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

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

NREL Transforming ENERGY

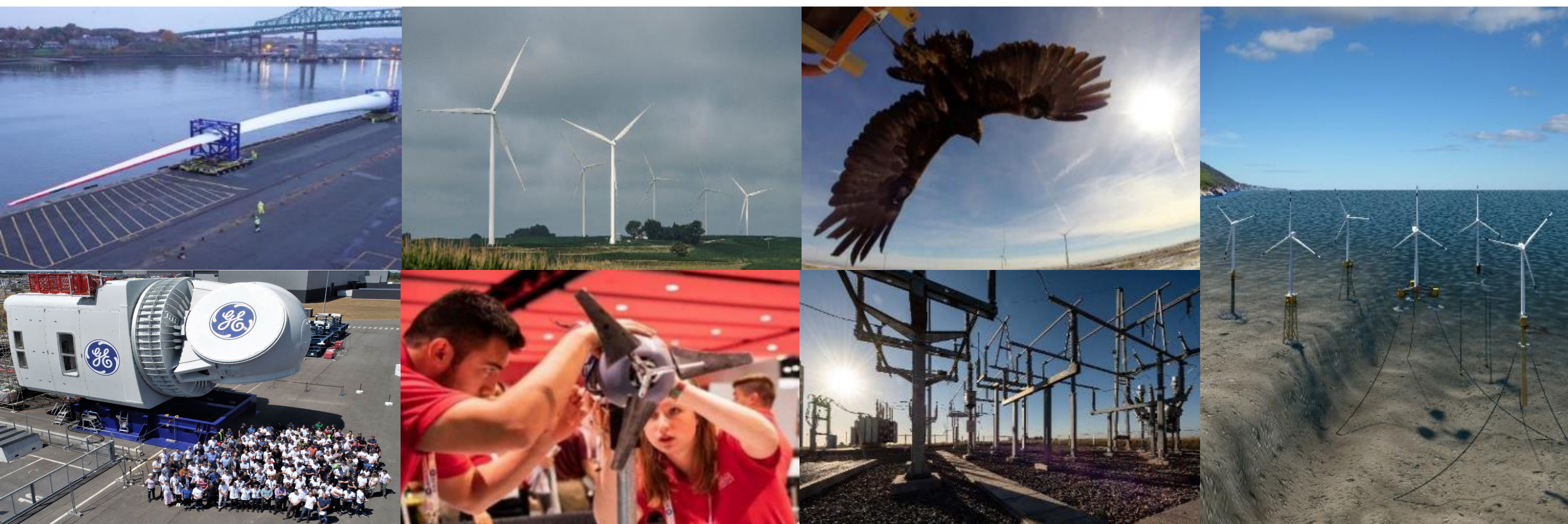
OAK RIDGE National Laboratory

T06 - 3D Printed Core Structures for Wind Turbine Blades

Program: Materials, Manufacturing, and Design Innovation

Presenter Name: Scott Carron
Presenter Organization: NREL

Date August 3rd 2021



FY21 Peer Review - Project Overview

Project Summary:

- The challenge is to develop longer, lighter, and lower cost wind turbine blades for the wind industry to reduce the Levelized Cost of Energy (LCOE) and increase deployment.
- The project addresses this challenge using the state-of-the-art in advanced manufacturing technologies.
- The project focuses on utilizing 3D printing technologies and topology optimization to develop large-scale 3D printed blade core structures for a 13m blade.
- The project will leverage cutting edge research and emerging technologies to develop 3D printed blade cores with the performance of aerospace honeycomb and the cost of balsa.
- The project is comprised of a world-class team of scientists and researchers at NREL with expertise in blade design, and ORNL with expertise in large-scale additive manufacturing.

Project Objective(s) 2019-2020:

- Develop the technical foundation to ensure technically robust 3D printed core solutions are developed throughout the conceptual, preliminary, and detailed design phases of the project.
- Document the technical foundation as a set of Technical Specifications and Requirements consisting of manufacturing design guidelines, material testing and characterization processes, material design properties, design load cases, and structural requirements.
- Conduct a project review to ensure the project has the tools, data, methodology, and processes in place to begin the conceptual design phase.

Overall Project Objectives (life of project):

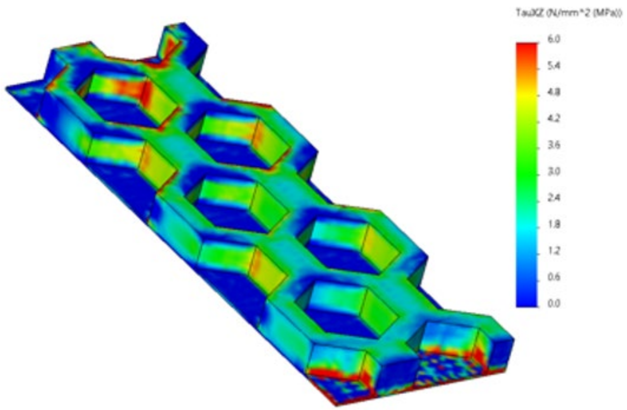
- Develop a robust set of technical requirements to ensure the structural integrity of blade core designs.
- Advance novel 3D printed blade core structural designs through rigorous conceptual, preliminary, and detailed design phases.
- Validate the final 3D printed core design through a full-scale build and test program.
- Deliver an extremely lightweight 3D printed blade core structure that outperforms traditional core structures such as balsa and foam on a strength, stiffness, mass, cost and durability basis.

Project Start Year: [2020]
Expected Completion Year: FY [2023]
Total expected duration: [4] years

FY19 - FY20 Budget:
$792,013 (TOTAL)
$434,013 (NREL)
$358,000 (ORNL)

Key Project Personnel:
Scott Carron (NREL)
Brian Post (ORNL)

Key DOE Personnel:
Benjamin Murray, Mike Derby

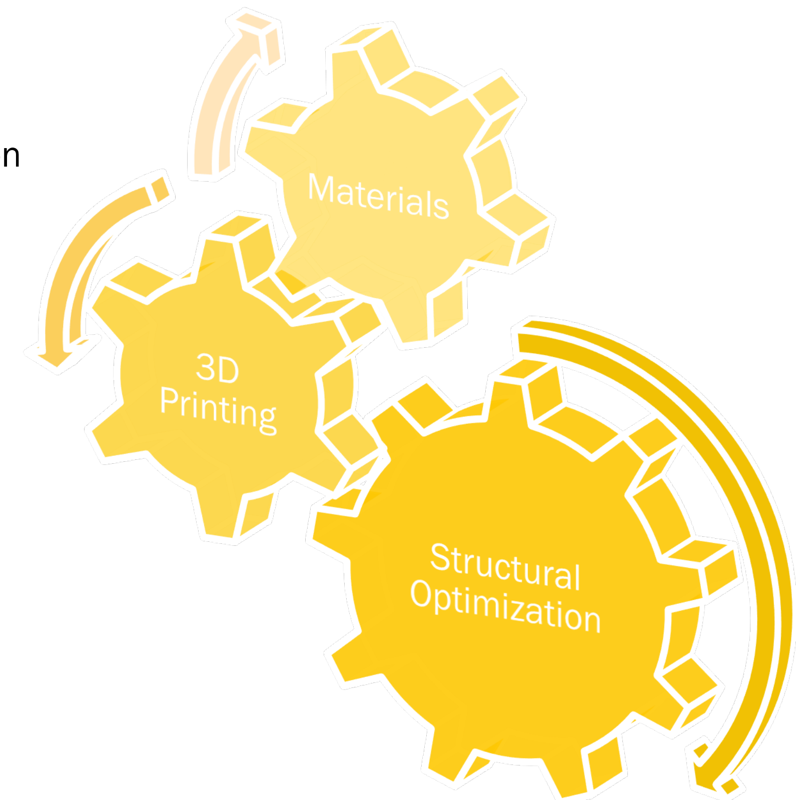


Project Impact

- **Benefits to the wind industry.**
  - Domestic manufacturing
  - Domestically sourced materials
  - Reduced transportation costs
  - Increased opportunities for recyclability
  - Higher performance blade structures
- **Research needed.**
  - Aerospace is driving high cost, small-scale, long cycle time, high strength.
  - Tooling is driving low cost, large-scale, long cycle time, low strength.
  - Wind blades require <u>low cost</u>, <u>large-scale</u>, <u>short cycle time</u>, <u>high strength</u>.
- **Project impact.**
  - 3D printing material property data
  - 3D printing design methods
  - Topology optimized blade structures
  - Next generation blade designs
  - Advanced structural design and validation methods

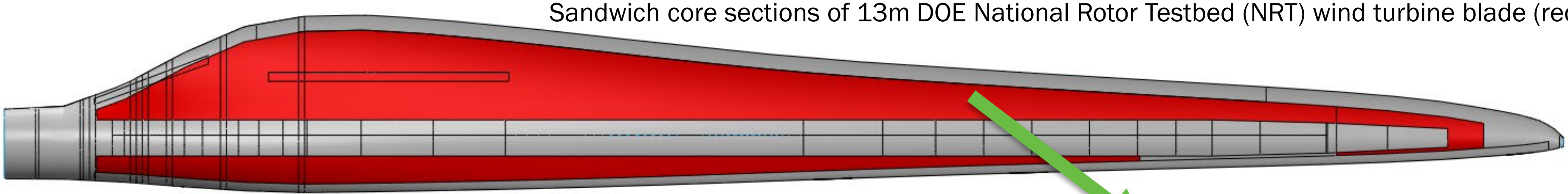
Program Performance – Scope, Schedule, Execution

- **Phase 1** - Technical Specifications and Requirements Development (FY 2020)
  - Additive Manufacturing Guidelines
  - Additive Manufacturing Materials Database
    - Additive Material Testing and Characterization
    - Additive Material Design Properties
  - Design Load Cases
  - Structural Requirements
  - Project Review and Go/No-Go Decision Gate
- **Phase 2** - Conceptual Design (FY2021)
- **Phase 3** - Preliminary Design (FY2021/FY2022)
- **Phase 4** - Detailed Design (FY2022/FY2023)
- **Phase 5** – Blade Manufacture (FY2023)
- **Phase 6** – Blade Validation (FY2023)

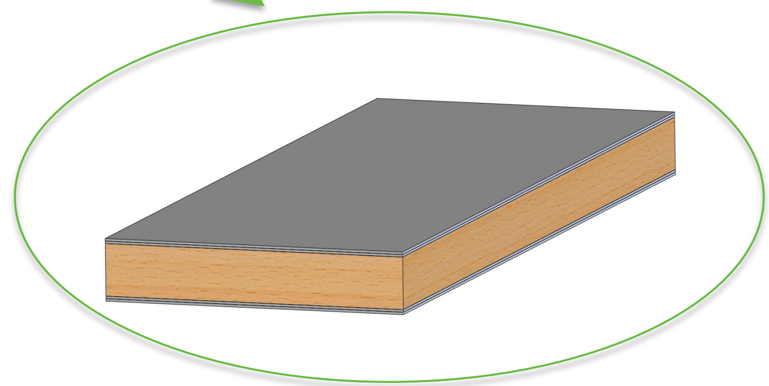


Additive Manufacturing Design Guidelines

Sandwich core sections of 13m DOE National Rotor Testbed (NRT) wind turbine blade (red)



- **Additive manufacturing technology assessment criteria for 3D printed blade core**
  - Strength-to-weight
  - Stiffness-to-weight
  - Cost
  - Cycle time
  - Build volume
  - Core cell size
  - Recyclability
  - Compatibility



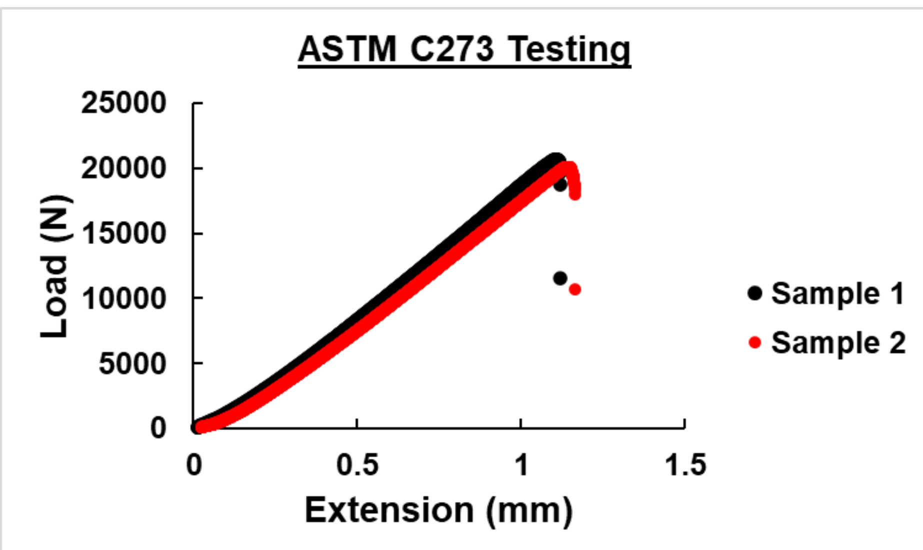
VAT Photopolymerization	Powder Bed Fusion	Binder Jetting
Material Jetting	Sheet Lamination	Material Extrusion
	Directed Energy Deposition	

7 Families of Additive Manufacturing Technologies (ASTM F2792)

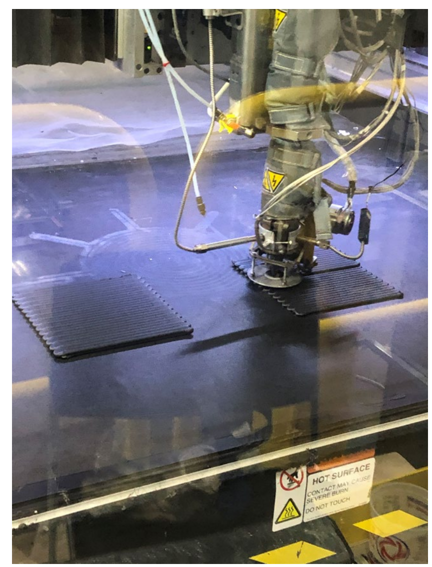
Additive Manufacturing Materials Database

Material Characterization
- Shear strength
- Shear modulus
- Tensile strength
- Tensile modulus
- Compressive strength
- Compressive modulus
- Density

Material Testing
- ASTM C273 – shear properties
- ASTM C393 – shear properties
- ASTM C297 – tensile properties
- ASTM C365 – compressive Properties
- ASTM C271 – density



ASTM C273 test data



3D printed coupons

ASTM C273 test set-up.

Structural Requirements

- **Core Design Options**
  - Balsa
  - Cellular Foam
  - Honeycomb
  - Corrugated
  - Lattice
  - Stiffened Panel

- **Core Failure Criteria**
  - Face sheet failure
  - Core shear failure
  - General buckling
  - Face wrinkling
  - Shear crimping
  - Face dimpling

- **Blade Surface**
  - 13m DOE NRT blade
  - 3D printed 13m blade mold

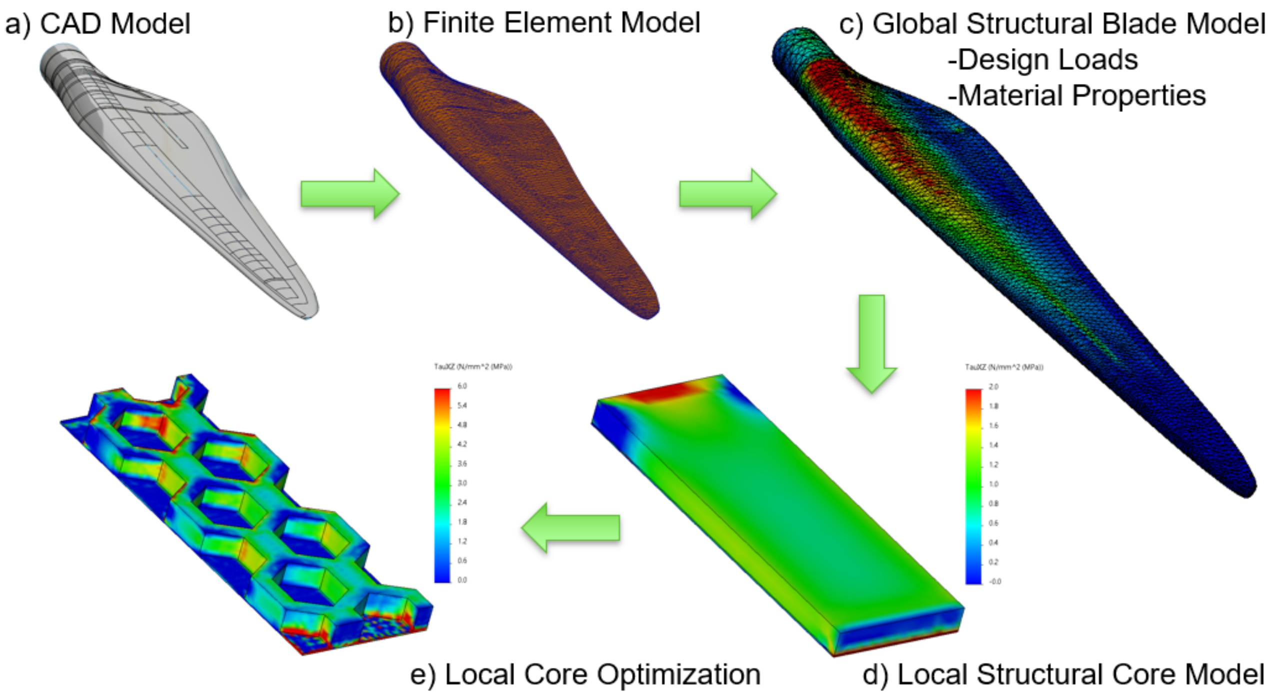
- **Core Design Targets**

3D Printed Core Design Targets		
Shear Strength (MPa) / Density (kg/m3)	Compressive Modulus (MPa)/ Density (kg/m3)	Cost ($/kg) / Density (kg/m3)
0.02	23.45	0.12

Note: Targets based on 150 kg/m3 end grain balsa material properties and 2020 costs.

Design Loads and Structural Optimization

- **Design Load Cases**
  - Edgewise - Ultimate Limit State (ULS)
  - Flapwise - Ultimate Limit State (ULS)
  - Maximum Resultant - Ultimate Limit State (ULS)
  - Maximum Tip Deflection



Sandwich core optimization process using finite element analysis

Project Performance - Upcoming Activities

FY2021:

- **Complete Technical Specifications and Requirements (partially delayed due to COVID-19 impact)**
- **Project Review (delayed due to COVID-19 impact)**
- **Begin Conceptual Design Phase**
  - Conceptual design (two-dimensional core geometries)
  - Material testing and characterization (conceptual design support)
  - Additive manufacturing (3D printing of core designs)

FY2022 - FY2023:

- **Conceptual Design Review**
- **Preliminary Design Phase**
  - Conceptual design (three-dimensional core geometries)
  - Material testing and characterization (conceptual design support)
  - Additive manufacturing (3D printing of core designs)
- **Detailed Design Phase**
  - Final down select and detailed structural analysis
  - Validate final design through testing and characterization
- **Blade Manufacturing Phase**
  - 3D print final core design
  - Manufacture full-scale 13m demonstrator blade
- **Blade Validation Phase**
  - Perform full-scale static testing

Stakeholder Engagement & Information Sharing

- Engagement Strategy
  - The project is currently at a Technology Readiness Level (TRL) of 2 and intends to increase industry engagement as the TRL advances from early-stage to mid-stage (TRL 4-5).
  - Industry engagement will include the additive manufacturing machine tool industry and wind turbine blade manufacturing industry.
  - The engagement strategy will leverage the 205 industry and 54 university partners associated with ORNL's Manufacturing Demonstration Facility (MDF), and NREL's partnerships and relationships with all major wind manufacturers.
- Commercialization Pathway
  - Commercialization pathways will be pursued as the TRL advances from early-stage to mid-stage.
- Communications and Outreach Strategy
  - Wind Energy and Additive Manufacturing Industry Conferences (e.g., JEC World, AWEA Wind Power, Sandia Blade Workshop, Torque, IMTS, Rapid + TCT)
  - Industry Magazine Publications (e.g., Composites World, Additive Manufacturing)
  - Social media channels (e.g., LinkedIn, DOE WETO news)
  - Journal Publications (e.g., AIAA, Additive Manufacturing)
  - NREL and ORNL technical publications