Outline

• Introduction to AM @ PADT
• AM Processes & Materials
• Key Drivers for AM
• Learn More & Get Involved
INTRODUCTION TO ADDITIVE MANUFACTURING AT PADT
PADT by the Numbers

- Founded in 1994, 22 years in business
- 85 employees
  - 19 years average experience, 4 PhDs & 13 Masters degrees
- R&D labs with $2M in equipment
- Over 1,700 Customers served
  - Over 100,000 Prototypes & Functional Parts Delivered
  - Over 350 product development projects completed
  - Over 7,200 numerical simulation models run
- Over 9,900 Support Cleaning Apparatus (SCA) Systems Sold
- Strong Partnerships:
  - Stratasys Platinum Partner 2015
  - Concept Laser Consultative Partner
  - ANSYS Channel Partner
- 13 Small Business Innovation & Research (SBIR) awards since 1999
PADT Capabilities: Additive Manufacturing

Fused Deposition Modeling (Fortus 450, 400, 250)

Selective Laser Sintering

Selective Laser Melting (Concept Laser MLab Cusing R)
Arriving Summer 2016

Stereolithography (SLA)

Material Jetting (Polyjet)
PADT Additive Manufacturing (AM) Technology Timeline

**Stereo lithography**
- SLA 250: 1994*

**Fused Deposition Modeling**
- FDM 2000: 1995*
- Prodigy: 2000*
- Dimension: 2002
- Viper Si2: 2006
- ProJet 6000: 2011

**Selective Laser Sintering**
- Sinterstation 2000 plus: 1999
- HiQ Thermal Sensing Upgrade: 2005
- Multi-zone Heating Upgrade: 2012
- Fortus 400: 2009
- Fortus 450: 2015

**Material Jetting (Polyjet)**
- ProJet 6000: 2009
- Connex 500: 2009
- Objet 500: 2014

**Selective Laser Melting (Metal)**
- MLab Cusing R

*retired
PADT Capabilities: AM Post-Processing & Finishing

FDM Support Cleaning Apparatus
(Designed, developed and sold by PADT)

Powerblast (High Pressure Water Cleaner)

Gas vac

Blue M Oven

Finishing (Support removal, painting, polishing)
PADT Capabilities: Rapid & Advanced Manufacturing

- NC Milling & Lathe
- Injection Molding (at partner site)
- Chemical Hood & Workspace
- Customized Testing Lab
PADT Capabilities: Reverse Engineering & Inspection

3D Scanning (Steinbichler)

3D Scanning (Geomagic Capture)

Cross-sectional Scanning (CGI)

File Formats (Including Inspection Results)
- Point Cloud
- STL
- IGES/STEP
- Feature-based SolidWorks
- 3D Colormap Inspection Analysis

Reverse Engineering Software (GeoMagic Design X)
PADT Capabilities: Simulation

Structural (Statics & Dynamics)  
 transient dynamics  
 Multiphysics

Simulation Tool Customization, Process Automation

High Performance Computing for Simulation

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We seek to address complex problems in Additive Manufacturing that benefit from a combination of experimental, theoretical and numerical approaches.
## PADT Recognition & Outreach

| **Stratasys** | Highest partner status for commercial resellers |
| **America Makes** | Silver Member |
| **AMUG** | Additive Manufacturing Users Group 2012 DINO Award (Brad Palumbo) |
| **ASTM** | Voting member, ASTM Standards F42 on Additive Manufacturing |
| **PADT StartUp Labs** | Supporting startups at the Center for Entrepreneurial Innovation (CEI) |
| **Arizona Technology Council** | 2011 Governor's Celebration of Innovation Pioneering Award |
| **ASU** | 2011 Spirit of Enterprise Award (Entrepreneurial Leadership) |
| **AZBio** | AZ Bio Fast Lane Award 2011 (PADT Medical) |

### Research Awards

- **13 awards, Commercialization Index of 90, Small Business Innovation Research (SBIR)**

  - Grant awarded July 2016 for research on AM lattice modeling (18 months)
INTRODUCTION TO ADDITIVE MANUFACTURING
Additive vs Conventional (Subtractive) Manufacturing

Conventional Manufacturing

Material → Machining → Product

3D Printing (Additive Manufacturing)

Material → Layer Deposition → Product

http://www.dainikdisha.com/
Additive Concept

Raw Material

Process Technology

Product
# Classification of Additive Manufacturing Processes

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Process Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder</td>
<td>Laser Fusion/Sintering</td>
</tr>
<tr>
<td>Liquid</td>
<td>Laser Polymerization</td>
</tr>
<tr>
<td>Filament / Wire</td>
<td>Fused Deposition</td>
</tr>
<tr>
<td>Sheet</td>
<td>Ultrasonic bonding</td>
</tr>
</tbody>
</table>
# Materials (Polymers)

## Thermoplastics (FDM)

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSplus</td>
<td>Opaque standard plastic in 9 colors</td>
</tr>
<tr>
<td>ABS-M30</td>
<td>Opaque standard plastic in 6 colors</td>
</tr>
<tr>
<td>ABS-ESD7</td>
<td>Static dissipative standard plastic</td>
</tr>
<tr>
<td>FDM Nylon 12</td>
<td>Tough plastic for advanced applications</td>
</tr>
<tr>
<td>PC-ABS</td>
<td>High-impact engineering plastic in black</td>
</tr>
<tr>
<td>PPSF/PPSU</td>
<td>Sterilizable, strong high-performance plastic</td>
</tr>
<tr>
<td>ULTEM 1010</td>
<td>Strongest, most heat-resistant FDM material</td>
</tr>
<tr>
<td>ABSi</td>
<td>Translucent standard plastic in 3 colors</td>
</tr>
<tr>
<td>ABS-M30i</td>
<td>Biocompatible, sterilizable engineering plastic</td>
</tr>
<tr>
<td>ASA</td>
<td>UV-resistant, durable standard plastic</td>
</tr>
<tr>
<td>PC</td>
<td>Strong engineering plastic in white</td>
</tr>
<tr>
<td>PC-ISO</td>
<td>Stronger biocompatible, sterilizable engineering plastic</td>
</tr>
</tbody>
</table>

## Photopolymers (Polyjet)

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Materials</td>
<td>Hundreds of composite materials created on-the-fly</td>
</tr>
<tr>
<td>Digital ABS Material</td>
<td>Simulate high-strength and temperature-resistant plastics</td>
</tr>
<tr>
<td>High-temperature</td>
<td>Combine thermal functionality with dimensional stability</td>
</tr>
<tr>
<td>Transparent</td>
<td>3D print clear and tinted models and prototypes</td>
</tr>
<tr>
<td>Rigid Opaque</td>
<td>3D print in brilliant color</td>
</tr>
<tr>
<td>Simulated Polypropylene</td>
<td>3D print smooth, tough snap-fit parts and properties</td>
</tr>
<tr>
<td>Rubber-like</td>
<td>3D print flexible materials with hundreds of colors and properties</td>
</tr>
<tr>
<td>Bio-compatible</td>
<td>3D print for medical and dental applications</td>
</tr>
<tr>
<td>Dental Material</td>
<td>3D print for dental and orthodontic applications</td>
</tr>
</tbody>
</table>
Non-Reactive Metal Alloys

- 316L Stainless Steel
- Maraging Hot-Work Steel
- Stainless Hot-Work Steel
- 17-4 PH Stainless Steel
- Inconel 718
- Inconel 625
- Bronze Alloy
- Biocompatible CoCrW Alloy

Reactive Metal Alloys

- 30Al/31Al Aluminum Alloy
- Ti6Al4V Titanium Alloy
- Commercially Pure Titanium
- Biocompatible Ti6Al4V Alloy

http://www.conceptlaserinc.com/materials/
Additive Manufacturing Trends

Worldwide AM Revenue (USD, Millions)

AM System Installations by Sector

Percentage of AM Revenue from Functional Parts

ADDITIVE MANUFACTURING DRIVERS
Top 5 AM Drivers

1. Rapid Prototyping and Tooling
2. Design Freedom
3. Lead Time Reduction
4. Manufacturing Cost Reduction
5. New Applications
Low-cost, rapid manufacturing of one of a kind parts allows for faster product development cycles
- 50-90% cost reductions
- 80-95% lead time reductions

Mock-Ups & Fit Tests (Lockheed Martin Corp.)

Wind Tunnel Models (Lockheed Martin Corp.)

Display Models (Lockheed Martin Corp.)
Organic Innovation, operators and engineers design and print tooling and improvements at low cost and fast turnaround time and see the results of their ideas.
**Layer-by-layer** manufacturing process allows for more complex geometries – design with (almost) no constraints!
Topology optimization allows for reducing the material requirements for any desired objective (stiffness, strength, extension etc.) – AM enables manufacturing of these designs!

Bracket with 30% weight reduction (Airbus)

Seat-belt buckle - 55% weight reduction, estd. 72.5kg on Airbus 380 (EOS)

Exhaust Sensor (RSC Engg.)

Bracket (Honeywell)
Parts previously designed for manufacturing and subsequent assembly can now be printed in a consolidated manner to eliminate assembly costs (labor and parts).

Satellite Waveguide, Renishaw (77 parts to 1)

Sensor Housing, GE (20 parts to 1)

Airbus Fuel Assembly (10 parts to 1)

ECS ducting, ULA

Assembly simplification: 140 part assembly reduced to 6

133 g

53 g
Additive Manufacturing enables point-of-use manufacturing!
Lead Time Reduction
Accelerate Development, Replacement & Repair

Super Draco Thruster: concept to hot firing in 100 days (Space X)

Replacement parts for a 30-year old component within a week (Airbus)

Turbine blade repair (DM3D, MT Additive)
Figure 2. Breakeven analysis comparing conventional and additive manufacturing processes


Graphic: Deloitte University Press | DUPress.com
5

New Applications

3D Printed Electronics (PEN, Inc.)

Space Construction (ESA)

Armor & Exoskeleton

On-Orbit Manufacturing (Tethers Unlimited)

Bioprinting
LEARN MORE & GET INVOLVED
Learn More

- **Online Courses:**

- **Reading:**

- **Conferences:**
  - AMUG: [http://www.additivemanufacturingusersgroup.com/events.htm](http://www.additivemanufacturingusersgroup.com/events.htm)
  - RAPID: [www.rapid3devent.com](http://www.rapid3devent.com)
  - SFF Symposium: [http://sffsymposium.engr.utexas.edu](http://sffsymposium.engr.utexas.edu)

- **America Makes Membership:** [www.americamakes.us](http://www.americamakes.us)
  - Online, Living Textbook expected in 2017 (PADT leading effort)
Arizona Additive Manufacturing Committee (AZ Tech Council)

Started June 2016, with goals:
- Promote AM and **educate** potential users
- Act as a forum to influence **local regulation**
- Inform progress of national certification and standards organizations
- Serve as a rallying point for collaboration

- 53 individuals representing 34 entities in AZ (and growing)
- Next meeting is at PADT (Monday, August 15, 4-5:30pm)
- Contact [dhruv.bhate@padtinc.com](mailto:dhruv.bhate@padtinc.com) to learn more
Thank You!