Realizing your Invention in Plastic: 3D Printing to Production
Realizing Your Invention in Plastic (9/4/2013)

Agenda

Goal: High level introduction to key things you need to know if you have a product that will be made out of plastic

- Introductions
- The Basics of Plastic Parts
- 3D Printing
- Things to Know for Plastic Part Design
- Getting Parts Made
- Advice from an Angel Investor
Eric Miller

- Co-Owner and Co-Founder of PADT
  - Three other jobs:
    - Dish washer in French restaurant
    - Summer intern at Lockheed Missiles & Space
    - Simulation Engineer at Garrett/AlliedSignal/Honeywell

- Mechanical Engineer by Education
  - Very diverse skill and interest set
  - Numerical Simulation, Computer Modeling, Software Development
  - All aspects of starting and running a business

- Grandson of an Inventor
- But Not an inventor
  - My career has been about enabling others innovation
“We Make Innovation Work”

- **PADT is an Engineering Services Company**
  - Mechanical Engineering Products and Services
  - 19 years of growth and happy customers
  - Any Industry, World Wide
  - Small to Large Companies
  - Based in Tempe Arizona
    - Office in Littleton Colorado and Albuquerque, NM
    - Employees based around the country
1000’s of Customers
Synergy

- Three Business Groups to Provide Focused Resources
- Flexibility of People and Tools Across Functions

www.PADTINC.com
The Basics of Plastic Parts
Why Plastic

1. Can be shaped
2. Very inexpensive for large quantities
3. Easy to obtain
4. Water proof
5. Inert
6. Durable
7. Insulator
8. Non-Toxic
9. Colored and transparent

Note: True for most plastics at normal operating temperatures

Think about alternatives: Metal, glass, ceramic, wood, stone, leather
What is Plastic

• Synthetic organic solid made from polymer molecules that:
  – When heated flows
  – When cooled hardens
• Usually made from petrochemicals
  – Sometimes other natural organics can be used
• Polymers
  – Polymers are chains of carbon atoms with other atoms added in
  – A Backbone is formed with a repeated pattern of molecules
  – Other molecular groups are then hung off the backbone to give each plastic its unique properties
  – Additives (organic and inorganic) are also added to change properties
    • Fillers to reduce cost, fibers to increase strength, fire retardants, coloring
    • Plasticizers are the most common – they make a plastic less rigid
Two Types of Plastic

- The type of plastic determines the shaping method
- Thermoset
  - When heated their chemical composition changes
  - They can be shaped only once
  - Most plastics
- Thermoplastic
  - Don’t change composition when heated
  - They can be heated and remolded over and over again
  - Acrylic, Nylon, Poly-ethylene/propylene/styrene/vinyl chloride, Teflon
How Parts are Made

• Many different methods
• Plastic is heated and shaped with a mold
• Each method has advantages and disadvantages
• Best method determined by:
  – Geometry
  – Material
  – Accuracy
  – Surface Finish
  – Cost
Injection Molding

- Most common process
- Process:
  - Plastic is heated till it is liquid
  - Injected under high-pressure into a mold
  - Cooled to harden
  - Ejected from the mold
- Makes thin-walled parts – variable thickness walls
- Mold forms a cavity that plastic is injected in
  - You need to be able to get the part out of the cavity easily
  - Start with two halves and add inserts, sliders, pins, etc… to get complex features
  - Liquid must be able to fill cavity without hardening or leaving voids
- One mold can have multiple cavities
  - And multiple materials can be injected on top of each other
- A cycle can be only a few seconds
- Great surface finish and accuracy
Blow Molding

- **Process:**
  - Soft hollow plug is injection molded
    - Sometimes key “inlet” features are injection molded
  - Plug is heated till it is soft then blown up like a bubble
  - Plastic is pushed against mold walls to shape part

- **Constant thickness, usually very thin**
  - No internal features

- **Makes most hollow parts**
  - Bottles and tanks of all kinds
  - Large volume with very little material
Rotational Molding

• Process:
  – Plastic is heated until a liquid or very soft, sometimes starts as a powder
  – Mold is rotated
  – Material is spread evenly across the entire inside surface with a uniform thickness
  – Gravity and centrifugal force push and keep material on the wall
  – Material is hardened and solidifies

• Constant thickness
  – No internal features

• So-so surface finish

• Great for large hollow parts
  – Often made in multiple pieces and sonic welded together
Extrusion Molding

- **Process:**
  - Material is heated and forced through a mold to make a continuous part
- **Part has constant cross section**
  - Variable thickness on a cross section, but constant along length
- **Very inexpensive**
- **No cycle, always making parts**
Vacuum Forming - Thermoforming

• Process:
  – Thin sheet is heated
  – Material is pulled down around a mold to make shape

• Constant thickness

• You can only make a “cup”
  – All surfaces must be visible from the opening

• Very inexpensive

• Can make small to very large parts

• Very common for packaging
Compression Molding

- **Process**
  - Heat a chunk of plastic
  - Squeeze it between two molds
  - Cool and harden
- **Can make sheet or thick parts**
- **Common for composites, rubbers, and other reinforced plastics**
- **Very inexpensive**
- **Source material needs to be near the shape of the final part**
  - Can’t have too much flow
Compression Molding

COMPRESSION MOLD - OPEN

MOLD CAVITY

TOP PLATE

LAND

ID-OD RUBBER PREFORM

BOTTOM PLATE

MOLD CAVITY

OVERFLOW GROOVE
Other Methods

• Rubber Molding/Soft Tooling
  – Low pressure injection molding with flexible molds
  – Good for low volume and parts that require a flexible mold

• Additive Manufacturing (3D Printing)
  – See next section

• Matched Molding
  – Compression Molding with a sheet of material

• Casting
  – Pour high-temp liquid plastic into a mold and let it harden
  – Injection molding without pressure
  – Can have very thick walls

• Resin Infusion Molding
  – Kind of vacuum forming and or compression molding combined with injection molding for laminated composites
  – Laminate material is shaped into a mold, resin is inject

• Machining
  – Cut away material
  – Often not good for mass production, but can me automated

• Combined
  – Two or more methods combined
Other Stuff to Know

- Deflection behavior is usually non-linear
  - Plastic or hyper-elastic
- Plastic shrinks and has residual stresses when they cool/harden
- Material properties can change over time with exposure to:
  - Radiation of various types
  - Hot or Cold
  - Other chemicals, including air
- Plastic components can be:
  - Coated
  - Machined
  - Bonded
  - Welded
- There are a dozen different specialties in Plastics Engineering
  - This is not generic or simple
  - But it is common
3D Printing
Additive Manufacturing

• Been around for over 25 years
• We are currently in a bubble
  – Cost has come way down because of patent expiration
  – Be careful: Huge Hyperbole
  – But real value there under the hype
• Very powerful tool for:
  – Prototyping
  – Tooling
  – Custom products
  – Very specific niche manufacturing
Basics of Additive Fabrication

• Step 1: Take a 3D Computer model and slice it into layers
• Step 2: Have machine create each layer
  – Option a: trim a solid layer
  – Option b: harden a layer of liquid
  – Option c: sinter or bind a layer of powder
  – Option d: deposit liquid that hardens
• Step 3: Remove supporting material, clean, and/or finish surfaces
First: You Need a Computer File

- Neutral and Common File for transferring geometry to systems
  - STL -> stereolithography

- Faceted representation
  - Surfaces are made up of thousands of triangles

- All CAD tools create STL files

- Key is to make refined STL file
  - Work with your supplier to get parameters
What Else Should you Know About RP

- To make a part, you need an STL file
  - Most CAD tools make one
- Most people are talking about Additive Manufacturing when they say Rapid Prototyping
- Rapid means “next day” for most
  - Some same day
- Technology can be in-house or purchased from a service provider.
- Each technology has strengths and weaknesses
  - Need to use the right one
- There is now a dizzying array of options!
Stereolithography (SLA)

- The first commercially successful technology
  - Uses a liquid that hardens when exposed to ultraviolet light
    - Photo curable polymer
  - Draw on top layer of liquid with ultraviolet laser
  - Supports made from same material – thin walled
- Often called SLA
  - Stereolithography Apparatus
- Largest Vendor: 3D Systems
  - Smaller players in Japan, China, and Europe
  - Now available in “3D Printer” level
- Pricing
  - $15K - $800K
- Sizes
  - 10x10x10
  - 59 x 30 x 22
Stereolithography
Stereolithography

• Strengths
  – Resolution
  – Surface Finish
  – Transparent material
  – Variety of materials
  – Can be fast
  – Mature technology

• Weaknesses
  – Nasty chemicals
  – Variety of materials
  – Support removal and sanding
  – Strength of material
  – Expensive materials
Fused Deposition Modeling (FDM)

- Most Common and Fastest Growing Technology
  - 3 times as many Stratasys machines were sold in 2010 than 2nd place
  - Many low cost systems are FDM based

- Simple
  - Melts material in head and extrudes a small bead
  - Head is numerically controlled to draw part
  - Separate support material

- 3D Printing to Digital Manufacturing

- Biggest Provider is Stratasys, Inc.
  - uPrint, Dimension & FORTUS product lines

- Prices:
  - $14k to $500k

- Build Sizes:
  - 8 x 6 x 6
  - 36 x 24 x 36
Fused Deposition Modeling (FDM)
Fused Deposition Modeling

• **Strengths**
  – Functional Parts
  – Part strength
  – Ease of operation
  – Low cost materials
  – Digital Manufacturing
  – 3D Printing
  – Range of materials
  – Perfect for education

• **Weaknesses**
  – Surface Finish
  – Thermoplastics only
  – Speed
  – Quality (on “hobby” machines)
Selective Laser Sintering (SLS)

- **Dominant Powder Technology**
  - Heat powder to near melting
  - Use laser to sinter particles together
  - Uses powder to support

- **Large, durable parts**

- **Several Powdered Metal Applications**

- **Dominated by 3D Systems**
  - A few competitors in Asia
  - EOS in Germany
  - European Laser Melting similar

- **Prices:**
  - $150k to $750k

- **Build Size**
  - 15 x 13 x 18
Selective Laser Sintering
Selective Laser Sintering

- **Strengths**
  - Strength
  - Large parts
  - Metal
  - Flexible but strong
  - Speed
  - Self supporting

- **Weaknesses**
  - Messy powder
  - Surface finish
  - Material options
Jetting

- **Largest New Development Activity**
  - **Binding**: Print head deposits binder into a powder (Z Corp)
  - **Direct**: Print head deposits actual material that hardens or is hardened (Objet, 3D Systems)

- **Goes under many names**
  - Usually vendors name: PolyJet, 3DP, etc…
  - Trying for 3D Printing market

- **Many Players**
  - **Objet**: Just merged with Stratasys
  - **Zcorp**: (#2 in market after Stratasys)
  - **3D Systems**
  - **Solidscape (Sanders)** (Now owned by Stratasys)
  - New players

- **Prices**
  - $8k to $250k
Jetting
Jetting

- **Strengths**
  - Speed
  - Resolution
  - Surface finish
  - Color (Z Corp)
  - Direct Wax (Solidscape)
  - Lower Cost
  - Mixed materials (Objet)

- **Weaknesses**
  - Messy materials
  - Reliability
  - Robustness (Not photopolymer)
  - Shrinkage
Other Technologies

• Laser Melting
  – Like sintering, but higher laser energy to melt
  – Popular with metals to get full strength parts
  – Still developing – direct creation of injection molds is goal
  – Strong in Germany: EOS, MTT, Concept Laser, Arcam

• DLP
  – SLA with DLP instead of laser
  – Envisiontec (Germany) is leader: 900+ systems

• Lamination
  – Sheets of material are cut to shape for each layer
  – Original was Helisys: LOM
  – Popular with casting
  – People working on 3D printers

• Deposition and Micromachining
  – Using plasma and chemical deposition/machining technologies
  – Still mostly R&D
Hobby Machines

- Major for “maker” solutions: DIY
  - Guy who made a gun…
- Most are based on Fused Deposition Modeling (FDM)
- Very popular in incubators and “maker” labs
- Some impact in education
- Lots of buzz
- But, part quality is very low
3D Printing for Inventors

• There are many prototyping resources out there for hire
  – Online, local, incubators, etc…

• You must have a valid 3D solid computer model

• Use the right process and material

• Do not buy a hobby/consumer machine unless you:
  – Want to make a hobby out of it
  – Do not need high quality parts
  – You are not pushed for time
3D Printing for Inventors

• Find a service provider you can work with
  – Pay up front, don’t offer equity or ask for credit, don’t work with one that will take equity or credit
  – Find someone that will take the time to understand what you want your part for
    • They will help you pick the right material and process
  – Keep track of your costs
    • At some point, getting your own commercial machine will be cost effective

• If you are doing custom/personal parts, 3D Printing may work
  – Take the time to evaluate all the technologies and other options
3D Printing is a Valuable Tool

• Look through the hype and find the value

• Prototyping
  – Fit, Form, Function evaluation
    • For entire product lifecycle
  – Model for early marketing and fundraising
  – If a picture is worth a thousand words…

• Manufacturing
  – Models to aid in planning the manufacturing and assembly process
  – Tooling!

• Almost every “corporate” product made today uses Additive Manufacturing in the product development process
Things to Know for Plastic Part Design
Design for Manufacturability

- The biggest challenge with plastic parts is balancing:
  - The “style” of your part
  - The function of your part
  - The manufacturability of your part

- Once you have the basic concept design, pick a manufacturing process
  - Then refine the design for manufacturability

- Even if you have a designer, get the design rules for the process(s) you will be using
  - This will avoid fighting with your designer
Part Assembly

• You figured out how to make your plastic parts, how are you going to put them together?
  – Assembly costs can drive up overall costs
  – Assembly can strongly effect design
  – Assembly impacts maintainability

• Keep it simple, but make it strong

• Look at similar items and understand how they assemble

• Glue is rarely an option
  – Sonic welding
  – Screws
  – Snap
  – Very specific bonding agents (dissolve the plastics)
Some Injection Molding Hints

• Start inspecting plastic parts
• Surface finish is a big driver
  – If you cover your surfaces you can get away with a lot
  – If you don’t, you have to be careful
• Conflicting issues:
  – Melted plastic has to fill full cavity before it hardens
  – It shrinks when it hardens and thin parts shrink more than thick parts
  – Mold lines – where tool metal touches you will get a line
• Basic hints
  – Keep walls at uniform thickness as much as possible
  – Keep walls thin: .02 – 0.16 for most plastics
  – Ribs should be around ½ wall thickness
  – Don’t put bosses in a corner
  – Your part must have draft and rounding
Injection Molding
Most Important Plastic Part Design Hint

• Hire a designer who understands plastic injection molded part design!
• If you can’t do that, find a manufacturer that you can work with
  – You should pay more for your tooling for this, but it is worth it
Go!Animate

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Resources

• Plastics One
  – http://www.plastics1.com/Articles/articles.php?Department=CIM&article=62

• Dupont Top Ten Design Tips
  – http://www2.dupont.com/Plastics/en_US/Knowledge_Center/TopTens/top10design.html

• Protomold design Guidelines
Getting Parts Made
The Process

• Find someone to make the tooling
• Modify the design to work with the tooling (maybe)
• Do sample shots to make sure everything is good
  – Tweak design a bit (maybe)
• Set up quality system
• Set up assembly process
• Set up packaging process
• Manage supplies
• Go in to production
• Assemble
• Ship
• Inspect
• Distribute
Getting the Part Made Right is only Half of It

• Assembly, quality, packaging, customs, shipping, etc…
• Getting a product made on shipped to distribution is an art and science in and of itself.
• You need to plan and manage the whole thing
Find a Partner

• Domestic or Foreign, you need a partner
  – Someone who you can work with
  – Not the lowest bidder
  – Someone that can patiently answer your questions

• A partnership is two ways
  – You need to pay 50% up front usually
  – Pay on time
  – Don’t fight about the little things
  – Respect their expertise

• If you don’t have a good plastics designer, find a partner who can do the design for manufacturing and assembly

• Consider a consultant
  – But, ask for references and talk to them
  – A lot of “consultants” are friends/relatives of people with shops
Understand the Vendors Side

- They make their money making parts
- Design, tooling, advising is all done at cost or at a loss
- Don’t switch vendors unless you have to
- Be reasonable about schedule
Advice from an Angel Investor
#1: Your Valuation is Too High

- Early stage investing is very high risk, you need to value your company reasonably
  - More than $2MM is probably too much.
- Ask for advice on valuation from a mentor or experienced angel investor
- Be willing to give up a serious chunk of your business
#2: Be Reasonable

- Don’t oversell your idea
  - It is not the next Google, Facebook, Baby Einstein, Pet Rock
    - It might turn out to be, but don’t sell it as such
    - Don’t exaggerate your claims

- Credibility is critical
  - Be open and honest about the problems you face
  - Be open and honest about you and your team’s shortcomings

- Except the fact that you need to give up ownership to get funding

- Give realistic growth projections
  - No hockey sticks
  - Maybe give a best case and a conservative case

- Have a reasonable valuation

- Show that you can take advice
#3: Reduce Risk, Increase Reward

- For the investor, it is a risk vs. reward equation
- You need to present your product in terms of risk and reward
- Minimize the risk
  - Don’t just spin it that way, do it
- Maximize the return
  - Not just to you, but to your investors
- If you want money, you have to find that sweet spot