The Use of Additive Manufacturing for Fabrication of Multi-Function Small Satellite Structures

Brian J. Horais, Lonnie J. Love, Ryan R. Dehoff

ORNL Manufacturing Demonstration Facility

AIAA/USU Small Satellite Conference
12 August 2013

SSC13-III-6
Overview

- ORNL has extensive involvement in advanced manufacturing and materials technologies with specific emphasis on additive manufacturing
  - Their Manufacturing Demonstration Facility (MDF) exists to promote energy efficient manufacturing research for industry

- Recent efforts have focused on applying the unique capabilities of additive manufacturing (AM) to new challenges
  - Multifunction Structures for Satellites
  - Micro-fluidic based robotic systems

- This presentation focuses on titanium multi-function satellite structures made by AM

Additive Manufacturing Enables Design Innovation
Mission Needs

• Flying multiple spacecraft in formation has long been a dream of space scientists

• Development of the technologies needed for satellite constellations has been hampered in the past by the cost of individual spacecraft and the cost to launch.

• Small satellites offer unique advantages to explore and implement satellite constellations
  - Onboard propulsion will be essential for station keeping
  - Development of integrated, multi-function structures can facilitate new satellite constellation concepts

Source: DARPA/TTO Phoenix Program Briefing DEC 2012
Why is DOE Interested in Additive Manufacturing?

- Industry consumes 31% of total U.S. Annual energy output
- U.S. innovation remains strong, but access to cutting-edge R&D and facilities to improve manufacturing energy efficiency is unattainable for most companies
- DOE/ORNL’s Manufacturing Demonstration Facility offers industry access to advanced, energy efficient manufacturing facilities to ‘try before you buy’


It’s about the Energy Savings

Source: Annual Energy Review 2010, US EIA

~100 quad/yea

Industry: 31% of total U.S. energy consumption
Multifunction Spacecraft Structures

• Multifunction spacecraft structures (MFSs) offer the potential for significant mass and volume savings in addition to reduced overall complexity and shorter system assembly times.

• Multifunction structures and devices for spacecraft applications are not a new idea
  – DERA developed and flew the STRV-1 c & d in 2000
  – In 2001 the Jet Propulsion Laboratories (JPL) developed a concept for multifunction structure solar panels
  – AFRL has developed a number of multifunction structure concepts, including integrated wiring and structures for NASA’s Deep Space 1 (DS1)

CUBESATS offer an ideal platform to develop and test multifunction spacecraft structures
Additive Manufacturing

- Additive manufacturing (AM) techniques create 3-D objects directly from a computer model, depositing material only where required

- AM offers advantages in:
  - Lower energy intensity
    - using only 2–25% of the energy required to make new parts by traditional methods
  - Less waste
    - reduce material needs and costs by up to 90%.
  - Reduced time to market
    - fabricate as soon as 3-D digital description is done
  - Innovation
    - eliminates traditional manufacturing-process design restrictions

SOURCE: DOE/AMO Brochure, AUG 2012

Additive Manufacturing offers significant opportunities for innovation in spacecraft components and structures
ORNL’s Manufacturing Demonstration Facility (MDF)

- MDF houses the ARCAM EBM equipment
ARCAM Electron Beam Melting (EBM) Additive Manufacturing (AM) Process

A. The jet turbine blade
B. Create a 3-D CAD model
C. Titanium Powder goes in the hoppers
D. The part is ‘grown’ layer by layer using EBM
E. Excess powder is removed
F. The finished AM part

A. Jet Engine Turbine Blade
B. Preparing the CAD model
C. Pouring the Ti Powder
D. ‘Growing’ the part in the A2
E. Removing the Ti powder
F. The final EBM product
The ORNL Multifunction CubeSat Structure

- Integrates propellant tank, nozzles, lines and sensor thermal control in a monolithic titanium structure

- Structure fabricated from titanium powder using electron beam melting (EBM) on an ARCAM A2
Design Iterations

- The use of automated design tools enables rapid iteration between design and fabricated parts.

Stress Analysis for Propellant Tank

Early Structural Model

Interim Design

'Build' Design
Fabrication Process

1. Final CAD Design Using SolidWorks
2. Full-Scale Prototype Using Stratasys 3-D printer
3. Final Build in Titanium Using ARCAM EBM
Additional Views

- ‘Interior View of Propellant Tank showing structural braces
- ‘Cutaway’ Polymer Prototype alongside final Titanium Structure
- End View of Titanium Structure showing Four Nozzles and Tubing
Additive manufacturing at ORNL

Electron Beam Melting
- Developing in-situ characterization, feedback and control
- Precision melting of powder materials
- Processing of complex geometries not possible through machining

Ultrasonic Additive Manufacturing
- Simultaneous additive and subtractive process for manufacturing complex geometries
- Solid-state process allows embedding of optical fibers and sensors

Laser Metal Deposition
- Site-specific material addition
- Application of advanced coating materials for corrosion and wear resistance
- Repair of dies, punches, turbines, etc.

Fused Deposition Modeling
- Development of high-strength composite materials for industrial applications
- Precision deposition of thermoplastic materials

Working with AM equipment providers to develop high-performance materials, low-cost feedstocks, processing techniques and in-situ characterization and controls to enable broad dissemination of technologies.

Managed by UT-Battelle for the U.S. Department of Energy
ORNL’s Unique assets for product prototyping

By combining processes in novel ways, unique manufacturing prototypes can be rapidly developed

ORNL has extensive R&D processes located on a single campus to support product prototyping for industry, large and small
Conclusions

• Additive Manufacturing offers exciting potential to revolutionize the fabrication of complex structures for aerospace applications
  – The small satellite community is a logical ‘first adopter’ of AM due to their reputation for innovation and progressive design/testing of space hardware
  – With the design and flexibility afforded by AM, new design processes can be implemented, such as multifunction structures, that were not feasible or economic using traditional machining methods

• The ORNL Manufacturing Demonstration Facility (MDF) offers a unique national resource for U.S. companies and organizations to try out new manufacturing and materials technologies before making the large capital investments associated with production
  – Consult the ORNL/MDF user program collaborative opportunity:
    http://web.ornl.gov/sci/manufacturing/mdf_user_program.shtml
What’s Next?
Acknowledgements

• I would like to acknowledge the significant contributions of my co-authors to this effort:
  – Dr. Lonnie Love, Leader, ORNL Automation, Robotics and Manufacturing (ARM) Group
  – Dr. Ryan Dehoff, Additive Manufacturing, ORNL MDF

• I would also like to thank the following individuals for their support throughout the concept development, paper approval and final fabrication:
  – Dr. Craig Blue, Director, ORNL MDF and Advanced Manufacturing Office
  – Ms. Karen Harber, ORNL MDF Administrative Assistant