NREL
Transforming ENERGY

Leveraging the Advantages of Additive Manufacturing to Produce Advanced Composite Structures for Marine Energy Systems

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Flatirons Campus Manufacturing and Validation

CoMET Multi-Scale Manufacturing

Subcomponents

Coupon Characterization

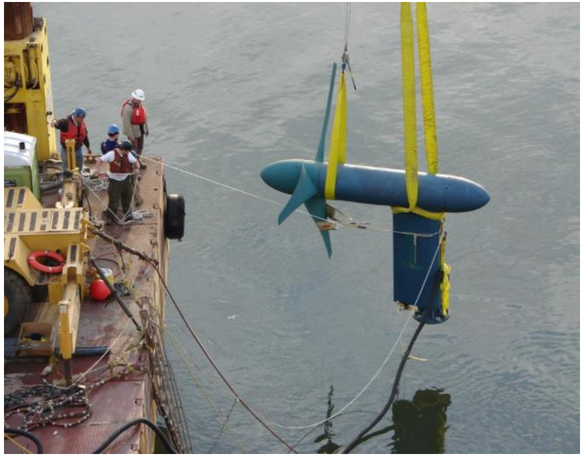
Full-Scale Validation

Contents

Marine Energy and Composites

- Marine energy industry is seeing rapid development
- Very broad variety of system designs
- Composite materials are an attractive choice for structural components
- Mold costs can be a significant barrier to implementation of composites, especially when prototyping
- Need cost-effective, low-volume manufacturing techniques
- Advances in additive manufacturing could fill the gap.

ORPC Cross-Flow Turbine



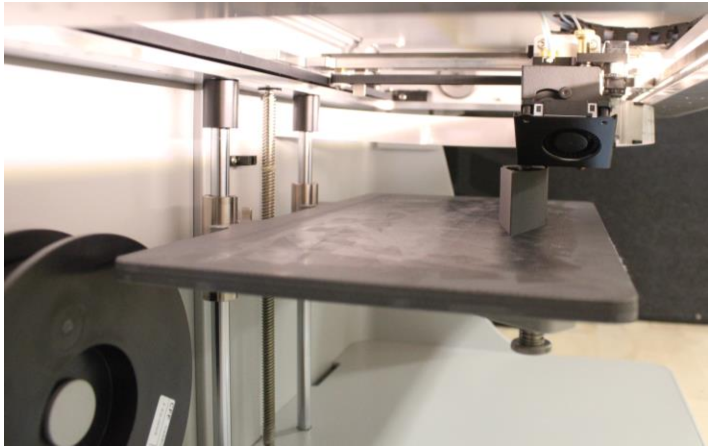
Verdant Axial-Flow Turbine

Additive Manufacturing (AM)

- Rapidly expanding industry
- Expensive, small-scale novelty items to viable, affordable manufacturing
- Being explored for large-scale structures
- Close to economic feasibility for mass-produced, end use parts

Current technologies:

- Fused deposition modeling (FDM)
- Stereolithography (SL)
- Powder-bed fusion
- Binder jet
- Selective laser sintering (SLS)



Markforged Mark Two desktop printer

AM for Composite Applications

- Mainly external molds for small components
- Dissolvable internal molds
- Large-scale mold making for wind turbine blades
- Continuous filament printing
- Increased automation, reduced waste, quicker concept to on-site manufacturing

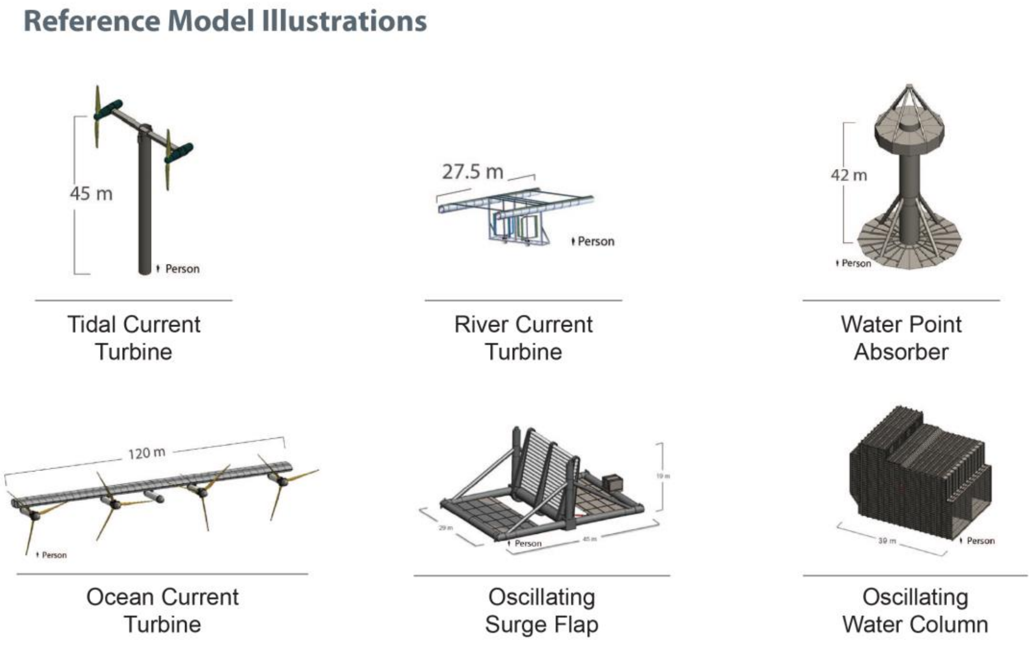
13 m blade mold printed by Oak Ridge National Laboratory

Seedling Project Goals

- Explore the current applications of AM in composites manufacturing
- Investigate potential for AM in marine energy industry
- Explore hybrid additive/composite manufacturing techniques and the potential of unique design features
- Produce a reduced-scale component utilizing the new, investigated techniques
- Evaluate benefits associated with the processes and areas for further development

Integrating with Marine Energy Systems

- Utilized examples from the Reference Model Project
- Identified components that may benefit from composite materials
- Down-selected composite components that could benefit from AM tooling
- Developed two case studies:
    1. Additive/composite manufactured hybrid tidal turbine blade
    2. Cross-flow river turbine strut T-joint soluble tool



Images courtesy of Sandia National Laboratories

Case Study 1

Additive/Composite Manufactured
Hybrid Tidal Turbine Blade

Objective

- Redesign a tidal turbine blade with AM internal mold
- Design with composite overlay to produce “hybrid” structure
- Explore unique design and manufacturing possibilities
- Manufacture reduced-scale blade section to highlight beneficial features

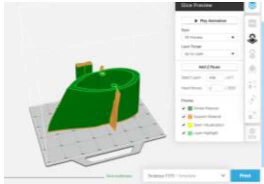
Reference Model 1
Image courtesy of Sandia National Laboratories

Mold Manufacturing

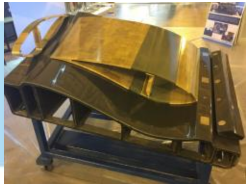
Traditional Mold Manufacturing

Plug Shaping → Plug Finish and Prep → 1st Side Layup → 1st Side Removal → 2nd Side Layup → 2nd Side Removal → Support Structure Construction → Finishing Process

Additive Mold Manufacturing



3D Printing Preprocesing → Printing → Post-Print Machining → Sealing and Finishing



Component Manufacturing

Traditional Composite Structure Manufacturing

Preprocessing
- Mold prep
- Material cutting
- Preform creation

→

Processing
- Structural component manufacturing
- Multiple skin layups
- Adhesive Bonding
- Demold

→

Postprocessing
- Trim
- Root, cut, drill, and insert bonding
- Surface grind and finish

Additive/Composite Hybrid Structure Manufacturing

Preprocessing
- Mold prep
- Material cutting

→

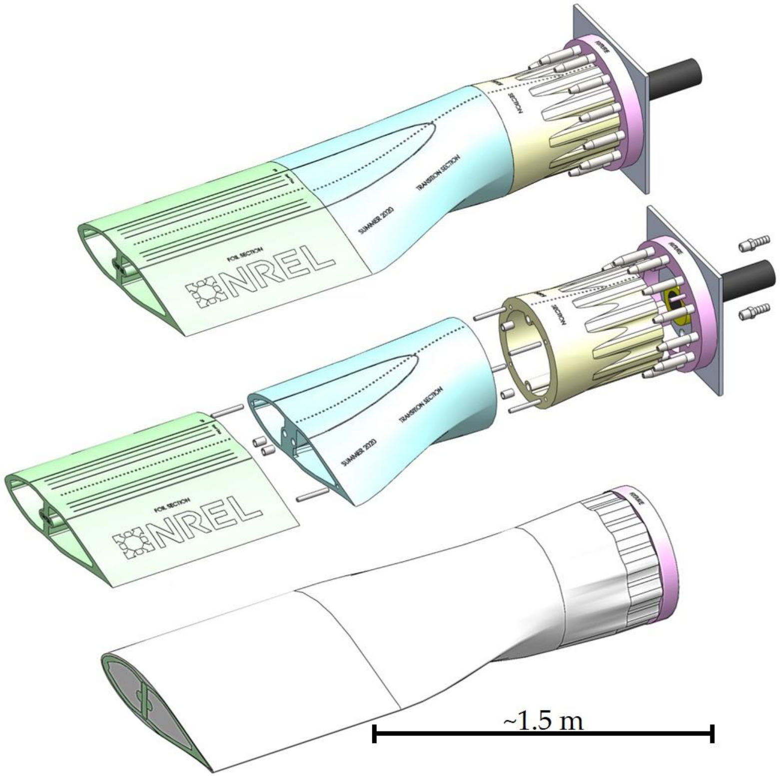
Processing
- Structural component manufacturing
- Mold assembly
- Layup of entire structure

→

Postprocessing
- Washout (optional)
- Root facing
- Surface grind and finish

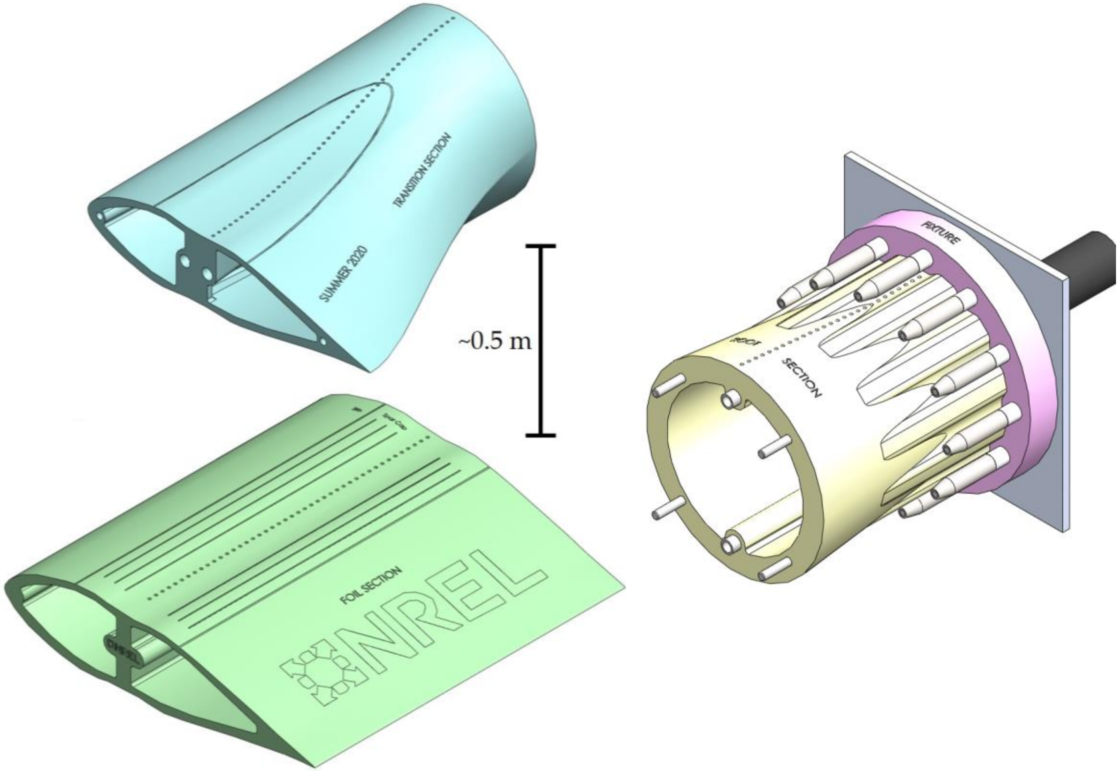
Conceptual Design

- Not an optimized hydrodynamic or structural design – showcasing manufacturing possibilities
- Overall structure designed to be representative of a typical blade
- Internal mold – unique design opportunities
- Segmented mold construction – not limited by printer size
- Composite layup and mold surface designed concurrently
- Single piece composite construction – no adhesive bond lines



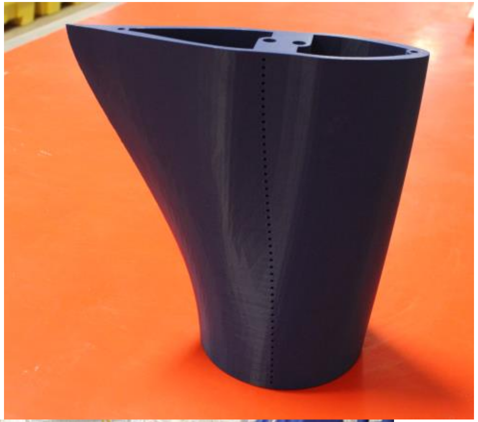
Conceptual Design (cont.)

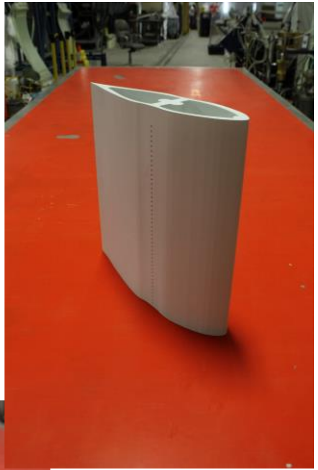
- In-situ root fasteners – minimize secondary tooling operations
- Slide in shear web to be co-infused during main infusion
- Integrated resin infusion lines – control of resin flow during infusion

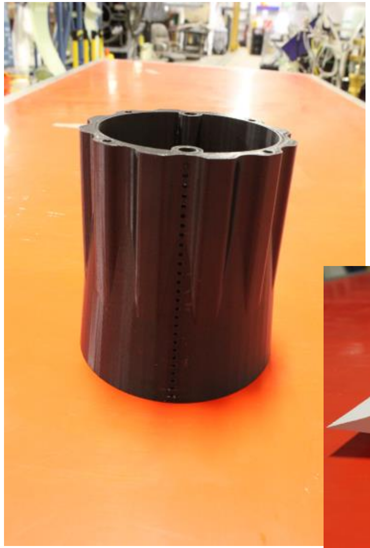


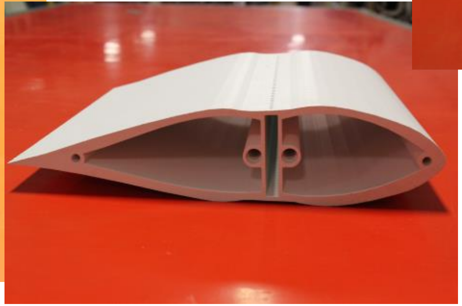
Manufacturing - Printing

- ~12 in. chord length and ~36 in. span
- Stratasys Fortus 400MC printer
- ABS filament print material



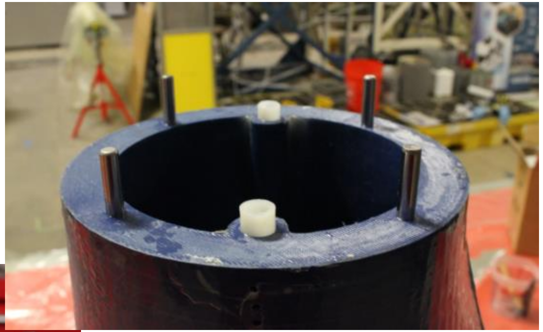


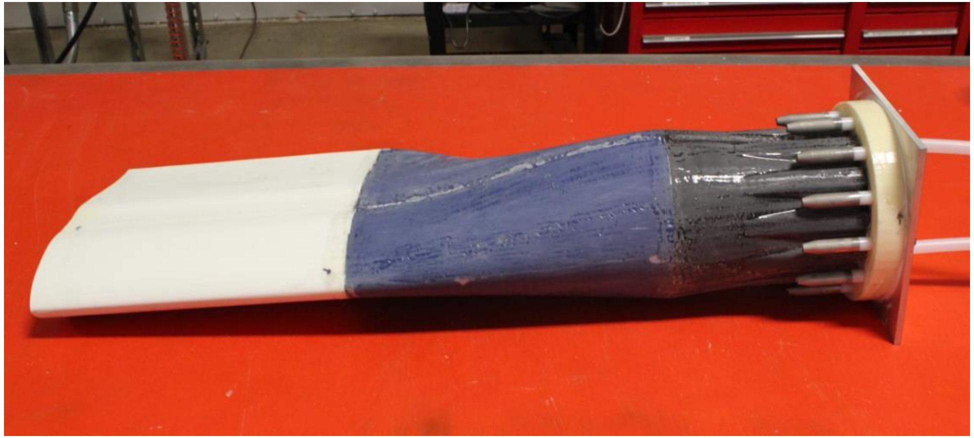


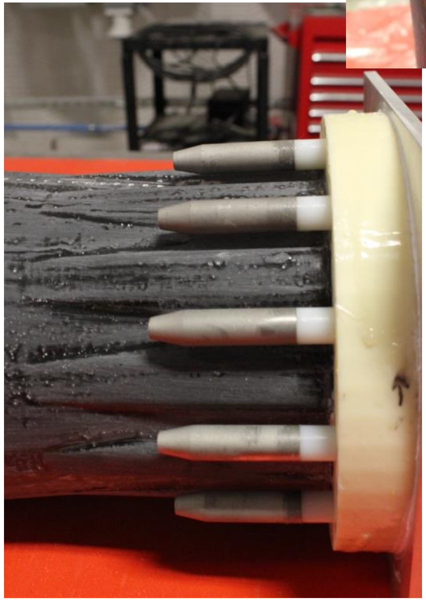


Manufacturing – Mold Assembly

- Sealing – sand surface, coat with epoxy, sand surface
- Bond segments together with shear web, dowel pins, and nylon bushings

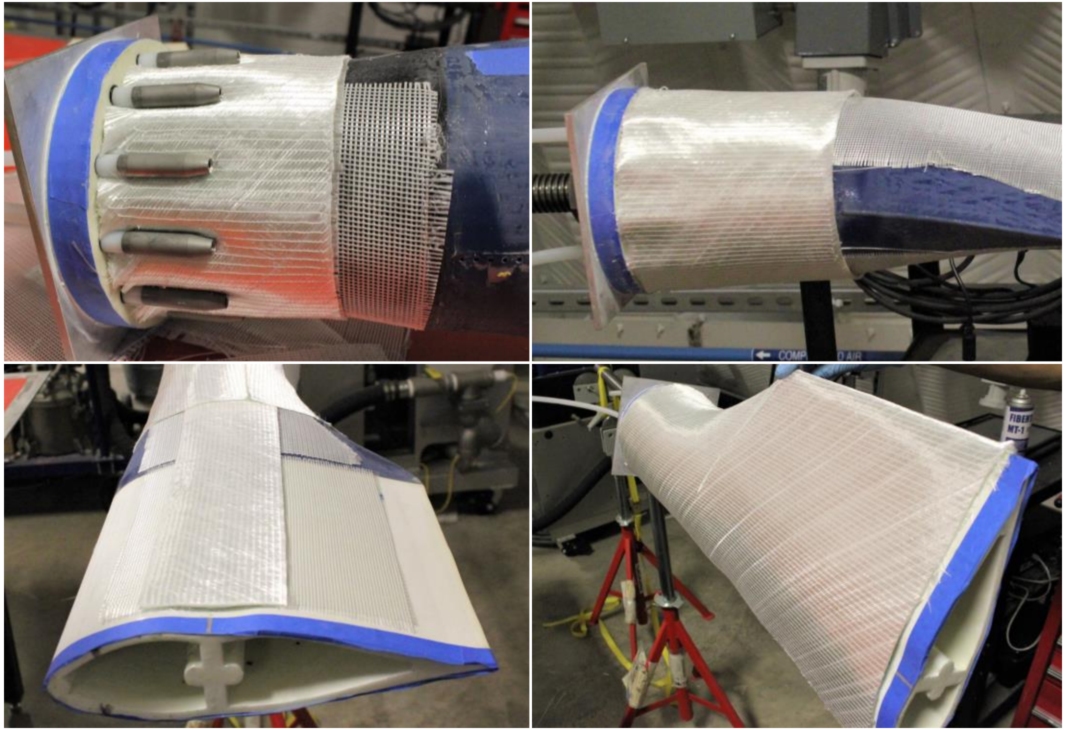






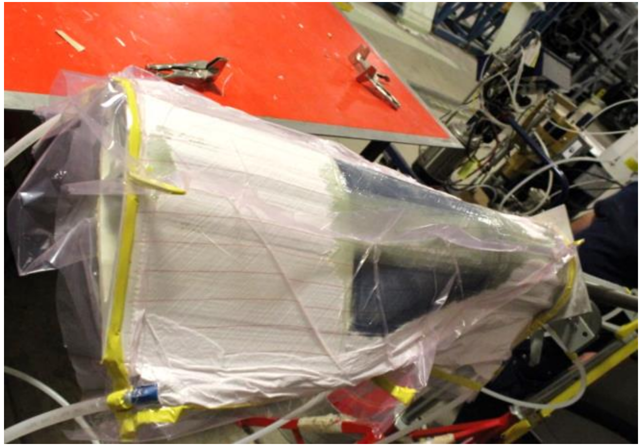
Manufacturing - Composite Layup

- Structural flow media
- Triaxial glass fabric
- 7x root plies -> fasteners -> 7 root plies
- 4x spar cap plies top and bottom
- 2x skin plies

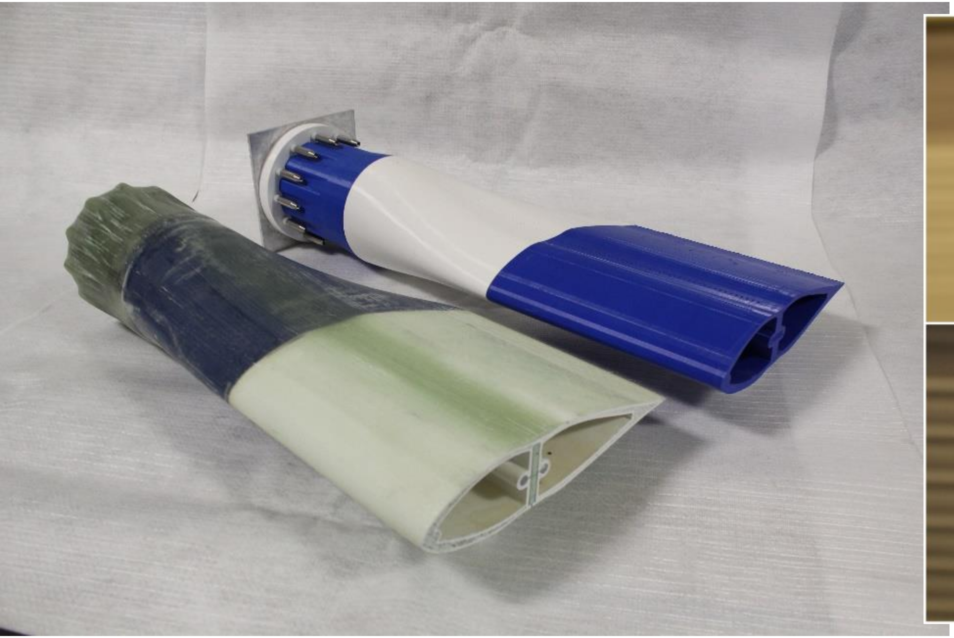


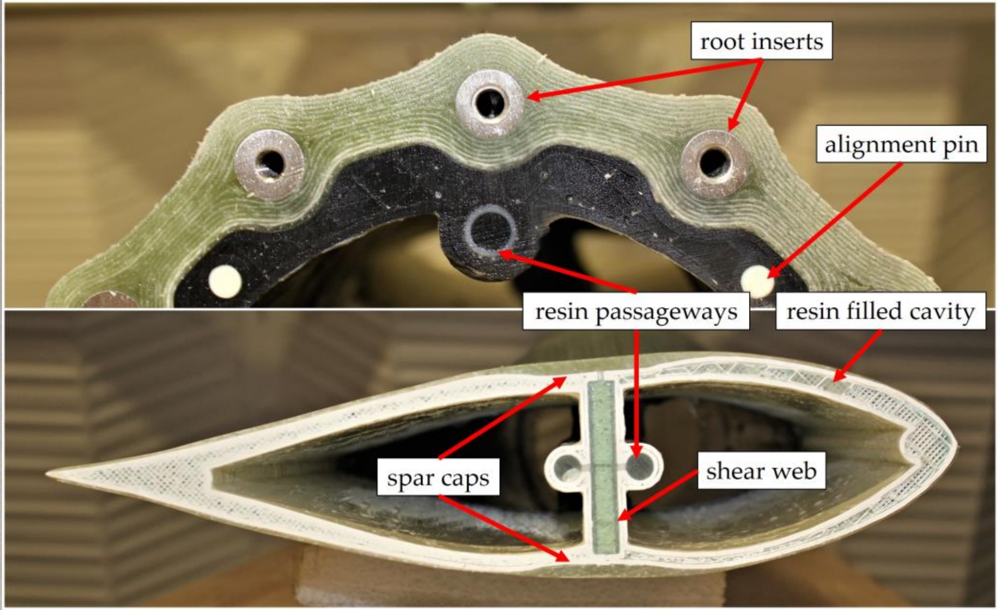
Manufacturing - Infusion

Room temperature cure with
2 part epoxy resin system



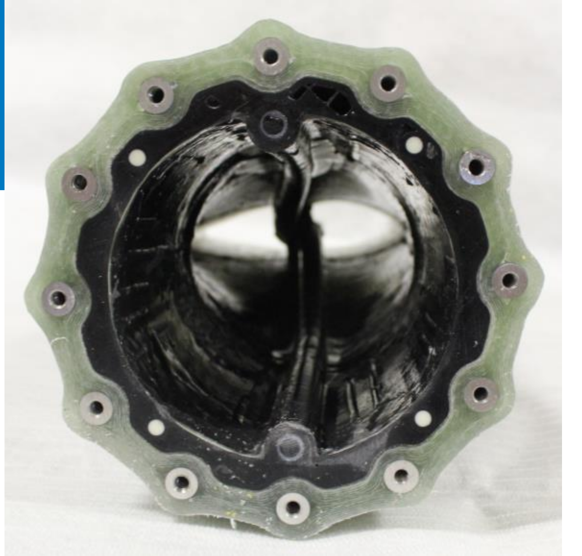
Manufacturing - Finishing





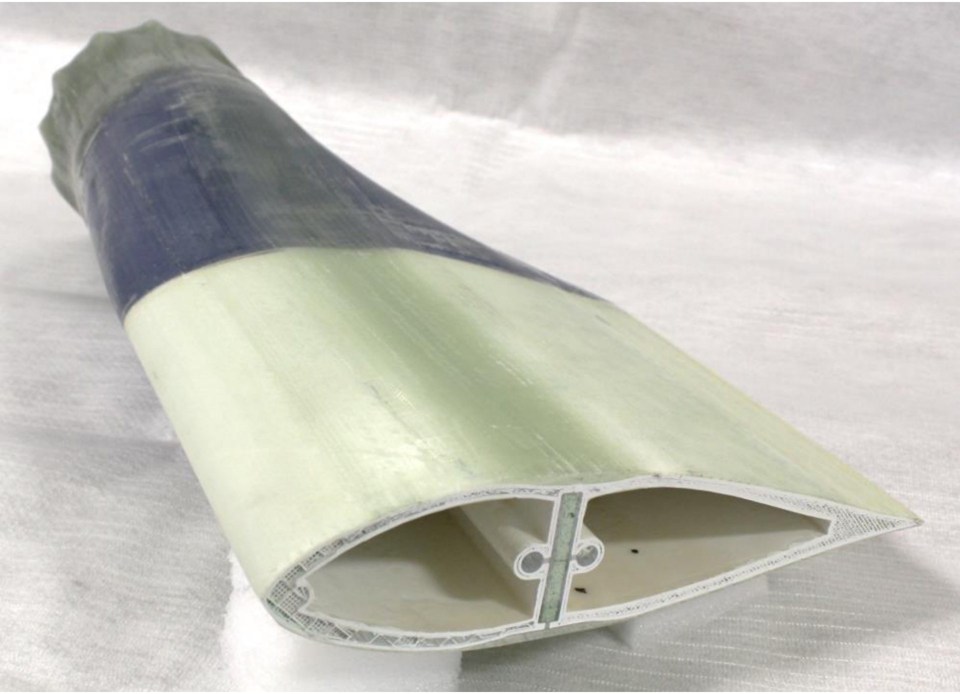
Case Study 1 - Summary

- Successful manufacturing of reduced-scale model
- Demonstrated internal tooling approach
- Sealing 3D print was time consuming and resin was drawn into mold cavities – integrated infusion lines
- Embedded fasteners simplified manufacturing
- Single piece construction – potential for increased reliability
- Unknown composite/3D print interface strength
- Journal article published (https://www.osti.gov/pages/biblio/1768280)



Case Study 1 – Next Steps

- Structural optimization – composite/additive co-design
- Techno-economic analysis – materials and design tradeoffs
- Manufacturing volume
- Better sealing methods
- Composite/additive interface characterization
- Enhanced recyclability with thermoplastic resin systems
- Full-scale demonstration

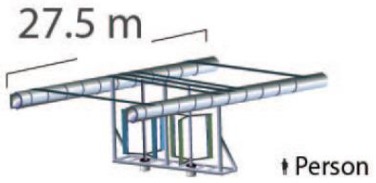


Case Study 2

Cross-Flow River Turbine Strut T-Joint
Washout Tool

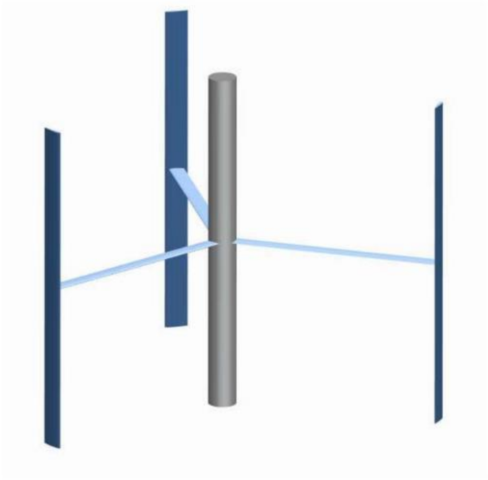
Reference Model 2

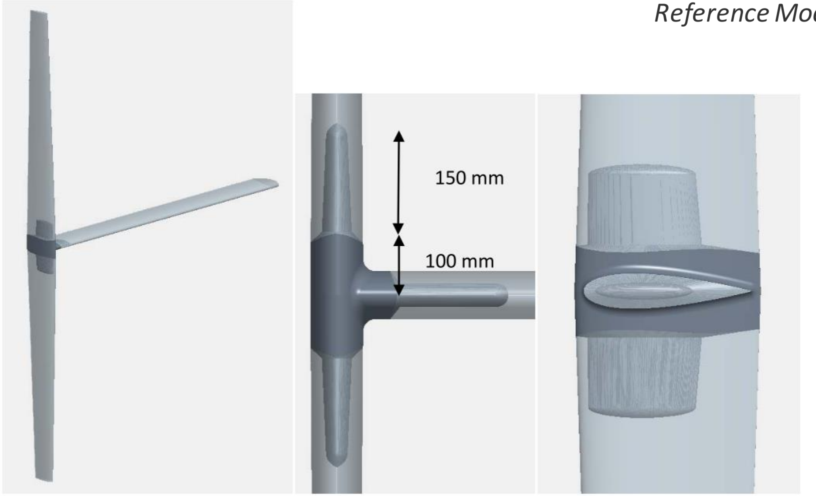
- Vertical axis river turbine
- Blade/strut T-joint design
- Not conducive to composite manufacturing
- Redesigned to suit a common composite manufacturing approach



River Current Turbine

Reference Model 2

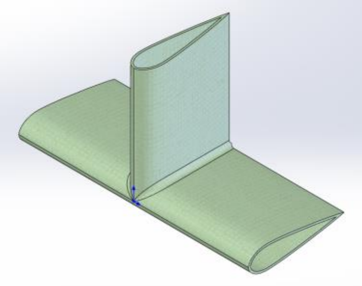


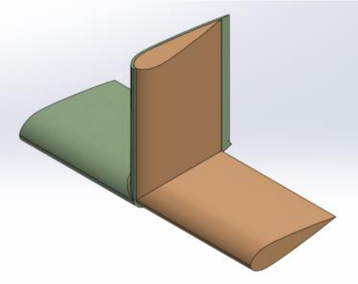


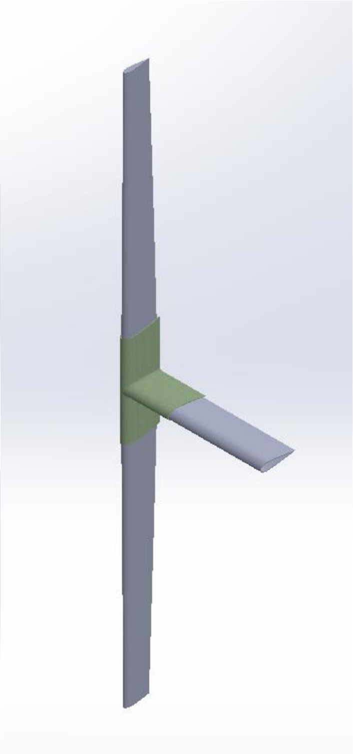
Images courtesy of Sandia National Laboratories

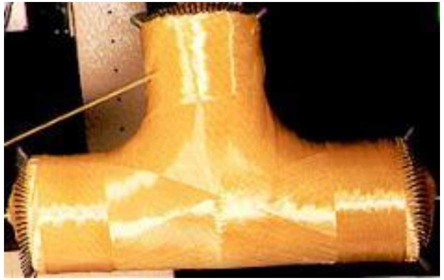
T-Joint Design

- External T-joint
- Soluble tool design
- Fused deposition modeling or binder jet printing
- 4-axis filament winding of composite over printed tool
- Dissolve tool and potentially reuse print media
- Strut and blade slide inside T-joint for adhesive bonding
- AM approach can be significantly cheaper than subtractive manufacturing of soluble molds (journal article in progress)









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Looking Ahead

Future Opportunities and Challenges

AM in the Future

- Technology continues to evolve – faster, bigger, better materials, and lower costs
- More applicable to end use products and large structures
- More versatility and possibility of site-specific devices
- Machines in the water faster
- Better understanding of environmental effects on print materials (corrosion and water absorption)
- Characterization of materials to better suit additive/composite hybrid approach
- Continue to explore a more versatile design space

Thank you for Listening

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