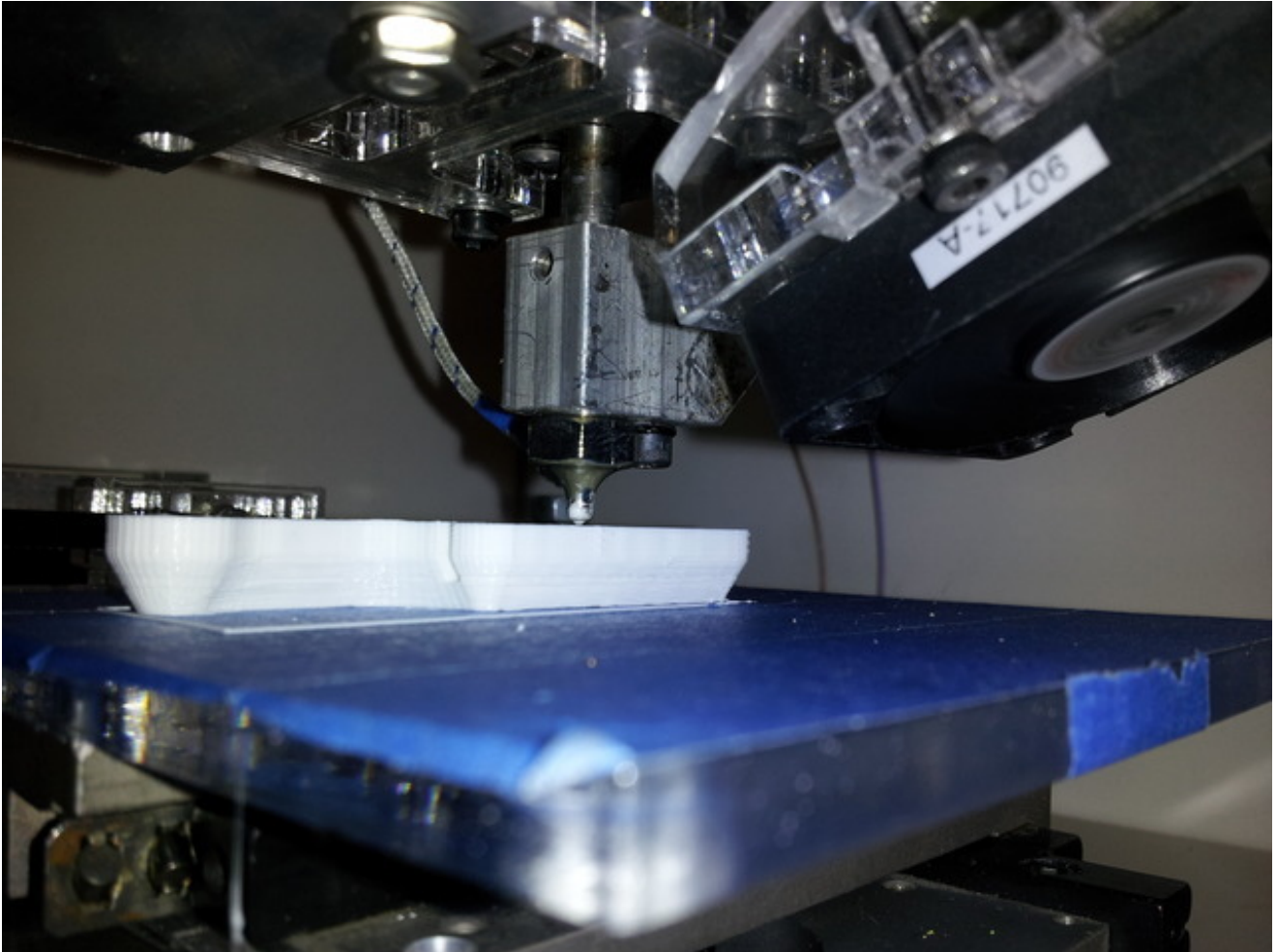


Scale calibration illustrates the process in which you compare the desired dimensions with the actual dimensions your printer produces. The easiest method for accomplishing this is to start by printing a calibration object, like a [Calibration Cube](http://adafru.it/cos) (<http://adafru.it/cos>) or the [Calibration Vector](http://adafru.it/cot) (<http://adafru.it/cot>). Once complete, use a set of calipers to check the dimensions and record your results.

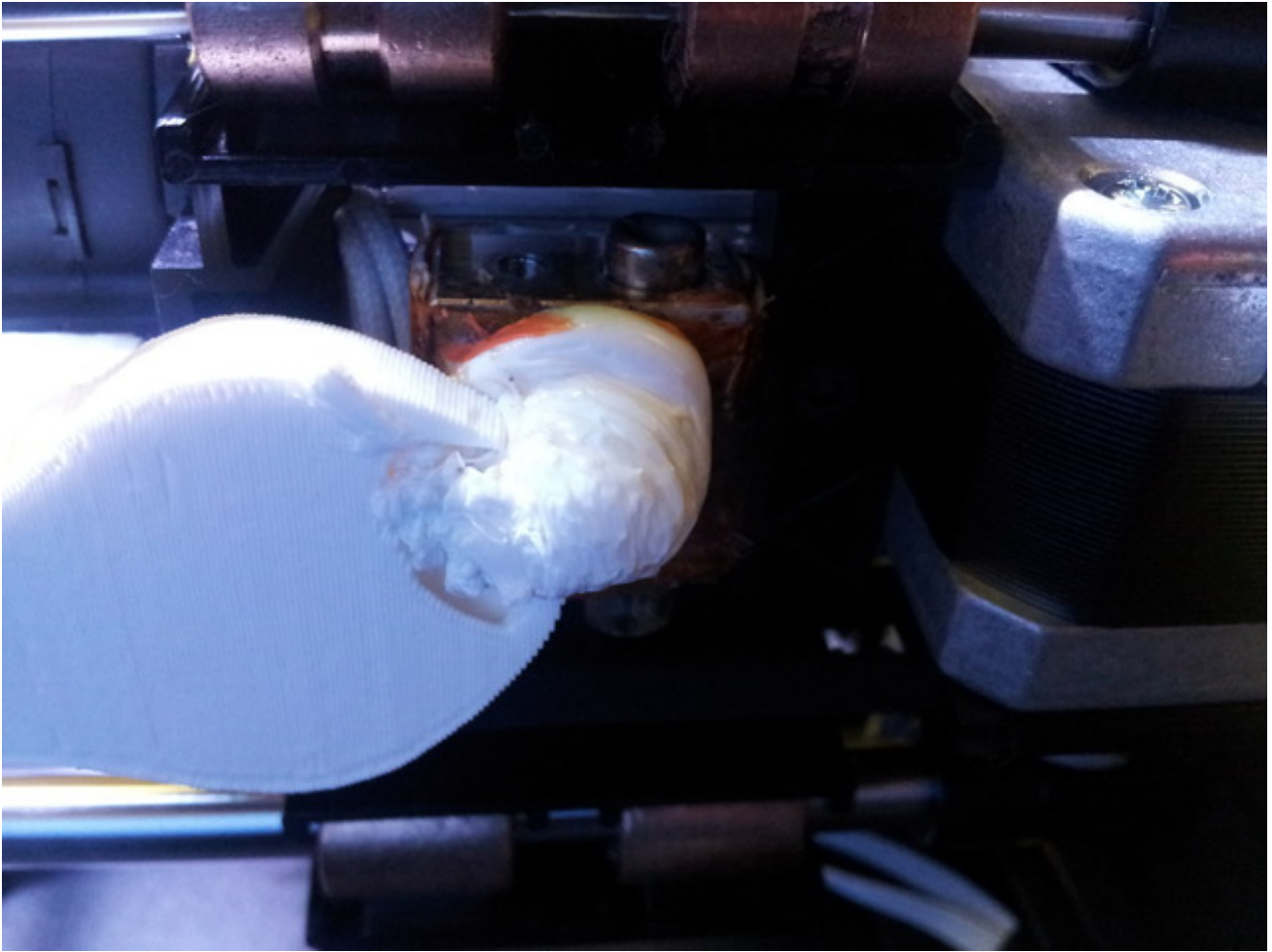
If the dimensions are not to your liking, there are a few quick tweaks you can implement to improve your results:

1. **Novice:** Simply scale your object before printing. If your calibration object measures 10.5mm, and it should be 10.0mm, scale the object down to 95.24%. $(10.0\text{mm} \times 100\%) / 10.5\text{mm} = 95.24\%$.
2. **Intermediate:** Edit the firmware to reflect a more accurate steps/mm calculating the required steps/mm vs the actual steps/mm.
3. **Expert:** Change both the feedrate and flowrate as they dictate how much plastic is distributed per mm. These settings can be used to fine tune your printer once you are close in calibration.

Running the machine



After you have completed your quick mechanical check, turn on the printer and open your control software (ReplicatorG, Makerware, etc.). Import your model into the virtual build area and preheat the extruder (and platform if a heated platform is used) since this usually takes a good bit of time. Depending on the software you used to create your model, it might be oriented improperly with respect to the build platform. Simply drag the model so that it is positioned within the printer's build area and have the software place it onto the platform. This will ensure that the first layer adheres correctly and that the object is level. Follow your printer's directions regarding sending the job to the printer, select your desired resolution and fill density, press print and watch the magic happen.



Like any machine, 3D printers should not be left unattended while they are printing. This is especially important with large print jobs as the heat generated by the printing process can cause mechanical failure that, if left unchecked, can cause a fire. Make sure you are familiar with your machine's emergency stop procedure. Most machines feature an emergency stop button (sometimes in the software) to immediately halt the machine. If all else fails, pull the plug!



When the print job is complete, let your model cool or you might unintentionally mush it while prying it off the platform. If your model is stuck, use a plastic putty knife to carefully work around the perimeter of the object until it pops off. Clean up any excess material and you are good to go!