Manufacturing Demonstration Facility

DOE Advanced Manufacturing Office Merit Review

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U.S. DEPARTMENT OF ENERGY | Advanced Manufacturing

OAK RIDGE National Laboratory

Outline

- **Manufacturing Demonstration Facility**
- **Impacts with Industry**
  - **Metal additive manufacturing**
  - **Polymer additive manufacturing**
- **STEM and Workforce Development**

Manufacturing Demonstration Facility

Providing leading edge technology and business solutions for industry

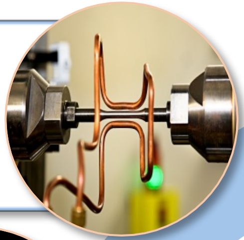
Reduce risk, accelerate commercialization of advanced technologies while reducing lifecycle energy

- Public-Private Partnership
- 50+ active projects
- Addressing technical challenges across complete supply chain
- MDF focus areas of advanced technologies
  - Metal additive manufacturing
  - Polymer additive manufacturing
  - Roll-to-roll processing
  - Feedstocks for additive manufacturing and R2R

Leveraging DOE assets at ORNL

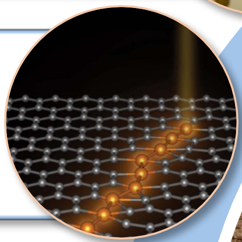
Neutron scattering: SNS and HFIR

- World's most intense pulsed neutron beams
- World's highest flux reactor-based neutron source



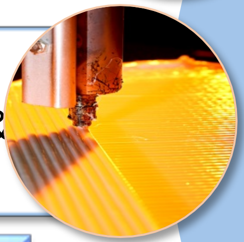
Leadership-class computing: Titan

- Nation's most powerful open science supercomputer



Advanced materials

- DOE lead lab for basic to applied materials R&
- Technology transfer: Billion dollar impacts



Demonstrated ability to work with and transition technologies to industry

- More than 800 on-going relationships with industry
- Leading DOE Laboratory for R&D 100 Awards (180)
- Mechanisms in place to rapidly implement working agreements allowing R&D to be initiated on industry's timeline
- Success in development and integration of multidisciplinary teams

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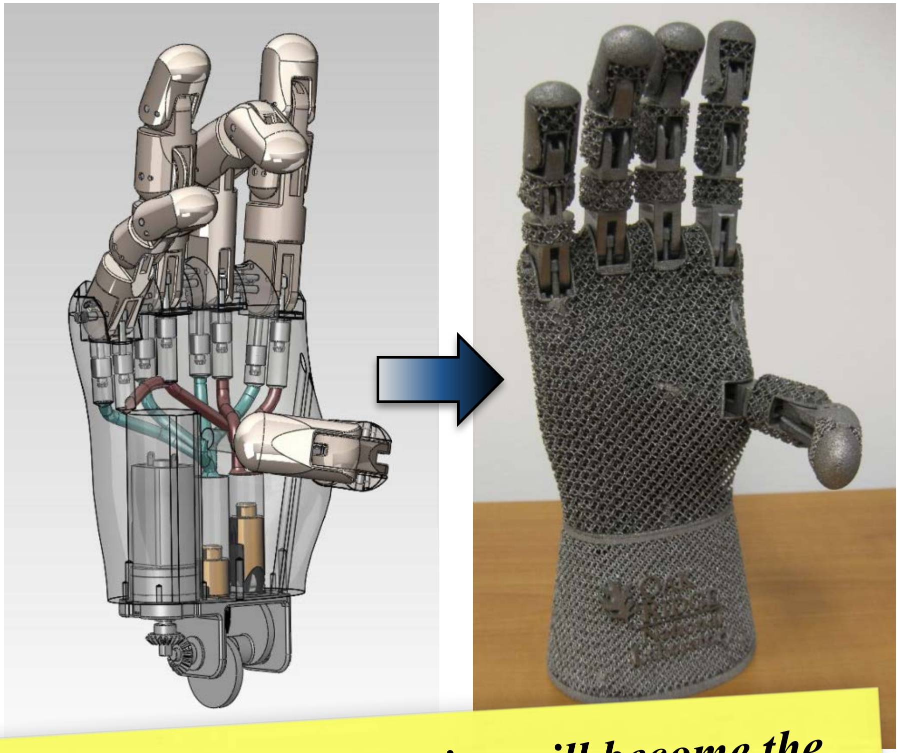
Additive manufacturing

CAD Model to Physical Part



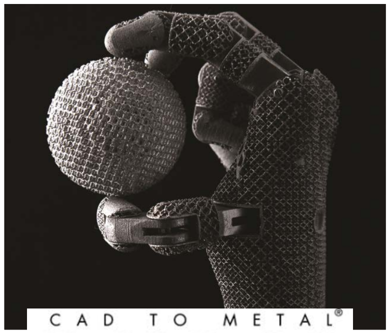
"Additive Manufacturing will become the most important, most strategic, and most used manufacturing technology ever."
Wohlers 2012

Faster. Cheaper. Better!

- Increased Complexity
- Less Material Scrap
- Shorter Design Cycle
- Reduced Part Count

Our additive manufacturing capabilities are dramatically expanded

Electron Beam Melting

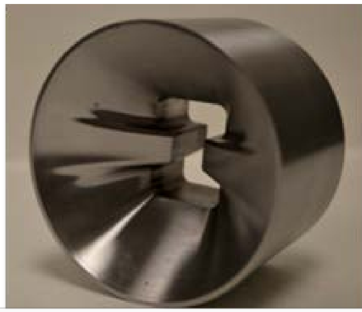


CAD TO METAL®
Arcam AB®

Laser Sintering

RENISHAW®

Laser Blown Powder Deposition

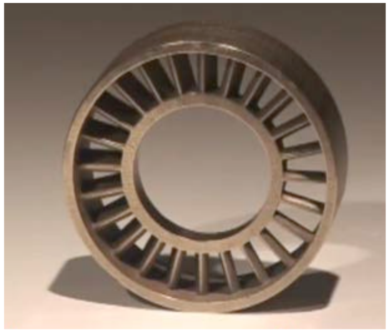


POM
DM3D

Ultrasonic Consolidation

SOLIDICA
FABRISONIC

Binder Jetting



ExOne™
DIGITAL PART MATERIALIZATION

Fused Deposition Modeling

Stratasys FOR A 3D WORLD™
AFINIA
MakerBot
Solidoodle
Cubify™

Multi-head Photopolymer

OBJET
Stratasys FOR A 3D WORLD™

Large-Scale Polymer Deposition

Objectives in additive manufacturing

- **Developing advanced materials, evolving the supply chain**
  - Titanium alloys, Ni superalloys, advanced steels
  - High-strength, carbon-reinforced polymers
- **Implementing advanced controls**
  - In-situ feedback and control for rapid certification and quality control
- **Understanding material properties and geometric accuracy**
- **Developing new design concepts**
- **Exploring next-generation systems to overcome technology barriers for manufacturing**
  - Bigger, Faster, Cheaper
  - Integrating materials, equipment and component suppliers with end users to develop and evolve the supply chain
- **Training next-generation engineers & scientists**

Outline

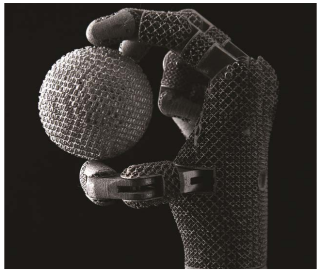
✓Manufacturing Demonstration Facility

- **Impacts with Industry**
  - **Metal additive manufacturing**
  - **Polymer additive manufacturing**
- **STEM and Workforce Development**

Metal additive manufacturing

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.

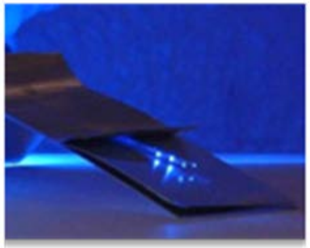
Electron Beam Melting (4)



- Developing in-situ characterization, feedback and control
- Heated powder bed
- Expanding range of materials (Ti64, 718, 625, CoCr)
- Precision melting of powder materials

CAD TO METAL® Arcam AB®

Ultrasonic Additive Manufacturing (1)

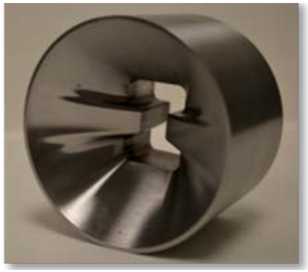


- Simultaneous additive and subtractive process for manufacturing complex geometries
- Solid-state process allows embedding of optical fibers and sensors

SOLIDICA

FABRISONIC

Laser Metal Deposition (1)

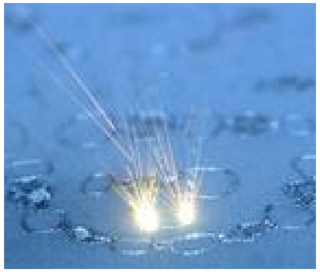


- Site-specific material addition
- Application of advanced coating materials for corrosion and wear resistance
- Repair of dies, punches, turbines, etc.

POM

DM3D

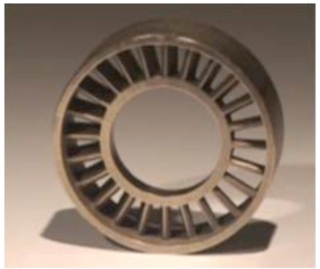
Laser Powder Bed (1)



- Unheated powder bed
- Wide range of material choices (316L, 17-4PH, H13, Al, Ti, 718, 625)
- 9.8 x 9.8 x 11.8 inch build volume
- Precision melting of powder materials

RENISHAW

Metal Binder Jetting (1)



- Metal matrix composites and sintered materials
  - Stainless steel/Bronze
  - Tungsten & Titanium
  - Ceramics & Sand
- Large build volumes (10 x 10 x 16 in)
- Fast build times (30sec / layer)

ExOne™ DIGITAL PART MATERIALIZATION

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Metal AM supply chain

Materials Suppliers

- Powder Injection Moulding International
- ATI
- AMETEK
- The NanoSteel Company, Inc.
- FMC Technologies
- Metal Powder Products (MPP)
- Erasteel
- TLS Technik Spezialpulver
- Sandvik
- Carpenter
- Cristal
- TIMET
- HMI Metal Powders
- Raymor Industries Inc.
- Fukuda Metal Foil & Powder Co., Ltd.

Equipment Suppliers

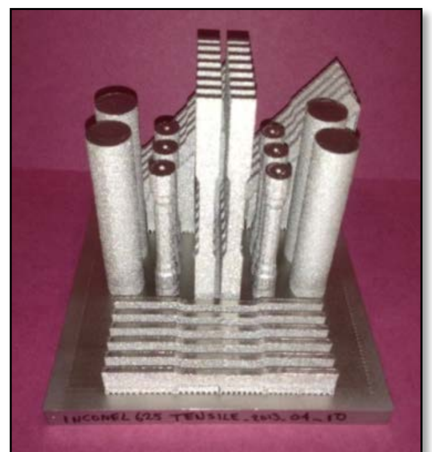
- Cad to Metal Arcam AB
- ExOne Digital Part Materialization
- Fabrisonic
- DM3D
- POM
- ECM Technologies
- Grid Logic
- Renishaw
- Solidica
- AO Applied Optimization

End Users

- S-RAM Dynamics
- Boeing
- Lockheed Martin
- Cummins
- GE
- Praxair
- Piedmont Propulsion Systems, LLC (A First Aviation Services Inc. Company)
- Honeywell
- Aerovalve
- Radio Systems Corporation
- Planetary Systems Corporation
- Northrop Grumman

Metal alloy development

- Engaging multiple metal powder suppliers
- Developing supply chain for tailored AM feedstocks



Key metals	Titanium alloys (Ti6-Al4-V, TiAl)
	High-temperature alloys (Inconel 625, 718, cobalt chrome)
	Refractory metals (tungsten)

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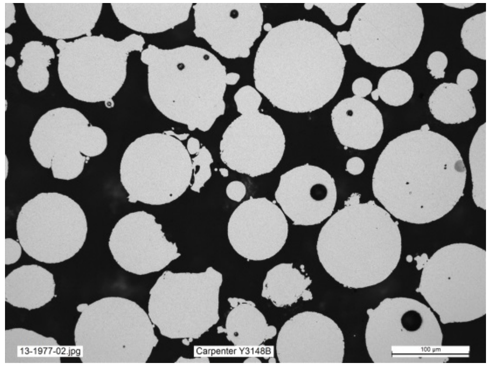
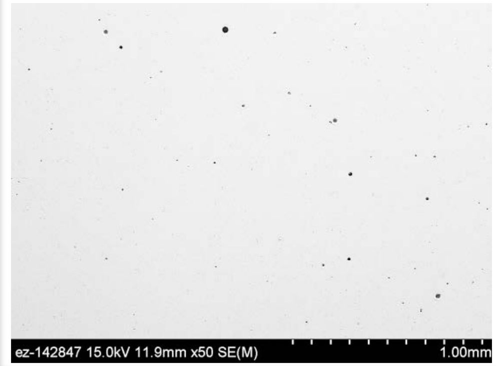
Porosity in Ni powders result in porosity in deposit

Powder | **As Deposited**

Gas Atomized

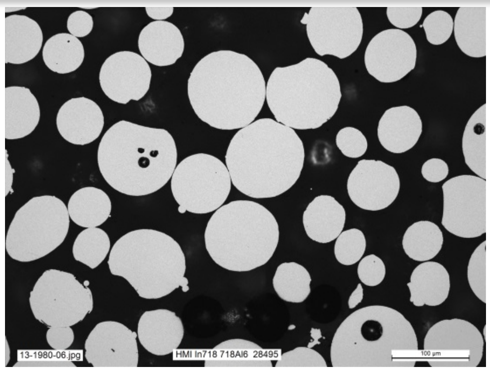


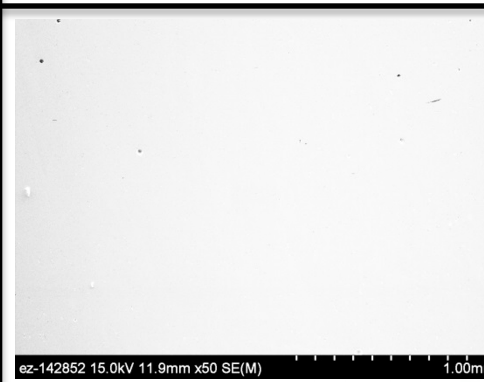


Porosity in Powder = 0.873%

Porosity in Deposit = 0.117%

Rotary Atomized

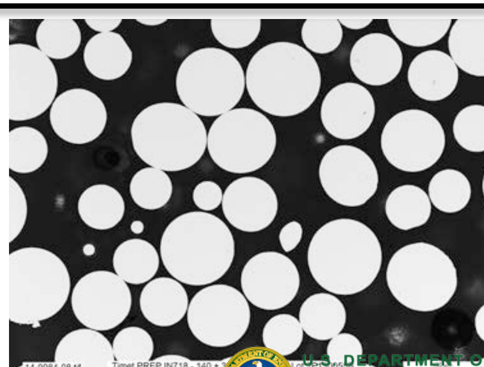


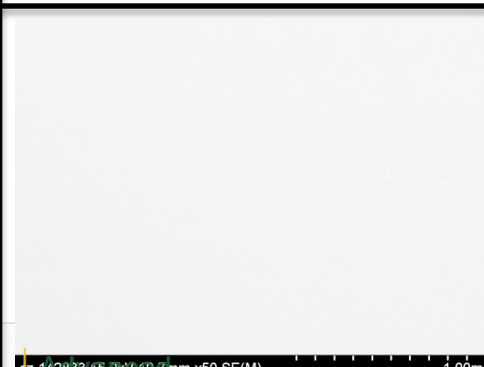


Porosity in Powder = 0.491%

Porosity in Deposit = 0.037%

Plasma Rotated Electrode



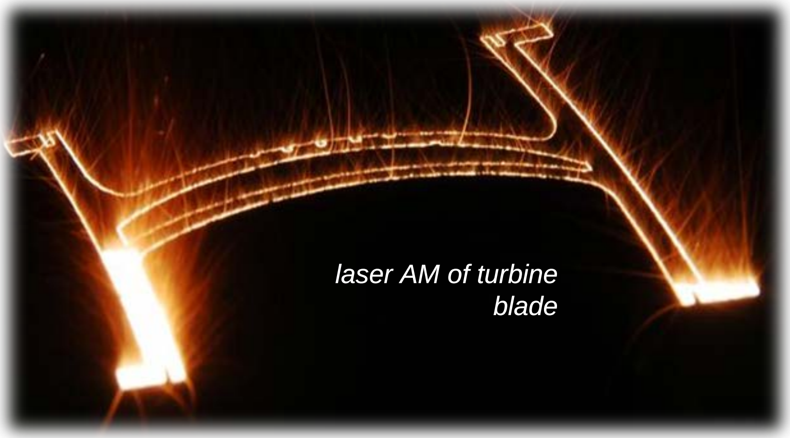


Porosity in Powder = 0.000%

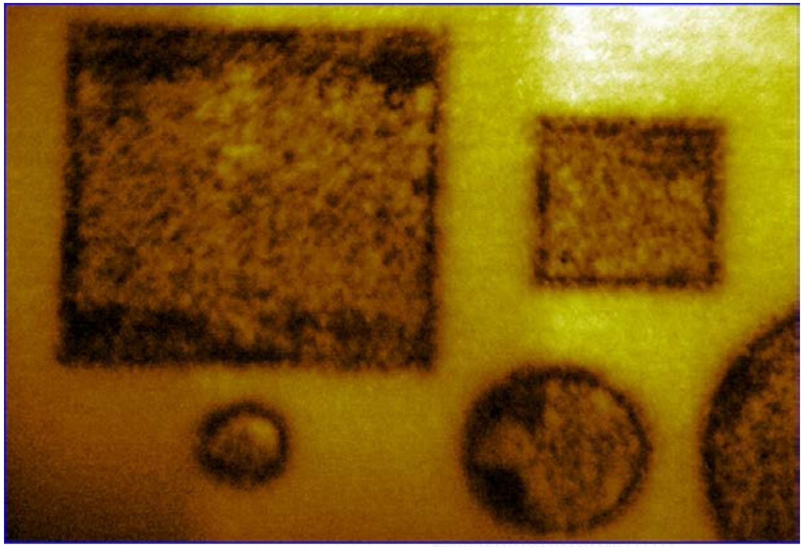
Porosity in Deposit = 0.000%

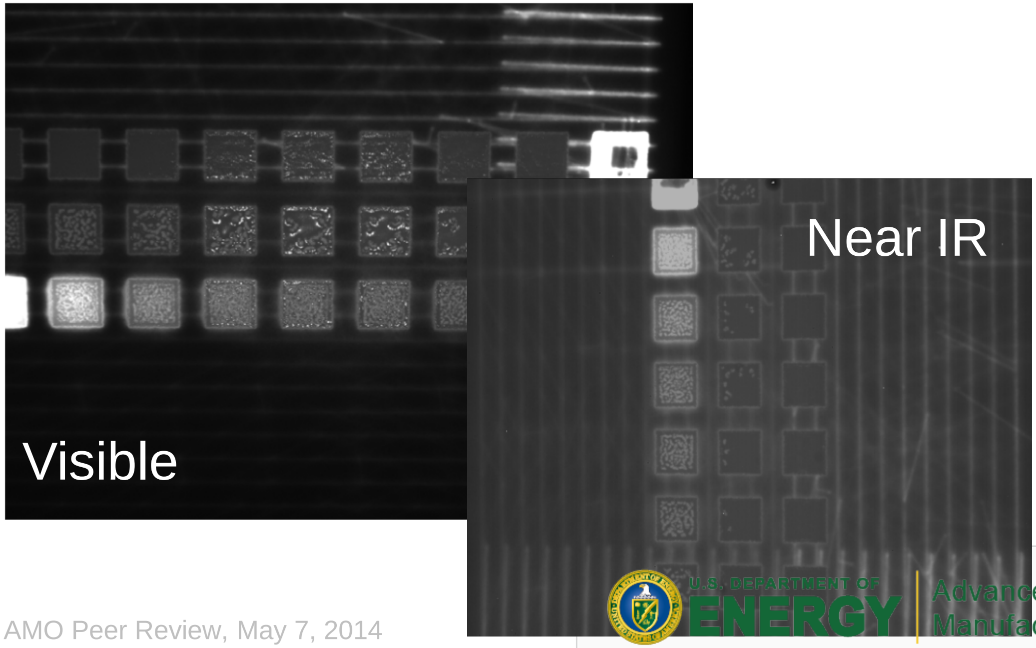
In-situ process monitoring

- Ability to understand defects, porosity and material behavior in each layer deposited (repair)
- Several methods examined for both R&D Environment and for cost effective manufacturing solution



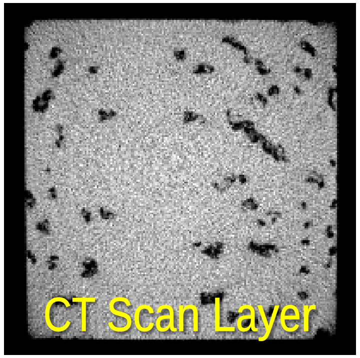
Video of High-Speed IR

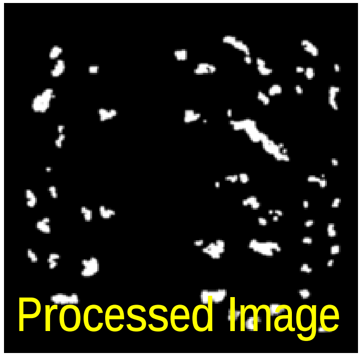


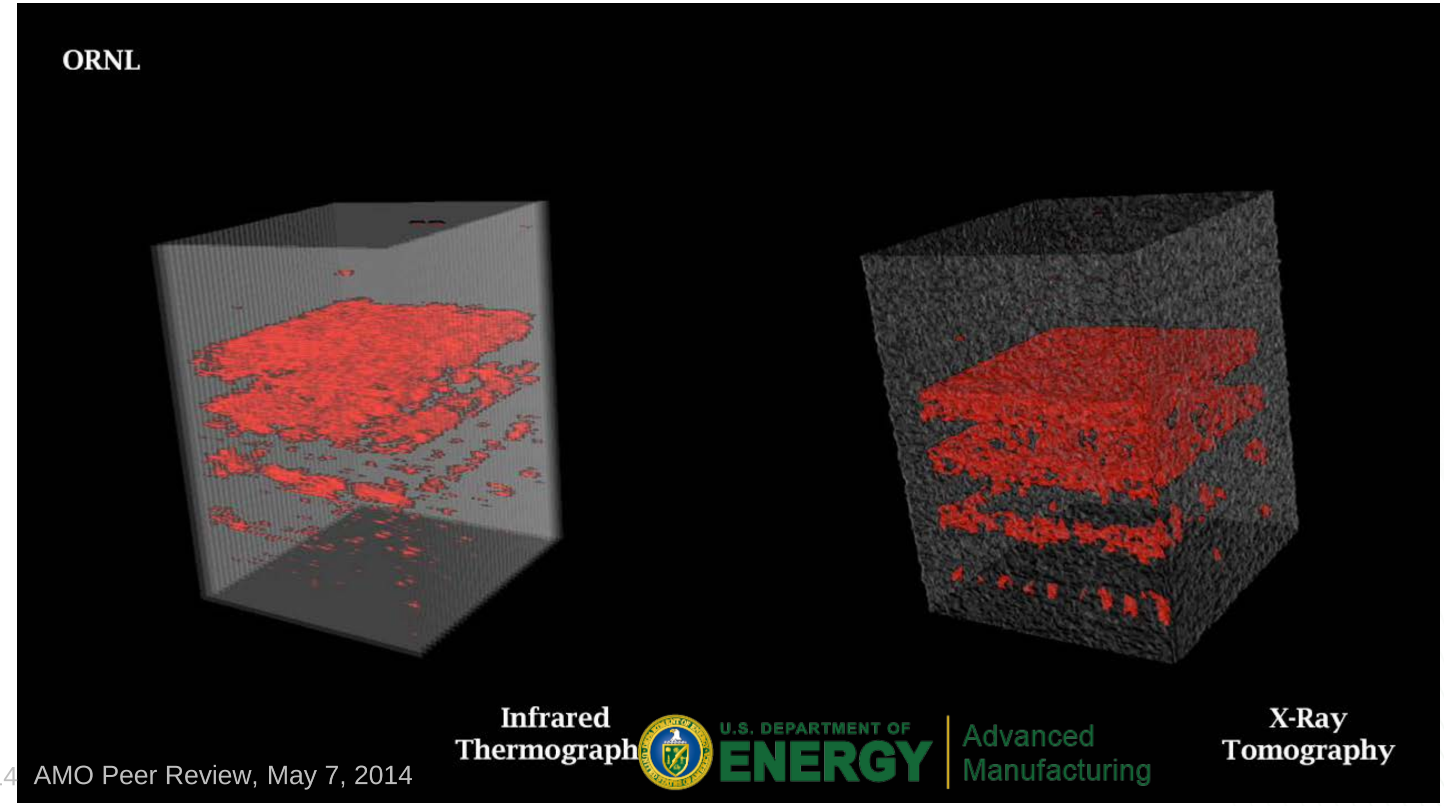


Post-process characterization of deposition

- Working with Savannah River Computational Tomography
- Validating In-situ monitoring from ORNL

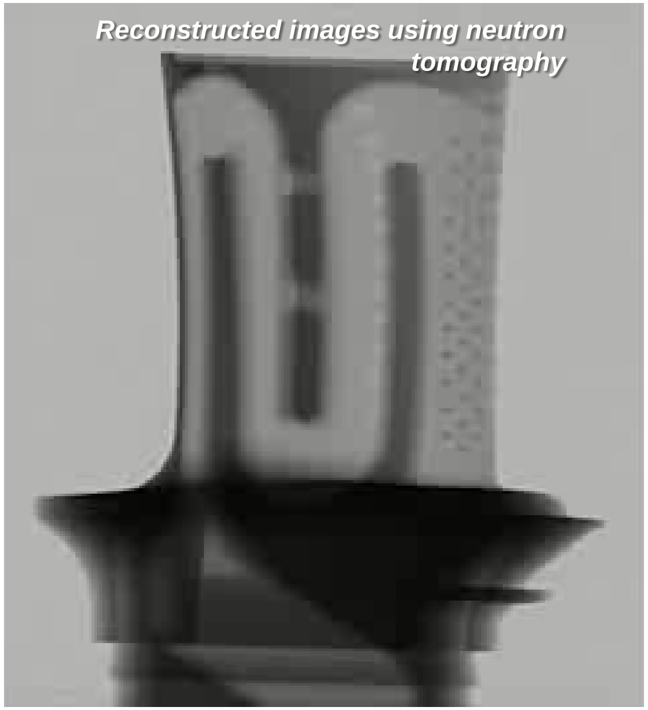


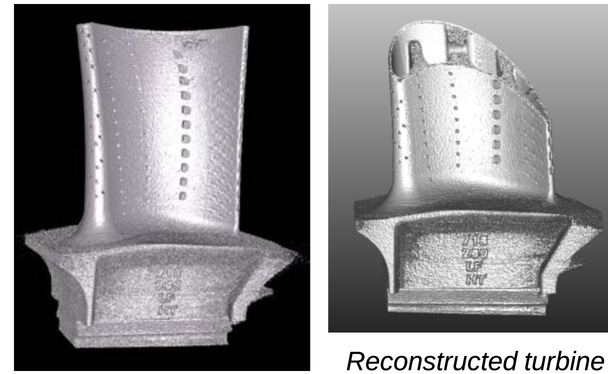




Neutron characterization of AM

Unique Capabilities


Reconstructed images using neutron tomography


Reconstructed turbine blade using neutron imaging

- 210 Images around 180 degree rotational axis
- Currently 50-75 μm resolution at HFIR, VENUS is targeting 10 μm at SNS
- Developing methodology to perform stress mapping with tomography

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Neutron characterization of AM

Leveraging Unique Capabilities

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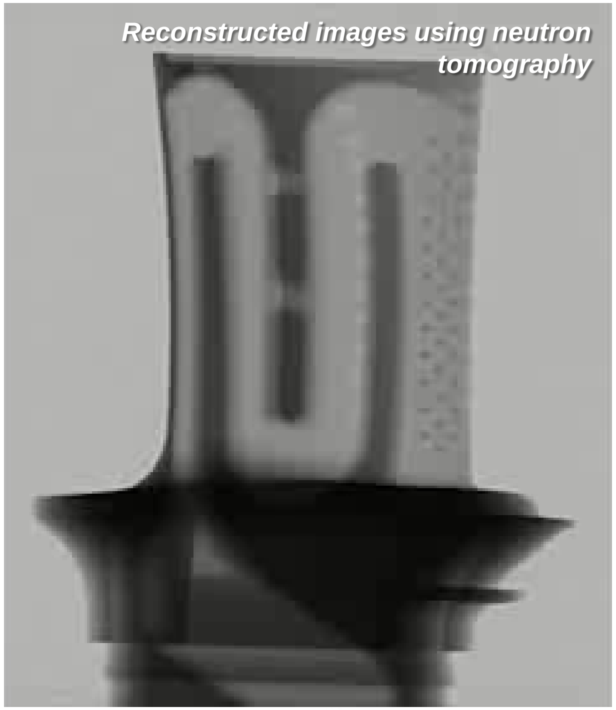

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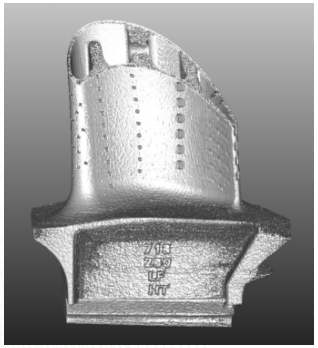


Reconstructed turbine blade using neutron imaging

Tour inside a turbine blade

Demonstrating new technologies

Last Year

- A2XX (Large volume machine) successfully utilized to deposit components
  - 3X Larger Previous Build Volumes for E-Beam Powder Bed Deposition (~14”x14”x15”)
  - Large field of view camera
  - 4 ports located on top of machine with shutter mechanism (1 port for CCD imaging, 1 port for infrared video imaging, 2 open ports)
- Technology Transitioned to Industry

This Year

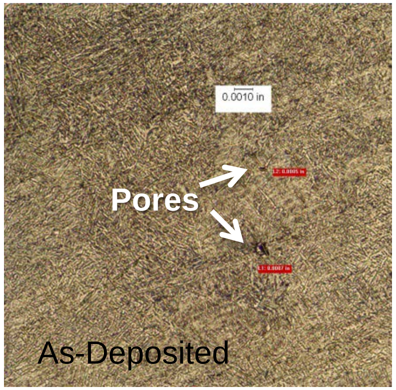
- Q10 System has new e-beam gun/filament
- Increase maximum melt current from 21 to 35 mA
- Potential to increase deposition rate to 200 cm^3/hr

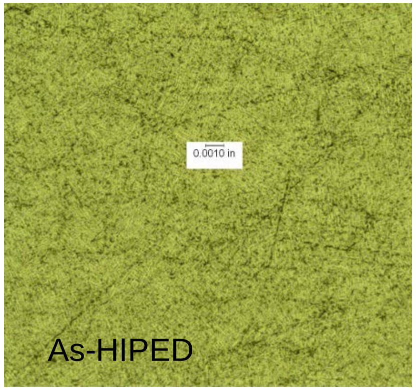
Arcam and ORNL success through cooperation

- $3.6MM CRADA established 2012
- Arcam applications engineer resident at MDF
- MDF serves as Arcam US training base
- Strategic alliance with DiSanto Technology gives Arcam a US manufacturing location
- Significant Arcam equipment capability at MDF
  - A2 is capable R&D machine
  - Second A2 owned by Arcam
  - Q10 is state-of-art production machine
  - S12 donated by Boeing and upgraded to A2 by Arcam

Creating data sets for qualification of parts

- Fabricated using Arcam EBM, followed by HIP, and machined





  - Met ASTM standards for tensile properties
  - Decrease *buy-to-fly* ratio from 33:1 to ~1.5:1
  - Decreased cost by over 50% using AM
- Bracket is currently being evaluated for JSF qualification

Property	**Min. Value**		**Max. Value**	
Ultimate Tensile Strength (ksi, MPa)	132	910	152	1,048
Elongation, %	12		22	
Over 60 tensile specimens tested within a matrix of processing conditions				

Working with Industry

Creating data sets for qualification of parts

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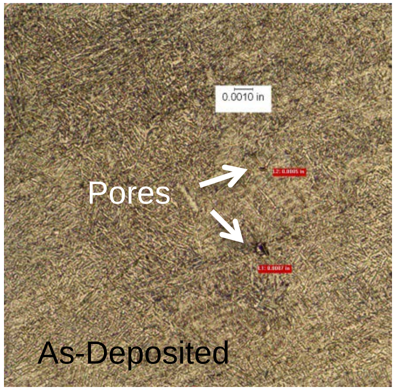
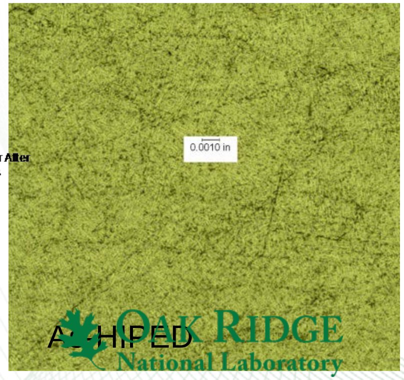
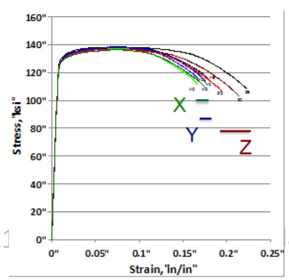
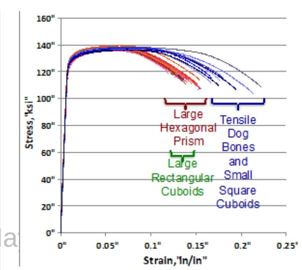




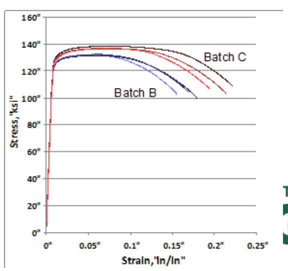
Orientation



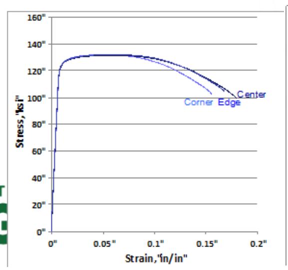
Geometry



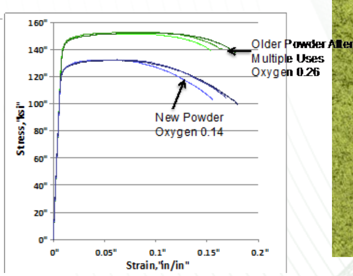
Batch-to-Batch



Location



Interstitals



AM enables reduced product life-cycle energy consumption through topology optimization

- **Life cycle assessment determines real energy used over lifetime of product, cradle to grave**
  - **Raw material, manufacturing, freight and distribution, use, and end of life**
- **Topology optimization methods solve material distribution problem to generate optimal topology or design**

Optimized Design

65% lighter, **saving manufacturing materials**

64.7 MBtu/part, **in-use phase energy savings**

CASE STUDY: Aircraft Brackets

- **Initial adoption of AM in aircraft has begun by targeting less critical components e.g. cabin brackets**
  - Affix cabin structures (kitchens, lavatories, galleys, etc.) to primary airplane structure and are less critical
- **A38 has approximately 25,000 different types of brackets which leads to more than 250,000 brackets**

Total energy savings per part:

66.2 MBtu/part over a 15 year lifetime

2.4 lb

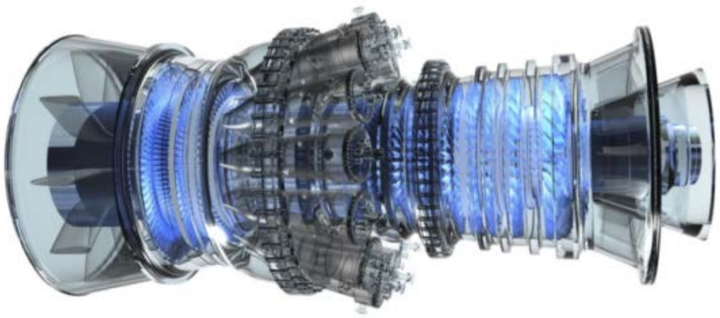
0.84 lb (optimized)

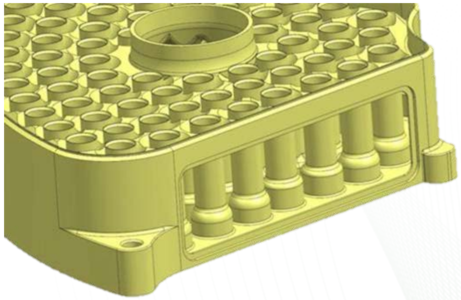
Partnership with GE

CRADA

- Design, develop, and commercialize a highly efficient AM turbine combustor
  - Enabling an increase in efficiency 1%-2% by eliminating leaks and reducing cooling requirements
- Full scale micromixer fabricated from CoCr
  - Reduced part count from 200+ to 1
  - 15,000 braze joints eliminated
  - Increased reliability
- Redesign of turbine combustor incorporating multi-tube mixer design enables:
  - Increase burn temperature by at least 100F
  - Reduce cooling requirements
  - Eliminate leakages by reducing part count
- 1% efficiency gain*
  - Potential 205 Tbtu/year energy and 12 million tons CO_2/year savings

Evaluation of AM technologies for gas turbine components



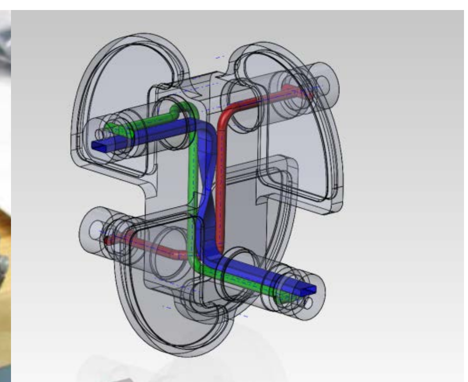


*38 Quads electrical generation in US with 18% coming from natural gas (7 Quads)
1% gain in efficiency (58% to 59%) correlates to 205 Tbtu/year and 12 million tons CO_2/year savings (100% penetration)

New applications for robotic systems

Leveraging Resources

Robo[illegible]ovided as backdrop in the White House as President Obama announced new two manufacturing innovation institutes.



All components produced by additive manufacturing

- 25-lbs total weight, 60” long arm
- Neutrally buoyant without floatation
- Fluid passages integrated into structure
- 7 degrees of freedom with 180 degree rotation at each joint
- Custom thermal valves for energy efficiency

Enabling New US Manufacturing: MDF partnership with Arcam leads to US manufacturing

Arcam AB and DiSanto strategic alliance, Feb. 2013

- DiSanto (Shelton, CT), full service medical device contractor
- Arcam AB, leader in electron beam melting additive manufacturing technology
- Agreement establishes US-based production facility for medical implants among other components (aerospace, automotive, etc.)
- Arcam distribution center will be co-located with DiSanto
- Approx. 8,000-ft of production with potential for 80 machines at full scale operation

Outline

✓Manufacturing Demonstration Facility

- Impacts with Industry
  ✓ Metal additive manufacturing
  – Polymer additive manufacturing
- STEM and Workforce Development

Polymer additive manufacturing

Fused Deposition Modeling (4)

- Developing in-situ characterization, feedback and control
- New high strength materials
- Increased z-strength

Stratasys FOR A 3D WORLD™

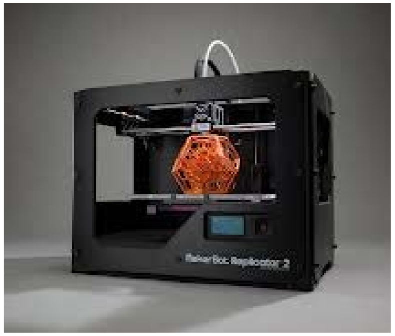
Stereolithography (1)

- Deposition of multiple materials, integrated structures, and material gradients
- High resolution, complex geometries, and smooth surface finish

OBJET

Stratasys FOR A 3D WORLD™

Desktops (15)



- Enormous growth
- Low-cost (<$2K)
- Open source so easy for new material and control development

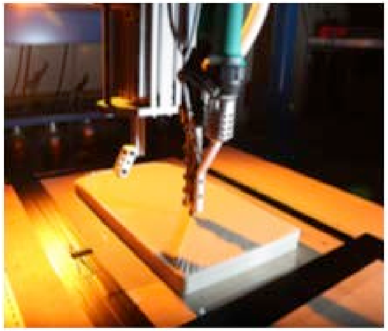
MakerBot

AFINIA

Cubify™

Solidoodle

Big Area Additive Manufacturing (BAAM)



- Large build volume, currently 8 x 8 x 8 ft
- Pellet to part manufacturing
- 10-20 lbs per hour throughput
- Amorphous & semi-crystalline materials

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Polymer AM supply chain

Materials Suppliers

- TECHMER PM — POLYMER MODIFIERS
- Stratasys — FOR A 3D WORLD™
- PolyOne
- sabic

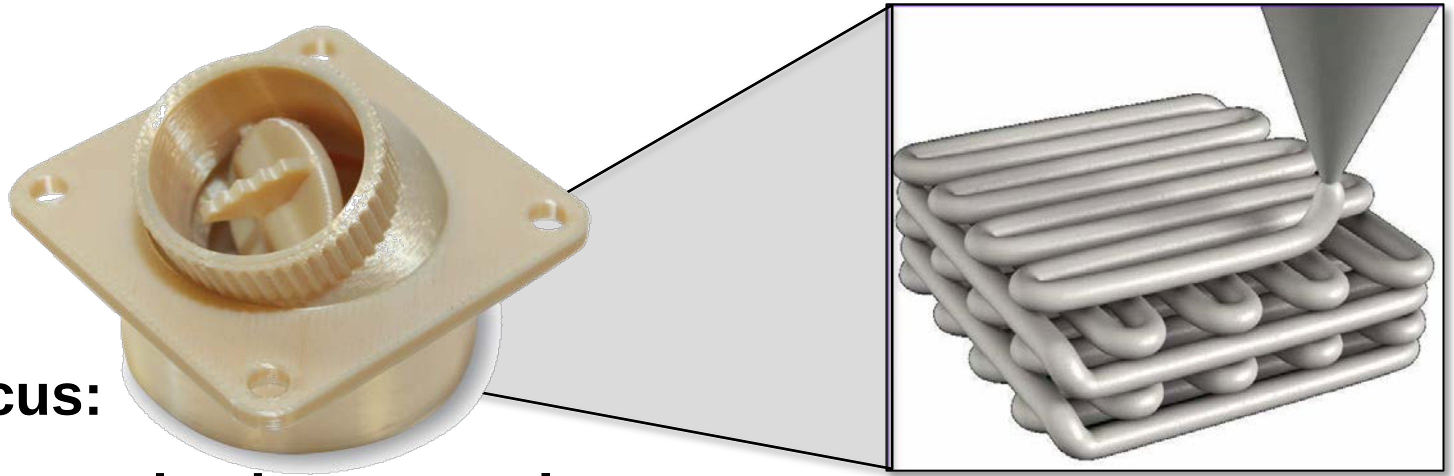
Equipment Suppliers

- Stratasys — FOR A 3D WORLD™
- CINCINNATI — CINCINNATI INCORPORATED
- Ajax Tocco
- OBJET
- MakerBot
- AFINIA
- Solidoodle
- Cubify

End Users

- EPRI — ELECTRIC POWER RESEARCH INSTITUTE
- PPG
- AMERICAN TRIM
- LOCKHEED MARTIN
- LOCAL MOTORS
- TruDesign
- NORTHROP GRUMMAN
- BOEING

Polymer additive manufacturing
Fused Deposition Modeling



Research focus:

- **In-situ characterization control**
  - **Thermography**
  - **Vision systems**
- **Materials development**
  - **Specific strength equivalent to heat treated Al alloys**
  - **High strength and fiber reinforced polymers**
- **Isotropic mechanical properties**
  - **Process modifications to improve build-direction strength**

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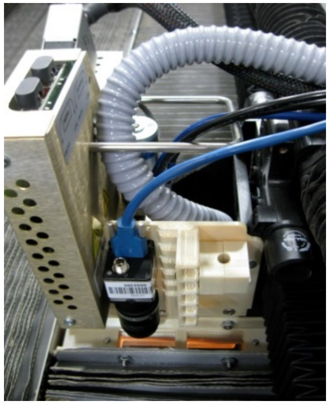
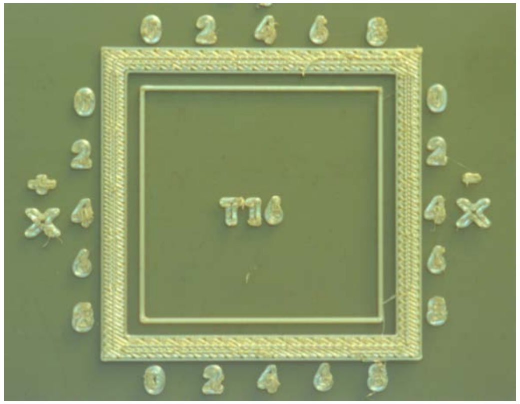
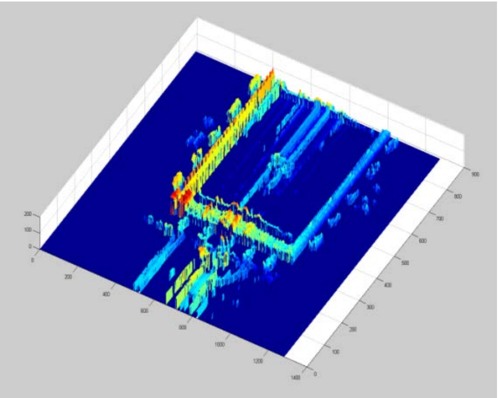
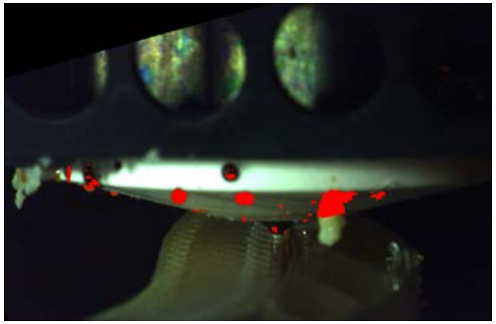
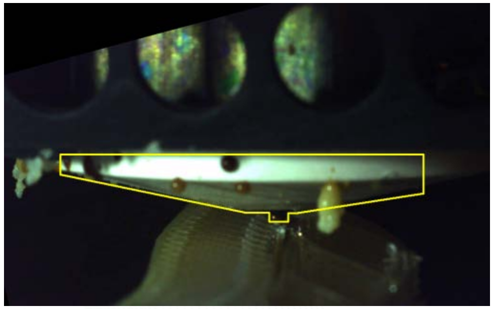
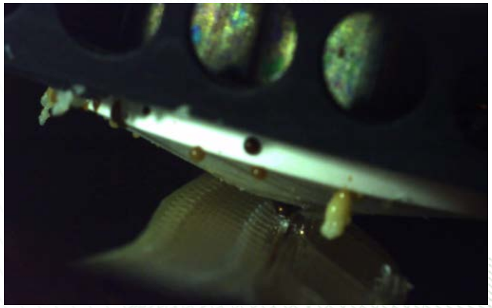
In-situ characterization visioning system

Stratasys
FOR A 3D WORLD™

- Integrated vision system on Fortus 900 MC located on extruder above bellows
- Provides real-time measurement of extrudant and part
- Enables:
  - Detection of part failure
  - Monitoring quality of time (embedded debris)
  - Enables automated tip calibration
  - What does this enable?

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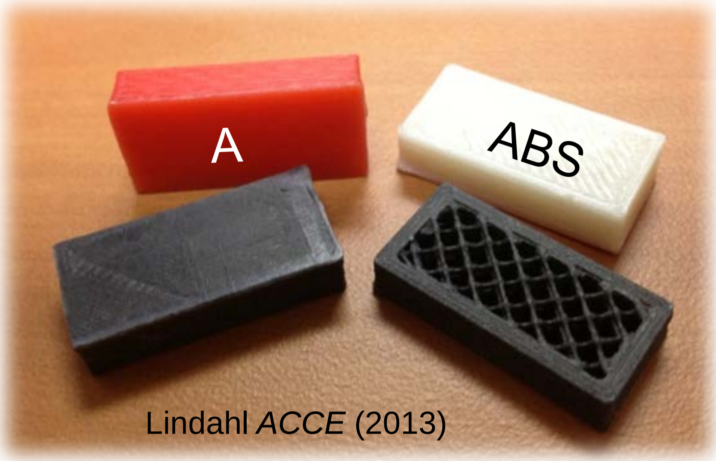
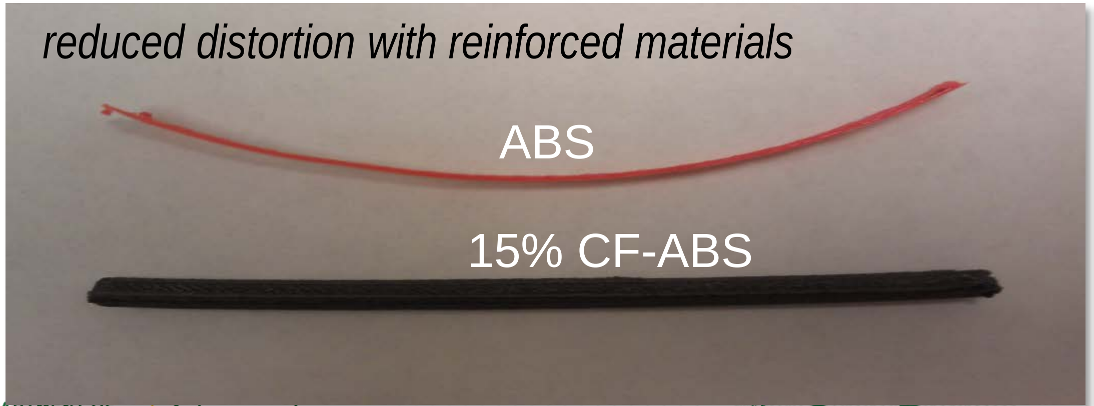
Polymers material development

- Low-cost desktop systems used for material development
- Reinforced polymers have demonstrated 2x increase in strength and 4x increase in stiffness
- Reinforced polymers allow high resolution, low distortion printing
- Performance of low-cost printers equivalent to higher-cost industrial systems when using reinforced materials

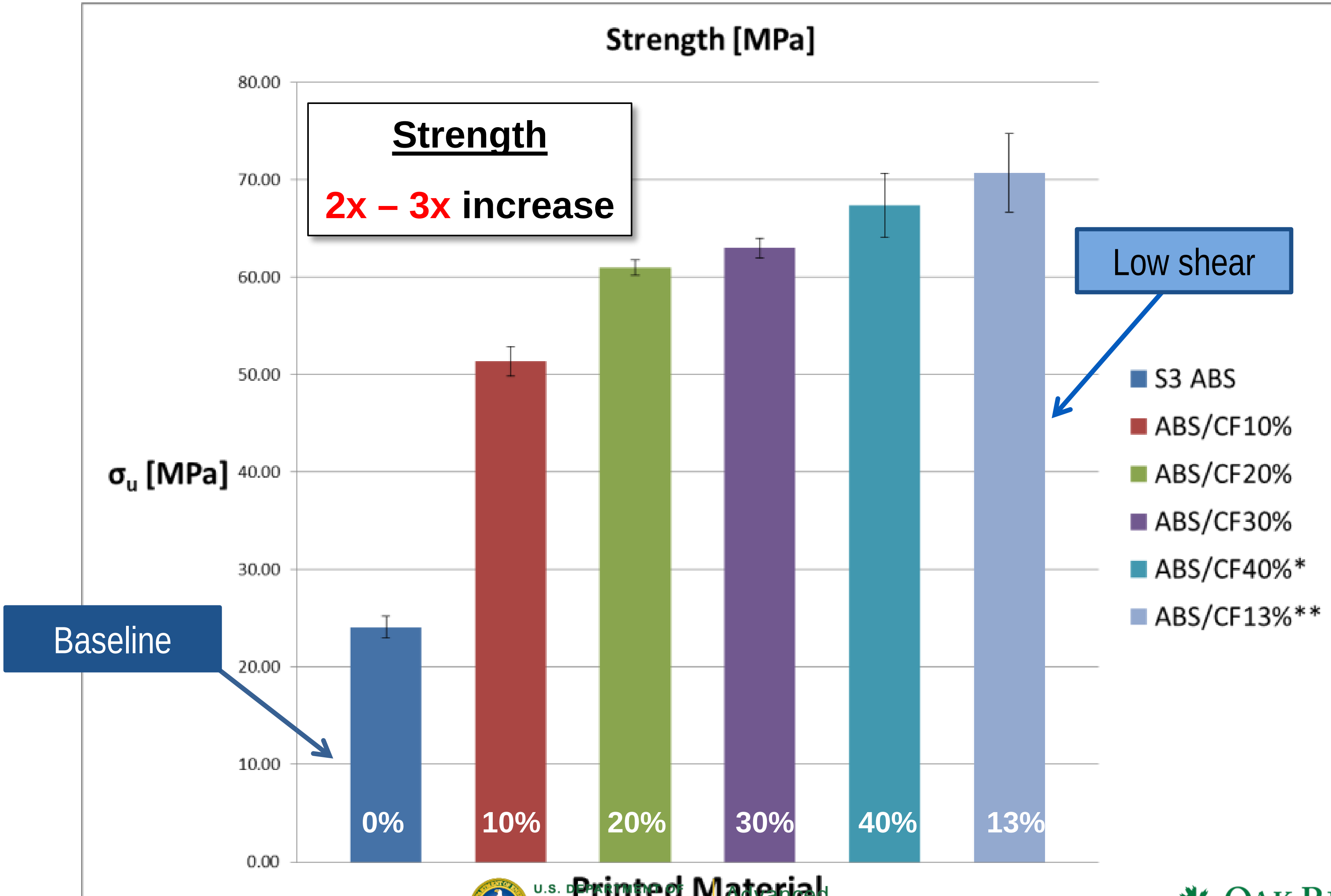


Lindahl *ACCE* (2013)



Reinforced-ABS printed parts

Mechanical Performance



*incomplete print, **no mixing, lower temperature

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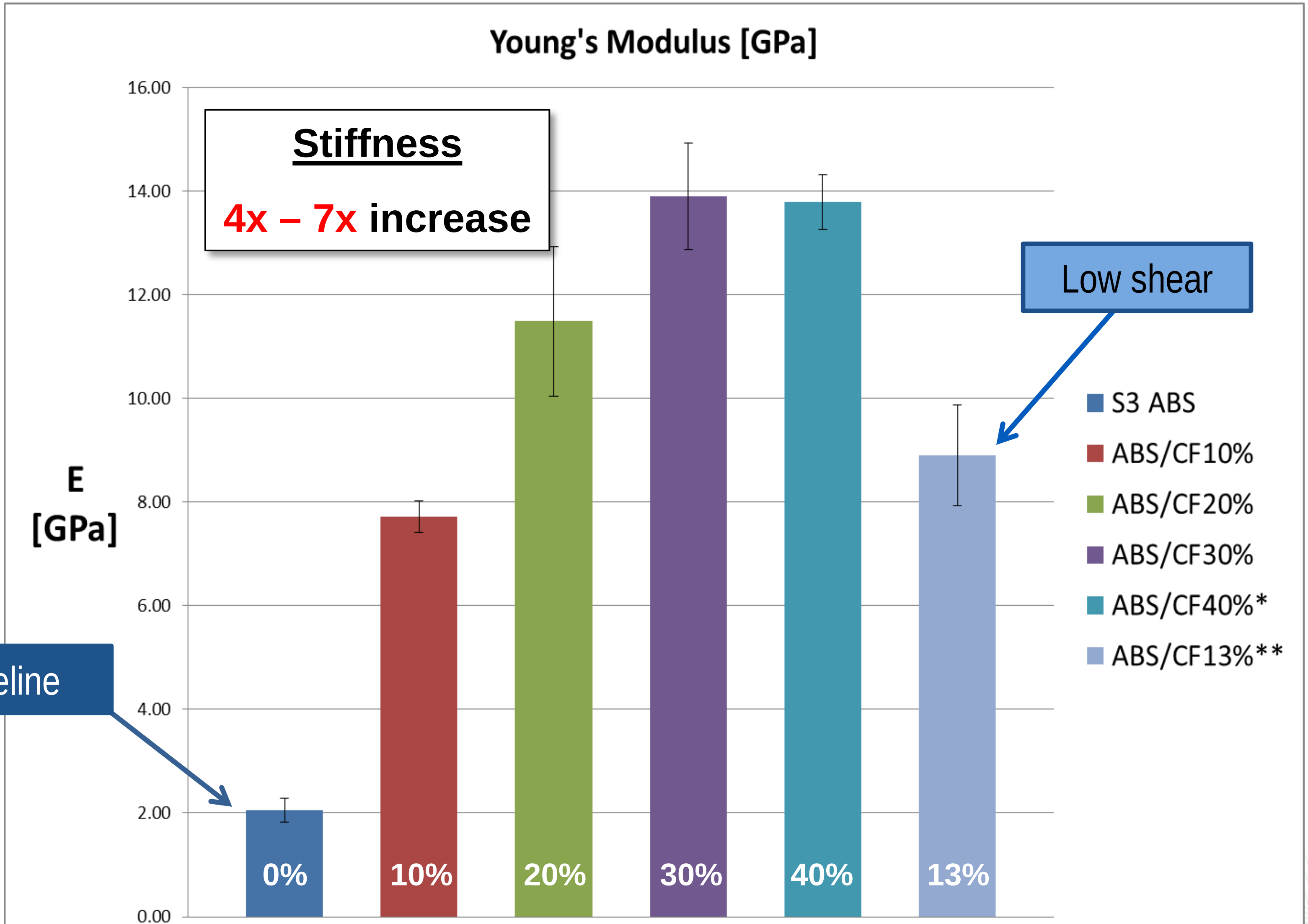
Reinforced-ABS printed parts

Mechanical Performance

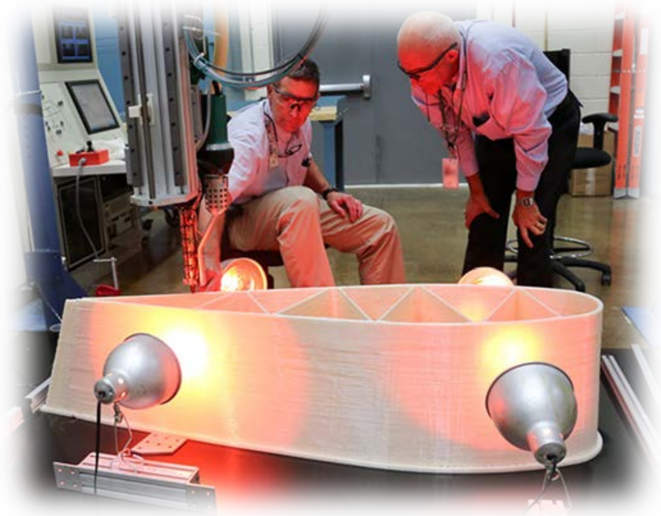


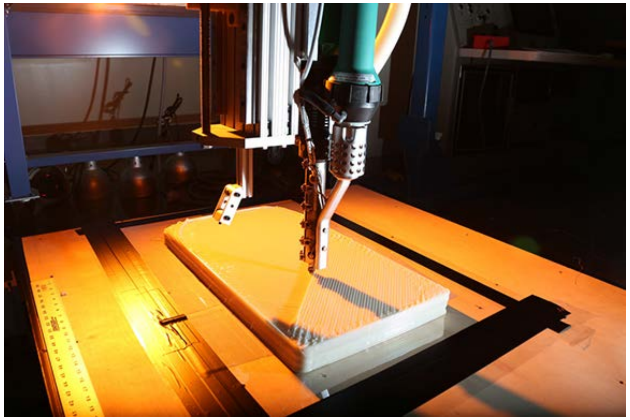
*incomplete print, **no mixing, lower temperature

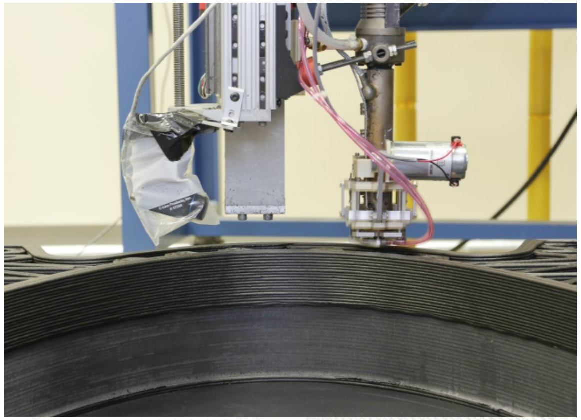
Large-Scale, Out-of-Oven Additive Manufacturing

Big Area Additive Manufacturing (BAAM)

- **Pellet-to-Part**
  - **Pelletized feed replaces filament to enable 50x reduction in material cost**
- **Deposition rate 100x commercially available systems**
- **Tooling, UAVs, and robotics applications**
- **Prototype system 8'x8'x8' build volume**
- **Huge initial interest by aerospace and tooling industry**







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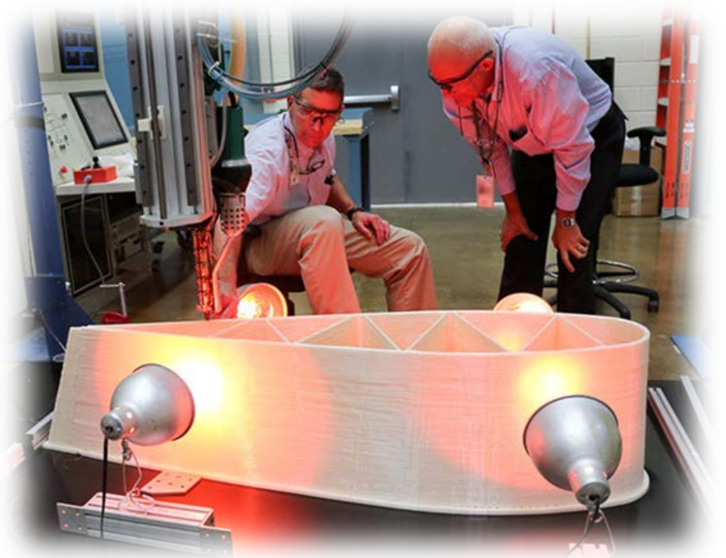
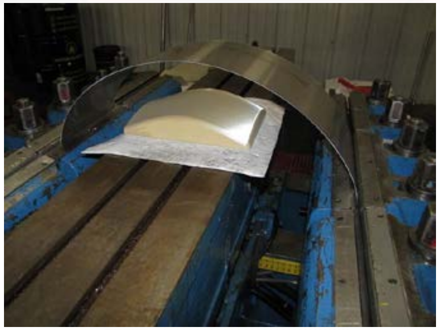
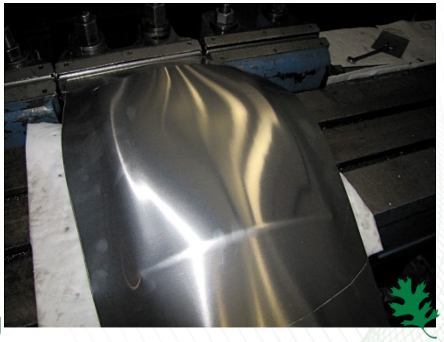
Big Area Additive Manufacturing (BAAM)

- Large scale deposition system
  - Unbounded build envelope
  - High deposition rates (~20 lbs/h)
    - FDM is 1 to 4 ci/hr
    - Large Scale is > 200 ci/hr to 400 ci/hr
  - Direct build components
  - Materials development leads to controlled thermal stresses/expansion enabling out-of-oven processing
  - Near term application – Tools, dies, molds, direct part manufacture







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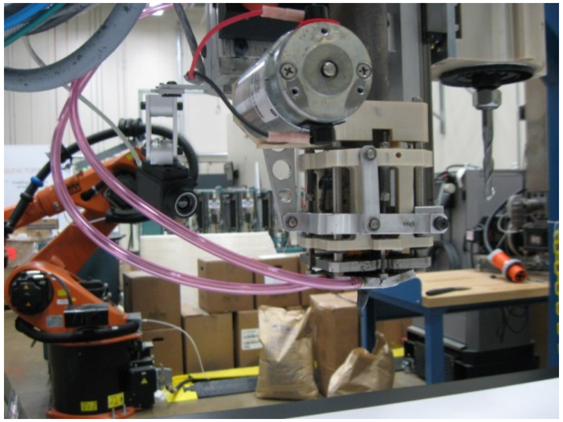
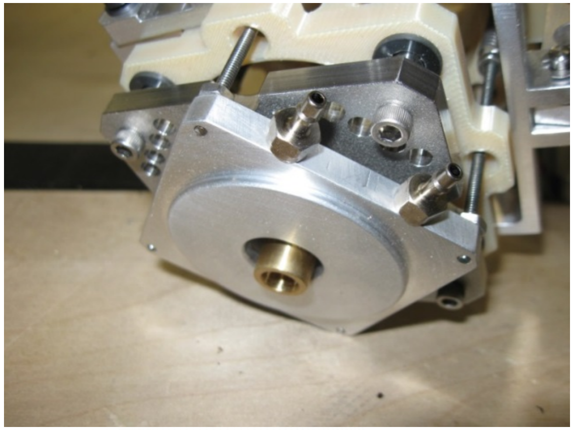
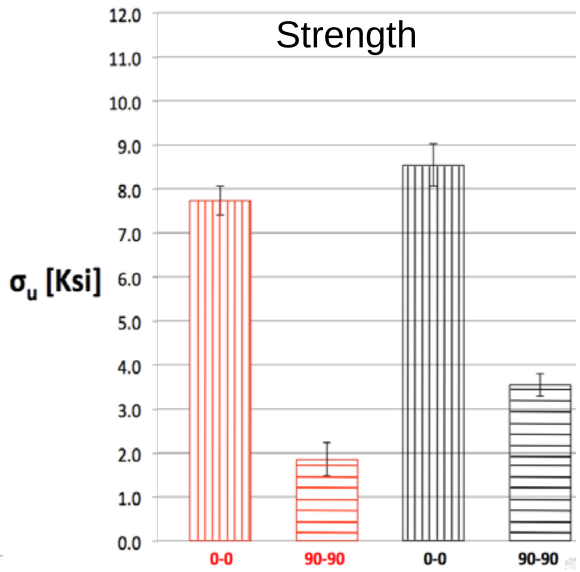
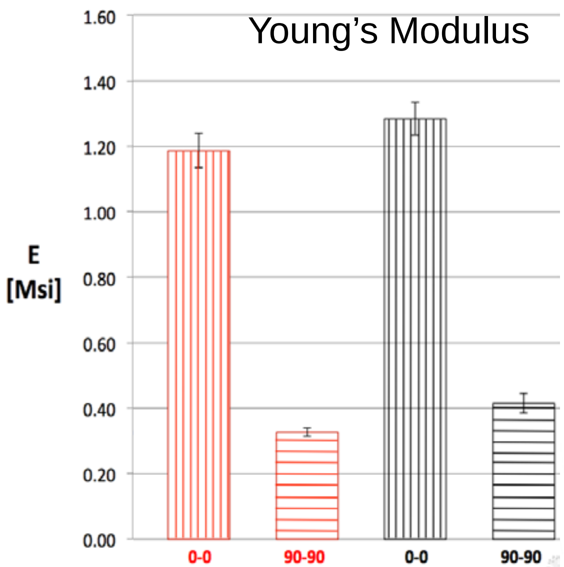
BAAM Z-dither

- Objective is to have a dither on the head of the extruder to push the material in seams, eliminate protrusions and level the layer
- Based on orientation:
  - 10% to 75% increase in strength and 10% to 30% increase in modulus



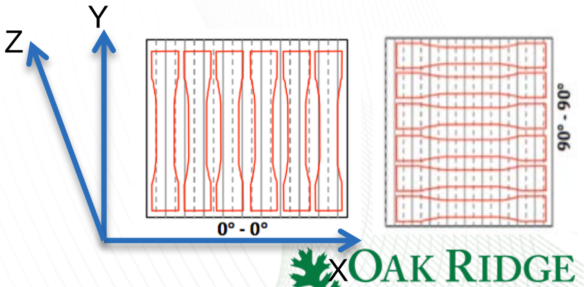




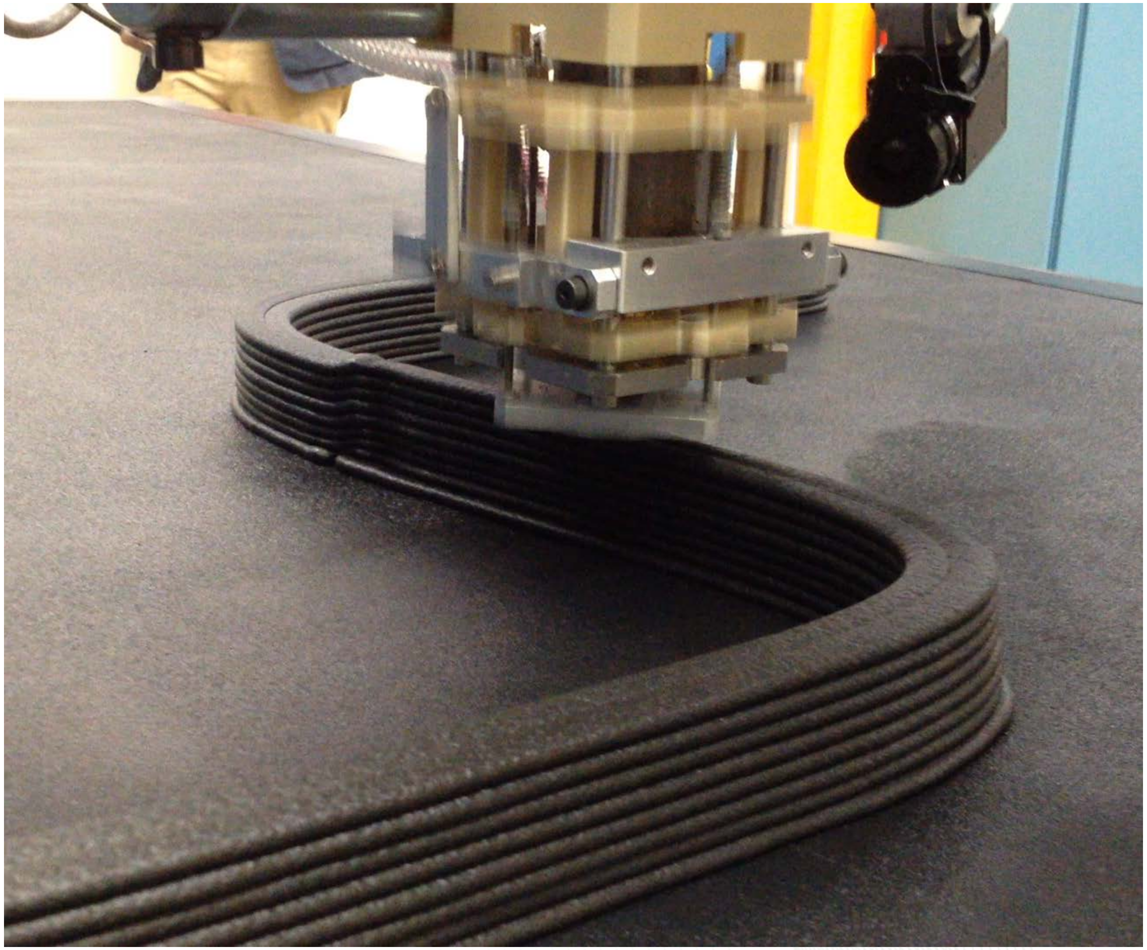


Z-dither

No Z-dither



Thermal Imaging of BAAM



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Thermal Imaging of BAAM

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Oak Ridge National Laboratory

Partnership with CINCINNATI®

CRADA

CINCINNATI INCORPORATED

ORNL and Cincinnati Incorporated collaborate to create commercial large-scale system

BAAMCI

BIG AREA ADDITIVE MANUFACTURING

Partnership to establish US-based large-scale AM equipment manufacturer

- **Targets tooling lead time and cost reduction**
- **Based on existing ORNL gantry system**
- **Cincinnati providing >$1M in cost share year one**
  - **First large-scale polymer AM system delivered to MDF, April 2014**
- **Interest from multiple automotive, aerospace and tooling industries**
- **Stretch form and hydroform tools demonstrated**

Partnership with TECHMER ES ENGINEERED SOLUTIONS

CRADA

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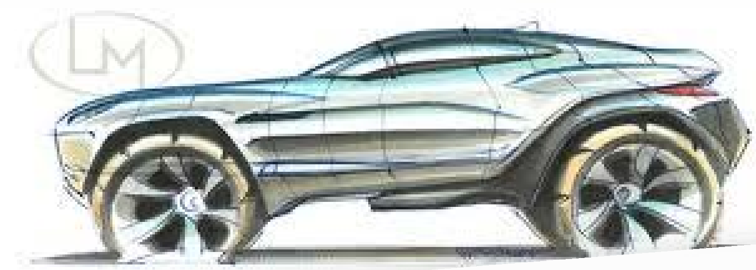
OAK RIDGE National Laboratory

Partnership with

CRADA



LOCAL MOTORS

Local Motors Launches Design Challenge for First 3D-Printed Car

Press Releases

ckish April 15, 2014, 9:04 p.m.

Local Motors Launches Design Challenge for First 3d-Printed Car

Initial challenge will inspire the overall design of the vehicle that Local Motors will manufacture at IMTS in September 2014

Extreme Innovation

Rapid automotive design and innovation using large-scale polymer additive manufacturing

- Demonstrate light-weighting of systems and subsystems
- Develop tools for additive + subtractive manufacturing
- Explore innovative assembly approaches

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Partnership with
Work for Others

NEUROLUTIONS
Restoring function by thought

"What fires together, wires together"
– Dr. Leuthard

MDF Enables New Startup
Neuralutions utilizes MDF to develop new product

- Dr. Eric Leuthard at Washington Univ. has shown that rapid retraining is key to stroke recovery
- Additive manufacturing allows custom fit glove device using brain machine interface to retrain movement
- Gloves are light-weight, low cost and customizable to patient
- First patient showing positive response

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Engaging New Startups

SENVOL

Advised Senvol, LLC on viability of business related to identifying AM-viable products

- **Startup consisting of two recent grads from U.Penn Wharton Business School**
- **ORNL educated team on technologies, costs, design guidelines, labor**
- **Senvol develop proprietary software for evaluating viability of using AM for manufacturing**
- **Recently won New York City Economic Development Corporations "NYC Next Idea" Competition**
  - **Received $35K and 6 months of free office space in Manhattan.**

NYC NEXT IDEA 2013-2014

Wharton UNIVERSITY of PENNSYLVANIA

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Working with ORNL's MDF

Manufacturing Demonstration Facility

- **Identify opportunities aligned with ORNL's MDF technology thrust areas**
- **Discuss ideas with MDF director**
- **Jointly pursue funding to support collaborative activity**

	Assess	Assist	Collaborate
Type of Agreement	User Agreement (Non Proprietary)	Work for Others Agreement (Proprietary)	Cooperative Research & Development Agreement
Length of Engagement	Up to 12 months	As defined by agreement	Longer-term basis of a year or more
Cost to Company	NO COST	Full cost recovery	Cost-share required
Intellectual Property Rights	Each party owns its own inventions. Jointly developed inventions will be jointly owned.	Companies own intellectual property made or created using corporate funds as a result of these engagements.	Companies own inventions they make during the collaboration and have an option to negotiate an exclusive license in a specific field of use to inventions made by ORNL.
Protection of Generated Information	Information generated is publicly available.	Companies paying for services with corporate funds can treat all generated data as their proprietary information.	Commercially valuable information generated under a CRADA may be protected for up to 5 years, depending on funding source.

MDF Supports Industry Innovation

- Engaging industry interest and participation in cost-shared collaboration to implement next-generation materials and processes.
- Helping companies access cutting-edge capabilities and equipment to design, test, and pilot new products and manufacturing processes.
- 15 new projects, so far, in FY 2014:

CINCINNATI®
CINCINNATI INCORPORATED

aerovalve

LOCAL MOTORS

PLANETARY SYSTEMS CORPORATION

GRID LOGIC

PIEDMONT PROPULSION SYSTEMS, LLC
A First Aviation Services Inc. Company

ECM Technologies

TruDesign

Sun Catalytix

TECHMER PM
POLYMER MODIFIERS

S-RAM DYNAMICS

AMERICANTRIM®

AO Applied Optimization

NORTHROP GRUMMAN

U.S. DEPARTMENT OF ENERGY

Advanced Manufacturing

ELECTRIC POWER RESEARCH INSTITUTE

OAK RIDGE National Laboratory

Working with Industry

2,952 Visitors
(578 Organizations)

117 NDAs
(105 active, 12 in progress)
Non-Disclosure Agreement

27 MOUs
Memorandum of Understanding

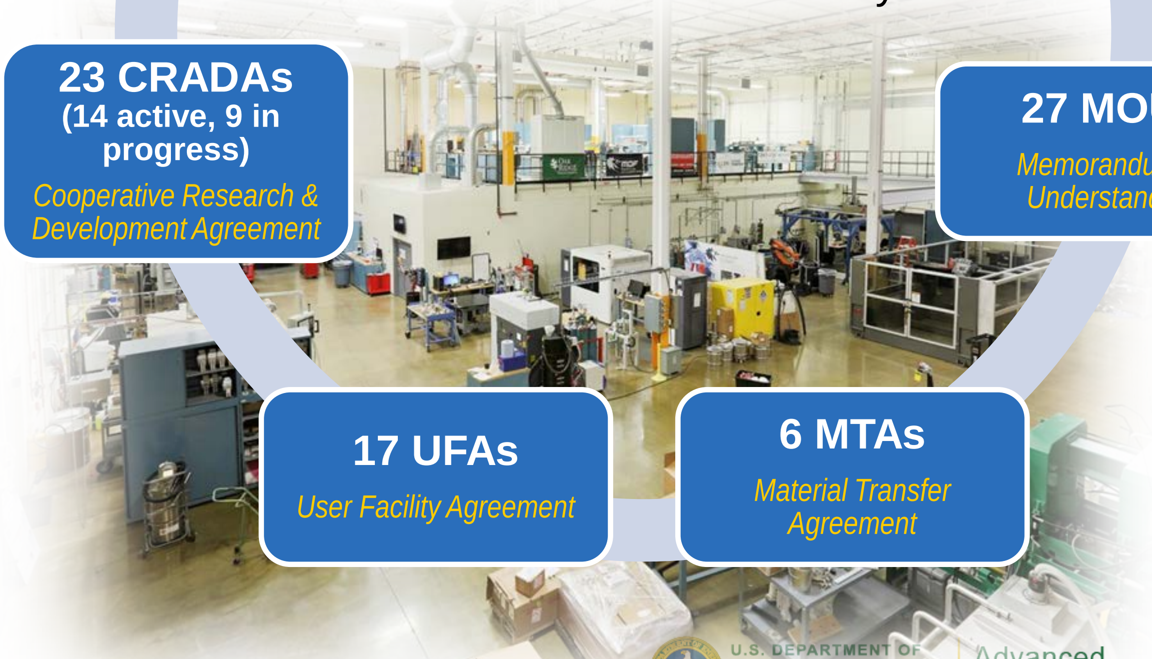
6 MTAs
Material Transfer Agreement

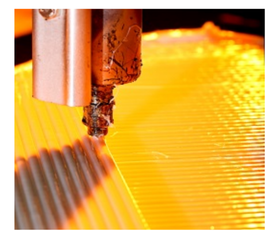
17 UFAs
User Facility Agreement

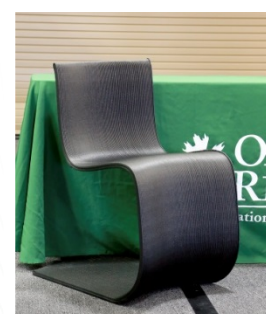
23 CRADAs
(14 active, 9 in progress)
Cooperative Research & Development Agreement

28 WFO
Work for Others

We partner extensively with industry to enable demonstration of next-generation materials and manufacturing technologies for advancing the US industrial economy.







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OAK RIDGE National Laboratory

Outline

- ✓ Manufacturing Demonstration Facility
- ✓ Impacts with Industry
  - ✓ Metal additive manufacturing
  - ✓ Polymer additive manufacturing
- **STEM and Workforce Development**

Science, Technology, Engineering & Mathematics (STEM)

MDF open to 26 schools, >750 students

Supporting FIRST Robotics and Lego League

FIRST®

FRC

FIRST® Robotics Competition

FLL

FIRST® LEGO® League

Science, Technology, Engineering & Mathematics (STEM)

MDF open to 26 schools, >750 students

DOE's MDF Partners with America Makes to Showcase AM at 2013 FIRST Championship in St. Louis

America Makes

DOE-AMO enables 3D printing in 2014 FIRST Robotics donating nearly 400 desktop printers to high school student teams.

FIRST

HVA team members (#3824), pose with Dean Kamen, FIRST Founder, at 2014 FRC Championship.

Team #4265, Secret City Wildbots win 2014 Excellence in Engineering

Team #3824, RoHAWKtics win 2014 Palmetto Regional

MDF Enable 2 new Lego League Teams to be Created,
STEM activities: FIRST Lego League (9-14 years)

Programming

Strategy

Robot game

- ORNL supports the TN region's FIRST Lego League activities with over 80 teams through financial tournament support and providing volunteers from team coaches to tournament organizers
- ORNL's MDF supports 40+ kids in FLL activities with space, mentors, and volunteers
- Between August and December, teams meet at the MDF to utilize facilities, research projects, and build autonomous robots on Lego's Mindstorm® technology
- Kids learn about original research, finding and analyzing information, mechanical engineering design, and programming to solve real world problems
- Awards for ORNL supported teams in 2013:
  - Knoxville regional: Championship (1st); Strategy and Innovation (1st); Inspiration (1st) ; Gracious Professionalism (1st)
  - East TN State Championship: Championship (3rd); Gracious Professionalism (1st); Programming (1st and 2nd); Strategy and Innovation (1st); Performance (2nd); Mechanical Design (2nd) all teams advanced to state championship

Engaging a growing workforce

- **Community Colleges**
  - Roane State: Advanced Materials Training and Education Center, 2 separate awards
  - Pellissippi State: Advanced Manufacturing & Prototyping Center of East Tennessee
  - 48 Summer Student in 2014
- **Industry Fellows**
  - David Dietrich, Boeing
    Metals Fabrication Technology on-site Leader
  - Frank Medina, Arcam
    US Technical Lead
  - Sid Palas, Lockheed Martin
    Mechanical engineer part of a group of up and coming LM employees experiencing/visiting multiple manufacturing facilities across LM's portfolio
  - Roger England, Cummins
    Director of Materials Engineering and Technology
  - James Earle, Local Motors
    Engineer, Advanced Manufacturing

Enabling workforce development and manufacturing clusters

Focused on carbon fiber and additive manufacturing

Roane State Community College

ORAU Oak Ridge Associated Universities

- Carbon Fiber Technology Facility
  - Leveraging Roane State Community College Advanced Materials Training Education Center and ORAU Internship program for workforce
  - March: Dedication ceremony and announcement of DOE Clean Energy Manufacturing Initiative
  - Working with textile-grade acrylic fiber
- Manufacturing Demonstration Facility
  - Working with National Additive Manufacturing Innovation Institute
  - April: Council on Competitiveness workshop on additive manufacturing and National Engineering Forum

Oak Ridge Carbon Fiber Composites Consortium

A 54+ member consortium of private industry, government agencies, and educational institutions

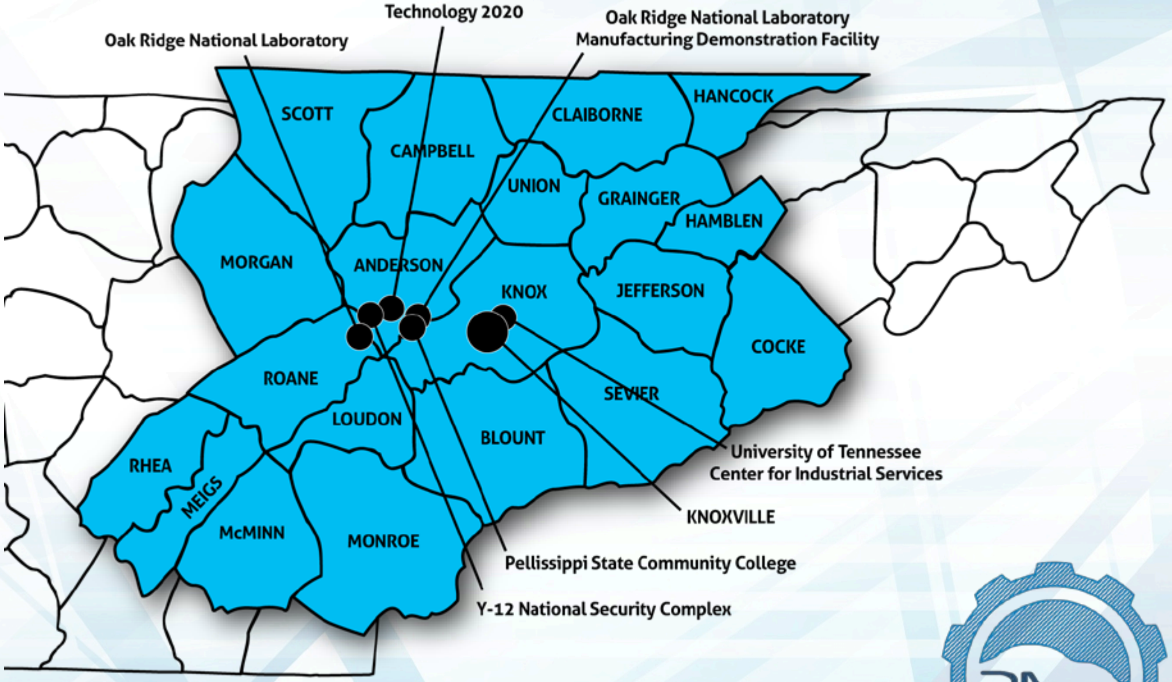
ramp

Regional Advanced Manufacturing Partnership
A 20-county industry cluster in East Tennessee, where manufacturers from disparate disciplines collaborate to develop and apply innovative technology to their existing operations, develop and foster a reliable, mature supply chain in the region, and develop and retain a properly trained next generation workforce.

Building Regional Success

AMP! – $2.4M Award for Advanced Manufacturing & Prototyping Center of East Tennessee

- Funded through the Advanced Manufacturing Jobs and Innovation Accelerator Challenge
- Connecting innovation through collaboration
- Spurring job creation
- Increasing US competiveness



tech 20/20 technology 2 commerce | The University of Tennessee UT Center for Industrial Services | Oak Ridge National Laboratory | Pellissippi State Community College

Workforce Development

Developing the Carbon Fiber workforce

- Leveraged Roane State Community College Advanced Materials Training Education Center program for candidate pool
- Technician Internship Program in collaboration with ORAU
  - Advanced manufacturing skills development
  - Progressive qualification through all unit operations and Control Room
  - Potential to earn credits toward A.S. degree at RSCC
- Training will develop advanced manufacturing workforce of the future

Roane State COMMUNITY COLLEGE

A VISION FOR THE FUTURE AMTEC ROANE STATE COMMUNITY COLLEGE Advanced Materials Training and Education Center

ORAU OAK RIDGE ASSOCIATED UNIVERSITIES

Creating an Ecosystem

Driving Innovation Through Federal Investments

2,952 Visitors (578 Organizations)

STEM
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User Facility Agreement

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Enabling Workforce Training in Materials, Manufacturing and AM

28 WFO
Work for Others

3D Printers in 450 High Schools
1000s of Students

Leveraging Resources

$DOE < $Other
(Other: Federal Agency, Industry)

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Discussion

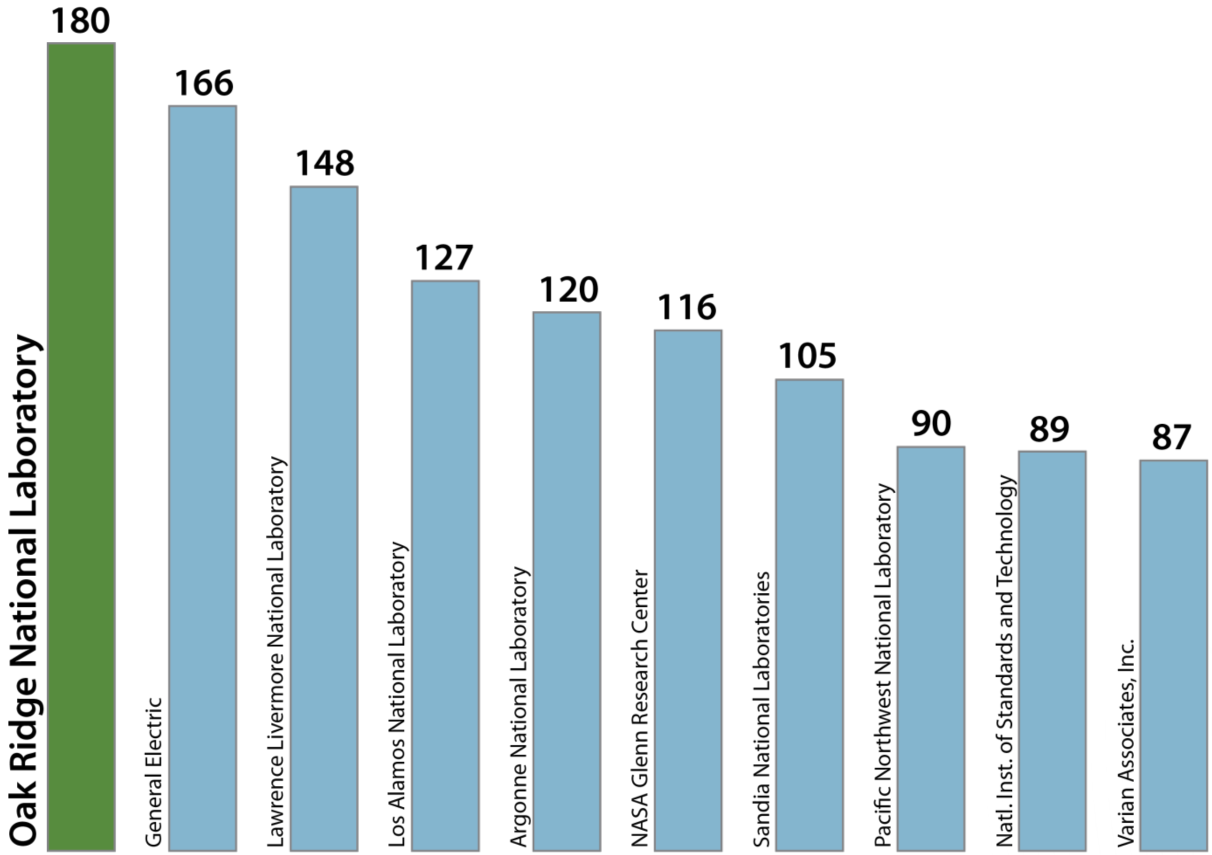
Craig Blue
865.574.4351
blueca@ornl.gov

www.ornl.gov/manufacturing

Reference slides

ORNL is the leader in R&D 100 Awards

Called the "Oscars of Innovation", the R&D 100 Awards recognize and celebrate the top 100 technology products of the year.



Technology categories

- Materials, processing, and manufacturing (**40%**)
- Electrical and mechanical systems
- Analytical instruments: Energy, Environmental Sciences

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Additive Manufacturing Enables Reduced Product Life-Cycle Energy Consumption Through Topology Optimization

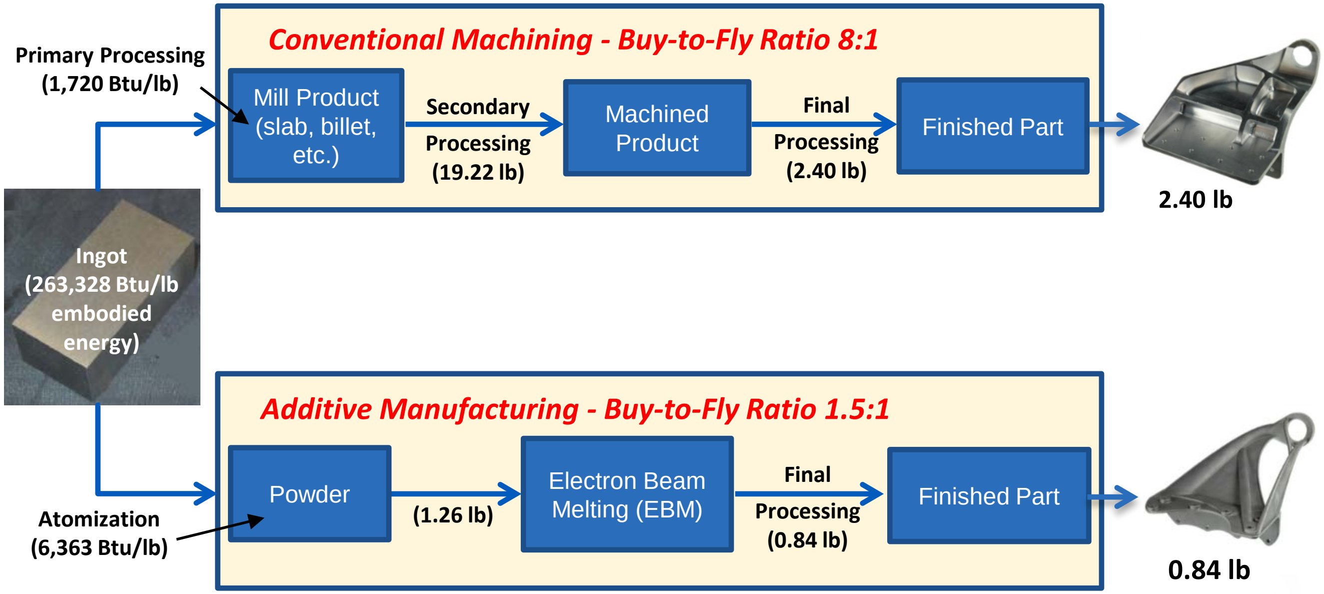
- Life cycle assessment determines the real energy used over the lifetime of a product, from cradle to grave
  - Raw material, manufacturing, freight and distribution, use, and end of life
- Topology optimization methods solve a material distribution problem to generate an optimal topology or design
- Case study – aircraft brackets
  - Initial adoption of AM in aircraft has begun by targeting less critical components e.g. cabin brackets
    - Affix cabin structures (kitchens, lavatories, galleys, etc.) to primary airplane structure and are less critical
  - A38 has approximately 25,000 different types of brackets which leads to more than 250,000 brackets
  - Optimized design: Results in bracket that is 65% lighter, saving manufacturing materials and resulting in use phase energy savings
    - Use phase energy savings: 64.7 MBtu/part

2.4 lb

0.84 lb (optimized)

Total energy savings per part: 66.2 MBtu/part over a 15 year lifetime

Case Study: Topologically Optimized Aerospace Bracket - EBM vs. Conventional Machining



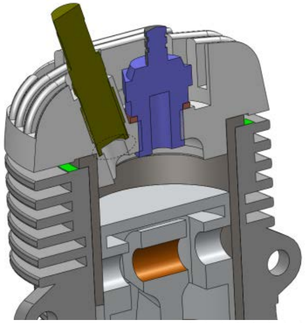
Life Cycle Phases	Unit	Conventional Manufacturing	Additive Manufacturing	Energy Savings per Part
Raw Material Energy	Btu/part	2,021,120	263,900	1,757,221
Manufacturing Energy	Btu/part	65,485	65,872	(387)
Freight and Distribution Energy	Btu/part	40,462	14,161	26,301
Use Phase Energy	Btu/part	99,583,158	34,854,105	64,729,052
Disposal Energy Use	Btu/part	(433,775)	(151,821)	(281,954)
Total Energy Use per Part	**Btu/part**	**101,276,449**	**35,046,216**	**66,230,233**

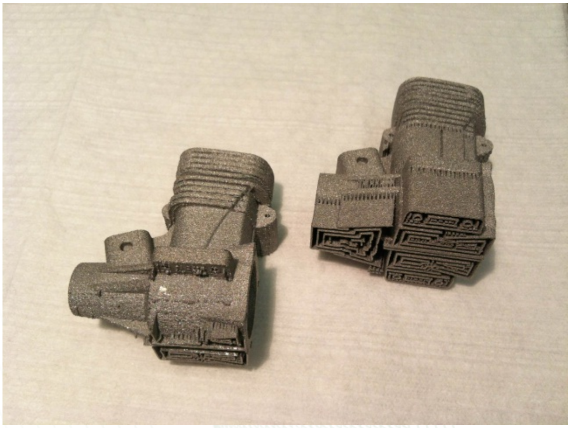
Case Study: Topologically Optimized Aerospace Bracket - EBM vs. Conventional Machining

Life Cycle Phase	Parameter	Conventional Manufacturing	Additive Manufacturing
Manufacturing Process	Process Name:	Forging , Primary Machining, Finishing	Electron Beam Melting (EBM)
Material Phase	Material Name and embodied energy:	Ti alloy - 263,328 Btu/lb (primary) 37,403 Btu/lb (recycled)	Ti alloy powder 269,691 Btu/lb (primary), 43,766 Btu/lb (recycled)
	Amount of material as a % of total initial mass:	100%	100%
	Total material initial mass:	19.22 lb	1.26 lb
	Final part mass:	2.4 lb	0.84 lb
Manufacturing Phase	Primary manufacturing or shaping process and embodied energy:	Metals - Rough rolling, forging – 1,720 Btu/lb	Electron Beam Melting (EBM) – 51,133 Btu/lb
Freight and Distribution	Primary mode for Freight and distribution and embodied energy:	Long-Distance Truck 3.06 Btu/lb/mile	Long-Distance Truck 3.06 Btu/lb/mile
	Average freight and distribution distance travelled by a part by primary mode:	3,107 miles	3,107 miles
	Secondary mode for Freight and distribution and embodied energy:	Local Truck 8.44 Btu/lb/mile	Local Truck 8.44 Btu/lb/mile
	Average freight and distribution distance travelled by a part by secondary mode:	870 miles	870 miles
Use Phase	Typical life-span of the product:	15 Years	15 Years
	Use phase sector:	Transportation	Transportation
	Fuel and mobility type (embodied energy):	Long haul aircraft – Kerosene 2.18 Btu/lb/mile	Long haul aircraft – Kerosene 2.18 Btu/lb/mile
	Distance travelled per day and usage per year	4,971 miles per day and 255 days per year	4,971 miles per day and 255 days per year
Disposal (End of Life)	Disposal method for material (embodied energy):	Closed Loop Recycling	Closed Loop Recycling
	Fraction of material # 1 disposed through the selected disposal method	80%	80%
	Disposal energy use per unit mass - material # 1 (difference between secondary (recycled)	-225,925 Btu/lb	-225,925 Btu/lb

Printed Engines

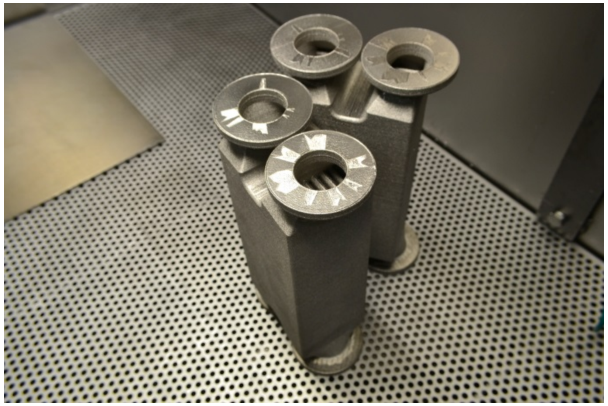
- **Printed engine components for the study of small scale combustion**
- **CAD model derived from model aircraft engine**
- **All components operable**
- **Surrogate for larger energy conversion systems**
- **Ready to bench test and collect combustion data by end of January**

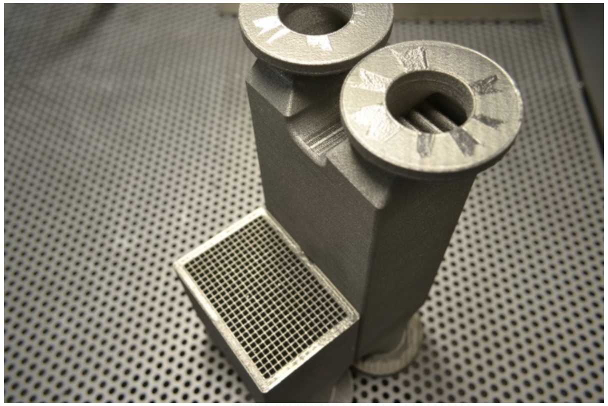




Example Technical Collaboration Project:

S-RAM Air Variable Compressor/Expander for Heat Pump and Waste heat to Power Applications





- New heat pump design utilizes air as refrigerant instead of hydrofluorocarbon (HFC) refrigerants
- Will reduce energy consumption by more than 50% when compared to other common refrigeration and heating systems
- AM of heat exchanger designs allows for improved prototype performance and efficiency and optimized fabrication costs
- Small privately owned company started in 2011 in Franklin, TN
  - Heat pumps manufactured in the U.S.
- Project currently on-going