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BAAM Additive Manufacturing of a Building Integrated Wind Turbine for Mass Production

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May 15, 2018

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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Energy and Transportation Science Division
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ABSTRACT

ORNL worked with Hover Energy LLC (Hover) on the design of Big Area Additive Manufacturing (BAAM) extrusion components. The objective of this technical collaboration was to identify and evaluate fabrication of components using alternative additive manufacturing techniques. Multiple candidate parts were identified. A design modification to fabricate diverters using additive manufacturing (AM) was performed and the part was analyzed based on anticipated wind loading. Scaled versions of two parts were printed using the BAAM for wind tunnel testing.

1. BAAM ADDITIVE MANUFACTURING OF A WIND TURBINE FOR MASS PRODUCTION

This phase 1 technical collaboration project (MDF-TC-2017-111) was begun on February 14, 2017 and was completed on March 31, 2018. The collaboration partner Hover Energy LLC is a small business. Alternative additive methods of fabrication for appropriate components were identified, analysis performed to assess viability and scaled sample parts were fabricated for wind tunnel testing.

1.1 BACKGROUND

Hover (www.hoverenergy.com) is a startup company that seeks to redefine wind power generation for the built environment by providing a vertical axis wind turbine that uses a unique aerodynamic design to capture more energy than a standard turbine. This unique design will enable the capture of wind energy with more energy generated per square foot of real estate compared to solar energy at very low annual average wind speeds. The size and scalability of Hover 's turbine make it a realistic renewable energy solution to address energy needs of urban environments, island communities and similar challenging applications.

After a successful field test in Lubbock with Group NIRE, in association with Texas Tech University and subsequent test built of the HE2.0 unit in Dallas, Texas (see figure 1), Hover Energy is designing its products for mass manufacturing for its market sized product with a rotor of approximately 10 feet by 10 feet. As part of this effort, Hover is evaluating different manufacturing methods that will reduce prototyping and manufacturing cost and result in a lower levelized cost of energy (LCOE) for the specific application Hover Energy is considering in the built environment and adjacent applications.

Specific areas of investigation include cost reduction for the fiber composite components, cost effective fabrication tooling and layup molds, and increase in design flexibility.

In this collaboration with DOE's Oak Ridge National Laboratory (ORNL) Manufacturing Demonstration Facility (MDF), Hover sought to assess and quantify the manufacturing and life cycle energy savings that are realized by using additive manufacturing to create tooling and layup mold, multi-material construction of components that are currently all carbon fiber composite and additive manufacturing of large turbine parts using the MDF's Big Area Additive Manufacturing (BAAM). The primary focus in Phase 1 is to identify the components best suited for additive manufacturing, assess manufacturing scalability, and quantify potential cost and life cycle energy savings. The success criteria for Phase 1 is the identification of components that would benefit from rapid manufacturing using the Big BAAM.

ORNL and Hover will investigate the revolutionary manufacturing processes that enable the production of wind turbine components at a high volume with high performance, but at low-cost. The key components of the turbine are currently composed of carbon fiber composite. While carbon fiber composite is strong, stiff, and lightweight, the manufacturing process is slow and costly. For example, manufacturing of tooling for large, contoured surfaces is labor and time intensive.

1.2 TECHNICAL RESULTS

Hover Energy designed and built the HE 2.0 as its prototype, as seen in Fig. 1. The unit is 12 feet across, 68 inches high and 15 feet long. The aerodynamic components, among them the diverters (green) and the air foils (black, in the center), are carbon fiber components fabricated using the standard technique. Mold tools are designed and built for each of the aerodynamic components, as seen in Fig. 2. This is followed by a *hand layup* of prepreg plies onto these tools and cured in an autoclave.

The lead time on these parts is a consideration. The vacuum infused high performance carbon fiber airfoils had a lead time of 12 weeks with a tooling cost of $72,000. The lesser structurally challenged components, the green large diverters and white top components, build by hand-layup had a lead time of 16 weeks tooling cost of about $29,000 for a very low volume build.

Fig. 1. Demonstration of HE 2.0 unit.

Fig. 2. HE2.0 unit without rotor blades installed.
Green and white diverters are hand layup vacuum infused molding of glass and carbon fibers.

Initial work focused on identifying appropriate parts for additive manufacturing. Several parts, including the major, minor and inner diverters as well as the major diverter flaps were identified as possible parts to investigate for additive manufacturing. As part of Hovers HE3.0 design, which is upscaled for performance, the largest component called the major diverter was selected as a demonstration because of the challenges this posed for Hover Energy:

- Reduce lead time for a pilot-built unit without investment in expensive tooling for such component. Note the previous smaller unit had a 16-week lead-time.
- Study how the BAAM structure could be designed in order to face design wind speeds, which are close to hurricane winds
- Study weight impact and cost impact on small first series manufacturing of the units.

A design of an additively manufactured major diverter, based upon the shape provided by Hover was then developed. The major diverter is about 12 feet long and 140.5 inches tall (see Fig. 4). To print the part on the ORNL BAAM, requires that the part be printed in two sections and then held together with a series of steel rods clamping the parts between two aluminum plates. Fig. 4 also shows a model of the major diverter design.

Fig. 3 HE2.0 rotor blades. Autoclave high performance carbon fiber airfoils.

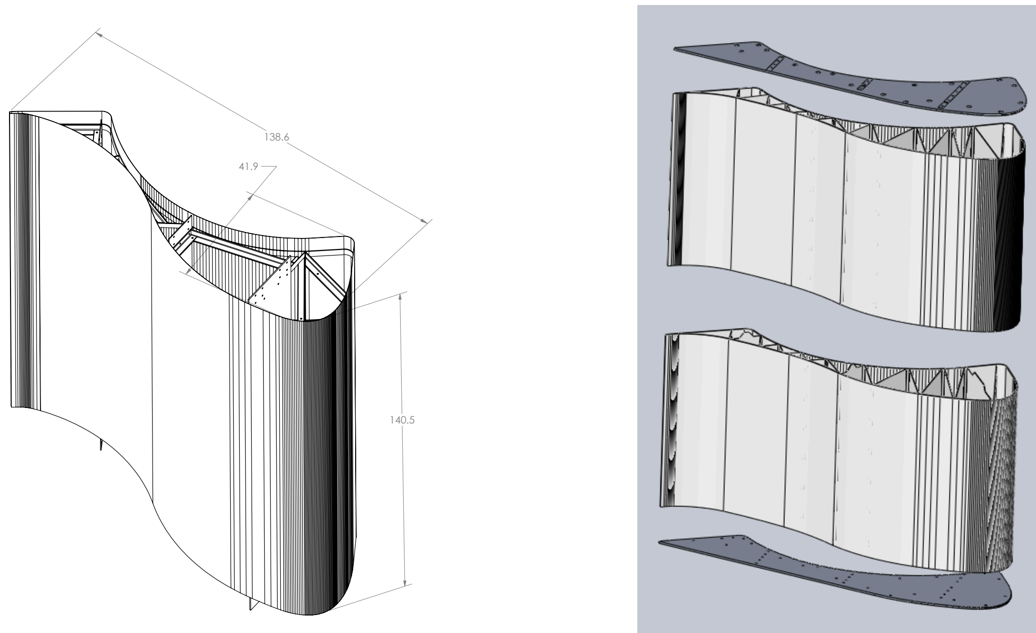

Fig. 4. Major diverter, original Hover design and design for additive manufacturing.

The model of the AM design was analyzed based upon wind loads supplied by Hover Energy. The worst-case wind loading was for 110 mph winds. The primary purpose of the spring-loaded steel rods is to ensure that the AM components are loaded in compression, with limited areas in tension, and those with very minor stresses. The plots in Fig. 5 show only the positive tensile stresses in the z-direction (vertical). Compressive stresses were suppressed for illustrative purposes. Peak stresses were 260 psi. Z-axis tensile strength of the material used for modeling and printing, Techmer Electrafil J-1200/CF/20, is 1494 psi[1].

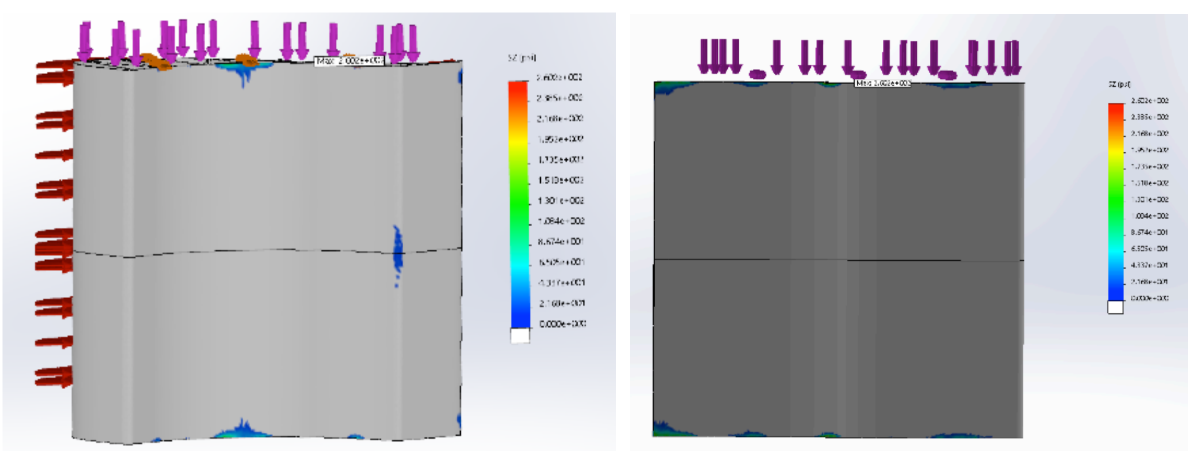

Fig. 5. Stress analysis on initial major diverter design.

Prior to printing the modeled major diverter, Hoover Energy made a significant design change. Rather than print the design that was modeled above, a scaled (1/3 scale) version of the new design was printed. The original design was going to be printed with a 0.2-inch nozzle. Due to the scaling of the new design, a 0.1-inch nozzle was used for the printing. Scaling also allowed for each part to printed as a single piece, instead of two sections that would have required joining. Hover Energy envisions using the printed scaled parts in a wind tunnel at some point in the future.

Due to the small nozzle size, starts and stops of the material flow from the BAAM extruder are not as clean as they are with the larger nozzle sizes. To compensate for potential printing defects, extra length was added to the "tail" of both the major and minor diverters. The extra material was removed after printing to remove any start/stop anomalies. Figures 6 through 9 show both diverters in both the as printed and post cleanup conditions.

Both parts were printed with a two bead exterior wall. Three polygons with a "tail" for starts and stops were added to the major diverter (Fig. 6) and one to the minor diverter (Fig. 7). The polygons were added for increased lateral stiffness.

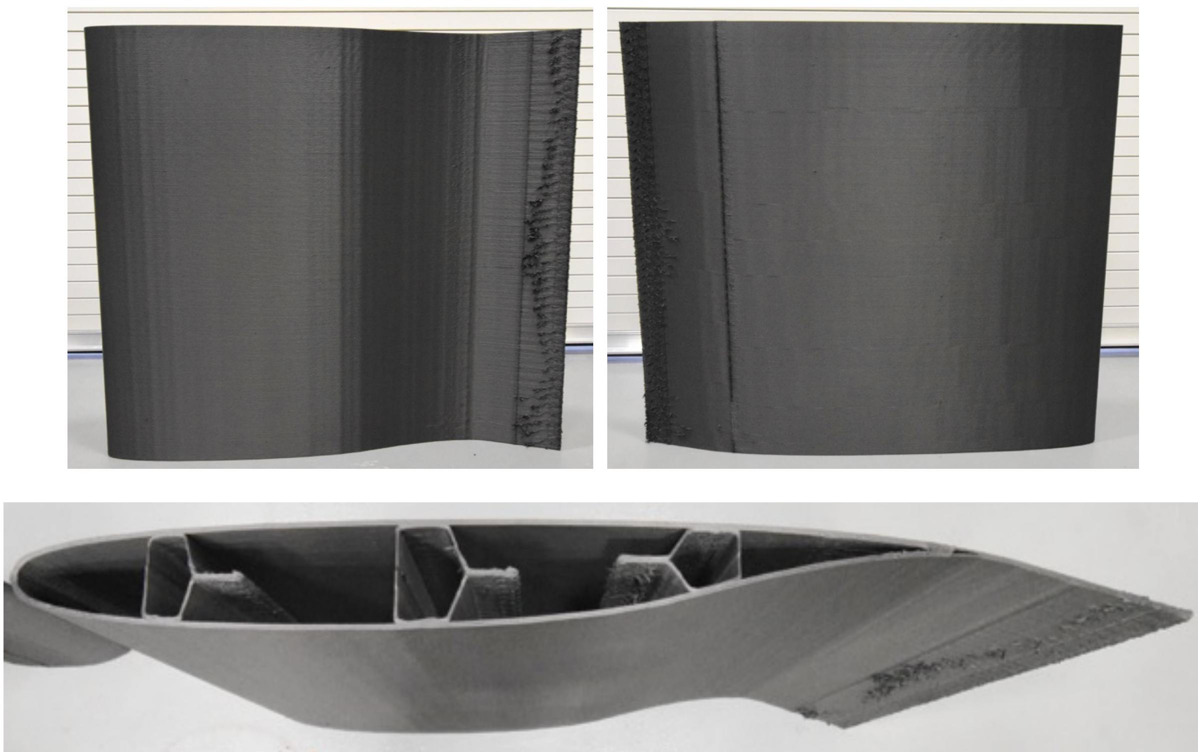

Fig. 6. Major diverter, printed 1/3 scale, as printed.

The external "tails" on both the major and minor diverters were removed using a band saw. Minor sanding was also done. Figures 8 and 9 show the completed parts. The major diverter weighed 38.8 lbs. and the minor diverter 10 lbs.

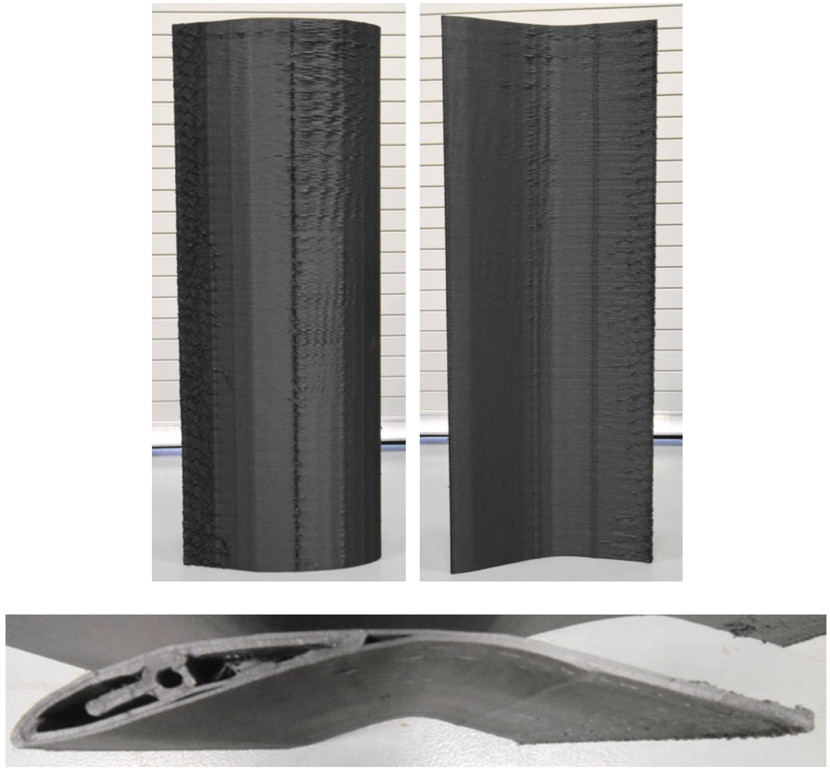

Fig. 7. Minor diverter, printed 1/3 scale, as printed.

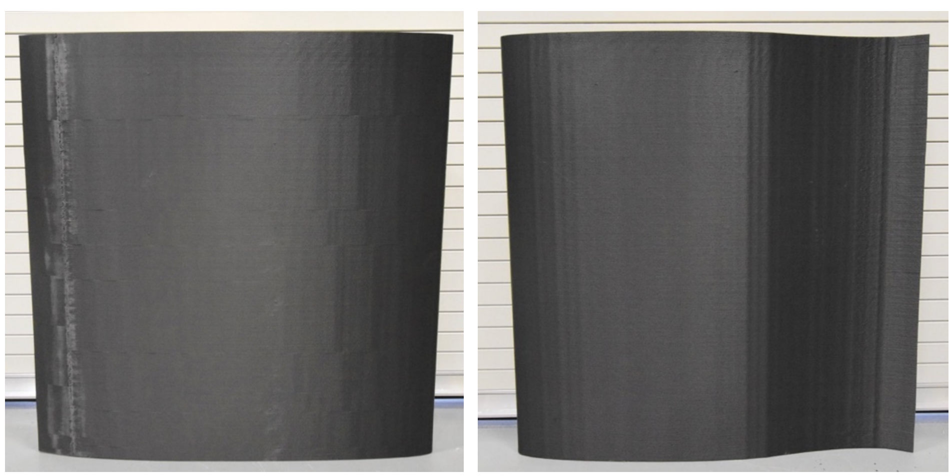

Fig. 8. Major diverter, 1/3 scale, post cleanup.

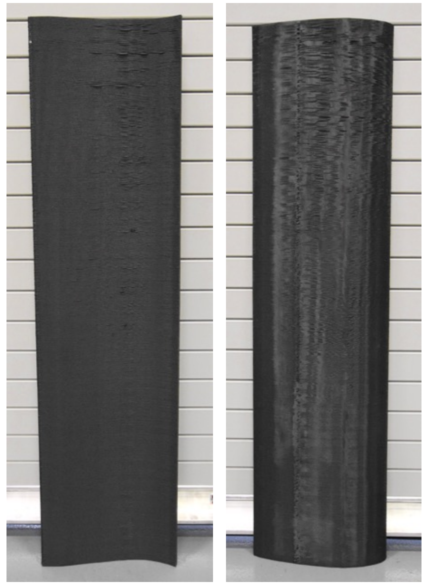

Fig. 9. Minor diverter, 1/3 scale, post cleanup.

1.3 IMPACTS

This project addressed the immediate needs of a startup company in the renewable energy space supporting both their R&D needs and their future manufacturing needs for this disruptive technology.

Specially, the new processes and materials were researched for the novel wind turbine. Several components are suitable to be additive manufactured by the ORNL at DOE's MDF Big Area Additive Manufacturing (BAAM).

This will impact the U.S. clean energy economy by providing a new technology for the underserved building integrated wind market.

1.3.1 Subject Inventions

There are no subject inventions associated with this CRADA .

1.4 CONCLUSIONS

Based on Hover Energy's input, a major diverter that could be additively manufactured was designed and analyzed. The focus of the design was how to satisfy load constraints while minimizing z-tensile stresses. The use of end plates and a series of rods spring loaded to place the part in compression, thus minimizing the tensile stresses was evaluated.

An alternative design major diverter was then chosen for fabrication for wind tunnel experiments. A 1/3 scale diverter and diverter flap were printed for the wind tunnel experiments. The wind tunnel experiment outside the scope of work of this project is current planned for the later part of 2018.

2. HOVER ENERGY LLC BACKGROUND

Hover Energy LLC is a clean-energy start up possesses a transformative wind turbine technology designed to provide exceptional onsite renewable power for the built environment at a competitive price. The Company was formed in 2015 and is based in Dallas, Texas.

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[1] Chad E. Duty, Vlastimil Kunc, Brett Compton, Brian Post, Donald Erdman, Rachel Smith, Randall Lind, Peter Lloyd, Lonnie Love, (2017) "Structure and mechanical behavior of Big Area Additive Manufacturing (BAAM) materials", Rapid Prototyping Journal, Vol. 23 Issue: 1, pp.181-189, https://doi.org/10.1108/RPJ-12-2015-0183