Enabling Technologies for Entrepreneurial Opportunities in 3D Printing of SmallSats

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Motivation
Goal

• Combine the best of:
  – Additive Manufacturing
  – Robotics
  – Space Expertise

• Planned Results:
  – Enable advanced technologies for smallsats
  – Maximize internal volume for sensors and experiments
  – Protect components
  – Minimize man in the loop
  – Improve smallsat affordability
3D Printed Thermoplastic Satellite

Two contracts

– **NASA SmallSat Technology Program (SSTP)**
  “Printing the Complete Cubesat”
  • Emphasis on advanced materials

– **America Makes (aka NAMII)**
  “3D Printing Multi-Functionality: Additive Manufacturing for Aerospace Applications”
  • Emphasis on advanced concepts and equipment

Progress
Inspiration – ORNL MDF Metallic Concept

• Structure fabricated using:
  ✓ Titanium powder
  ✓ Electron beam melting (EBM)
  ✓ ARCAM A2 printer

Courtesy ORNL MDF
Key Challenges - Enablers

- Multi$^3$D Manufacturing
- Material Alternatives
- Embedded Wiring
- Embedded Electronics
- Communications / RF
- Radiation Shielding
- Thermal Management
- Propulsion
Multi3D Manufacturing System

An integrated, comprehensive AM suite including:

- Extrusion of thermoplastics and metals
- Micromachining
- Laser ablation
- Embedding of wires and fine-pitch meshes within the thermoplastics
- Robotic component placement
## Material Alternatives

<table>
<thead>
<tr>
<th>Category</th>
<th>Material</th>
<th>Advantages</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polycarbonate with 5% by weight loading</td>
<td>CaTi03</td>
<td>Relative Permittivity-165</td>
<td>EM properties</td>
</tr>
<tr>
<td></td>
<td>SrTi03</td>
<td>Relative Permittivity-233</td>
<td>EM properties</td>
</tr>
<tr>
<td></td>
<td>Ti02, Anatase</td>
<td>Relative Permittivity-48</td>
<td>EM properties</td>
</tr>
<tr>
<td></td>
<td>Ti02</td>
<td>Relative Permittivity-114</td>
<td>EM properties</td>
</tr>
<tr>
<td></td>
<td>NaCl</td>
<td>Relative Permittivity-6</td>
<td>EM properties</td>
</tr>
<tr>
<td></td>
<td>Fe304</td>
<td>Magnetic material</td>
<td>EM properties</td>
</tr>
<tr>
<td></td>
<td>Tungsten</td>
<td>Radiation shielding</td>
<td>EM properties</td>
</tr>
<tr>
<td>Polymer Blends</td>
<td>ABS/UHMWPE</td>
<td>Radiation shielding</td>
<td>Blending enables UHMWPE to be printed</td>
</tr>
<tr>
<td></td>
<td>ABS/HDPE</td>
<td>Radiation shielding</td>
<td>Blending enables HDPE to be printed</td>
</tr>
<tr>
<td>Baseline data from commercial materials</td>
<td>ULTEM</td>
<td>Best tensile strength</td>
<td>High temperature resistance</td>
</tr>
<tr>
<td></td>
<td>PC</td>
<td>Good tensile strength</td>
<td>Print temperature suitable for electronics</td>
</tr>
<tr>
<td></td>
<td>PC-ABS</td>
<td>Resolution</td>
<td>Impact resistance, low print temperature</td>
</tr>
<tr>
<td></td>
<td>NYLON</td>
<td>Chemical resistance / Mechanical toughness</td>
<td>Better elongation and superior fatigue resistance</td>
</tr>
<tr>
<td></td>
<td>ABS ESD</td>
<td>Conductive</td>
<td>Electrostatic Discharge</td>
</tr>
<tr>
<td>Other</td>
<td>Zeonex</td>
<td>Low loss / Teflon-like EM properties</td>
<td>Relatively Novel Material</td>
</tr>
<tr>
<td></td>
<td>Thermally Conductive PC</td>
<td>Thermal management</td>
<td>Relatively Unknown</td>
</tr>
<tr>
<td></td>
<td>Polymide</td>
<td>Low loss</td>
<td>Low hygroscopy</td>
</tr>
</tbody>
</table>
Embedded Wiring
Embedded Electronics
Embedded Electronics - “Process Experiment”

Dytran Sensors to Embed

Planned Approach

Process Halted

Caps Placed – Continue Printing

Finished Product
Communications / RF

- Embedded Wiring Enables Efficient Communication Systems
  - Wireless Plug and Play

- Demonstration 1U CubeSat Panels
  - Every panel houses its own:
    - Battery
    - Solar panel
    - Custom circuitry
Radiation Shielding

- **Base**: Low-Z materials (Thermoplastics) capture large particles - protons and neutrons
- **Adds**: High-Z materials – tungsten, tantalum, boron
- **AM offers two techniques for combining materials**
  - Changing materials during printing for a layered effect
  - Creating new filament stock by combining materials into a hybrid source
- **Low energy X ray testing conducted at AFRL/KAFB with the following results:**

![Graph showing Attenuation Factor % for different materials](image-url)
Thermal Management

• Sources
  – Heat generated from space vehicle components
  – Earth IR
  – Earth albedo
  – Direct solar

• Challenges
  – Space prevents convection - must rely on thermal radiation
  – SmallSats have limited surface area - thermal radiation is difficult

• Solutions
  – AM materials allow varying emissivity and absorption
  – Apply surface topologies
    • ULTEM with carbon fibers
    • Polycarbonate (PC) with boron nitride
  – Add heat pipes in structure walls
Propulsion

Tank Molded to Structure

Thruster (Moog Type 58-118)

Fill/Vent Port

Avionics/Electronics Card Bay

150 mm

100 mm

100 mm
Effective Commerce requires

- Strong marketable product
- Affordable and innovative way to produce it

Why is AM printed smallsats a strong market?

Easy entry to the technology!
- Low capital machine cost
- Easy learning to operate
- Unlimited related products

Examples: Made in Space, Cesaroni, PDC
Conclusion

• Strong team of AM, robotic and space experts are pursuing development of smallsats exploiting advances in additive manufacturing

• Key aspects of space flight requirements are being investigated to design a space ready thermoplastic concept

• Guidance and funding from NASA and America Makes makes it possible

• Results to date are very promising

• The commerce of using AM for smallsats is promising as well