U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE

T13 - Additive Manufacturing in Wind Turbine Components and Tooling

Program – Materials, Manufacturing, and Design Innovation
Dr. Brian K. Post
Oak Ridge National Laboratory

5/27/2021

Oak Ridge National Laboratory

NREL National Renewable Energy Laboratory
Innovation for Our Future

tpi COMPOSITES

Vestas

FY21 Peer Review - Project Overview

Project Summary:

- Investigate the efficacy of additive manufacturing (AM) as a tool for manufacturing wind turbine components and tooling
- Use AM to reduce manufacturing cost and lifecycle energy
- Identify associated value propositions to accelerate the development and deployment of advanced wind energy technologies.

Project Partners: TPI Composites, Vestas Wind Systems, NREL

Project Objective(s) 2019-2020:

- Comparative analysis of the fabrication of a Skeleton Node (SN) using 3 different AM approaches
    - Indirect - casting using a printed pattern
    - Direct – large scale metal AM printed steel SN
    - Direct – composite node using a combined print and reinforce strategy

Overall Project Objectives (life of project):
Evaluate and deploy AM processes in manufacturing of wind turbine components and tooling to accelerate design innovation, reduce costs, decrease scraps, and reduce time-to-market

Project Start Year: FY15
Expected Completion Year: FY21
Total expected duration: 6 years

FY19 - FY20 Budget:
ORNL $227K
NREL $196K

Key Project Personnel:

ORNL PI: Brian K. Post
NREL PI: Scott Carron

Key DOE Personnel:

Program Manager: Ben Murray
DOE Lead: Michael R. Derby

Project Impact

- Ability to include appropriate AM processes in the manufacturing toolbox of wind turbine components and tooling will accelerate design innovation, reduce costs, decrease scraps, and reduce time-to-market
- Accelerate the deployment of wind and increasing the number of domestic renewable and manufacturing jobs.
- Leverage the successes of the 3D printed blade mold to move beyond tooling to end use parts (indirect to direct manufacturing)

Potential benefits in applying AM to wind include:

- ✓ **Increased design, materials and production location flexibilities**
- ✓ **Inform manufacturers on production process decisions**
- ✓ **Can impact all wind options - land-based, offshore, distributed**
- ✓ **Potential to innovate, reduce cost, first to market**
- ✓ **Potential to transform business models (e.g. digital inventory vs. warehousing)**

Program Performance – Scope, Schedule, Execution

Approach: - Evaluate what major components/tooling may be addressable by *existing* and *forthcoming* AM processes.
- Leverage a companion project which produced a set of 13 meters-long
- Research blade molds as a focused example for performance, value propositions, cost modeling, etc.
- Work directly with the wind industry (Vestas and TPI composites) to identify manufacturing challenges and evaluate AM solutions

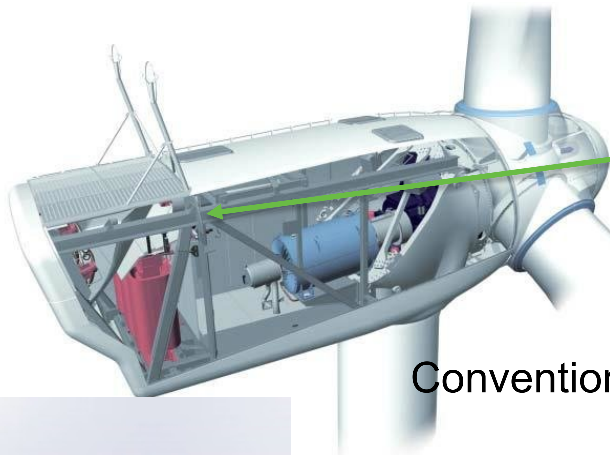
Task 1: Survey of process and performance challenges in wind turbine manufacturing (ORNL and NREL). (Complete)
Task 2: Cost/performance analysis of AM wind components/tools (*present* AM capability). (ORNL and NREL). (Complete)
Task 3: Risk analysis and mitigation strategies (*present* AM capability). (ORNL and NREL). (Complete)
Task 4: Cost/performance analysis, risk analysis and mitigation strategies of wind turbine components/tools (forthcoming AM capability). (ORNL and NREL). (Report Published: The Current State of Additive Manufacturing in Wind Energy Systems)

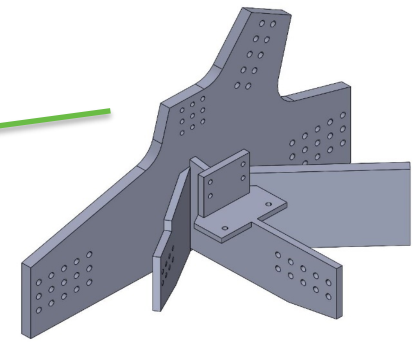
FY15-17

Task 5: Industry collaboration to refine AM cost/performance analysis (ORNL, NREL and Vestas). (Complete)
Task 6: Utilize AM techniques to fabricate a nacelle structural skeleton node (SN) for comparative analysis and publish results. (Publication Awaiting Release)

FY18-21

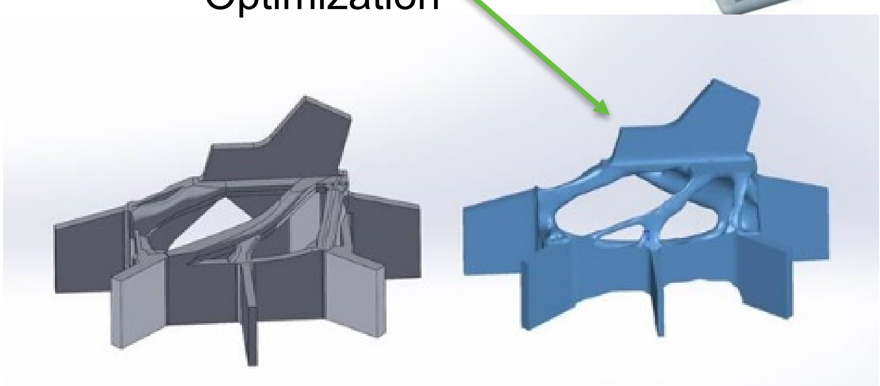
Vestas Skeleton Node Comparative AM Fabrication Study



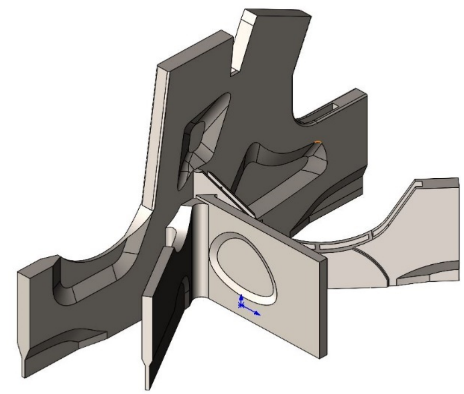


Conventional Manufacturing

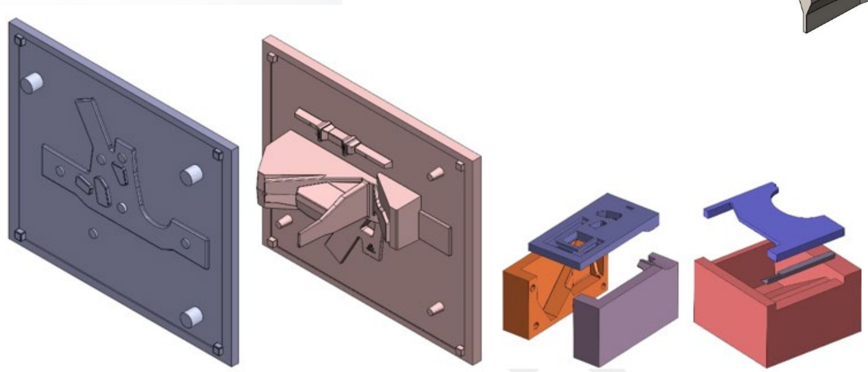
Topology Optimization



Direct Additive Manufacturing Approach



Indirect Additive Manufacturing Approach

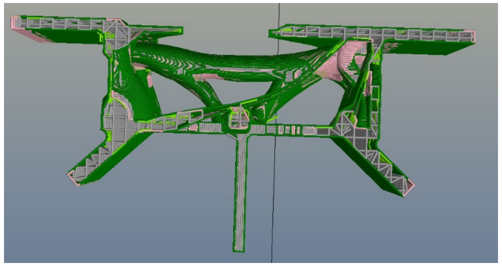


(a) Top Pattern (b) Bottom Pattern (c) Core Box 1 (d) Core Box 2

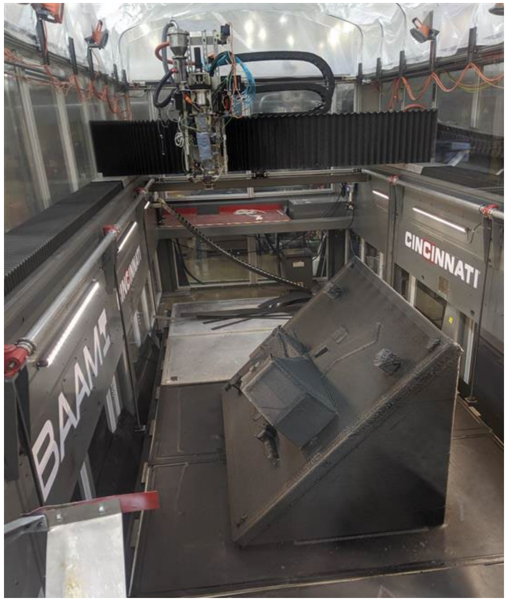
Program Performance – Accomplishments & Progress (FY19-20)

Composite SN

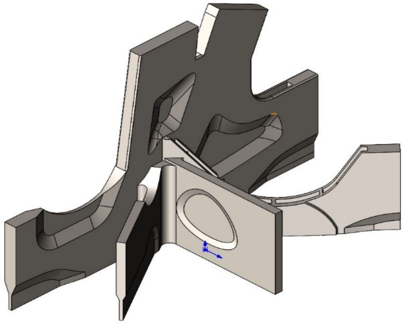
Hollow core print reinforced with low viscosity thermoset resin

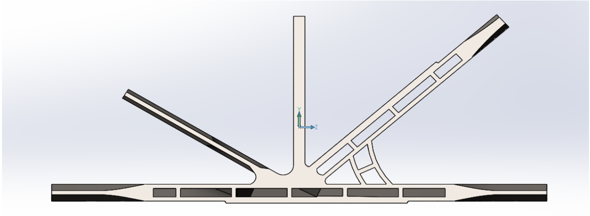


Cast SN

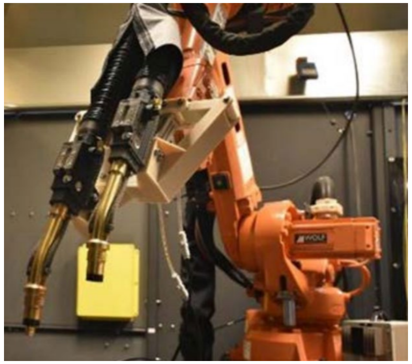


Directed Energy Deposition (DED) SN



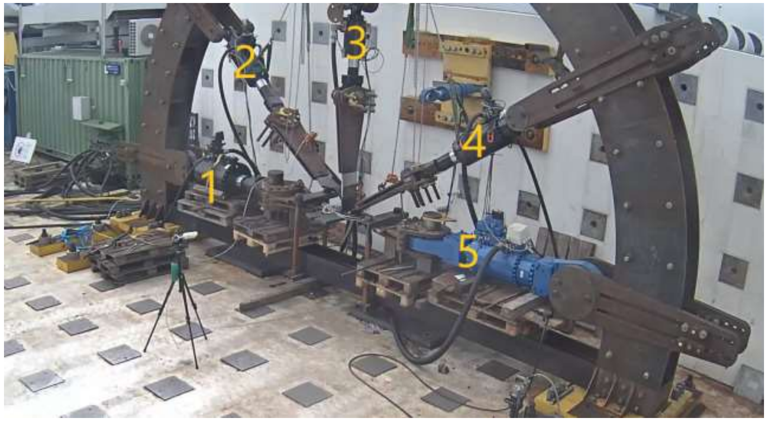


Fabricated using a large-scale AM MIG welding DED system - mBAAM



Program Performance – Accomplishments & Progress (FY19-20)

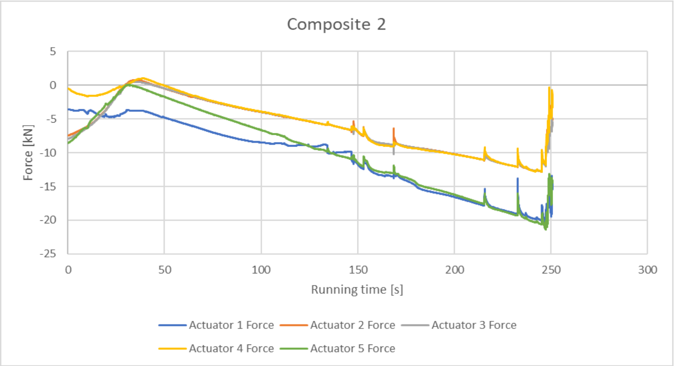
SN Testing

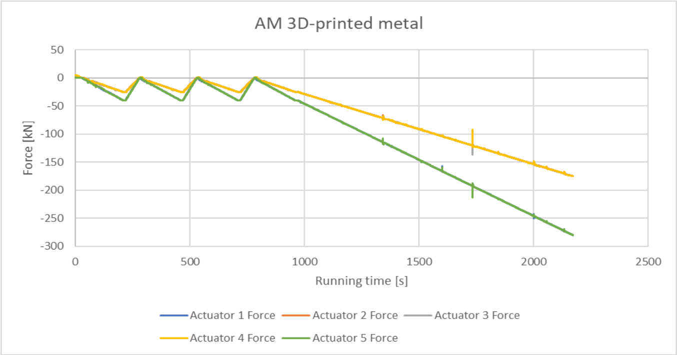


Order	Name
1	Prototype
2	Composite_V02_1
3	Composite_V02_2
5	Cast_1
6	Cast_3
7	Cast_2
8	AM 3D printed Metal
9	Reference

Arm	*Design load [kN]*
1	40
2	25
3	25
4	25
5	40

Cast and DED nodes met design loads
Composite reached 56% of design load
(higher than expected)

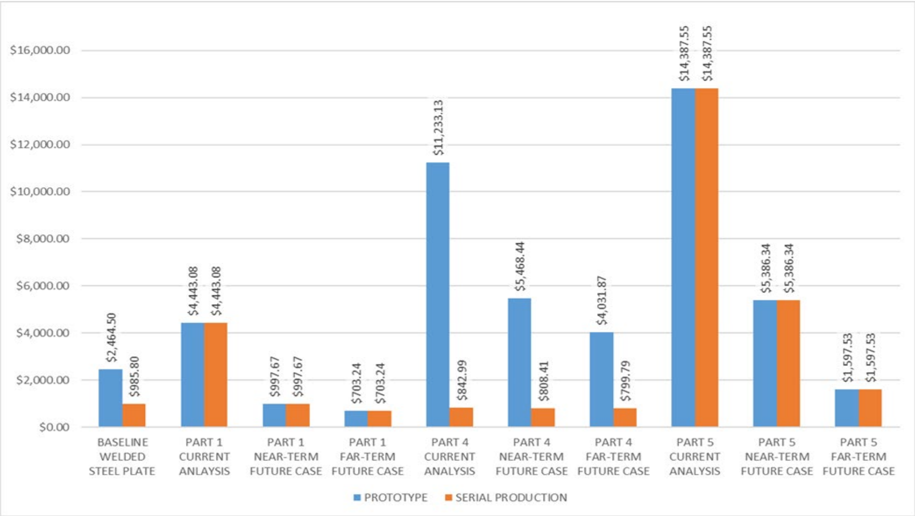


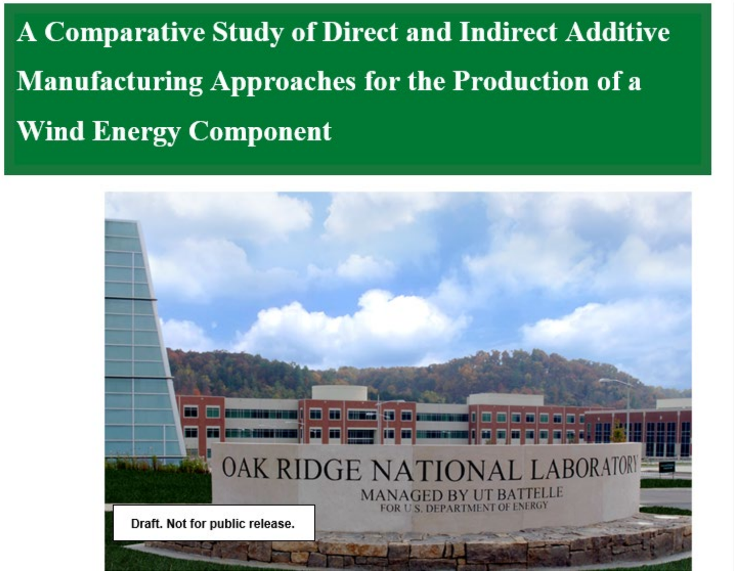


Project Performance - Upcoming Activities

FY21 Work concludes the research program

- Final techno-economic analysis comparing AM vs conventional manufacturing approaches
  - Conventional welding currently remains the most cost-effective manufacturing method to produce a large-scale steel nacelle component of the type considered unless deposition rates increase
  - Of the technologies used the mBAAM produced nodes were the most cost-competitive in terms of lead time, transport cost, and production cost
- Final report is awaiting publication
  - Will be followed by a journal article





Stakeholder Engagement & Information Sharing

- Results and findings have been disseminated through open literatures, presentations, and direct communication with industry and stakeholders.
- Special effort to communicate to manufacturing community that is less familiar with opportunities for wind.
  - ➢ Manufacturing-centric conferences
  - ➢ Mold project included in standard AM slide deck for ORNL
  - ➢ Follow on work with multiple industries (aerospace, marine, and naval) using lessons learned from Blade mold success
- Direct partnership with wind Industry (TPI Composites and Vestas)

Meetings:

- ➢ Solid Freeform Fabrication Conference Austin (Plenary)
- ➢ RAPID + TCT Conference
- ➢ JEC Knoxville Composites Conference
- ➢ SME Smart Manufacturing Seminar Series

Publications:

- ➢ ORNL Reports

Awards:

- ➢ **FLC Awards**
  - ➢ ***Technology Focus Award 2018*** - Successful Collaboration Accelerates Testing of New Blade Designs
  - ➢ ***Partnership Award 2017*** - National Rotor Testbed: Using Large Scale 3D Printing to Test New Wind Blade Designs

FLC
Federal Laboratory Consortium for Technology Transfer

Key Takeaways and Closing Remarks

Project Impact:

- Ability to include appropriate AM processes in the manufacturing toolbox of wind turbine components and tooling will accelerate design innovation, reduce costs, decrease scraps, and reduce time-to-market

Project Performance:

- Design, fabrication, testing and tecno-economic analysis
- Industry partnership to understand and develop solutions to real problems

Build Functional Prototypes and Test

Stakeholder Engagement:

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