3D Printing Concepts

James R. Mireles

10 September 2014

Topics

- Three Prominent Technologies
  - Extrusion ("Fused Deposition Modeling")
  - Laser Sintering ("Selective Laser Sintering")
  - Polymer Jet
- Other Developments in the Field
  - Medical and Other Applications and Technologies
  - Software, Technical and Legal Developments
- 3D Printing at NASA – Made In Space, Rocket Engine Parts
- Tips and Tricks
  - CAD Pointers
  - Printing Pointers for Extrusion Printing
- 3D Printers at JSC
- Show-and-Tell!

Presenter's Caveat(s)

- I know just enough 3D printing to be dangerous
- Technology evolving rapidly
- This presentation is out-of-date tomorrow
  - Learned of a new ceramics printer last week.
  - Learned of a new inexpensive polymer jet printer this week.
  - Learned of a new UV-resistant plastic this week.

Technology – Extrusion

Technology – Extrusion

- Popular types of plastic (ABS, PLA)
  - Other types
- The Ultimaker and the MakerBot
- Now ceramics, too
- Made In Space – 3D printing on orbit

Plastics

ABS

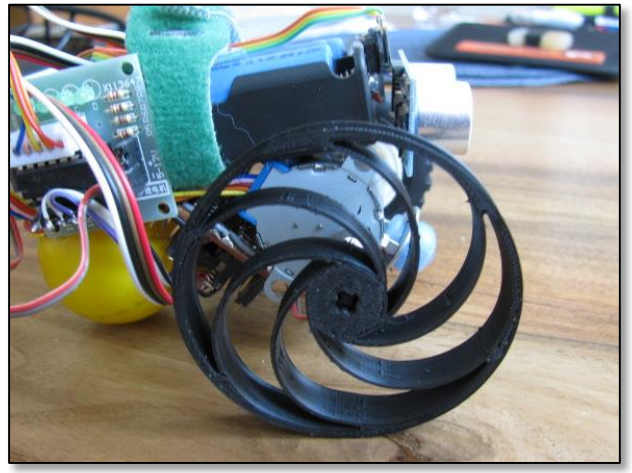
- Prints hotter
  - ~230° - 300° C.
- More prone to shrinkage
  - Best to cool slowly
- Requires support—"rafting"
- High impact resistance
- High strength
  - Used with Legoes
- Degrades in sunlight

PLA (SPI resin code 7)

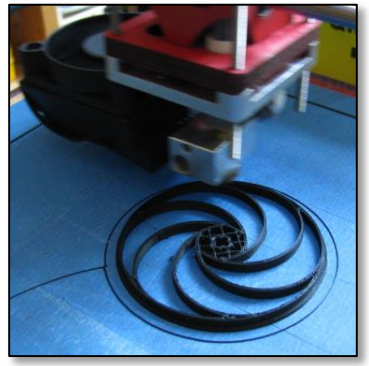
- Prints (slightly) cooler
  - ~210° C.
- Less prone to shrinkage
  - Best to cool quickly
- Usually requires no support
- More brittle
- Biodegradable—Used in implantable medical devices.

Flexible PLA*

- Softer material – Can grind down
  - Slower printing speeds – 20mm/sec
  - Disable retraction on the Ultimaker (the pullback action that manages feed rate)



- Bonding between layers requires tuning
  - Prints hotter than standard PLA – ~220° C.
  - Thinner layers - ~0.1mm height



*Source: Ultimaker.com, http://blog.ultimaker.com/cura-user-manual-flexible-pla/
Model: http://umforum.ultimaker.com/index.php?/gallery/image/1095-flexible-pla-suspension-wheel/

PVA Plastic (Polyvinyl Alcohol)*

- Dissolves in water
- Provides integrated build supports and rafts
  - Use with dual extrusion
- Extrudes cooler - ~190° C.
- Must be stored carefully
  - Absorbs ambient moisture easily
  - Freezer bags are good
- More expensive (~2x cost of ABS and PLA)

*Source: 3DPrintingForBeginners.com, http://3dprintingforbeginners.com/filamentprimer/

Technology – Laser Sintering

Technology – Laser Sintering

- Lay a sheet of powdered feedstock
- Laser fuse that layer's pattern
- Repeat until finished.
  - Does not require support
- Remove the finished part and clean
  - Dust off the unfused powder, cake.
- Plastic, metal, glass, ceramic

Technology – Polymer Jet

Technology – Polymer Jet

- Liquid photopolymer jet sprayed simultaneously with wax or other removable support material sprayed in the voids for support
  - UV light cures the plastic with each layer printed
- Prints as thin as 29 microns (usually 32 µ)
- After print, the wax or other support is melted or drained out

Other 3D Printing Developments

Other Technology Developments

- Large Format 3D Printers becoming common
  - Gigabot - 24”x24”x24”, Objet1000 - 39.3”x31.4”x19.6”
  - Ceramics printer by Olivier van Herpt – 31” tall x 16.5” sq.
  - NY man 3D printing a 2400 SF house.
- High-end printers becoming approachable
  - Polymer Jetting 3D Printer for Under $2K by UK inventor

Medical Technology Applications

- Prosthetics, exoskeletons, casts in various materials
- Scaffolding for living cells to re-grow an organ
- Bone replacement
  - 2014: S. Africa Cancer Patients - 3D Printed Titanium Jaw Implants
  - 2012: Netherlands – 83-Year Old Woman, Titanium Jaw
- Airway (bronchus) splint SLS printed in 2011
  - Kaiba Gionfriddo – Saved by 3D printed airway tube
  - Used laser sintering of PCL biodegradable plastic
- Man 3D Prints His Own Tumor - Before and After

Software and File Developments

- STL format becoming the de facto standard for extrusion 3D Printing
  - Interchangeable among printers
  - Repositories of ready parts available – Thingiverse
- 3D print services that will print and ship to you.
- Windows 8.1 3D Printing API
  - Native 3D printer support – File | Print
  - 3D Manufacturing Format (3MF) – XML-based data
  - Plug-and-play – Printer makers write their drivers.

Legal Developments

- Patent expirations open the market
  - Expiration of Fused Deposition Modeling (extrusion) patents brought prices down and grew the market.
  - Laser Sintering patent #US5597589 expired in January 2014.
- Copyright, patent protection and legal issues
  - Piracy concerns similar to music/video/software copying
  - Printing hazardous objects such as guns
  - The legal environment is maturing with the technology

3D Printing at NASA

3D Printing on ISS – 2014

- Additive Manufacturing Technology Demonstration (AMTD)
- ABS plastic, extrusion printing
- Objective: Compare microgravity printing with Earth-based
  - Parabolic flights are too short
- Objective: Advance the TRL
- Objective: Develop the ability to fabricate parts on orbit
- Files delivered on board the printer. None uplinked.
- First prints: Small enough to print in 30 minutes
- 25 – 30 prints before astronauts replace feedstock filament
- Easy swap-out of extruder by astronauts if needed

Made in Space

MADE IN SPACE
Additive Manufacturing for Space

- 2011 - Awarded NASA Phase 1 SBIR Contract to deliver 3D printer to the ISS
- Fall 2011 and June 2013 – Tested at Ellington and JSC
  - 1 in-house and 2 COTS printers (incl. MakerBot)
- Fall 2013: At TRL 5. "*Component and/or breadboard validation in relevant environment*"
- 19 September 2014: Fly on Incr 39/40/41 (SpaceX-5 supply)
  - Install into a Microgravity Science Glovebox (MSG)

3D Printing Rocket Parts

- Direct Metal Laser Sintering
  - Sintering Inconel steel powder
- SLS Injector Plate printed at Marshall
  - 40 hours to print, 2 weeks to polish and inspect
  - Required 2 parts instead of 115
  - About the size of a soda can.
  - Test article withstood 20,000 lbs. of thrust and 6,000° F. (3316° C.) on 24 July 2013

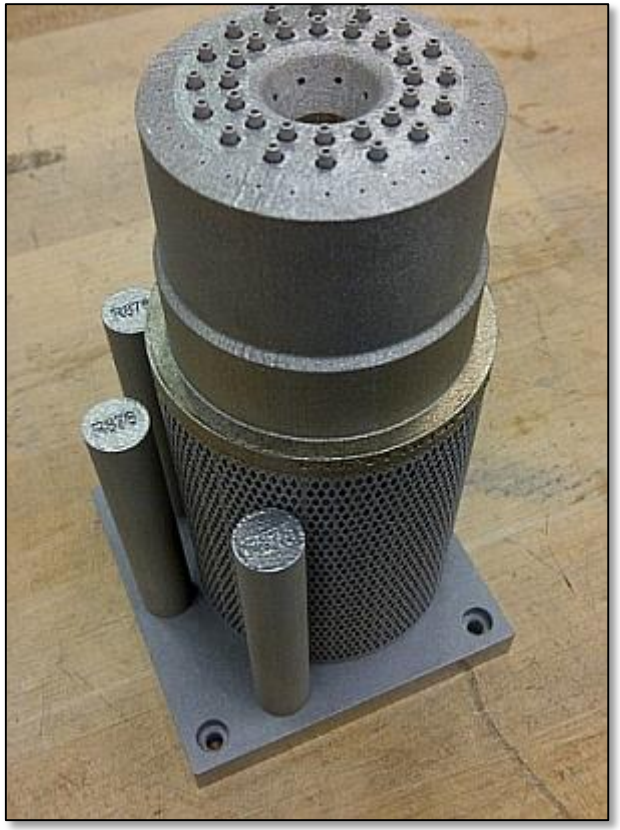
http://www.nasa.gov/exploration/systems/sls/3dprinting.html#.UmFYCVDkt8E

3D Printing Rocket Parts

Design

Note the complex internal geometry

Print



Finish (trim, polish and assemble)

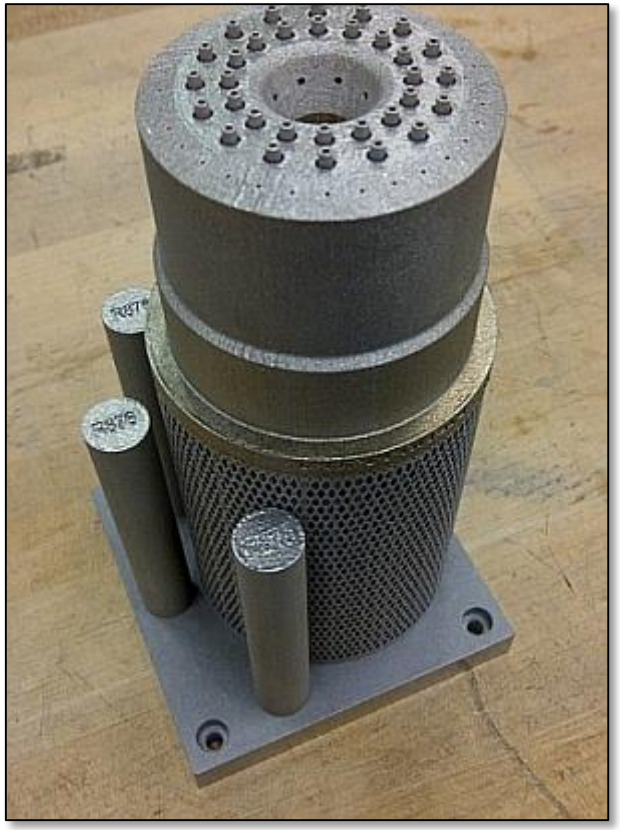
http://www.nasa.gov/exploration/systems/sls/3dprinting.html

3D Printing Rocket Parts

Design

Note the complex internal geometry

Print



Finish (trim, polish and assemble)

August 2013: Test

http://www.nasa.gov/exploration/systems/sls/3dprinting.html

SpaceX – 3D Printed Main Oxidizer Valve

- Falcon 9 launched in January 2014 carrying a commercial satellite with the MOV in one of its nine Merlin 1D engines.
- Not announced until July 31
- 2 days to print in Inconel
  vs. months to cast
- Next up—the engine
  chamber of a SuperDraco
  for the Dragon rocket's LES.

SpaceX SuperDraco Thruster Firing

SpaceX – 3D Printed Main Oxidizer Valve

- Falcon 9 launched in January 2014 carrying a commercial satellite with the MOV in one of its nine Merlin 1D engines.
- Not announced until July 31
- 2 days to print in Inconel vs. months to cast
- Next up—the engine chamber of a SuperDraco for the Dragon rocket's LES.

SpaceX SuperDraco Thruster Firing

3D Printing Food

- Systems and Materials Research Corporation
  - NASA SBIR Phase 1 $125K
  - Combination technology
    - Extrusion delivers macronutrients (starch, protein, and fat), structure, and texture onto a cook plate
    - Ink jet delivers micronutrients, flavor and smell.
- The Sugar Lab, Los Angeles
  - Patented process to print food safe confections

Tips and Pointers

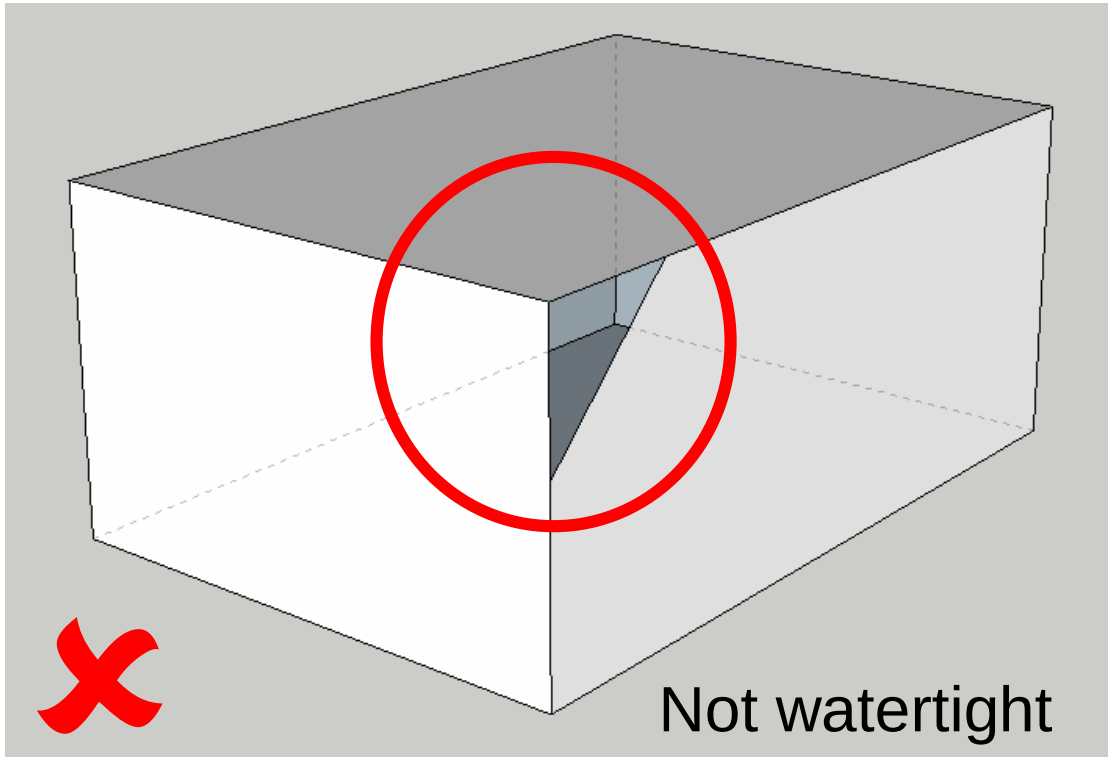
CAD: Things to Keep in Mind*

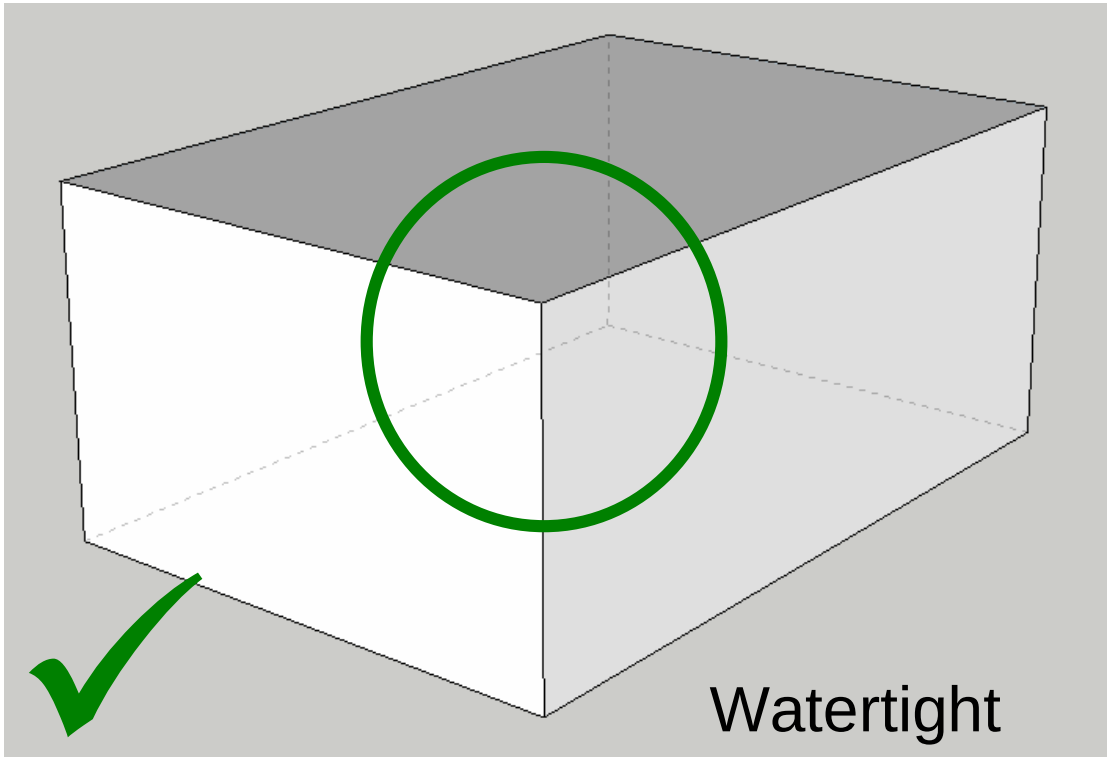
- Objects must be Closed
- Objects must be Manifold
- Objects must have correct Normals

*Source: Shapeways.com, https://www.shapeways.com/tutorials/things-to-keep-in-mind

Closed

- Also described as “Watertight”
  - There should be no gaps in outside faces.

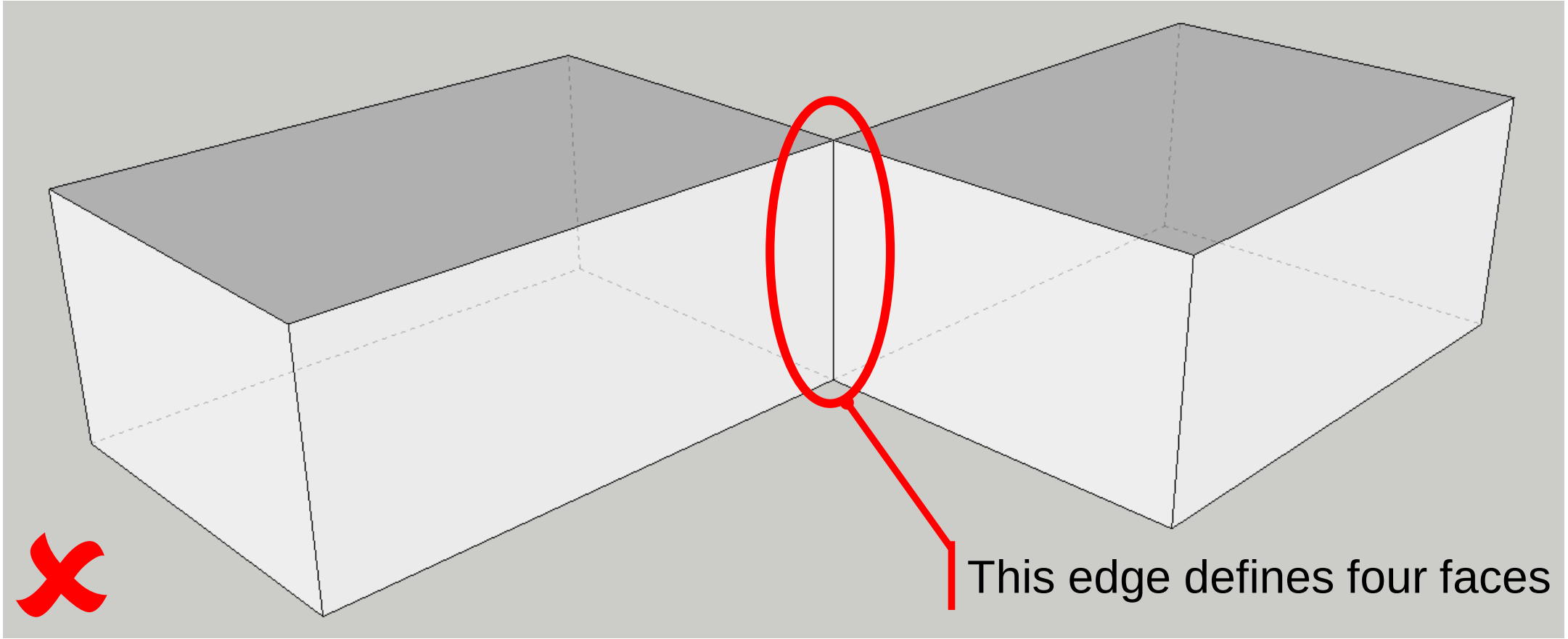




*Source: Shapeways.com, https://www.shapeways.com/tutorials/things-to-keep-in-mind

Manifold

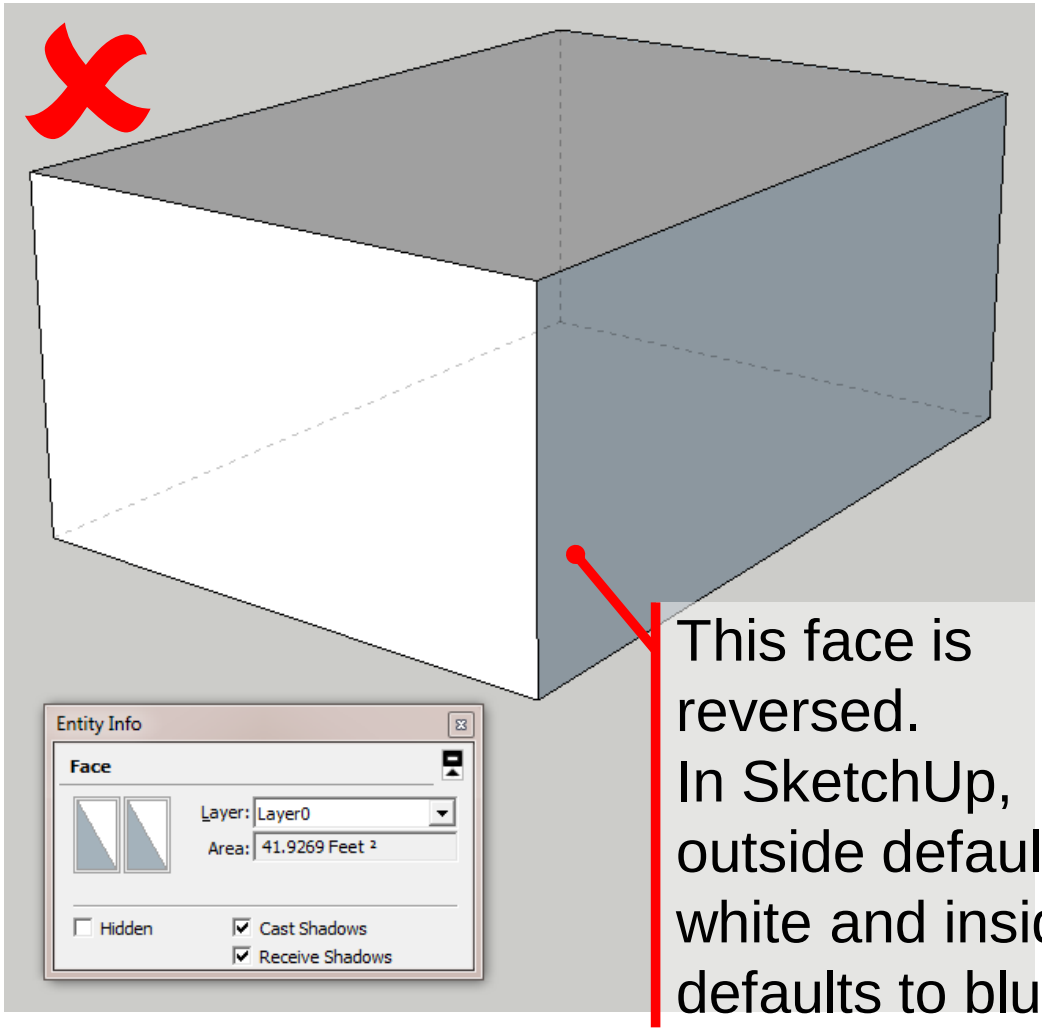
- Each edge should define only two faces.*



*The author's experience is that this is not always a problem if the faces have correct normals (next slide).

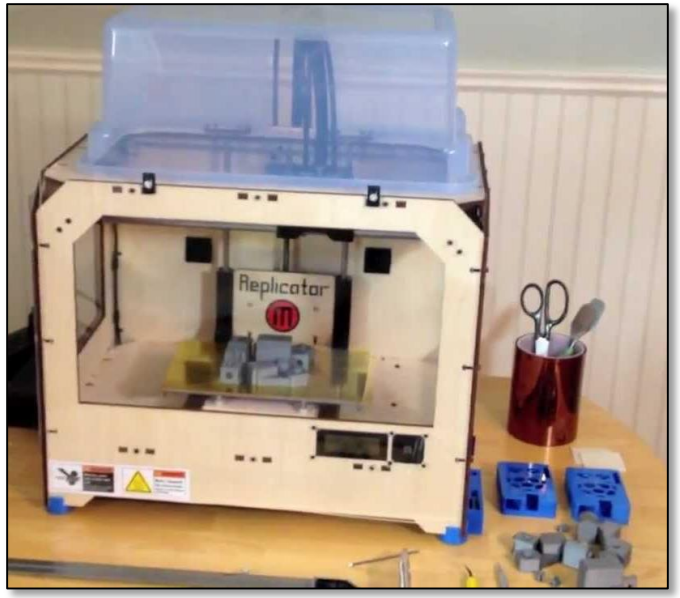
Correct "Normals"

- Faces define the boundary between solid (what is printed) and void.
- Each face will have an inside and an outside face.
- Reversed faces may confuse the printer as to what is solid.



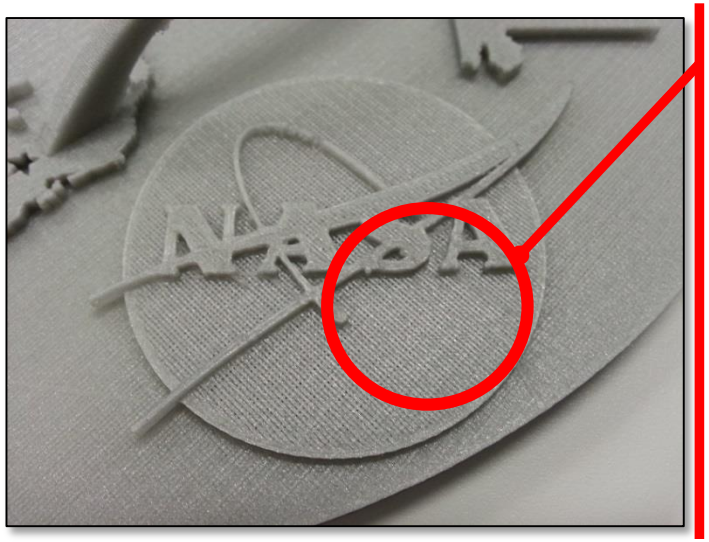
Printing Pointers – Plastic Shrinkage

- Enclose the build space – Video by BusyBotz
  - Slows the cooling process
  - Minimizes drafts
- For ABS
  - Heating the build plate hot ~118° C.
  - Add blown heat (hair dryer)
- For PLA
  - PC fan at the extrusion – Immediate cooling
  - Moderate heating of the build plate ~50° C



Printing Pointers - Quality

- Know the limitations of your printer
  - Very fine details may not resolve or print on some extrusion printers



Bottom of Orbit missing. Too fine a detail as it tapers off.

Modify the CAD to fix it.

- Keep the printer tuned and maintained
  - Check the bed level periodically
  - Clean the extruders and drive gears of loose plastic
  - Keep tabs on consumable parts
    - Plunger which pushes the filament against the drive gear

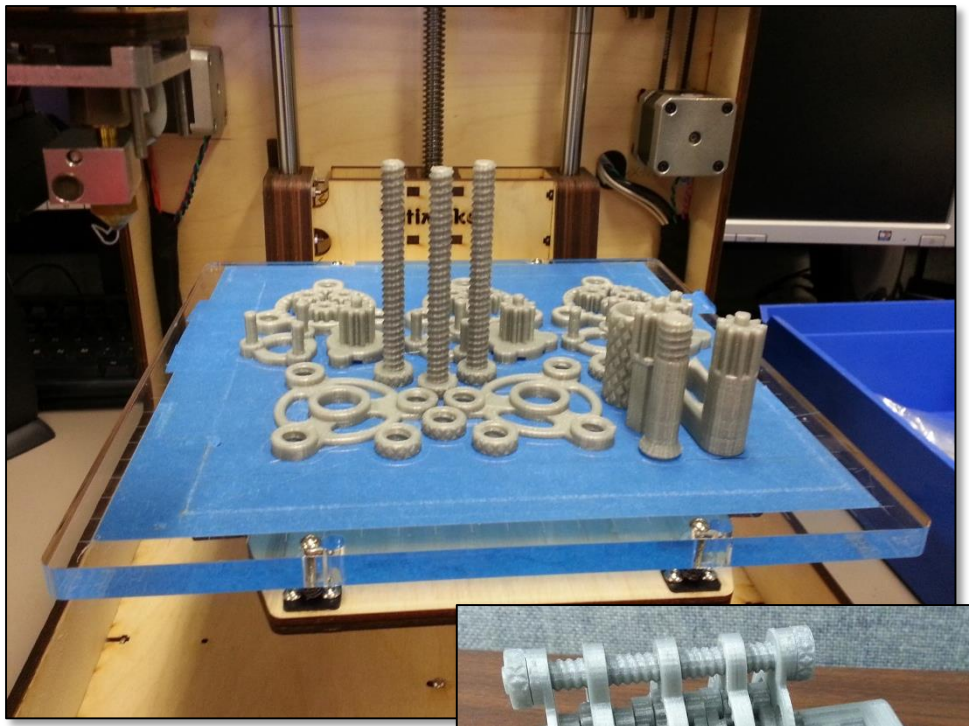
3D Printers at JSC

3D Printing at JSC

Location	Printer
348 (Innovation Design Center, AKA the Sandbox)	MakerBot Replicator 2. PLA only MakerBot Replicator Dual Extruder. ABS, PLA
OTF (30A:2085D)	Ultimaker 8”x8”x8”. PLA only
1958 (Building 35), Hacker Space	Ultimaker 8”x8”x8”. PLA only Thing-O-Matic : 4”×4”x4”. ABS, PLA
EA3 Rapid Prototype Lab (Building 57) (High-res 3D printers)	Maxum: 24”x20”x24”. ABS Fortus eV: 16”x14”x16”. ABS, PLA Objet 30 Pro: 11.81”x7.87”x5.9”. Vero plastic
4N – For FCOD, Orion Cockpit Design (As available, if materials provided)	Stratsys Dimension 1200es, 10”x10”x12”, ABS
7 – Crew and Thermal Systems Div	3DSystems ProJet HD 3000, MakerBot 2X

The OTF's Ultimaker

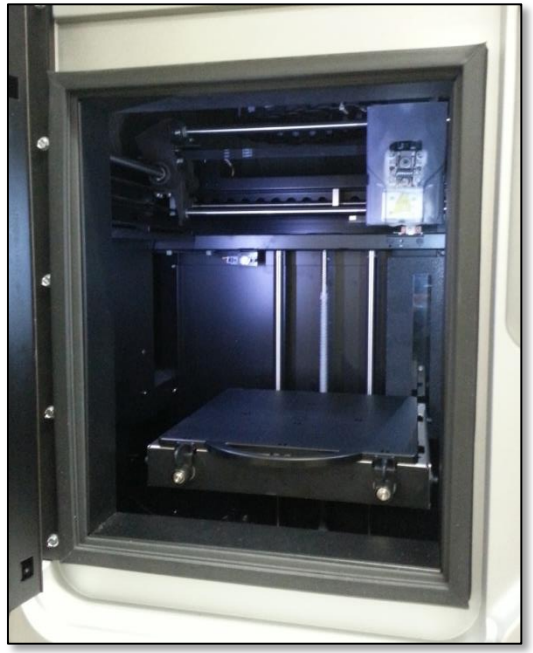
- Single extrusion – Can be fitted for dual
- PLA plastic only – No heated bed
- Push-feed
- Print from PC/Mac/Linux
- Print from SD Card



Ultimaker

Stratsys Dimension 1200es

- ABS plastic extruded at 300°
- Print bed enclosed in an "oven" heated to 100° C.
- Used to prototype Orion cockpit elements
- Located in 4S, 5th Floor



3DSystems ProJet HD 3000

- SLA plastic jet sprayed with wax sprayed in the voids for support
  - UV light cures the plastic with each layer printed
- Build envelope 11.75 x 7.3 x 8 in
- Prints as thin as 29 microns (usually 32 µ)
- After print, the wax support is melted out
- Supports Engineering, PLSS teams
- Located in CTSD area Building 7, 3rd floor

Thanks To*

- Operations Technology Facility (DD23, 30A)
  - Eric Wolfer, Lindolfo Martinez, Mike Brown, Eddie Villalva
- Innovation Design Center (AKA the "Sandbox", Building 348) and 1958 Center (Building 35)
  - James Brown, Facility Manager, Building 348
  - Christopher Gerty, JSC IT Labs Team
- CEV Rapid Prototyping Lab (CB, 4S)
  - Lee Morin, Jeff Fox, George Scheuch
- Crew and Thermal Systems Division
  - Kurt Henninger, Travis Snyder, Mike Ewert

* The most important side in the deck!

Thank You!

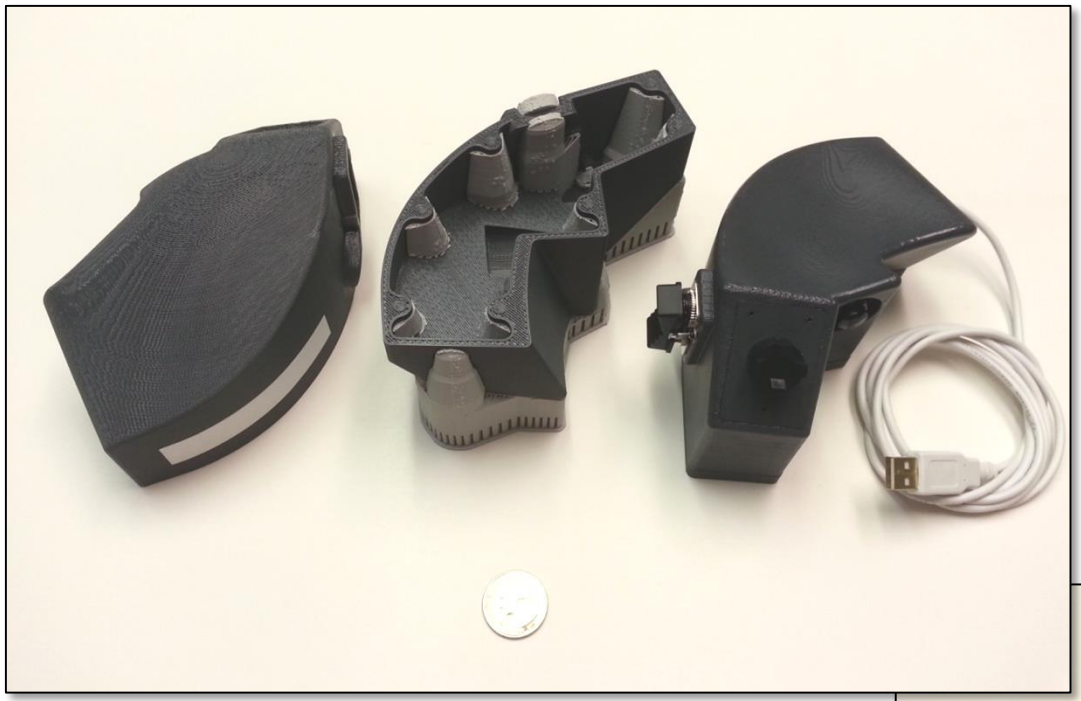
About The Presenter

- Software/Database developer for 21 years
- With Barrios Technology since September 2004
  - Leaving due to RIF at the end of September 2014
  - Returning to my roots, but in a slightly different field: Independent consultant in VR development on the Oculus Rift platform.

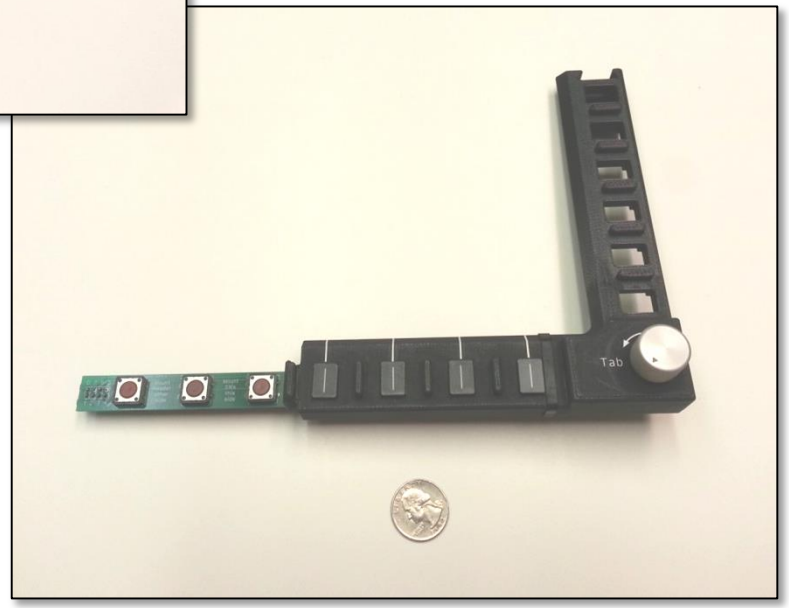
- Active with Engineers Without Borders since Summer 2013
- 2006 – 2013: Supported the MOD Operations Technology Facility in Building 30A
  - Where I cut my teeth on 3D Printing
  - Also Java, VB, Tcl/Tk, TurboCAD, SketchUp, some C++
  - Proudest to be the only one in the 25 person lab with a non-technical degree.
- B.A., American History, University of Texas at Austin, 1983

Show and Tell

Stratsys Dimension 1200es



3 iterations of the right-hand controller. Note the print support scaffolding (light gray) in the second article.

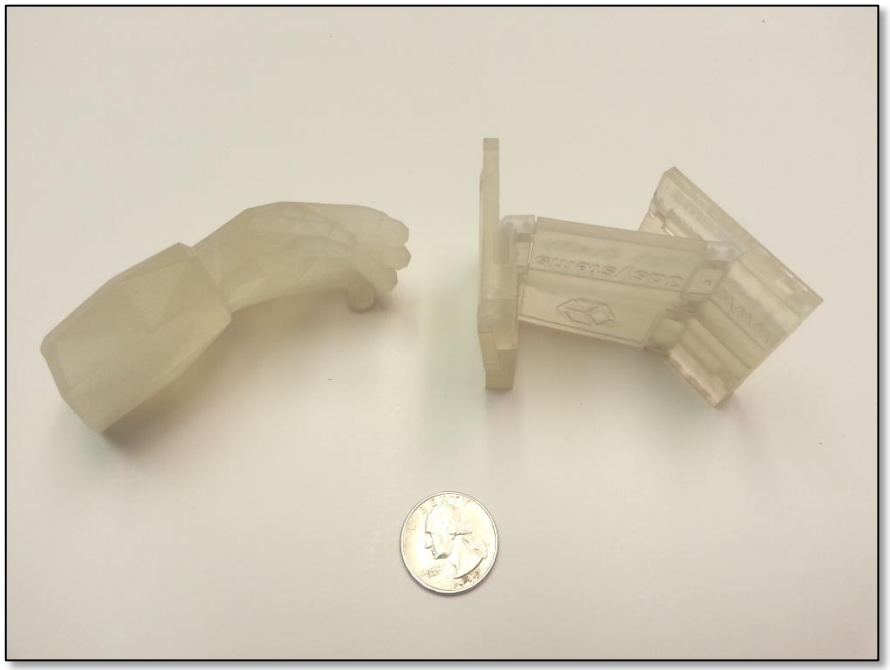


Demonstration article of the cockpit display bezel

3DSystems ProJet HD 3000

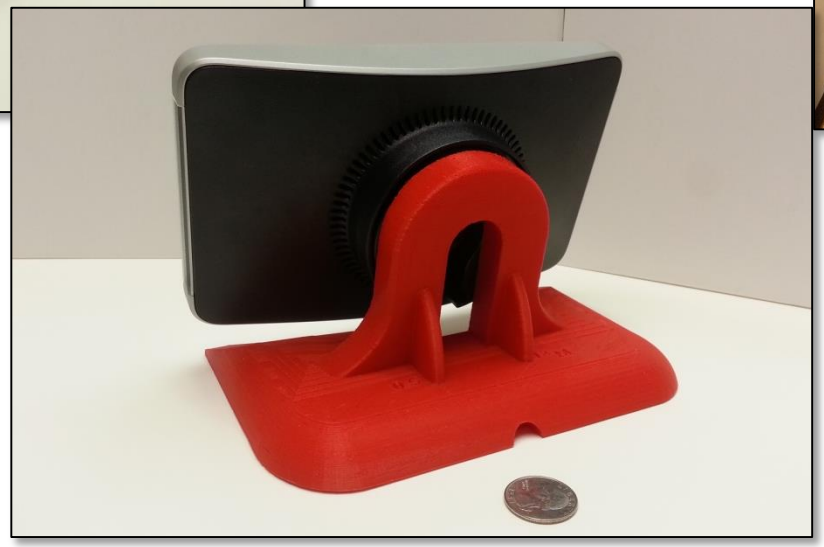
Lever handle

Demonstration articles

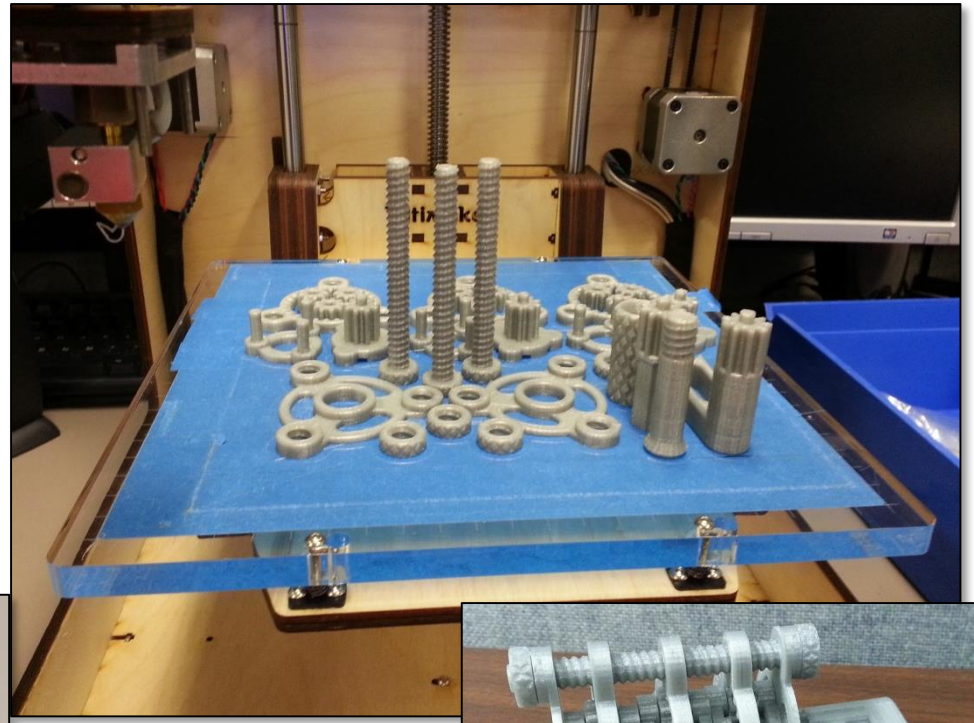


The OTF's Ultimaker

Steelcase RoomWizard Table Mount
by James R. Mireles



Designed in SketchUp



Planetary Gears Assembly (Thingiverse)

Resources

General Resources

- 3DPrinterHub.com
- 3d Printing Era (News and Commentary)
- Make: magazine
- Groups on LinkedIn
  - **3D Printing** ✓
  - Additive Manufacturing (AM)
  - 3D Printing for Architects

STL Repositories

- Thingiverse.com (hosted by MakerBot, 100K objects)
- yeggi.com (hosted by Ultimaker)
- YouMagine.com
- SketchUp 3D Warehouse
  - *.skp files. Requires 3rd-party plug-in or extension
  - STL for SketchUp (Ver 8 and earlier, export only)
  - SketchUp STL Extension (both export and import)
- shapeways.com (requires login)
- NASA 3D Resources (Beta) - 3D Printable Models

3D Printing Services*

Company	Focus	Materials	Max Build (In)	Delivery	Shipping	Website
shapeways	Hobbyists, Designers	12 Types	28" x 15" x 23"	10-21 Days	International, Included	shapeways.com
i.materialise	Artists, Designers	13 Types	24" x 20" x 24"	5-15 Days	International, Included on orders>$99	i.materialise.com
REDEYE	Industry, Engineers, Inventors	20 Types	36" x 24" x 36"	3-5 Days	International	redeyeondemand.com
sculpteo	Hobbyists, Designers	35 Types	27" x 25" x 22"	1-3 Days	International, Not included	sculpteo.com
CORE	Industry, Engineers, Inventors	4 Types	24" x 20" x 24"	4-10 Days	International, Not included	core-usa.com
ZoomRP	Hobbyists, Engineers	6 Types	19.3" x 15.4" x 7.8"	1-7 Days	International, not included	zoomrp.com
Ponoko	Hobbyists, Designers	11 Types	19" x 19" x 19"	14-21 Days	International Not Included	ponoko.com
proparts	Industry, Engineers	18 Types	36" x 24" x 36"	5-10 Days	International Not Included	3dproparts.com

*Source: 3DPrinterHub.com, http://3dprinterhub.com/3d-printer-services, 30 September 2013