Finding a Place for 3D Printing In Your Prototype Shop

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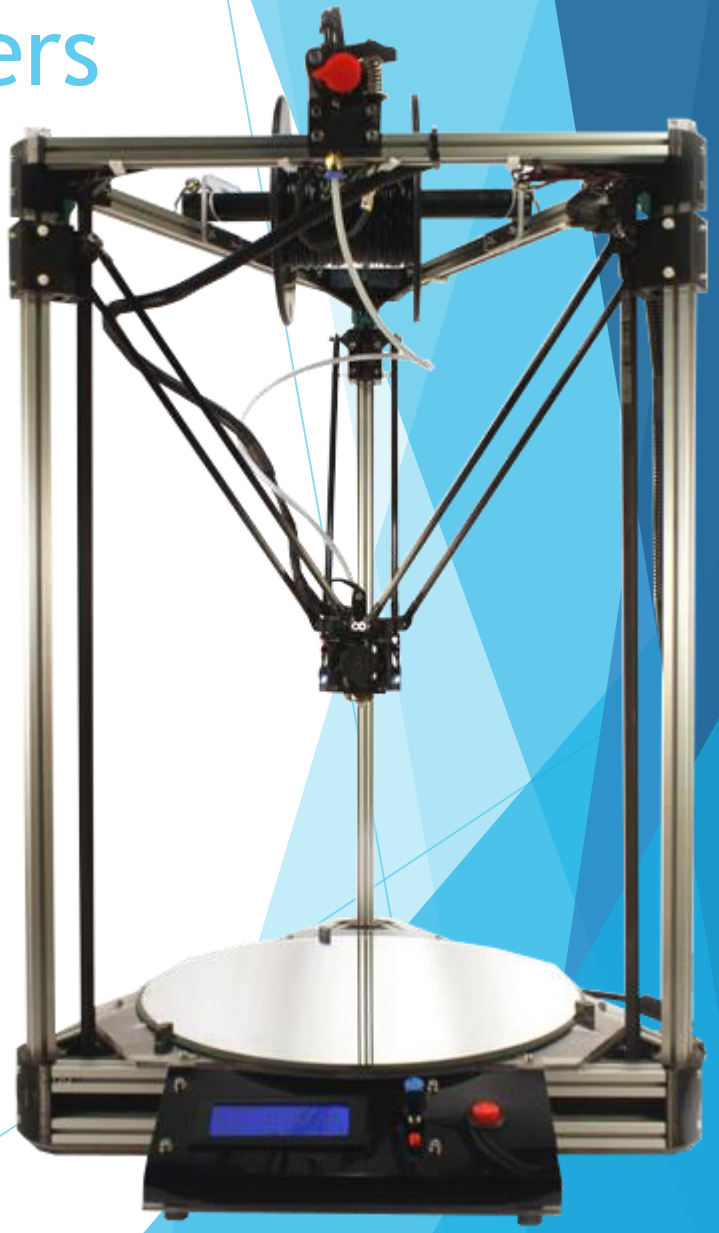
The Progression of Rapid Prototyping

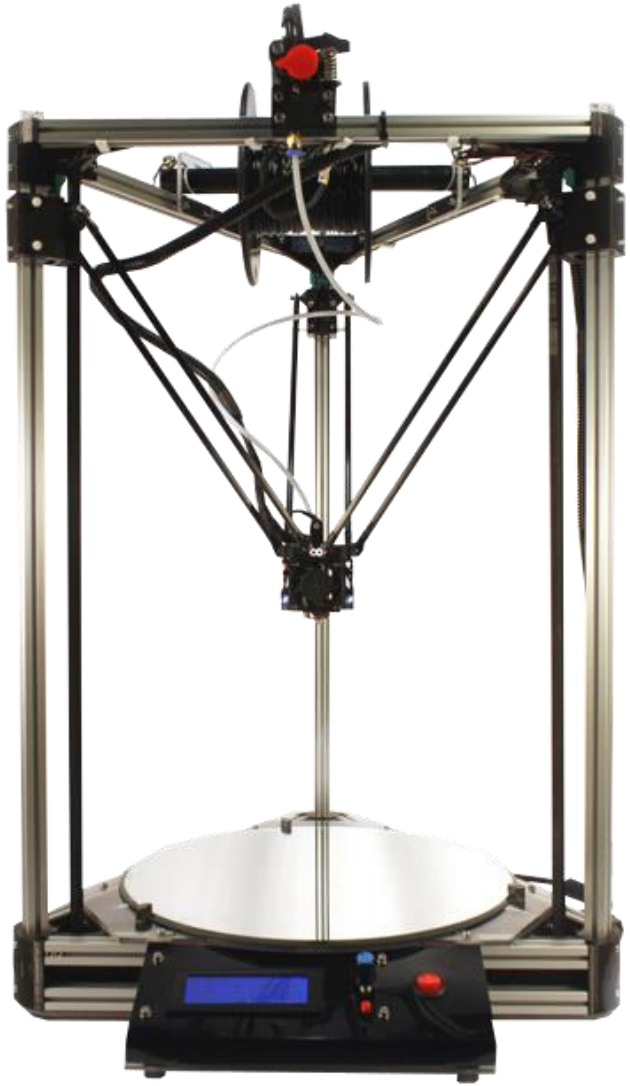
- Over the last 20 years, rapid prototyping has moved from quarter of a million dollar laser based equipment down to the current $300-Do It Yourself 3D Printers.
- The price of Rapid Prototype (RP) service providers has dropped along with the cost of equipment, but even the best shops take time and money to produce prototypes.
- In response to this, Anida Technologies purchased a CNC mill.
- However, there were still parts that weren't machinable, so RP service providers were used, although less frequently.

Tormach PCNC 1100.

Rapid Prototyping and Desktop 3D Printers

- Last year we acquired a MakerBot 5th Generation Replicator, and an Autotroph Delta 3D printer earlier this summer to reduce the need for RP service providers.
- They are Fused Deposition Modeling (FDM) 3D printers that have have a single extruder which can print in Polylactic Acid (PLA) and Acrylonitrile butadiene styrene (ABS) at 100-micron layer resolution.
- The MakerBot has fulfilled most of our needs, however we still see some need for accurate Stereo Lithography (SLA) models for some projects.
- Whenever we tell an engineer that we now have 3D printer capabilities, they will invariable dismiss it as a nice toy, but don't see how it would work for them day in and day out.
- As I describe 3D printer systems, I will try and help you find a place for 3D-printing in your own prototype shop.



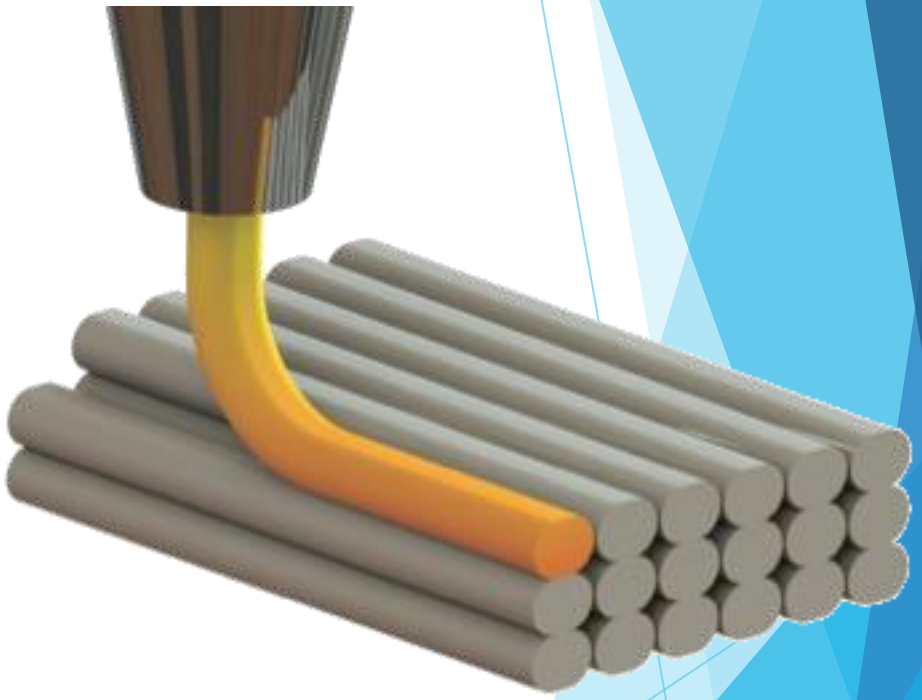


The Autotroph Delta printer is an open-source printer that is sold as a kit. It uses a delta style gantry.

The MakerBot 5th Gen. Replicator is a closed source 3D-printer.

Desktop 3D Printers: Fused Deposition Modeling

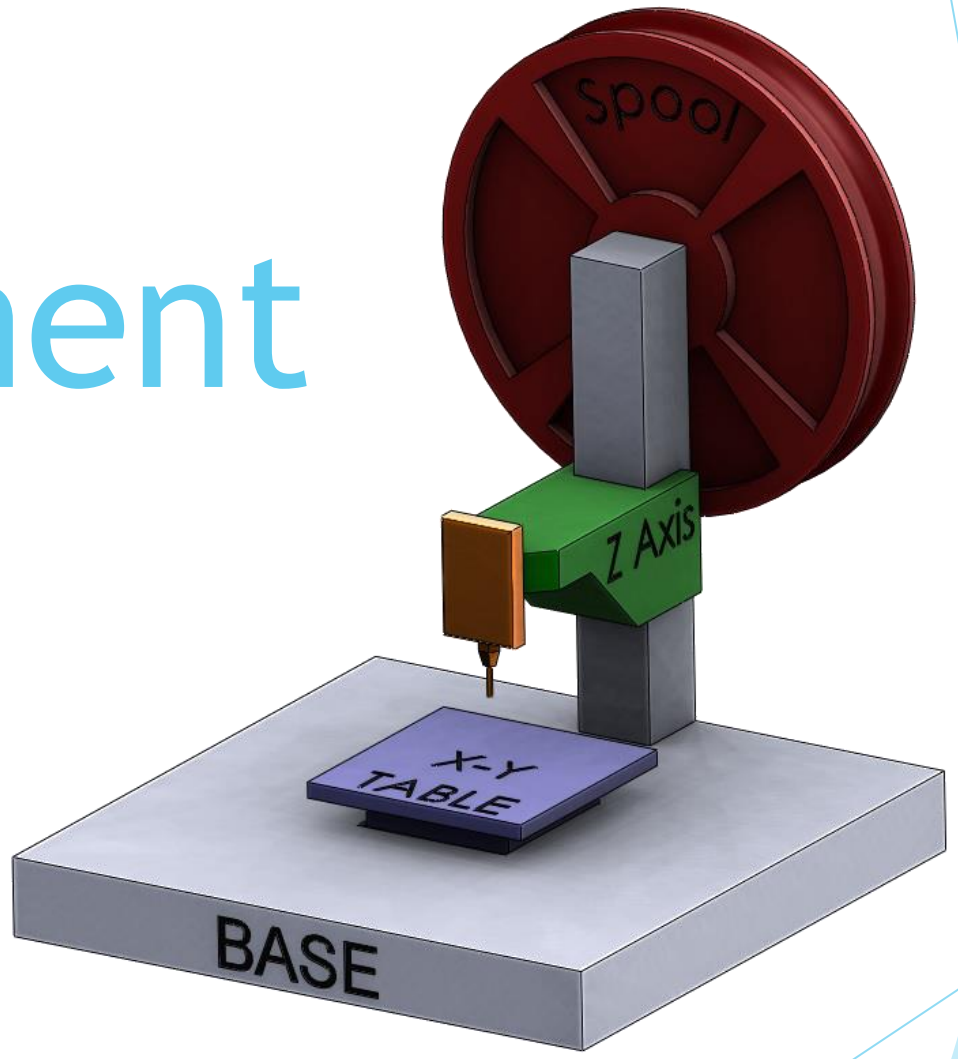
- Most current desktop 3D printers create parts using a process known as Fused Deposition (FDM).
- FDM printers extrude thin layers of thermoplastic filament to create a part.
- This type of rapid prototyping is known as “additive manufacturing” since material is added to a blank platform. This stands in contrast to traditional milling and lathes where material is removed or “subtracted” from a piece of existing material.



Fused deposition modeling (FDM) uses extruded material printed in thin layers to create a part in a process known as additive manufacturing.

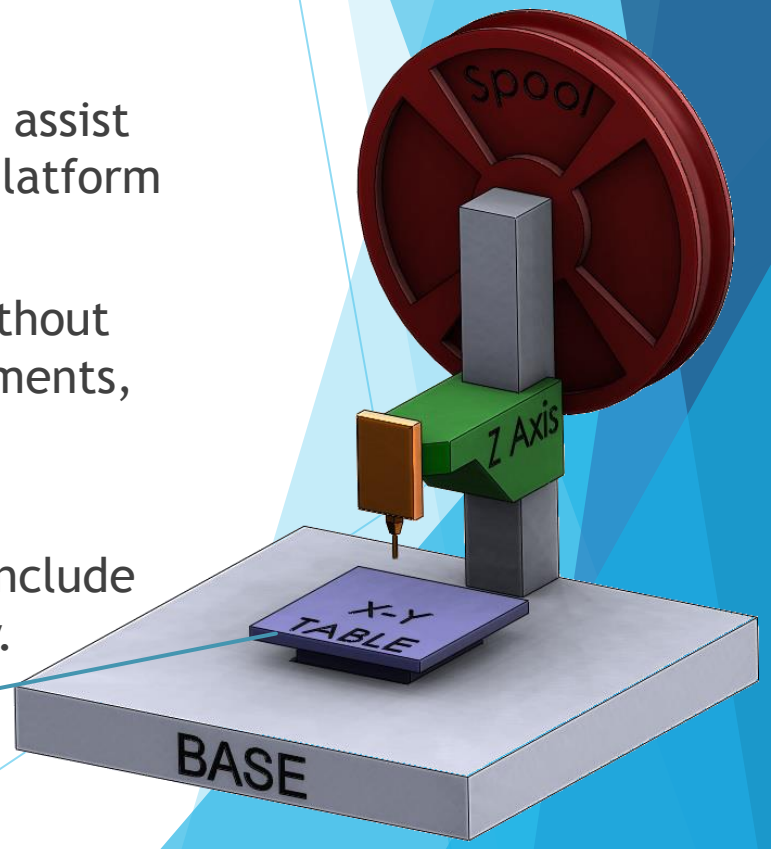
Ghose, Shuvom. “How to Design for 3D Printing Success.”N.p., 4 Dec. 2015. Web. 19 July 2015.

The Equipment



The Equipment: Build Platform

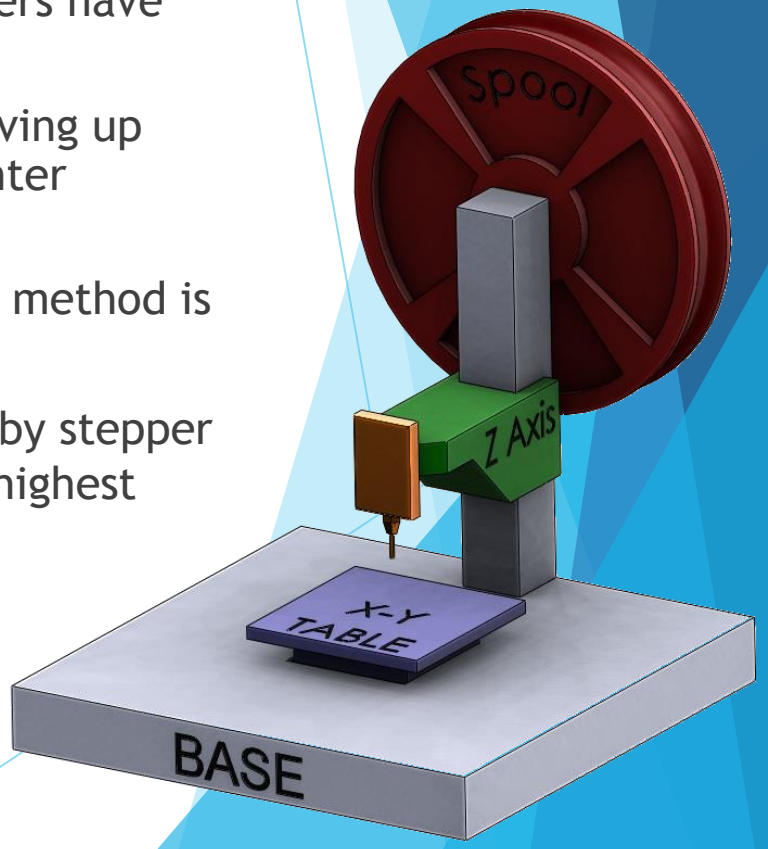
- Whether it be a DIY or high-end production 3D printer, all 3D printers share some basic components as shown in the diagram to the right.
- 3D printing necessitates that the object adhere to a build platform without sticking too much.
- 3D printers all have a build platform that may or may not be heated to assist some materials to adhere to the surface. ABS requires a heated build platform to print.
- Glass makes a good platform, but filaments don't stick well to them without modifying the surface. Caption sheets are an excellent surface for filaments, but are expensive and fragile. Blue-painters tape is a good, low-cost alternative that’s readily available.
- Alternatives methods to allow the filament to stick to the build table include covering the glass surface in hairspray or Elmer's glue and letting it dry.

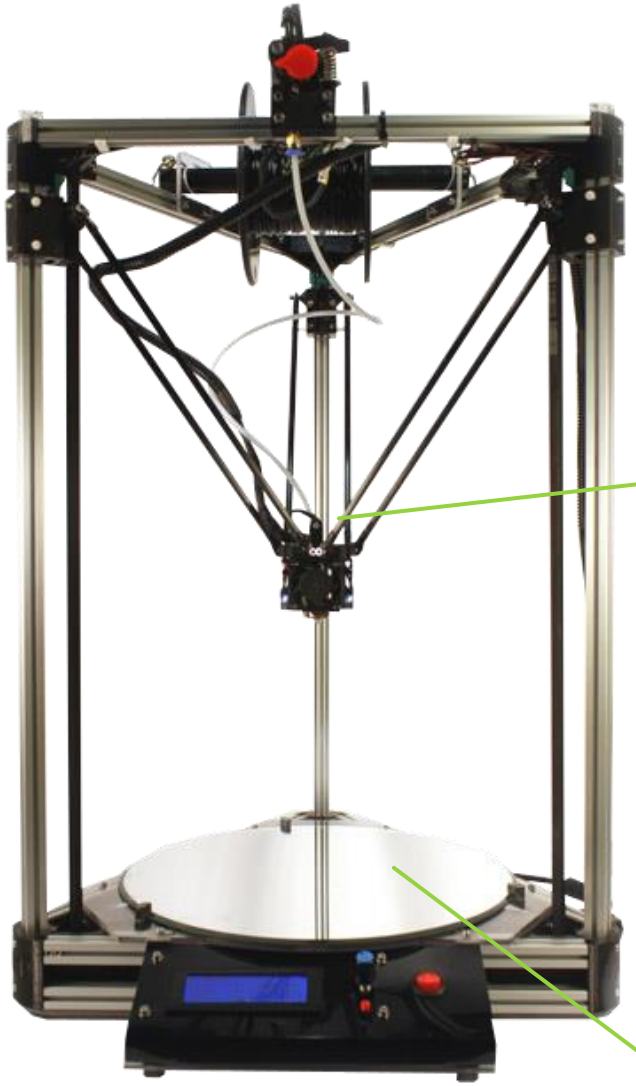


Build Platform

The Equipment:
Vertical and Horizontal Movement

- X-Y movement on some printers is controlled by an X-Y table below or an X-Y gantry above that carries the extruder assembly. The MakerBot and delta 3D-printers have the latter.
- Vertical movement is controlled on some printers by the build platform moving up and down to set the Z-layer height (ex: MakerBot) and in others the 3D printer mounts the extruder on a Z-axis that travels on the gantry (ex: delta).
- Both methods have merits, with 3D printer designers each advertising their method is best.
- X, Y and Z axes are all driven by some form of servo, or (more commonly) by stepper motors. The smallest distance that the motor can move in each axis is the highest resolution of the printer.
- Normally the resolution is listed in the hundreds of microns in advertisements.





Autotroph Delta

The X-Y axes on the MakerBot is controlled by an overhead gantry.

The X, Y, and Z axes on the Autotroph are controlled by the overhead gantry.

The build platform raises and lowers, controlling the z-height of each layer

The build platform of the Autotroph is fixed at the bottom.

The MakerBot 5th Gen. Replicator

Printing Resolutions

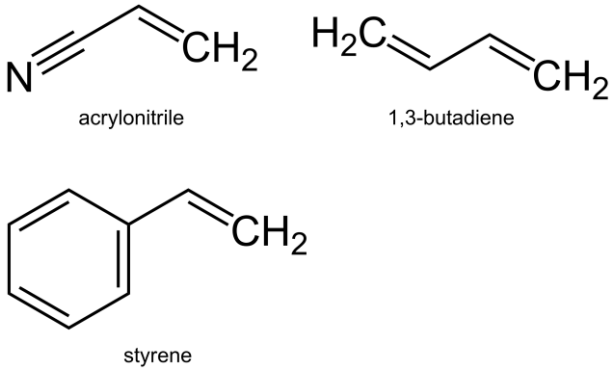
- The use of the word “micron” makes it sound incredibly accurate in advertisements.
- 1 micron is 1 millionth of a meter, so 100 microns are 1 ten-thousandth of a meter, or 1/10th of a millimeter.
- A millimeter is 0.039 inches, so a tenth of a millimeter is 0.004 inches.
- Printing 3D-parts with the highest resolutions requires more slices so the parts are higher quality, but the build times are much longer.

Common 3D Printer Resolutions		
in microns	in mm	in inches
100	0.10	0.004
150	0.15	0.006
200	0.20	0.008
300	0.30	0.012

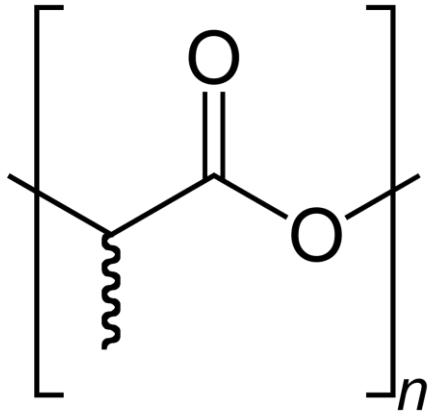
Material

Materials: ABS and PLA

- Current 3D printers use a filament of material that looks a lot like colorful weed-eater cutting line.
- The most common materials are Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA).



Acrylonitrile Butadiene Styrene (ABS) monomers

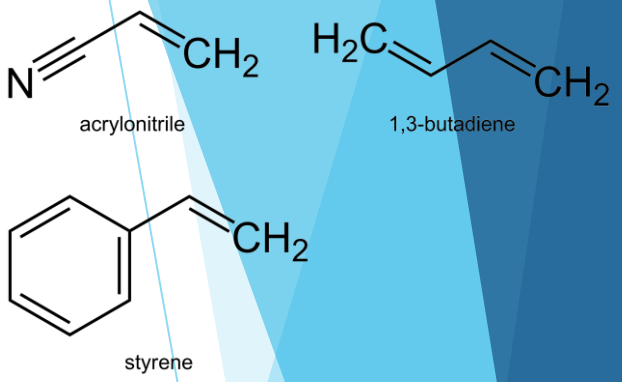


Polylactic Acid (PLA)

Interestingly enough, you can print using nylon weed-eater line as filament. But it isn't recommended due to its sometimes toxic nature.

Materials:
Acrylonitrile Butadiene Styrene (ABS)

- Introduced in 1948, ABS is a common thermoplastic polymer.[1]
- ABS is from a family of thermoplastic polymers called terpolymers.[1]
- Terpolymers are composed of three different monomers, in this case: acrylonitrile, butadiene and styrene, that creates a material that draws on properties of all three.[1]
- According to the SPI, Society of the Plastics Industry, ABS is characterized by having, *"outstanding impact strength and high mechanical strength which makes it suitable for use in tough consumer and industrial products, including: appliances, automotive parts, pipe, business machines and telephone components."*[1]
- ABS is also a common substrate used for metallizing plastic, and can be found in bathroom faucets, automotive trim and grills, door handles, and trophies.[1]
- It is also has a good shock absorbency, finding uses in helmets, car bumpers, golf club handles, and in certain whitewater canoes made of Royalex®.[2,3]



Acrylonitrile Butadiene Styrene (ABS) monomers

ABS canoe on the Upper Magnetawan River.[4]

1. "SPI - About Plastics - Definitions of Resins - Acrylonitrile-Butadiene-Styrene (ABS)." N.p., n.d. Web. 19 July 2015.
2. "ABS - Acrylonitrile Butadiene Styrene." *Design inSite*. N.p., n.d. Web. 19 July 2015.
3. "Canoe Materials | CANOEING.COM Canoe Guide." *The Ultimate Guide Canoeing.com*. N.p., n.d. Web. 19 July 2015.
4. Robertson, D. Gordon E. "File:ABS Canoe on Upper Magnetawan River.jpg - Wikimedia Commons." N.p., 15 July 2007. Web. 19 July 2015.

Materials:
Acrylonitrile Butadiene Styrene (ABS)

Metallized car parts.[2]

Plastic faucet made from metallized ABS.

Everybody's favorite childhood toy, LEGOS, are made from ABS.[1]

Parts that are commonly metallized on a car are shown in red.[2]

Sturdy and impact resistant, helmets made with ABS help prevent brain injury.[1]

What's made of ABS? Why a spork, of course.[1]

1. Bell Plastics. "Top 5 Coolest Things Made out of ABS | Bell Plastics." *Bell Plastics*. N.p., 19 Dec. 2013. Web. 19 July 2015.

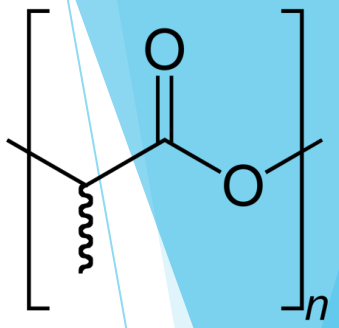
2. "Plastic Metallisation, ePD Embedded PVD for Design Parts, PVD Coating « Oerlikon Balzers." *Oerlikon balzers*. N.p., n.d. Web. 19 July 2015.

As a 3D Printing Material:
Acrylonitrile Butadiene Styrene (ABS)

- ABS is toxic, and you must be in a well ventilated area to safely print.
- Despite its toxicity during fabrication, ABS is a very common engineering material because it is easily injection molded and extruded (hence its use in 3D printers), and is inexpensive.
- ABS makes up a lot of plastic covers for office equipment. MakerBot's 5th gen plastic enclosure is ABS.
- If you use ABS in a 3D printer, you may need a heated platform to keep the parts from warping.
- It is very recyclable but NOT bio-degradable so it is not considered a "green" material.
- ABS also has the advantage of being able to "smoothed" in acetone vapor, which helps give the part a finished look.

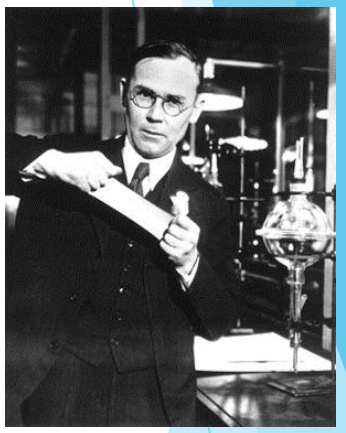
The MakerBot's external enclosure is made of ABS.

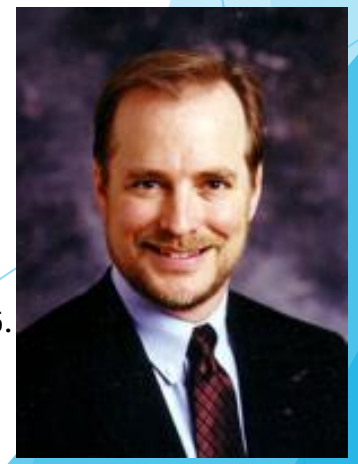
Materials:
Polylactic Acid (PLA)



Polylactic Acid (PLA)

- Polylactic Acid (PLA) is a biodegradable thermoplastic that was invented in the 1920's by Wallace Carothers at DuPont while working to find an environmentally friendly plastic.[1]
- PLA was too costly to commercially produce at the time, and so it never caught on in the plastic industry.[1]
- In 1989, Dr. Patrick R. Gruber and his wife Sally, discovered a commercially viable process to produce PLA from corn on his kitchen stove. He currently holds 48 US patents related to the production of PLA.[2]
- PLA can be created from processing any number of plants including corn, potatoes or sugar beets.[3]
- Characteristics of PLA include: naturally transparent, can be colored with various degrees of translucency and opacity. It's stronger than ABS, but is brittle and has a lower impact capacity.[1]
- At high temperatures, it can depolymerize in the presence of water.[4]
- It its pure form, it is 100% recyclable.
- Research is underway to impregnate PLA food containers with antioxidants that will then pass them on to food.[4]


Wallace Hume Carothers, famous organic chemist and inventor working at DuPont. He's also famous for the invention of Nylon.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1. "Polylactic Acid (PLA) Plastic | WhiteClouds." *Whiteclouds*. N.p., n.d. Web. 20 July 2015.
2. "Minnesota Inventors Hall of Fame - Dr. Patrick R. Gruber - 2003 Inductee." *MinnesotaInventors.org*. N.p., n.d. Web. 20 July 2015.
3. Chilson, Luke. "The Difference Between ABS and PLA for 3D Printing." *ProtoParadigm*. N.p., 26 Jan. 2013. Web. 20 July 2015.
4. Jamshidian, Majid. "Poly-Lactic Acid: Production, Applications, Nanocomposites, and Release Studies - Jamshidian - 2010 - Comprehensive Reviews in Food Science and Food Safety - Wiley Online Library." *Comprehensive Reviews in Food Science and Food Safety* 9.5 (2010): 552–571. Web. 20 July 2015.

Materials:

Polylactic Acid (PLA)

- Polylactic Acid is still finding its niche in commercial applications.
- It has been used as food packaging containers, consumer displays and electronics packaging, disposable cold drink cups, lamination film, die cut labels, tapes, bottles for milk, food oils, bottled water, apparel, wipes and hygiene products, automotive door liners, blankets, industrial carpets and pillows.[2]

1. "PLA Plastic." *UPPI: Universal Protective Packaging*. N.p., n.d. Web. 20 July 2015.

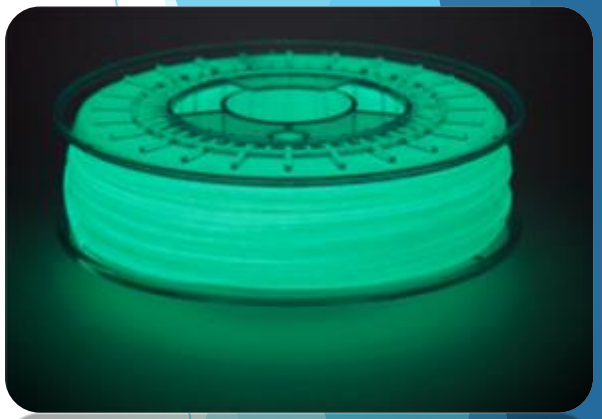
2. Jamshidian, Majid. "Poly-Lactic Acid: Production, Applications, Nanocomposites, and Release Studies - Jamshidian - 2010 - Comprehensive Reviews in Food Science and Food Safety - Wiley Online Library." *Comprehensive Reviews in Food Science and Food Safety* 9.5 (2010): 552–571. Web. 20 July 2015.

As a 3D Printing Material: Polylactic Acid (PLA)

- PLA is derived from corn. In fact, running PLA in a 3D printer without ventilation will occasionally give off the spell of waffles.
- PLA does not require a heated platform, although it has been known to help.
- PLA is hydrophilic, and thus has the drawback that the filament absorbs water out of the atmosphere and degrades its ability to extrude. Thus, unused spools need to be kept sealed in bags with desiccant.
- You might want to invest in some thick industrial press to close Ziplock© bags like those available from McMaster-Carr (prt #: 14545T27), and desiccant (prt # 2189K16) .
- PLA is a truly “green” material, being readily degradable by microorganisms present in the environment, and can even be composted (at industrial composters).
- ABS and PLA are comparable in strength so it really comes down to what your extruder nozzle and temperature controller will support.

Filament

- After selecting your material, you must then select your filament size.
- Filament comes in 1.75mm and 3mm diameters.
- Nozzle size will dictate what diameter of filament you can use.
- Your final decision comes down to color, and at that point the sky is the limit. You can have any color you can imagine. Solid colors, translucent colors, glow in the dark colors, PLA composite.
- Changing colors doesn't use a lot of filament so it's possible to change colors between every part if required.
- Some printers use two or more extruders, so you can print in multiple colors, or use a dissolvable support material that we will discuss later.



Software

SOLIDWORKS

cura.

Slic3r
G-code generator

RepRap

MakerBot

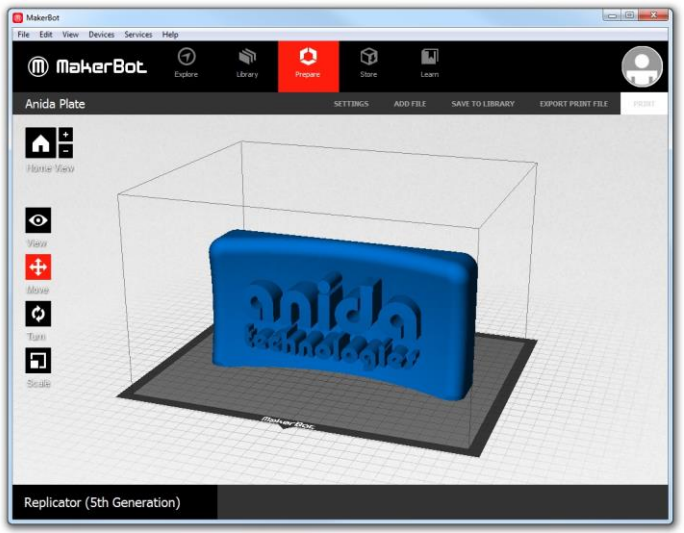
Software

- There are 3 pieces of software that you need to make a 3D print.
- The first piece of software you need is your 3D CAD software to create the models to print, such as SolidWorks, AutoCAD or other CAD programs. After creating the part you will then need to export it as a .STL file in order to 3D print.
- Alternatively, you can use a model that someone else has already created. There are several 3D printing model sites, such as Thingiverse.com.
- The next you need a “slicer” program which resides in your computer and converts the 3D model you want to print into actions the 3D printer can act upon.
- The last software you need is the printer controller and is usually called the “firmware” in that it normally resides in the 3D printer hardware.
- The controller firmware and the 3D CAD program don’t require a lot of explanation, but the slicer program is something new just for 3D printers.

Software:

Slicer

- There are a dozen or more slicing programs including MakerBot's latest slicer program called "MakerBot Desktop" and a free open source program known as "Slic3R".
- Slicer programs load a 3D model, usually in a neutral 3D file format like .STL, which are the same file types used to create stereo lithography rapid prototype machines.
- Slicer programs then convert the 3D models and create instructions for the printer. Ironically, the printer instructions are almost always regular G-Code just like the code sent to your CNC mill, but instead of tool changes and spindle controls, the program turns on and off the extruder.
- Most of the slicer programs recognize that the printer does not have to print all of the interior material for most parts, and allows for a "honeycomb" or other internal feature that connects the surfaces, speeds up the build time, and saves material.

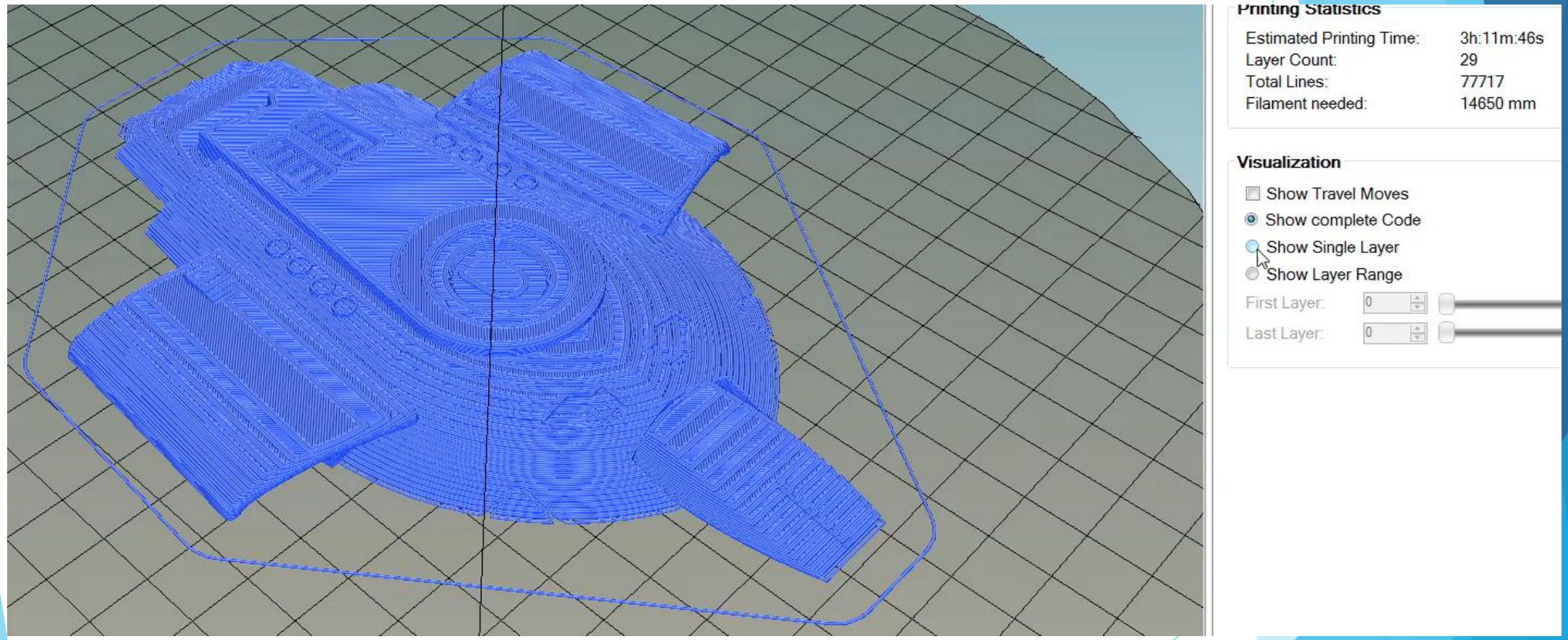


Software: Slicer

- A sample part, shown to the right, was stopped in the middle of printing to show the honeycomb interior.
- Features available in some slicer programs allow for things like moving the location and orientation of the model on the platform.
- Even more advanced tools give the option of the addition of features that facilitate printing a 3D object, such as supports, to allow overhangs to build correctly.

The honeycomb interior provides the part will strength and rigidity, but allows the part to be printed with minimal use of filament.

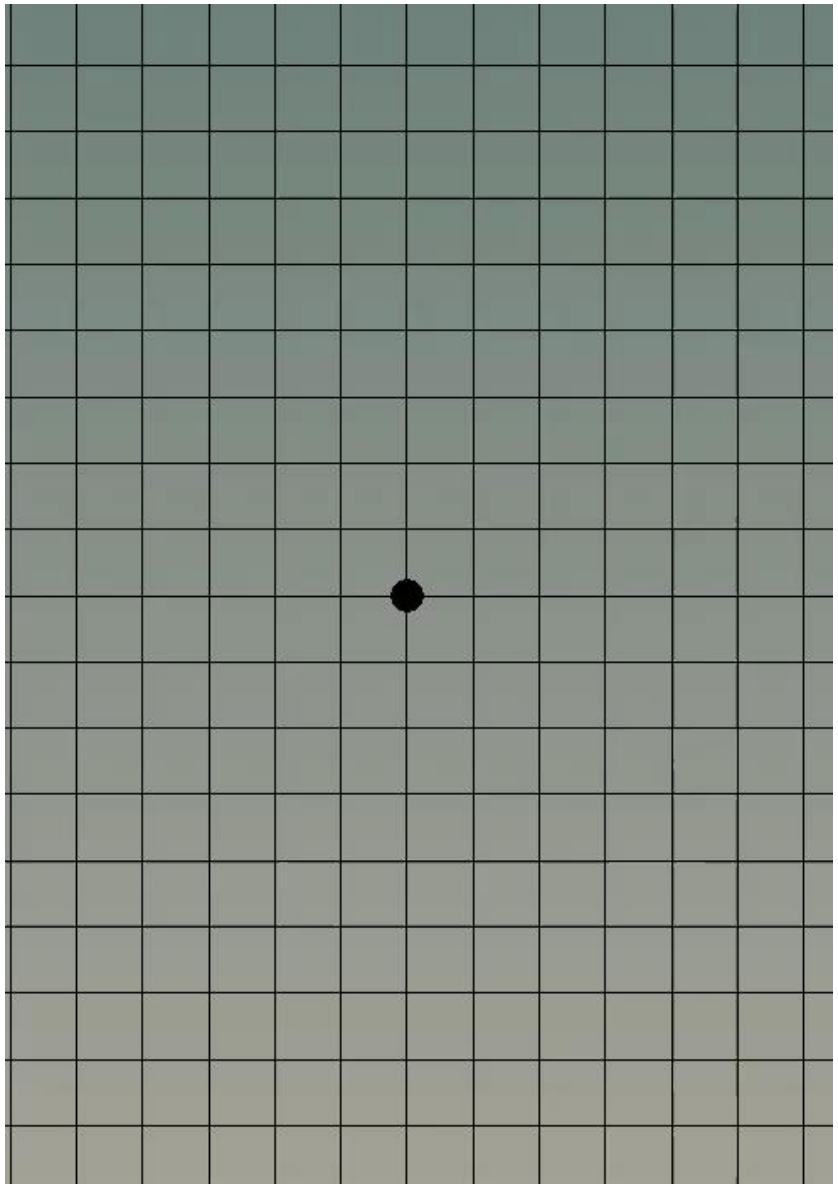
The Slicer in Action

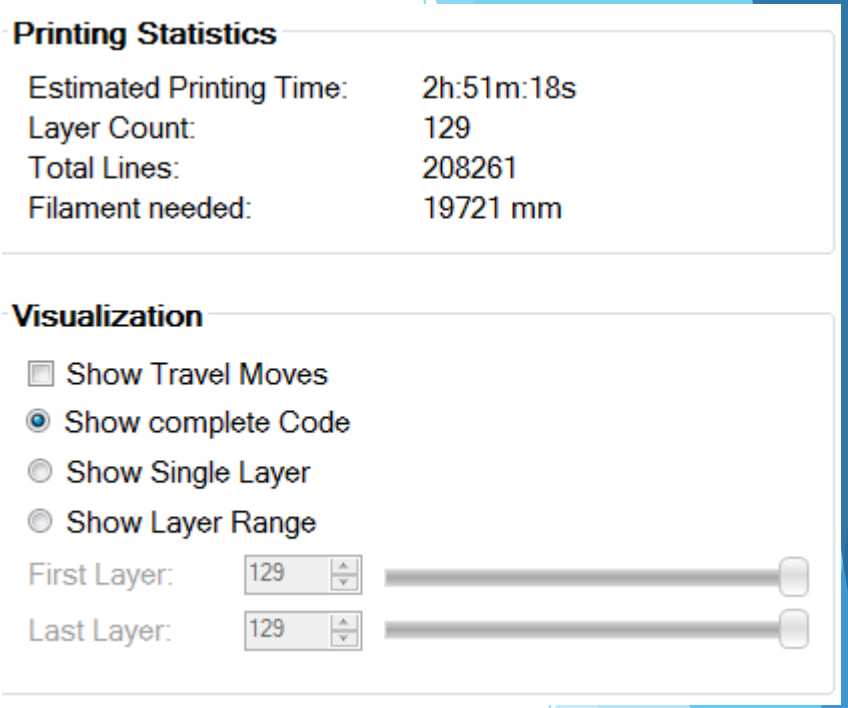


Captured on Repetier-Host using Slic3r to create the sections.

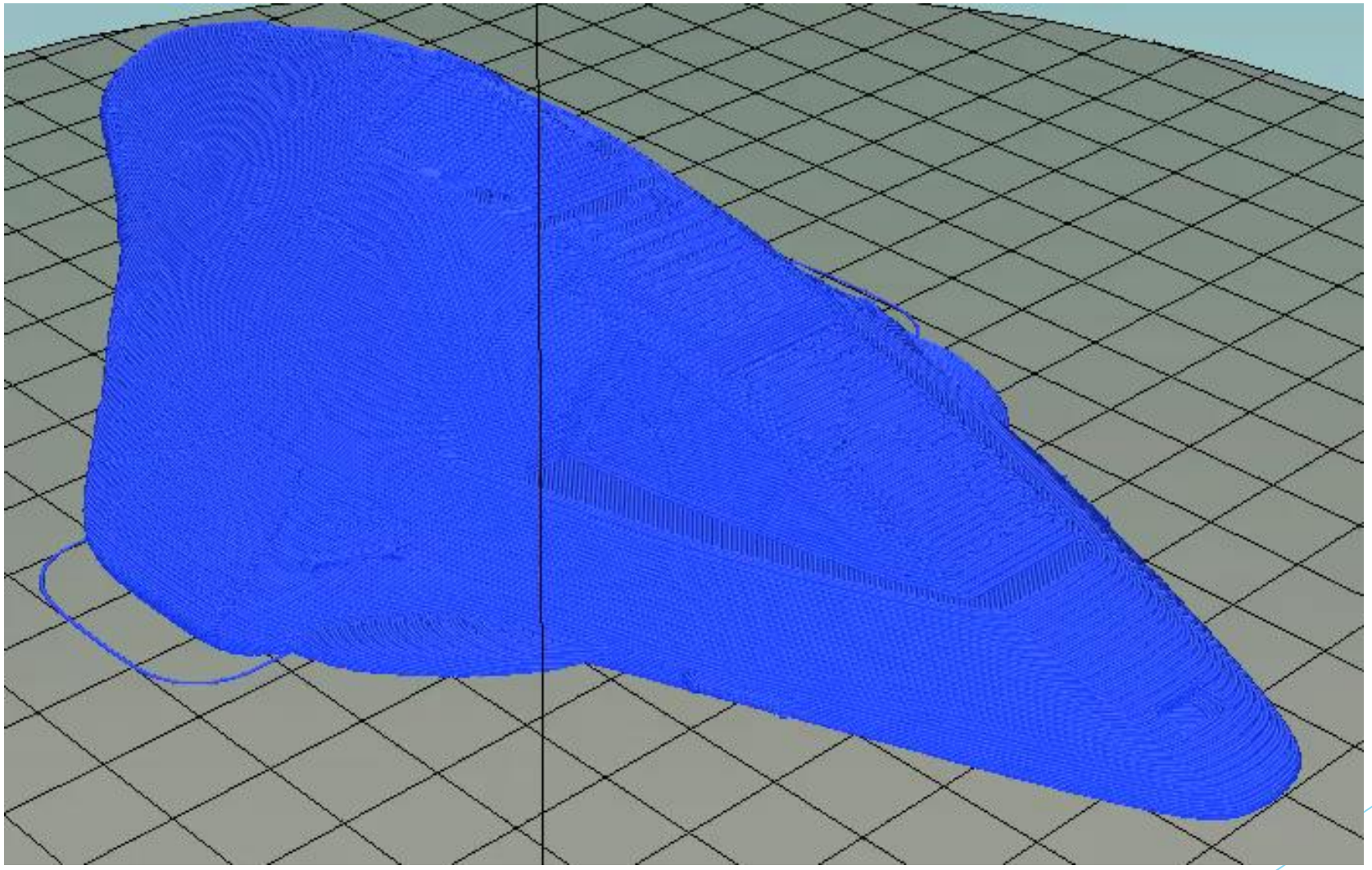
Here is another example of a “part” being put through the slicer.

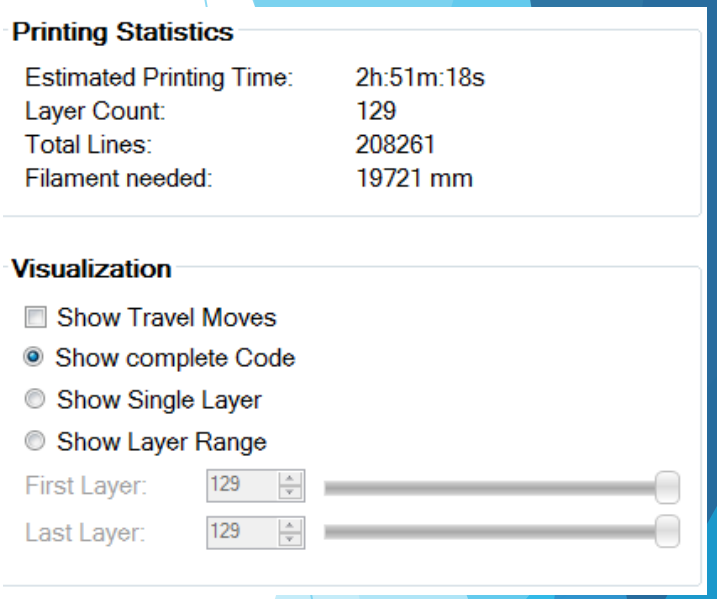
Captured on Repetier-Host using Slic3r to create the sections.





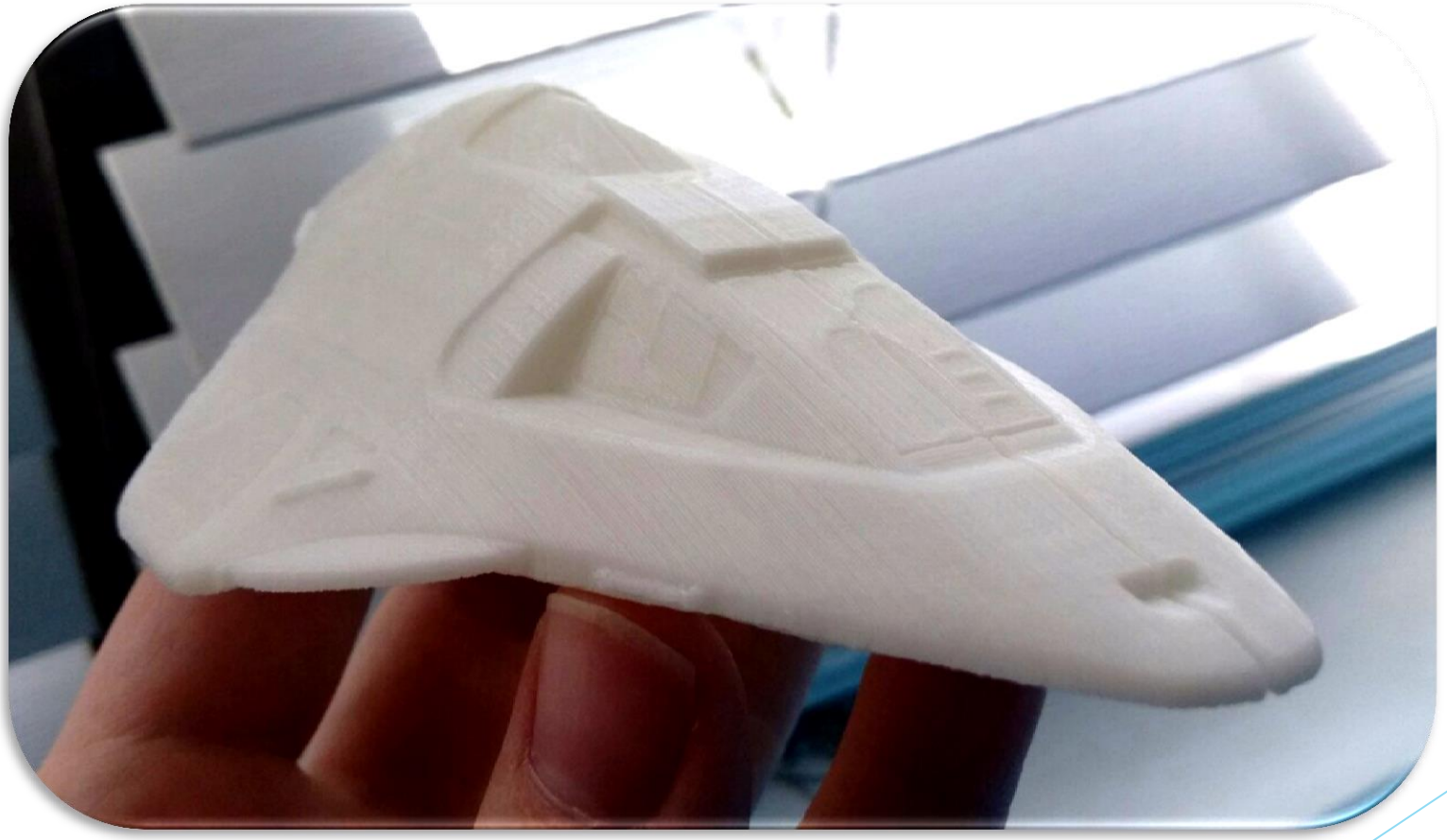
The Slicer in Action





Same “part” as before, but from a different perspective.

Ok, Sci-Fi fans, it’s time to play: name that ship and the show it comes from… and go!



If you said the Delta Flyer from ST: Voyager, you're correct!

STAR TREK VOYAGER

<Insert comment about how Voyager was the worst show in the Star Trek franchise here.>

Process

First, let’s make some assumptions:

- Let’s assume that you have already acquired and set up you 3D printer according to whatever instructions came with the printer.
- Let’s also assume that you have already loaded the filament color you wish to use for the parts.
- While we are assuming, we’ll also assume the platform has been cleared of any previous prints and you put down painter’s tape or a caption tape.

Step 1: Determine what you want to print.

- You can create your own 3D model using CAD software, or you can search the internet for models that others have created and are willing to share for free or a small fee.
- The only thing that you shouldn’t print are working guns or suppressors, especially suppressors… While American citizens do have the right to make their own firearms, 3D printed firearms are a complex legal issue that the federal government is actively working to regulate. It’s best to safely avoid it.

Joel Thompson | Google

https://www.google.com

Apps | Send A Gun To Defe... | SMITH&WESSON S... | Email access | ABET - Engineering ... | DHS employee spen... | Handloading Cost C... | Other bookmarks

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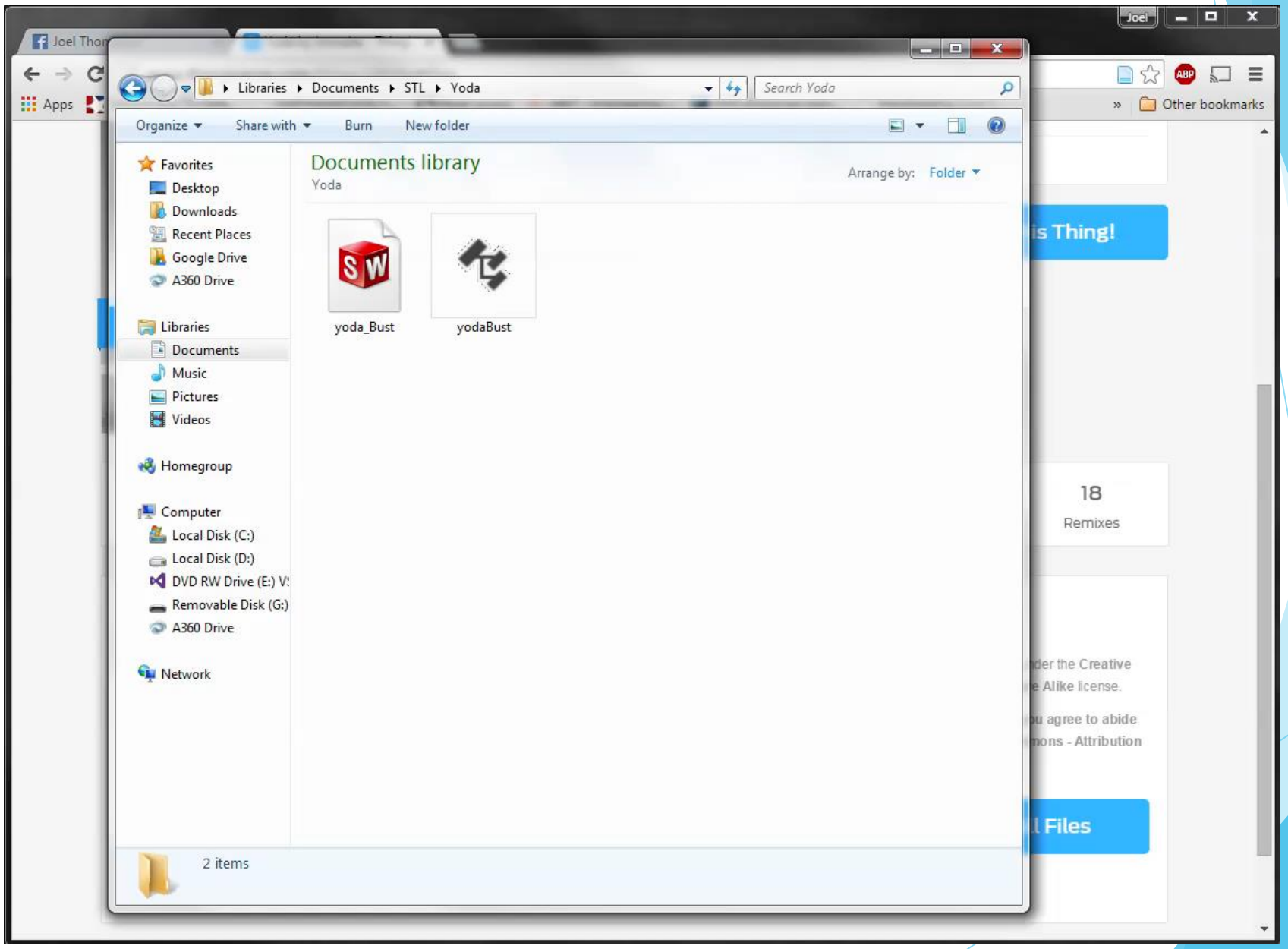
Step 2: Send the .STL file to the slicer

- Depending upon your slicer program you may be able or require to move, rotate, and scale your model.
- You will set the resolution and other parameters and create the printing instructions.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Search Yoda
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Burn
New folder
Documents library
Yoda
Arrange by: Folder
Favorites
Desktop
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Recent Places
Google Drive
A360 Drive
Libraries
Documents
Music
Pictures
Videos
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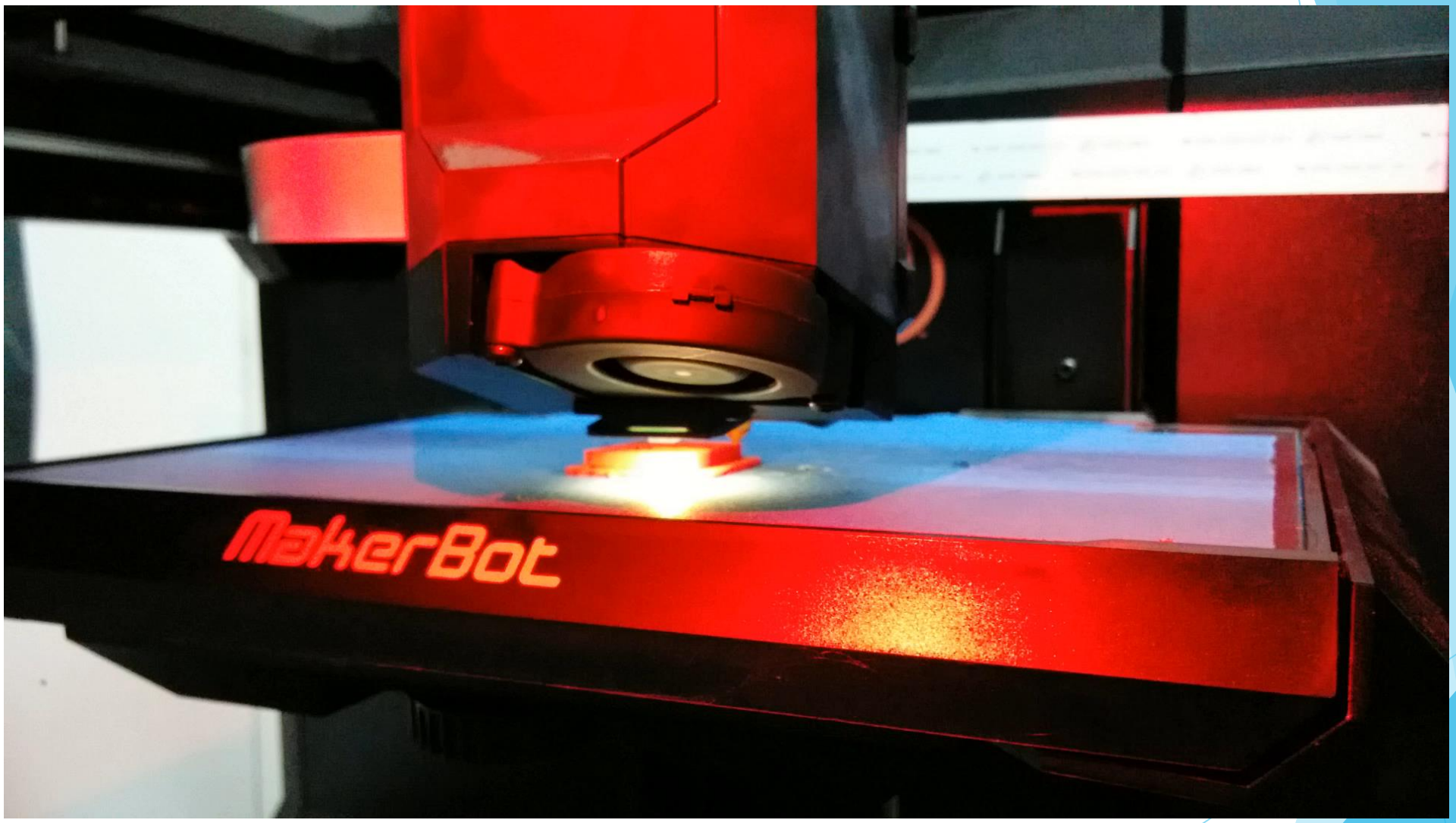
DVD RW Drive (E:) V:
Removable Disk (G:)
A360 Drive
Network
yoda_Bust
yodaBust
2 items
Apps
Other bookmarks
18
Remixes

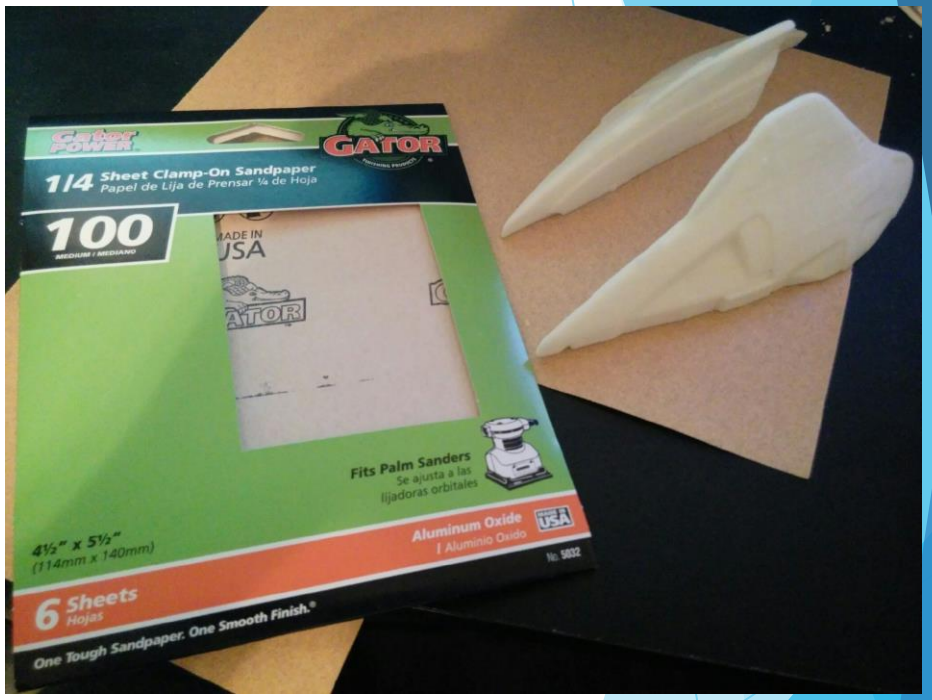
Step 3: Print your model.

- Print time will vary from 30 minutes to 10 hours depending on your settings.
- There is a saying about a watched pot that never boils, and it certainly applies to 3D printers.
- It’s fun to watch it print and check on the progress, but each layer is very thin and seems to take forever.


MakerBot

Step 4: Clean-up your model

- This is where the artistic and detail oriented among us will excel.
- A sharp knife edge, sandpaper, and some patience will clean up most parts.
- I have discovered that it is occasionally better to divide a part, print them separately, and then glue them together, but more on that in the next section.
- Both ABS and PLA can be painted if need but normally you want to use the color of filament you desire for the finished part as the base.



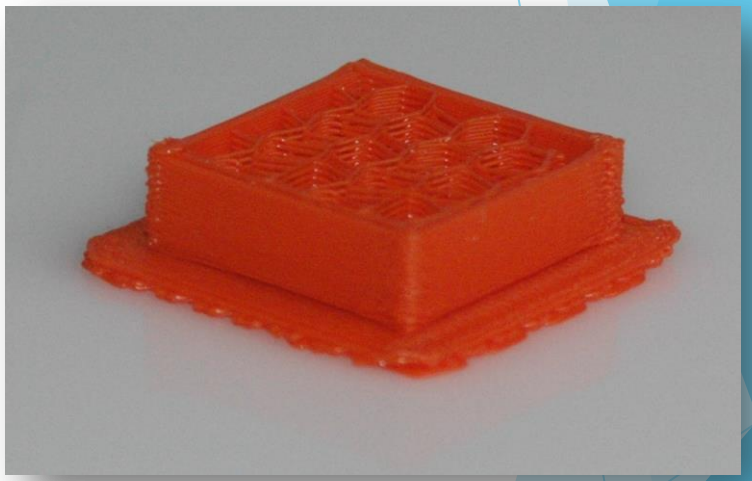
The Delta Flyer was printed in 2 pieces to allow the model to be printed without supports. It will then be sanded down by hand, glued together, and painted.

Art

- Like so many things in our prototype shop, nothing is easy.
- The 3D printer can do amazing things, but it has it’s limitations.
- Imagine wanting to make a paint stencil with your inkjet printer. No matter what data you send to the inkjet printer, the sheet of paper will always be whole and you will have to go back and cut out the lettering.
- An inkjet printer can print a lot of images, but it can’t print holes in the paper.
- In the same way, 3D printers can get you close to many designs with a few workarounds.
- Here are some areas of concern when you are first building a new part.

Art: Rafts

- We've already discussed that printing directly onto the build platform may not stick or may warp, so you may want to look for options of heating you build platform and/or creating a disposable sheet of plastic to build your part upon.
  - This plastic sheet is called a "raft", "base" or "platform".



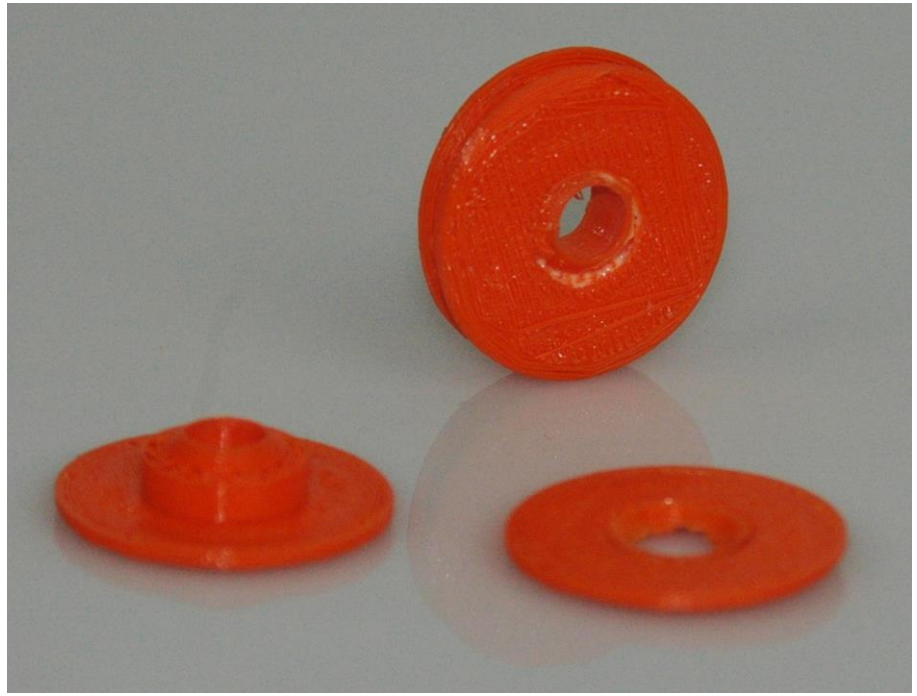
Rafts, such as the one in this picture, help prevent the part from delaminating from the build platform. When you are done, just pop off the raft and you're done.

Art: Printing cantilevered surfaces.

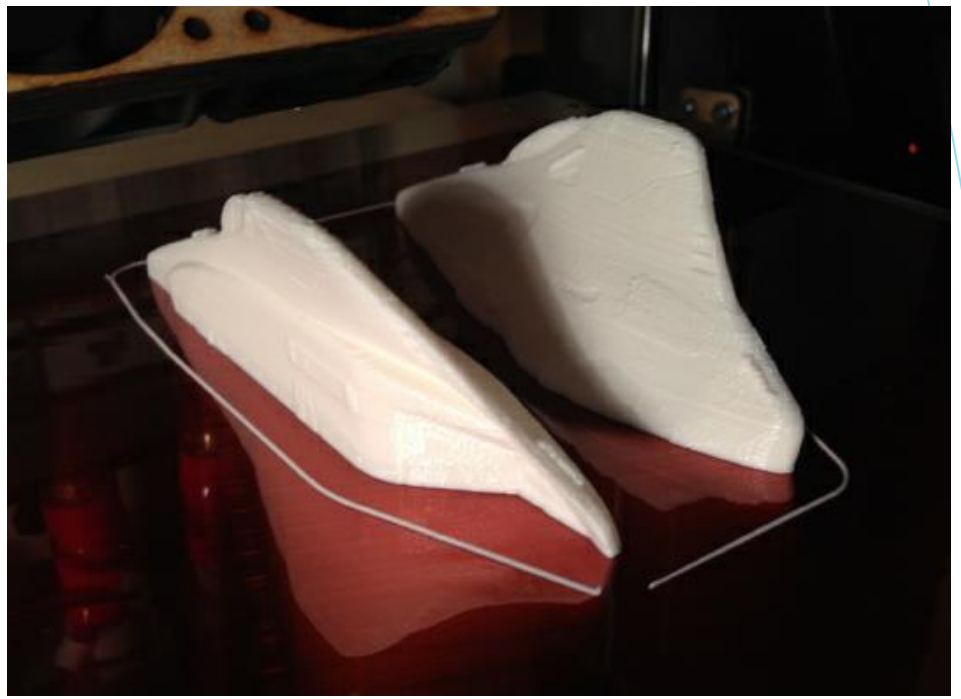
- As long as you can print a solid piece of material with no voids, each layer has something below it to build upon.
- As long as you limit yourself to printing cubes and miniature Washington Memorials, you have no problem.
- With proper orientating on the build platform, you can print more complicated shapes and still have each build layer supported.
- Some shapes just can't be oriented without having a cantilevered surface.
- When this happens you have two options:
  - One is to have the slicer program add supports (using support material) that can be easily removed after the print is complete. (Having dual extruders and dissolvable support filament is highly recommended.)
  - Or two, use your 3D design program and break the part into simpler structures that can be printed separately and then reassembled with some adhesive.
    - Both PLA and ABS can easily be glued together with cyanoacrylate (superglue), simple wood glue, or hot glue.

Perhaps the easiest 3D printed shape ever.

Art: Printing cantilevered surfaces.

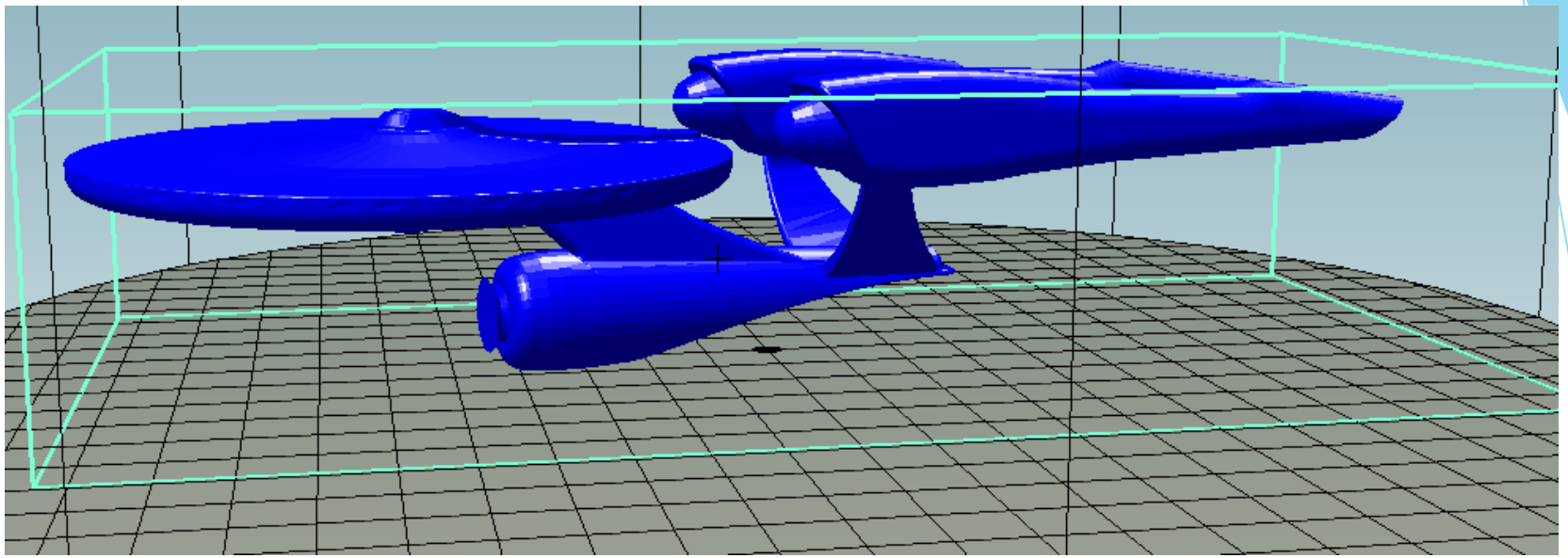


Double flanged pulleys are prime examples of simple parts that can't be printed without separation of the parts or adding supports.

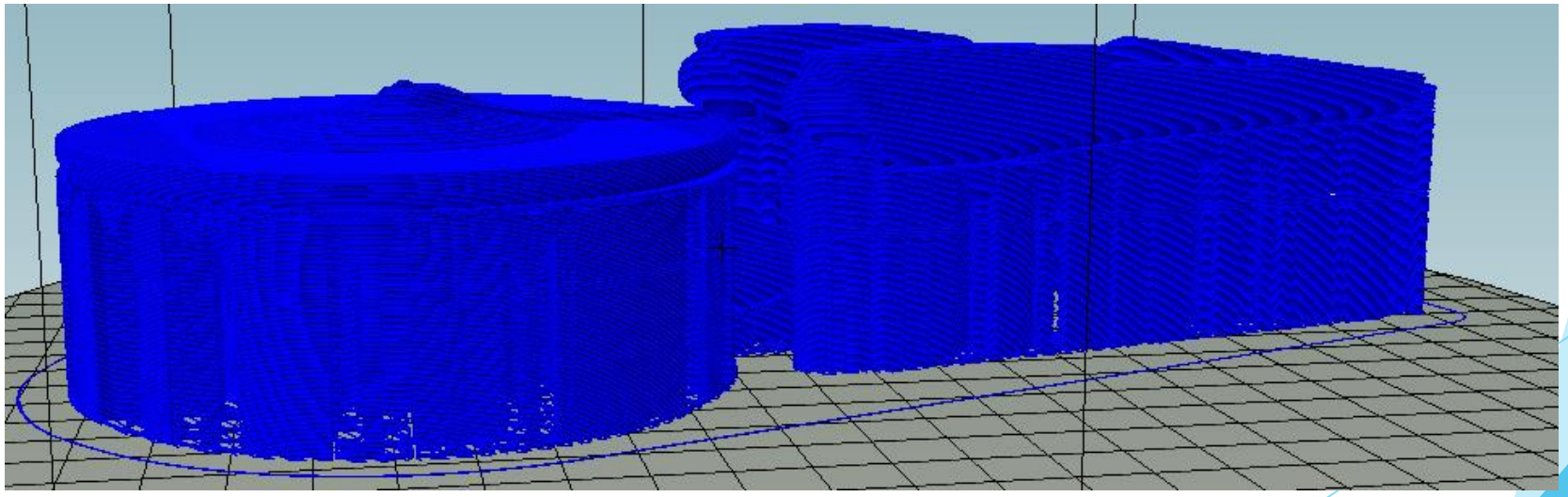


The Delta Flyer could not be printed in a single piece without support material because of it's cantilevered surfaces.


Raft / No Supports
Raft & Supports
Supports Removed



J.J. Abrams' 2009 Enterprise shown with extreme cantilevered surfaces. Also, if you haven't guessed, I like Star Trek.



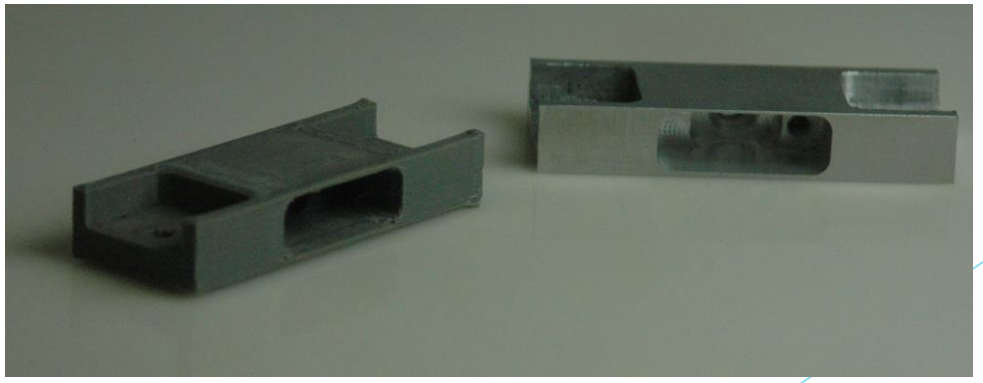
The same model, but sliced with support material. It is highly recommended that if you use supports that you also have a dual extruder with dissolvable filaments, otherwise, you'll have a bad time cleaning your model.

Practice

- When the MakerBot was first unpacked, I printed several sample parts from files shipped with the printer.
- These parts were a little more artistic than my typical machined parts but they showed some interesting capabilities.
- We’ve tried printing with different filaments and settings as we printed each part to learn even more of the printer capabilities.
- While printing 20 example parts, we had a new design pop up for an aluminum bar from with an unusual pocket.
- We sent the model of the aluminum bar to the printer as we started to program the pocket cuts and planning the three setups for the CNC mill.
- Two hours later, we had the program ready to machine, and at the same time the 3D print was complete.

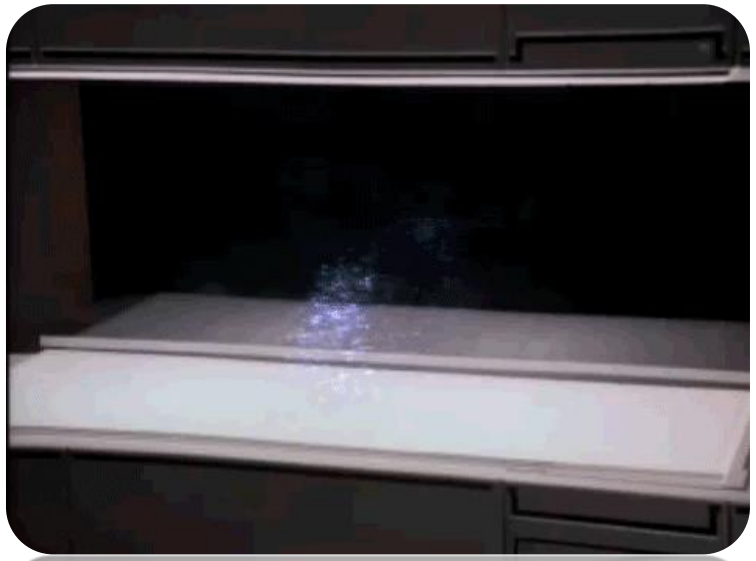
Practice

- We assembled the parts into the plastic printed part and discovered several design flaws that were quickly fixed.
- We reprogrammed the CNC and produced a nearly perfect part for the client.
- Since that time, the scenario of printing a part before cutting it has repeated several times – each time, the printed part has shown some small (and in one case, a large) improvement that could be implemented before metal was cut.



Conclusion:

- We are not quite up to the Star Trek replicator speed (I had to work in another Star Trek reference), but every time I take a custom designed part and hold it in my hands only a few hours after designing it in CAD software, I do feel like we are truly living in the future.
- Hopefully your prototyping future includes a 3D printer as well!



Cheers!